5. Assessment of the Deepwater Flatfish Stock Complex in the Gulf of Alaska

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Executive Summary

Summary of Changes in Assessment Inputs

(1) 2014-2015 catch data were included in the model
(2) 2013 catch was updated to include October-December catch in that year
(3) 2014 and 2015 fishery length composition data were added to the model and 2013 fishery length composition data were updated to include October-December data in that year
(4) The 2015 survey biomass index was added to the model
(5) Survey length composition data for 2015 were added to the model
(6) 2015 Survey ages measured within each length bin were added to the model
(7) Effective sample sizes for fishery and survey length and age data were changed to the number of hauls for which length or age data were measured, respectively.
(8) Length and age composition data were iteratively re-weighted using the harmonic mean of effective sample size, with effective sample size calculated according to the methods described in McAllister and Ianelli (1997).
(9) Bias adjustment parameters were updated
(10) Length-based fishery selectivity was estimated using an asymptotic selectivity curve (double normal selectivity without descending limbs). In the previous model, dome-shaped selectivity was estimated, but standard deviations associated with descending limb parameter estimates were very large, indicating that data are not informative about the descending limb parameter.

Summary of Results

The key results for the assessment of the deepwater flatfish complex are compared to the key results from accepted 2014 assessment in the table below. The results for Dover sole are based on the author's base case model and Tier 3a management.

Species	Quantity	As estimated or *specified last* year for: 2015	2016	As estimated or *recommended this* year for: 2016*	2017*
Dover sole	*M* (natural mortality rate)	0.085	0.085	0.085	0.085
	Tier	3a	3a	3a	3a
	Projected total (3+) biomass (t)	182,160	181,691	141,824	143,007
	Projected Female spawning biomass (t)	67,156	67,868	49,179	49,271
	$B_{100\%}$	70,544	70,544	56,729	56,729
	$B_{40\%}$	28,218	28,218	22,692	22,692
	$B_{35\%}$	24,690	24,690	19,855	19,855
	F_{OFL}	0.12	0.12	0.12	0.12
	$maxF_{ABC}$	0.1	0.1	0.1	0.1
	F_{ABC}	0.1	0.1	0.1	0.1
	OFL (t)	15,749	15,559	10,858	10,924
	maxABC (t)	13,151	12,994	9,043	9,097
	ABC (t)	13,151	12,994	9,043	9,097
Greenland turbot	Tier	6	6	6	6
	OFL (t)	238	238	238	238
	maxABC (t)	179	179	179	179
	ABC (t)	179	179	179	179
Deepsea sole	Tier	6	6	6	6
	OFL (t)	6	6	6	6
	maxABC (t)	4	4	4	4
	ABC (t)	4	4	4	4
Deepwater Flatfish Complex	OFL (t)	15,993	15,803	11,102	11,168
	maxABC (t)	13,334	13,177	9,226	9,280
	ABC (t)	13,334	13,177	9,226	9,280
	Status	As determined in 2014 for: 2013	2014	As determined in 2015 for: 2014	2015
	Overfishing	no	n/a	no	n/a
	Overfished	n/a	no	n/a	no
	Approaching overfished	n/a	no	n/a	no

*Projections are based on estimated catches of 256.8 t and 345.6 t used in place of maximum permissible ABC for 2015 and 2016, respectively. The 2015 projected catch was calculated as the current catch as of October 10, 2015 added to the average October 10 – December 31 catches over the 5 previous years. The 2016 projected catch was calculated as the average catch from 2010-2014. The maximum permissible ABC for 2017 was used as the projected catch for 2017.

The table below specifies apportionment of ABCs among management areas. Area-specific ABCs are calculated as the total ABC multiplied by the proportion of deepwater flatfish survey biomass found in each area from 2005-2015.

Quantity	Western	Central	West Yakutat	Southeast	Total
	2.0%	37.9%	32.5%	27.6%	100.0%
2016 ABC (t)	186	3,496	2,997	2,548	9,226
2017 ABC (t)	187	3,516	3,015	2,563	9,280

Responses to SSC and Plan Team Comments on Assessments in General

GPT comment: *The Teams recommend that the random effects survey smoothing model be used as a default for determining current survey biomass and apportionment among areas.*

The random effects model was used in the current assessment to estimate 2016 and 2017 survey biomass, proportion of survey biomass expected in each management area in 2016 and 2017, and apportionment of ABCs and OFLs according to these estimates of survey biomass in each area.

SSC comment: *Of the options presented in the Joint Plan Teams minutes <for model numbering>, the SSC agrees that that Option 4 has several advantages and recommends that this Option be advanced next year. Under Option 4, analysts would number their models as follows: "Alpha-numeric model identifiers incorporating two-digit year labels of the form "yy.jx," where the digit after the decimal ("j") represents a major accepted model change and the alphabetic character ("x") represents a proposed model change (e.g., "12.1c" and "13.4a" might describe two models introduced in 2012 and 2013, respectively)". Differences between major and minor changes would be calculated based on "average difference in spawning biomass" (ADSB: see equation in Team Procedures) or as noted in sub-option c below, some other improvement to the model.*

The above system for numbering models will be adopted for the next assessment, as recommended by the SSC.

Responses to SSC and Plan Team Comments Specific to this Assessment

GPT, Nov. 2013: The Team recommended that the random effects survey averaging approach be explored for potential application to the apportionment calculations for this stock assessment.

The random effects survey averaging approach was considered for use for apportionment calculations for this stock assessment; the GPT decided to base apportionment on the average survey biomass of deepwater flatfish from 2005-2015.

GPT, Nov. 2013: Based on suggestions from the author, the Team recommended that the next assessment include additional investigation of catchability, and natural mortality (perhaps not assuming a fixed value).

Additional investigations of natural mortality and catchability will be addressed in the next Dover sole assessment.

GPT, Nov. 2013: The Team requests the author complete the stock structure template for review in September.

A stock structure template will be completed in 2016.

GPT, Nov. 2013: The Team also recommended that the items listed for future research by the author be pursued.

The 2015 assessment re-visited effective sample sizes, setting effective sample sizes to the number of hauls. The 2015 assessment also re-visited data weighting, as well as the shape of the fishery selectivity curve.

SSC, Dec. 2013: The SSC looks forward to completion of the stock structure template for this complex next year as well as additional investigation of catchability and natural mortality in the next assessment of Dover sole.

A stock structure template will be completed in 2016.

Introduction

The "flatfish" species complex previous to 1990 was managed as a unit in the Gulf of Alaska (GOA). It included the major flatfish species inhabiting the region, with the exception of Pacific halibut. The North Pacific Fishery Management Council divided the flatfish assemblage into four categories for management in 1990; "shallow flatfish" and "deep flatfish", flathead sole and arrowtooth flounder. This classification was made because of significant differences in halibut bycatch rates in directed fisheries targeting the shallow-water and deepwater flatfish species. Arrowtooth flounder, because of high abundance and low commercial value, was separated from the group and managed under a separate acceptable biological catch (ABC). Flathead sole were likewise assigned a separate ABC since their distribution over depths overlaps with that of the shallow-water and deepwater groups. In 1993, rex sole was split out of the deepwater management category because of concerns regarding the bycatch of Pacific ocean perch in the rex sole target fishery.

The deepwater complex, the subject of this chapter, is composed of three species: Dover sole (*Microstomus pacificus*), Greenland turbot (*Reinhardtius hippoglossoides*) and deepsea sole (*Embassichthys bathybius*). Dover sole dominates the biomass of the deepwater complex in research trawl surveys and fishery catch (typically over 98%). Little biological information exists for Greenland turbot or deepsea sole in the GOA. More information exists for Dover sole, which allowed the construction of an age-structured assessment model in 2003 (Turnock et al., 2003).

Greenland turbot have a circumpolar distribution and occur in both the Atlantic and Pacific Oceans. In the eastern Pacific, Greenland turbot are found from the Chukchi Sea through the Eastern Bering Sea and Aleutian Islands, in the GOA and south to northern Baja California. Greenland turbot are typically distributed from 200-1600 m in water temperatures from 1-4 °C, but have been taken at depths up to 2200 m.

Dover sole occur from Northern Baja California to the Bering Sea and the western Aleutian Islands; they exhibit a widespread distribution throughout the GOA (Hart, 1973; Miller & Lea, 1972). Adults are demersal and are mostly found at depths from 300 m to 1500 m.

Dover sole are batch spawners; spawning in the GOA has been observed from January through August, peaking in May (Hirschberger & Smith, 1983). The average 1 kg female may spawn 83,000 advanced yolked oocytes in about 9 batches (Hunter, Macewicz, Lo, & Kimbrell, 1992). Although the duration of the incubation period is unknown, eggs have been collected in plankton nets east of Kodiak Island in the summer (Kendall & Dunn, 1985). Larvae are large and have an extended pelagic phase that averages about 21 months (Markle, Harris, & Toole, 1992). They have been collected in bongo nets only in summer over mid-shelf and slope areas in the GOA. The age or size at metamorphosis is unknown, but pelagic postlarvae as large as 48 mm have been reported and juveniles may still be pelagic at 10 cm (Hart, 1973). Juveniles less than 25 cm are rarely caught with the adult population in bottom trawl surveys (Martin & Clausen, 1995).

Dover sole move to deeper water as they age and older females may have seasonal migrations from deep water on the outer continental shelf and upper slope where spawning occurs to shallower water mid-shelf in summer time to feed (tagging data from California to British Columbia; Demory et al., 1984, Westrheim et al., 1992). Older male Dover sole may also migrate seasonally but to a lesser extent than females. The maximum observed age for Dover sole in the GOA is 59 years.

Fishery

Since passage of the MSFMCA in 1977, the flatfish fishery in the GOA has undergone substantial changes. Until 1981, annual harvests of flatfish were around 15,000 t, taken primarily as bycatch by foreign vessels targeting other species. Foreign fishing ceased in 1986 and joint venture fishing began to account for the majority of the catch. In 1987, the GOA-wide flatfish catch increased nearly four-fold, with joint venture fisheries accounting for all of the increase. Since 1988, only domestic fishing fleets are allowed to harvest flatfish. As foreign fishing ended, catches decreased to a low of 2,441 t in 1986. Catches subsequently increased under the joint venture and then domestic fleets to a high of 43,107 t in 1996. Catches then declined to 23,237 t in 1998 and were 22,700 t in 2004.

The GOA deepwater flatfish complex of species is caught in a directed fishery primarily using bottom trawls. Fewer than 20 shore-based catcher-type vessels participate in this fishery, together with about 6 catcher-processor vessels. Fishing seasons are driven by seasonal halibut PSC apportionments, with fishing occurring primarily in April and May because of higher catch rates and better prices. The deepwater flatfish complex catch is dominated by Dover sole (over 98%, typically;Table 1). Dover sole have been taken primarily in the Central GOA in recent years, as well on the continental slope off Yakutat Bay in the eastern GOA (based on fishery observer data).

Deepwater flatfish are also caught in pursuit of other bottom-dwelling species as bycatch. They are taken as bycatch in Pacific cod, bottom pollock and other flatfish fisheries. The gross discard rates for deepwater flatfish across all fisheries are relatively high, with 39% discarded in 2010 and 49% in 2011 (Stockhausen et al., 2011).

Historically, catch of Dover sole increased dramatically from a low of 23 t in 1986 to a high of almost 10,000 t in 1991 (Table 1, Figure 1). Following that maximum, annual catch has declined rather steadily. Catch of Greenland turbot has been sporadic and has been over than 100 t only 5 times since 1978. The highest catch of Greenland turbot (3,012 t) occurred in 1992, coinciding with the second highest catch of Dover sole (8,364 t) since 1978. This was followed by a catch of 16 t for Greenland turbot the next year. Annual catch has been less than 25 t since 1995. Deepsea sole is the least caught of the three deepwater flatfish species. It has been taken only intermittently, with less than a ton of annual catch occurring 14 times since 1978. The highest annual catch occurred in 1998 (38 t), but since then annual catch has been less than 3 t in every year, except for 2009 when 6 t were caught.

Annual catches of deepwater flatfish have been well below the TACs in recent years (Table 2). Annual TACs, in turn, have been set equal to their associated ABCs (Table 2). Low catches relative to the TAC in the deepwater flatfish complex are driven by targeting decisions based on restrictions on halibut PSC. Closures of the deepwater flatfish fishery in 2015 are shown in Table 3. Currently, ABCs for the entire complex are based on summing ABCs for the individual species. Tier 6 calculations are used to obtain species-specific contributions to the complex-level ABC and OFL for each year because population biomass estimates based on research trawl surveys for Greenland turbot and deepsea sole are considered unreliable and there is little basic biological information from these two species. As such, ABCs for Greenland turbot and deepsea sole are based on average historic catch levels and do not vary from year to year. Since 2003, the ABC for Dover sole has been based on an age-structured assessment model (Turnock et al., 2003).

Data

The following table specifies the source, type, and years of all data included in the assessment models.

Source	Type	Years
Fishery	Catch biomass	1978-2015
Fishery	Catch length composition	1991-2004, 2009-2012 (2005-2008, 2013 data are excluded), 2014-2015
GOA survey bottom trawl	Survey biomass	Triennial: 1984-1999, Biennial: 2001-2015
GOA survey bottom trawl	Catch length composition	Triennial: 1990-1999, Biennial: 2003-2015 (1984, 1987, and 2001 data are excluded)
GOA survey bottom trawl	Catch age composition, conditioned on length	Triennial: 1990-1999, Biennial: 2003-2015 (1984, 1987, and 2001 data are excluded)

Fishery

The assessment included catch data from 1978 to October 10, 2015 (Table 1, column 3, Figure 1). Fishery length composition data were included in 2cm bins from 6-70cm in 1991-2004 and 2009-2012; data were omitted due to low sample size in 2005-2008 and 2013. Fishery length composition data were voluminous and can be accessed at (http://www.afsc.noaa.gov/REFM/Docs/2015/GOA_Dover_Composition_Data_And_SampleSize_2015.xlsx).

Survey

Biomass and Numerical Abundance

Survey biomass estimates originate from a cooperative bottom trawl survey between the U.S. and Japan in 1984 and 1987 and a U.S. bottom trawl survey conducted by the Alaska Fisheries Science Center Resource Assessment and Conservation Engineering (RACE) division thereafter. Calculations for final survey biomass and variance estimates by strata are fully described in Wakabayashi et al. (1985). Survey depth and area coverage was variable over time; the 1990, 1993, and 1996 surveys sampled only 0-500m depths, while the 2001 survey excluded the West Yakutat and Southeast management areas (the eastern GOA). In addition, the 700-1000 m depth range was sampled only in select survey years and areas (Table 4). Maps of survey catch-per-unit-effort (CPUE) for 2011-2015 survey are shown in Figure 2. A random effects model developed for survey averaging (presented at the September 2013 Plan Team Meeting, http://www.afsc.noaa.gov/REFM/stocks/Plan_Team/2013/Sept/SAWG_2013_draft.pdf) was used to estimate survey biomass and variance in missing depth and area strata (Table 4, Table 5). Table 5 describes the random effects model configurations and data used to estimate survey biomass and variance for each missing strata-year combination. The final survey biomass estimates and CVs used in the assessment are shown in Table 6.

Survey size and age composition

Sex-specific survey length composition data and age frequencies of fish by length (conditional age-at-length) were used in the assessment and can be found at (http://www.afsc.noaa.gov/REFM/Docs/2015/GOA_Dover_Composition_Data_And_SampleSize_2015.xlsx). There are several advantages to using conditional age-at-length data. The approach preserves information on the relationship between length and age and provides information on variability in length-at-age such that growth parameters and variability in growth can be estimated within the model. In addition, the approach resolves the issue of double-counting individual fish when using both length- and age-composition data (as length-composition data are used to calculate the marginal age compositions). See Stewart (2005) for an additional example of the use of conditional age-at-length data in fishery stock assessments.

Analytic Approach

Model Structure

Tier 3 Model

The assessment was an age- and sex-structured statistical catch-at-age model implemented in Stock Synthesis version 3.24u (SS3) using a maximum likelihood approach. SS3 equations can be found in Methot and Wetzel (2013) and further technical documentation is outlined in Methot (2009). Before 2013 assessments were conducted using an ADMB-based age- and sex-structured population dynamics model (Stockhausen et al., 2011). A detailed description of the transition of the 2011 model to SS3 and potential benefits of transitioning the assessment to SS3 were presented at the 2013 September Plan Team Meeting and the September SAFE chapter is included in the 2013 assessment (McGilliard et al., 2013).

The bottom trawl survey was modeled as two separate surveys. A “full coverage” survey was modeled and fit to bottom trawl survey length and age-at-length composition data in years where depths greater than 500m were sampled, as well as bottom trawl survey biomass and variance estimates listed in Table 6. An additional “shallow coverage” survey was modeled and fit to length and age-at-length composition data for years when the bottom trawl survey excluded depths deeper than 500m (1990, 1993, and 1996). Adjusted bottom trawl survey biomass data were only associated with the “full coverage” survey fleet, as the random effects modeling approach was used to transform these data to reflect a best available estimate of what would have been caught had all strata been sampled in all survey years. Selectivity curves in SS3 account for selectivity and availability. Therefore, separate selectivity curves were estimated for the “full coverage” and “shallow coverage” surveys because Dover sole move ontogenetically from shallow to deep depths and older ages are expected to be less available in a “shallow coverage” survey. Selectivity for both surveys was modeled with a double-normal curve and assumed to be age-based and sex-specific. Selectivity for the “full coverage” survey was assumed to be asymptotic, while selectivity for the “shallow coverage” allowed the potential for dome-shaped selectivity. Fishery selectivity was modeled with a double-normal length-based, sex-specific curve and allowed the potential for dome-shaped selectivity.

Conditional Age-at-Length

A conditional age-at-length approach was used: expected age composition within each length bin was fit to age data conditioned on length (conditional age-at-length) in the objective function, rather than fitting the expected marginal age-composition to age data (which are typically calculated as a function of the conditional age-at-length data and the length-composition data). This approach provides the information necessary to estimate growth curves and variability about mean growth within the assessment model. In addition, the approach allows for all of the length and age-composition information to be used in the assessment without double-counting each sample.

Data Weighting

In the 2013 assessment, the assumptions about data-weighting were re-evaluated using a more formal approach for assessing variability in mean proportions-at-age and proportions-at-length (Francis, 2011). To account for process error (e.g. variance in selectivities among years), relative weights for length or age composition data (lambdas) were adjusted according to the method described in Francis (2011), which accounts for correlations in length- and age-composition data (data-weighting method number T3.4 was used). The 2013 assessment used weights calculated using the Francis (2011) method, but fishery length-composition data were up-weighted slightly to improve model stability.

In the current assessment, the method described in Francis (2011) again resulted in model instability and a new approach was needed. The effective sample size for length composition data was changed to the number of hauls (Volstad and Pennington 1994). The harmonic mean of the effective sample sizes, with effective sample size calculated using the methods described in McAllister-Ianelli (1997), Appendix 2 was used to determine the relative weighting of data sources with respect to one another in the current assessment.

Ageing Error Matrix

Ageing uncertainty was incorporated into the assessment model. An ageing error matrix estimated from age-read data from the U.S. West Coast Dover sole ageing program (CAP) and used in the 2011 U.S. West Coast Dover sole assessment (Hicks & Wetzel, 2011) was used. Future Dover sole assessments should analyze GOA Dover sole age-read data to develop an ageing error matrix to use in the assessment instead of the west coast matrix. However, the CAP and AFSC ageing programs employ equivalent methods where ages are determined based on break-and-burn methods and each otolith is aged by two readers. Hicks and Wetzel (2011) estimated an ageing error matrix using methods described in Punt et al. (2008) whereby a relationship between true and estimated age is modeled and used to construct a probability that an otolith is observed to be age *a'* given a true age *a*. The ageing error matrix estimated in Hicks and Wetzel (2011) and used in this assessment shows that ageing uncertainty increases non-linearly with age and does not include ageing bias (Table 7). Accounting for ageing error is an important addition to the assessment methods because many Dover sole otoliths are particularly difficult to age (Kastelle, Anderl, Kimura, & Johnston, 2008). Ignoring ageing error in assessments can lead to bias in estimation of management quantities (Reeves, 2003).

Recruitment Deviations

Recruitment deviations from 1947-1983 (“early-period recruits”) were estimated separately from main-period recruits (1984-2012) such that the vector of recruits for each period was subject to a sum-to-zero constraint, rather than forcing a sum-to-zero constraint across all recruitment deviations. Recruitment deviations for 2012-2015 were fixed at 0 because Dover sole are generally not observed until age 3 and little to no data exist to inform recruitment deviations for the most recent years.

Model structures considered in this year’s assessment

One model is presented as the current, base case 2015 assessment for Dover sole. The 2015 base case model is very similar to the most recent (2013) accepted model for Dover sole with two differences.

First, fishery selectivity is not allowed to be dome-shaped; the descending limb of the age-based male and female selectivity curves were fixed at a large number to force the curves to be asymptotic. This choice was made because the standard deviation for the descending limb parameter was very large (267.55 in log space in the 2013 model), both in the 2013 assessment and in model runs of the 2013 assessment with new data added, indicating that the data do not inform the model fit of the descending limb parameter and thus evidence for dome-shaped fishery selectivity is very weak. The catch of Dover sole is very small (Table 1, Figure 1) and therefore data informing fishery selectivity parameters are sparse.

Second, the data weighting approach was changed from the approach described in Francis (2011) to use of the harmonic mean of effective sample size, with effective sample size calculated according to methods described in McAllister and Ianelli (1997), Appendix 2. In addition the effective sample sizes assumed for each year of length composition data were changed to the number of hauls due to correlations within hauls, which was analyzed in Volstad and Pennington (1994). As described in the section on data weighting (above), the Francis (2011) approach created instability in the Dover sole model. It is possible that perceived process-related correlations in the fishery length composition data, as calculated by the Francis (2011) method, are just noise due to low sample size (given that catches are so low for Dover sole).

Parameters Estimated Outside the Assessment Model

Natural Mortality

Natural mortality was fixed at 0.085. This value was used in previous accepted Dover sole assessment models (McGilliard et al. 2013) and was estimated using the Hoenig method (Hoenig, 1983). Natural mortality for GOA Dover sole should be re-evaluated in future GOA Dover sole assessments.

Weight-Length Relationship

The weight-length relationship used in the assessment was estimated for GOA Dover sole by Abookire and Macewicz (2003). The relationship was $w_L = \alpha L^{\beta}$, where $\alpha = 2.9E-06$ and $\beta = 3.3369$, length (L) was measured in centimeters and weight (w) was measured in kilograms.

Maturity-at-Age

Maturity-at-age (O_a) in the assessment was defined as $O_a = 1/(1+\gamma e^{(a-a_{50})})$, where the slope of the curve was $\gamma = -0.363$ and the age-at-50%-maturity was $a_{50} = 12.47$.

A logistic maturity-at-length relationship estimated in Abookire and Macewicz (2003) was converted into a maturity-at-age relationship using the mean length-at-age relationship estimated within the assessment model. The maturity curve does not influence the estimation of the mean length-at-age relationship because spawning stock biomass (SSB) is the only quantity influenced by maturity in the model and SSB does not influence model fits because no stock-recruitment relationship is used.

A maturity-at-length curve was not used because slow growing fish in the model never become large enough to mature, regardless of age. This is unrealistic. Abookire and Macewicz (2003) estimated maturity-at-age as well as a maturity-at-length. However, the relatively low sample size of aged fish used in the Abookire and Macewicz (2003) study, combined with the large magnitude of ageing error known to exist for Dover sole suggested that the maturity-at-age relationship estimated in the paper may be unreliable.

Standard deviation of the Log of Recruitment (σ_R)

The standard deviation of the log of recruitment was not defined in previous assessments. Variability of the recruitment deviations that were estimated in previous Dover sole assessments was approximately σ_R =0.49 and this value was used in the current assessment.

Catchability

Catchability was equal to 1, as for previous Dover sole assessments. Future assessments should explore this assumption further.

Select selectivity parameters

Selectivity parameter definitions and values are shown in (Table 8).

Parameters Estimated Inside the Assessment Model

Parameters estimated within the assessment model are the log of unfished recruitment (R_0), log-scale recruitment deviations, yearly fishing mortality, sex-specific parameters of the von-Bertalanffy growth curve, CV of length-at-age for ages 2 and 59, and selectivity parameters for the fishery, the “full coverage” survey, and the “shallow-coverage” survey. The selectivity parameters are described in greater detail in Table 8).

Results

Model Evaluation

Comparison of the current base case model to the 2013 model and variants

Figure 3-Figure 6 and Table 9 compare results of the current base case model to results from the 2013 model, as well as for the current base case model without 2014-2015 new data and the current base case model without 2014-2015 new data and with dome-shaped fishery selectivity estimated (as it was in the 2013 model). Fits to the survey biomass index are very similar among models (Figure 3). The survey biomass estimate for 2015 is the lowest on record (Figure 3, Table 6); none of the models fit the 2015 survey biomass estimate closely. Catches for 2014 and 2015 are not above average (Table 1 and Figure 1) and do not explain the low survey biomass that was observed in 2015.

The likelihood components for survey biomass were similar among base case models run without new data and for the 2013 model (Table 9). The likelihood component for survey biomass worsened with the addition of new data (Table 9) because fits to the 2015 survey biomass were poor (the survey biomass estimate was very low in 2015 and could not be fully explained by the model; Figure 3). In addition, survey, length, and age composition likelihood components for the base case model without new data and the base case model without new data and with dome-shaped fishery selectivity are very similar, indicating that estimating the descending limb of the fishery selectivity curve did not improve any likelihood components. Likelihood components from the 2015 base case model cannot be compared directly with likelihood components from models without new data. Also, likelihood components for length and age composition data from the 2013 model cannot be compared to other models because the effective sample sizes and data weighting differed.

Estimates of recruitment deviations are similar among models (Figure 4 and Figure 5). The 2013 model estimated a larger number of recruits in the early 2000s (Figure 5) than the other models, indicating that the new data influenced the estimates of recruitment in those years. The 2015 model estimated a larger number of recent (2010-2012) recruits than the other models. However, little information is available on the number of recruits in 2010-2012, as the youngest Dover sole that are observed in the data are three years old and thus have only been observed for 0-2 years.

Estimated spawning stock biomass was lower in all years than for the 2013 model (Figure 6). The current base case model without new data and the current model without new data and with dome-shaped selectivity both yielded estimates of spawning stock biomass that were lower than for the 2013 model and higher than for the current model. The only difference between the 2013 model and the 2015 model with no new data and dome-shaped selectivity was the data weighting approach. Hence, the 2014-2015 data and the changes in data weights both influenced the estimates of spawning stock biomass over time (Figure 6). Model estimates of full-coverage survey selectivity differed among models (Figure 7). Both male and female selectivity increase at earlier ages than for the 2013 model, effectively creating an increase in catchability for the 2015 base case model, which then results in lower estimates of SSB in the 2015 base case model than for the 2013 model.

The Current Base Case Model

The estimated asymptotic fishery selectivity curves are shown in Figure 9 and selectivity for the full-coverage and shallow-coverage surveys are shown in Figure 10. Parameter estimates for the selectivity curves are shown in (Table 11). For the fishery and surveys, estimated selectivity occurs at smaller lengths and younger ages for males than for females. Further research could look into reasons for this pattern. The full-coverage survey selectivity was restricted to be asymptotic because the composition data associated with these survey years covered depths up to 1000 m and therefore (theoretically) all ages (Figure 10, Table 11). Age-based Dover sole selectivity was used because sensitivity analyses using length-based selectivity curves showed that the oldest Dover sole were never selected in the full coverage survey years (due to variability in length at older ages); this inadvertently decreased catchability in the model. Estimates of selectivity for the shallow-water survey were dome-shaped and suggest that females were more available to the fishery than males at most ages when only shallow depths were sampled (Figure 10, Table 11); this is consistent with tagging studies showing that female Dover sole may move between deeper and shallower depths more than males to spawn and feed (Demory et al., 1984; Westrheim et al., 1992). Estimates of selectivity for the shallow-water survey years correspond only to composition data and were not informed by an index of biomass.

Plots of observed and expected proportions-at-length aggregated over years are shown in Figure 11 and yearly fits to proportion-at-length data are shown in Figure 12-Figure 15. Fits to aggregated fishery and full-coverage survey proportions-at-length are very close to the observed values for females and males. Estimated aggregated proportions-at-length for the shallow water survey show that the model expected fewer 40-50cm females and fewer 35-45 cm males, but otherwise the estimated aggregated survey proportions-at-length were very close to the observed values (Figure 12).

Fits to conditional age-at-length data and variability in age-at-length are generally close to the observed mean length at age (Figure 16-Figure 18). Mean age-at-length observations do not always increase monotonically with length, indicating that data are variable. Expected standard deviation in age-at-length often diverges from observed standard deviation in age-at-length at large lengths because there are few data points observed (resulting in low observed standard deviations). Pearson residuals for conditional age-at-length fits are shown in Figure 19-Figure 21. Estimated values for growth parameters are shown in Table 9.

Time Series Results

Time series results are shown in Table 14-Table 15 and Figure 22-Figure 23. A time series of numbers at age is available at (http://www.afsc.noaa.gov/REFM/Docs/2015/GOA_Dover_TimeSeries_of_NumbersAtAge_2015.xlsx). Age 3 recruitment, age 0 recruitment, and standard deviations of age 0 recruitment estimates are presented in Table 15 for the previous and current assessments. Total biomass for ages 3+, SSB, and standard deviations of SSB estimates for the previous and current assessments are presented in Table 14. Figure 22 shows SSB estimates and corresponding asymptotic 95% confidence intervals. Figure 23 is a plot of biomass relative to $B_{35\%}$ and F relative to $F_{35\%}$ for each year in the time series, along with the OFL and ABC control rules.

Retrospective analysis

Figure 24 and Figure 25 show the spawning stock biomass, recruitment deviations, and age-0 recruits for model runs excluding 0 to 10 years of data. Recruitment is assumed to be at its estimated mean value for years where data are excluded. Figure 24 appears to show a slight retrospective pattern for some model runs excluding 2015 data. However, the 2015 data has a large effect on the estimated spawning stock biomass. This is not surprising, given the low 2015 survey biomass estimate. Figure 25 shows that models excluding 0 to 10 years of data each estimate a large cohort of recruits in 1999 and again in 2001.

Harvest Recommendations

Tier 3 Approach for Dover Sole

The reference fishing mortality rate for Dover sole is determined by the amount of reliable population information available (Amendment 56 of the Fishery Management Plan for the groundfish fishery of the GOA). Estimates of $F_{40\%}$, $F_{35\%}$, and $SPR_{40\%}$ were obtained from a spawner-per-recruit analysis. Assuming that the average recruitment from the 1978-2012 year classes estimated in this assessment represents a reliable estimate of equilibrium recruitment, then an estimate of $B_{40\%}$ can be calculated as the product of $SPR_{40\%}$ times the equilibrium number of recruits. Since reliable estimates of the 2016 spawning biomass (B), $B_{40\%}$, $F_{40\%}$, and $F_{35\%}$ exist and B>$B_{40\%}$, the Dover sole reference fishing mortality is defined in Tier 3a. For this tier, $FABC$ is constrained to be ≤ $F_{40\%}$, and F_{OFL} is defined to be $F_{35\%}$. The values of these quantities are:

SSB 2016	49,179
$B_{40\%}$	22,692
$F_{40\%}$	0.1
maxF_{ABC}	0.1
$B_{35\%}$	19,855
$F_{35\%}$	0.12
F_{OFL}	0.12

Because the Dover sole stock has not been overfished in recent years and the stock biomass is relatively high, we do not recommended adjusting F_{ABC} downward from its upper bound of the maximum permissible F_{ABC} (maxF_{ABC}).

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the MSFCMA. For each scenario, the projections begin with the vector of 2015 numbers-at-age estimated in the assessment. This vector is then projected forward to the beginning of 2028 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2015. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2016 and 2017, are as follow ("max F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, *F* is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

Scenario 2: In all future years, *F* is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2016 recommended in the assessment to the *max*F_{ABC} for 2016. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.)

Scenario 3: In all future years, *F* is set equal to 50% of max F_{ABC}. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

Scenario 4: In all future years, *F* is set equal to the 2011-2015 average *F*. (Rationale: For some stocks, TAC can be well below ABC, and recent average *F* may provide a better indicator of F_{TAC} than F_{ABC}.)

Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

The 12-year projections of the mean SSB, fishing mortality, and catches for the five scenarios are shown in Table 16-Table 18. The recommended F_{ABC} and the maximum F_{ABC} are equivalent in this assessment, so scenarios 1 and 2 yield identical results.

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether the Dover sole stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follows (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be 1) above its MSY level in 2015, or 2) above ½ of its MSY level in 2015 and expected to be above its MSY level in 2025 under this scenario, then the stock is not overfished.)

Scenario 7: In 2016 and 2017, F is set equal to $maxF_{ABC}$, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2028 under this scenario, then the stock is not approaching an overfished condition.)

The results of these two scenarios indicate that the stock is not overfished and is not approaching an overfished condition. With regard to assessing the current stock level, the expected stock size in the year 2015 of Scenario 6 is 48,918, more than 2 times $B_{35\%}$ (19,855). Thus the stock is not currently overfished. With regard to whether the stock is approaching an overfished condition, the expected spawning stock size in the year 2028 of Scenario 7 (24,742) is greater than $B_{35\%}$; thus, the stock is not approaching an overfished condition.

Area Allocation for Harvests

ABCs and TACs for deepwater flatfish in the GOA are divided among four smaller management areas (Eastern, Central, West Yakutat and Southeast Outside). Area-specific ABCs are calculated as the total ABC multiplied by the proportion of deepwater flatfish survey biomass found in each area from 2005-2015.

Quantity	Western	Central	West Yakutat	Southeast	Total
	2.0%	37.9%	32.5%	27.6%	100.0%
2016 ABC (t)	186	3,496	2,997	2,548	9,226
2017 ABC (t)	187	3,516	3,015	2,563	9,280

Ecosystem Considerations

Ecosystem Effects on the Stock

Based on results from an ecosystem model for the GOA (Aydin et al., 2007), Dover sole adults occupy an intermediate trophic level (Figure 26 and Figure 27). Dover sole commonly feed on brittle stars, polychaetes and other miscellaneous worms (Figure 27; Buckley et al., 1999). Trends in prey abundance for Dover sole are unknown.

Important predators identified in the GOA ecosystem model include walleye pollock and Pacific halibut; however, the major source of Dover sole mortality is from the flatfish fishery (Figure 28). The ecosystem model was developed using food habits data from the early 1990s when GOA pollock biomass was much larger than it is currently and fishing mortality on Dover sole was much higher than it is now.

Little is known regarding the roles of Greenland turbot or deepsea sole in the GOA ecosystem. Within the 200-mile limits of the Exclusive Economic Zone of the United States, Greenland turbot are mainly found in the Bering Sea and the Aleutian Islands (Ianelli et al., 2006). Although the GOA component of Greenland turbot may represent a marginal stock, the species range in the eastern Pacific extends to northern Baja California. It thus seems somewhat unlikely that stock size in the GOA is limited by simple environmental factors such as temperature, rather it seems more likely that substantial biomass exists beyond the depth range of the fishery and the surveys. Greenland turbot are epibenthic feeders and prey on crustaceans and fishes. Walleye pollock are important predators on turbot in the Bering Sea, but it is unknown whether this holds true in the GOA as well.

Fishery Effects on the Ecosystem

Table 19 shows the catch of non-target species in the deepwater flatfish fishery in recent years. In 2014, the deepwater flatfish fishery caught 100% of the lanternfish captured in GOA. In 2015, the deepwater flatfish fishery did not catch a substantial proportion of any of the non-target species. A table of the proportions of prohibited species catch taken in the deepwater flatfish fishery is not shown because values are currently confidential.

Data Gaps and Research Priorities

The 2013 and 2015 stock assessment incorporated ageing error by using an existing ageing error matrix for West Coast Dover sole. A priority for future assessments is to analyze ageing error data for GOA Dover sole using methods described in Punt et al. (2008) and to incorporate a resulting ageing error matrix into the assessment. The assessment would benefit from an exploration of ways to better account for scientific uncertainty, especially uncertainty associated with parameters that are currently fixed in the model, including an exploration of natural mortality and catchability. The full coverage survey selectivity estimates indicate that males are selected at younger ages than females, which is counterintuitive. Future research could be done to explore this phenomenon.

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Tables

Table 1. Total annual catch of GOA deepwater flatfish by species through October 3, 2015.

Year	Greenland turbot	Dover sole	Deepsea sole	Total
1978	51	827	5	883
1979	24	530	5	559
1980	57	570	2	629
1981	8	457	8	473
1982	23	457	31	511
1983	145	354	11	510
1984	18	132	1	151
1985	0	43	3	46
1986	0	23	0	23
1987	44	56	0	100
1988	256	1,087	0	1,343
1989	56	1,521	0	1,577
1990	0	2,348	30	2,378
1991	446	9,741	2	10,189
1992	3,012	8,364	3	11,379
1993	16	3,804	3	3,823
1994	17	3,108	4	3,129
1995	116	2,096	1	2,213
1996	15	2,177	0	2,192
1997	11	3,652	1	3,664
1998	18	2,230	38	2,286
1999	14	2,270	0	2,284
2000	23	961	1	985
2001	4	800	0	804
2002	5	554	0	559
2003	10	936	0	946
2004	1	679	1	681
2005	5	407	0	412
2006	12	390	3	405
2007	1	286	0	287
2008	5	568	0	573
2009	5	469	2	476
2010	0	545	0	545
2011	0	466	0	466
2012	0	262	0	262
2013	0	242	0	242
2014	29	324	1	354
2015	3	218	0	221

Table 2. Historical OFLs, ABCs, TACs, and the percent of catch retained each year.

Year	OFL	ABC	TAC	Percent Retained
1995	17,040	14,590	11,080	79%
1996	17,040	14,590	11,080	72%
1997	9,440	7,170	7,170	82%
1998	9,440	7,170	7,170	90%
1999	8,070	6,050	6,050	80%
2000	6,980	5,300	5,300	71%
2001	6,980	5,300	5,300	75%
2002	6,430	4,880	4,880	64%
2003	6,430	4,880	4,880	50%
2004	8,010	6,070	6,070	81%
2005	8,490	6,820	6,820	42%
2006	11,008	8,665	8,665	40%
2007	10,431	8,707	8,707	41%
2008	11,343	8,903	8,903	37%
2009	11,578	9,168	9,168	21%
2010	7,680	6,190	6,190	61%
2011	7,823	6,305	6,305	51%
2012	6,834	5,126	5,126	25%
2013	6,834	5,126	5,126	61%
2014	16,159	13,472	13,472	24%
2015	15,993	13,334	13,334	47%

Table 3. 2015 closures of the GOA deepwater flatfish fishery

Sub-Area	Program	Status	Reason	Effective Date
GOA - Central 620/630	All	Bycatch	Regulations	01-Jan
GOA - Western 610	All	Bycatch	Regulations	01-Jan
GOA - Central 620/630	All	Open	Regulations	20-Jan
GOA - Western 610	All	Open	Regulations	20-Jan
West Yakutat - 640	All	Open	Regulations	20-Jan
West Yakutat - 640	All	Bycatch	Regulations	01-Jan
GOA - Central 620/630	Catcher Vessel	Bycatch	Chinook Salmon	03-May
GOA - Western 610	Catcher Vessel	Bycatch	Chinook Salmon	03-May
GOA - Central 620/630	Catcher Vessel	Open	Regulations	10-Aug
GOA - Western 610	Catcher Vessel	Open	Regulations	10-Aug

Table 4. Survey biomass by depth and area

		Depth (meters)					
		1-100	**101-200**	**201-300**	**301-500**	**501-700**	**701-1000**
CENTRAL GOA		42,328	265,732	134,787	53,187	35,516	19,128
	1984	1,870	24,506	5,598	4,039	5,147	11,309
	1987	1,260	12,728	8,587	3,706	6,757	1,539
	1990	11,233	42,188	15,644	2,043		
	1993	3,937	24,054	10,883	4,640		
	1996	1,674	21,452	8,691	5,327		
	1999	3,619	14,068	8,085	4,779	2,889	716
	2001	3,785	16,241	7,303	4,200		
	2003	2,842	23,005	10,070	4,629	8,738	
	2005	4,255	19,805	6,691	4,742	1,617	1,772
	2007	1,748	22,417	9,543	4,437	3,604	1,655
	2009	2,372	15,668	12,619	3,158	1,769	236
	2011	1,810	14,528	15,131	2,578	1,501	
	2013	1,196	7,789	9,896	2,026	2,273	
	2015	728	7,284	6,044	2,885	1,222	1,901
EASTERN GOA		54,946	161,580	105,826	115,897	20,119	1,736
	1984	925	4,989	1,975	1,645	1,728	330
	1987	3,137	12,995	3,419	4,126	2,518	
	1990	896	14,869	4,290	3,784		
	1993	651	18,901	8,893	11,219		
	1996	4,753	16,066	9,121	10,988		
	1999	2,806	14,425	11,448	6,887	2,476	606
	2003	7,119	21,636	7,491	8,153	2,466	
	2005	1,924	12,340	10,732	12,577	1,206	69
	2007	903	6,887	9,945	6,430	1,298	278
	2009	4,008	10,253	10,979	5,595	4,144	411
	2011	2,377	10,065	11,102	16,704	902	
	2013	23,355	7,928	11,178	14,994	1,125	
	2015	2,094	10,225	5,254	12,796	2,256	42
WESTERN GOA		1,665	5,875	2,023	8,606	9,319	2,930
	1984	34	725	355	1,138	1,290	919
	1987	5	108	32	1,103	1,267	108
	1990	161	716	50	721		
	1993	172	1,044	154	1,001		
	1996	134	337	290	698		
	1999	7	56	43	651	685	0
	2001	18	53	188	636		
	2003	194	541	270	811	1,333	
	2005	475	468	275	455	312	848
	2007	78	405	110	468	208	1,056
	2009	154	565	88	548	3,712	0
	2011	235	146	8	134	311	
	2013	0	627	126	84	142	
	2015	0	85	34	157	60	0

Table 5. Description of random effects models and data used to estimate survey biomass and variance for missing strata-year combinations.

Random effects model	**Missing Strata**	**Missing Years**	**Survey data used in random effects model to estimate biomass and variance for missing strata**
1	Eastern, 0-500m	2001	Eastern, All survey years except 2001
2	All GOA, 500-700m	1990, 1993, 1996, 2001	All GOA, 1984, 1987, 1999, 2003, 2005, 2007, 2009, 2011, 2015
3	Western, 700-1000m	1990, 1993, 1996, 2001, 2003, 2011, 2015	Western, 1984, 1987, 1999, 2005, 2007, 2009
4	Central, 700-1000m	1990, 1993, 1996, 2001, 2003, 2011, 2013	Central, 1984, 1987, 1999, 2005, 2007, 2009, 2015
5	Eastern, 700-1000m	1987, 1990, 1993, 1996, 2001, 2003, 2011, 2013	Eastern, 1984, 1999, 2005, 2007, 2009,2015

Table 6. Final survey biomass estimates and CVs used in the assessment, after an adjustment using the survey-averaging random effects model to estimate biomass in missing year-strata combinations.

Year	Biomass Estimate	CV
1984	68,521	0.09
1987	63,724	0.12
1990	106,717	0.12
1993	94,886	0.08
1996	88,174	0.07
1999	74,980	0.07
2001	79,140	0.12
2003	101,649	0.10
2005	80,560	0.08
2007	71,469	0.10
2009	77,327	0.08
2011	79,648	0.09
2013	85,205	0.21
2015	54,117	0.09

Table 7. Ageing error uncertainty assumed in the assessment model.

True Age	Standard Deviation	True Age	Standard Deviation
0	0.210	30	4.224
1	0.210	31	4.464
2	0.284	32	4.715
3	0.361	33	4.975
4	0.441	34	5.247
5	0.525	35	5.530
6	0.612	36	5.824
7	0.703	37	6.131
8	0.797	38	6.450
9	0.896	39	6.783
10	0.998	40	7.129
11	1.105	41	7.490
12	1.216	42	7.866
13	1.332	43	8.257
14	1.452	44	8.664
15	1.578	45	9.089
16	1.709	46	9.531
17	1.845	47	9.991
18	1.987	48	10.470
19	2.134	49	10.969
20	2.288	50	11.489
21	2.448	51	12.031
22	2.615	52	12.594
23	2.789	53	13.182
24	2.970	54	13.793
25	3.158	55	14.430
26	3.354	56	15.093
27	3.559	57	15.784
28	3.771	58	16.503
29	3.993	59	17.252

Table 8. Estimated and fixed double-normal selectivity parameters. “Estimated” indicates that the parameter was estimated within the assessment and a numeric value indicates a fixed parameter value.

Double-normal selectivity parameters	Fishery	"Full-coverage" Survey	"Shallow-coverage" Survey
Peak: beginning size for the plateau (in cm)	Estimated	Estimated	Estimated
Width: width of plateau	0	8	Estimated
Ascending width (log space)	Estimated	Estimated	Estimated
Descending width (log space)	10	8	Estimated
Initial: selectivity at smallest length or age bin	-10	-10	Estimated
Final: selectivity at largest length or age bin	999	999	Estimated
Male Peak Offset	Estimated	Estimated	Estimated
Male ascending width offset (log space)	Estimated	Estimated	Estimated
Male descending width offset (log space)	0	0	Estimated
Male "Final" offset (transformation required)	0	0	Estimated
Male apical selectivity	1	1	Estimated

Table 9. Negative log likelihood components for the 2015 base case model, the base case model without new data (data are as for the 2013 model), the base case model without new data and with dome-shaped selectivity, and the 2013 model. Values for likelihood components for the 2015 base case model cannot be compared directly with the other models. Only the value for the survey index likelihood component can be compared between the models using data up to 2013 because effective sample sizes, data weights, and the estimation of the most recent recruitment deviations differ between models.

Likelihood Component	2015 Base Case	Base Case w/o new data	Base case w/o new data and w/ dome-shaped selectivity	2013 Base Case
TOTAL	1,423.78	1,249.07	1,248.87	3,410.61
Survey	-4.13	-11.23	-11.12	-11.43
Length_comp	393.51	330.57	330.15	644.75
Age_comp	1,025.87	922.55	922.68	2,764.74
Recruitment	8.49	7.15	7.12	12.51

Table 10. Final parameter estimates of growth and unfished recruitment parameters with corresponding standard deviations for the current base case model for females (f) and males (m). "Std. Dev" is the standard deviation of the estimate.

Parameter	Estimate	Std. Dev.
Length at age 2 (f)	25.366	0.624
Linf (f)	52.101	0.451
von Bertalanffy k (f)	0.113	0.007
CV in length at age 2 (f)	0.150	0.010
CV in length at age 59 (f)	0.107	0.004
Length at age 2 (m)	27.110	0.695
Linf (m)	43.968	0.277
von Bertalanffy k (m)	0.158	0.013
CV in length at age 2 (m)	0.151	0.010
CV in length at age 59 (m)	0.090	0.003
R0 (log space)	9.876	0.046

Table 11. Final fishery, full coverage survey, and shallow coverage selectivity parameters for the current base case model. "Est" refers to the estimated value and "Std. Dev" is the standard deviation of the estimate.

	Fishery		**Full Coverage Survey**		**Shallow Coverage Survey**	
Double-normal selectivity parameters	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**
Peak: beginning size for the plateau	48.81	1.27	45.00	0.09	23.16	1.80
Width: width of plateau	Fixed		Fixed		-0.28	0.25
Ascending width (log space)	4.26	0.24	11.96	1.21	5.06	0.22
Descending width (log space)	Fixed		Fixed		-0.73	14.80
Initial: selectivity at smallest length or age bin	Fixed		Fixed		-498	11236.20
Final: selectivity at largest length or age bin	Fixed		Fixed		-4.99	0.44
Male Peak Offset	-9.28	1.37	-13.35	1.41	-15.00	0.05
Male ascending width offset (log space)	-1.46	0.37	4.68	119.24	-2.74	0.65
Male descending width offset (log space)	Fixed		Fixed		3.75	14.12
Male "Final" offset (transformation required)	Fixed		Fixed		0.03	0.88
Male apical selectivity	Fixed		Fixed		0.58	0.06

Table 12. Estimated recruitment deviations and associated standard deviations for the current model. “Std. Dev” is the standard deviation of the estimate.

Year	Recruitment Deviations	Std. Dev.	Year	Recruitment Deviations	Std. Dev.
1947	-0.107	0.463	1981	0.206	0.472
1948	-0.113	0.462	1982	0.300	0.497
1949	-0.118	0.460	1983	0.683	0.461
1950	-0.124	0.462	1984	0.430	0.432
1951	-0.140	0.456	1985	-0.003	0.415
1952	-0.137	0.456	1986	0.418	0.323
1953	-0.133	0.462	1987	0.001	0.380
1954	-0.140	0.455	1988	-0.040	0.351
1955	-0.119	0.458	1989	-0.249	0.337
1956	-0.085	0.479	1990	-0.357	0.352
1957	0.011	0.486	1991	0.053	0.292
1958	0.085	0.501	1992	-0.290	0.338
1959	0.175	0.523	1993	-0.166	0.360
1960	0.272	0.550	1994	0.194	0.347
1961	0.360	0.578	1995	0.195	0.345
1962	0.407	0.596	1996	-0.028	0.369
1963	0.395	0.591	1997	-0.256	0.324
1964	0.340	0.570	1998	-0.492	0.352
1965	0.278	0.548	1999	1.292	0.161
1966	0.229	0.531	2000	-0.202	0.393
1967	0.188	0.517	2001	0.863	0.172
1968	0.143	0.504	2002	-0.805	0.332
1969	0.094	0.490	2003	0.212	0.234
1970	0.045	0.478	2004	-0.216	0.327
1971	0.000	0.467	2005	0.274	0.246
1972	-0.033	0.460	2006	-0.619	0.329
1973	-0.045	0.457	2007	-0.068	0.263
1974	-0.020	0.460	2008	-0.691	0.320
1975	0.061	0.475	2009	-0.375	0.325
1976	0.223	0.506	2010	-0.466	0.376
1977	0.448	0.535	2011	0.910	0.409
1978	0.417	0.531	2012	0.764	0.510
1979	0.207	0.494	2013	-0.283	0.390
1980	0.165	0.473			

Table 13. Estimated fishing mortality rates for the current model. "Std. Dev" is the standard deviation of the estimate.

Year	Fishing Mortality	Std. Dev.	Year	Fishing Mortality	Std. Dev.
Initial F	0.0058	0.0003	1998	0.0254	0.0009
1978	0.0081	0.0005	1999	0.0263	0.0009
1979	0.0052	0.0003	2000	0.0113	0.0004
1980	0.0056	0.0003	2001	0.0094	0.0003
1981	0.0045	0.0002	2002	0.0065	0.0002
1982	0.0044	0.0002	2003	0.0110	0.0004
1983	0.0034	0.0002	2004	0.0079	0.0003
1984	0.0013	0.0001	2005	0.0047	0.0002
1985	0.0004	0.0000	2006	0.0044	0.0002
1986	0.0002	0.0000	2007	0.0031	0.0001
1987	0.0005	0.0000	2008	0.0061	0.0002
1988	0.0100	0.0004	2009	0.0050	0.0002
1989	0.0139	0.0006	2010	0.0058	0.0002
1990	0.0215	0.0009	2011	0.0049	0.0002
1991	0.0921	0.0036	2012	0.0027	0.0001
1992	0.0836	0.0032	2013	0.003	0.000
1993	0.0394	0.0015	2014	0.003	0.000
1994	0.0328	0.0012	2015	0.002	0.000
1995	0.0225	0.0008			
1996	0.0237	0.0008			
1997	0.0406	0.0014			

Table 14. Time series of age 3+ total biomass, spawning biomass, and standard deviation of spawning biomass for the 2013 assessment and this year's assessment. "Stdev_SPB" is the standard deviation of the estimate of spawning biomass.

	2013 Assessment			*2015 Assessment*		
Year	**Total Biomass (age 3+)**	**Spawning Biomass**	**Stdev_SPB**	**Total Biomass (age 3+)**	**Spawning Biomass**	**Stdev_SPB**
1978	150,904	68,209	4,072	120,778	51,020	3,107
1979	185,711	69,750	3,989	134,217	51,407	3,045
1980	185,077	71,027	3,892	134,229	51,802	2,971
1981	184,742	71,905	3,783	135,421	52,070	2,886
1982	184,336	72,470	3,670	136,746	52,284	2,794
1983	183,944	72,729	3,555	137,648	52,424	2,696
1984	183,503	72,795	3,443	138,410	52,565	2,595
1985	183,358	72,796	3,338	139,318	52,791	2,495
1986	184,127	72,762	3,242	140,679	53,095	2,392
1987	186,554	72,706	3,155	143,724	53,454	2,292
1988	188,222	72,661	3,079	146,052	53,857	2,195
1989	189,251	72,278	3,013	147,024	53,942	2,096
1990	189,456	71,833	2,961	148,060	53,925	2,002
1991	189,393	71,174	2,923	147,451	53,649	1,909
1992	187,522	67,776	2,888	145,726	50,560	1,787
1993	177,928	65,059	2,876	136,787	48,081	1,684
1994	168,975	64,190	2,886	128,845	47,410	1,612
1995	164,339	63,574	2,906	125,731	46,984	1,550
1996	159,389	63,278	2,932	122,511	46,901	1,500
1997	155,549	62,812	2,960	120,281	46,702	1,461
1998	152,196	61,559	2,988	118,793	45,791	1,430
1999	147,904	60,684	3,012	116,188	45,337	1,412
2000	144,763	59,612	3,032	114,512	44,740	1,401
2001	142,898	58,946	3,049	112,363	44,576	1,395
2002	142,716	58,321	3,070	110,906	44,486	1,393
2003	147,785	57,781	3,094	116,657	44,417	1,391
2004	151,086	57,174	3,131	117,503	44,244	1,391
2005	153,738	56,874	3,187	121,498	44,195	1,393
2006	157,353	56,939	3,268	121,783	44,358	1,400
2007	161,071	57,353	3,383	123,584	44,624	1,413
2008	167,239	58,116	3,532	124,228	45,064	1,433
2009	171,218	59,090	3,716	125,778	45,495	1,463
2010	173,726	60,361	3,931	125,144	46,072	1,503
2011	175,221	61,765	4,170	125,025	46,670	1,552
2012	174,950	63,279	4,422	123,584	47,300	1,608
2013	173,853	64,776	4,673	122,244	47,939	1,666
2014	182,727	66,147	0	120,702	48,516	1,726
2015				123,619	48,918	1,782
2016				141,926	49,180	0

Table 15. Time series of age 3 and age 0 recruits and standard deviation of age 0 recruits for the previous and current assessment models. "Std. dev" is the standard deviation of the estimate of Age 0 recruits.

	2013 Assessment			*2015 Assessment*		
Year	**Recruits (Age 3)**	**Recruits (Age 0)**	**Std. dev**	**Recruits (Age 3)**	**Recruits (Age 0)**	**Std. dev**
1978	21,119	28,539	11,024	16,025	29,490	15,584
1979	21,119	27,002	11,028	18,841	23,807	11,720
1980	21,162	26,758	11,158	23,597	22,749	10,716
1981	22,452	29,477	12,565	22,852	23,592	11,090
1982	21,242	35,723	15,951	18,449	25,838	12,820
1983	21,051	41,973	17,258	17,628	37,721	17,055
1984	23,190	29,830	12,265	18,281	29,205	12,768
1985	28,103	21,826	8,415	20,022	18,855	7,899
1986	33,021	26,159	9,082	29,231	28,628	9,151
1987	23,467	28,067	8,488	22,632	18,791	7,177
1988	17,171	17,985	5,537	14,611	17,966	6,308
1989	20,579	12,330	3,614	22,184	14,524	4,924
1990	22,081	11,107	3,272	14,561	12,981	4,617
1991	14,149	18,392	4,068	13,922	19,497	5,662
1992	9,700	10,716	3,126	11,255	13,788	4,695
1993	8,738	18,305	4,584	10,059	15,540	5,618
1994	14,469	25,201	6,135	15,108	22,192	7,662
1995	8,430	24,962	6,233	10,684	22,122	7,622
1996	14,401	18,435	5,717	12,042	17,638	6,534
1997	19,826	30,834	7,544	17,196	13,993	4,582
1998	19,638	30,254	8,178	17,143	11,008	3,946
1999	14,503	81,845	12,167	13,668	65,463	10,035
2000	24,257	26,127	6,716	10,843	14,696	5,896
2001	23,801	21,324	5,690	8,530	42,611	7,319
2002	64,388	35,127	7,706	50,728	8,036	2,727
2003	20,554	34,510	9,091	11,388	22,223	5,218
2004	16,775	65,198	12,566	33,020	14,484	4,797
2005	27,635	23,449	7,108	6,227	23,644	5,831
2006	27,149	17,518	5,337	17,221	9,683	3,243
2007	51,291	18,156	5,398	11,224	16,798	4,464
2008	18,448	10,803	3,764	18,322	9,103	2,972
2009	13,782	16,263	6,442	7,503	12,625	4,179
2010	14,283	23,651	9,849	13,017	11,648	4,468
2011	8,499	26,619	11,407	7,054	46,614	18,935
2012	12,794	24,106	10,589	9,783	40,703	20,978
2013	21,163	29,542		9,026	14,435	5,777
2014				36,122	19,452	889
2015				31,541	19,452	
Average	21,234	26,892		17,409	21,884	

Table 16. Projected spawning biomass for the seven harvest scenarios listed in the "Harvest Recommendations" section.

Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2015	48,918	48,918	48,918	48,918	48,918	48,918	48,918
2016	49,179	49,179	49,179	49,179	49,179	49,179	49,179
2017	49,271	49,271	49,271	49,271	49,271	44,933	45,680
2018	45,678	45,678	49,291	48,474	49,416	41,103	42,454
2019	42,435	42,435	49,278	47,682	49,525	37,730	38,918
2020	39,586	39,586	49,293	46,962	49,657	34,838	35,877
2021	37,158	37,158	49,393	46,370	49,869	32,432	33,336
2022	35,141	35,141	49,615	45,942	50,200	30,482	31,265
2023	33,496	33,496	49,971	45,683	50,660	28,930	29,604
2024	32,157	32,157	50,440	45,566	51,230	27,695	28,274
2025	31,047	31,047	50,979	45,543	51,867	26,692	27,186
2026	30,096	30,096	51,535	45,563	52,519	25,847	26,267
2027	29,253	29,253	52,063	45,581	53,140	25,107	25,462
2028	28,488	28,488	52,535	45,569	53,700	24,443	24,742

Table 17. Projected fishing mortality rates for the seven harvest scenarios listed in the "Harvest Recommendations" section.

Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2015	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2016	0.00	0.00	0.00	0.00	0.00	0.12	0.10
2017	0.10	0.10	0.00	0.02	0.00	0.12	0.10
2018	0.10	0.10	0.00	0.02	0.00	0.12	0.12
2019	0.10	0.10	0.00	0.02	0.00	0.12	0.12
2020	0.10	0.10	0.00	0.02	0.00	0.12	0.12
2021	0.10	0.10	0.00	0.02	0.00	0.12	0.12
2022	0.10	0.10	0.00	0.02	0.00	0.12	0.12
2023	0.10	0.10	0.00	0.02	0.00	0.12	0.12
2024	0.10	0.10	0.00	0.02	0.00	0.12	0.12
2025	0.10	0.10	0.00	0.02	0.00	0.12	0.12
2026	0.10	0.10	0.00	0.02	0.00	0.12	0.12
2027	0.10	0.10	0.00	0.02	0.00	0.12	0.12
2028	0.10	0.10	0.00	0.02	0.00	0.12	0.12

Table 18. Projected catches for the seven harvest scenarios listed in the "Harvest Recommendations" section.

Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2015	257	257	257	257	257	257	257
2016	346	346	346	346	346	10,858	9,043
2017	9,097	9,097	304	2,290	0	10,001	8,461
2018	8,546	8,546	307	2,275	0	9,303	9,588
2019	8,085	8,085	310	2,267	0	8,732	8,980
2020	7,693	7,693	314	2,263	0	8,258	8,472
2021	7,354	7,354	318	2,261	0	7,857	8,041
2022	7,054	7,054	321	2,258	0	7,511	7,668
2023	6,788	6,788	325	2,254	0	7,208	7,342
2024	6,549	6,549	327	2,248	0	6,943	7,056
2025	6,336	6,336	330	2,242	0	6,709	6,804
2026	6,145	6,145	332	2,234	0	6,503	6,583
2027	5,975	5,975	333	2,225	0	6,320	6,389
2028	5,824	5,824	335	2,216	0	6,147	6,209

Table 19. Non-target catch in the directed GOA deepwater flatfish fishery as a proportion of total weight of bycatch of each species. Conditional highlighting from white (lowest numbers) to green (highest numbers) is applied. Birds (recorded in numbers) have not been recorded as bycatch in the Deepwater flatfish fishery.

Non-Target Species	2003	2004	2007	2010	2013	2014	2015
Corals Bryozoans - Corals Bryozoans Unidentified	0.000	0.000	0.000	0.000	0.000	0.003	0.000
Giant Grenadier	0.000	0.000	0.002	0.012	0.000	0.000	0.000
Grenadier - Ratail Grenadier Unidentified	0.040	0.015	0.000	0.000	0.424	0.000	0.000
Invertebrate unidentified	0.000	0.000	0.000	0.000	0.000	0.000	0.001
Lanternfishes (myctophidae)	0.000	0.000	0.000	0.000	0.000	1.000	0.075
Large Sculpins	0.013	0.003	0.000				
Large Sculpins - Yellow Irish Lord				0.000	0.000	0.000	0.000
Misc fish	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other Sculpins	0.000	0.000	0.000	0.000	0.000	0.003	0.001
Scypho jellies	0.000	0.000	0.000	0.003	0.000	0.000	0.000
Sea anemone unidentified	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sea pens whips	0.000	0.000	0.000	0.000	0.000	0.001	0.000
Sea star	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sponge unidentified	0.000	0.000	0.000	0.000	0.000	0.003	0.021

Figures

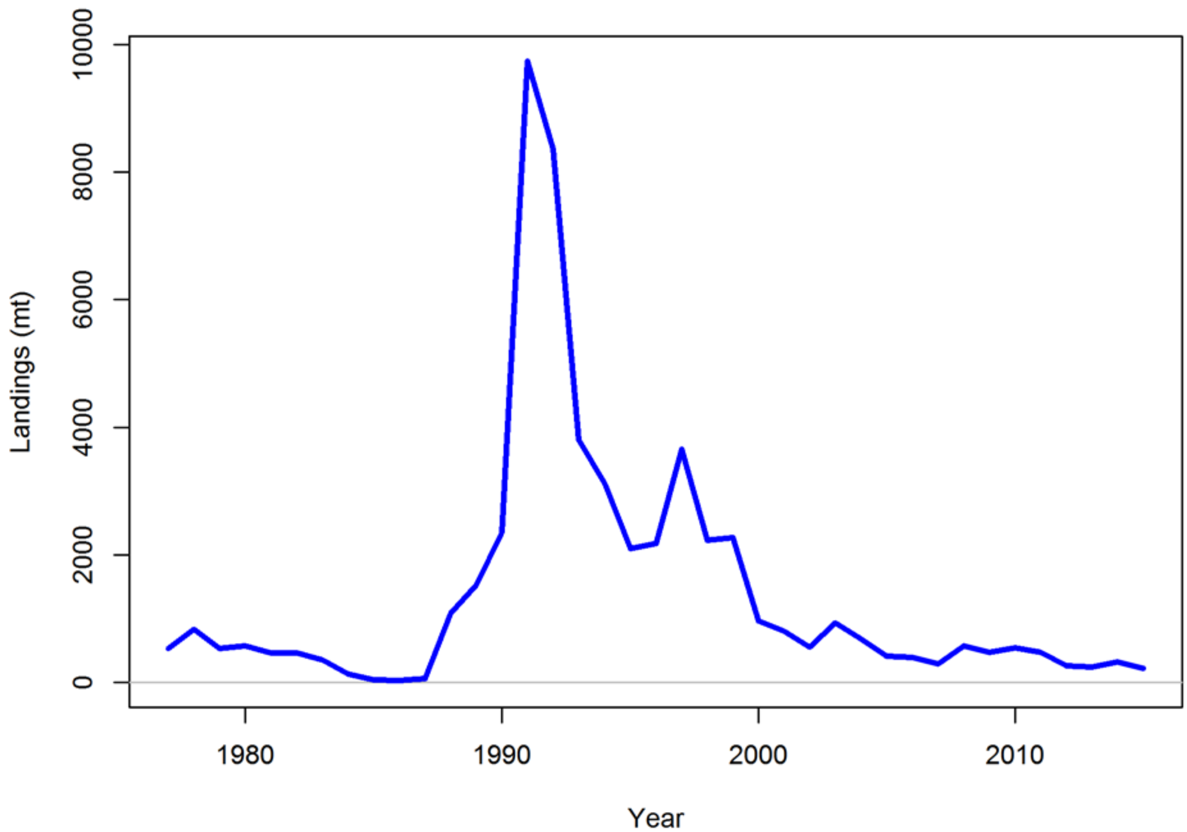


Figure 1. Catch biomass of Dover sole in metric tons 1978-2015 (as of October 10, 2015).

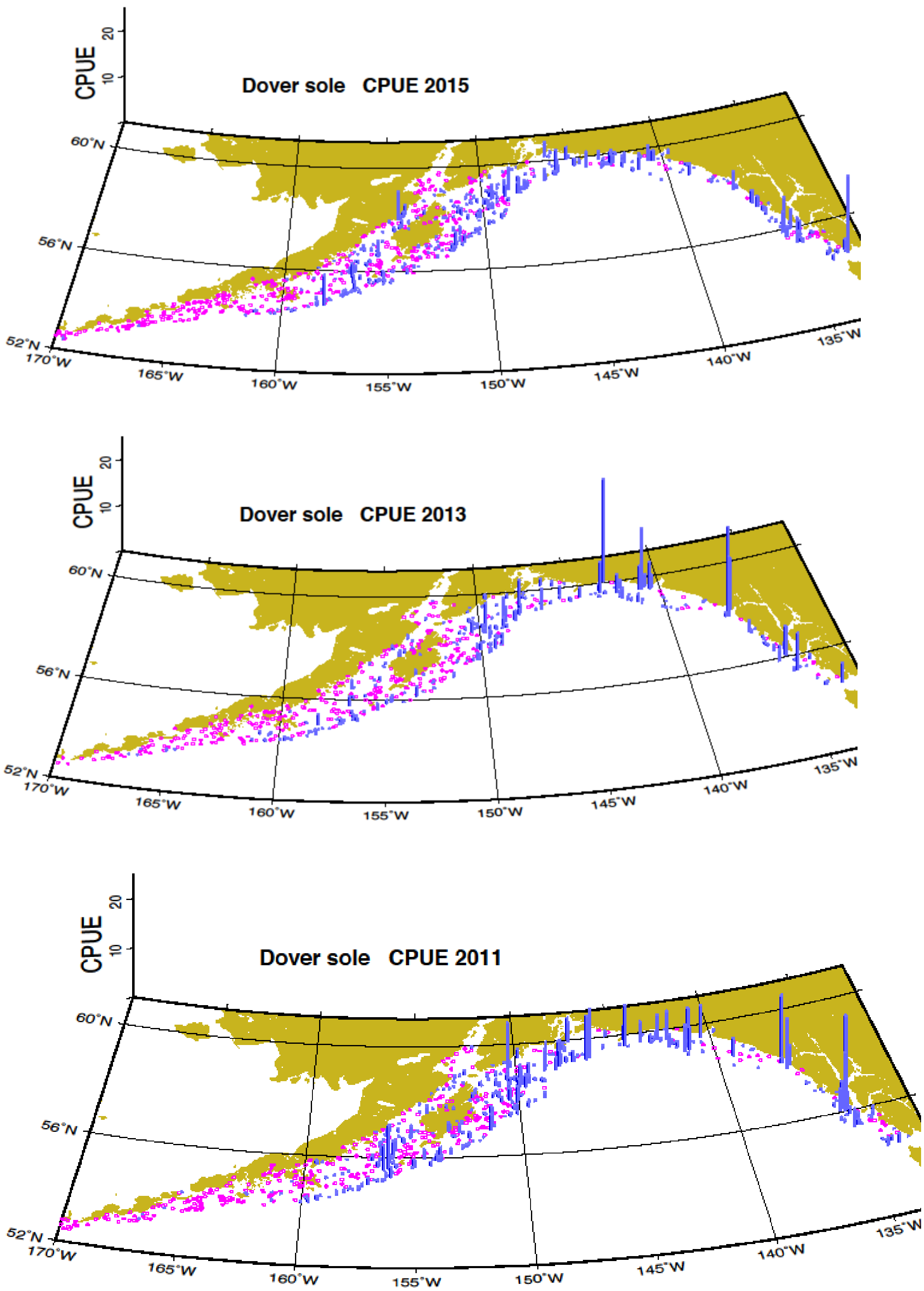


Figure 2. Maps of survey catch-per-unit-effort (CPUE) from the 2015, 2013, and 2011 GOA Groundfish Trawl Survey.

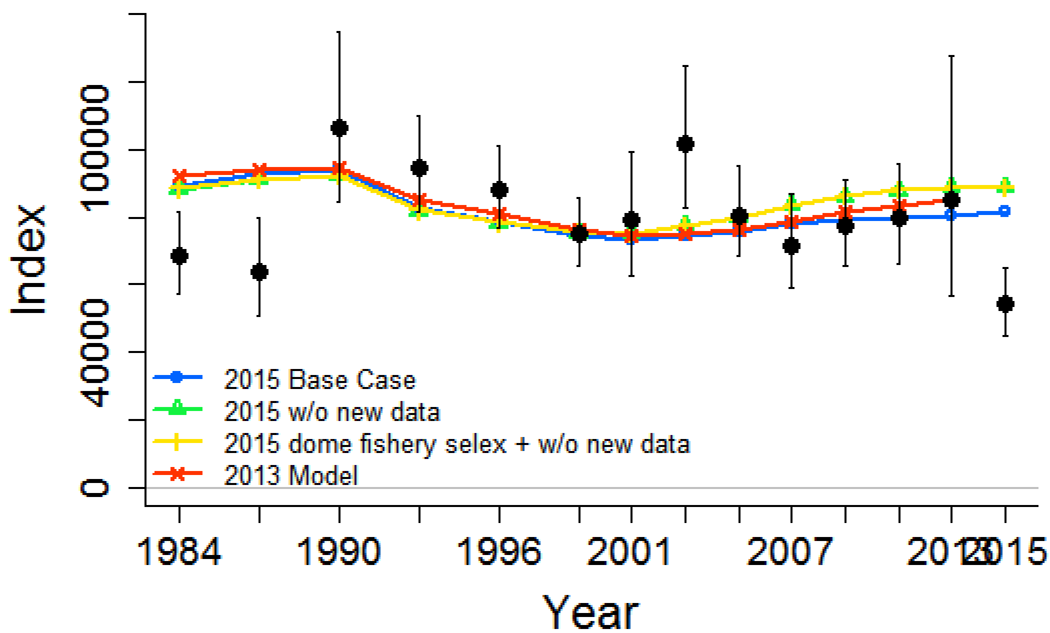


Figure 3. Survey biomass index (black dots), asymptotic 95% confidence intervals (vertical black lines), and estimated survey biomass for the current base case model (blue), the base case model with new data removed (data up to 2013 only; green), the base case model with new data removed and dome-shaped selectivity (yellow), and the 2013 model (red).

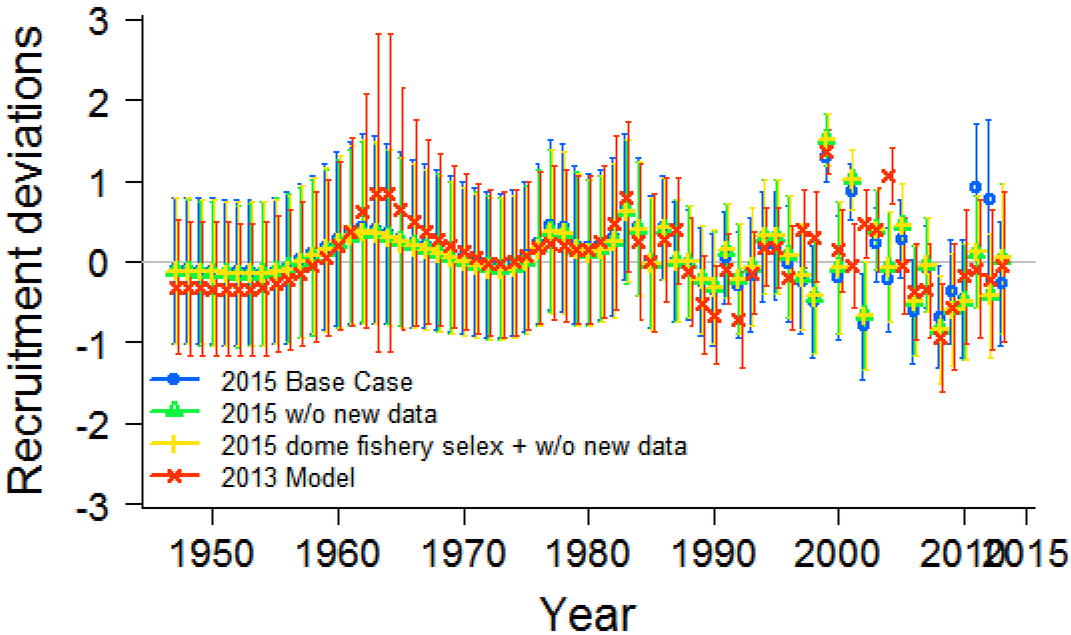


Figure 4. Recruitment deviations for years 1947-2012 and 95% asymptotic confidence intervals for the current base case model (blue), the base case model with new data removed (data up to 2013 only; green), the base case model with new data removed and dome-shaped selectivity (yellow), and the 2013 model (red).

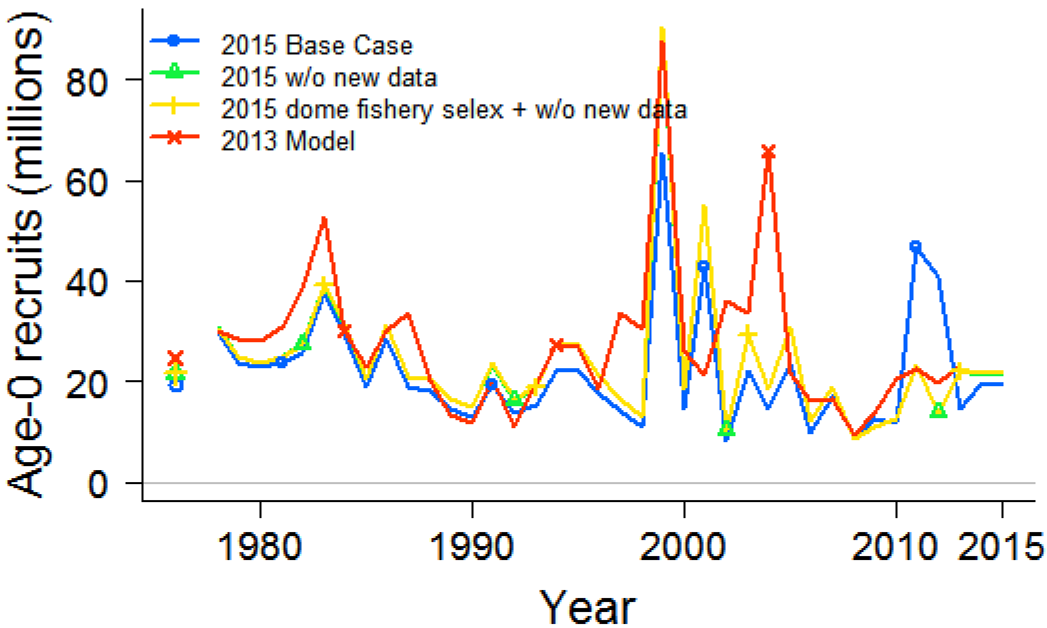


Figure 5. Time series of age 0 recruits for the current base case model (blue), the base case model with new data removed (data up to 2013 only; green), the base case model with new data removed and dome-shaped selectivity (yellow), and the 2013 model (red).

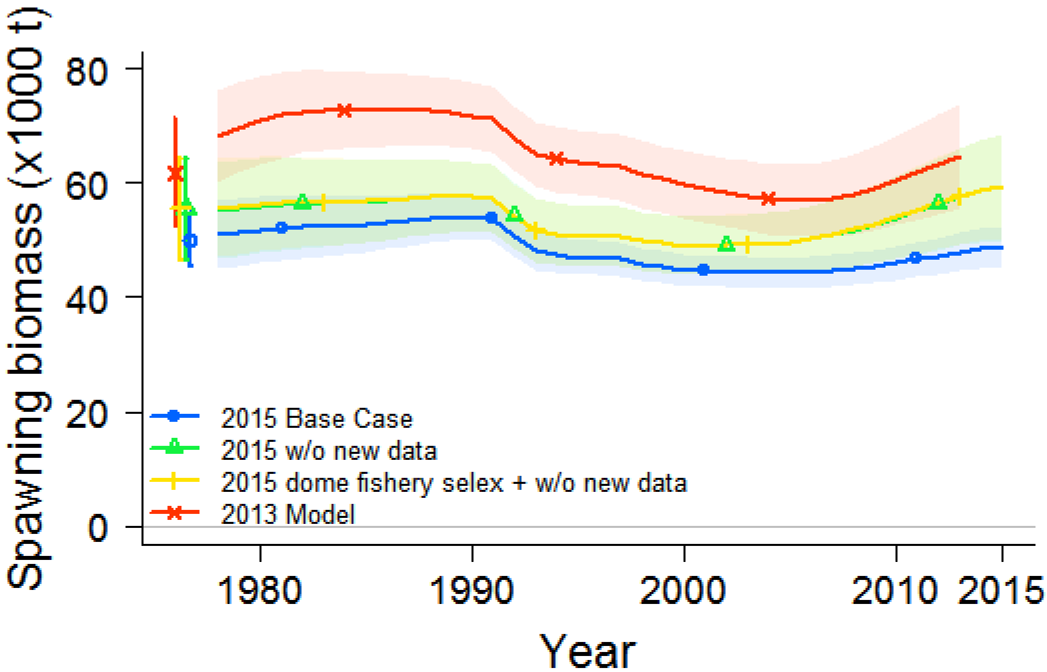


Figure 6. Time series of spawning biomass and 95% asymptotic confidence intervals for the current base case model (blue), the base case model with new data removed (data up to 2013 only; green), the base case model with new data removed and dome-shaped selectivity (yellow), and the 2013 model (red).

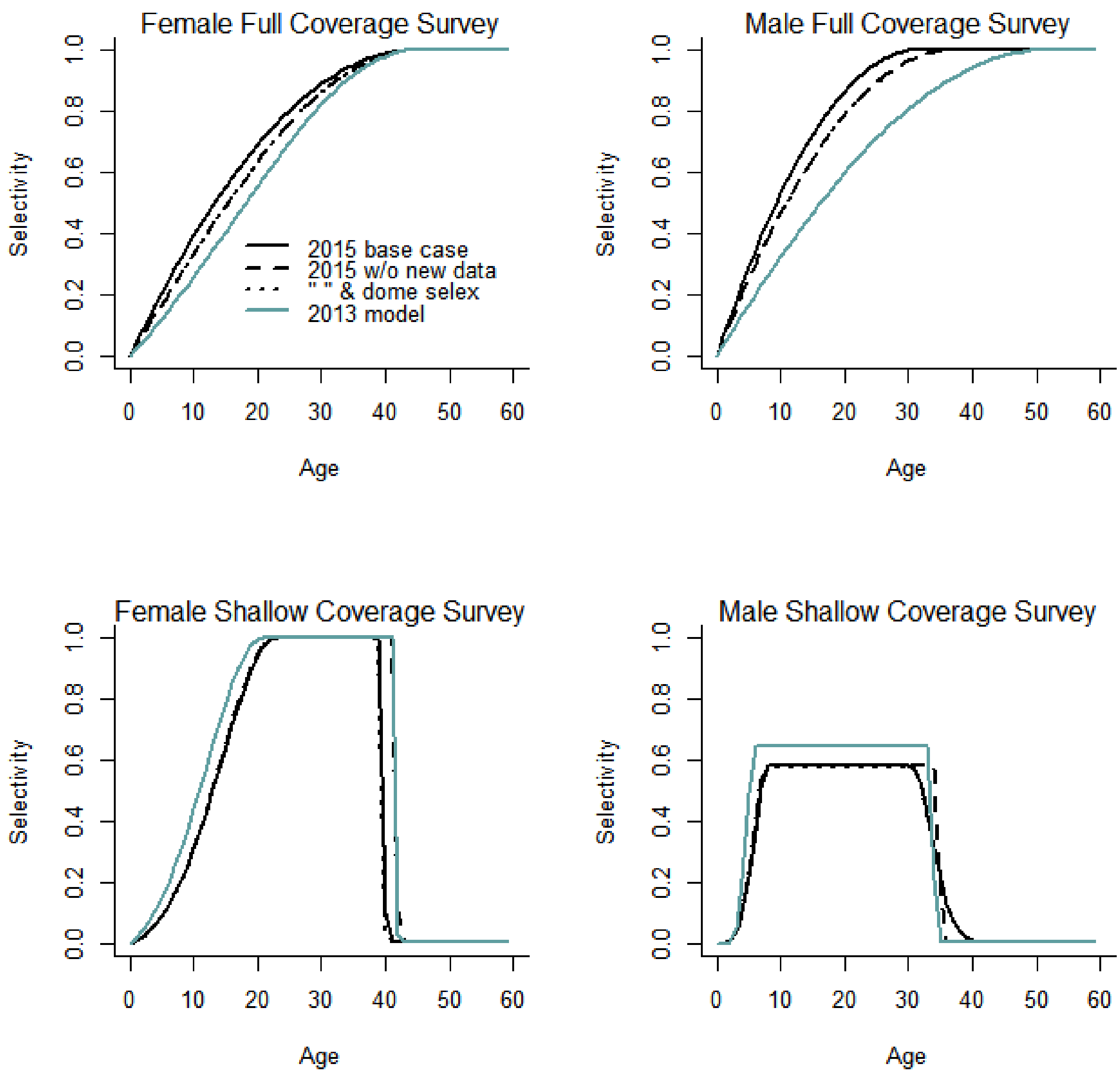


Figure 7. Selectivity-at-age for the full coverage (top panel) and shallow coverage (bottom panel) surveys for the 2015 base case model, the 2015 model without new data (data is as for the 2013 model), the 2015 model without new data and with dome-shaped selectivity, and the 2013 model for females (left panel) and males (right panel).

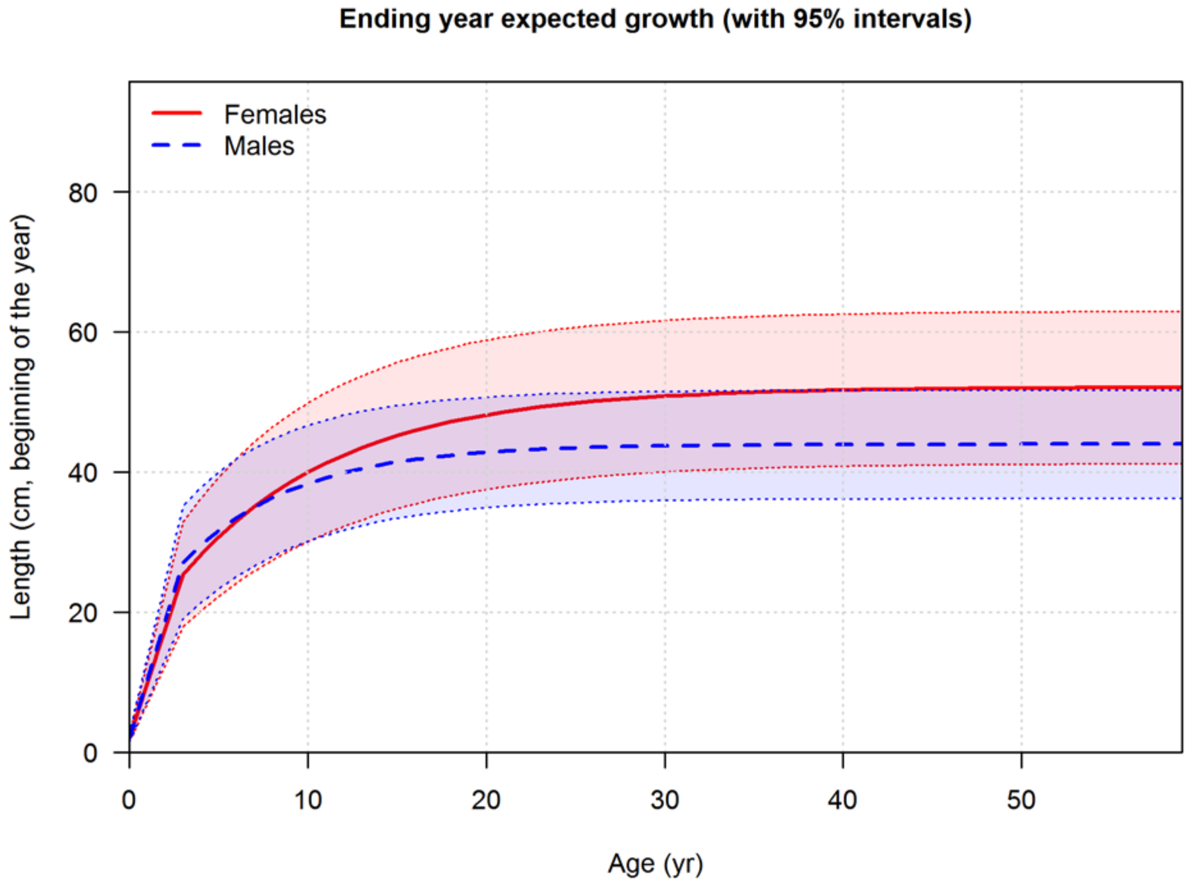


Figure 8. Estimated mean length-at-age (solid lines) and variability about the length at age curve (dashed lines) defined by the estimated CVs of length at age 2 and 59 for females (red) and males (blue) for the current base case model.

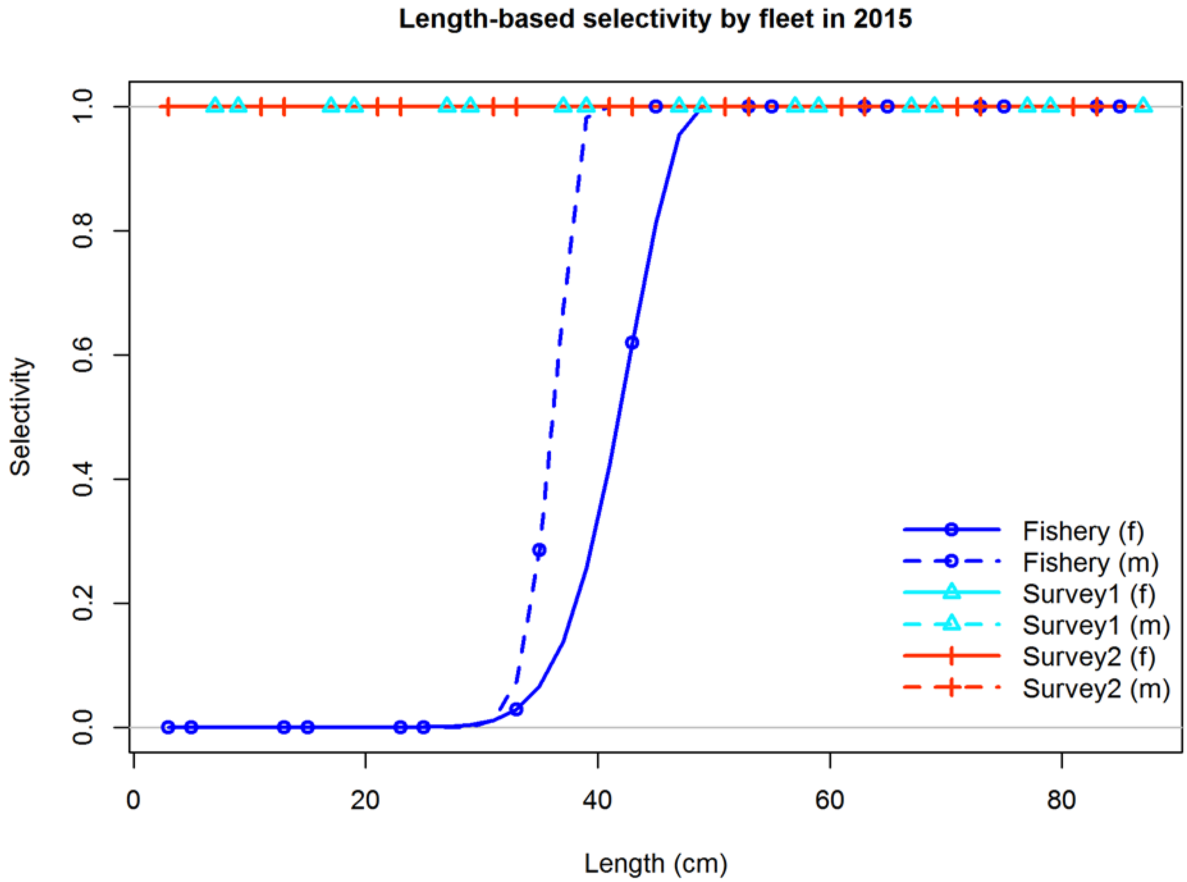


Figure 9. Sex-specific, length-based, asymptotic fishery selectivity for the current base case model for females (solid line) and males (dashed lines).

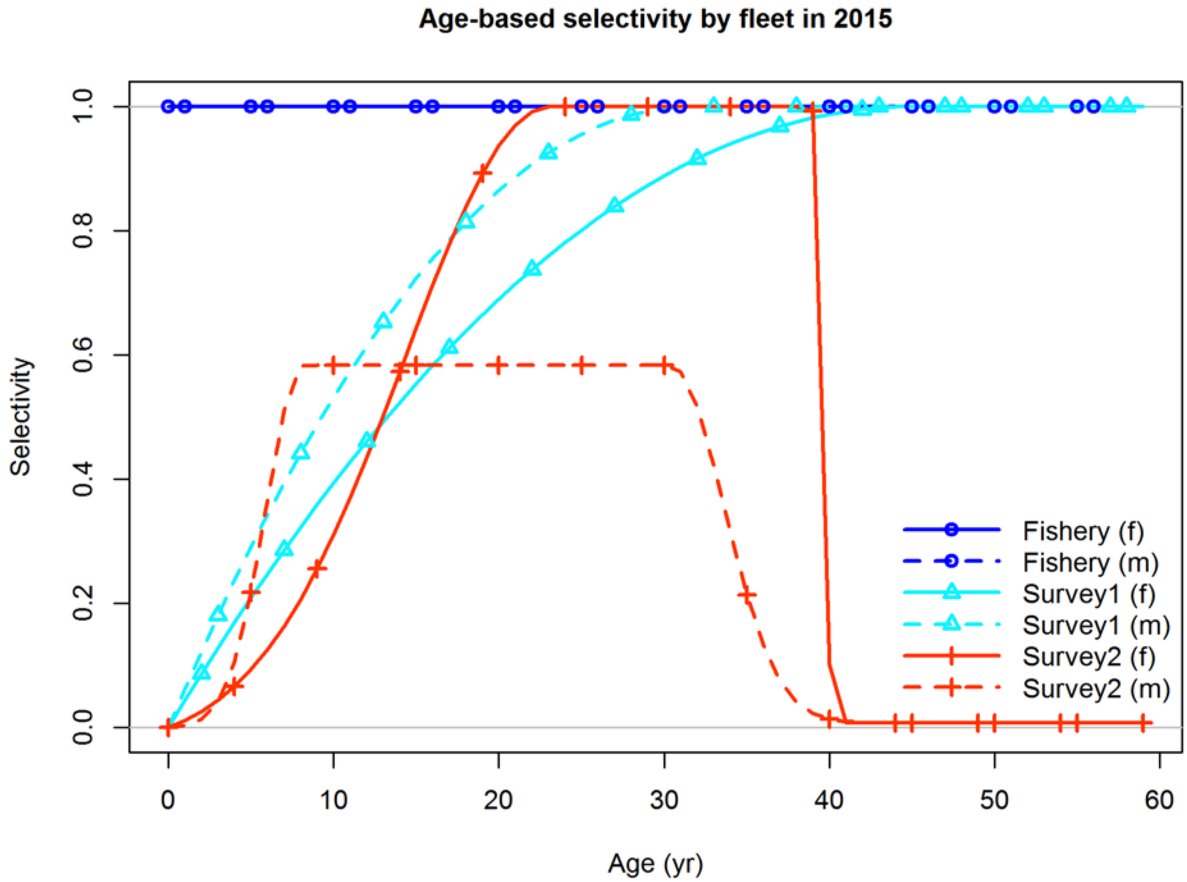


Figure 10. Selectivity for the full coverage survey (turquoise lines, triangles) and for the shallow-water survey (red lines, "+" symbols) for females (solid lines) and males (dashed lines) for the current base case model.

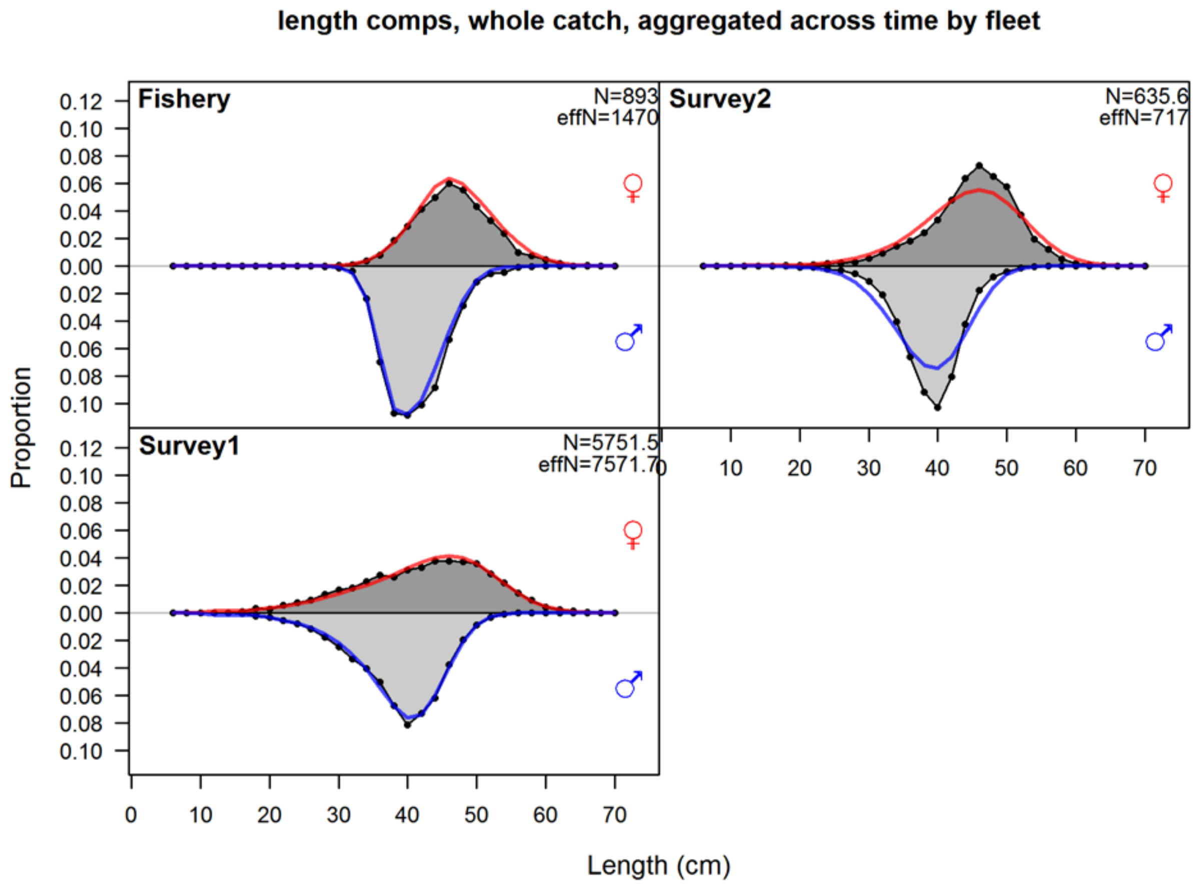


Figure 11. Observed (black lines, dots, and shaded areas) and expected (red lines) proportions-at-length, aggregated over years for the fishery, the full coverage survey, and the shallow coverage survey for the current base case model.

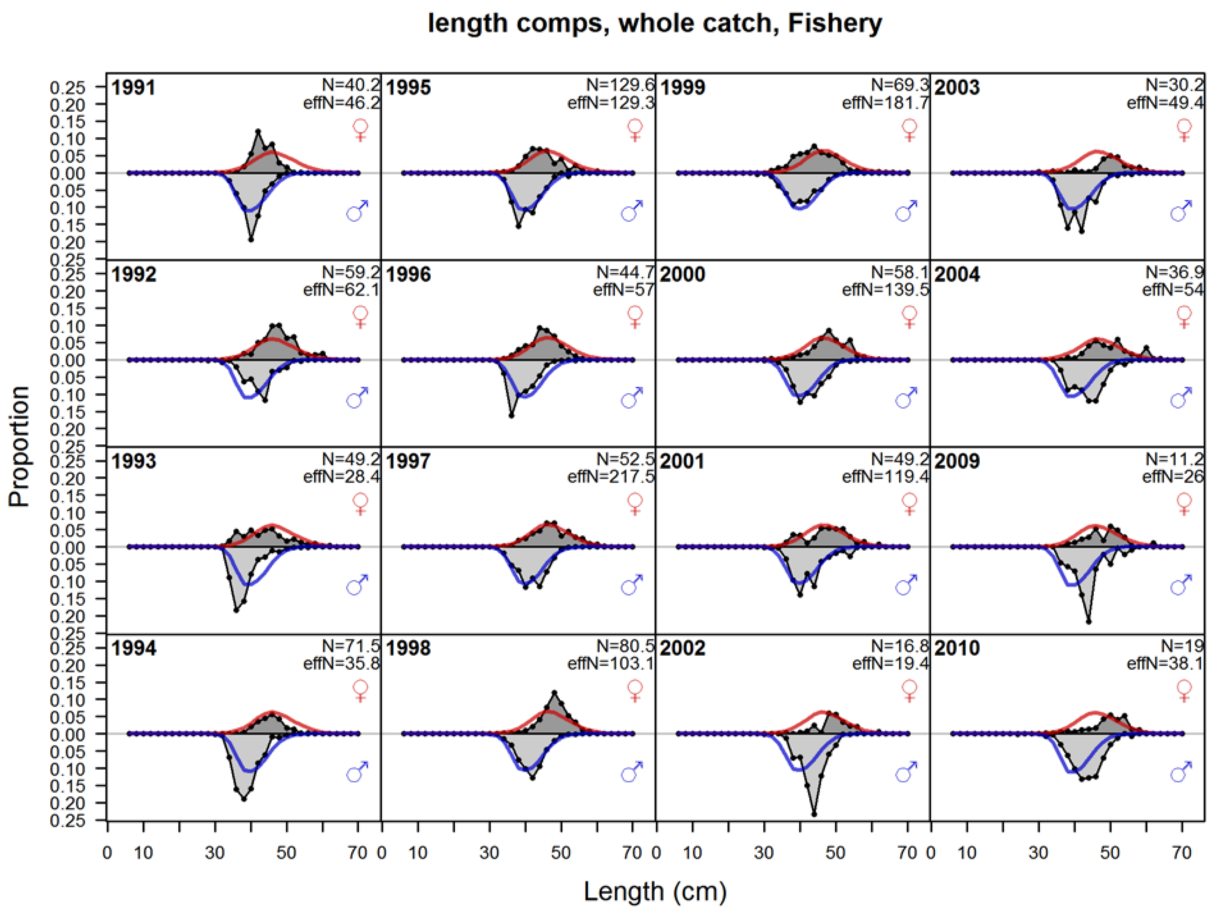


Figure 12. Observed (black lines, dots, and shaded areas) and expected (red and blue lines) yearly fishery proportions-at-length for the current base case model for years 1991-2010. Females are plotted above the x-axis; males are plotted below the x-axis.

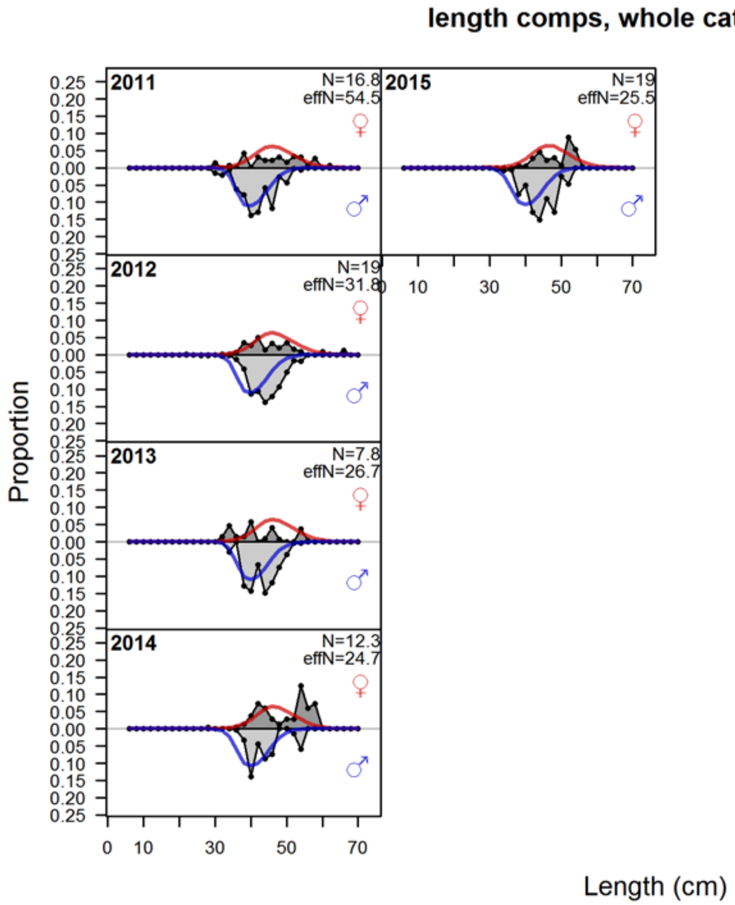


Figure 13. As for Figure 12 for years 2011-2015.

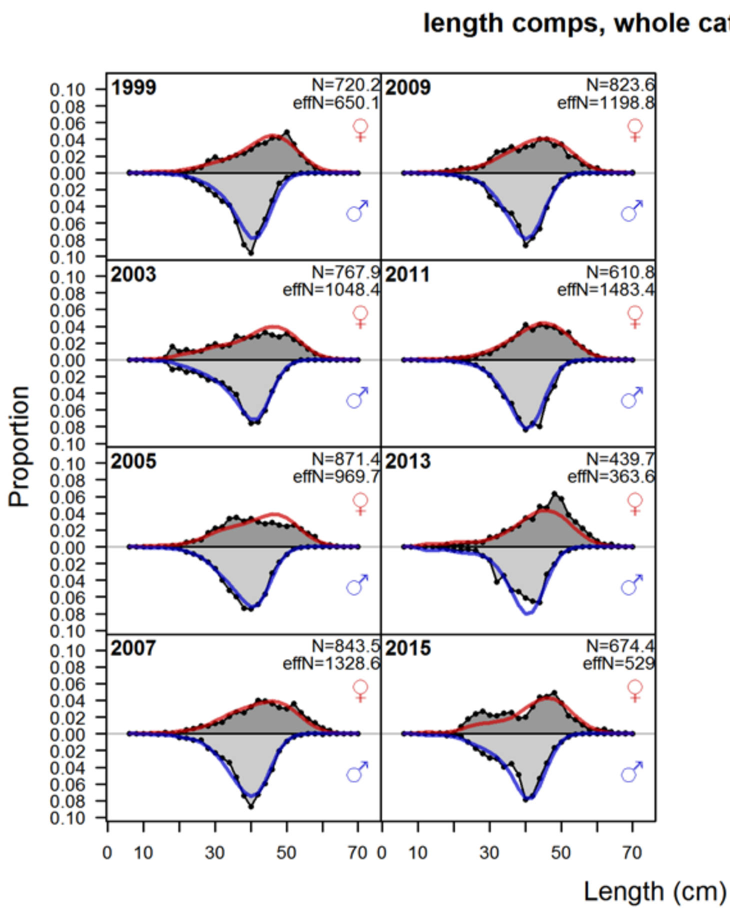


Figure 14. Observed (black lines, dots, and shaded areas) and expected (red and blue lines) yearly full-coverage survey proportions-at-length for the current base case model. Females are plotted above the x-axis; males are plotted below the x-axis.

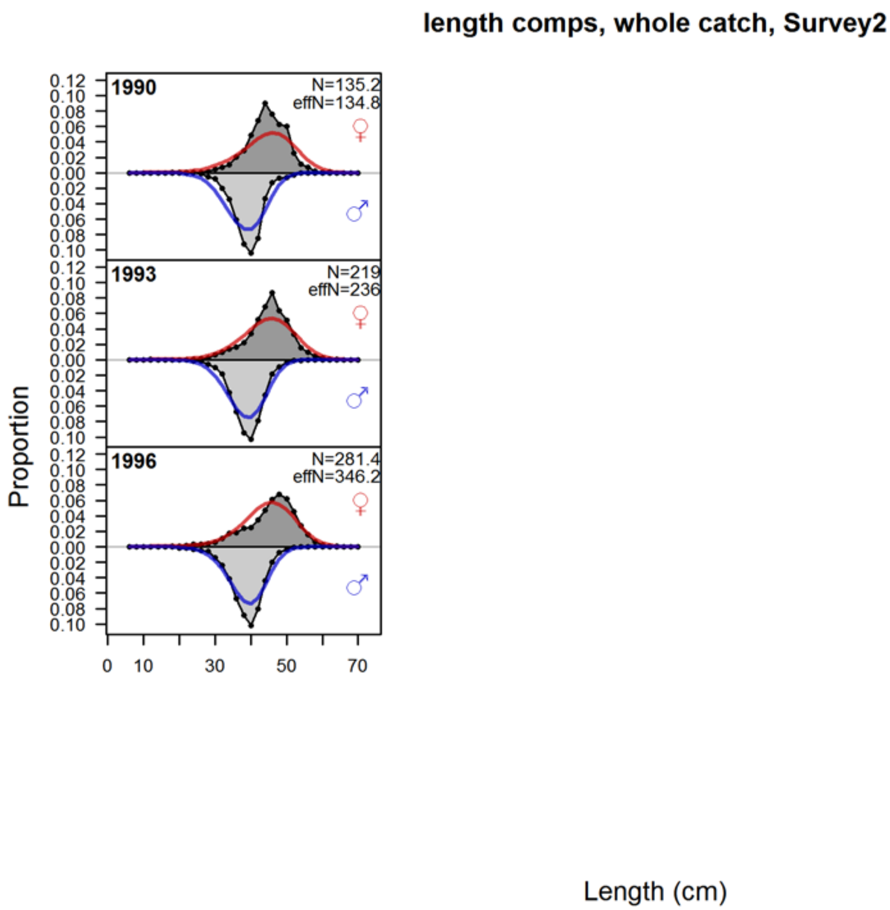


Figure 15. Observed (black lines, dots, and shaded areas) and expected (red and blue lines) yearly shallow coverage survey proportions-at-length for the current base case model. Females are plotted above the x-axis; males are plotted below the x-axis.

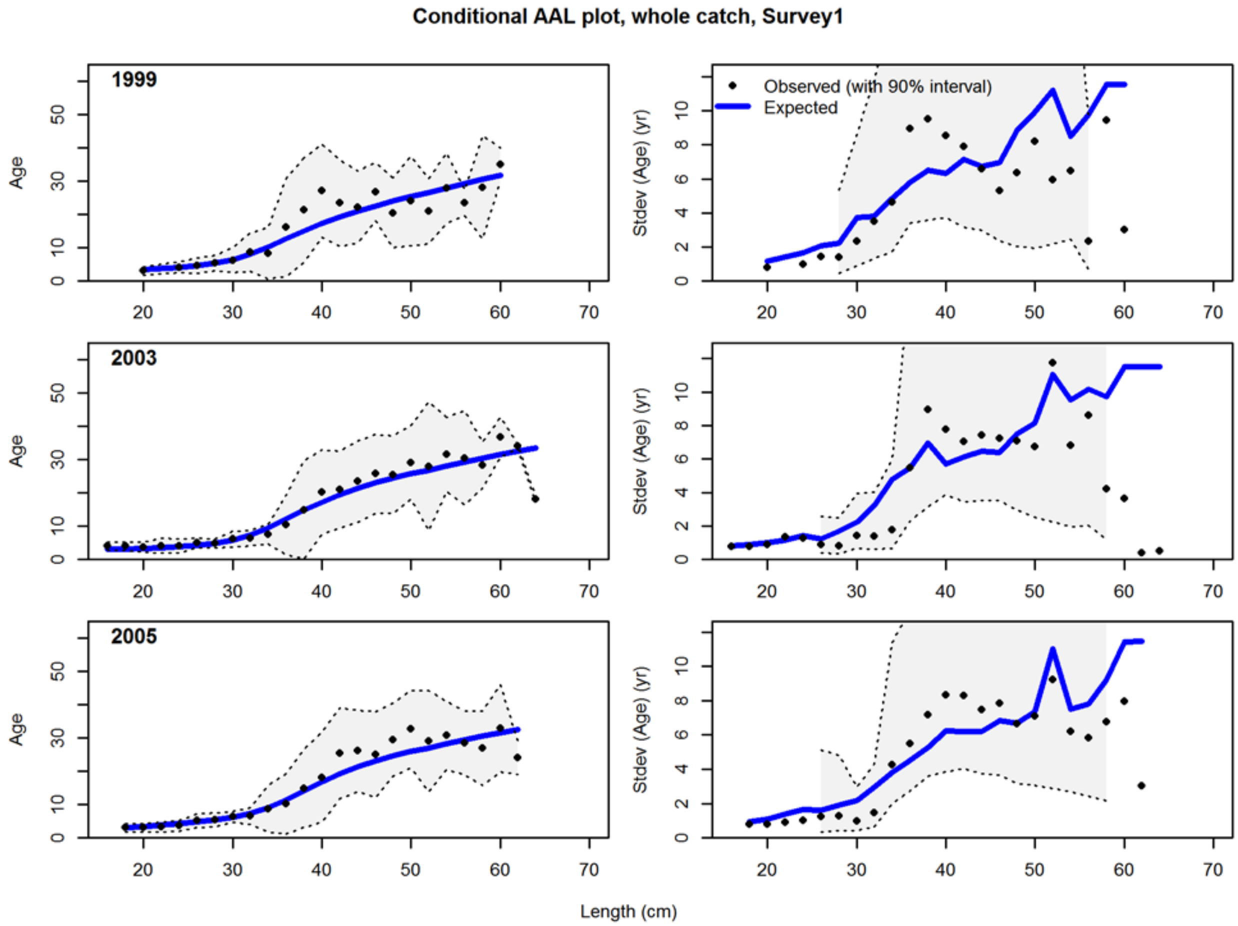


Figure 16. Observed and expected mean age-at-length for males and females combined with 90% intervals about observed age-at-length (left panels) and observed and expected standard deviation in age-at-length (right panels) for the full coverage survey (1 of 2).

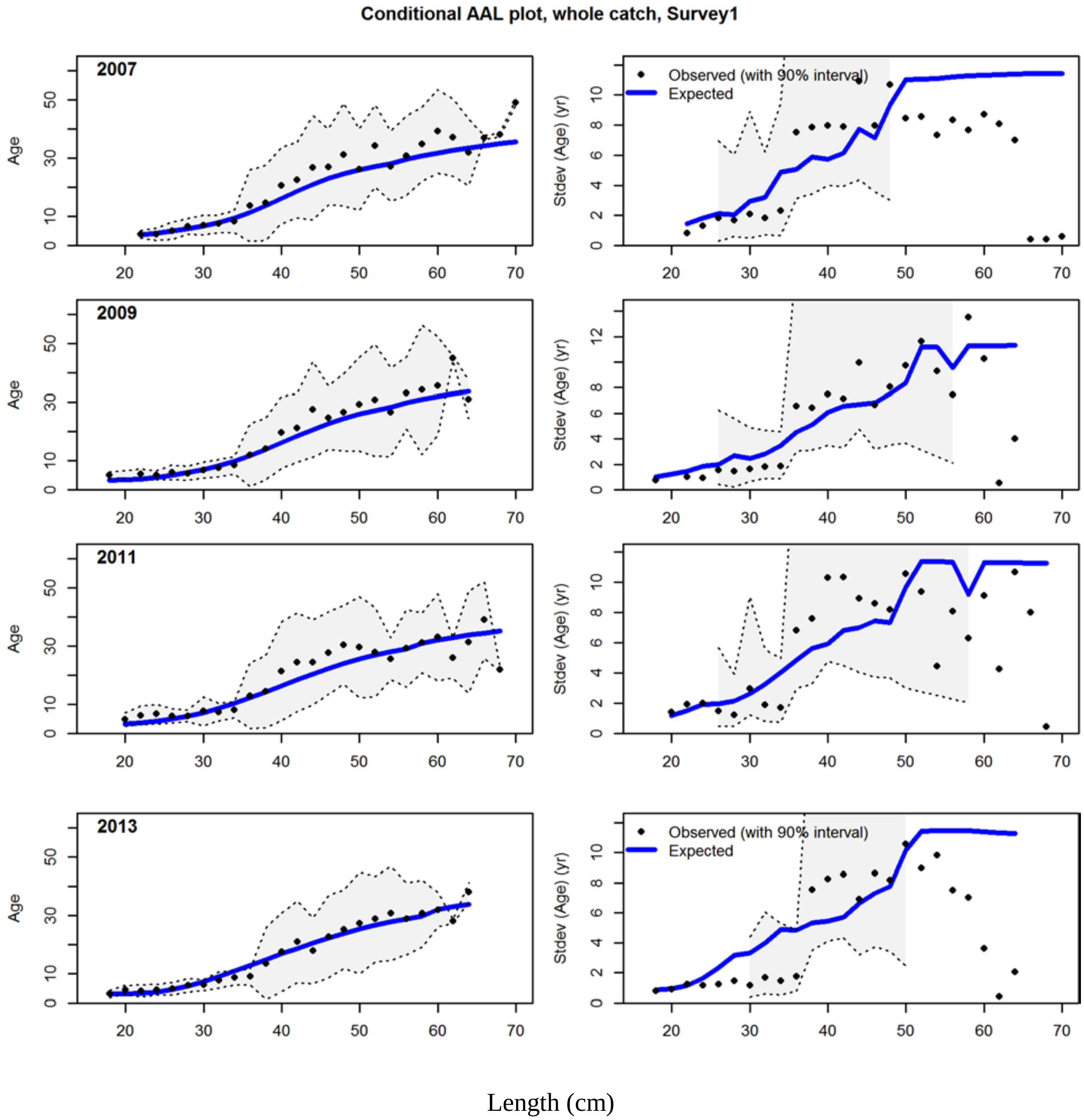


Figure 17. Observed and expected mean age-at-length for males and females combined with 90% intervals about observed age-at-length (left panels) and observed and expected standard deviation in age-at-length (right panels) for the full coverage survey (2 of 2).

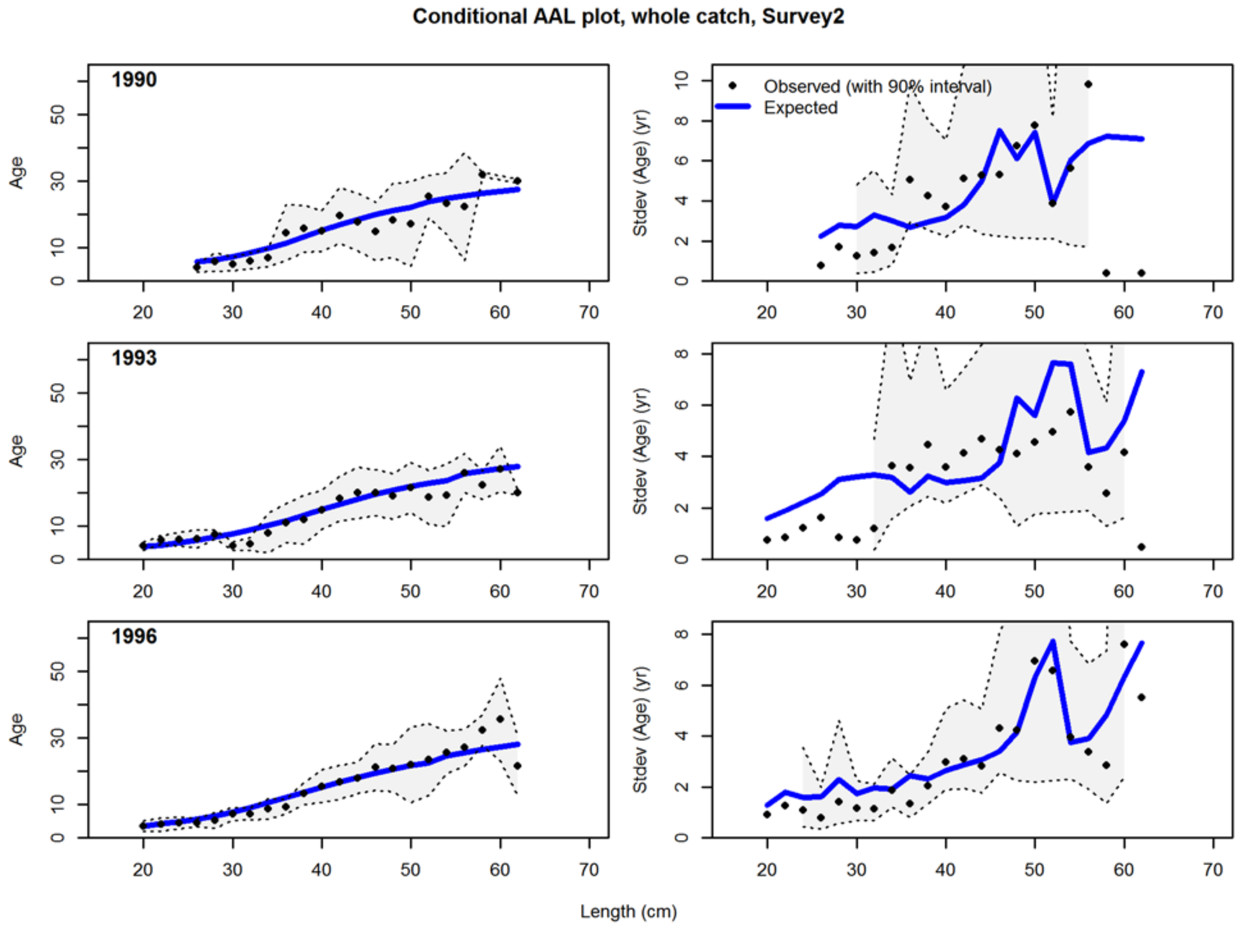


Figure 18. Observed and expected mean age-at-length for males and females combined with 90% intervals about observed age-at-length (left panels) and observed and expected standard deviation in age-at-length (right panels) for the shallow coverage survey.

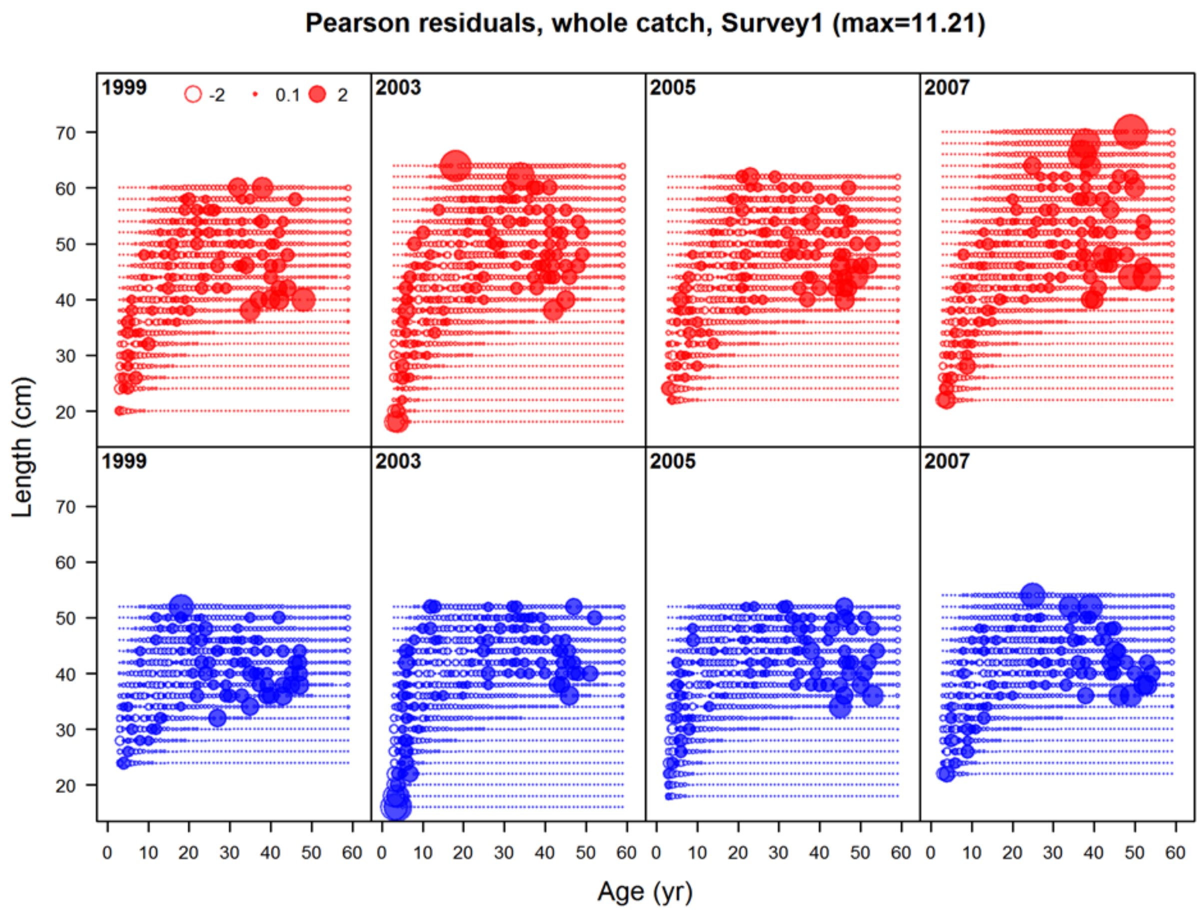


Figure 19. Pearson residuals associated with fits to the length-at-age relationship within the model for females (red, top panel) and males (blue, bottom panel) for the full coverage survey (1 of 2).

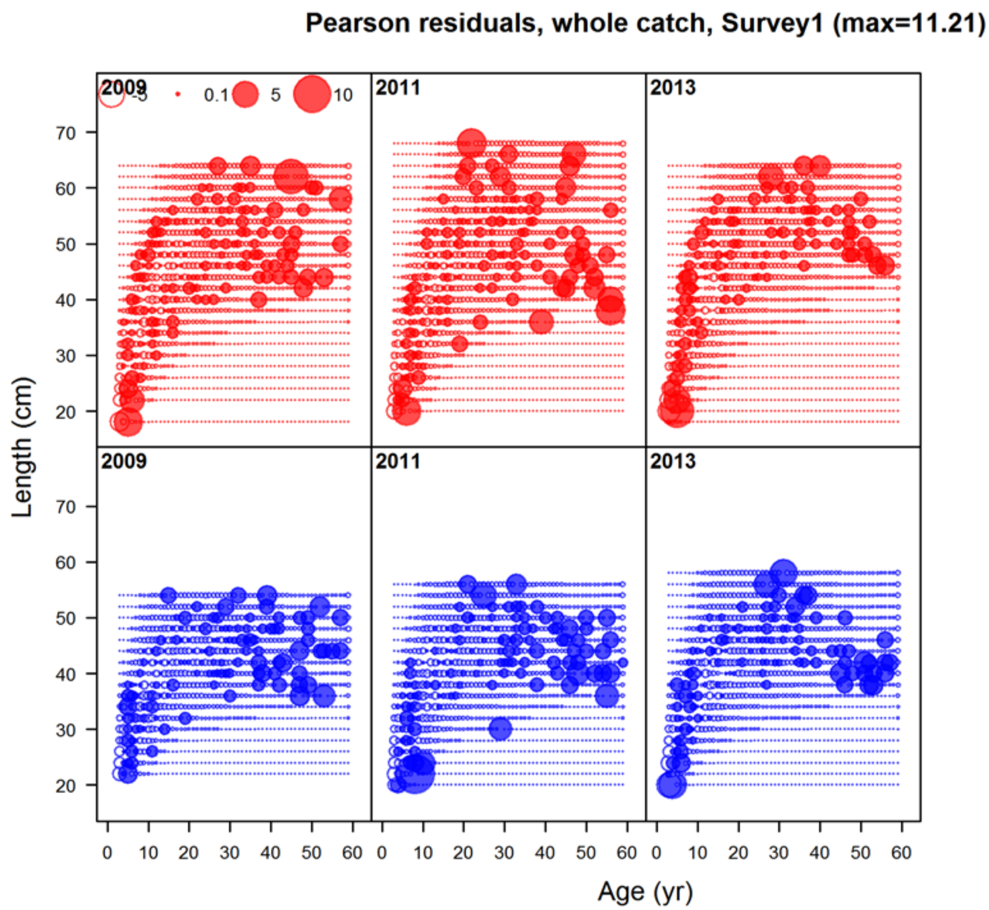


Figure 20. Pearson residuals associated with fits to the length-at-age relationship within the model for females (red, top panel) and males (blue, bottom panel) for the full coverage survey (2 of 2).

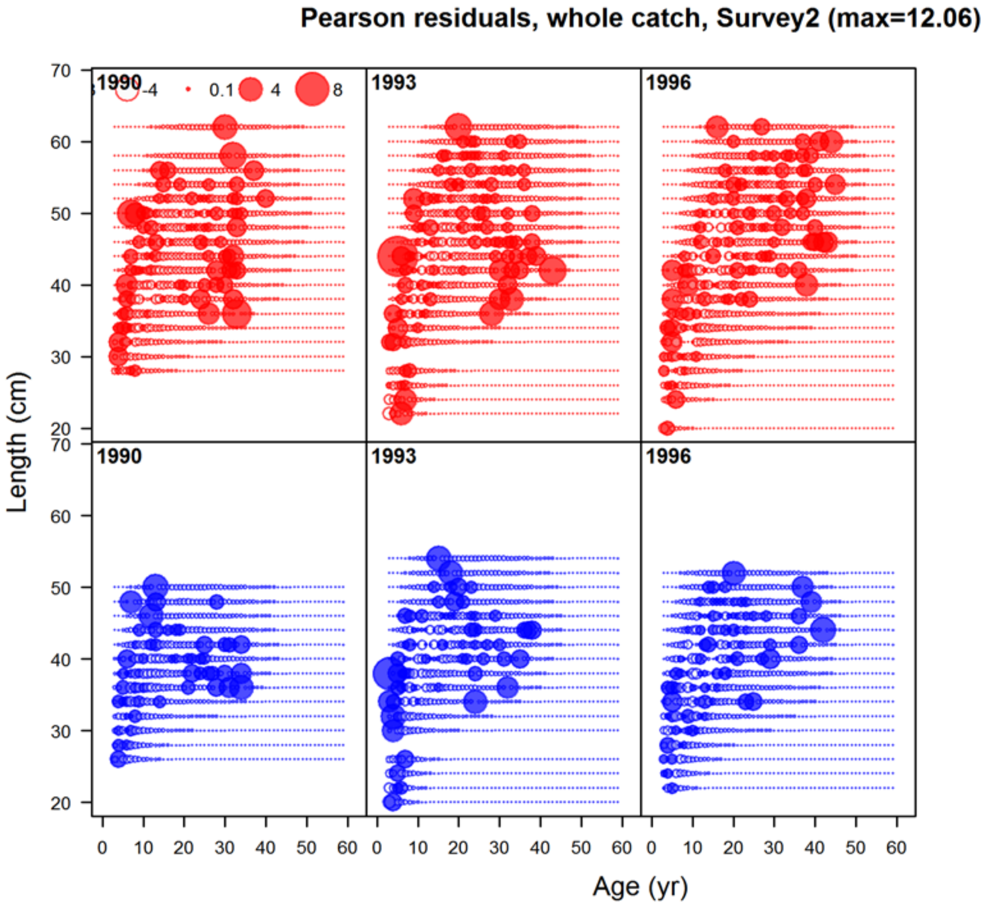


Figure 21. Pearson residuals associated with fits to the length-at-age relationship within the model for females (red, top panel) and males (blue, bottom panel) for the shallow coverage survey.

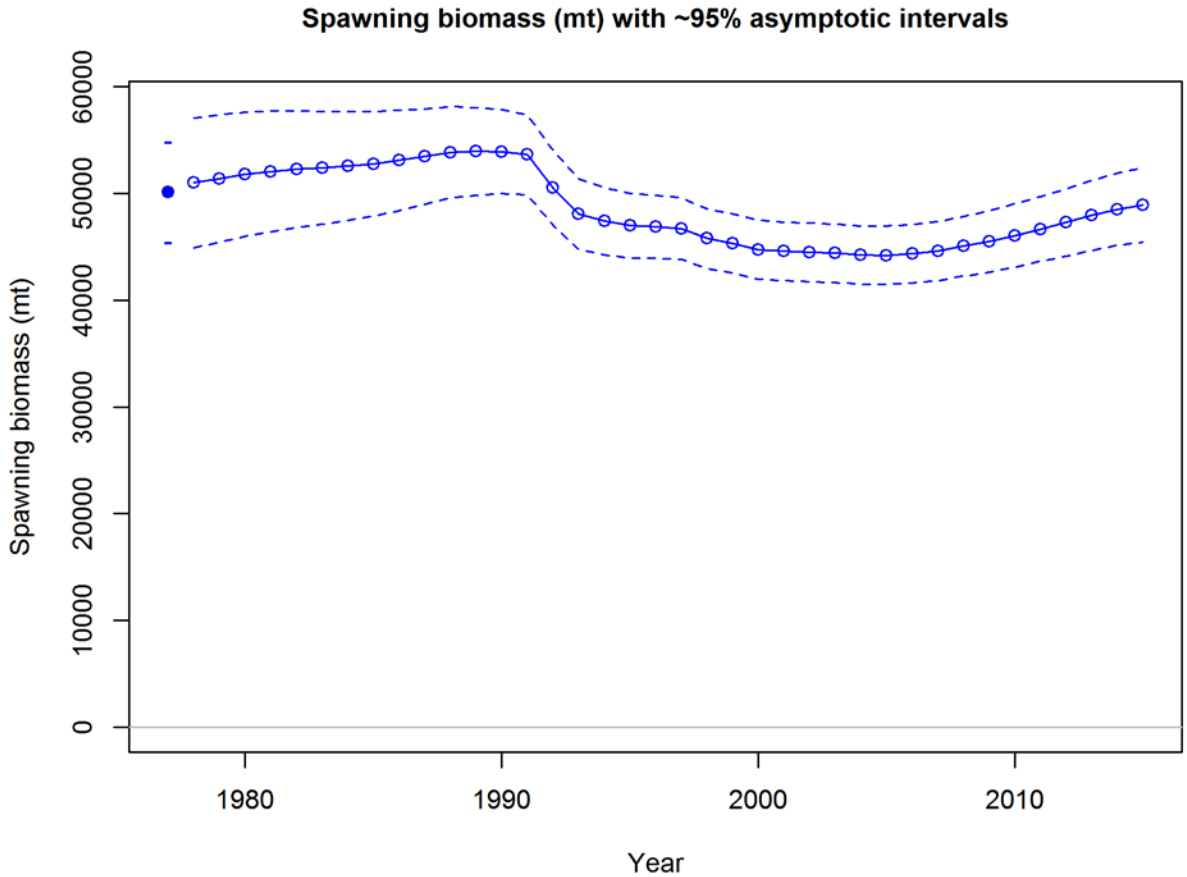


Figure 22. Time series of estimated spawning stock biomass (mt) over time (solid blue line and circles) and asymptotic 95% confidence intervals (blue dashed lines) for the current base case model.

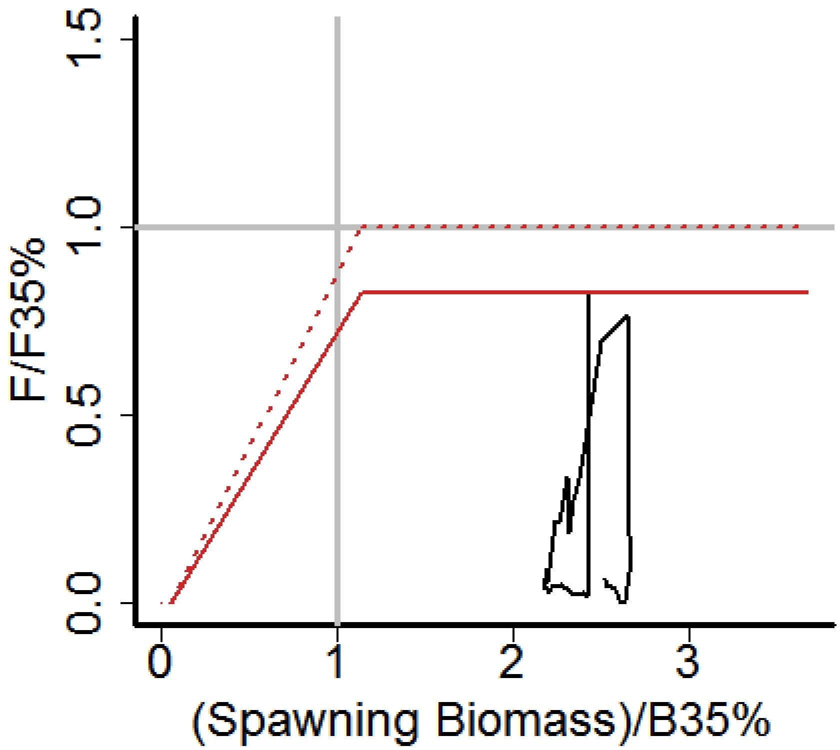


Figure 23. Spawning stock biomass relative to $B_{35\%}$ and fishing mortality (F) relative to $F_{35\%}$ from 1978-2017 (solid black line), the OFL control rule (dotted red line), the maxABC control rule (solid red line), $B_{35\%}$ (vertical grey line), and $F_{35\%}$ (horizontal grey line). Projected biomass for 2016 and 2017 are included.

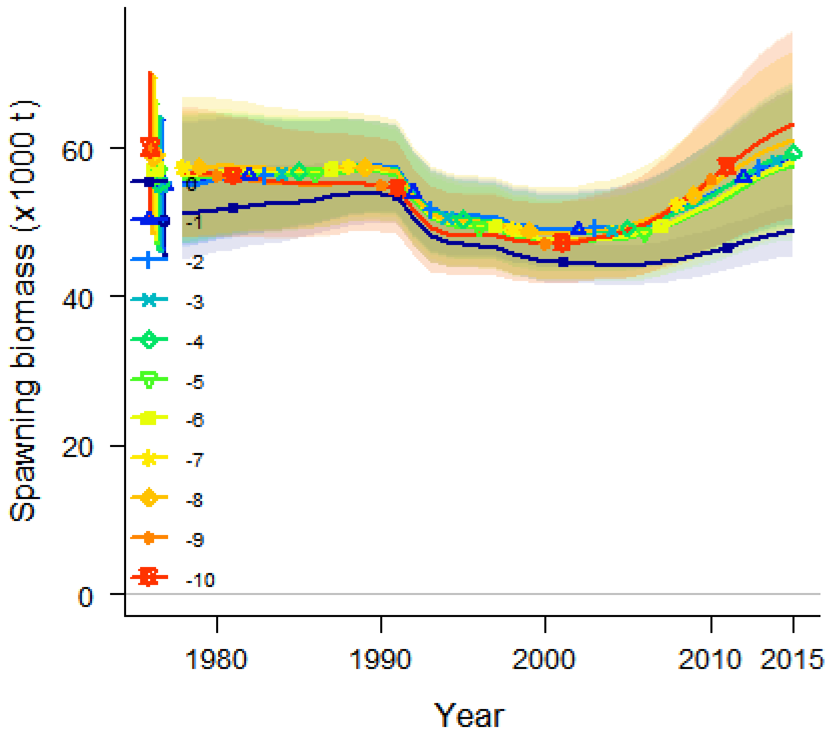
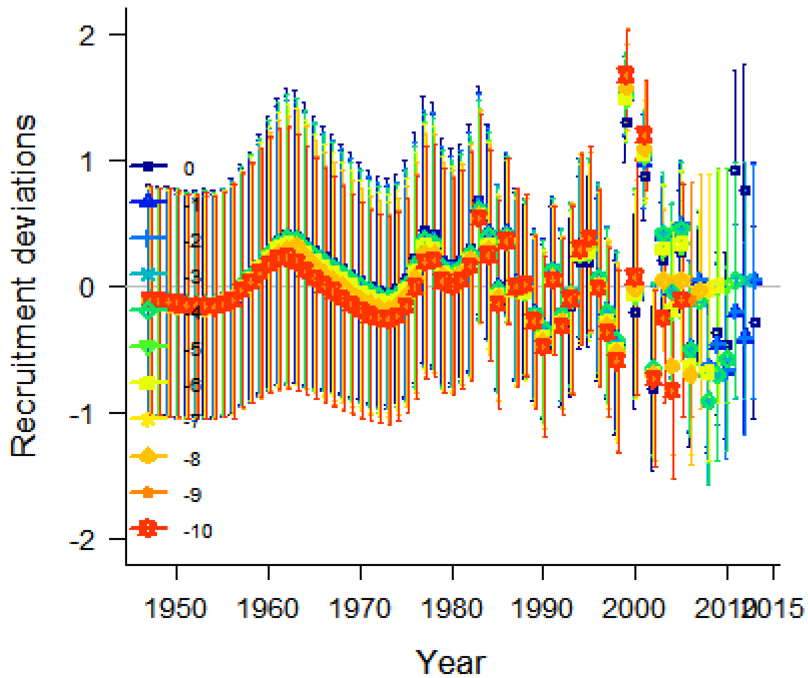


Figure 24. Spawning stock biomass and corresponding 95% asymptotic confidence intervals for base case model runs excluding 0 to 10 years of the most recent data. Each model assumes that recruitment deviations are 0 for years where data are excluded.



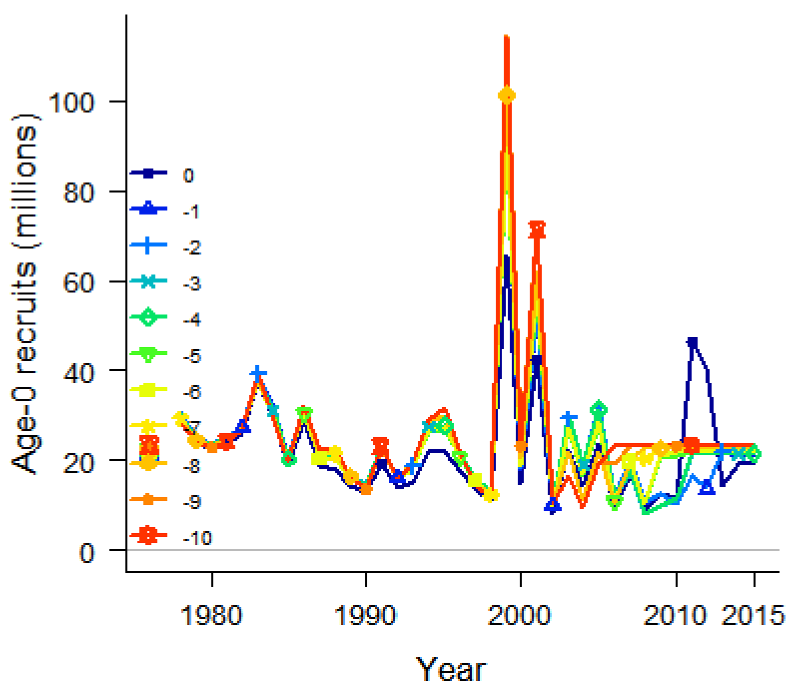


Figure 25. Recruitment deviations with corresponding 95% asymptotic confidence intervals (top panel) and age-0 recruits (bottom panel) for base case model runs excluding 0 to 10 years of data. Recruitment deviations are fixed at 0 for years where data are excluded.

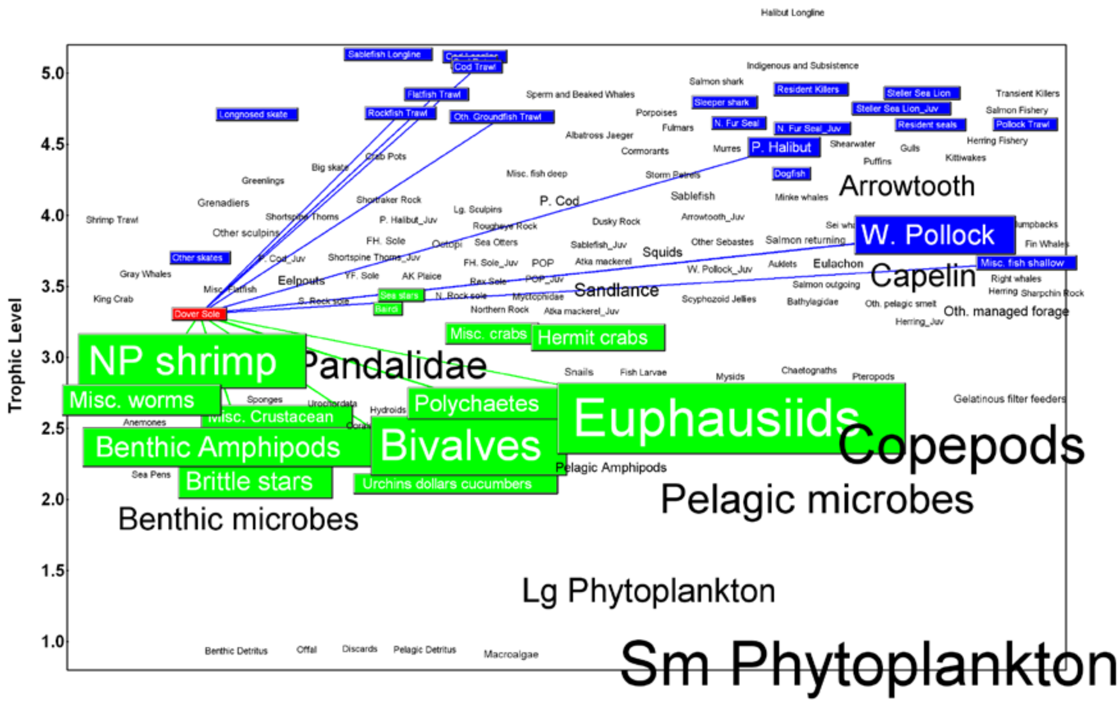


Figure 26. The food web from the GOA ecosystem model (Aydin et al., 2007) highlighting Dover sole links to predators (blue boxes and lines) and prey (green boxes and lines). Box size reflects relative standing stock biomass.

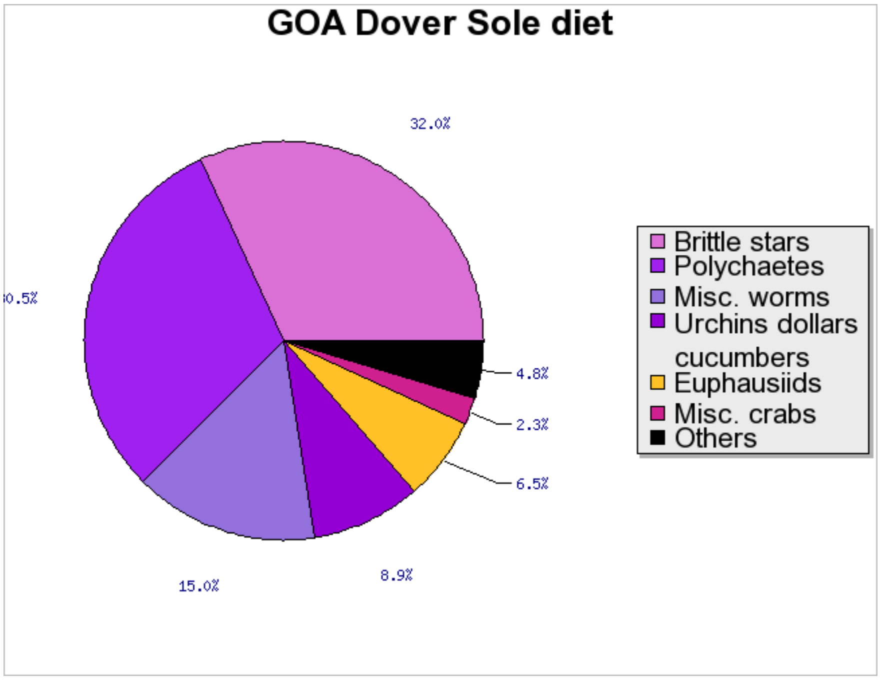


Figure 27. Diet composition for Dover sole from the GOA ecosystem model (Aydin et al., 2007).

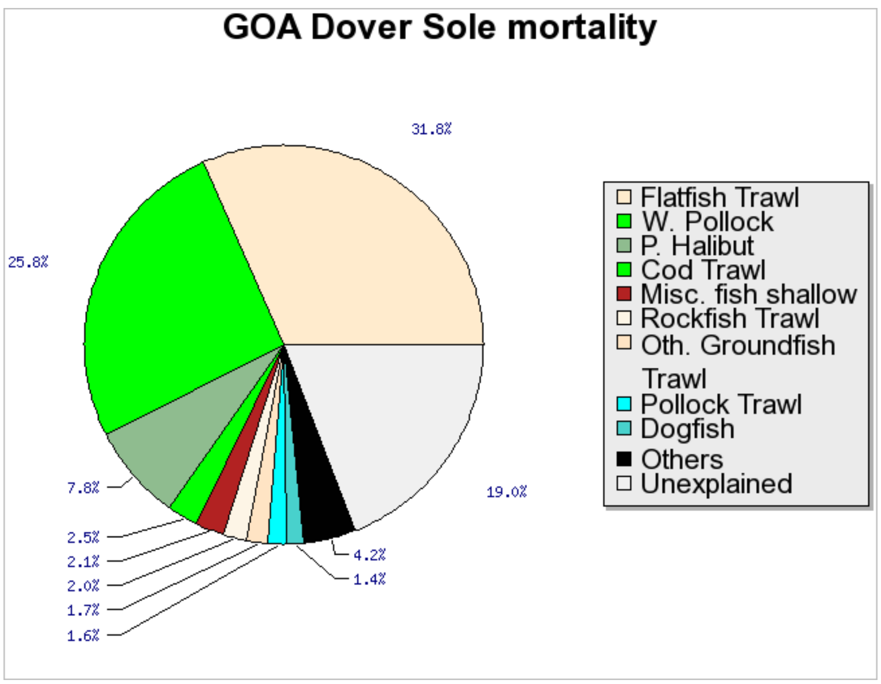


Figure 28. Decomposition of natural mortality for Dover sole from the GOA ecosystem model (Aydin et al., 2007).

Appendix 5A: Non-Commercial Catches of GOA Deepwater Flatfish (mt)

	ADF&G Data Sources					
Year	Golden King Crab Pot Survey	Large-Mesh Trawl Survey	Prince William Sound Sablefish Tagging	Sablefish Longline Survey	Scallop Dredge Survey	Small-Mesh Trawl Survey
1998		386.26		1.7	0.4	
1999		1278.85		4.5		
2000		300.76		3.5		12.09
2001		577.56		5.1		
2002		339.65		10.8	1.84	
2003		2093.49		20.8	0.2	83.75
2004	3.709	959.56		12.85	0.06	225.97
2005	12.98	1304.72			3.27	511.54
2006	1.854	250.96		4.463	72.11	169.53
2007		870.07			3.8	28.66
2008		176.31			7	
2009		1018.12			4.17	
2010		2463.475			35.54	137.78
2011		2666.038			6.35	49.14
2012		1990.99			5.88	28.81
2013		1749.6	37.087		10	23.1
2014		940.04				54.9

Year	IPHC Annual Longline Survey
2011	12
2012	1
2013	40
2014	75

(Continued on next page)

Appendix 5A, continued: Non-commercial catches of deepwater flatfish (mt)

	NMFS Data Sources (excludes NMFS GOA bottom trawl survey used in assessment)		
Year	**Annual Longline Survey**	**Shumigans Acoustic Survey**	**Structure of Gulf of Alaska Forage Fish Communities**
1990	306.46		
1991	319.55		
1992	601.28		
1993	601.63		
1994	623.63		
1995	905.46		
1996	699.18		
1997	618.90		
1998	575.59		
1999	755.28		
2000	524.85		
2001	977.06		
2002	899.57		
2003	471.09		
2004	558.13		
2005	911.85		
2006	751.21		
2007	653.24		
2008	946.91		
2009	895.49		
2010	840.45	2.07	4.37
2011	480.48		
2012	895.54		
2013	920.78		
2014	630.72		

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