Accounting for increased uncertainty in setting precautionary harvest limits from past assessments

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Abstract

Estimates of current population status, often express as spawning output, derived from stock assessments are uncertain. Management has adopted approaches to account for this uncertainty when setting harvest limits that will avoid overfishing for U.S. west coast groundfish stocks, as mandated by the Magnuson Stevens Fishery Conservation and Management Act. Currently, the Overfishing Limit (OFL), derived from the stock assessment and management proxies, is reduced by the uncertainty (σ) surrounding the estimated final year spawning output as a proxy for the OFL uncertainty when setting the Acceptable Biological Catch (ABC) for subsequent years. However, σ increases during the projection period of a stock beyond the final assessment year due to the increasing period over which true population dynamics may differ from the expected values (e.g. annual recruitment) for the modeled stock. While the current adjustment for σ may be appropriate for the years immediately following an assessment, subsequent future ABCs should account for the increased uncertainty in projected spawning output. Age-structured data-rich stock assessments for West Coast groundfish stocks were evaluated for changes in σ during the projection period where a low state of nature spawning output time series was compared to the management base assessment model time series values. The median σ between the low and base model's spawning output increased over the projection period across all stocks, ranging from the pre-defined σ value of 0.36 in the assessment year to 0.6 after projecting the stocks 10 years into the future. Grouping the results by life history categories, rockfish, roundfish, and flatfish stocks, used by the Pacific Fishery Management Council the σ values increased for all groupings with the rockfish stocks having the smallest increase in σ (0.36-0.46) and the flatfish stocks having the largest increase in σ (0.36-0.96) during the projection period. Applying the estimated σ values across life history groupings would result in ABC values that would be set at 0.956, the value applied when $\sigma = 0.36$, of the OFL in the assessment year with ABCs being set at

decreasing proportions to the OFL to 0.89 by year 10 of the projection period.

1 Motivation

Estimates of stock size and status produced by stock assessments are uncertain. It is important to account for this uncertainty when setting harvest limits that would avoid overfishing. The Pacific Fishery Management Council has specified levels of uncertainty based upon stock categorization (higher categories assume a higher level of uncertainty) when setting Annual Biological Catches (ABCs). The reduction between the assessment estimated Overfishing Limit (OFL) and the ABC is based on uncertainty surrounding stock size, termed "σ". The σ value adopted by management is based on the amount of uncertainty in the assessment year to reduce the forecasted OFLs. However, the more years removed from the year of the assessment the more uncertainty there is surrounding stock size and status based recruitment to the stock for unobserved years. To date, management has not adjusted the σ applied to set ABCs based on the time since last assessment. This work provides a way to account for increased uncertainty between assessments for US West Coast groundfish stocks based on the time since the last assessment for U.S. west coast groundfish stocks.

2 Materials and Methods

U.S. west coast groundfish stock assessments models were used to quantify potential changes in uncertainty given the length of time since the last assessment. Category 1, data rich age-structured population models, were examined. U.S. west coast groundfish assessment models used for management, referred to as the *base models*, were projected

-years into the future. Calculations for removals during the projection period and the resulting spawning output are based on the estimated base model parameters with recruitment set equal to that predicted from the stock-recruitment curve. The removals during the projection period were equal to the acceptable biological catch (ABC) where the ABC equaled the overfishing limit (OFL) reduced by 0.956, termed *the buffer*. The buffer value was based on the pre-defined default levels of scientific uncertainty ($\sigma_{\text{default}} = 0.36$) and management risk tolerance ($p = 0.45$) for a category 1 stock assessment. The default scientific uncertainty value for category 1 stocks managed by the PFMC is based on a meta-analysis that determined across and within stock assessment uncertainty for West Coast stocks for the final year estimated spawning output was 0.36 (Ralston et al. 2011). The meta-analysis used spawning output uncertainty as a proxy for OFL uncertainty.

U.S. west coast groundfish stock assessments express within model uncertainty through a Decision Table which creates a range of potential alternative states of nature, termed *low* and *high states of nature*, for the assessed population relative to the base model. The low and high states of nature are conditioned based on a single key parameter or a combination of multiple parameters that are considered highly uncertain or influential to estimated stock status or size. The Decision Table approach assigns a probability value for each state of nature where the base model is considered the most likely and is assigned a 50% probability and, both the low and high states of nature, are defined based on a 25% probability of being the true state of the stock.

This work applied the framework of alternative states of nature with corresponding probabilities associated with each state of nature as the true state of the stock to evaluate projection uncertainty. The states of nature available in assessment document Decision Tables are highly variable between assessments and can be based on a single parameter (most often) or a combination of parameters that were not necessarily the same across stocks (e.g., natural mortality, steepness, catchability by a survey). Here a standardized approach was developed and applied to define the low state of nature model relative to the base assessment model for West Coast groundfish stocks with category 1 assessments in order to quantify the change in uncertainty during the projection period. The first step in creating a standardized low state of nature population model was to identify the spawning output value that was a predefined fraction of the spawning output in the base model for the final model year. The low state of nature spawning output value in year y for the final year of the assessment model was calculated as:

$$SB_{\text{low},s,y=1} = \frac{SB_{\text{base},s,y=1}}{e^{\sigma_{\text{default}} * z_{\text{value}}}} \quad (1)$$

where $SB_{\text{base},s,y=1}$ is the spawning output of the base model for stock s in year y for the final year of the assessment model, σ_{default} is equal to 0.36, and z_{value} is set a 1.15. The z_{value} is based on the 75% confidence interval of the standard normal distribution (i.e., mean of 0 and standard deviation of 1).

A low state of nature spawning output time series was created in two steps; 1) finding and fixing the initial recruitment value, $R0$, to the value that results in the desired $SB_{\text{low},s,y=1}$ defined in equation 1 within a 1% margin while allowing for all other parameter values (e.g., recruitment deviations, selectivity, growth) to be estimated in the same manner as the base model and 2) fix the future removals in the low state of nature model during the projection period equal to the ABC catches from the base model. During the projection period, recruitment was predicted from the stock-recruit curve, same as future recruitments in the base model (however the realized recruits differed based on the between the low and base model varying spawning output levels). Each model was projected 10 years into the future. The projection period was selected based on current PFMC guidelines which require a 10 year projection to be included in each stock assessment to inform future management decision making.

The change in the spawning output during the projection period between the base and low states of nature were compared and the uncertainty between the projection spawning output time series was calculated as:

$$\sigma_{s,y} = \frac{log(SB_{\text{base},s,y}/SB_{\text{low},s,y})}{z_{\text{value}}} \tag{2}$$

The $\sigma_{s,y}$ value was standardized relative to the $\sigma_{s,y=1}$ for each stock comparison among stocks because the process for finding $R0$ allowed for a 1% difference between the target and accepted spawning biomass for the low state of nature model and hence the first year σ had minor differences (<0.01) among stocks. The notation for σ with subscripts dropped was used to refer to results that were summarized across stocks and represents a vector of yearly values across the 10 projection years.

Life history parameters from each base assessment model (e.g., natural mortality, maximum length) were recorded to investigate linkages between biological traits and assessment model projection uncertainty. Many U.S. west coast groundfish assessments assume sex-specific biology. Only the female biological parameters were used for comparisons with σ. A simple linear model was used to determine the predictive power of each life history parameter.

A list of the stocks that were evaluated are show in Table 1. The most recent benchmark assessment model for each stock was selected for evaluation. The PFMC defines a benchmark assessment model as a new evaluation of a stock where all previous data and modeling assumptions may be re-evaluated. One exception was made in the case of chilipepper rockfish, where an update assessment was used instead of the benchmark assessment because the most recent benchmark assessment, performed in 2007, was conducted using an out-of-date modeling platform which prohibited the creation of a low state of nature. In contrast to a benchmark assessment, an update assessment is defined as a re-evaluation of a stock where all previous data and modeling assumptions are retained and only the most recent data are added to the assessment model. Gopher rockfish was not included in this analysis since the stock assessment was down graded to category 3 in 2016, formerly category 1, because the assessment has not been performed since 2005.

The list of stocks included in this analysis include three species that have multiple area-based stock assessments; black rockfish, cabezon, and lingcod. Black rockfish has three area models used for management, however, only the California and Washington models are classified as category 1 assessments. The results from each area-based stock assessment were weighted, such that each species received the same weight in the final analysis when summarizing results across all species and life history groupings.

Based on management practices at the PFMC for U.S. west coast groundfish stocks, there are three groupings of species to consider; rockfish, roundfish, and flatfish. The three groundfish categories have group-specific proxy F_{MSY} harvest rates (Dorn 2002, Ralston 2002) which have been defined based upon life history traits. The change in σ during the projection period was evaluated by individual stock, grouped by life history, and across all species combined. The grouped results, either by life history or all species, were done using the weighted results. California scorpionfish are a member of the *Scorpaenidea* family within the *Scorpaeniformes* order, the same order that includes the rockfish genus (*Sebastes*). Hence, California scorpionfish were included in the rockfish life history based calculations. Finally, the estimated σ values for each projection year was used to calculate new yearly buffer values. The buffer was calculated based on the estimated σ values and a risk tolerance as:

$$\text{buffer} = e^{\sigma \Phi^{-1}(p^*)} \tag{3}$$

where Φ^{-1} is the inverse cumulative normal distribution function and p^* was equal to 0.45.

Coastal pelagic species, including Pacific Mackerel and Pacific sardine, are managed by the PFMC similarly to Groundfish stocks. However, due to the dynamics of pelagic species, they are typically assessed on an annual basis in contrast to groundfish species that often have multiple years between assessments. Due to the annual assessment frequency, pelagic species were not included in this analysis.

3 Results

The change in σ during the projection period between the base and low state of nature spawning outputs for each category 1 stock is shown in Figure 1. The rate of change in σ was variable across stocks. Kelp greenling, bocaccio rockfish, and Dover sole each had the largest increases in σ during the projection period with increases to 3, 3.1, and 3.4 times the initial σ in first year of the projection period, respectively. In contrast, some stocks had very little change in σ during the projection period. Aurora rockfish, yelloweye rockfish, splitnose rockfish and black rockfish (CA) had the smallest change between the base and low state of nature spawning output ranging between 1 - 1.2.

The species managed using separate area based assessment models, black rockfish, cabezon, and lingcod, often had variable results by area. The California north and California south models for cabezon had generally similar trends in the changes between the base and low spawning output values resulting in similar changes in σ, while the Oregon south model had a larger increase in σ during projections (Fig. 1). The projection period for the California and Washington black rockfish assessment models demonstrate two different patterns in σ during projections (Fig. 1). The Washington state black rockfish assessment model had small increases in σ while the California black rockfish model had little to no change, with even a small decrease in σ at the end of the projection period between the base and low spawning outputs. Both lingcod models had increasing uncertainty over the projection period, but the North model had a sharper increase in uncertainty by the end of the projection period. The contrast in results by area for black rockfish, cabezon, and lingcod suggests that both life history based population dynamics and modeling structure impact the change in σ.

Combining the individual results with area based models weighted accordingly there was an increasing trend in σ where the median change was 1.67 times the base σ of 0.36 resulting in an increase of σ to 0.6 by year 10 of the projection period (Table 4 and Fig. 2a). Grouping the results based of life history category, the change in σ over the projection period varied based on the life history grouping where rockfish had the smallest change in the median σ compared to roundfish and flatfish (Fig. 2b-d). The increase in σ by year 10 of the projection period for the rockfish, roundfish, and flatfish groups were 1.27, 1.69, and 2.66 times the base value of 0.36, respectively (Table 4). However, the results from the flatfish life history is based on only two stocks, petrale sole and Dover sole, and may not be representative of the uncertainty for future assessments of flatfish species.

The rockfish species were subdivided into two groups based on low and high natural mortality (M) where the estimated or fixed M values from the base models ranged from 0.035 - 0.235. The rockfish species included in the low M group, defined as $M < 0.10\text{yr}^{-1}$, listed in ascending order of M values were: aurora, yelloweye, splitnose, darkblotched, and canary rockfish. Widow, chilipepper, black, yellowtail, and bocaccio rockfish, listed in order of ascending M values, comprise the group with the relatively higher M values. The change in σ during the projection period when rockfish species were sub-divided showed a larger increase in σ for species with higher M (Fig. 3). The outlier for the low M rockfish species was canary rockfish which had a trend in σ that was more similar to the high M group than the low M species. The canary rockfish assessment has a unique specification of M where is is lower for fish younger than 6 years of age at a value of 0.052 and linearly increasing between age 6 and 13, peaking at a value of 0.10 for fish of age 14 and greater. For simplicity, this analysis used a weighted across age M value of 0.088.

Various life history parameters were examined in an attempt to determine predictive power for the change in σ. The year 10 projection standardized σ values and biological parameter values for females from each species, estimated or fixed with equally weighted biological values for area based assessments was plotted (Fig. 4). A linear model was fit to the data for each biological parameter separately with the line of the linear relationship and the R-squared associated with each parameter shown on each figure panel. None of the biological parameters examined had explanatory power related to the change in σ (Fig. 4). The subset of biological parameters examined were selected because they were thought to possibly be indicative of the population turn-over rate (e.g., M), the pace of life history dynamics (e.g., maturity, growth), or the variability of recruitment (e.g., σ_R) which could be influential in the rate of σ changes during the projection period.

While no relationship between the biological parameters examined and the final year σ was identified across all species, two potential relationships, primarily for rockfish species were identified when results were grouped by life history (Fig. 5). As observed in Figure 3, rockfish species with lower M values have reduced changes in σ compared to rockfish species with higher M (Fig. 5a). However, the relationship between M and σ for the higher natural mortality group was highly variable. The ratio between length at 50% maturity and maximum length and the σ for rockfish explained 54% of the total variation (Fig 5c). The ratio of length at 50% maturity and maximum length was derived as a measure of the rate of growth but that would also incorporate the trait of some rockfish maturing later at life, at sizes near their maximum length. The groupings of small and larger ratio values was similar to the low and high M grouping where species with low M had lower ratio values relative to species with higher M values. The only exception was black rockfish which was a higher M (0.17) but a lower ratio between length at 50% maturity and maximum length (1.24). The relationship between M and σ explained a large percentage of the total variation for the roundfish life history (Fig. 5b), but was only base upon four observations. The flatfish life history group was not explored because only two species were available for analysis.

The σ value by year, when all stock were combined, range from the current default projection year 1 value of 0.36 to 0.6 by year 10 (Table 5). The range over the projection period for rockfish was 0.36-0.46, roundfish 0.36-0.61, and flatfish 0.36-0.96. Currently, management applies a buffer fraction (or multiplier, eqn3), calculated based on a σ of 0.36 and p^* of 0.45, to reduce the OFL when setting ABCs across all projection years (e.g., ABC = 0.956$*$OFL). Applying the new σ values by year to determine the annual buffer value resulted in larger reductions to the OFL with a multiplier of 0.93 when calculated across all species and a reduction ranging between 0.89 - 0.94 dependent upon life history group, 10 years post the assessment year.

4 Tables

Table 1: Each stock and assessment model year used in the analysis

Life history	Stock	Model year
Rockfish	Aurora	2013
	Black (CA)	2015
	Black (WA)	2015
	Bococcio	2015
	California scorpionfish	2017
	Canary	2015
	Chilipepper	2015
	Darkblotched	2015
	Splitnose	2009
	Widow	2013
	Yelloweye	2017
	Yellowtail (north)	2017
Roundfish	Cabezon (OR-south)	2009
	Cabezon (CA-north)	2009
	Cabezon (CA-south)	2009
	Kelp greenling	2015
	Lingcod (north)	2017
	Lingod (south)	2017
	Sablefish	2011
Flatfish	Dover sole	2011
	Petrale sole	2013

Table 2: The median change in the standardized sigma across the projection period for all species combined and grouped by life history.

Projection year	All species	Rockfish	Roundfish	Flatfish
1	1.00	1.00	1.00	1.00
2	1.09	1.08	1.16	1.13
3	1.18	1.16	1.31	1.28
4	1.28	1.25	1.42	1.44
5	1.38	1.34	1.47	1.63
6	1.43	1.43	1.51	1.83
7	1.52	1.49	1.55	2.04
8	1.60	1.54	1.62	2.24
9	1.64	1.60	1.69	2.45
10	1.67	1.65	1.77	2.66

Table 3: New sigma values by projection year and the resulting OFL buffer value assuming a 0.45 risk tolerance probability for all species combined and by life history groups.

Projection	All		Rockfish		Roundfish		Flatfish	
year	Sigma	Buffer	Sigma	Buffer	Sigma	Buffer	Sigma	Buffer
1	0.36	0.96	0.36	0.96	0.36	0.96	0.36	0.96
2	0.39	0.95	0.39	0.95	0.42	0.95	0.41	0.95
3	0.43	0.95	0.42	0.95	0.47	0.94	0.46	0.94
4	0.46	0.94	0.45	0.95	0.51	0.94	0.52	0.94
5	0.50	0.94	0.48	0.94	0.53	0.94	0.59	0.93
6	0.51	0.94	0.51	0.94	0.54	0.93	0.66	0.92
7	0.55	0.93	0.54	0.93	0.56	0.93	0.73	0.91
8	0.58	0.93	0.56	0.93	0.58	0.93	0.81	0.90
9	0.59	0.93	0.57	0.93	0.61	0.93	0.88	0.90
10	0.60	0.93	0.59	0.93	0.64	0.92	0.96	0.89

5 Figures

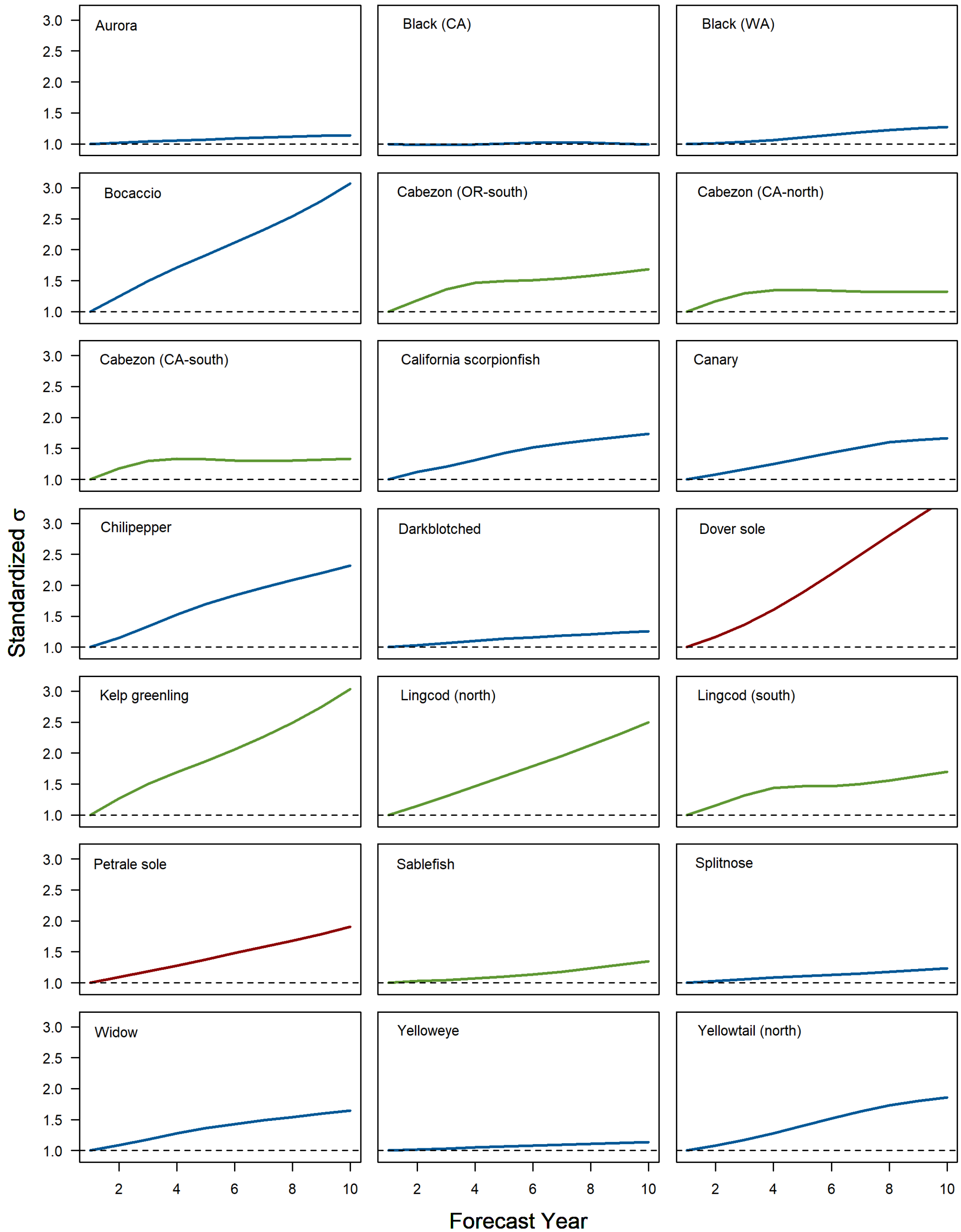

Figure 1: The change in σ during the projection period between the base and low state of nature for each stock. The final year value for dover sole of 3.4 was not shown due to scale. The life history groupings are indicated by line color where rockfish are shown in blue, roundfish in green, and flatfish in red.

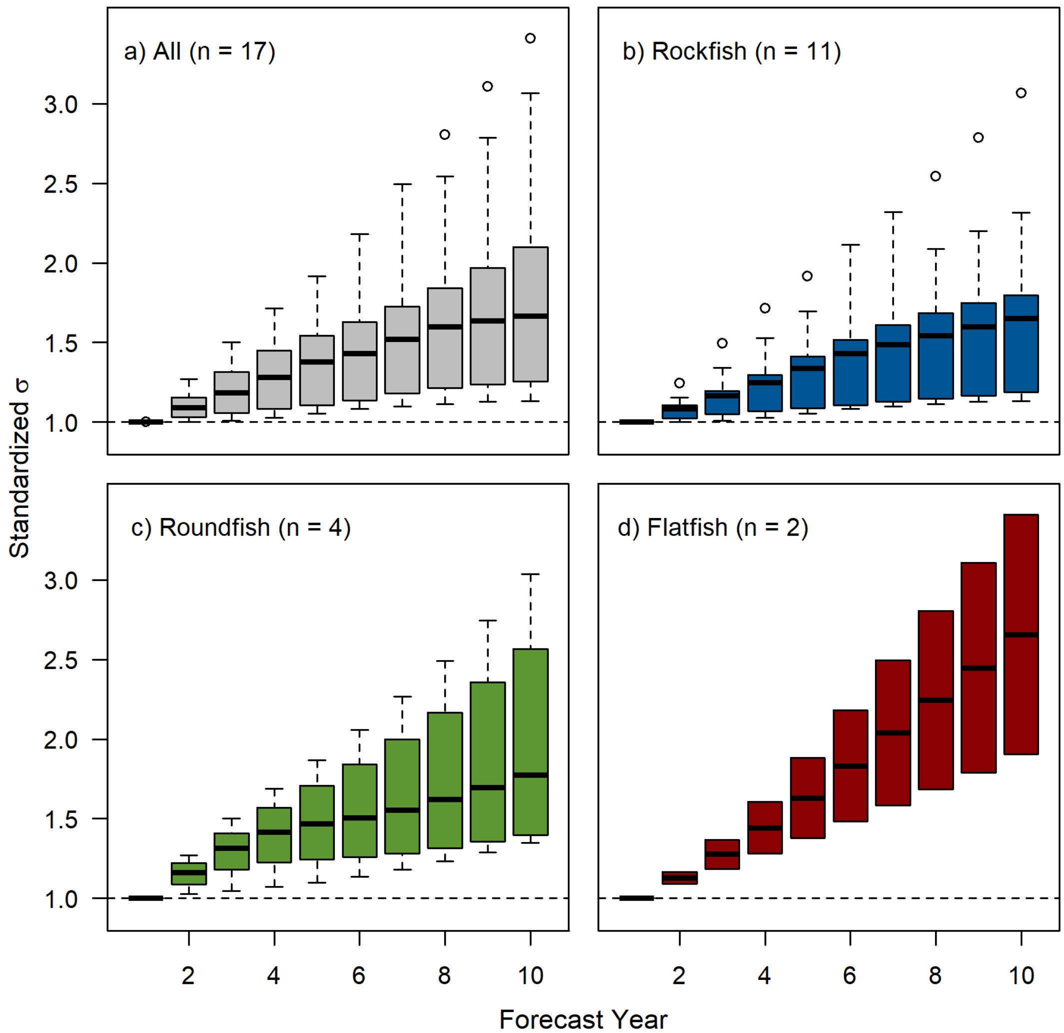

Figure 2: The change in σ during the projection period between the base and low state of nature grouped by life history. The number of species in each life history grouping is shown in each figure.

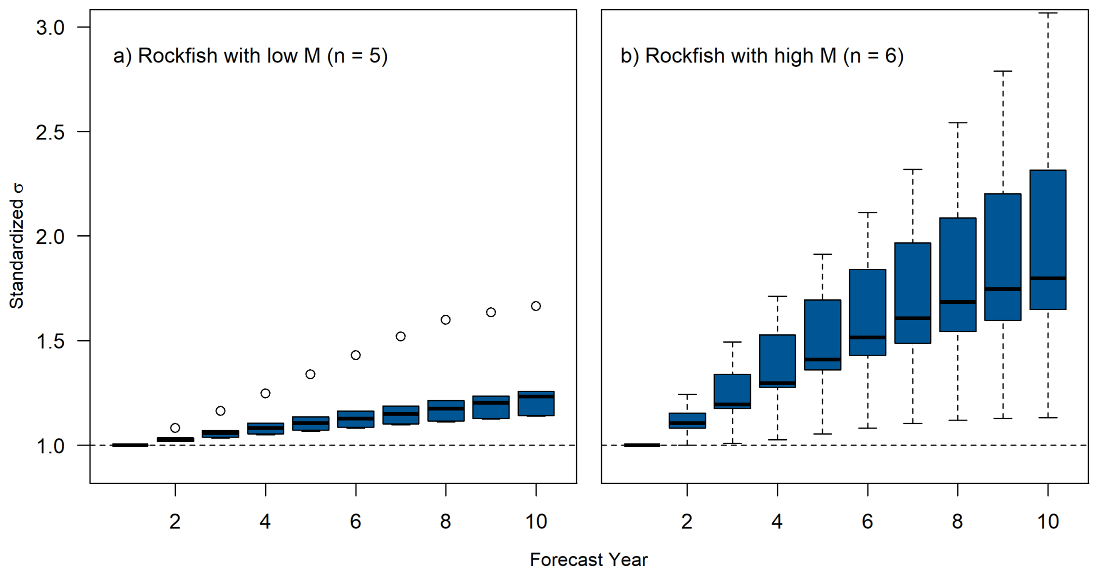

Figure 3: The change in σ during the projection period between the base and low state of nature for rockfish species with the results grouped by low natural mortality (>0.10 yr^{-1}) and higher natural mortality (<0.10 yr^{-1}) values. The low natural mortality group was composed of aurora, canary, darkblotched, splitnose, and yelloweye rockfish and the high mortality group was comprised of black, bocaccio, California scorpionfish, widow, and yellowtail rockfish.

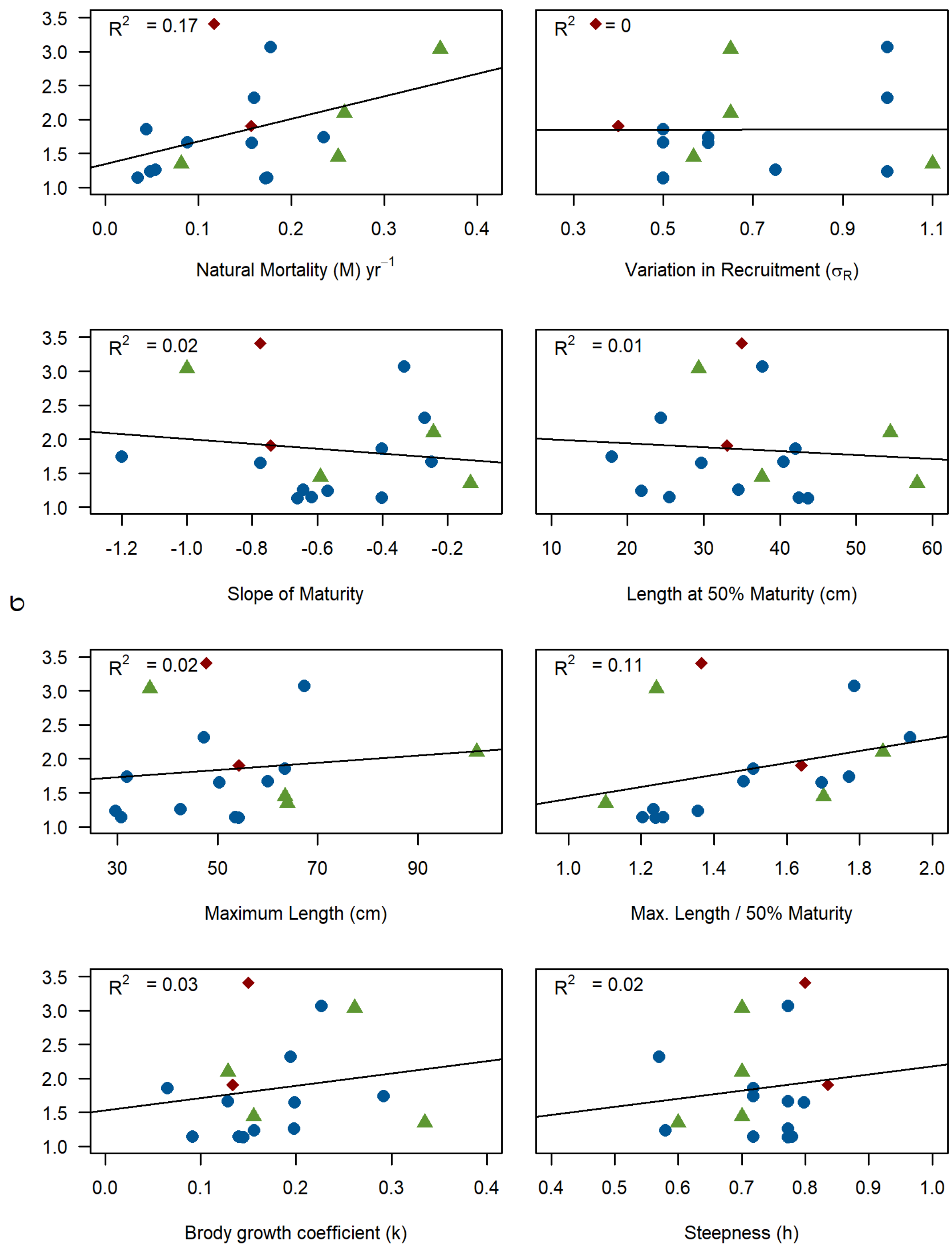

Figure 4: The relationship between the value of the in the standardized σ in year 10 and a range of life history parameters from the base models with rockfish species in blue circles, roundfish in green triangles, and flatfish in red diamonds. A linear model was fit to each life history parameter separately and the R-squared value calculated.

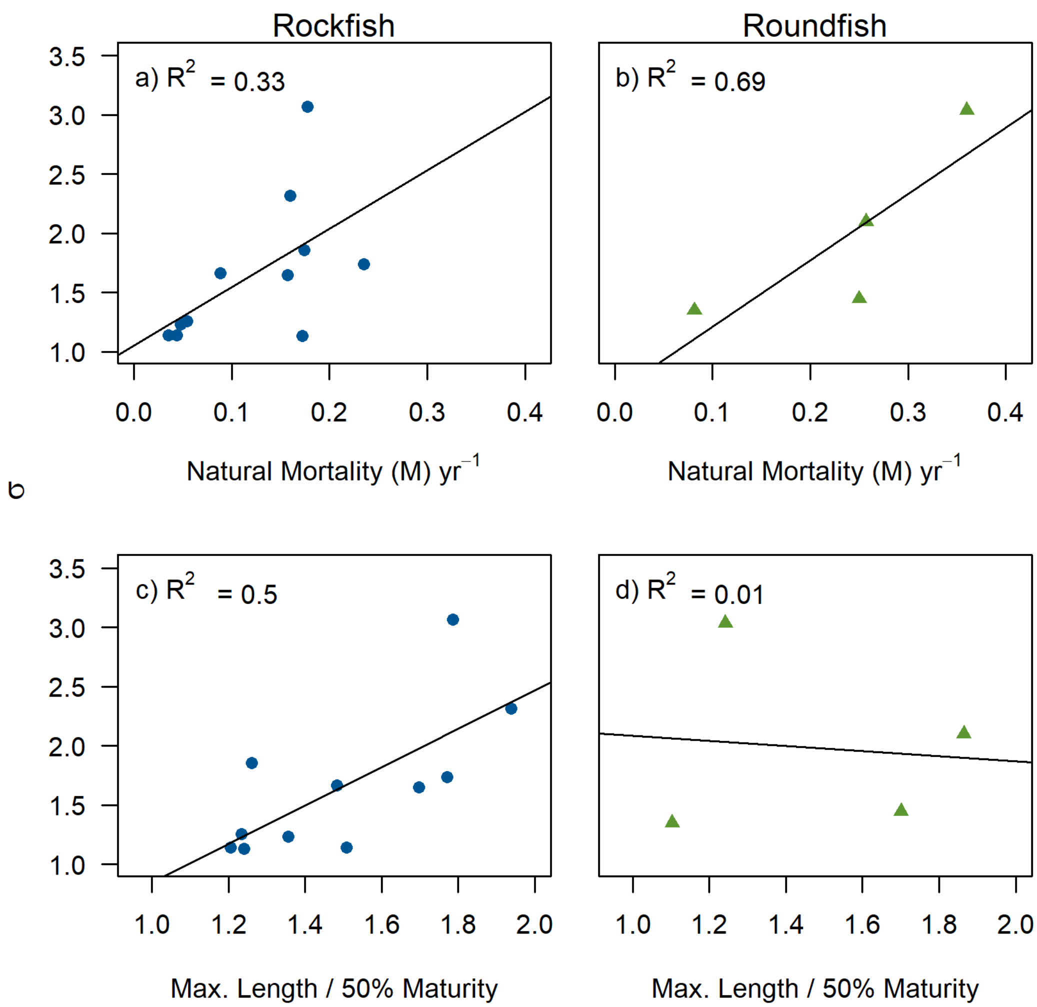

Figure 5: The relationship between the value of the in the standardized σ in year 10 and the ratio of length at maturity and maximum length for rockfish and roundfish species plotted separately. A linear model was fit to each life history parameter separately and the R^2 calculated.

6 Appendix

Fishery attainment of the ABC for Dover sole and chilipepper rockfish has been low in recent years due to interactions with catch limits for other species (e.g., sablefish ABC limits Dover sole catches and bocaccio rockfish ABC has limited chilipepper catches). Given the low attainments for each of these species the divergence between the base and low states of nature for each of these species with the full ABC removed may give an over-estimate of the divergence between the base and low states of nature given the low ABC utilization for each of these species. In order to understand the impact of including these species on the results these two species were removed from summary analyses here.

Table 4: The median change in the standardized sigma across the projection period for all species combined and grouped by life history when chilipepper and Dover sole were excluded from analysis. Flatfish only includes petrale sole and was not reported.

Projection year	All species	Rockfish	Roundfish
1	1.00	1.00	1.00
2	1.08	1.06	1.16
3	1.18	1.12	1.31
4	1.28	1.18	1.42
5	1.36	1.24	1.47
6	1.43	1.30	1.51
7	1.49	1.34	1.55
8	1.54	1.38	1.62
9	1.60	1.42	1.69
10	1.65	1.45	1.77

Table 5: New sigma values by projection year and the resulting OFL buffer value assuming a 0.45 risk tolerance probability for all species combined and by life history groups where chilipepper rockfish and Dover sole are excluded. Flatfish only includes petrale sole and was not reported.

Projection	All		Rockfish		Roundfish	
year	Sigma	Buffer	Sigma	Buffer	Sigma	Buffer
1	0.36	0.96	0.36	0.96	0.36	0.96
2	0.39	0.95	0.38	0.95	0.42	0.95
3	0.42	0.95	0.40	0.95	0.47	0.94
4	0.46	0.94	0.42	0.95	0.51	0.94
5	0.49	0.94	0.45	0.95	0.53	0.94
6	0.51	0.94	0.47	0.94	0.54	0.93
7	0.54	0.93	0.48	0.94	0.56	0.93
8	0.56	0.93	0.50	0.94	0.58	0.93
9	0.57	0.93	0.51	0.94	0.61	0.93
10	0.59	0.93	0.52	0.94	0.64	0.92

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