Alaska sablefish research update

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Summary

In this document we describe some completed and ongoing sablefish research related to stock assessment. In addition, a number of sensitivity model scenarios were conducted that incorporated some of the results of this research. Each section below provides a brief summary of current research and include some model scenarios related to that research. We also provide some guidance on our focus for future research projects.

Whale depredation and survey modeling

Accounting for whale depredation

Whale depredation has been an ongoing source of uncertainty for the sablefish assessment. Killer whale depredation of the sablefish catch on the longline survey has been a problem in the Bering Sea since the beginning of the survey (Sasaki, 1987). Depredation by killer whales has since been documented commonly in the Aleutian Islands and Western Gulf of Alaska. Since 1990, the depredated hachis (skates of 45 hooks), which were identified as depredated by a combination of damaged fish and damaged hooks, were excluded from calculations of abundance indices. At some stations this might result in a large amount of hachis being unused, or the entire station being unused. In management areas like the Bering Sea where there is limited sampling, this can lead to very few stations left to calculate abundance. In addition, if killer whales are non-randomly depredating on stations where fish are typically most abundant, this can lead to a downward bias of the index.

Sperm whale depredation has only been documented since 1998 and had primarily been a problem in the two Eastern Gulf of Alaska (GOA) management areas, but has recently become more common in the Central GOA and occasionally occurs in the Western GOA. Apparent sperm whale depredation is defined as sperm whales being observed and the occurrence of damaged fish. In contrast to killer whale depredation, sperm whale depredation is much more difficult to detect because sperm whales often only take a few fish, and rarely leave behind damaged fish like killer whales. Because actual depredation is difficult to detect, and therefore difficult to document by haul or specific hachis, we use sperm whale presence at a station as a proxy for depredation. Sperm whale presence and evidence of depredation has been variable since 1998.

A number of studies have examined whale depredation in different ways. An early study using data collected by fisheries observers in Alaskan waters found no significant effect on catch (Hill et al. 1999). In the 2002 SAFE, an analysis was completed using longline survey data from 1998-2001 and found that sablefish catches were significantly less at stations affected by sperm whale depredation. This work was redone in 2006 using additional data from 2002-2004 which were analyzed by fitting the data to a general linear model (Sigler et al. 2007). The 2007 study found that neither sperm whale presence (p = 0.71) nor depredation rate (p = 0.78) increased

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significantly from 1998 - 2004. Catch rates were about 2% less at locations where depredation occurred, but the effect was not significant (p = 0.34). This analysis was updated through 2009 and showed a significant effect of approximately four kilograms per hundred hooks for stations in the CGOA and EGOA, which translates into approximately a 2% decrease in the overall catch rates in those areas (J. Liddle pers. comm.). Another study using data collected in southeast Alaska, found a small, significant effect comparing longline fishery catches between sets with sperm whales present and sets with sperm whales absent (3% reduction, 95% CI of (0.4 – 5.5%), t-test, p = 0.02, Straley et al. 2005).

Hanselman et al. (2010) applied fixed effects zero-inflated negative binomial models to estimate the effect of sperm whale and killer whale depredation on the longline survey by individual management areas. They estimated that sperm whales decreased the EY/SE area index by 1-10% annually, while killer whales affected the Western GOA index by 5-30% annually. Petersen et al. (2013) used similar methods to estimate depredation effects of killer whales on fishery catch rates of six species including sablefish, Pacific cod, and halibut. They estimated that killer whales when present removed 54-72% of sablefish.

Given perfect data, most of these studies would have provided adequate estimates of the effects of whales. However, the occurrence of whale depredation is sporadic which creates unbalanced data. Analysis of unbalanced designs using fixed-effects models can result in poor estimation and inference compared to mixed-effects models (Zuur et al. 2009). The utility of accounting for depredation effects on survey estimates depends on the precision of model estimates as well as the nature of depredation effects. In particular, if depredation effects are themselves highly variable (e.g., reductions in catch differ appreciably from one event to the next, like killer whales), then it may not be advisable to “correct” for depredation using a single point estimate derived across numerous depredation events. Other options, such as discarding data from depredated skates, may provide preferable survey estimates.

Since Hanselman et al. (2010), we have conducted simulations and model comparisons to show that a generalized linear mixed effect model (GLMM) performs better than previous modeling methods, in terms of both accuracy and capturing an appropriate amount of uncertainty. A sperm whale correction derived from the GLMM performed better under simulation, whereas the benefits of a GLMM model correction for killer whales performed similarly to discarding depredated skates. We show applications of the estimated sperm whale depredation from these GLMM models in the ***Applications to the stock assessment*** section. These are in the model runs OAW, NAW, NAWK, and NAWA. The effect on the overall abundance index (e.g., Figures 1, 2) is between 2-5% for sperm whale depredation. Further details of these analyses will be presented as an appendix to the full November stock assessment.

While we believe we have determined a satisfactory correction for sperm whales, and possibly killer whales, it remains questionable when and whether to utilize these corrected indices in the assessment. First, we do not know the extent of sperm whale depredation prior to 1998 in the survey. Considering its apparent increase, we believe historically it may have been a minor impact, but it is an added uncertainty. Second, it may not be prudent to adjust for whale depredation in the survey and increase the estimates of spawning biomass and ABC, while still not accounting for the additional mortality in the fishery that can be attributed to whale depredation. We regard accounting for this additional mortality in the fishery as the second phase of this project, in which we will use similar modeling methods. The data available to estimate mortality in the fishery are sparse and obtaining precise estimates will be challenging. A post-doctoral researcher from the National Research Council will be starting in December 2014 to aid in this project. Finally, adjusting apportionment for the additional whale depredation is also an important consideration.

Applications to the stock assessment model

We conducted a number of sensitivity models with different potential mechanisms of accounting for mortality by sperm whale depredation on the survey and in the fishery (Table 1). There are a variety of ways one might consider accounting for this mortality. In Table 1 there are 21 model runs that have some scenario that could be related to whales. The major scenario groups are variations on these five themes that have what we consider to be plausible “low” and “high” states of nature:

1) Whale depredation is a source of fishing mortality, and it occurs on longline gear.
2) Whale depredation is an increase in natural mortality, as in the sablefish vulnerability to predators has been increased
3) Whale depredation began in 1998
4) Whale depredation has occurred throughout the modeled time series
5) Whale depredation has reduced survey catch rates

Most scenarios gave reasonably similar predictions for key parameters (Table 2).The lowest ABC projection was for the ICB scenario which added an increasing amount of catch to the fixed gear fleet since 1998. The highest ABC projections occurred for those scenarios where either natural mortality or survey RPNs was monotonically increasing since 1998 (IMB, ISB, Figure 3). As expected, most scenarios showed higher spawning biomass, ABCs, and recruitment from the reference model (BASE, Table 2, Figure 3). The range of estimates of female spawning biomass appear to be relatively insensitive to these different accounting of whale depredation (Figure 4, Table 3). However, when we look only at the recent series of female spawning biomass estimates in terms of absolute and relative differences (Figures 5, 6), the effects can be more easily perceived and appear more substantial. We believe that this range of scenarios sets reasonable boundaries on how accounting for whale depredation inside the stock assessment would affect model results. Some of the ABCs resulting from these scenarios are considerably larger than the reference case. However, it would be expected that if ABCs are increased by correcting for survey depredation, it would be necessary to somehow decrement those ABCs for the additional mortality caused by depredation in the fishery.

Variance estimation and missing areas

The longline survey index currently uses a fixed CV of 5% for sablefish in the stock assessment model. Some bootstrap analyses were conducted to arrive at this number (Sigler 2000), but it was an approximation because there is covariance between depth strata within a station and between station depth strata combinations. We have since developed more appropriate analytical variance estimates that include covariances and the additional variance introduced by correcting for whale depredation. For the most part, the coefficients of variation (CVs) for the all-area index were not on average much different than the assumed 5%. However, there is some interannual variability, and the method now provides variance estimates for smaller geographic regions, which will be useful for spatial models and other groundfish assessments that utilize the longline survey index. The estimated coefficients of variation for sablefish from 1990-2013 are shown in Figure 7.

The Aleutian Islands (AI) and Bering Sea (BS) are sampled biennially. The abundance index for the unsampled years are filled in using the previous survey of the area scaled by the average change in the Gulf of Alaska areas, which are sampled annually. In this case, the average GOA index is calculated from the four management areas in the GOA. This approach has an obvious drawback if the six areas are relatively uncorrelated in trend. For example, when the observed

mean catch/hachi is plotted by area, it is clear that the Bering Sea index is not positively correlated with any of the other areas, and the Aleutian Islands area is significantly negatively correlated with the Central Gulf of Alaska. Therefore, using this approach across all areas may result in a retrospective bias if estimates in unsampled areas do not match the underlying trend for that area. To fill in the missing years, we demonstrated two alternative methods that have been shown to be useful by the Plan Team working group on survey averaging. In our sensitivity results we show the effect of using an ARIMA (0,2,2, local linear smoothing) model and a random effects model to fill in the BS and AI missing years from 1996-2013. The choice of which of these methods is superior is not yet clear, but they have large effects on the overall RPN index in some years (Figure 8). These are shown in models NAWA and NAWK in Table 1.

New survey area sizes

Previous estimates of the size of each geographic area used to estimate RPNs and RPWs were devised before geographic information systems (GIS) and accurate, high resolution bathymetric maps were readily available. Echave et al. (2013) estimated the area sizes currently used in the AFSC longline survey using GIS methods and updated bathymetry. The largest increase in estimated area sizes occurred in Spencer Gully (in the EY/SE management area) and Bering 3 slope areas (Figure 9). The largest negative changes were in the NW Aleutians slope and East Yakutat slope areas. Overall, more areas were calculated to be smaller than the previously used estimates. Only the shallowest depth stratum used in standard RPN/RPW calculations (200-300 meters) increased, while the areas in deeper depths decreased slightly (Figure 10). In addition, Echave et al. (2013) estimated the size of the areas in the depths sampled between 150-200 m which previously were not used in abundance index calculations. The addition of these depths in the RPN/RPW index increases the potential utility of the longline indices for species such as Pacific cod, halibut and rockfish. We show the effect of the area recalculation on the overall sablefish RPN index for the base model (Figures 11, 12) and in model runs beginning with OA, and NA in Table 1.

Maturity research

The first age at maturity and fecundity study of female sablefish sampled in Alaska near their spawning period was undertaken in 2011. Skipped spawning was documented for the first time in sablefish. These winter samples provided a similar age at 50% maturity estimate (6.8 years) as the mean of visual observations taken during summer surveys from 1996-2012 (mean = 7.0 years) and the estimate currently used in the assessment (mean =6.6 years), when skipped spawners were classified as mature. Interestingly, skipped spawning appeared to be occurring for a substantial portion of the older mature population in shallower shelf waters which could have implications for population dynamics. In addition, four female sablefish were fit with pop-off satellite tags during the winter survey. Despite being a highly migratory species throughout their lives, preliminary results of this tagging data suggest that these sablefish exhibited site fidelity during the spawning season. This may be related to whether a fish is spawning in the current season. The paper describing the study is in the process of being submitted for publication.

Movement

A study on sablefish movement and mortality has been accepted for publication. The analysis included over 300,000 tag releases and over 27,000 tag recoveries from 1979-2009. Movement

was modeled in three size groups, small (<57 cm), medium (57 – 66 cm), and large (>66 cm) which corresponded approximately to immature, maturing, and mature fish. Annual movement probabilities were high, with annual probabilities ranging from 10-88%, depending on area of occupancy at each time step, and size group. Overall, movement probabilities were very different between areas of occupancy and moderately different between size groups (Figure 13). Estimated annual movement of small sablefish from the Central GOA had the reverse pattern of a previous study using a small subset of these data, with 29% moving westward and 39% moving eastward. The previous study showed movement of small fish to be primarily westward. Movement probabilities in the current study also varied annually with decreasing movement until the late 1990s, and increasing movement until 2009. Year specific magnitude in movement probability of large fish was highly negatively correlated with the total female spawning biomass estimate from the federal stock assessment. This may indicate that slower somatic growth at high population sizes leads to lower movement probabilities. Total average mortality estimates from time at liberty were similar to the values estimated by the stock assessment model. Results do not show an obvious ecologically directed movement pattern. The analysis in this study was conducted using sablefish lengths, but efforts are underway to read ages from a sample of otoliths taken from tag recoveries. These data will aid in estimating age-specific movement and be more useful for conducting management strategy evaluations of spatial stock assessment models.

Fishery abundance index

Estimating abundance from fishery dependent data is a well known challenge. Alaska sablefish is the only model in Alaska that incorporates fishery CPUE data as an index of abundance. Presently, longline CPUE is determined through a targeting algorithm, but not statistically standardized. During a one year National Research Council appointment, Mateo and Hanselman (2014) developed several statistical models that appear to hold promise for modeling fishery CPUE for standardization. Covariates that explained the most variation in the models were CPUE of giant grenadier, depth, longitude, and Pacific halibut CPUE. We wish to extend these models to develop an index for use in the sablefish model, and to potentially estimate whale depredation effects on the fishery. This work will continue as a new postdoctoral researcher from the NRC joins us in December, 2014.

Apportionment

In 2013, we recommended that the apportionment proportions to each area be fixed at 2012 values. We justified this because the apportionment strategy was devised to reduce interannual variability in catch recommendations while still reflecting shifts in abundance. We showed that this variability in catch recommendations by area had been increasing since 2007. While some of these changes may actually reflect interannual changes in regional abundance, they most likely reflect the high movement rates of the population and the high variability of our estimates of abundance in the Bering Sea and Aleutian Islands due to whale depredation and estimating abundance index values in years when these areas are not sampled.

Because of the high variability in apportionment seen in recent years, we suggested that the standard method was not meeting the goal of reducing the magnitude of interannual changes in the apportionment. We, therefore, proposed that the apportionment scheme be reevaluated.

A Ph.D. project with the University of Alaska-Fairbanks was initiated in 2012 to conduct management strategy evaluations to re-examine the apportionment strategy with respect to biological and economic yield. The student involved has been working closely with us and has begun testing spatial sablefish stock assessment models to be used in evaluating apportionment. It will also be important to integrate continuing research into whale depredation effects into analyses regarding the implications of different apportionments. The apportionment strategies being tested will focus on objectives that include but are not limited to:

1) Reduce annual variation in TAC changes
2) Maximizing economic yield by region and for the total fishery
3) Maximizing sustainable yield by region and for the total fishery
4) Maintaining a minimum level of harvest in every region

Some apportionment strategies that may attain these goals may include:

1) Status quo (5 year exponential average of fishery and survey abundance)
2) Apportion from terminal year abundance of a spatially explicit model
3) Apportion based on a longer term (e.g., 10 year) average
4) Equal allocation (Divide TAC by the number of regions)
5) Apportion based on size or numbers (to protect spawning biomass)

Meanwhile, for the same reasons we presented in 2013, until the apportionment scheme has been adequately evaluated it seems prudent to keep the apportionment fixed until there are other viable options to be considered. Therefore, for 2015, we recommend keeping the apportionment fixed from 2014, so that all areas ABCs change equally in accordance with the model results.

Future

There has been much recent research progress on sablefish stock assessment. However, several major challenges remain that include estimating and accounting for whale depredation in the fishery, evaluating the current apportionment strategies, developing a spatial research model of sablefish that includes movement, and determining the ecological basis of year class strength. There is ongoing or planned research for each of these challenges. We are trying to develop a portfolio of complementary model changes before implementing work already accomplished because many changes require other work to balance them. The most obvious example is accounting for whale depredation. We have the potential to correct survey estimates now, but developing estimates for the fishery that account for whale depredation is more difficult. Because it is fishery data, it is noisy, and the observations of depredation are sparse and unbalanced. Thus, we can develop these estimates but they will be less certain than those we can obtain for the survey. In addition, part of our fishery abundance index includes logbook data which do not include whale depredation observations. Until we have both fishery and survey estimates and a good way to use them in concert, it would be unwise to apply one alone. We will be conducting a sablefish CIE review in 2016.This review will provide expert opinion

regarding the results of these research projects and provide advice to help integrate the findings into the sablefish stock assessment. We then hope to incorporate this work into the assessment model and bring forward a benchmark assessment.

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Table 1. List of scenarios with different ways to correct for sperm whale depredation, including new variance estimates for longline survey abundance, and using new area sizes.

Test	***Description***
BASE	Base model
CB	Increase fixed gear catch by 5% in all years
CS	Increase fixed gear catch by 2% in all years
CSB	Increase fixed gear catch and longline RPN by 5% in all years
CSS	Increase fixed gear catch and longline RPN by 2% in all years
EM	Estimate M deviations from 1998
ICB	Increasing trend on fixed gear catch by 1% per year since 1998
ICS	Increasing trend on fixed gear catch by 0.5% per year since 1998
ICSB	Increasing trend of fixed gear catch and longline RPN by 1% since 1998
ICSS	Increasing trend on fixed gear catch and longline RPN by 0.5% since 1998
IMB	Increasing trend of M by 1% per year since 1998
IMS	Increasing trend of M by 0.5% per year since 1998
ISB	Increasing trend on longline RPN by 1% per year since 1998
ISS	Increasing trend on longline RPN by 0.5% per year since 1998
MB	Increase M by 5% in all years
MS	Increase M by 2% in all years
NA	New longline survey area sizes
NAW	New longline survey area sizes with survey sperm whale correction
NAWA	New longline survey area sizes with survey sperm whale correction, and ARIMA area fill
NAWK	New longline survey area sizes with survey sperm whale correction, and random effects area fill
OA	Base model with survey variance estimates
OAW	Base model with survey sperm whale correction
SB	Increase longline RPN by 5% in all years
SS	Increase longline RPN by 2% in all years

Table 2. Key results from various scenarios for accounting for sperm whale depredation, re-estimating survey variance, and new survey areas (see descriptions of scenarios in Table 1).

Test	-lnL	ABC	Catchability	Projected SSB	2008 YC	B40
BASE	1390.54	13.70	7.75	91.14	20.75	106.36
CB	1389.98	13.52	7.66	91.43	21.28	108.97
CS	1390.12	13.62	7.71	91.26	20.95	107.41
CSB	1389.98	13.53	8.04	91.47	21.29	108.99
CSS	1390.19	13.63	7.86	91.26	20.96	107.41
EMS	1390.54	13.70	7.75	91.14	20.75	106.36
ICB	1385.73	13.09	7.67	89.29	21.69	108.13
ICS	1387.98	13.39	7.71	90.22	21.21	107.22
ICSB	1395.85	17.20	7.63	104.24	25.34	112.51
ICSS	1392.21	15.37	7.69	97.52	22.93	109.36
IMB	1385.89	17.57	7.60	88.72	23.14	85.33
IMS	1387.84	15.84	7.67	90.00	21.87	95.35
ISB	1399.85	17.93	7.70	106.23	24.34	110.79
ISS	1394.55	15.70	7.72	98.47	22.46	108.51
MB	1390.88	14.81	7.61	91.81	21.84	103.78
MS	1390.45	14.14	7.69	91.42	21.18	105.28
NA	1398.37	13.88	7.41	91.61	21.58	106.66
NAW	1403.19	14.79	7.40	95.17	22.01	107.72
NAWA	1399.36	15.75	7.38	98.65	22.89	108.76
NAWK	1426.32	16.92	7.32	101.60	25.65	109.45
OA	1399.74	13.84	7.57	91.57	21.30	106.64
OAW	1404.07	14.74	7.56	95.05	21.75	107.69
SB	1390.54	13.71	8.13	91.18	20.75	106.38
SS	1390.54	13.70	7.90	91.16	20.75	106.37

Table 3. Female spawning biomass trajectories from model scenarios for accounting for sperm whale depredation, re-estimating survey variance, and new survey areas (see descriptions of scenarios in Table 1).

Year	BASE	CB	CS	CSB	CSS	EMS	ICB	ICS	ICSB	ICSS	IMB
1977	129	132	130	132	130	129	129	129	129	129	129
1978	117	120	119	120	119	117	117	117	118	118	118
1979	112	115	113	115	113	112	112	112	113	113	112
1980	107	109	108	109	108	107	107	107	108	108	107
1981	106	108	106	108	106	106	106	106	106	106	106
1982	109	111	110	111	110	109	109	109	110	109	109
1983	121	123	122	123	122	121	121	121	122	121	121
1984	136	139	138	139	138	136	137	137	138	137	137
1985	152	155	153	155	153	152	152	152	154	153	153
1986	165	169	167	169	167	165	166	166	168	166	167
1987	171	175	173	175	173	171	172	172	174	173	173
1988	170	174	172	174	172	170	171	171	173	172	172
1989	164	167	165	167	165	164	164	164	166	165	165
1990	154	157	155	157	155	154	155	154	157	155	156
1991	143	146	144	146	144	143	144	144	146	145	145
1992	132	134	133	134	133	132	133	133	135	134	134
1993	122	123	122	123	122	122	123	122	125	123	124
1994	111	112	111	112	111	111	112	111	114	113	113
1995	103	104	103	104	103	103	104	103	106	104	105
1996	98	99	98	99	98	98	99	98	101	100	100
1997	95	96	95	96	95	95	96	95	99	97	97
1998	92	93	92	93	92	92	93	93	96	94	94
1999	88	89	89	89	89	88	90	89	93	91	91
2000	85	86	85	86	85	85	87	86	90	87	88
2001	82	83	82	83	82	82	83	83	87	85	84
2002	82	82	82	82	82	82	83	82	87	84	84
2003	84	85	84	85	84	84	85	84	90	87	86
2004	87	88	87	88	87	87	89	88	95	91	90
2005	92	92	92	92	92	92	93	92	100	96	95
2006	98	98	98	99	98	98	99	98	108	103	101
2007	103	104	103	104	103	103	104	103	114	108	106
2008	105	106	105	106	105	105	106	105	117	111	107
2009	104	105	104	105	104	104	105	104	116	110	106
2010	102	103	102	103	102	102	102	102	115	108	103
2011	100	100	100	100	100	100	100	100	112	106	100
2012	96	97	97	97	97	96	96	96	109	103	96
2013	93	94	93	94	93	93	92	93	106	100	92

Table 3 (cont.). Female spawning biomass trajectories from model scenarios for accounting for sperm whale depredation, re-estimating survey variance, and new survey areas (see descriptions of scenarios in Table 1).

Year	IMS	ISB	ISS	MB	MS	NA	NAW	NAWA	NAWK	OA	OAW	SB	SS
1977	129	129	129	134	131	129	129	129	128	129	129	129	129
1978	118	118	118	122	119	117	118	118	117	117	118	117	117
1979	112	113	113	117	114	112	113	113	112	112	113	112	112
1980	107	108	108	111	109	107	108	108	107	107	107	107	107
1981	106	106	106	109	107	105	106	106	105	105	106	106	106
1982	109	110	109	113	110	109	109	109	109	109	109	109	109
1983	121	122	121	125	122	120	121	121	121	120	121	121	121
1984	137	138	137	141	138	136	137	137	137	136	137	136	136
1985	152	153	152	157	154	151	152	152	152	151	152	152	152
1986	166	167	166	171	167	165	166	166	166	165	166	165	165
1987	172	173	172	177	174	171	172	172	172	171	172	171	171
1988	171	172	171	176	173	170	171	171	171	170	171	170	170
1989	164	166	165	169	166	163	164	164	164	163	164	164	164
1990	155	156	155	159	156	154	154	155	155	154	154	154	154
1991	144	145	144	147	145	143	144	144	144	143	144	143	143
1992	133	134	133	136	134	132	133	133	133	132	133	132	132
1993	123	124	123	125	123	121	122	122	122	121	122	122	122
1994	112	113	112	114	112	111	112	112	112	111	112	111	111
1995	104	105	104	105	104	103	103	104	104	103	104	103	103
1996	99	100	99	100	99	98	99	100	100	98	99	98	98
1997	96	98	96	97	96	96	96	97	97	96	97	95	95
1998	93	95	93	94	93	93	94	95	95	93	94	92	92
1999	90	92	90	90	89	90	91	91	91	90	91	88	88
2000	86	89	87	87	86	86	88	88	88	86	88	85	85
2001	83	86	84	84	83	83	85	85	85	83	85	82	82
2002	83	86	84	83	82	83	84	85	84	83	84	82	82
2003	85	89	86	85	84	85	86	88	86	85	87	84	84
2004	88	93	90	89	88	88	90	91	89	88	90	87	87
2005	93	99	95	94	92	92	95	96	93	92	95	92	92
2006	99	106	102	100	98	98	101	103	100	98	101	98	98
2007	104	113	107	105	103	103	106	108	105	103	106	103	103
2008	106	116	110	107	105	105	108	111	108	105	108	105	105
2009	105	116	110	106	105	104	107	110	108	104	107	104	104
2010	103	115	108	104	103	102	105	108	107	102	105	102	102
2011	100	113	106	101	100	99	103	106	106	99	103	100	100
2012	96	110	103	97	97	96	100	103	104	96	100	96	96
2013	93	108	100	94	94	93	97	100	102	93	97	93	93

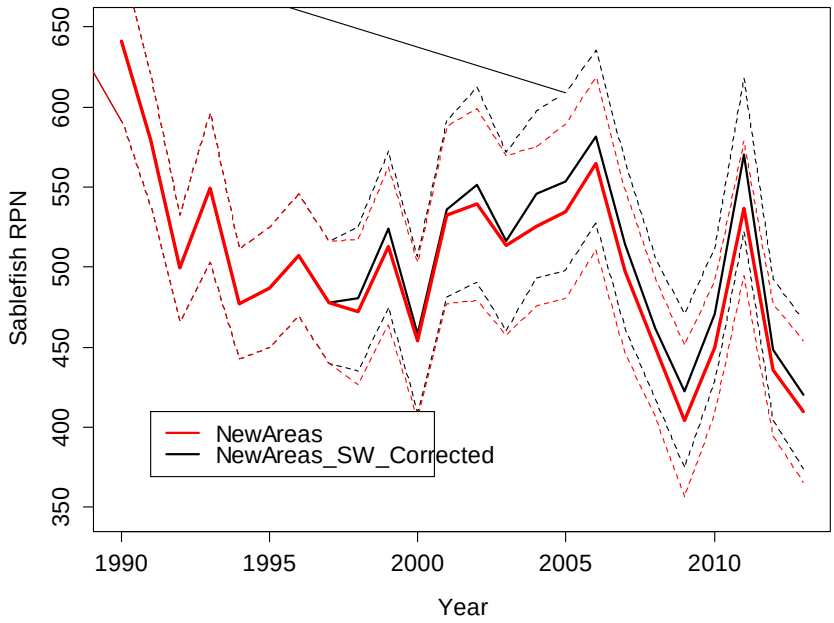

Figure 1. An example of the effect of correcting for sperm whale depredation. Models correspond to NA and NAW in Table 1.

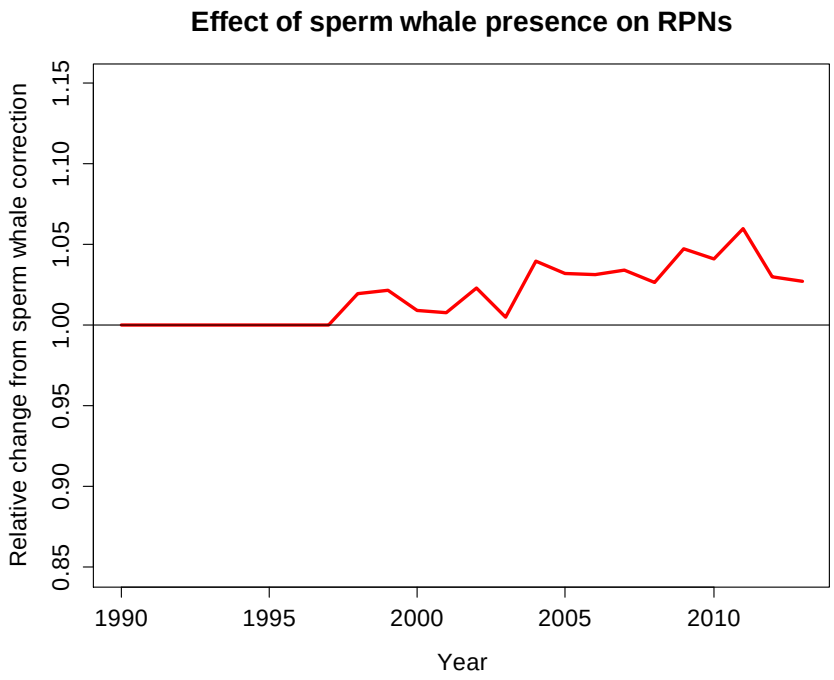

Figure 2. The net increase in the index from the base model after correcting for sperm whale depredation. Black line at 1 corresponds to the NA model, red line is the NAW model in Table 1.

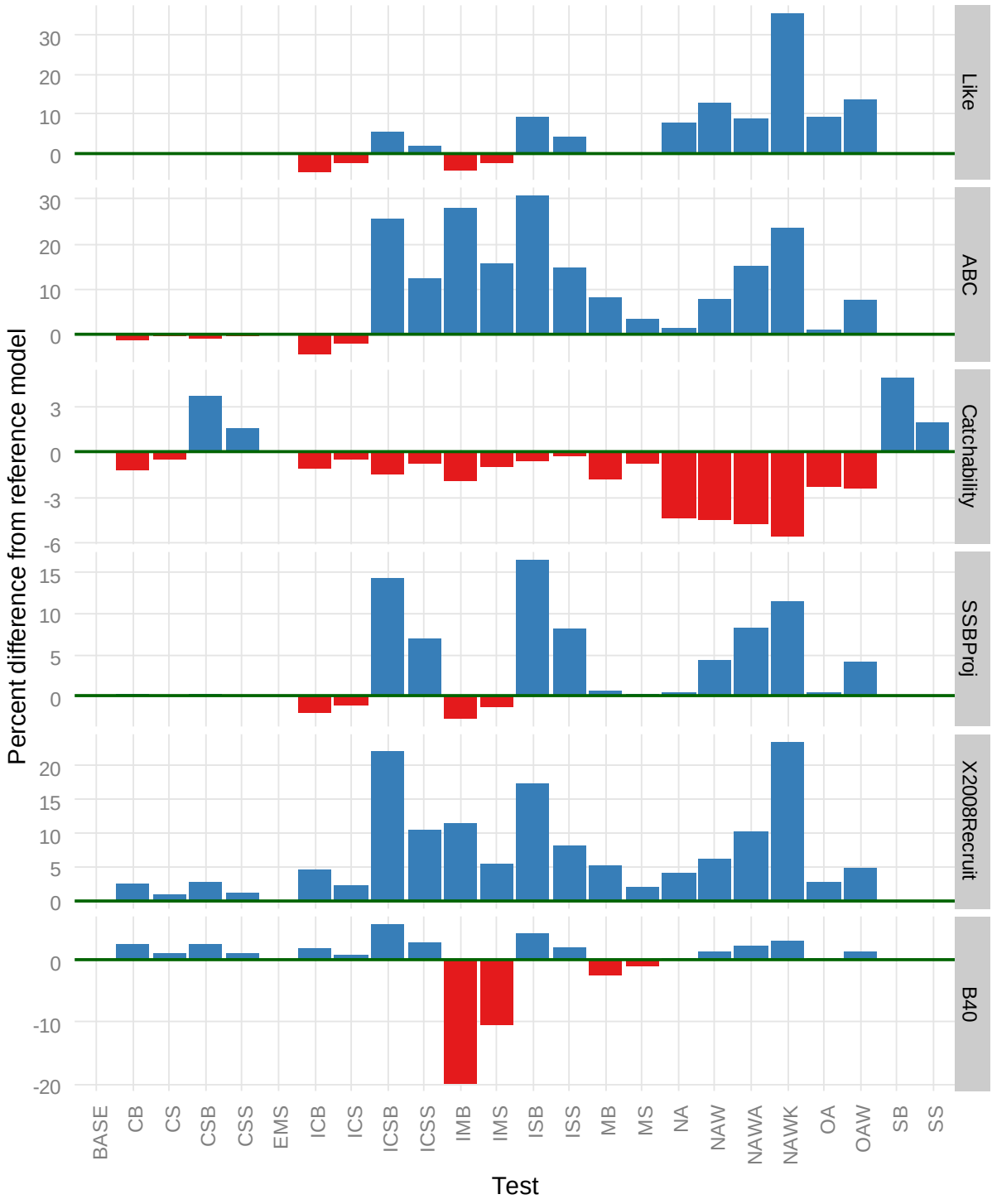

Figure 3. Relative change in key results from sensitivity tests described in Table 1.

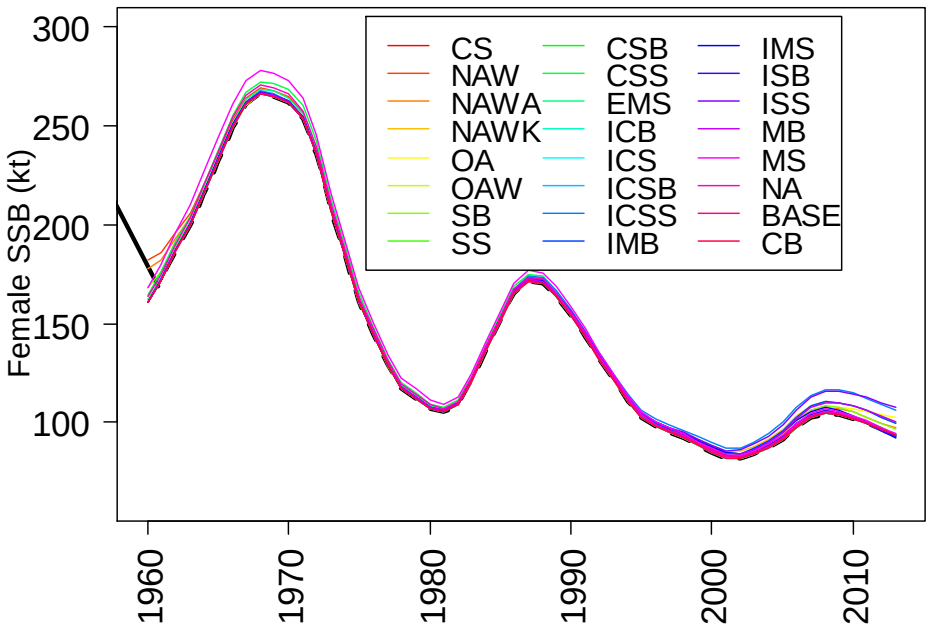

Figure 4. Plots of female spawning biomass for sablefish model sensitivity tests from 1960-2013. Dashed black line is overplotted on the line for BASE model.

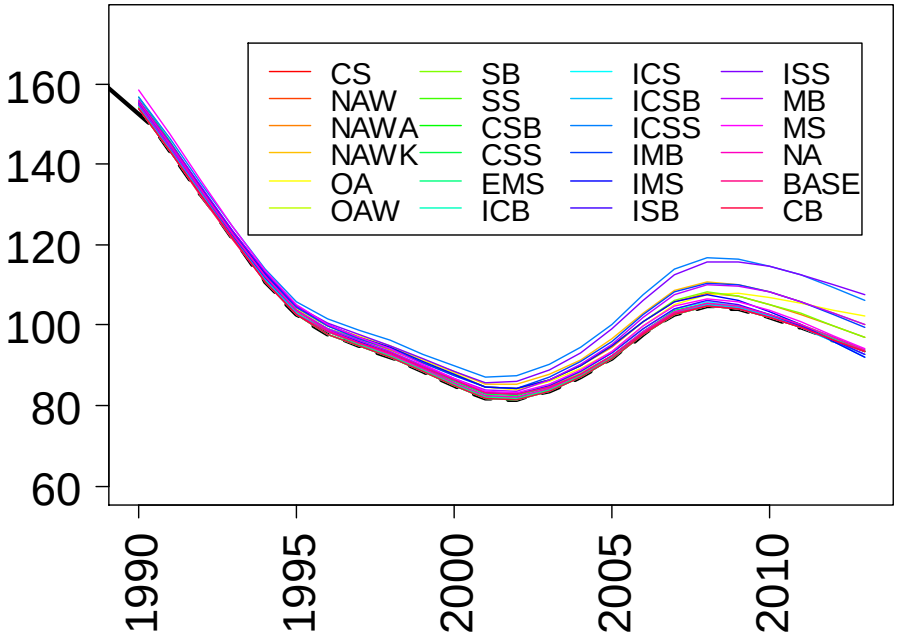

Figure 5. Plots of female spawning biomass for sablefish sensitivity tests from 1990-2013. Dashed black line is overplotted on the line for BASE model.

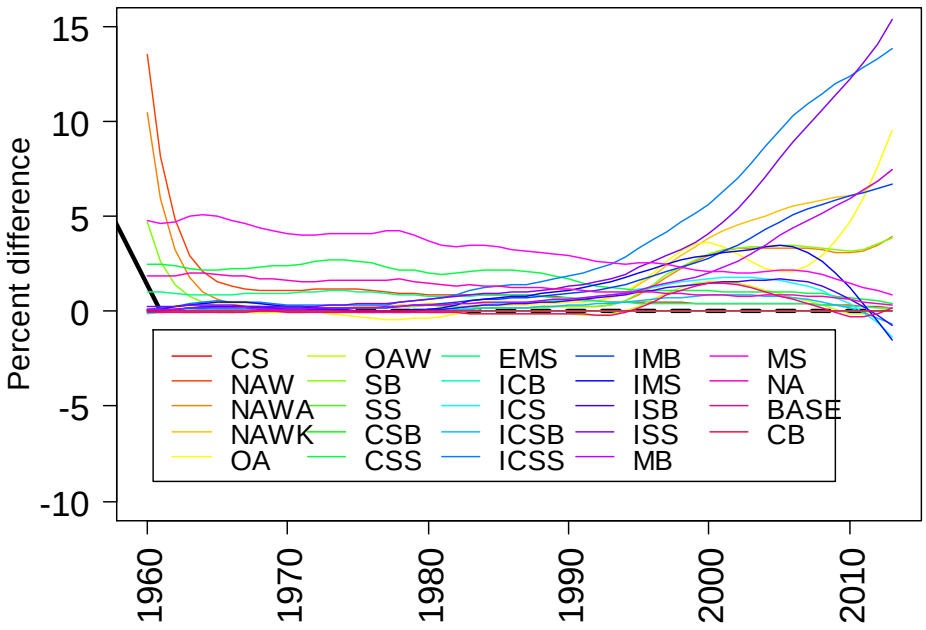

Figure 6. Plots of relative female spawning biomass to reference model for sablefish sensitivity tests from 1990-2013. Dashed black line is overplotted on the line for BASE model.

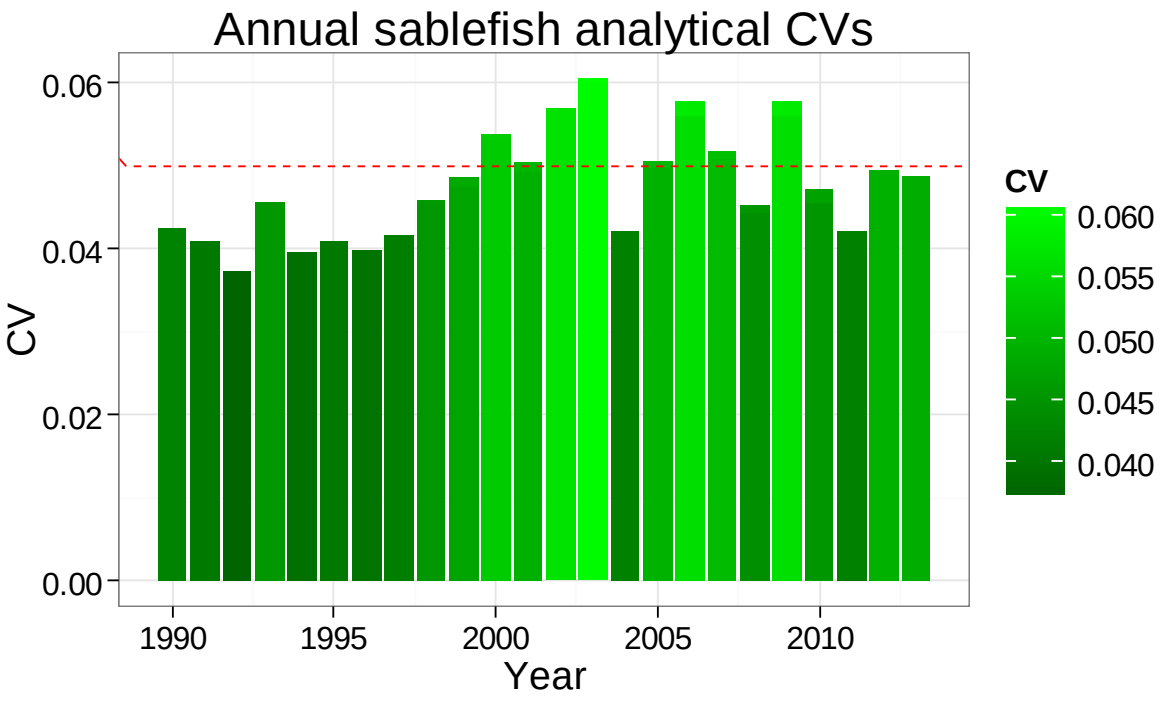

Figure 7. Time series of coefficients of variation (CV) for the all-area sablefish longline RPN index. Five percent CV line is marked as a red dash line.

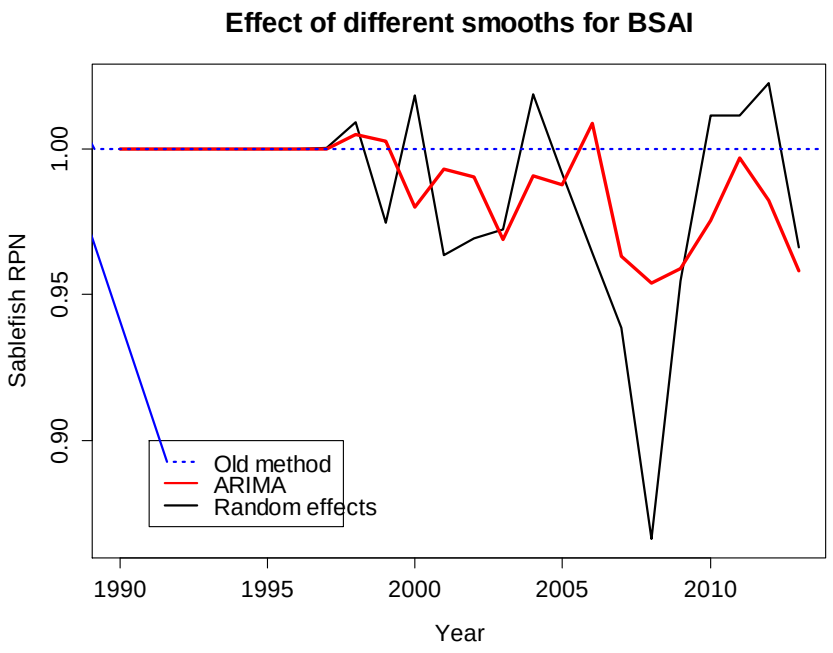

Figure 8. The use of an ARIMA model and a random effects model to fill in missing years for the Bering Sea and Aleutian Islands areas and the effect on the sablefish RPN index.

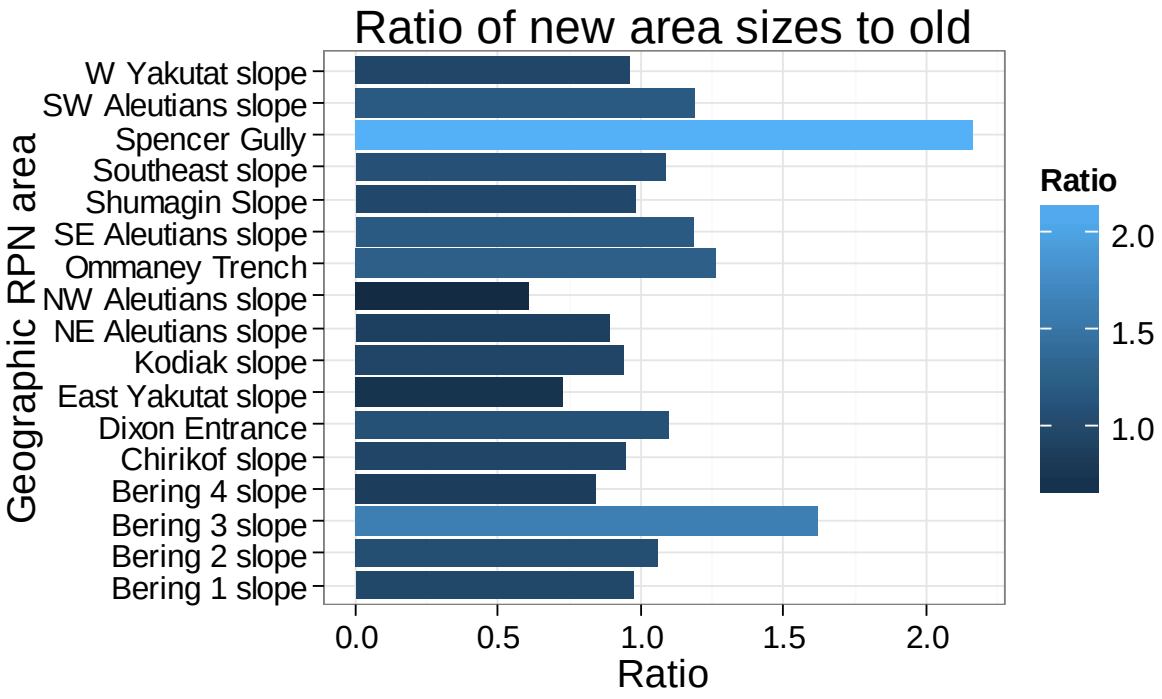

Figure 9. The ratio of new area sizes calculated in Echave et al. (2013) to the area sizes currently used in the sablefish stock assessment by small geographic areas.

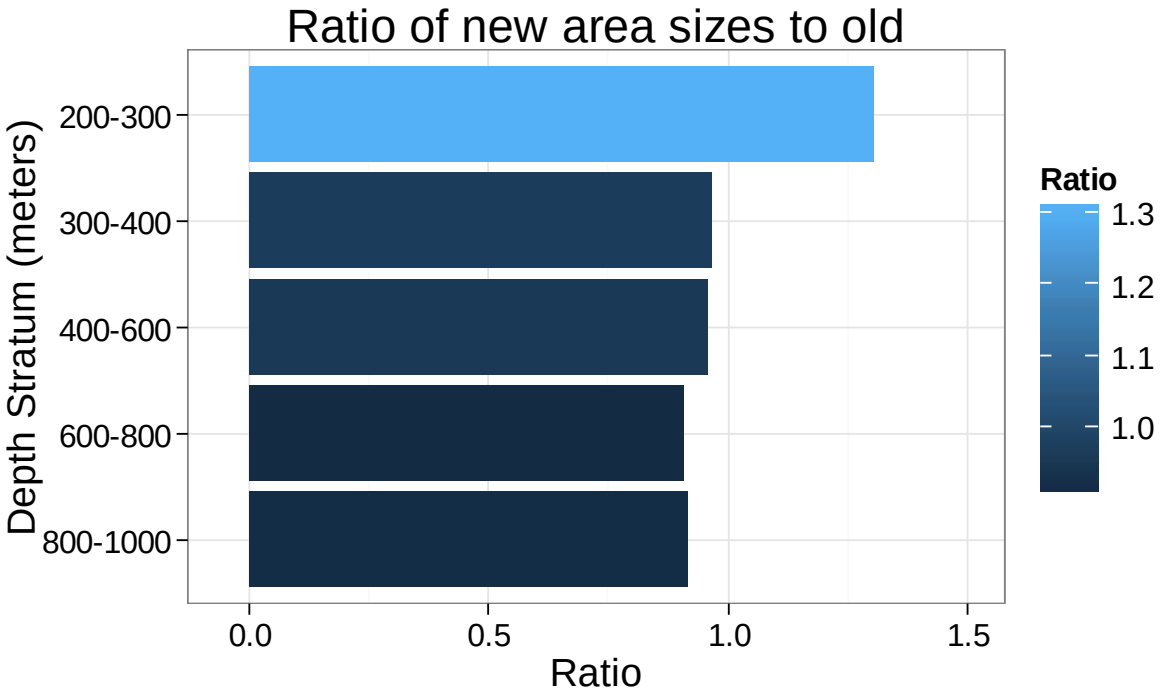

Figure 10. The ratio of new area sizes calculated in Echave et al. (2013) to the area sizes currently used in the sablefish stock assessment by depth strata.

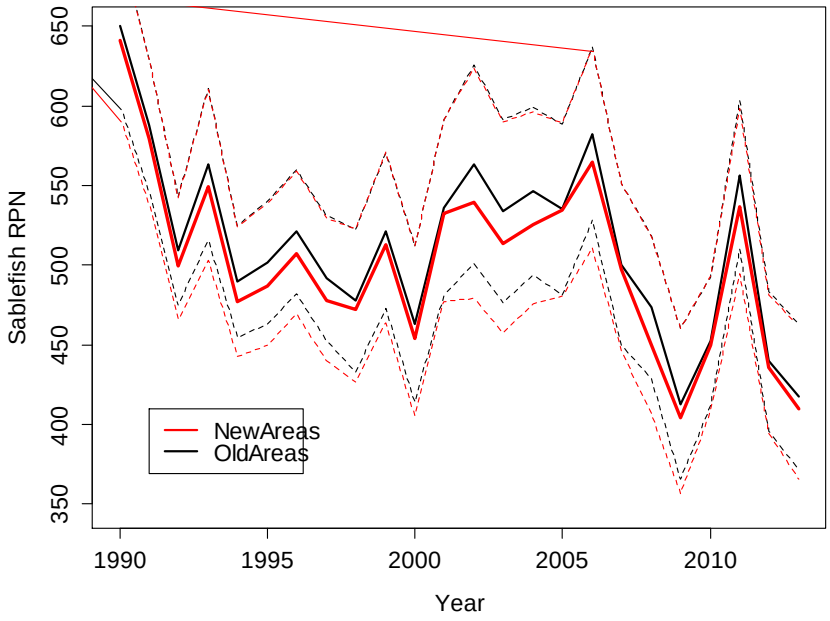

Figure 11. Estimates of sablefish RPNs using new calculated area sizes from Echave et al. (2013) versus using old area sizes used in Hanselman et al. (2013).

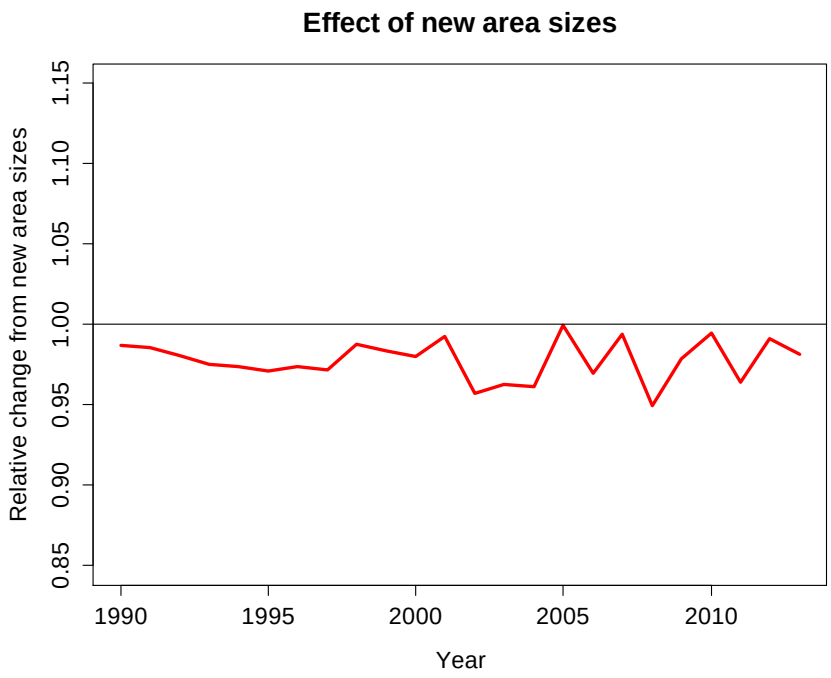

Figure 12. Net effect of new area sizes. Line at 1 is the reference line from the base model in Hanselman et al. (2013).

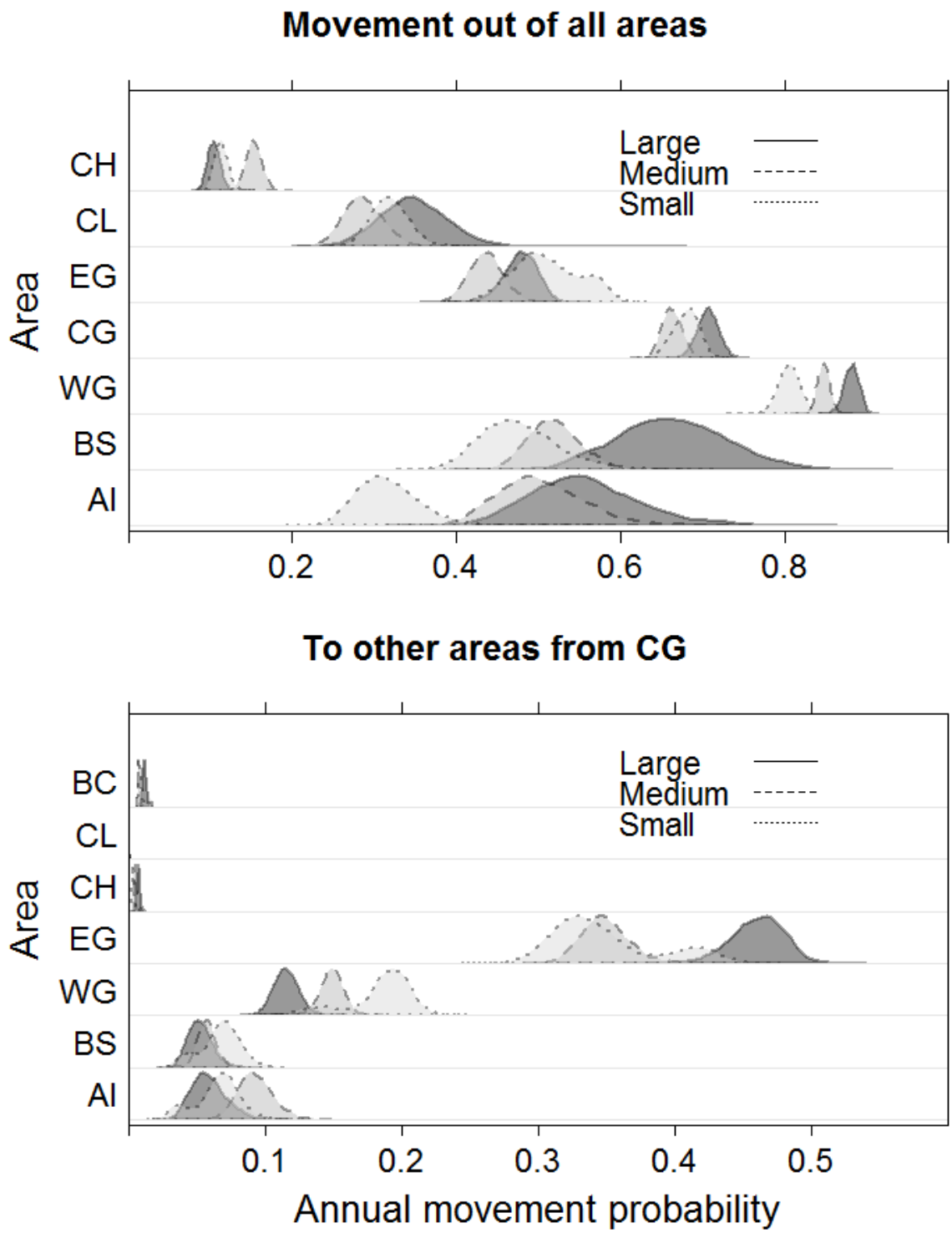

Figure 13. Posterior probability distributions of annual sablefish movement probability by size group and area. Top panel is movement probability out of each area. Bottom panel is movement probability to each area from the central Gulf of Alaska. AI = Aleutian Islands, BS = Bering Sea, WG = western Gulf of Alaska, CG = central Gulf of Alaska, EG = eastern Gulf of Alaska, CH = Chatham Strait, CL = Clarence Strait, Small = <57 cm, Medium = 57-66 cm, Large = >66 cm.