Estimating among-assessment variation in overfishing limits

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Abstract

An update of among-assessment variation, σ, based on estimates of spawning biomass is described. The method utilized by Ralston et al. (2011) to estimate σ was applied to an expanded data set of stock assessments (through the 2015 assessment cycle when applicable) of the original case study of 17 groundfish and coastal pelagic species stocks. The original point estimate was σ=0.357, with an approximate 95% confidence interval of $0.342 \leq \sigma \leq 0.374$ and the new estimate is σ=0.364, with an approximate 95% confidence interval of $0.350 \leq \sigma \leq 0.380$ after the addition of recent stock assessment results. A method for estimating σ based on projections of overfishing limits (OFLs) and spawning biomass is outlined. This method for estimating σ differs from previous approaches by quantifying how projected OFLs and spawning biomass (rather than historical estimates of biomass) vary among assessments of the same stocks, and is thus a more direct measure of the quantity of interest. Additionally, the projections can be started from multiple historical years to further characterize uncertainty, as the best estimates of growth, biomass, age-structure, and selectivity change over time.

Introduction

Answering the legislative call to arms to improve US fisheries involves pursuing new ways to characterize and quantify the scientific uncertainty that informs fisheries management (Cadrin et al. 2015). In this context, scientific uncertainty is defined as the uncertainty inherent in data collection as translated through stock assessment methods (Federal Register 2009). The overall goal of this mandate under the Magnuson-Stevens Fishery Conservation and Management Act (or MSA for short) is to manage US fisheries to ensure that the amount of fish harvested each year will provide the greatest overall benefit, particularly in food production and recreational opportunities, to the nation, and thoroughly account for the conservation and sustainability of marine ecosystems (Federal Register 2009).

One outcome of the pursuit of this goal is the adoption of “precautionary harvest control rules that are designed to reduce ‘risk-neutral’ point estimates of catch based on the amount of uncertainty in the estimates” (Ralston et al. 2011). For example, groundfish stocks managed in the US northeast Pacific are classified into three categories based on the quantity and quality of data available for assessments: 1) a Category 1 stock has catch-at-age, catch-at-length, or other data that inform a relatively data-rich, quantitative stock assessment; 2) a Category 2 stock has some biological indicators, which may include a relatively data-limited quantitative stock assessment or non-quantitative assessment; and 3) a Category 3 stock has few available data (*e.g.* landed biomass)(PFMC 2014a). The harvest control rules that define the Allowable Biological Catch (ABC) for US west coast groundfish and coastal pelagic species rely on the estimation of an

Overfishing Limit (OFL) and an uncertainty buffer for scientific uncertainty (Figure 1). The catch limit for any stock must be equal to, or lower than, the ABC.

The default magnitude of the uncertainty buffer for a stock is defined by Category, and was first described by Ralston et al. (2011). In that work, it was assumed that scientific uncertainty can be characterized using a log-normal distribution with a mean of one and a standard error in log-space, σ. Sigma, σ, for Category 1 stocks (most data rich and robust stock assessments) was quantified by the estimated coefficient of variation (CV) of the among-assessment variation in annual estimates of spawning biomass (based on 81 Category 1 assessments from 17 groundfish and coastal pelagic species stocks.). Due to the data-limited nature of Category 2 and 3 stocks, the uncertainty associated with estimates of an OFL are difficult to quantify and the scientific uncertainty is presumed to be higher. The Scientific and Statistical Committee of the Pacific Fishery Management Council recommended, and the PFMC adopted, setting a minimum CV at 0.36 for Category 1 stocks, doubling the (assumed) uncertainty (CV=0.72) for Category 2 stocks, and quadrupling the assumed uncertainty (CV=1.44) for Category 3 stocks (Ralston et al. 2011).

The document provides an update to the value of σ using the same method applied by Ralston et al. (2011). It also proposes, but does not apply, an alternative approach to characterize scientific uncertainty that expands on the precedent set by Ralston et al. (2011). More specifically, patterns in overestimating or underestimating derived quantities more directly related to setting of catch limits (*i.e.* the OFL) are analyzed using the results of stock assessments conducted for groundfish and coastal pelagic species stocks along the west coast of the United States. Previous work used historical estimates of spawning stock biomass to calculate σ and assumed the uncertainty in the OFL arises only from the uncertainty in terminal-year biomass; this assumption can lead to negatively biased estimates of scientific uncertainty (Ralston et al. 2011). Here, a method is proposed to estimate σ based on how projections of OFLs vary among multiple assessments of the same stock. This method for estimating σ differs from previous approaches by quantifying how projected OFLs and spawning biomass (rather than historical estimates of biomass) vary among assessments of the same stocks, and is thus a direct measure of the management quantity of interest. Quantifying the variation in projections is informative because the OFL is utilized by managers to set a catch limit for a stock for multiple years and a misspecification may result in significant implications for a fishery. Conducting projections also provides an opportunity to evaluate how sigma changes by taxon and with varying forecast durations.

Materials and Methods

Variation in OFLs and spawning biomass among multiple assessments of the same stock can arise from multiple sources: 1) chosen model structure; 2) fixed parameter values and prior distribution selection for other parameters; 3) changes in data availability; 4) the composition of the review panel; 5) the members of the stock assessment team conducting the assessment; and 6) the version of software that was used (Ralston et al. 2011). Accounting for this variation among historical assessments and projected values for OFL is integral for informing the PFMC Scientific and Statistical Committee as they compile scientific advice for fisheries managers.

Scientific uncertainty is associated with each step of calculating an OFL: 1) estimating the current exploitable biomass; 2) projecting the population biomass for a pre-specified number of years while applying an estimate of F_{MSY} to the forecasts of future biomass (Ralston et al. 2011).

The two methods outlined in this document differ in terms of how many of these sources of uncertainty are considered when calculating σ.

Data sets utilized

Since the inception of σ in 2011, 12 of the 17 groundfish and coastal pelagic species stocks used to inform σ have new assessments (not including the 2017 assessment cycle)(Table 3). The assessments were included in this update to the species-specific σ and pooled σ produced using the terminal-biomass method. For direct comparison to the projections-based method proposed in this paper, the Ralston et al. (2011) method will also repeated for only the stocks and assessments that could be used in this projections-based analysis.

Four stocks (bocaccio, chilipepper rockfish, darkblotched rockfish, and yelloweye rockfish) now report 'spawning biomass estimates' in terms of spawning output (eggs/kg) based on the relationship described by Dick (2009). Stock Synthesis outputs were used to calculate spawning biomass (metric tons):

$$SB_y = \sum_{a}^{A} W_a N_{y,a} m_a \qquad \text{(Equation 1)}$$

where SSB_y is spawning biomass in year y, a is age, A is the age plus group, $W_{a,f}$ is female weight-at-age, $N_{y,a}$ is female numbers-at-age, and m_a is the female maturity-at-age. Female weight-at-age was calculated as follows:

$$W_a = \sum_{l} W_l \, m_l \, \rho_{a,l} \qquad \text{(Equation 2)}$$

here W_l is female weight-at-length, m_l is the female maturity-at-length, and $\rho_{a,l}$ is the proportion of animals of age a than in length-class l.

To ground truth this conversion approach, the calculated spawning biomass for the 2009 assessments of yelloweye rockfish and bocaccio were compared to the spawning biomass values used in the Ralston et al. (2011) analysis (Figure 2). The general trends in spawning biomass are similar, but the scales of time series are different. The Stock Synthesis report files available for these two assessments report spawning biomass in terms of spawning output (eggs/kg) and there was no documentation on how the spawning biomass was calculated for the 2009 assessments of yelloweye rockfish and bocaccio in Ralston et al. (2011).

Update to the Ralston (2011) analysis

Time series for spawning biomass and OFL projections produced by assessments conducted in Stock Synthesis (Methot and Wetzel 2013) demonstrate variation among assessments, and the method of Ralston et al. (2011) uses the former variation to quantify assessment uncertainty. The updated estimate of σ in this paper was based on method B of Ralston et al. (2011) [see Equations 10 and 11 below].

Quantifying uncertainty using OFL projections

The method proposed in this paper attempts to quantify assessment uncertainty by forecasting OFLs and spawning biomass. These projections capture some of the uncertainty in the estimates of current stock abundance and age-structure and how the abundance and structure change over time. As prescribed by Shertzer et al. (2008), quantifying the variation in OFL projections captures some of the uncertainty in the estimation of F_{MSY}. Additionally, undertaking projections of OFLs and spawning biomass provide an opportunity to quantify how σ varies across taxon.

The projections will be started from multiple historical years to further characterize uncertainty because projections use the best estimates of biomass, age-structure, and selectivity, and these change over time. To ensure comparability between the results of this paper and those of Ralston et al. (2011), it is pertinent to utilize the PFMC groundfish and coastal pelagic species stock assessments from the US west coast fishery management plans. The stocks and accompanying assessments are a subset of those available because not all historical assessments were conducted in Stock Synthesis (*e.g.* stock assessments published before 2007) or in a version of Stock Synthesis that does not produce the derived quantities required to project spawning biomass or OFLs (*e.g.* stock assessments completed in an older version of Stock Synthesis [pre-V2.00] that use an obsolete selectivity pattern).

Projecting OFLs and spawning biomass

OFLs are computed by applying a target harvest rate, F_{target} (U.S. west coast groundfish: $F_{50\%}$ for rockfish, $F_{45\%}$ for roundfish, and $F_{30\%}$ for flatfish) to estimates of current biomass. F_{target} is the target harvest rate that results in an expected decline in spawning biomass-per-recruit equal to 50% (for rockfish), 45% (for roundfish), or 30% (for flatfish) for US west coast stocks (PFMC 2014a). Projections of OFLs and historical biomass will be completed for stocks with assessments completed in Stock Synthesis V3.03a or later (Methot and Wetzel 2013). Table 1 shows the stock assessments (indicated with asterisks) that will be converted to V3.24 from older versions (V2.00) and sensitivities to the use of these converted assessments will be conducted. Under assumptions outlined by stock assessments conducted in different years for the same stock, the goal of the projections is to evaluate the extent to which uncertainty changes into the future. The among-assessment variation will be used to estimate σ for both spawning biomass and OFL.

Several quantities will need to be extracted from completed stock assessments to compute and project spawning biomass and OFLs (Table 2).

The estimated natural mortality and projected fishing mortality for the time series covered in the assessment will be used to calculate total mortality, *Z* for projections:

$$Z_{a,s} = M_{a,s} + \sum_{f} F_{target} S_{s,a,f} \psi_f \qquad \text{(Equation 3)}$$

where *a* represents age, *s* represents sex, and *f* represents fleet. *S* is selectivity by age, sex, and fleet in the end of last year before the projections start, and ψ is the fishing mortality rate by fleet, *f*, *Z* will then be used to project the numbers-at-age matrices for both sexes forward:

$$\begin{aligned} N_{y+1,s,a} &= N_{y,s,a-1} e^{-Z_{s,a-1}} && \text{if } 0 \le a < A \\ N_{y+1,s,A} &= N_{y,s,A} e^{-Z_{s,A-1}} + N_{y,s,A} e^{-Z_{s,A}} && \text{if } a = A \end{aligned} \qquad \text{(Equation 4)}$$

where *N* is the numbers-at-age in year *y* and for sex *s*, and *A* is the plus group. The numbers-at-age corresponding with the first year of projection are extracted from the stock assessment numbers-at-age matrix found in the Stock Synthesis report file.

The projected numbers-at-age are converted to spawning stock biomass:

$$SSB_{y+1} = \sum_a \omega_a N_{y+1,s,a} \qquad \text{(Equation 5)}$$

where ω is the fecundity of a fish of age a.

The projected numbers of fish at age-0 are calculated using the Beverton Holt stock-recruitment relationship:

$$N_{y,s,a=0} = \frac{4hR_0 SSB/SSB_0}{(1-h) + (5h-1)SSB/SSB_0} \qquad \text{(Equation 6)}$$

where R_0 is the unfished recruitment, h is the steepness parameter, and SSB_0 is the unfished spawning stock biomass. The unfished spawning stock biomass will be computed using numbers-at-age and fecundity at unfished equilibrium. OFLs by year are calculated as follows:

$$OFL_y = \sum_s \sum_f \sum_a W_{s,f,a} F_{target} S_{s,a,f} \psi_f \frac{N_{y,s,a}(1-e^{-Z_{s,a}})}{Z_{s,a}} \qquad \text{(Equation 7)}$$

where W is the selected-weighted retained weight by age for end of last year before the projections start.

Quantifying uncertainty in projections

Among-assessment variability in OFLs will be quantified by forecasting time series of OFLs from historical assessments of U.S. west coast groundfish and coastal pelagic species stocks (Table 1). The variation in OFL projections among a set of stock assessments will be quantified by considering the mean of the OFL estimates among years for a given start year as the best estimate of central tendency for that year.

$$\overline{\ln[OFL_t]} = \frac{1}{n_t} \sum_i \ln[OFL_{i,t}] \qquad \text{(Equation 8)}$$

where n_t is the number of available assessments for year t $(n_t \geq 2)$ and i is the individual assessment. The standard deviation (σ) is then calculated as:

$$\sigma = \sqrt{\frac{1}{\sum_t n_t - 1} \sum_t \sum_i (\ln[OFL_{i,t}] - \overline{\ln[OFL_t]})^2} \qquad \text{(Equation 9)}$$

The variation in historical estimates of spawning biomass among multiple assessments (*sensu* Ralston et al. 2011) will also be calculated in a similar fashion.

$$\overline{\ln[SSB_t]} = \frac{1}{n_t} \sum_i \ln[SSB_{i,t}] \qquad \text{(Equation 10)}$$

$$\sigma = \sqrt{\frac{1}{\sum_t n_t - 1} \sum_t \sum_i (\ln[SSB_{i,t}] - \overline{\ln[SSB_t]})^2} \qquad \text{(Equation 11)}$$

Results

Updating σ based on spawning biomass estimates

Consistent with Ralston et al. (2011), the groundfish and coastal pelagic species stock assessments utilized in the update of σ were data-rich stocks that have been assessed more than once (15 groundfish and two coastal pelagic species stocks) and updated assessments, where data were simply refreshed and not extensively reviewed, were not included. With the additional assessments included, the number of assessments used for this meta-analysis ranged from three (chilipepper rockfish and cabezon) to 23 (Pacific whiting). Biomass trajectories for the 17 stocks are presented in Figure 3. For quick reference, Tables 4 and 5 present estimates reported in Ralston et al. (2011).

Stock specific results

The distribution of residuals for the 17 stocks is shown in Figure 4. These distributions are bimodal for the species with few assessments available and biomass trajectories that do not intersect (*e.g.* shortspine thornyhead and yelloweye rockfish). Chilipepper rockfish no longer appears to be bimodal with the addition of the 2015 stock assessment. Most of the distributions still appear to be unimodal and centered on or near zero. Some distributions exhibit long tails (yellowtail rockfish and petrale sole). Darkblotched rockfish and widow rockfish have a more uniform distribution with the addition of recent stock assessments. This may be related to the increased number of assessments and many biomass trajectories that do not intersect. The number of deviations and the estimated log-scale standard deviation for each of the stocks are presented in Table 3. The log-scale standard deviations range from 0.154 (cabezon) to 0.974 (shortspine thornyhead), with an average of 0.367.

Pooled results

The unweighted, pooled distributions of residuals for the four groupings of stocks are shown in Figure 5. The distributions are close to normal for all groupings, whereas before roundfish, flatfish, and coastal pelagic species exhibited some non-normal features (Fig. 3 of Ralston et al., 2011). The pooled point estimates of σ from this update, the accompanying approximate 95% confidence intervals, and the original pooled point estimates of σ from Ralston et al. (2011) are reported in Table 4. Pooling the deviations across all stocks (Figure 6) leads to a point estimate of $\sigma=0.364$ and if the residuals are assumed to be independent, an approximate 95% confidence interval is $0.350 \leq \sigma \leq 0.380$.

Projecting OFLs and spawning biomass

TBA for future review by the SSC.

Discussion

The point estimate of σ for 17 groundfish and coastal pelagic species stocks was updated using the same method employed by Ralston et al. (2011). The comparison of stock-specific and group-specific estimates after the addition of recent assessments reaffirms that $\sigma=0.36$ is still a reasonable way to quantify uncertainty. This update provides a foundation for comparison with the proposed alternative method for estimating σ based on projections of OFLs and spawning biomass. Forecasting OFLs and spawning biomass will expand on the findings of Ralston et al. (2011) by capturing some of the uncertainty in the estimates of current stock abundance and age-structure and how these estimates change over time. The projections of OFLs will also capture some of the uncertainty in the estimation of F_{MSY}. These additional quantifications of uncertainty will be presented to the PFMC SSC for review.

Acknowledgements

KPJ was funded by the National Science Foundation Graduate Research Fellowship Program. AEP was funded by partially funded by the Joint Institute for the Study of the Atmosphere and Ocean (JISAO) under NOAA Cooperative Agreement and NA15OAR4320063. We would like to offer our thanks to J. Cope, P. Crone, J. DeVore, O. Hamel, R. Methot, S. Ralston, I. Taylor, and C. Wetzel for providing stock assessment data and for providing guidance in the development and implementation of this project thus far.

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Table 1. The US west coast groundfish and coastal pelagics species stock assessments proposed for use in the alternative method for estimating σ by quantifying overfishing limit and spawning biomass projection variation. * indicates assessments that will be converted to Stock Synthesis Version 3.24 from Version 2.00.

Stock Group	Species	Year	Author(s)
Rockfish	bocaccio (*Sebastes paucisipinis*)	2015	Xi He et al.
		2013	Field
		2011	Field
		2009	Field et al.
	canary rockfish (*Sebastes pinniger*)	2015	Thorson and Wetzel
		2009	Stewart
		2007	Stewart
		2005	Methot and Stewart
	darkblotched rockfish (*Sebastes crameri*)	2015	Gertseva et al.
		2013	Gertseva and Thorson
		2011	Stephens et al.
		2009	Wallace and Hamel
		2007*	Hamel
	Pacific ocean perch (*Sebastes alutus*)	2017	Wetzel
		2011	Hamel and Ono
		2009*	Hamel
	widow rockfish (*Sebastes entomelas*)	2015	Hicks and Wetzel
		2011	Xi He et al.
		2009	Xi He et al.
	yelloweye rockfish (*Sebastes ruberrimus*)	2017	Gertseva and Cope
		2009	Stewart et al.
		2007	Wallace
Roundfish	cabezon (*Scorpaenichthys marmoratus*)	2009	Cope and Key
		2005	Cope and Punt
	Pacific whiting (*Merluccius productus*)	2017	IJTC
		2016	IJTC
		2015	IJTC
		2014	IJTC
		2013	IJTC
		2012	IJTC
		2011	IJTC
		2010	Stewart and Hamel
		2009	Hamel and Stewart
		2008	Helser et al.
		2007	Helser and Martell
		2006	Helser et al.
	lingcod (*Ophiodon elongatus*)	2017	Haltuch et al.

Stock Group	Species	Year	Author(s)
		2009	Hamel et al.
		2005	Jagielo and Wallace
	sablefish (*Anoplopoma fimbria*)	2011	Stewart et al.
		2007	Schirripa
Flatfish	Dover sole (*Microstomus pacificus*)	2011	Sampson
		2005	Hicks and Wetzel
	petrale sole (*Eopsetta jordani*)	2013	Haltuch et al.
		2011	Haltuch et al.
		2009	Haltuch and Hicks
Coastal pelagic	Pacific mackerel (*Scomber japonicus*)	2015	Crone and Hill
		2011	Crone et al.
		2009	Crone et al.
	Pacific sardine (*Sardinops sagax*)	2017	Hill et al.
		2014	Hill et al.
		2011	Hill et al.
		2009	Hill et al.

Table 2. The quantities extracted from Stock Synthesis report files to calculate OFL and spawning biomass projections. Reference year of interest refers to the last year of the assessment, as defined by the first year for which spawning biomass and OFL are projected.

Stock Assessment Output
Numbers-at-age for reference year of interest, *N*
Fecundity (unfished and fished) for reference year of interest, *ω*
Selectivity at age by fleet, *S*
Selected-weighted retained weight by age and fleet, *W*
Natural mortality, *M*
Relative exploitation rate by fleet, *F*
Stock-recruit parameters
Unfished recruitment, R_0
Steepness, *h*

Table 3. Summary of stock-specific analyses of variation for estimates of terminal stock size from assessments of groundfish and coastal pelagic species for the update of Ralston et al. (2011). * indicates stocks that have not been assessed since 2009 (not including the 2017 assessment cycle).

Stock group	Common name	Scientific name	No. of stock assessments	Squared deviations (n)	Log-scale standard deviation
Rockfish	bocaccio	*Sebastes paucisipinis*	8	85	0.242
	canary rockfish*	*Sebastes pinniger*	7	85	0.375
	chilipepper	*Sebastes goodei*	3	27	0.289
	darkblotched rockfish	*Sebastes crameri*	6	72	0.314
	Pacific ocean perch	*Sebastes alutus*	4	43	0.228
	widow rockfish	*Sebastes entomelas*	7	68	0.417
	yelloweye rockfish*	*Sebastes ruberrimus*	4	58	0.492
	yellowtail rockfish*	*Sebastes flavidus*	6	66	0.269
	shortspine thornyhead	*Sebastolobus alascanus*	4	32	0.974
Roundfish	cabezon*	*Scorpaenichthys marmoratus*	3	46	0.154
	lingcod*	*Ophiodon elongatus*	4	56	0.263
	Pacific whiting	*Merluccius productus*	23	191	0.228
	sablefish	*Anoplopoma fimbria*	8	72	0.314
Flatfish	Dover sole	*Microstomus pacificus*	4	42	0.658
	petrale sole	*Eopsetta jordani*	5	69	0.199
Coastal pelagic	Pacific mackerel	*Scomber japonicus*	6	76	0.484
	Pacific sardine	*Sardinops sagax*	6	72	0.347

Table 4. Summary of pooled stock-specific estimates of σ from assessments of groundfish and coastal pelagic species. CV=coefficient of variation.

		σ		
Group	Number of stocks	2017 estimate	95% CI	Ralston 2011
rockfish	9	0.399	(0.377, 0.425)	0.418
roundfish	4	0.245	(0.228, 0.3264)	0.281
flatfish	2	0.431	(0.381, 0.497)	0.299
coastal pelagic	2	0.422	(0.378, 0.476)	0.339
All stocks	17	0.364	(0.350, 0.380)	0.358

Table 5. From Ralston et al. (2011): Summary of stock-specific analyses of variation for estimates of terminal stock size from assessments of groundfish and coastal pelagic species. CV=coefficient of variation.

Stock group	Common name	Scientific name	No. of stock assessments	Squared deviations (n)	Log-scale standard deviation	Statistical uncertainty CV
Rockfish	bocaccio	*Sebastes paucispinis*	5	61	0.367	15%
	canary rockfish	*Sebastes pinniger*	8	85	0.375	15%
	chilipepper	*Sebastes goodei*	2	22	0.354	14%
	darkblotched rockfish	*Sebastes crameri*	3	45	0.103	13%
	Pacific ocean perch	*Sebastes alutus*	3	20	0.352	15%
	widow rockfish	*Sebastes entomelas*	5	61	0.241	31%
	yelloweye rockfish	*Sebastes ruberrimus*	4	58	0.492	14%
	yellowtail rockfish	*Sebastes flavidus*	6	66	0.269	24%
	shortspine thornyhead	*Sebastolobus alascanus*	3	39	0.923	9%
Roundfish	cabezon	*Scorpaenichthys marmoratus*	3	46	0.154	21%
	lingcod	*Ophiodon elongatus*	4	56	0.263	10%
	Pacific whiting	*Merluccius productus*	15	151	0.286	28%
	sablefish	*Anoplopoma fimbria*	7	82	0.340	10%
Flatfish	Dover sole	*Microstomus pacificus*	3	41	0.360	9%
	petrale sole	*Eopsetta jordani*	3	41	0.227	15%
Coastal pelagic	Pacific mackerel	*Scomber japonicus*	4	66	0.415	25%
	Pacific sardine	*Sardinops sagax*	3	51	0.206	41%

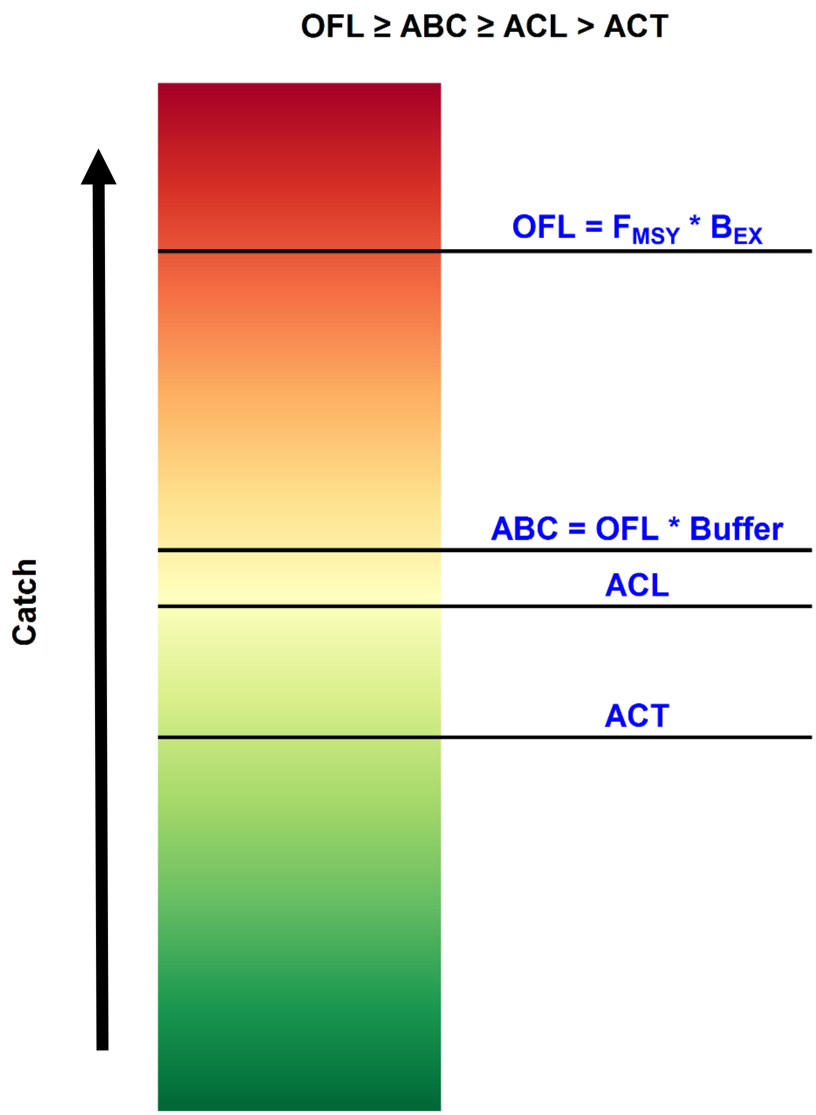
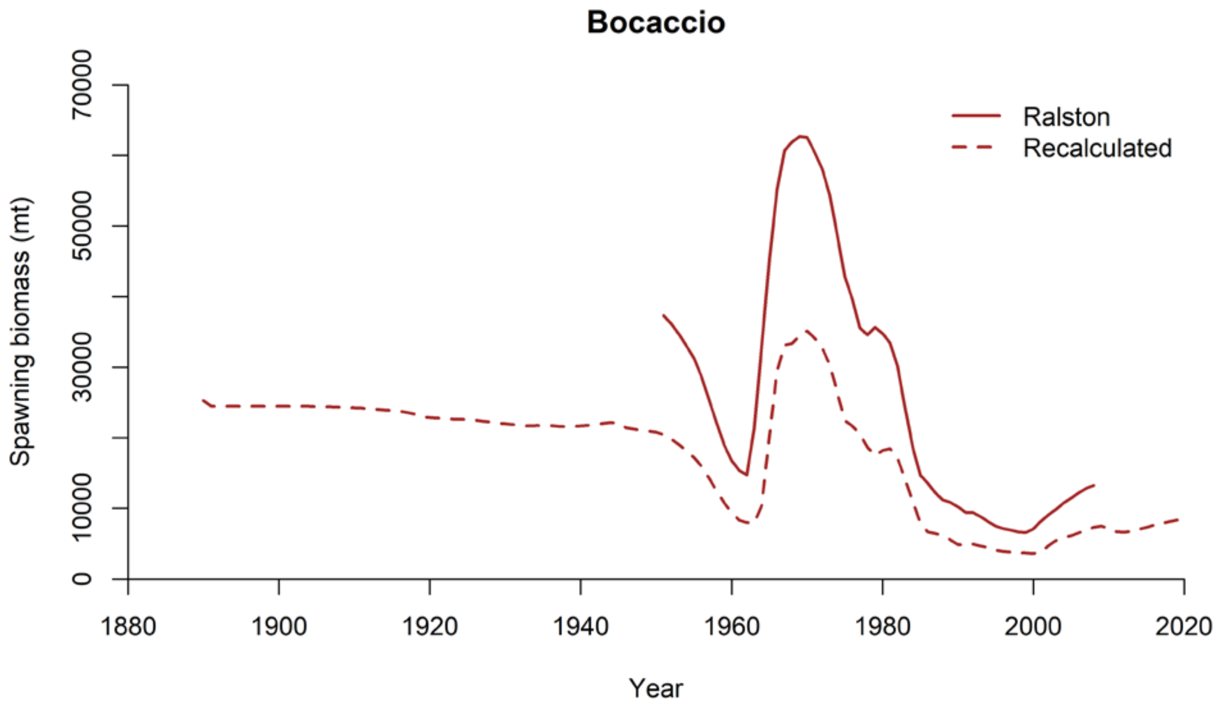


Figure 1. The relationships between harvest-related terms utilized in U.S. fisheries management. OFL is the overfishing limit, F_{MSY} is fishing mortality (often expressed as an exploitation rate) corresponding to maximum sustainable yield, B_{EX} is exploitable biomass, ABC is the allowable biological catch, Buffer is a multiplier based on scientific uncertainty, ACL is the annual catch limit, and ACT is the annual catch target.



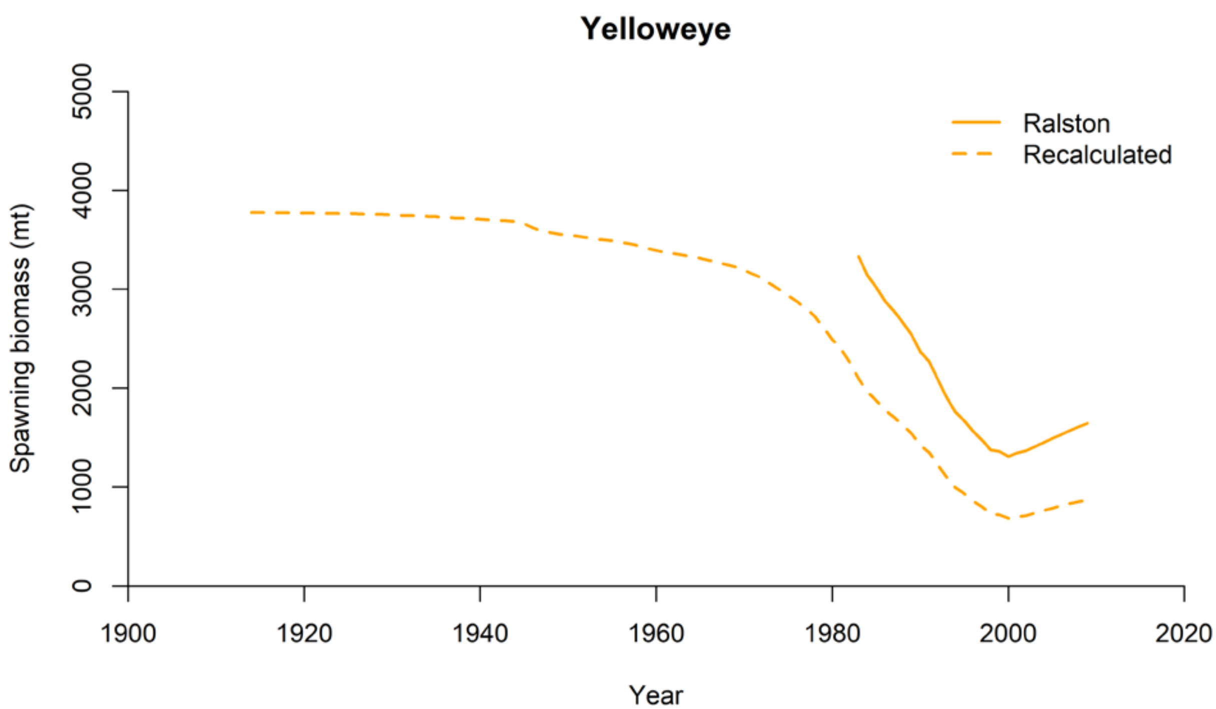


Figure 2. Comparison of the estimates of spawning biomass (mt) used by Ralston et al. (2011) and the estimated spawning biomass calculated recalculated by converting egg production to spawning biomass using the approach outlined in the text for the 2009 stock assessment models for bocaccio and yelloweye rockfish.

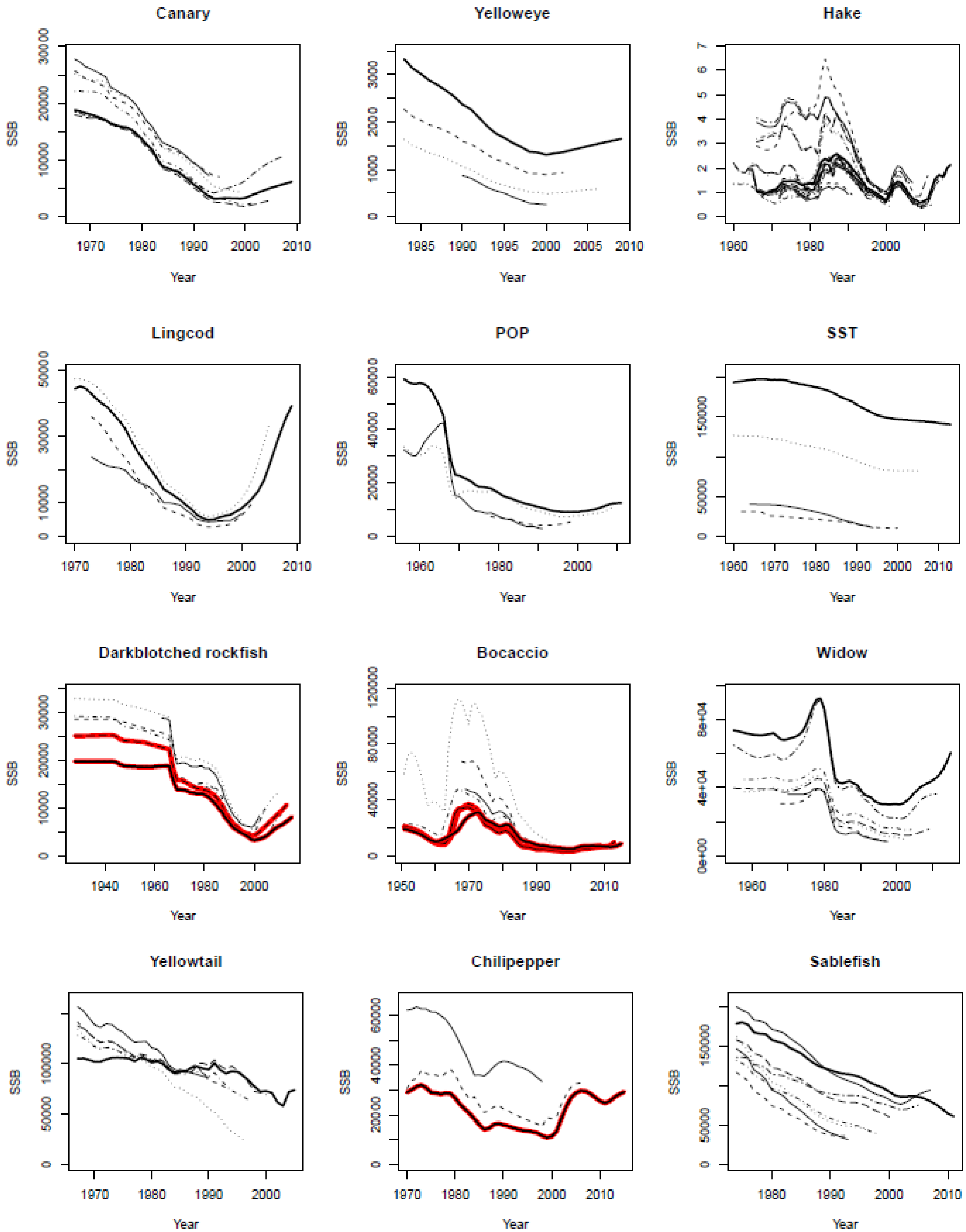


Figure 3. Biomass time series for the 17 groundfish and coastal pelagic species from stock assessments conducted for the Pacific Fishery Management Council on the west coast of the United States. The thick, solid black line denotes the most recent assessment. The lines highlighted in red are the biomass trajectories that were recalculated to be in metric tons based on outputs from Stock Synthesis.

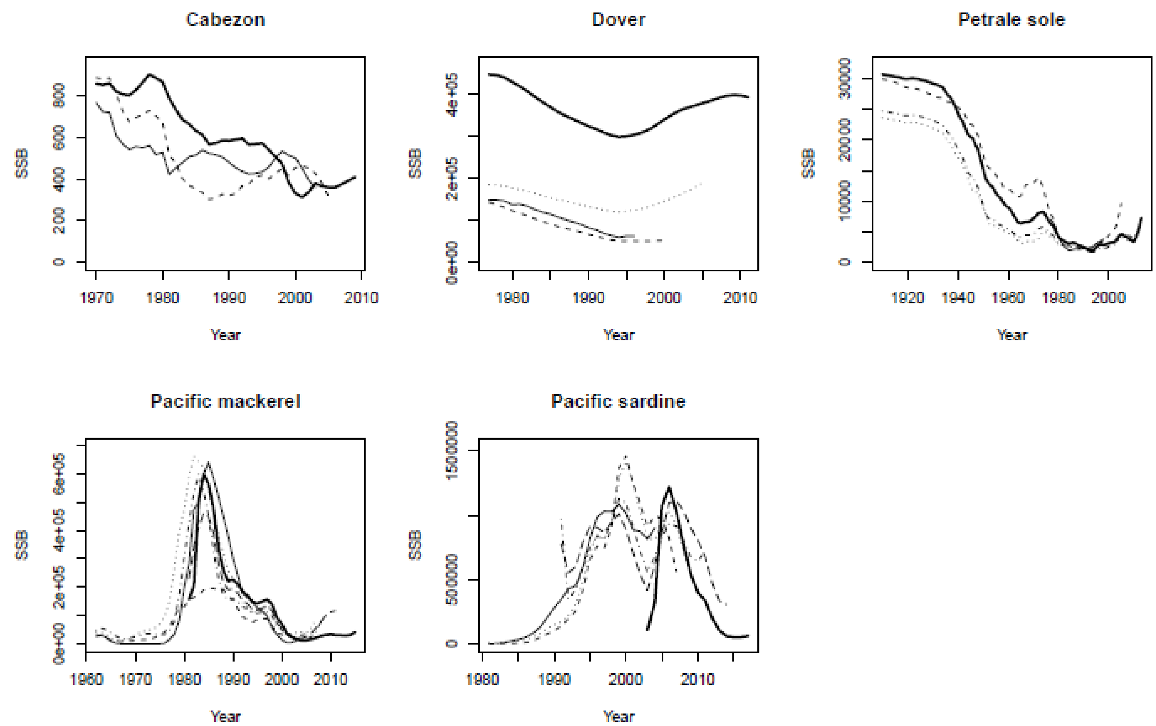


Figure 3 continued.

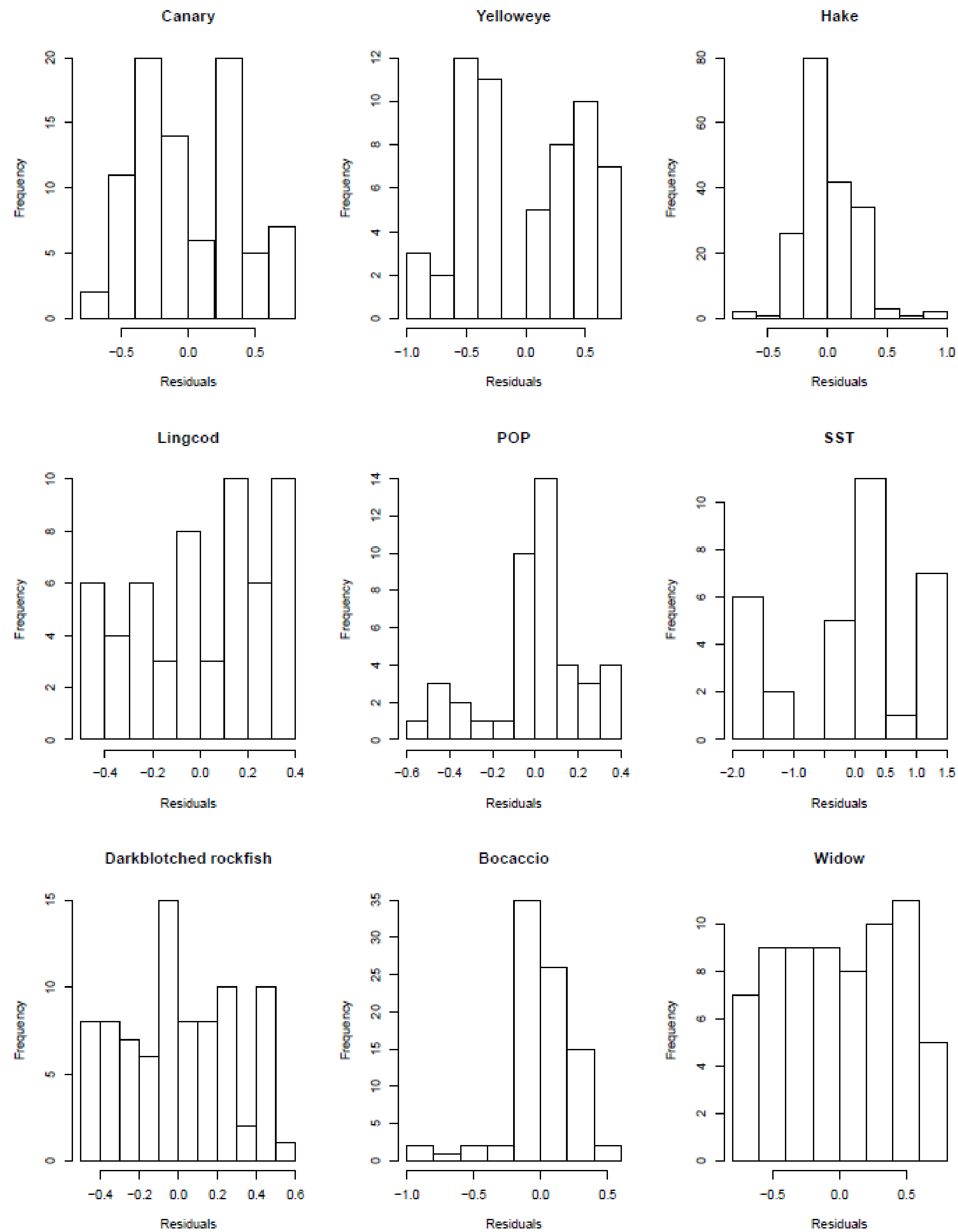


Figure 4. Frequency distributions of log-scale biomass deviations for the 17 groundfish and coastal pelagic species in stock assessments conducted for the Pacific Fishery Management Council. Deviations were calculated from annual means taken from the biomass time series presented in Figure 3.

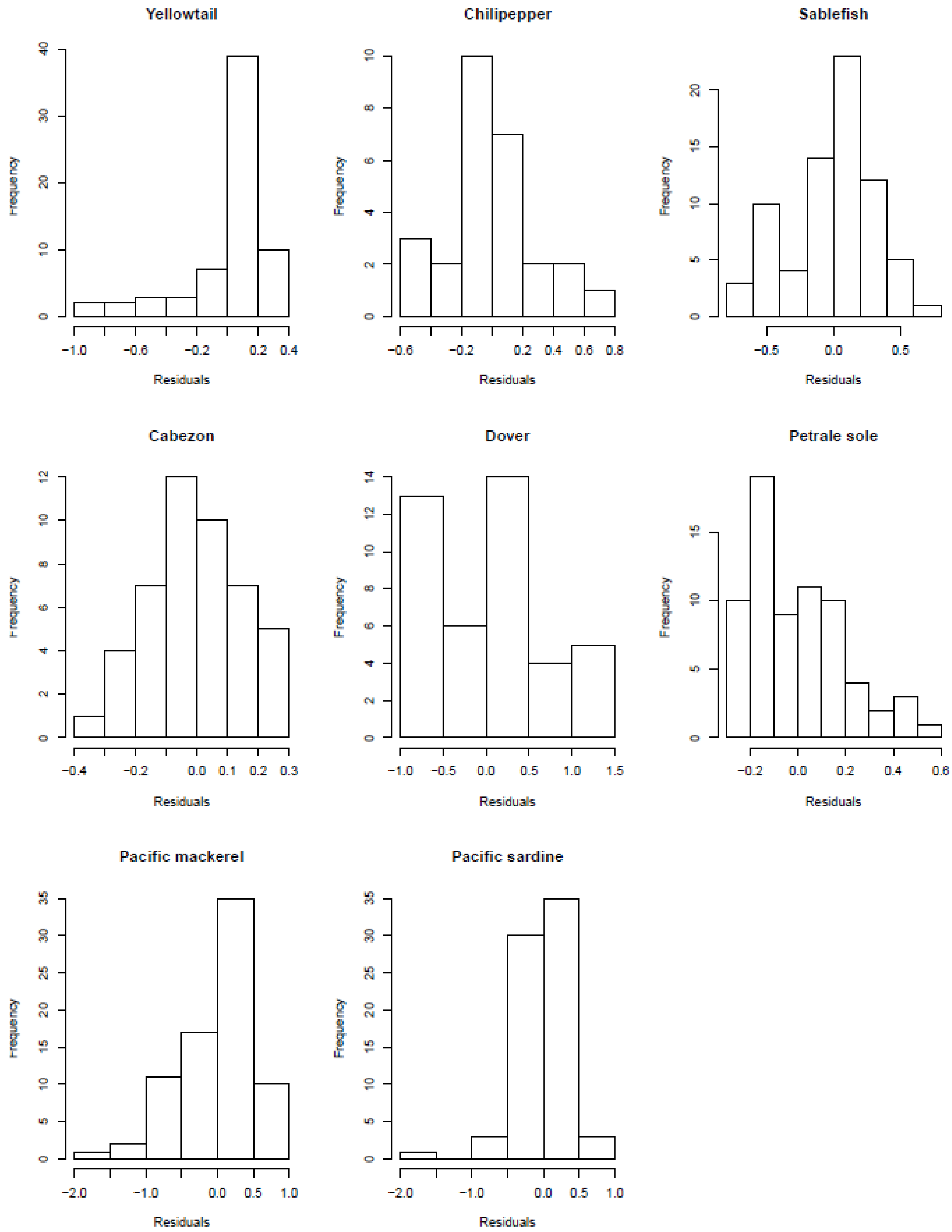


Figure 4 continued.

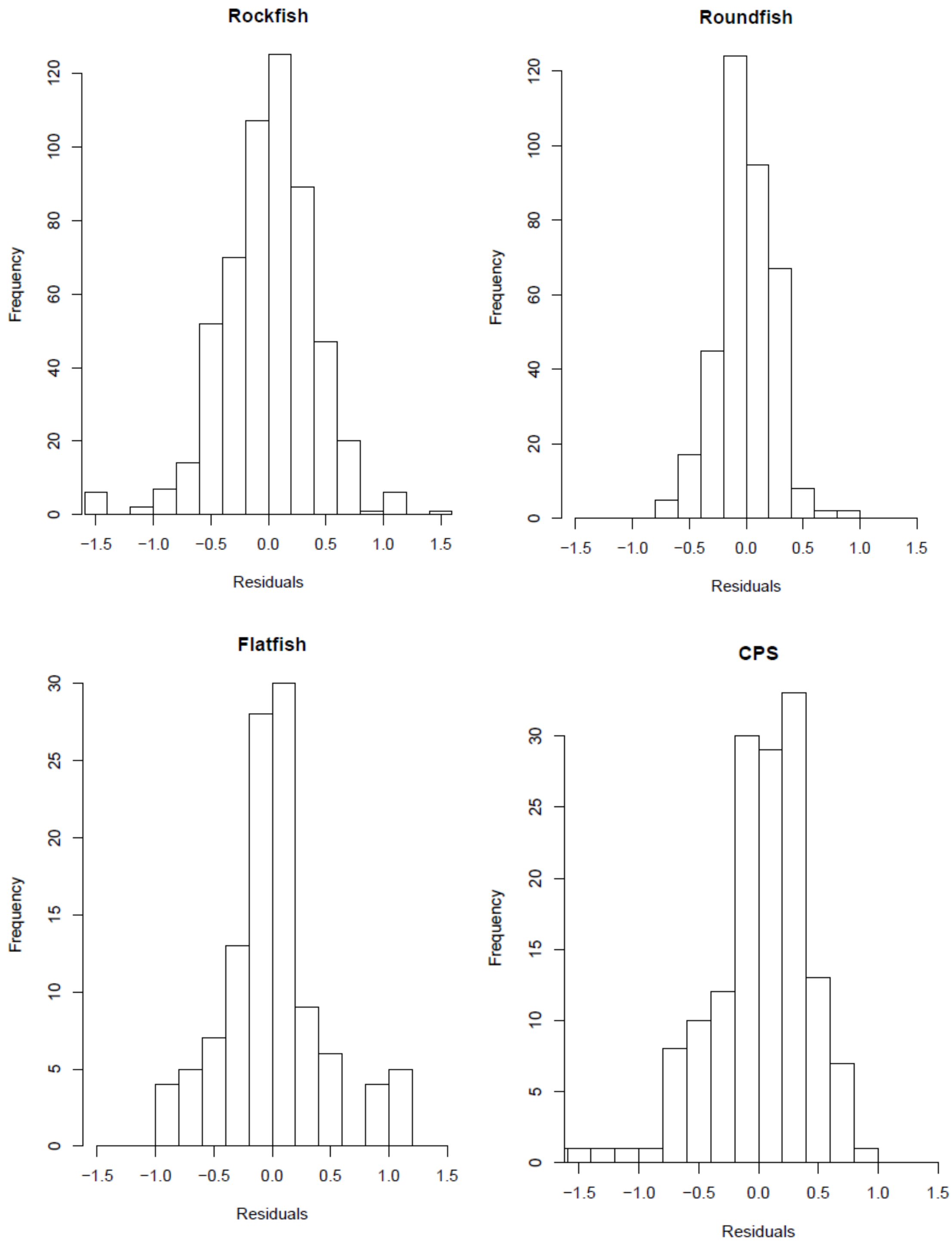


Figure 5. Composite distributions of log-deviations from the mean, pooled for four meta-analytic groupings (rockfish, roundfish, flatfish, and coastal pelagic species).

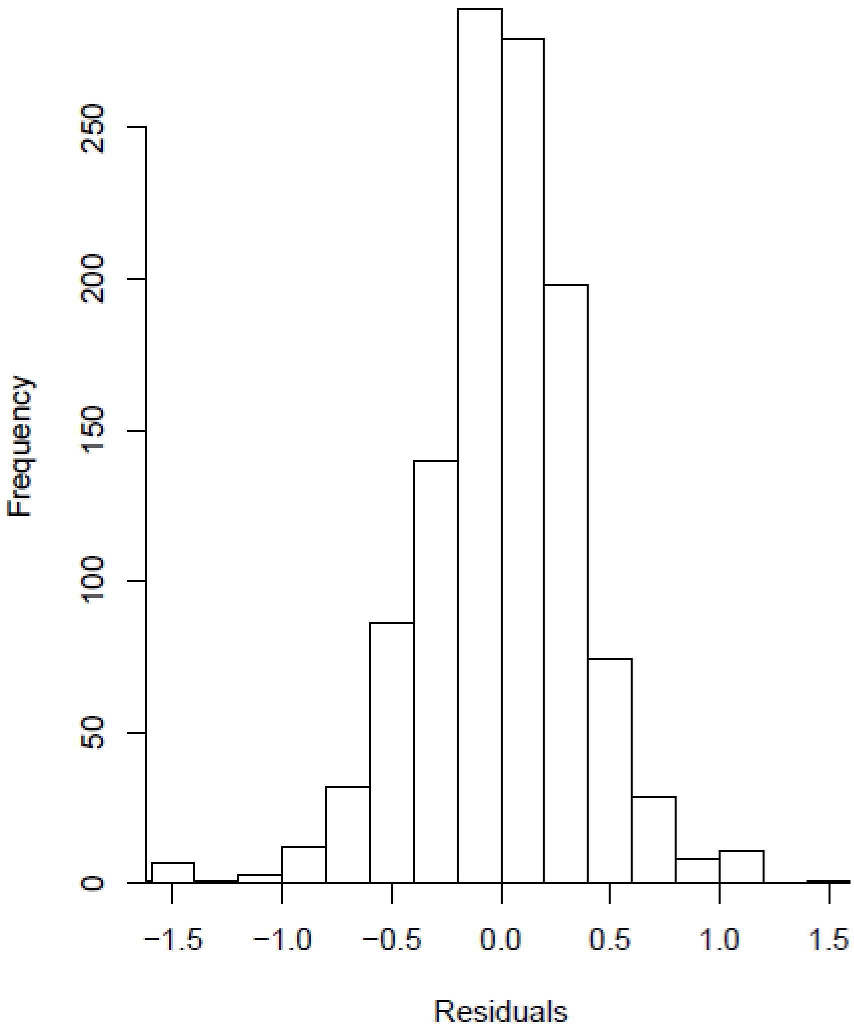


Figure 6. Aggregate distribution of log-deviations pooled over all 17 stocks.