14: ASSESSMENT OF THE DEMERSAL SHELF ROCKFISH STOCK COMPLEX IN THE SOUTHEAST OUTSIDE DISTRICT OF THE GULF OF ALASKA

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Executive Summary

The demersal shelf rockfish (DSR) complex (yelloweye, quillback, copper, rosethorn, canary, China, and tiger rockfish) (Table 1) is assessed on a biennial cycle, with full stock assessments typically conducted in odd calendar years, however we are presenting a full stock assessment this year to coincide with new survey data and the development of a new model. Historically, the stock assessment was based on relative abundance estimates from a manned submersible (*Delta*), however as of 2010, the submersible was retired from use. No surveys were conducted in 2010 and 2011 while an alternate vehicle was sought. In 2012, we transitioned the survey from a submersible to a remote operated vehicle (ROV), and conducted stock assessment surveys in 2012 and 2013. In 2014, we planned to conduct a survey but had to cancel due to weather. The acceptable biological catch (ABC) and overfishing level (OFL) for this year's SAFE (Table 2) are based on the most recent ROV and submersible density estimates of yelloweye rockfish in each management area using our historical methodology (Brylinsky et al. 2009). However, the results of a preliminary statistical age-structured model, which incorporates submersible and ROV yelloweye rockfish density estimates, commercial, sport, and subsistence fishery data, and International Pacific Halibut Commission (IPHC) survey data, are presented in Appendix B.

Summary of Changes in Assessment Inputs

Changes in the input data:

Catch information and average weights for yelloweye rockfish catch from the commercial fishery were updated for 2014. Average weight of yelloweye rockfish changed from 4.06 kg to 3.69 kg in East Yakutat (EYKT), from 3.19 kg to 3.34 kg in Central Southeast Outside (CSEO), and 3.24 to 3.68 kg in Northern Southeast Outside (NSEO). There was not a directed fishery in Southern Southeast Outside (SSEO) and no samples were taken from bycatch in the halibut fishery in this area so average weight from 2013 was used (3.53 kg).

Yelloweye rockfish density was derived from the most recent survey data for all management areas (Table 3) with the exception of NSEO. The 2012 CSEO density estimate was used as a proxy for the NSEO area, as the last time it was surveyed with a sufficient sample size was in 1994. NSEO is a small management area directly adjacent to CSEO, and should have similar habitat attributes, and yelloweye rockfish recruitment potential as CSEO. Fishing pressure in NSEO is likely slightly less than in CSEO as there has not been a directed fishery since 1995, however, like the other management areas, incidental catch of DSR in the halibut fishery is the primary source of commercial mortality. Yelloweye rockfish density was also updated in this stock assessment for SSEO using the 2013 survey data (ROV-derived). DSR habitat area was updated for this stock assessment based on the best available information from fishery logbooks, side scan, and multibeam data.

Changes in the assessment methodology:
There are no changes to the assessment methodology data from the previous habitat-based assessment using submersible and ROV density estimates as the primary survey data.

However, a preliminary area-specific age-structured assessment model is presented in Appendix B. The data used in the age-structured assessment model consist of total annual catch (tons) from the directed DSR commercial fishery in the four SEO management areas through 2014 (Table 1; Appendix B), age composition data from the commercial fisheries (directed and incidental from the halibut fishery) through 2013 and projected catch for 2014, total annual catch from the commercial longline halibut fishery through 2013 (Appendix B), estimates of yelloweye density (individuals per square kilometer) derived from submersible and ROV surveys through 2013 (Table 3; Appendix B), updated estimates of total rockfish habitat per management area in square kilometers derived from sonar, sounding, and fishery data (Table 4; Appendix B), recreational harvest, IPHC survey relative abundance through 2013, and historical estimates of length, weight, and maturity composition derived from commercial fisheries data.

Summary of Results
DSR are managed under Tier 4 of North Pacific Fishery Management Council (NPFMC) harvest rules, where maximum allowable $F_{ABC} \leq F_{40\%}$ and $F_{OFL}=F_{35\%}$. The maximum allowable ABC for 2015 is 293 t based on Tier 4 status for DSR. DSR are particularly vulnerable to overfishing given their longevity, late maturation, and habitat-specific residency. As in previous years, we recommend a harvest rate lower than the maximum allowed under Tier 4; F=M=0.02. This results in an author's recommended ABC of 225 t for 2015, a decrease from the 2014 ABC of 274 t. The overfishing level (OFL) is set using $F_{35\%}=0.032$; which is 361 t for 2015. The ABC and OFL are calculated after adjusting for the non-yelloweye rockfish species landed in the complex.

Per the 2009 Board of Fisheries (BOF) decision, subsistence DSR removals are deducted off the ABC prior to the allocation of the total allowable catch (TAC) between the commercial and sport fisheries. In the current assessment, 8 t was deducted from the ABC for DSR caught in the subsistence fisheries, for a TAC of 217 t. In 2006 the BOF allocated the SEO DSR TAC in the following manner: 84% to the commercial fishery and 16% to the sport fishery. Thus 182 t is allocated to commercial fisheries, and 35 t is allocated to sport fisheries for 2015.

Reference values for DSR are summarized in the following table, with the recommended ABC and OFL values in bold. The stock was not subjected to overfishing last year.

Quantity	As estimated or *specified last* year for: 2014	2015	As estimated or *recommended this* year for: 2015	2016
M (natural mortality rate)	0.02	0.02	0.02	0.02
Tier	4	4	4	4
Yelloweye Biomass (t)	13,274		10,933	
$F_{OFL} = F_{35\%}$	0.032	0.032	0.032	0.032
$maxF_{ABC}$	0.026	0.026	0.026	0.026
Specified/recommended F_{ABC}	**0.020**	**0.020**	**0.020**	**0.020**
Total DSR ABC (Yelloweye ABC/0.97) (t) [1]	274		225	
Total DSR OFL (Yelloweye OFL/0.97) (t) [1]	438		361	
Total DSR max ABC (t)	**356**		**293**	
Status	As determined last year for: 2012	2013	As determined this year for: 2013	2014
Is the stock being subjected to overfishing?	No	n/a	No	n/a

[1] The DSR ABC and OFL were increased by 3% as the previous year's commercial catch is used to determine the percentage of non-yelloweye DSR.

Updated catch data (t) for DSR in the Gulf of Alaska as of October 19, 2014 (NMFS Alaska Regional Office Catch Accounting System via the Alaska Fisheries Information Network (AKFIN) database, http://www.akfin.org are summarized in the following table.

Year	EGOA Catch Total[1]	EGOA ABC	EGOA TAC[1]
2013	212	303	230
2014	93	274	182

[1] TAC and Catch are for the commercial fishery only. The recreational harvest for the SEO (16% of the ABC after the subsistence harvest removal, or 35 mt) was 34 t in 2014 and is projected to be 34 t in 2015.

Area Apportionment

The ABC and OFL for DSR are for the SEO Subdistrict. The State of Alaska manages DSR in the Eastern regulatory area with Council oversight and any further apportionment within the SEO Subdistrict is at the discretion of the State.

Summaries for Plan Team

Species	Year	Biomass	OFL	ABC	TAC[1]	Catch[2]
	2012	14,307	467	293	240	180
	2013	14,588	487	303	249	212
	2014	13,274	438	274	224	93[2]
	2015	10,933	361	225	182	

[1] TAC and Catch are for the commercial fishery only. The TAC is calculated after the subsistence projected catch is deducted from the ABC. The estimated recreational catch was 34 t for 2014.

[2]Updated commercial catch data (t) for demersal shelf rockfish in the Southern Outside District as of October 19, 2014.

Responses to SSC and Plan Team Comments on Assessments in General

The SSC supports the GOA Plan Team recommendation that there should be an investigation into the use of different survey averaging methods, particularly with respect to estimates for species complexes. The SSC requests that both Plan Teams note when area ABCs have been exceeded in the prior year. For assessments involving age-structured models, this year's CIE review of BSAI and GOA rockfish assessments included three main recommendations for future research: Authors should consider: (1) development of alternative survey estimators, (2) evaluating selectivity and fits to the plus group, and (3) re-evaluating natural mortality rates. The SSC recommends that authors address the CIE review during full assessment updates scheduled in 2014.

The SSC noted that different stock assessment scientists often use different methods for catch estimation to estimate catches between late October and December 31 of the current assessment year, as well as catches to be taken during the following two years for use in the catch specification process. The SSC understands that Dana Hanselman will compile the various methods in use. The SSC looks forward to Plan Team advice on the merits of the various alternatives.

We also look forward to these data. Currently, since the directed DSR fisheries are completed by March, and the DSR bycatch in the halibut fishery is usually completed by early November, we have been simply running the final catch numbers in early November and assuming that is the final catch for the calendar year. Very little (<2 t) DSR catch is reported after early November.

Responses to SSC and Plan Team Comments Specific to this Assessment

"The SSC looks forward to preliminary results of the age-structured model next year and asks that the authors evaluate and include IPHC survey data as one of the data inputs. The SSC also looks forward to seeing the results of the final report by Yoklavich et al. comparing fish abundances derived from an ROV versus a submersible. The SSC shares the Plan Team's concern regarding the decreasing biomass trend in CSEO and agrees that the evaluation of catch trends in CSEO compared to other areas may be helpful."

We present the preliminary ASA model in this document in Appendix B, including the IPHC survey data for the Plan Team and SSC's review. We also present the commercial catch per unit effort (CPUE) to compare catch trends in CSEO compared to other areas. There have not been any new published results from the ROV/submersible comparison work done by Yoklavich et al. (2013) but we will continue to keep appraised of the latest ROV and submersible research.

"For September, the Team recommends the authors present preliminary results of the age structured model if available. Contingent on the working group's efforts on the random effects model, the authors may consider including the results of the random effects model incorporating the new recommendations. The Team also recommends that recreational harvest (16% of the allocation) be footnoted in the catch table of the assessment to reflect the total DSR catch and to help clarify apportionments."

We present the preliminary ASA model in this document, including the IPHC survey data for the Plan Team and SSC's review. The random effects model has not, at this time, been incorporated into the stock assessment for 2015, but we await the Plan Team review in September. We added the recreational harvest to the catch table in a footnote per the Plan Team's request.

Introduction

Biology and Distribution
Rockfishes of the genus *Sebastes* are found in temperate waters of the continental shelf off North America. At least thirty-two species of *Sebastes* occur in the Gulf of Alaska. The DSR assemblage is comprised of the seven species of nearshore, bottom-dwelling rockfishes (Table 1). These fish are located on the continental shelf, reside on or near the bottom, and are generally associated with rugged, rocky habitat. For purposes of this report, emphasis is placed on yelloweye rockfish, as it is the dominant species in the DSR fishery (O'Connell and Brylinsky 2003).

All DSR are considered highly K-selective, exhibiting slow growth and extreme longevity (Adams 1980, Gunderson 1980, Archibald et al. 1981). Estimates of natural mortality are very low. These types of fishes are very susceptible to over-exploitation and are slow to recover once driven below the level of sustainable yield (Leaman and Beamish 1984, Francis 1985). An acceptable exploitation rate is assumed to be very low (Dorn 2000).

Management Units
Prior to 1992, DSR was recognized as a Fishery Management Plan (FMP) assemblage only in the waters east of 137° W. longitude. In 1992, DSR was recognized in EYKT, and management of DSR extended westward to 140° W. longitude. This area is referred to as the Southeast Outside (SEO) Subdistrict and is comprised of four management sections: EYKT, NSEO, CSEO, and SSEO. In the SEO, the State of Alaska and the National Marine Fisheries Service (NMFS) manage DSR jointly. The two internal state water Subdistricts, Northern Southeast Inside (NSEI) and Southern Southeast Inside (SSEI) are managed entirely by the State of Alaska and are not included in this stock assessment (Figure 1). Please see Appendix A for a more complete description of historical DSR management changes.

Stock structure
Siegle et al. 2013 detected subtle population genetic structure in yelloweye rockfish from the outer British Columbia coast and inner waters, but a lack of genetic structure on the outer coast (between the Bowie Seamount and other coastal locations in British Columbia). These data suggest that due to the long pelagic larval duration for *Sebastes* spp. (several months to one year) there is not significant genetic stock structure for the DSR complex in the SEO management area. However, additional life history data analyses at finer spatial scales are needed to evaluate DSR stock structure in the Eastern GOA. In

addition, the limited movements of yelloweye rockfish can lead to serial depletion of localized areas if overharvest occurs.

Life History
Rockfishes are considered viviparous although different species have different maternal contribution (Boehlert and Yoklavich 1984, Boehlert et al. 1986, Love et al. 2002). Rockfishes have internal fertilization with several months separating copulation, fertilization, and parturition. Within the DSR species complex, parturition occurs from February through September with the majority of species extruding larvae in spring. Yelloweye rockfish extrude larvae over an extended time period, with the peak period of parturition occurring in April and May in Southeast Alaska (O'Connell 1987). Although some species of *Sebastes* have been reported to spawn more than once per year in other areas (Love et al. 1990), no incidence of multiple brooding has been noted in Southeast Alaska (O'Connell 1987).

Rockfishes have a closed swim bladder that makes them susceptible to embolism mortality when brought to the surface from depth. Full retention regulations for the commercial fleet have been in place since 2005. Full retention of DSR had been required for the recreational fleet, but beginning in the 2013 season, all charter operators in Southeast Alaska were required to possess and utilize deep-water release devices for releasing non-pelagic (i.e. DSR) rockfish. Historically, release mortality biomass has been estimated using the assumption that released rockfish experience 100% mortality (Green et al. 2013).

Fishery

Description of directed fishery
The directed fishery for DSR began in 1979 as a small, shore-based, hook and line fishery in Southeast Alaska. This fishery targeted the nearshore, bottom-dwelling component of the rockfish complex, with fishing occurring primarily inside the 110 m contour. The early directed fishery targeted the entire DSR complex (Table 1), which at that time also included silvergray, bocaccio, and redstripe rockfish (Appendix A). In more recent years the fishery has targeted yelloweye rockfish and fished primarily between the 90 m and the 200 m contours. Over the past five years, yelloweye rockfish accounted for 96 to 98% (by weight) of the total DSR catch (Table 5). Quillback rockfish are the next most common species landed in the complex, accounting for approximately 2% of the landed catch between 2009 and 2013 (Table 5). The directed fishery is prosecuted almost exclusively by longline gear. Although snap-on longline gear was originally used in this fishery, most vessels now use conventional (fixed-hook) longline gear. Markets for this product are domestic fresh markets and fish are generally brought in whole, bled, and iced. Processors will not accept fish delivered more than three days after being caught.

In SEO, regulations stipulate one season only for directed fishing for DSR opening January 5^{th} (unless closed by emergency order) and continuing until the allocation is landed or until the day before the start of the IFQ halibut season (to prevent over-harvest of DSR), whichever comes first. The directed DSR fleet requested a winter fishery, as the ex-vessel price is highest at that time. Directed fisheries are opened by management area if there is sufficient commercial TAC remaining after subtracting the estimated DSR incidental catch in other fisheries.

Description of Effort and CPUE
Figure 14 in Appendix B discusses the CPUE for each of three of the four management areas since 1997, when the commercial logbook program became mandatory. There has not been directed fishery in the

NSEO area since 2001; thus it is not shown. Prior to the logbook requirement, the department did not have access to location and effort by set from the commercial fishery. Some fishermen kept logbooks voluntarily, but this was not required.

Catch History

Although the DSR fishery has been active since the late 1970s, catch reconstruction for DSR prior to 1992 is problematic due to changes in the species assemblage as well as the lack of a directed fishery harvest card prior to 1990 for CSEO, SSEO, and NSEO, and 1992 for EYKT (Appendix A). Thus, the history of domestic landings of DSR from SEO is shown from 1992–2014 in Table 2. The directed DSR catch in SEO was above 350 mt in the mid-1990s. Since 1998, landings have been below 250 mt, and since 2005, directed landings have typically been less than 100 mt. During the reported years (1992 to 2014), total catches peaked at 604 mt in 1994, and directed catch peaked at 381 mt in 1994. Although directed landings were higher in the 1990s, since 2000, most of the DSR total reported catch is from incidental catch of DSR in the halibut fishery. It should be emphasized, however, that prior to 2005, unreported mortality from incidental catch of DSR associated with the halibut and other non-directed fisheries is unknown and may have been as great as a few hundred tons annually. Directed commercial fishery landings have often been constrained by other fishery management actions. In 1992, the directed DSR fishery was allotted a separate halibut prohibited species cap (PSC) and is therefore no longer affected when the PSC is met for other longline fisheries in the GOA. In 1993, the fall directed fishery was closed early due to an unanticipated increase in DSR incidental catch during the fall halibut fishery.

Directed fisheries are held in the four management areas (EYKT, NSEO, SSEO, and CSEO) if there is sufficient quota available after the DSR mortality in other commercial fisheries (primarily the IFQ halibut fishery) is estimated. The directed fishery in NSEO has been closed since 1995; the total allocation for this management area has not been sufficient to prosecute an orderly fishery. The directed commercial DSR fisheries in the CSEO and SSEO management areas were not opened in 2005 because it was estimated that total mortality in the sport fishery was significant and combined with the directed commercial fishery would likely result in exceeding the TAC. No directed fisheries occurred in 2006 or 2007 in the SEO district as ADFG took action in two areas; one was to enact management measures to keep the catch of DSR in the sport fishery to the levels mandated by the BOF, and the other was to further compare the estimations of incidental catch in the halibut fishery to the actual landings from full retention regulations in the commercial fishery in those years to see how closely our predicted incidental catch matched the landed catch. Between 2006 and 2013, there was sufficient quota to hold directed commercial fisheries in at least two of the four SEO management areas. In 2014, only the EYKT area was opened to directed fishing.

DSR mortality in other fisheries

DSR have been taken as incidental catch in domestic longline fisheries, particularly the halibut fishery, for over 100 years. Some incidental catch was also landed by foreign longline and trawl vessels targeting slope rockfish in the EGOA from the late 1960s through the mid-1970s. Other sources of DSR incidental commercial catch are the lingcod, Pacific cod, and sablefish fisheries; however the halibut longline fishery is the most significant contributor to the commercial mortality of DSR.

In 1998 the NPFMC passed an amendment to require full retention of DSR in federal waters. Seven years later, in mid-season 2005, the final rule was published and fishermen must now retain and report all DSR caught in federal waters; any poundage above the 10% incidental catch allowance may be donated or kept for personal use but may not enter commerce. In July of 2000, the State of Alaska enacted a parallel regulation requiring DSR landed in state waters of Southeast Alaska to be retained and reported on fish tickets. Proceeds from the sale of DSR in excess of legal sale limits are forfeited to the State of Alaska.

Since the implementation of the state and federal full retention regulations for DSR, over 95% of the landed overages of DSR in the state and federal waters are now retained for personal use rather than being donated or sold. There appears to be increasing compliance with the full retention. In addition, the Alaska Longline Fishermen's Association has developed a database of rockfish "hotspots" so that halibut and sablefish longline fishermen can avoid making sets in these areas in an effort to reduce rockfish incidental catch.

The DSR mortality anticipated in the halibut fishery needs to be deducted from the total commercial TAC before a directed fishery can be prosecuted. From 2006 to 2011, we estimated the amount of DSR incidental catch in the halibut fishery using the IPHC stock assessment survey data to determine the weight ratio of yelloweye rockfish to halibut by depth and area. The yelloweye/halibut weight ratio by strata was applied to the IPHC halibut catch limit by strata. For a complete description of estimating the incidental catch of DSR in the halibut fishery prior to 2011, please see Brylinsky et al. (2009). Since 2012, we have used full retention data to calculate the ratio of DSR to halibut landed in the halibut fishery, by management area, and applied this to the estimated halibut quota, to project DSR incidental mortality. The results of this analysis showed that on an annual basis, the commercial fleet incidental catch rate was consistent (8 to 10%) over a five year period, while the IPHC survey incidental catch rate was highly variable by strata and year (ranging from 3 to 20%). An additional 10% is added to the estimation preseason for unreported incidental catch. Our modeled estimates using the full retention data are accurate when compared to actual catch.

Discards in the directed DSR Fishery

Discards in the directed DSR fishery include lingcod, Pacific cod, spiny dogfish, skates, and other rockfishes (Table 6). The magnitude of at-sea discard in the directed DSR fishery is difficult to quantify, as the fleet was unobserved until 2013, when the observer program was expanded to the small boat fleet in Southeast Alaska. Logbook data indicate that the primary discards were halibut and small numbers of lingcod and skates when fishermen reached their incidental catch allowance for those species.

Other removals

Other removals (subsistence, recreational, and research catch) are documented in Table 2. In July 2009, the ADF&G Division of Subsistence published the results of a study done to estimate the subsistence harvest of rockfish near four Alaskan communities, one of which was Sitka (Turek et al. 2009). ADF&G Subsistence Division conducted a call-out survey of "high harvesting households" to obtain additional information on the species composition of subsistence-caught rockfish. This survey revealed that 50% of the rockfish harvested are DSR species, predominantly quillback rockfish. These "high harvesting households" fished predominantly in the Sitka Local Area Management Plan (LAMP) area. The DSR subsistence harvest is reported in numbers of fish by location (northern southeast, southern southeast, and the Sitka LAMP area); these data are converted to biomass using the average weights provided from creel sampled recreational harvest. For 2015 estimates, the voluntary mail survey indicated 9,116 rockfish (not defined by species) had been taken in the EGOA subsistence fisheries.[1] Applying the data methodology described above to make a prediction about what might be taken in the subsistence fishery in 2015, the total anticipated harvest is 8 t.

Small research catches of yelloweye rockfish occur during the annual IPHC longline survey (Table 2). Research catch data are based on yelloweye rockfish reported on fish tickets from the IPHC survey. These are deducted, by management area, from the TAC prior to the opening of the directed commercial fishery.

Sport Fishery Removals

The Alaska Board of Fisheries currently allocates 16% of the DSR TAC for the Southeast Outside District to the recreational fishery after deduction of the estimated subsistence harvest. The sport fishery allocation includes estimated harvest and release mortality. Prior to 2006, the daily bag limit in the Southeast Alaska sport fishery for nonpelagic (DSR and slope/other) rockfish was 3 to 5 fish, depending upon the area fished, and there were no annual limits on any rockfish species. Since then, the board has established management provisions that may be implemented by the department on an annual basis to manage the sport fishery within the allocation. Sport fishery regulations for the Southeast outside waters in 2013 and 2014 were as follows:

1. For resident anglers, the daily bag limit was two nonpelagic rockfish, only one of which could be a yelloweye rockfish; the possession limit was four nonpelagic rockfish, only two of which could be yelloweye.
2. For nonresident anglers, the daily bag limit was two nonpelagic rockfish, only one of which could be a yelloweye; the possession limit was four nonpelagic rockfish, only one of which could be a yelloweye. In addition, nonresidents were restricted to one yelloweye per year. Immediately upon harvesting a yelloweye, the angler was required to log the harvest in ink on the back of their fishing license or on a nontransferable harvest record.
3. All nonpelagic rockfish caught were required to be retained until the angler's daily bag limit was reached.
4. Guides and crew members were not allowed to retain nonpelagic rockfish when clients were on board the vessel.

In addition, effective January 1, 2013, all nonpelagic rockfish released from a charter vessel are required to be released with a deepwater release device at the depth of capture or at a depth of at least 100 feet. All charter vessels are required to have at least one functional deepwater release device on board, have it readily available for use while anglers are fishing, and present it for inspection upon request by department or enforcement personnel.

Data sources for the recreational fishery include the ADF&G statewide harvest survey (SWHS), mandatory charter logbooks, and interview and biological sampling data from dockside surveys in major ports throughout Southeast Alaska. The SWHS is an annual mail survey sent to a stratified random sample of approximately 45,000 households containing resident and nonresident licensed anglers. The survey provides estimates of harvest and catch (kept plus released) in numbers of fish, for all rockfish species combined. Up to three questionnaires may be mailed to unresponsive households. Responses are

[1] With the exception of the fish reported from the Sitka LAMP area, it cannot be determined how many of DSR were caught in the SEO Subdistrict versus internal state waters.

coded by mailing, which allows adjustments for nonresponse bias. Estimates are provided for SWHS reporting areas, which closely mirror ADF&G Sport Fish management areas.

Logbooks have been mandatory for the charter fishery since 1998. Before 2006, charter logbook data were reported for pelagic and non-pelagic rockfish assemblages. Since 2006 logbooks have required reporting of the numbers of pelagic rockfish, yelloweye rockfish, and all other non-pelagic species kept and released by each individual angler. Charter operators are also required to report the primary ADF&G statistical area for each boat trip.

Creel survey sampling is conducted at public access sites in major ports throughout Southeast Alaska. There is also some sampling of fish landed at private docks and lodges. Prior to 2006, there were no biological data collected by creel samplers beyond species composition of sport-caught rockfish. Length and weight data were collected in 2006 and 2007 to estimate length-weight functions for each species. Only species composition and length have been collected since 2008. The numbers of rockfish kept and released per boat-trip have been collected by DSR species since 2006. The creel survey interviews also include reporting of the primary statistical area fished for each boat trip.

Final estimates of recreational fishery removals used a combination of data from the SWHS, creel survey, and charter logbook. The total removals were estimated as the sum of the mass of the harvest (retained catch) and release mortality. Harvest biomass *HB* was estimated for the outside waters portion of SWHS areas B, D, G, and H, which correspond roughly with the SSEO, CSEO, NSEO, and EYKT groundfish management districts, and summed:

$$HB = \sum_{a} \sum_{c} \sum_{s} \hat{H}_{ac} \hat{p}_{ac} \hat{\iota}_{acs} \hat{\bar{w}}_{acs}$$

where:

$\hat{H}_{ac}$ = the SWHS estimate of the number of rockfish (all species combined) harvested in SWHS area *a* by class *c* (charter or noncharter),

$\hat{p}_{ac}$ = the estimated proportion of harvest by class *c* from outside waters portion of area *a*,

$\hat{\iota}_{acs}$ = the estimated proportion of species *s* in the sport harvest of all rockfish by class *c* from the outside waters of area *a*, and

$\hat{\bar{w}}_{acs}$ = the estimated average round weight of species *s* in the sport harvest by class *c* from outside waters of area *a*.

Because the SWHS areas include inside waters, harvest estimates must be apportioned to obtain the outside waters harvest using $\hat{p}_{ac}$. Neither SWHS estimates nor creel survey interviews are adequate for this apportionment. SWHS reporting locations are not precise enough to identify outside waters, and many survey respondents are too unfamiliar with where they were fishing to report accurately. Creel survey data are precise, but surveys are only conducted in major ports and interviewed anglers may not accurately represent the spatial distribution of total harvest. Logbook data are mandatory and presumably represent a complete census of the charter harvest. Therefore, logbook data were used to apportion both charter and noncharter harvest to outside waters. This proportion is treated as a constant in calculation of variance.

Average weight was estimated for each species by applying species-specific length-weight relationships to length measurements of all harvested fish from outside waters in each SWHS area (Brylinsky et al. 2009).

Release mortality biomass (*RB*) was estimated by area and species for each class using different methods. For the noncharter sector, the mortality rate of all species of rockfish released was assumed to be 100 percent, and the average weight of released rockfish was assumed to equal the average weight of harvested rockfish for each species. Therefore, release mortality was estimated as a function of harvest biomass and the release rate by SWHS area for the noncharter sector:

$$RB_{Noncharter} = \sum_{a}\sum_{s}\left(\frac{\widehat{HB}_{as}}{1-r_{as}} - \widehat{HB}_{as}\right)$$

where:

$\widehat{HB}_{as}$ = the estimated harvest biomass of species *s* in SWHS area *a* by noncharter anglers, and

r_{as} = the proportion of the catch of rockfish species *s* that was released in area *a*.

The release rate r_{as} for the noncharter and charter sectors was obtained using charter logbook data from outside waters. Logbook data were used for noncharter sector estimates because SWHS estimates are for all species combined and could not be apportioned to species for the noncharter sector. Creel survey interview data on noncharter fishery releases were spotty and incomplete. Given the similarity in resident (mostly noncharter) and nonresident (mostly charter) bag limits, logbook data were felt to provide a reasonable proxy for release rates in the noncharter fishery.

Starting in 2013, release biomass was estimated for the charter sector taking into account a higher survival rate due to mandatory use of deepwater release devices. There is now substantial evidence that survival of benthic rockfish species is dramatically increased when fish are released at depth (Jarvis and Lowe 2008, Hochhalter and Reed 2011, Hannah et al. 2012, GMT 2014). Point estimates of survival for yelloweye rockfish and other DSR species held in cages for two days ranged from 0.90 to 1.00 (Hannah et al. 2012, Hannah et al. 2014). Hochhalter and Reed (2011) estimated 17-day survival of fish caught and released in the wild at 0.988. The Pacific Fishery Management Council has adopted depth-specific mortality rates for yelloweye, canary rockfish, and cowcod. The mortality rates for yelloweye rockfish are based on 90% confidence limits and range from 0.22 to 0.27 for depths shallower than 50 fathoms, and 0.57 for depths of 50-75 fathoms (GMT 2014). Hochhalter and Reed (2011) captured yelloweye at depths of 18-72 m but were unable to discern an effect of depth of capture on survival.

Based on the above studies, we assumed a mortality rate of 20% for estimation of 2013 and 2014 charter release mortality for DSR species. This rate is higher than most scientific study results for yelloweye rockfish, but is precautionary in order to take into account the lack of depth information for sport-caught fish, expected variation in types of gear used, less than ideal handling, and potential noncompliance with the release requirement. The choice of 20% is somewhat arbitrary and will be adjusted if better information becomes available.

Release mortality biomass *RB* was estimated for the charter sector as:

$$RB_{Charter} = \sum_{a}\sum_{s} \hat{R}_{as}\,\widehat{MR}\hat{\hat{w}}_{as}$$

where:

- $\hat{R}_{as}$ = the estimated number of rockfish of species *s* released in the outside waters of SWHS area *a* by charter anglers,
- $\widehat{MR}$ = the assumed short-term mortality rate due to capture, handling, and release of demersal shelf rockfish (all species, all depths), and
- $\hat{\hat{w}}_{as}$ = the estimated average round weight of species *s* released by charter anglers from outside waters of area *a*.

As noted above, the assumed mortality rate was 0.20, with a standard error of 0.03. The assumed standard error was “borrowed” from the Pacific Council adopted mortality rates for yelloweye rockfish (GMT 2014). The average weight of harvested rockfish was used as a proxy for the average weight of released rockfish because there are no size data available for rockfish released in the charter fishery. This is not an unreasonable proxy given the requirement that anglers must retain all rockfish until their bag limit is reached.

The number of rockfish released in each area in the equation above (R_{acs}) was estimated as:

$$\hat{R}_{as} = r_{as}\frac{\hat{H}_{as}}{(1 - r_{as})}$$

where $\hat{H}_{as}$ is the estimated charter harvest in SWHS area *a* of species s, and r_{as} is proportion of rockfish catch by charter anglers that was released, as described above.

As noted previously, SWHS estimates were used to calculate final estimates of the biomass of harvest and release mortality. However, SWHS estimates are not available until September of the year following harvest. In order to produce a preliminary harvest estimate for the current year, the number of rockfish of all species harvested in each SWHS was projected. Charter harvest estimates were projected using regressions of SWHS estimates on partial-year logbook data (through July 31). Regression through the origin was used because some SWHS areas had very little contrast in the harvest estimates, producing insignificant slopes and illogical intercepts. Harvest projections for the noncharter sector were obtained from time series forecasts of SWHS estimates. The Box-Jenkins procedure was used to identify suitable ARIMA models (Box and Jenkins 1976). All models were evaluated using Akaike’s Information Criteria corrected for small sample sizes (AICc). For most SWHS areas, no autoregressive or moving average components were identified, leaving the naïve forecast, or the previous year’s harvest, as the best model. However, for 2014, a simple exponential smoother (SAS 2011: Proc ESM) produced superior forecasts for all areas. For SWHS Area G (Glacier Bay), rockfish harvest has increased dramatically in the last two years, departing from the previous trend. Therefore, even though the exponential forecast has the lowest AICc, the previous year's harvest was higher and was used for the preliminary estimate in order to be precautionary.

Final estimates of 2013 sport fishery removals and preliminary estimate of 2014 removals (in mt) are as follows:

Type of Estimate		***2013***	***2014***
Retained Harvest	Estimate	31.4	32.8
	StdErr	1.4	1.7
	95% CI[a]	28.6-34.2	29.4-36.2
Release Mortality	Estimate	2.3	1.5
	StdErr	0.2	0.1
	95% CI[a]	1.8-2.7	1.2-1.8
Total	**Estimate**	**33.6**	**34.3**
	StdErr	1.6	1.8
	95% CI[a]	30.5-36.8	30.8-37.8

Data

Submersible and ROV surveys

ADF&G began conducting a fishery-independent, habitat-based stock assessment for DSR using visual survey techniques to record yelloweye rockfish observations on line transects in rock habitat in 1988. The DSR stock assessment surveys have historically rotated among management areas on a biannual basis; it would be time and cost-prohibitive to survey the entire SEO in one field season due to the large size of the area (Figure 1). Instead, the most recent abundance estimate from a management area is used to update the annual stock assessment for SEO, but four to six years may elapse between surveys (Brylinsky et al. 2009). Between 1988 and 2010, density estimates derived from yelloweye rockfish counts from submersible video observations were extrapolated over the total yelloweye rockfish habitat. Average weight for yelloweye rockfish landed in the halibut and directed commercial fisheries was applied to the density estimate to obtain a biomass estimate for each management area (O'Connell and Carlile 1993, Brylinsky et al. 2009).

In 2012, ADF&G transitioned to using an ROV for visual surveys given the unavailability of a cost-effective and appropriate submersible. ROVs are a low-cost and versatile tool that have been increasingly used to study marine habitats and organisms (e.g. Pacunski et al. 2008). Although the survey vehicle has changed, the basic methodology to perform the stock assessment for the DSR complex remains unchanged. We use a Phantom ROV (HD 2+2) "*Buttercup*" that is owned and operated by ADF&G Central Region. The ROV is outfitted with a pair of high definition machine-vision stereo cameras that are used to record video data from line transects. Two additional cameras are mounted to the ROV, the "main" camera, which is a wide-angle, color camera that the pilot uses to drive the ROV, and a "forward-facing" camera. Two scaling lasers, mounted 10 cm apart and in line with the camera housing, are used as a measurement reference for objects viewed in the non-stereo cameras. However, objects viewed in the stereo cameras are most accurately measured during video review in the stereo camera software viewing package. All stereo camera video data are reviewed and analyzed using SeaGIS software (SeaGIS Pty Ltd., EventMeasure version 3.50). The SeaGIS software is a measurement science software used to log and archive events in digital imagery (Seager 2012).

The initial ROV survey was conducted in 2012 in the CSEO management area. Forty-six transects were conducted, and the resulting yelloweye rockfish density estimate was 752 fish/km^2 with a coefficient of variation (CV) of 13% (Table 3; Figure 2). Ralston et al. (2011) examined stock assessments for 17 data-rich groundfish and coastal pelagic species, and found the mean CV for biomass estimates to be 18%. In this context, a CV of 13% was considered a high level of precision, a view supported by Robson and Regier (1964) and Seber (1982). Although we were not able to compare the ROV results directly with the submersible or account for natural changes in the yelloweye rockfish population between years, the ROV yelloweye rockfish density estimate for 2012 was comparable to previous submersible estimates with a similar magnitude (Figure 3). The ROV was successfully deployed in most weather conditions and able to navigate the seafloor and currents in the preferred direction and orientation for the majority of the planned dive transects. In 2013, 31 transects were successfully surveyed in the SSEO; the density estimate was 986 fish/km^2 (CV=22%). In 2014, we planned to survey EYKT, but had to cancel the survey due to poor weather. Plans are pending to reschedule the survey for May 2015.

Habitat

Visual surveys are conducted only in yelloweye rockfish habitat; which is defined as rock habitat inshore of the 100-fathom depth contour. Seafloor is designated as "rock" based on information from sonar surveys, directed commercial fishery logbook data, and substrate information from NOAA charts. Substrate information obtained from sonar surveys is considered the best information available on rock habitat. In the absence of sonar data, directed commercial fishery logbook data are considered a proxy for rocky habitat (O'Connell and Carlile 1993, Brylinsky et al. 2009). In NSEO management area, where no sonar surveys have been performed and commercial fishery logbook data are limited, yelloweye rockfish habitat was delineated by buffering locations designated as coral, rock, or hard seafloor on NOAA charts by 0.5 miles. Locations were only considered preferred yelloweye rockfish habitat if <100 and ≥35 fm; this criterion was based on observations from the submersible that indicated that 90% of yelloweye rockfish were recorded between those depths.

Seafloor mapping has been performed across 3,058 km^2 of SEO (Figure 3). Backscatter data have been collected during side scan and multibeam surveys and comprehensive bathymetry data during multibeam surveys with some limited bathymetric soundings collected during side scan surveys. Seafloor has been classified into habitat type by Moss Landings Marine Laboratories' Center for Habitat Studies using bathymetry, backscatter, and direct observations from the *Delta* submersible and reduced to substrate induration of soft, mixed, or hard (Greene et al. 1999). Seafloor identified as hard substrate is considered yelloweye rockfish habitat.

In CSEO management area, 832 km^2 have been surveyed with 442 km^2 of this area considered rocky habitat (Table 4). A side scan survey covering 538 km^2 was performed west of Cape Edgecumbe (located on Kruzof Island) in 1996 (Figure 3), and in 2005, a high resolution 8 km^2 multibeam survey, which encompasses the Pinnacles Marine Reserve, was performed within the southern portion of the area originally side scanned. In 2001, a 294 km^2 area west of Cape Ommaney (located on the southern tip of Baranof Island) was surveyed.

In EYKT management area, 1,072 km^2 have been surveyed on the Fairweather grounds with 500 km^2 of this area composed of rocky habitat. A total of 784 km^2 were side scanned on the west bank in 1998 and 288 km^2 multibeamed on the east bank in 2002 and 2004 (Table 4).

In SSEO management area, 1,154 km^2 have been multibeamed, with 322 km^2 considered rocky habitat. Multibeam surveys have been performed around the Hazy Islands west of Coronation Island in 2001 (400 km^2), west of Cape Addington on Noyes Island in 2006 (84 km^2), at Learmonth Bank in Dixon Entrance in 2008 (530 km^2), and south of Cape Felix on Suemez Island in 2010 (140 km^2) (Table 4; Figure 3).

For areas without seafloor mapping information, we delineate rocky habitat using directed commercial fishery logbook data. Locations where catch per unit effort is ≥ 0.04 yelloweye rockfish per hook are considered preferred yelloweye rockfish habitat. Longline sets with only start positions are buffered by 0.5 miles (this established buffer size was retained for consistency). Starting in 2003, fishermen were required to include both start and end set positions; sets with both locations are buffered 0.5 km around the entire track. This buffering criterion was based on the minimum range of travel of four yelloweye rockfish tagged with transmitters in Oregon (P. Rankin, Oregon Department of Fish and Wildlife, personal communication). Buffered logbook sets were merged, and segments were included in the delineated habitat if ≥2,300 m in length (to ensure rocky segments were large enough for two non-overlapping submersible transects). To consider habitat segments as "continuous", no gaps > 0.5 nautical miles were allowed.

Total yelloweye rockfish habitat is estimated for SEO at 3,892 km^2. The Fairweather grounds in EYKT management area composes 739 km^2 of rocky habitat with 68% derived from sonar; CSEO management area is composed of 1,661 km^2 rocky habitat with 27% from sonar; SSEO composed of 1,056 km^2 of rock with 30% from sonar; and NSEO with 436 km^2 rock with no sonar surveys performed in this area (Table 4). Rock habitat not derived from sonar is defined based on fishery logbook data.

Analytic approach

Distance sampling methodology is used to estimate yelloweye rockfish density from ROV and submersible surveys. Density estimates are limited to adult and subadult yelloweye rockfish, the principal species targeted and caught in the directed DSR fishery, and our ABC recommendations for the entire assemblage are based on adult yelloweye biomass. Biomass of adult yelloweye rockfish is derived as the product of estimated density, the estimate of rocky habitat within the 200 m contour, and average weight of fish for each management area. Variances are estimated for the density and weight parameters but not for area. Estimation of both transect line lengths and total area of rocky habitat are difficult and contribute to the uncertainty in the biomass estimates. As a result of this uncertainty in the habitat area estimation, the lower 90% confidence interval of the biomass estimate is used to calculate the ABC.

Yelloweye Rockfish Density Estimates from Submersible Surveys (1988-2009)
In a typical submersible dive, two transects were completed per dive with each transect lasting 30 minutes. During each transect, the submersible pilot attempted to maintain a constant speed of 0.5 km and to remain within 1 m of the bottom, terrain permitting. A predetermined compass heading was used to orient each transect line. Line transect sampling entails counting objects on both sides of a transect line. Due to the configuration of the submersible, with primary view ports and imaging equipment on the starboard side, we only counted fish on the right side of the line. All fish observed from the starboard port were individually counted and their perpendicular distance from the transect line recorded (Buckland et al. 1993). An externally mounted video camera was used on the starboard side to record both habitat and audio observations. In 1995, a second video camera was mounted in a forward-facing position. This camera was used to ensure 100% detectability of yelloweye rockfish on the transect line, a critical assumption when using line transect sampling to estimate density. The forward camera also enabled counts of fish that avoided the sub as the sub approached and removals of fish that swam into the transect from the left side because of interaction with the submersible. Yelloweye rockfish have distinct coloration differences between juveniles, subadults, and adults, so these observations were recorded separately.

Hand-held sonar guns were used to calibrate observer estimates of perpendicular distances. It was not practical to make a sonar gun confirmation for every fish. Observers calibrated their eye to making visual estimates of distance using the sonar gun to measure the distance to stationary objects (e.g. rocks) at the beginning of each dive prior to running the transect and between transects.

Yelloweye Rockfish Density Estimates from ROV Surveys (2012-present)
Random dive locations for line transects (Figure 4) are selected in preferred yelloweye rockfish habitat using ArcGIS. Random locations were removed from the survey design if they were in depths ≥200 m, which is the maximum operating depth for the ROV. Transects of 1-km length were mapped at each suitable random point with four possible orientations along the cardinal directions and crossing through the random point (Figure 5). A transect length of 1-km was selected after consideration of visual surveys conducted by other agencies (personal communication, Robert Pacunski, WDFW, Mike Byerly, ADF&G), the encounter rate of yelloweye rockfish based on our previous surveys, and ROV pilot fatigue. The number of planned transects was based on yelloweye rockfish encounter rates from previous surveys and our targeted precision (CVs of less than 15%).

Transect Line Lengths – Submersible
Beginning in 1997, we positioned the support ship directly over the submersible at five-minute time intervals and used the corresponding Differential Global Positioning System (DGPS) fixes to determine line length. In 2003 the submersible tracking system was equipped with a gyro compass, enabling more accurate tracking of the submersible without positioning the vessel over the submersible. In 2007 and 2009, in addition to collecting the position of the submersible using five minute time intervals, we also collected position data every 2 seconds using the WinFrog tracking software provided by *Delta*. Outliers were identified in the WinFrog data by calculating the rate of travel between submersible locations. The destination record was removed if the rate of travel was greater than 2 meters per second. In 2007, a 9-

point running average was used to smooth the edited WinFrog data and then smoothed data were visually examined in ArcGIS. If any additional irregularities in data were observed, such as loops or back tracks, then these anomalies were removed and the data resmoothed. After a 27-point smoother was applied to the data, these smoothed line transects were examined in ArcGIS. If any irregularities still existed in the line transects that were thought to be misrepresentations of the actual submersible movements, then these anomalies were edited out of the line transect and the line transect data were resmoothed.

Transect Line Lengths - ROV

Transect line length is estimated by editing ROV tracking data generated from Hypack software. Tracking data are filtered for outliers using Hypack® singlebeam editor (positioning errors are removed and data are filled in to one second intervals using linear interpolation). Video data are "pre-reviewed" to remove any video segments where poor visbility would obscure yelloweye rockfish observations or when the ROV was not moving forward (i.e. stalled, or stopped due to some logistical problem). Navigation data are mapped in ArcGIS after treatment with a smoothing spline and video quality segments are overlaid navigation data using linear referencing. The total line length for each transect is estimated using the good quality video segments only.

Video Review-Submersible

The side facing and forward facing video from the submersible dives were reviewed post-dive while listening to the verbal recording made by the scientist-observer in the submersible. The audio transcript includes the scientist's observations of the species observed, and each individual fish's distance away from the submersible. These data are recorded in the database, as well as any additional yelloweye rockfish seen in either video camera that the observer may have missed while underwater. The observer is able to see farther out the window than the camera field of view, thus the verbal transcript is critical for data collection.

Video Review-ROV

Fish are recorded on the right and left side of the "center line" of the line transect when reviewing video within the SeaGIS Event Measure software (Figure 6). The video reviewer will identify and enumerate yelloweye rockfish for density estimation, and other DSR, lingcod, halibut and other large-bodied fish, as time allows, for species composition. Fish total length will be recorded for individual yelloweye rockfish, lingcod, and halibut. Fish behavior and maturity stage are recorded for yelloweye rockfish only.

For each fish, a perpendicular distance from the origin of the transect line to the fish will be obtained through the SeaGIS software. The precision of a 3D point is a geometric function of the camera resolution, camera focal length, camera separation, camera distance from object (close is better precision) and object distance from center of field of view (center of field of view is more precise than at the edges). Fish will be marked in both the left and right stereo cameras to obtain a 3D point measurement with coordinates of x, y, and z; the perpendicular distance to the fish corresponds to "x" (Figure 7). Fish that swim into the field of view more than once will not be double counted (this behavior is obvious, and based on our observations, rare for yelloweye rockfish).

Fish total length is recorded from the tip of the snout to the tip of the caudal fin. Length measurements are most accurate when fish are close, straight (i.e. not curled), and parallel, relative to the cameras; the video reviewer will measure each fish in the best possible orientation and position. The best possible horizontal direction will be obtained; the horizontal direction is the angle between the horizontal component of the measured length and the camera base and represents the degree to which a fish is turned away from the camera. For example, if a fish is parallel to the camera then it has a horizontal direction of 0° and if a fish is facing directly toward or away from the camera, the horizontal direction is 90°. As the horizontal direction increases, the precision of a length measurement decreases because the Δz (the difference in the z coordinate between the snout and tail) becomes larger (Δz=0 when fish parallel) as

$$\sigma_d = \frac{1}{d}\sqrt{2(\Delta x^2\sigma_x^2 + \Delta y^2\sigma_y^2 + \Delta z^2\sigma_z^2)} \tag{4}$$

for which σ_d = the standard deviation of a given length measurement (Seager 2012). Precision is expressed in terms of the difference between the x, y, and z coordinates for each endpoint of the length measurement (Δx, Δy, Δz), the standard deviation (precision) of x, y, and z (σ_x, σ_y, σ_z), and the length of the fish (d). The standard deviation of x and y is equivalent and small compared to the standard deviation of z. When a fish is parallel $\Delta z = 0$ and there is no contribution to the error from Δz, but as a fish turns away from the camera, Δz increases resulting in a decrease in precision (σ_d).

Density and Biomass Estimates

Yelloweye rockfish density is estimated using DISTANCE 6.0 software (Thomas et al. 2010) which utilizes the following equations to estimate density with the principal function to estimate the probability of detection evaluated at the origin of the transect line ($\hat{f}(0)$):

$$\hat{D} = \frac{n\hat{f}(0)}{2L} \tag{5}$$

$$\hat{f}(0) = \frac{1}{\mu} = \frac{1}{wP_a} \tag{6}$$

where:

n = total number yelloweye rockfish included in the density estimate

$\hat{f}(0)$ = the probability density function evaluated at the origin of the transect line

L = total line length

μ = the effective width

w = width of line transect

P_a = probability of observing an object in the defined area

Yelloweye rockfish lengths are examined to determine whether to exclude any small yelloweye rockfish identified as adults or subadults from the density model data. The best probability detection model is selected in order to obtain a valid density estimate. Models are explored with and without binning and truncation (i.e. at some predefined maximum distance) of distance data and with different key model functions and adjustment terms. The best model is selected based on visual fit of model, the Akaike information criterion (AIC) value, X^2 goodness of fit test, and the CV for the density estimate ($cv_t(\hat{D})$). Probability detection functions are visually examined to determine if the model fits the data well; it is most important to have a good fit at the origin. In addition, the model is examined to determine if the shape is biologically realistic, and if the model has the preferred “shoulder” at the origin of the transect line (Burnham et al. 1980). The probability detection functions for the most recent survey (ROV and submersible) in each management area are shown in Figure 8a-8c.

The average weight of yelloweye rockfish sampled from the directed commercial fishery and from the halibut fishery has been used to expand density estimates to biomass for each management area.

Evaluation of Distance Sampling Assumptions

Distance sampling (Buckland et al. 1993) requires that three major assumptions are met to achieve reliable estimates of density from line transect sampling: (1) objects on the line must be detected with certainty (i.e. every object on the line must be detected); (2) objects must be detected at their initial location, (i.e. animals do not move toward or away from the transect line in response to the observer before distances are measured); (3) distances from the transect line to each object are measured accurately. Failure to satisfy these assumptions may result in biased density estimates. All assumptions were carefully evaluated and met during the ROV and submersible surveys.

To ensure that (1) all objects on the transect line are detected with certainty, the probability detection function and histograms of the distance data are examined. If the detectability at the transect line is close to 100%, then the probability detection function will have a broad shoulder at the line that will drop off at some distance from the line (Buckland et al. 1993). In the past submersible surveys, the observer looked out the side window for fish identification, and fish under or in close proximity to the submersible were sometimes missed by the observer and the main camera prior to installing a “forward-facing” camera in 1995 to record fish on or close to the transect line. The ROV stereo cameras are already oriented forward, so the video reviewer can easily detect fish on the transect line.

The second assumption (2) that yelloweye rockfish are detected at their initial location and are not moving in response to the vehicle (submersible or ROV) prior to detection in the video is evaluated by examining the probability detection function and the behavioral response of yelloweye rockfish to the vehicle. The shape of the probability detection function may indicate if there is yelloweye rockfish movement response to the vehicle. If the probability detection function has a high peak near the origin line, this may indicate an attraction. Whereas, if there are lower detections near the line and an increase in detection at some distance away from the origin of the line this may indicate avoidance behavior. Yelloweye rockfish behaviors during the 2012 survey indicate that yelloweye rockfish are not moving in response to the ROV; generally yelloweye rockfish moved very little or slowly (85%), with the majority (76%) not indicating any directional movement (i.e. milling, resting on the bottom). These results are consistent with those observed in other ROV and submersible surveys and indicate that yelloweye rockfish move slowly relative to the speed of the survey vehicle. If undetected movements are random and slow relative to the speed of the vehicle then this assumption will not be violated (Buckland et al. 1993). Byerly et al. (2005) found that yelloweye rockfish movement prior to detection by the ROV cameras was random.

The third assumption of distance sampling: (3) distances from the transect line to the fish are recorded accurately is met through the use of the stereo cameras in conjunction with the SeaGIS software (Seager 2012). In the submersible surveys, the observer visually estimated the perpendicular distance from the submersible to a fish, which is subject to measurement error despite observer calibration before a dive using a hand-held sonar gun.

Harvest Recommendations

Amendment 56 Reference Points

Amendment 56 to the GOA Groundfish Fishery Management Plan defines the "overfishing level" (OFL), the fishing mortality rate used to set the OFL (F_{OFL}), the maximum permissible ABC, and the fishing mortality rate used to set the maximum permissible ABC. The fishing mortality rate used to set the ABC (F_{ABC}) may be less than this maximum permissible level but not greater. DSR are managed under Tier 4 because reliable estimates of spawning biomass and recruitment are not available. Demersal shelf rockfish are particularly vulnerable to overfishing given their longevity, late maturation, and habitat-specific residency. We recommend and use a harvest rate lower than the maximum allowed under Tier 4; F=M=0.02. This rate is more conservative than would be obtained by using Tier 4 definitions for setting the maximum permissible F_{ABC} is $F_{40\%}$ ($F_{40\%}$=0.026). Continued conservatism in managing this fishery is warranted given the life history of the species and the uncertainty of the biomass estimates.

Specification of F_{OFL} and the maximum permissible ABC

Under tier 4 projections of harvest scenarios for future years is not possible.

Yields for 2014 are computed for scenarios 1-5 as follows:

Scenario 1: F equals the maximum permissible F_{ABC} as specified in the ABC/OFL definitions. For tier 4 species, the maximum permissible F_{ABC} is $F_{40\%}$. $F_{40\%}$ equals 0.026 corresponding to a yield of 293 t (including 3% for other DSR).

Scenario 2: F equals the stock assessment author's recommended F_{ABC}. In this assessment, the recommended F_{ABC} is F=M=0.02, and the corresponding yield is 225 t (including 3% for other DSR).

Scenario 3: F equals the 5-year average F from 2010 to 2014. The true past catch is not known for this species assemblage so the 5-year average is estimated at F=0.02 (the proposed F in all 5 years), and the corresponding yield is 225 t (including the 3% other DSR).

Scenario 4: F equals 50% of the maximum permissible F_{ABC} as specified in the ABC/OFL definitions. 50% of $F_{40\%}$ is 0.013, and the corresponding yield is 147 t (including 3% other DSR).

Scenario 5: F equals 0. The corresponding yield is 0 t.

Ecosystem Considerations

In general, ecosystem considerations for the DSR complex are limited. Table 7 consolidates information regarding ecosystem effects on the stock and the stocks effect on the ecosystem. Specific data to evaluate these effects are mostly lacking

Ecosystem Effects on the Stock

Prey availability

Like many rockfishes, the DSR complex is highly influenced by periodic abundant year classes. Zooplankton prey availability and favorable environmental conditions may affect the survivability of larval rockfishes. Yelloweye rockfish consume rockfishes, herring, sandlance, shrimps, and crabs and seasonally lingcod eggs, and changes in the abundance of these food sources could impact yelloweye rockfish abundance (Love et al. 2002).

Predator population trends

Many predators, including other rockfishes consume larval and juvenile yelloweye rockfish. Adult yelloweye rockfish have been found in the stomachs of longline caught lingcod and halibut but this may be opportunistic feeding as the yelloweye rockfish were caught on the fishing gear. A yelloweye rockfish was also found in the stomach of an orca whale (Love et al. 1990). Yelloweye rockfish are considered mid to high in trophic level (Kline et al. 2007). Predator effects, or an increase in predation on any one of the life stages of the DSR complex could have negative effects on the stock.

Changes in physical environment:

Strong year classes for many species of fish correlate with good environmental conditions. Black et al. (2011) documented seasonal (winter and summer modes) upwelling as an index for predicting rockfish productivity. For yelloweye rockfish, increased growth was associated with the winter upwelling mode but not summer upwelling in the California Current Ecosystem. Thorson et al. (2013) found that a multi-species approach to estimating recruitment may be promising for some species (e.g. for yelloweye rockfish, a shared index of cohort strength decreased coefficient of variation for recruitment for the modeled year by 40%). Thus, recruitment estimates for data poor species such as yelloweye rockfish may be improved by using multispecies recruitment indices.

Availability of physical bottom habitat would impact yelloweye rockfish at many different stages of life. Both juveniles and adults are associated with high relief rock habitat, as well as corals and sponges (O'Connell and Carlile 1993). Bottom trawling is not a legal gear type in the Eastern Gulf of Alaska so the effects of commercial fishing on the bottom habitat are minimal, although there is some removal of coral and sponges from non-trawl gear that comes in contact with the bottom (e.g. hook and line, dinglebar gear.)

Fishery Effects on the Ecosystem

Fishery specific contribution to HAPC biota

HAPC biota such as corals and sponges are associated with some of the same habitats that yelloweye and other demersal shelf rockfish inhabit. On ROV and submersible dives, we have recorded many observations of yelloweye rockfish in close association with corals and sponges. However, as described above, bottom trawling is prohibited in the EGOA, so contact with the bottom and therefore biogenic habitat removal is limited to primarily hook and line and dinglebar gear. The expanded observer program should provide additional data on invertebrate incidental catch in the DSR directed and halibut fisheries.

Fishery specific concentration of target catch in space and time relative to predator needs in space and time (if known) and relative to spawning components
Insufficient research exists to determine yelloweye rockfish catch relative to predator needs in time and space. Yelloweye rockfish are winter/spring spawners, with a peak period of parturition in April and May in Southeast Alaska (O'Connell 1987). The directed fishery, if opened, occurs between late January and early March, but the bulk of the mortality for the DSR complex is taken as incidental catch in the halibut longline fishery. Reproductive activities do overlap with the fishery, but since parturition takes place over a protracted period, there should be sufficient spawning potential relative to fishery mortality.

Fishery-specific effects on amount of large size target fish
Full retention of the DSR complex is required in the EGOA, therefore high grading should be minimized in the reported catch and lengths sampled in port should be representative of lengths composition of yelloweye rockfish captured on the gear. The commercial directed fisheries landing data show that most fish are captured between 450 and 650 mm (Figure 9). There are some differences in the length compositions of yelloweye rockfish from the commercial fishery compared with the measurements of yelloweye rockfish derived from the ROV survey, however we are still exploring those differences.

Fishery contribution to discards and offal production
Full retention requirements of the DSR complex became regulation in 2000 in state waters and 2005 in federal waters of the EGOA, thus making discard at sea of DSR illegal. There may be some unreported discard in the fishery. Data from the observer restructuring program may shed additional light on the magnitude of unreported catch.

Fishery-specific effects on age-at-maturity and fecundity of the target fishery
Fishery effects on age-at-maturity and fecundity are unknown. Age composition of the fishery, by management area, is shown in Figure 10. The age at 50% maturity used in this stock assessment for yelloweye rockfish in Southeast Alaska is 17.6 years. This age is based on a maturity-at-age curve for males and females combined and was derived from directed DSR commercial fishery data from 1992 – 2013 from all four management areas (Figure 13 in Appendix B). Most yelloweye rockfish are captured at ages greater than the length at 50% maturity (Figure 10).

Fishery-specific effects on EFH living and non-living substrate:
Effects of the DSR fishery on non-living substrates are minimal since no trawl gear is used in the fishery. Occasionally fishing gear is lost in the fishery, so longline and anchors may end up on the bottom. There is likely minimal damage to EFH living substrate as the gear used in the fishery is set on the bottom but does not drag along the bottom.

Data Gaps and Research Priorities

There is a need for better estimation of rockfish habitat through more complete geophysical surveys (NSEO, SSEO areas in particular) and validation of the technique of using commercial fishery logbook data as a proxy for rock habitat in areas without geophysical surveys.

We also plan to explore the conversion of yelloweye rockfish lengths collected from the ROV video observations to weight using length-weight relationships for yelloweye rockfish. We will determine if weights derived from length-weight relationships are appropriate for estimating biomass while considering the sample size of the length data obtained from the ROV.

There is limited information on yelloweye rockfish fecundity; a fecundity study specific to southeast Alaska would be useful. Little is known about the timing of parturition for yelloweye rockfish recruitment or post larval survival. A recruitment index for yelloweye rockfish would improve modeling estimates for total yelloweye rockfish biomass.

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Table 1. Species included in the demersal shelf rockfish assemblage.

Common name	Scientific Name
canary rockfish	*S. pinniger*
China rockfish	*S. nebulosus*
copper rockfish	*S. caurinus*
quillback rockfish	*S. maliger*
rosethorn rockfish	*S. helvomaculatus*
tiger rockfish	*S. nigrocinctus*
yelloweye rockfish	*S. ruberrimus*

Table 2. Reported landings of demersal shelf rockfish (t) from research, incidental commercial, directed commercial, recreational and subsistence fisheries in the Southeast Outside Subdistrict (SEO), 1988–2014[a], acceptable biological catch (ABC), Overfishing Level (OFL) and total allowable catch (TAC) for commercial and recreational sectors combined.

YEAR	Research	Directed	Incidental[d]	Recreational[b]	Subsistence[c]	Total[d]	ABC[e]	OFL	TAC
1988							660		660
1989							420		420
1990							470		470
1991							425		425
1992		359	119			478	550		550
1993	13	334	188			535	800		800
1994	4	381	219			604	960		960
1995	13	155	103			271	580		580
1996	11	344	81			436	945		945
1997	16	267	97			380	945		945
1998	2	241	118			361	560		560
1999	2	241	125			368	560		560
2000	8	183	104			295	340		340
2001	7	173	144			324	330		330
2002	2	136	147			285	350	480	350
2003	6	102	167			275	390	540	390
2004	2	174	153			329	450	560	450
2005	4	42	191			237	410	650	410
2006	2	0	203	75		269	410	650	410
2007	3	0	196	60		273	410	650	410
2008	1	42	152	68		246	382	611	382
2009	2	76	139	36		250	362	580	362
2010	7	30	131	47	8	217	295	472	287
2011	5	22	87	32	6	144	300	479	294
2012	4	105	76	40	7	223	293	467	286
2013	4	129	83	31	7	247	303	487	296
2014		33	60		7	100	274	438	267
2015					8		225	361	217

[a]Landings from ADF&G Southeast Region fish ticket database and NMFS weekly catch reports through October 19, 2014.
[b]Sport fish catch from 2006 to 2008 includes EYKT and IBS. These data are not available prior to 2006.
[c]Projected subsistence catch for the fishery year, i.e. 2010 is for the 2010 fishery. These data were not available or deducted from the ABC prior to 2009.
[d]Data are from reported landings. Full retention of DSR went into effect in 2005, and unreported DSR discard associated with halibut fishery prior to 2005 is not reported in these totals.
[e]No ABC prior to 1988, 1988–1993 ABC for CSEO, NSEO, and SSEO only (not EYKT).

Table 3. Submersible (1994–1995, 1997, 1999, 2003, 2005, 2007, 2009) and ROV (2012–2013) yelloweye rockfish density estimates with 95% confidence intervals (CI) and coefficient of variations (CV) by year and management area. The number of transects, yelloweye rockfish (YE), and meters surveyed included in each model are shown, along with the encounter rate of yelloweye rockfish. Values in bold were used for this stock assessment. The 2012 CSEO density estimate was used as a proxy for the NSEO management area yelloweye rockfish density estimate. The NSEO area was surveyed in 2001, but too few yelloweye rockfish were observed to be used for a density estimate.

Area	Year	# transects	# YE[b]	Meters surveyed	Encounter rate (YE/m)	Density (YE/km^2)	Lower CI (YE/km^2)	Upper CI (YE/km^2)	CV
EYKT[a]	1995	17	330	22,896	0.014	2,711	1,776	4,141	0.20
	1997	20	350	19,240	0.018	2,576	1,459	4,549	0.28
	1999	20	236	25,198	0.009	1,584	1,092	2,298	0.18
	2003	20	335	17,878	0.019	3,825	2,702	5,415	0.17
	2009	**37**	**215**	**29,890**	**0.007**	**1,930**	**1,389**	**2,682**	**0.17**
CSEO	1994[c]					1,683			0.10
	1995	24	235	39,368	0.006	2,929			0.19
	1997	32	260	29,273	0.009	1,631	1,224	2,173	0.14
	2003	101	726	91,285	0.008	1,853	1,516	2,264	0.10
	2007	60	301	55,640	0.005	1,050	830	1,327	0.12
	2012	**46**	**118**	**38,590**	**0.003**	**752**	**586**	**966**	**0.13**
SSEO	1994[c]	13	99	18,991	0.005	1,173			0.29
	1999	41	360	41,333	0.009	2,376	1,615	3,494	0.20
	2005	32	276	28,931	0.010	2,357	1,634	3,401	0.18
	2013	31	118	30,439	0.004	986	641	1,517	0.22
NSEO	**1994[c]**	**13**	**62**	**17,622**	**0.004**	**765**	**383**	**1,527**	**0.33**

[a] Estimates for EYKT management area include only the Fairweather grounds, which is composed of a west and an east bank. In 1997, only 2 of 20 transects and in 1999, no transects were performed on the east bank that were used in the model. In other years, transects performed on both the east and west bank were used in the model.

[b] Subadult and adult yelloweye rockfish were included in the analyses to estimate density. A few small subadult yelloweye rockfish were excluded from the 2012 model based on size; length data were only available for the ROV surveys (not submersible surveys). Data were truncated at large distances for some models; as a consequence, the number of yelloweye rockfish included in the model does not necessarily equal the total number of yelloweye rockfish observed on the transects.

[c]Only a side-facing camera was used in 1994 and earlier years to video fish. The forward-facing camera was added after 1994, which ensures that fish are observed on the transect line.

Table 4. Area estimates for sonar locations and rocky habitat by management area in Southeast Alaska.

	Sonar location	Sonared area (km^2)	Area rocky habitat (km^2)
EYKT	Fairweather West Bank	784	402
	Fairweather East Bank	288	98
Total Sonar		1,072	500
Total rock (Sonar & fishery)			739
Percentage rocky habitat from sonar			68%
CSEO	Cape Edgecumbe	538	328
	Cape Ommaney	294	114
Total Sonar		832	442
Total rock (Sonar & fishery)			1,661
Percentage rocky habitat from sonar			27%
SSEO	Hazy Islands	400	120
	Addington	84	47
	Cape Felix	140	78
	Learmonth Bank	530	77
Total Sonar		1,154	322
Total rock (Sonar & fishery)			1,056
Percentage rocky habitat from sonar			30%
NSEO			
NOAA chart			364
Total rock (NOAA chart & fishery)			436

Table 5. Commercial landings (t) of demersal shelf rockfish species in Southeast Outside Subdistrict between 2008 and 2014. Discards (Harvest Code 98 (Discard at sea) included.

Species	2008	2009	2010	2011	2012	2013	2014	Sum (t)
Canary rockfish	0.67	0.86	0.87	0.34	2.87	2.88	0.26	8.75
China rockfish	0.01	0.04	0.03	0.02	0.02	0.05	0.02	0.19
Copper rockfish	0.01	0.04	0.01	0.01	0.03	0.03	0.01	0.13
Quillback rockfish	2.88	3.82	4.08	1.68	3.79	3.72	1.80	21.76
Rosethorn rockfish	0.09	0.01	0.00	0.00	0.02	0.04	0.00	0.17
Tiger rockfish	0.26	0.50	0.28	0.11	0.41	0.31	0.25	2.12
Yelloweye rockfish	189.71	209.34	155.62	106.16	172.83	205.37	90.46	1130.44
Sum (t)	193.63	214.61	160.89	108.32	179.97	211.86	75.09	1163.57
% yelloweye rockfish of total	98.0%	97.5%	96.7%	98.0%	96.0%	96.9%	97.8%	97.2%

Table 6. Other Fishery Management Plan (FMP) groundfish species landed (t) in DSR directed commercial fisheries in the Southeast Outside Subdistrict.

Species	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Black rockfish					0.3	0.8
Bocaccio rockfish	0.1					0.1
Pacific cod	0.5	0.4	0.9	1.0	2.3	5.1
Redbanded rockfish	0.2	0.1		0.1	1.1	1.7
Dark rockfish		0.1				
Dusky rockfish	2.1	2.0	0.5	0.3	3.8	5.3
Rougheye rockfish	0.1					
Shortraker rockfish	0.1					
Silvergray rockfish	0.7	0.5	0.4	0.3	0.7	1.9
Skate, general		1.7			0.2	
Spiny dogfish shark					0.2	
Yellowtail rockfish					0.1	0.1
Total	**3.8**	**4.8**	**1.8**	**1.7**	**8.7**	**15**

Table 7. Ecosystem effects on GOA DSR

Indicator	Observation	Interpretation	Evaluation
Prey availability or abundance trends			
Phytoplankton and Zooplankton	Important for larval and post larval survival but no information known	May help determine recruitment strength, no time series.	Possible concern if more information known
Predator population trends			
Marine mammals	Not commonly eaten by marine mammals	No effect	No concern
Birds	Stable, some increasing some decreasing	Affects young-of-year mortality	Probably no concern
Fish (Pollock, Pacific cod, halibut)	Stable	No effect	No concern
Changes in habitat quality			
Temperature regime	Higher recruitment after 1977 regime shift		No concern
Winter-spring environmental conditions	Affects pre-recruit survival	Different Phytoplankton bloom timing	Causes natural variability, rockfish have varying larval release to compensate
Production	Relaxed downwelling in summer brings nutrients to the Gulf	Some years highly variable, i.e. El Nino 1998	Probably no concern, contributes to high variability in rockfish recruitment

GOA DSR fishery effects on the ecosystem			
Prohibited species	Halibut are taken as incidental catch but released	Minor contribution to mortality, soak times are short for DSR gear, separate PSC cap for DSR	Little concern
Forage (including herring, Atka mackerel, cod, and pollock)	A small amount of cod incidental catch is taken in this fishery	Incidental catch levels small relative to forage biomass	No concern
HAPC biota	Low incidental catch levels of Primnoa coral, hard coral, and sponges.	Longline gear has some incidental catch but levels small relative to HAPC biota	Little concern
Marine mammals and birds	Minor take associated with longline gear, little impact	Data limited for discards, fishery has been largely unobserved until recently.	No concern
Sensitive non-target species	Likely minor impact	Data limited, likely to be harvested in proportion to their abundance.	No concern
Fishery concentration in space and time	Majority of catch is harvested during halibut IFQ season (March to November), the directed fishery is concentrated during the winter	Fishery does not hinder reproduction	Little concern
Fishery effects on amount of large size target fish	Fishery is catching primarily adults but difficult to target largest individuals over others	Large and small fish both occur in population	Little concern
Fishery contribution to discards and offal production	Discard rates low for DSR fishery but can include dogfish and skates	Data limited for discards, fishery has been largely unobserved until recently	Possible concern
Fishery effects on age-at-maturity and fecundity	Fishery is catching some immature fish but small proportion of total catch. Larger fish likely contribute more to spawning output via exponentially greater and higher quality larvae.	If increased could reduce spawning potential and yield	Possible concern

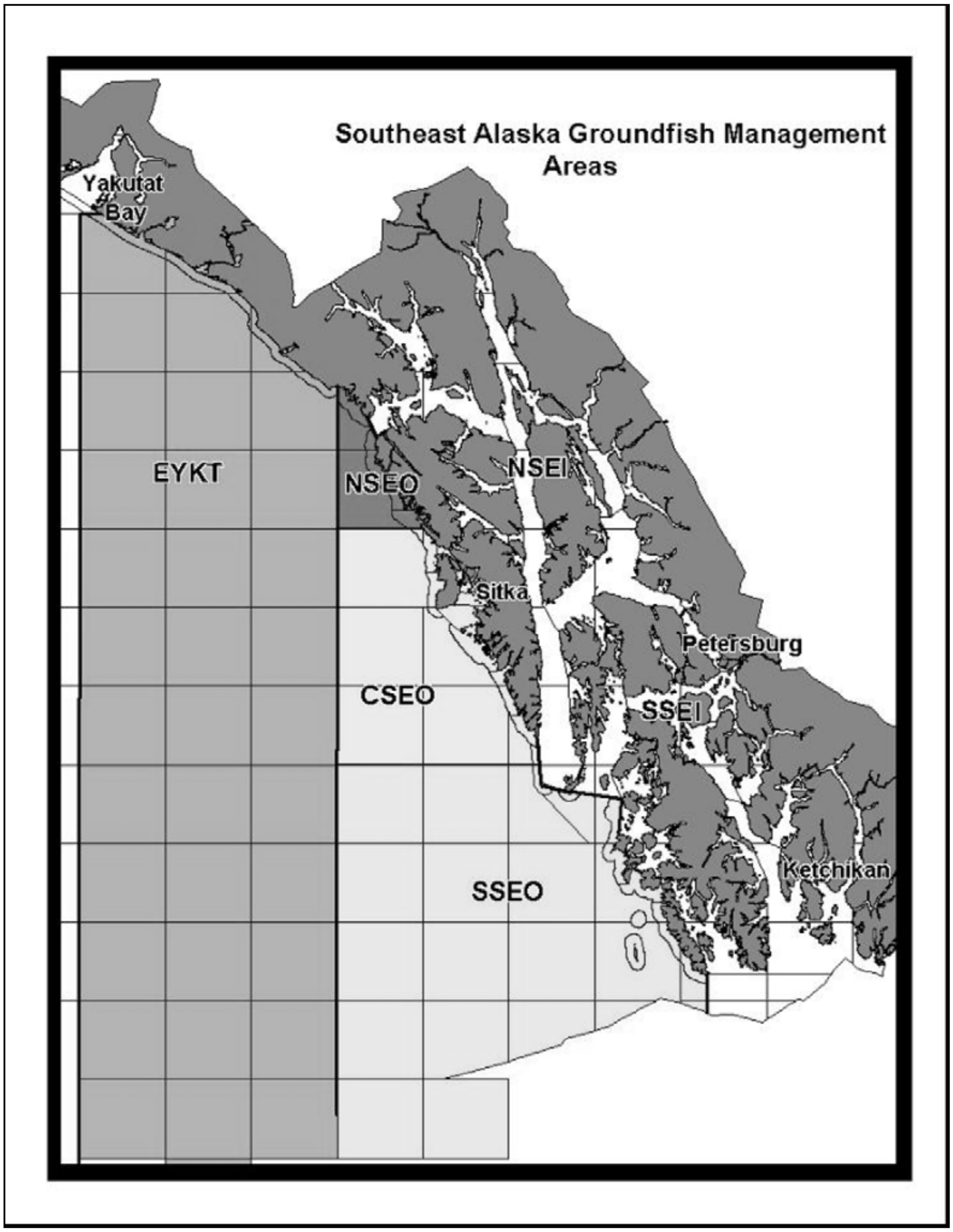

Figure 1. Southeast Alaska Outside Waters (SEO), or Eastern Gulf of Alaska (EGOA) with the Alaska Department of Fish and Game groundfish management areas; East Yakutat (EYKT), Central Southeast Outside (CSEO), Northern Southeast Outside (NSEO), and Southern Southeast Outside (SSEO).

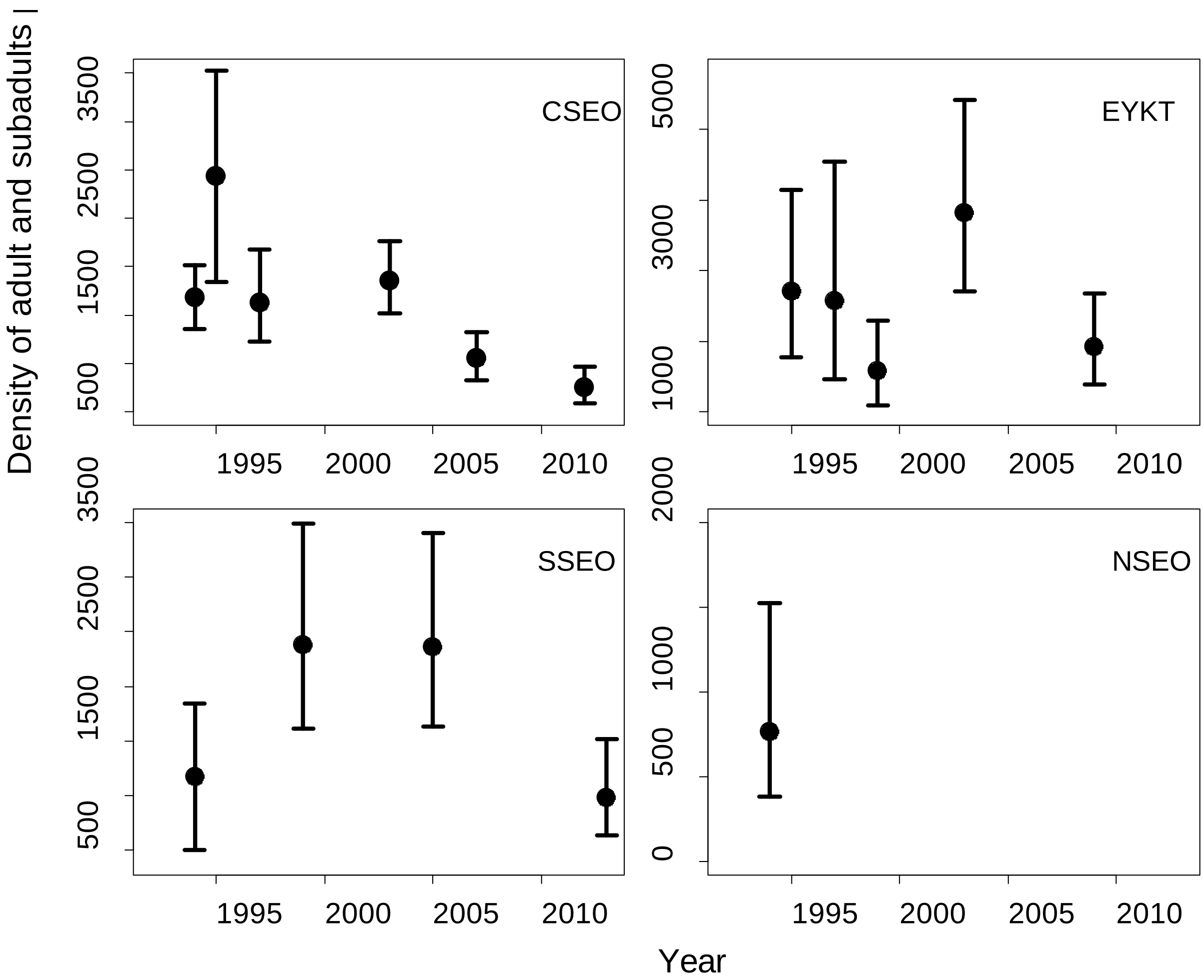

Figure 2. Density (adults and sub-adults per square kilometer) predicted by DISTANCE (circles) +/- two standard deviations in each management area (Central Southeast Outside (CSEO), East Yakutat (EYKT), , Southern Southeast Outside (SSEO), Northern Southeast Outside (NSEO).

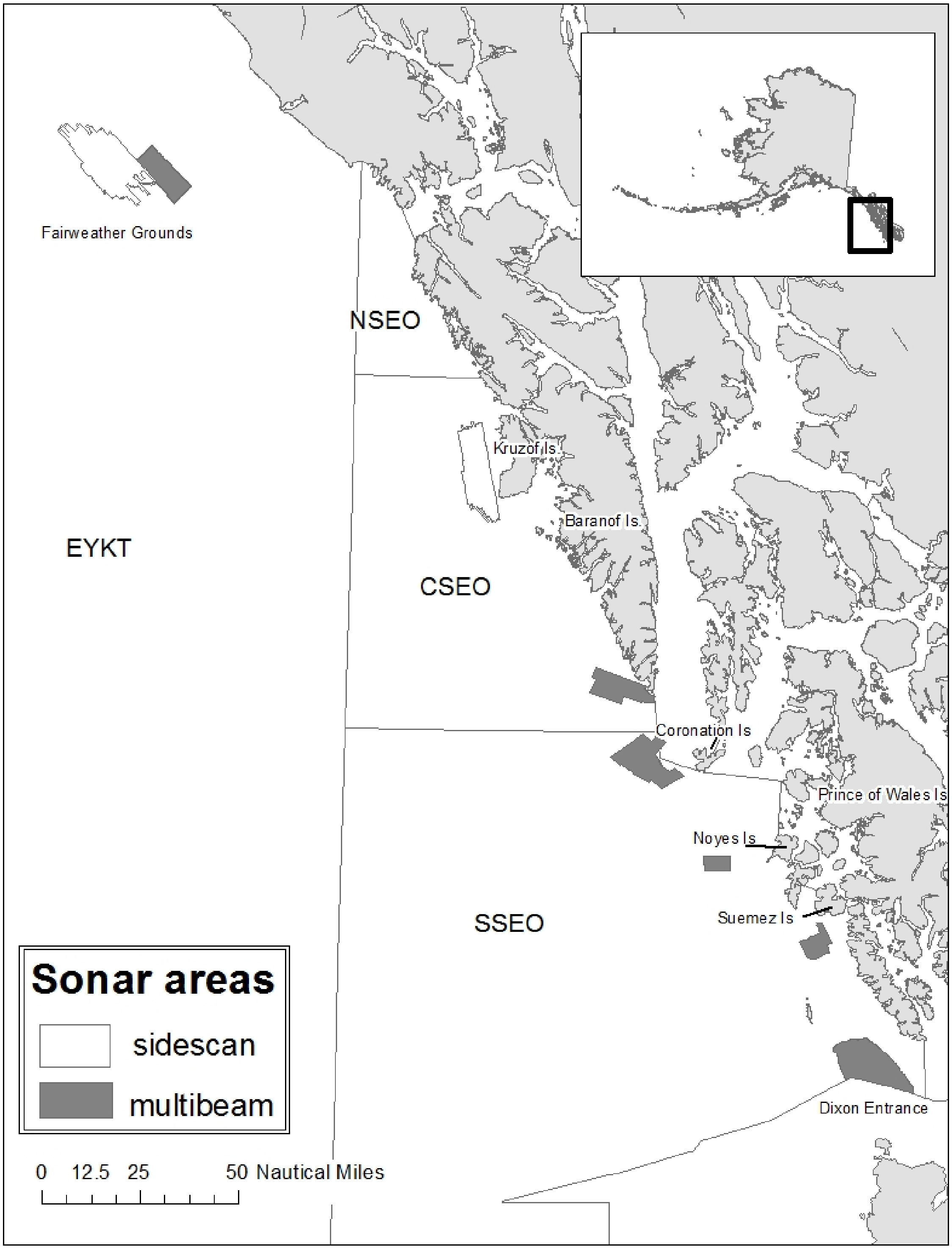

Figure 3. Sonar surveys performed in southeast Alaska and used in yelloweye rockfish habitat delineation.

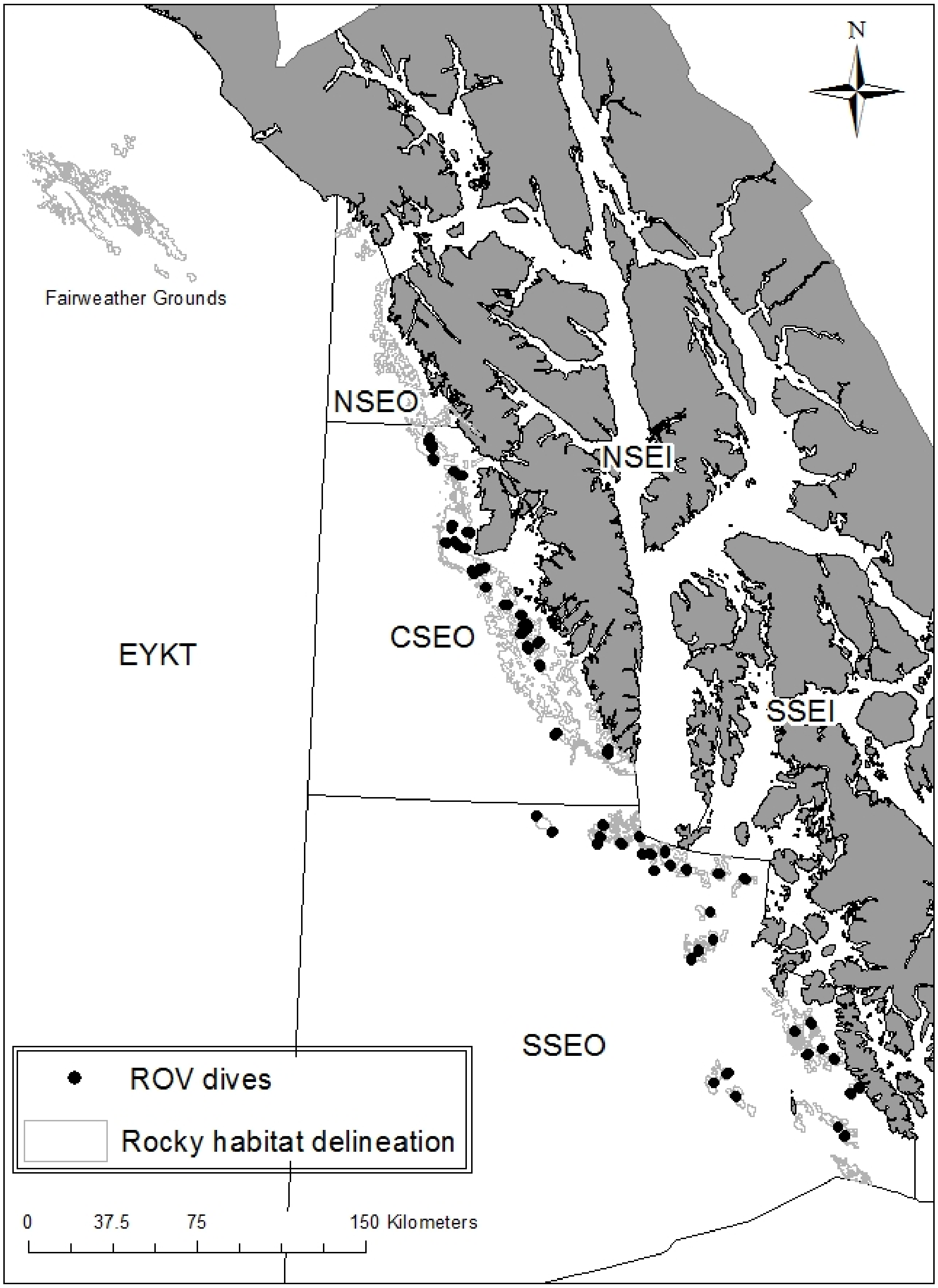

Figure 4. ROV transects conducted in Central Southeast Outside (CSEO) in 2012 and Southern Southeast Outside (SSEO) in 2013.

Figure 5. Example of 1-km transect plan lines for remote operated vehicle (ROV) dives. Plan lines have been adjusted in some cases to remain within the delineation of rocky habitat (solid gray).

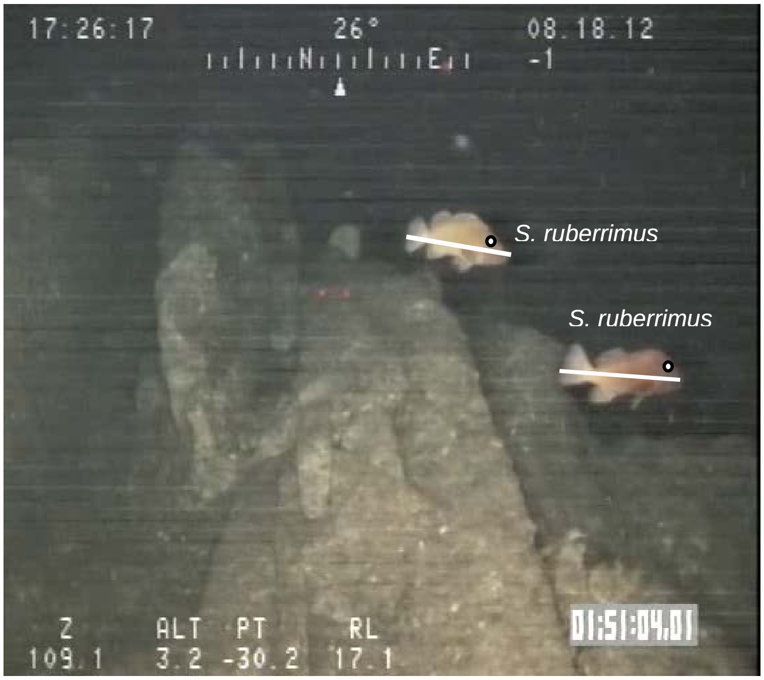

Figure 6. Yelloweye rockfish with a 3D point (circle with black outline) and a total length (white line) measured in the stereo camera overlapping field of view in the SeaGIS Event Measure software.

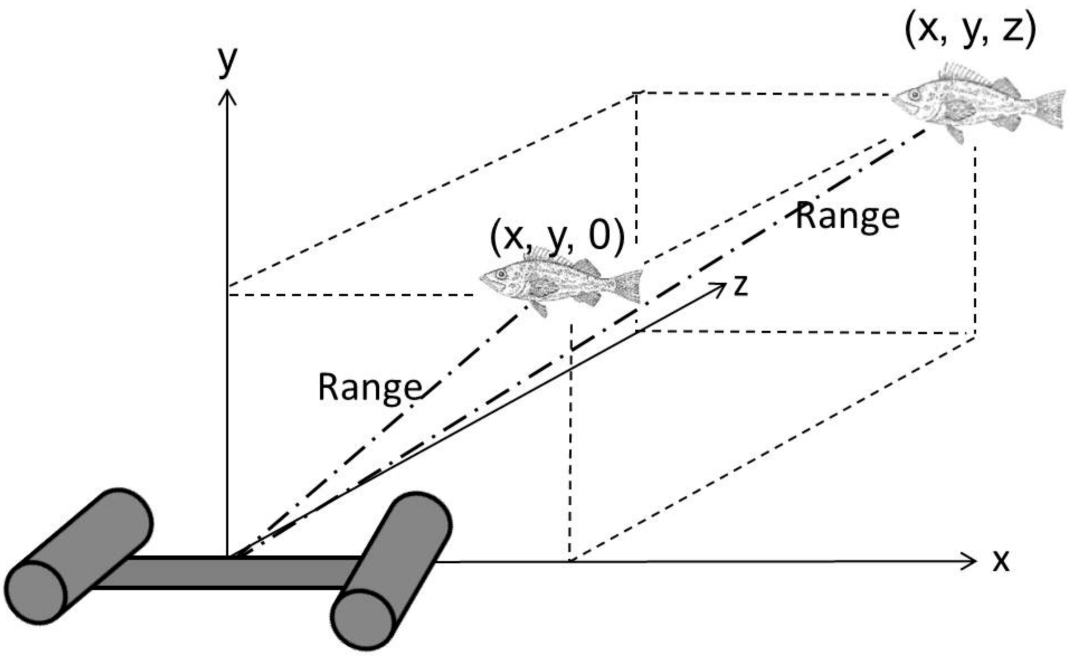

Figure 7. The components of a 3D point measurement.

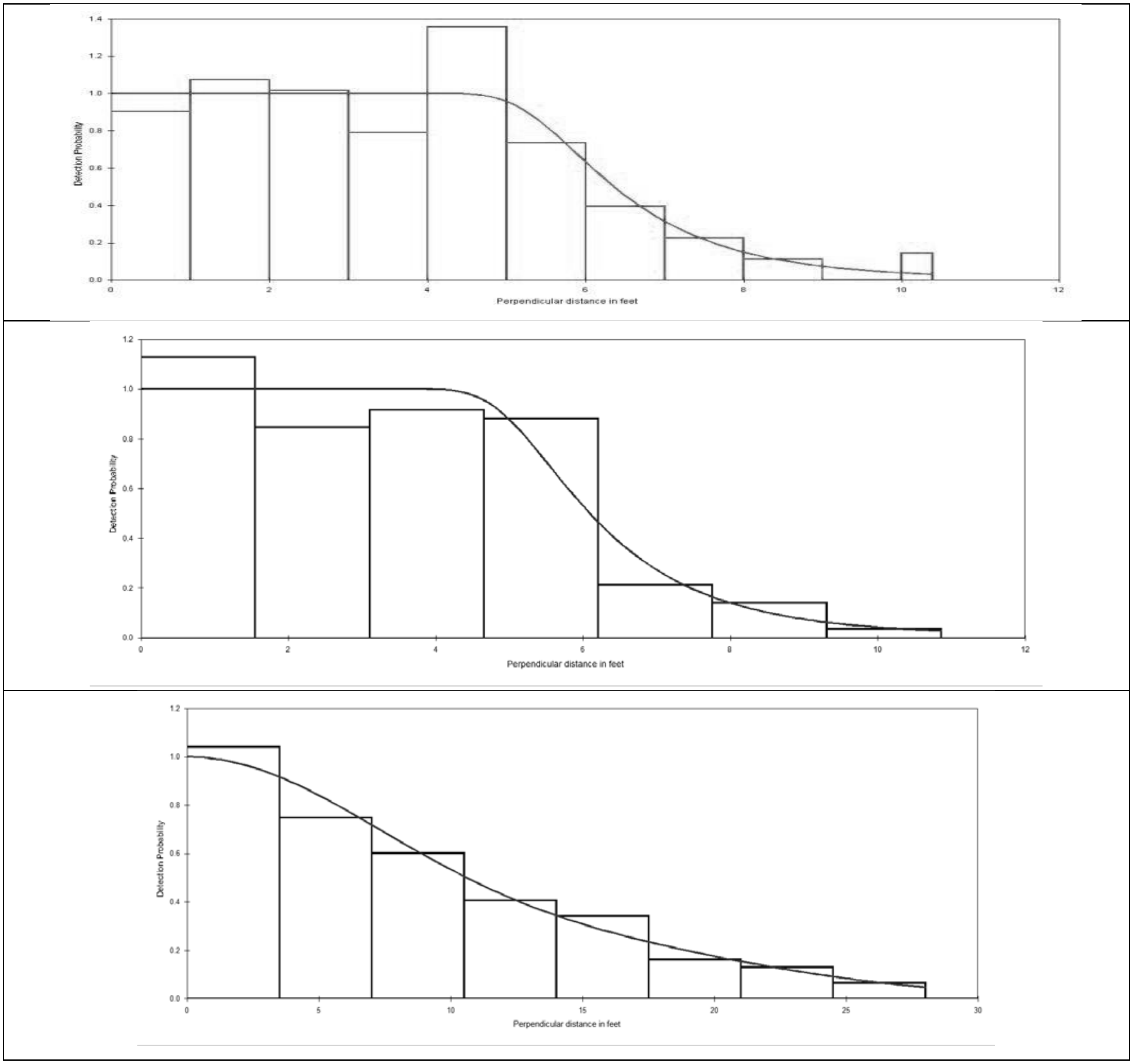

Figure 8a. The selected probability detection function for yelloweye rockfish from the 2012 ROV survey in Central Southeast Outside (CSEO) shown with expected data bins at 1-ft intervals. Data were not binned to estimate density in the CSEO selected model. The CSEO data were used as a proxy for the Northern Southeast Outside (NSEO) management area in this stock assessment since over 13 years have elapsed since the last usable NSEO survey.

Figure 8b. The selected probability detection function for yelloweye rockfish from the 2013 ROV survey in Southern Southeast Outside (SSEO) shown with expected data bins at 1.55 ft intervals. Data were not binned to estimate density with the selected model.

Figure 8c. The selected probability detection function for East Yakutat (EYKT) in 2009 shown with with 3.5 ft bins and truncation at 28 ft. This is ahalf normal cosine model.

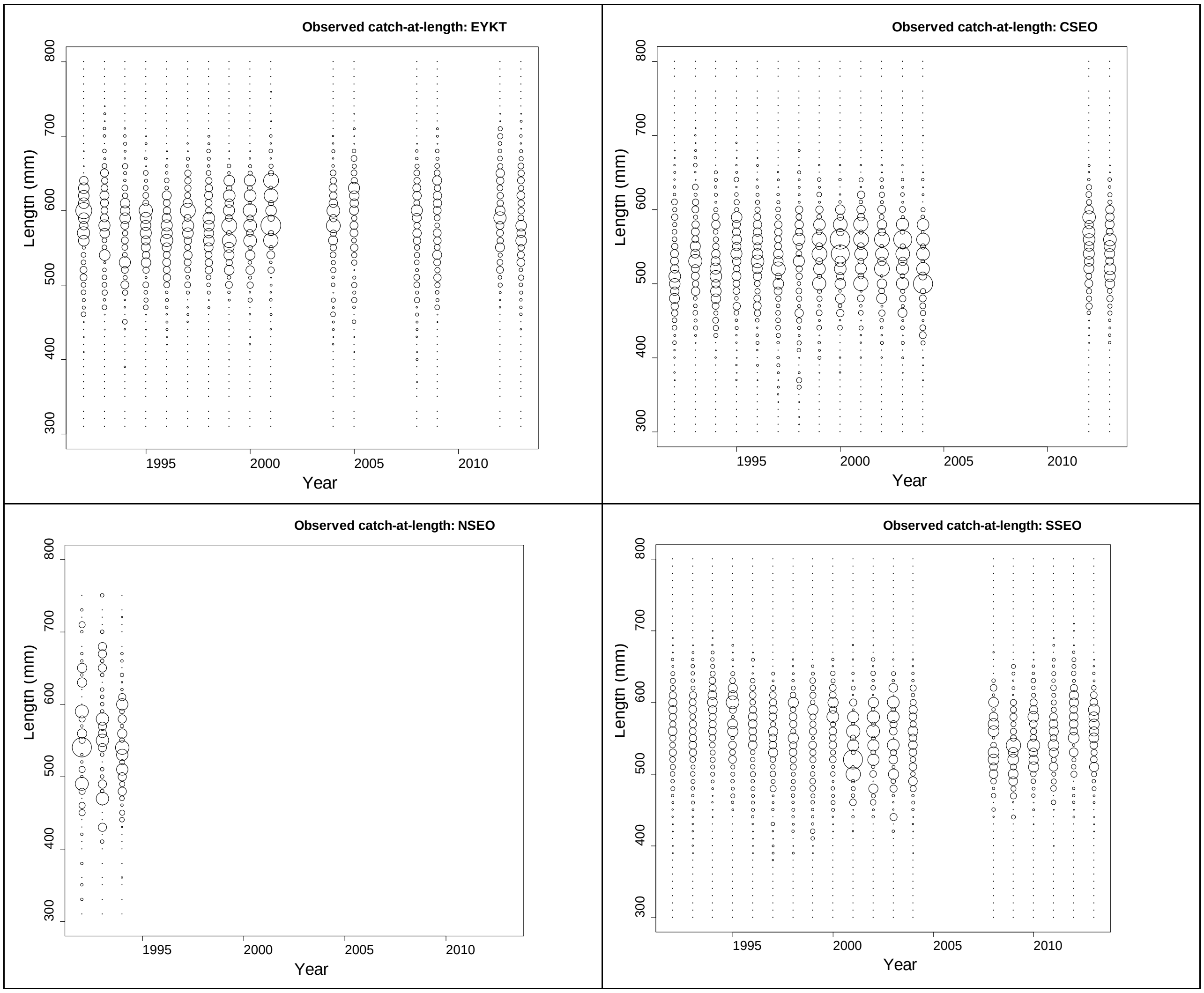

Figure 9. Length compositions from DSR captured in the directed fishery in East Yakutat (EYKT), Central Southeast Outside (CSEO), Northern Southeast Outside (NSEO), and Southern Southeast Outside (SSEO).

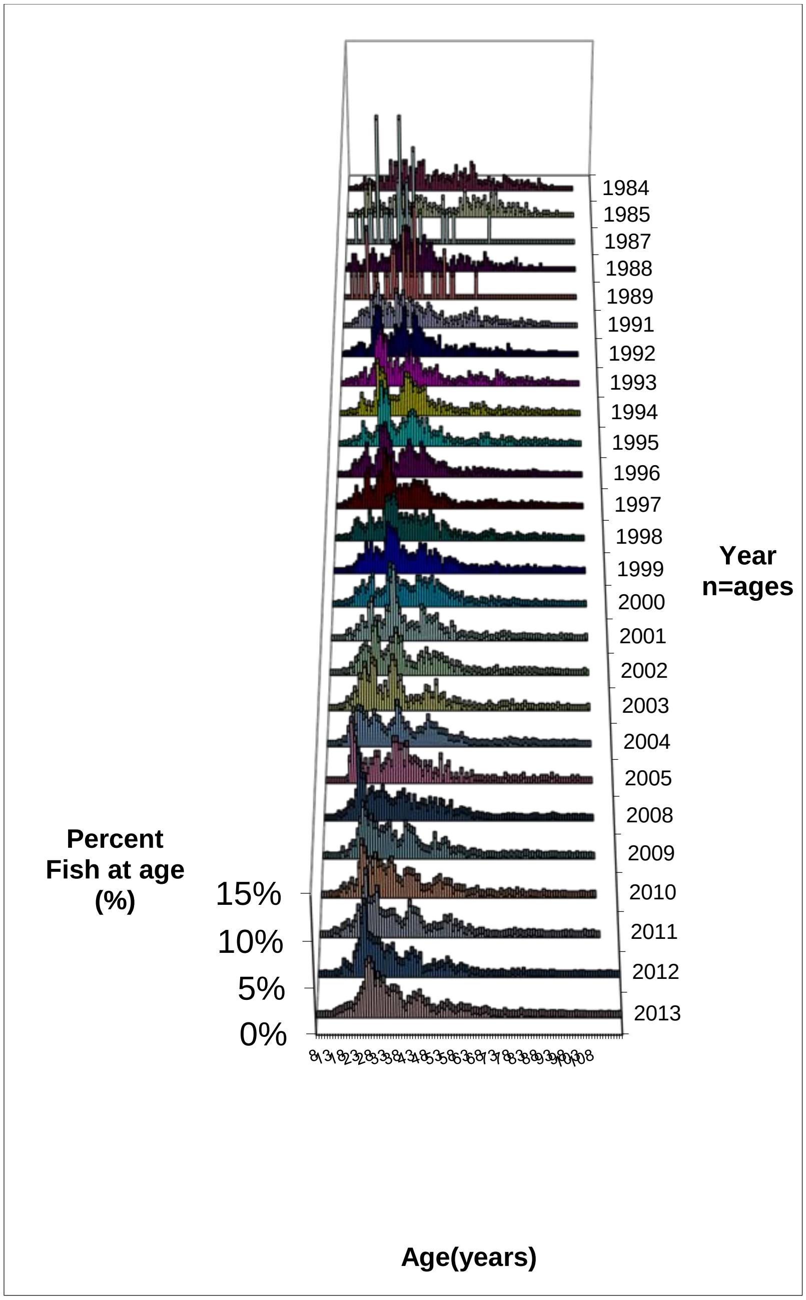

Figure 10. Age (year) frequency histogram from yelloweye rockfish landed in both the commercial directed and as incidental catch in the halibut fishery from 1984 through 2013.

Appendix A. History of DSR management action, Board of Fisheries (BOF), North Pacific Management Council (NPFMC) and Alaska Department of Fish and Game (ADF&G).

YEAR	ACTION
1984	Marine reserves recommended to BOF by ADF&G – rejected 600 t Guideline harvest limit for 10 species of DSR in CSEO directed fishery NPFMC defines 10 species assemblage as DSR (yelloweye, quillback, china, copper, canary, rosethorn, tiger, silvergrey, bocaccio, redstripe) October 1-Sept 30 accounting year
1986	ADF&G restricts gear for rockfish in the Southeast Region to hook and line only NPFMC gives ADF&G management authority for DSR to 137^0 W long. (Southeast Outside SEO) Guideline harvest limit (GHL) for directed fishery reduced to 300 t (CSEO) GHL for directed fishery set for SSEO (250 t), SSEI (225 t), NSEO (75 t), and NSEI (90 t)
1987	Sitka Sound closed to commercial fishing for DSR
1988	NPFMC implements 660 t total allowable catch for all fisheries (TAC) for SEO
1989	NPFMC imposes TAC of 470 t (catch history average) Industry working group discusses ITQ options with NPMFC (rejected) IWG recommends 7,500 lb trip limits, mandatory logbooks, and seasonal allocations (10/1-11/31 43%, 12/1-5/15 42%, 7/1-9/30 15%). Ketchikan area closure implemented GHL for directed fishery reduced in all areas (CSEO 150 t, SSEO 170 t, NSEO 50 t).
1990	Directed permit card required for CSEO, SSEO, NSEO, NPFMC TAC of 470 t
1991	NPFMC TAC of 425 t. Change in assemblage to 8 species (removed silvergrey, bocaccio, redstripe added redbanded). Craig and Klawock closures implemented
1992	East Yakutat area included in SEO (NPFMC extends ADF&G mgt authority to 140^0) NPFMC TAC of 550 t. Directed fishery permit card required in EYKT. Submersible line transect data used to set ABC in EYKT
1993	BOF changes seasonal allocation to calendar year: 1/1-5/15 (43%), 7/1-9/30 15%, and 10/1-12/31 (42%), DSR opened for 24 hour halibut opening 6/10 (full retention) NPFMC TAC of 800, yelloweye line transect data used to set TAC NPFMC institutes a separate halibut prohibited species cap (PSC) for DSR
1994	Trip limits reduced to 6,000 in SE and 12,000 lb trip limit implemented in EYKT NPFMC TAC 960 t line transect yelloweye plus 12% for other species. Last time a directed fishery in NSEO was held.
1995	NPFMC TAC 580 t
1996	NPFMC TAC 945 t
1997	NPFMC TAC 945 t, redbanded removed from assemblage definition
1998	NPFMC TAC 560 t, revised estimates of rock habitat in EYKT, 10% included for other species, Directed fishery season changed to prevent overlap with IFQ fishery 1/1-3/14 (67%), 11/16-12/31 (33%)
1999	NPFMC TAC 560 t

2000	NPFMC TAC 340 t, revised estimates of rock habitat in SEO. Regulation to require full retention for all DSR landed incidentally in the commercial halibut fishery was adopted for state waters.
2001	NPFMC TAC 330 t , Fall directed fishery season initially 24 hours in CSEO and SSEO due to small quota then re-opened 11/26 until quotas taken, no directed fishery NSEO
2002	NPFMC TAC 350 t, no directed fishery in EYKT due to changes in estimated incidental mortality in that area, no directed fishery in NSEO.
2003	NPFMC TAC 390 t, no directed fishery in EYKT or NSEO, protocol for classifying habitat revised resulting in changes in TAC. Registration required before participating in directed fishery.
2004	NPFMC TAC 460 t, directed fishery reopened in EYKT, no directed fishery in NSEO.
2005	NPFMC Final rule to require full retention for all DSR landed incidentally in the commercial halibut fishery for federal waters.
2006	DSR TAC is allocated as follows: 84% to the commercial fleet, 16% to the recreational fleet. SEO DSR restricted to winter fishery only and must close before the start of the halibut fishery. All directed fisheries closed.
2007	All directed fisheries closed.
2008	SSEO and EYKT directed fisheries opened. CSEO and NSEO closed.
2009	Subsistence catch to be deducted from the ABC before allocation of the TAC to the commercial and recreational sectors. SSEO and EYKT directed fisheries opened. CSEO and NSEO closed.
2010	SSEO and EYKT directed fisheries opened. CSEO and NSEO closed.
2011	SSEO and EYKT directed fisheries opened. CSEO and NSEO closed.
2012	Rockfish release devices required on recreational charter vessels. SSEO, CSEO and EYKT directed fisheries opened. NSEO closed.
2013	SSEO, CSEO and EYKT directed fisheries opened. NSEO closed.
2014	EYKT directed fishery opened. SSEO, CSEO, and NSEO remain closed.

Appendix B: An initial exploration of an age-structured model for yelloweye rockfish (*Sebastes rubberimus*) in Southeast Alaska Outside Waters

Introduction

This appendix to the 2014 Demersal Shelf Rockfish SAFE represents an effort to develop an age-structured assessment (ASA) model for yelloweye rockfish in Southeast Alaska outside waters (Fig. 1). This model is in response to previous commentary from both the Gulf of Alaska Plan Team and the Sciences and Statistical Committee to develop such an assessment. Model data, structure, assumptions and results are presented below.

Changes in model structure and data following September Plan Team meeting

1. *Model years*

Model years now run from 1985 – 2013 instead of 1992 – 2013.

2. *Mortality division*

Estimates of recruitment and natural mortality *M* begin in 1896 to populate the first model year (1985) with estimates of cohort abundance, conditioned on age-composition data. Prior to 1985, however, *M* = *Z*, as no fisheries data are available despite the existence of commercial fisheries. The revised model structure therefore separates *Z* into two estimates, one applied to 1896 – 1984, the other to 1985 – 2013, for each management area to prevent higher estimates of *Z* from earlier years from affecting estimates for *Z* for the period 1985 - 2013.

3. *Catch-curve estimate of total mortality Z set as model prior*

Model estimate of mean natural mortality *M*, averaged over all management areas, was 0.0716 in the original version. Comments from the Plan Team indicated this was high for yelloweye and efforts should be made to reduce it. Yelloweye are managed as a Tier 4 species, with the assumption $F = M = 0.02$. Rather than implement a high penalty on model deviation from a prior for *M* set to 0.02, which is a management criteria independent of data, a prior for total mortality *Z* for 1985 – 2013 was taken from catch-curve analysis and implemented with a very large penalty for model deviation.

4. *Assumptions regarding morphology and maturity*

The submarine and ROV survey estimates of density are conditioned on yelloweye morphology-only adult and subadults are counted. It was initially assumed that changes in morphology-at-age were equivalent to changes in maturity-at-age; this assumption has been shown to be wrong. Scaling model estimates of total abundance to density estimates of adult/subadult abundance is now a function of a morphology-at-age curve, made possible by the length-morphology data gathered by the recent ROV surveys.

5. *Submarine survey data*

Submarine survey data from 1994 were removed from model data sets. The 1994 submarine survey lacked the forward-facing camera standard on all subsequent submarine surveys. Analysis of fish counts showed a significant reduction of fish detected on the transect line in 1994 relative to all other submarine survey years, producing artificially low estimates of yelloweye density for 1994.

6. Management areas

Removal of the 1994 submarine survey data left no survey data points for NSEO. Without survey data, model estimates of abundance cannot be scaled, and NSEO was removed from the list of management areas for which an age-structured assessment was prepared.

7. IPHC survey CPUE

CPUE data from the IPHC were initially conditioned on the assumption that survey skates with no yelloweye present were deployed over habitat suitable for halibut but not yelloweye, and removed from CPUE calculations. This approach has been discarded. IPHC survey skate locations have been compared to rocky habitat suitable for yelloweye and only those skates deployed on rockfish habitat selected for calculation of IPHC survey CPUE.

8. *CPUE (directed commercial fisheries and IPHC*)

Efforts to find normal distributions for CPUE data from the directed commercial longline fishery initially merged data from all management areas to increase sample size; the same was done with IPHC longline survey data. This has been changed so that CPUE data for each management area are analyzed separately, allowing for different transformations to normality for each area.

9. Halibut longline bycatch age-composition and selectivity

Age-composition data from yelloweye caught as bycatch in the commercial longline halibut fishery were available for a small number of years for CSEO and EYKT. These data are now included along with estimates of selectivity-at-age curve separate from the curves derived from directed commercial yelloweye fisheries age composition data.

Executive Summary of Results

- Estimates of abundance, natural mortality *M*, and full-recruitment fishing mortality *F* were improved following revisions to model structure. Mean *M* dropped from 0.0716 to 0.0307, and estimates of F_{OFL} and F_{ABC} were more reasonable (Summary Table);
- Population trends showeddeclines in SSEO but remained relatively steady for CSEO and EYKT, which is different from the original model output which showed declines in all areas. Averaged over all areas, however, biomass estimates show a gradual decline (Summary Table);
- The revised model was able to estimate reasonable values for unfished spawning biomass, which suggest that current biomass levels range between $SB_{40\%}$ to $SB_{55\%}$;
- Models were highly sensitive to both density surveys and age data; efforts to continue surveys and improve ageing methods should be supported;

Summary Table					
Quantity	**Current assessment**		**ASA structure**		
	2014	**2015**	**2013**	**2014**	**2015**
M (natural mortality, ages 8+)	0.02		0.0307[1]		
Tier	4		4		
Biomass - total (metric tons)[3]	13,274	10,933	10,512[2]	10,467[2]	10,277[2]
Female spawning biomass (metric tons)			4,751[2]	4,662[2]	4,543[2]
$F_{OFL} = F_{35\%}$	0.032		$F_{35\%} = 0.0487$[1]		
Max F_{ABC} (maximum = $F_{40\%}$)	0.026		$F_{40\%} = 0.0393$[1]		
F_{ABC} (*recommended* = $F_{45\%}$)	0.02		$F_{45\%} = 0.032$[1]		

[1]Mean over all management areas scaled by relative area (km^2)
[2]Summed over all management areas

Model Data

Data used in the age-structured model:

1. total annual catch (metric tons) from the directed DSR commercial fishery in the three SEO management areas (Southern Southeast Outside Waters (SSEO), Central Southeast Outside Waters (CSEO), and East Yakutat (EYKT)) (Table 1);
2. total annual incidental bycatch (metric tons) from the commercial halibut longline fishery (Table 2);
3. total annual catch (metric tons) from the sport fishery from 1996 – present (Table 3);
4. estimates of yelloweye density (individuals per square kilometer) derived from ADF&G submarine and remote operated vehicle (ROV) bottom surveys (Table 4);
5. estimates of total rockfish habitat per management area in square kilometers derived from sonar and other bathymetric surveys (Table 4);
6. age composition data from the commercial fishery;
7. age composition data from the commercial longline halibut fishery bycatch;
8. commercial fishery catch-per-unit effort (CPUE) derived from logbooks and fish tickets;
9. International Pacific Halibut Commission (IPHC) longline survey bycatch CPUE from IPHC survey logs;
10. estimates of length, weight, age, and maturity composition derived from commercial fisheries data from 1985 - 2013.

Total Annual Catch

Estimates of total annual catch were obtained through analyses of fisheries logbook data and fish tickets for each year in which a commercial fishery for yelloweye was implemented in the three management areas. Fisheries data from the early 1990's and prior are characterized by varied record-keeping methods in addition to changes in management areas and harvest regulations. Logbook data were re-assessed in construction of model data sets, and the numbers presented in Table 1 may differ somewhat from previous DSR stock assessments (Table 1, Fig. 2)

Halibut fishery incidental catch

In contrast to the directed commercial fishery for yelloweye, which has not been opened in every management area for every year included in the assessment model, incidental catch removals in the commercial longline halibut fishery have occurred every modeled year (Fig. 2). These incidental catch data stabilize model performance and compensate for years in which no commercial catch data exist. For years prior to 2006, yelloweye rockfish incidental catch data from the commercial halibut longline fishery were taken from halibut processor fish tickets; after 2006 these data were taken from the Interagency Electronic Reporting System (IERS), a joint effort between ADF&G, the IPHC, and the National Marine Fisheries Service (NMFS) to consolidate landing, IFQ, and logbook reporting (Table 2, Fig. 2).

Sport and Subsistence Catch

Sport catch refers to total removal from subsistence and recreational efforts, with an assumption of 100% mortality for any fish released. Total tonnage is calculated as the product of total number and the estimated mean weight over all ages for a given year. Data are available from 2006 – present (Table 3, Fig. 2). The assumption of 100% mortality may be relaxed in future assessment with the implementation of mechanisms designed to reduce mortality of released fish.

Density - Submarine and ROV *surveys*

ADF&G utilized a manned submersible to conduct line-transect surveys with direct observations of yelloweye abundance from 1990 - 2009. Survey locations were selected randomly but constrained to fall within rocky habitat considered appropriate for rockfish (a detailed description of ADF&G submarine and ROV survey methods is found in Green et al. 2014). After 2009, the submersible became unavailable, and was replaced by a ROV controlled directly from the survey ship. Surveys utilizing the ROV were conducted from 2012 onward. Line transect methods implemented in the software package DISTANCE 6.0 (Thomas et al. 2010) were used to calculate density of adult and sub-adult yelloweye from count data from both submarine and ROV surveys along with estimates of variance (Table 4). For the purposes of the ASA model, density and variance estimates from the submarine and ROV are assumed equivalent.

Fishery Age Composition

Estimates of fishery age composition for each management area were derived from data collected through port sampling of catch from the directed commercial fishery and bycatch taken in the commercial halibut longline fishery. Sampled otoliths were sent to the ADF&G Age Determination Unit for aging and the results used to construct length-age relationships. Age-composition was estimated from the catches specific to each area to potentially identify region-specific differences in age composition and recruitment. Years in which sample size was less than 50 were omitted.

CPUE

IPHC survey

The IPHC standardizes survey effort into “effective skates” relative to hook spacing and hook type as

$$effskt = noskt * 1.52 * (1 - e^{-0.06*hkspc}) * nohk / 100 * hkadj$$

where *noskt* = the number of skates hauled, *hkspc* = the mean spacing between hooks on a given skate, *nohk* = mean number of hooks per skate, and *hkadj* = hook type. If no hook type is available, a circle hook is assumed. Prior to 2009, yelloweye were counted for the first 20 hooks of each skate; total skate counted were extrapolated. From 2009 onward, yelloweye have been counted in full for each skate.
For model fitting, skates for which no yelloweye were retained were discarded from CPUE consideration under the assumption that they were set over halibut habitat unsuitable for rockfish. Catch-per-unit data were expressed as individual rockfish caught relative to hooks deployed.

Commercial fisheries
Catch-per-effort data for the directed commercial fishery, expressed as total pounds of rockfish retained relative to hooks deployed, were taken from logbook entries and fish tickets. Catch was determined sensitive to hook spacing, average depth fished, and the number of boats entered into the permitted fishery by year and management area (Fig. 3). A generalized linear model assuming a Poisson error distribution was used to fit the pounds of yelloweye rockfish caught to hook spacing, average depth fished, and number of boats participating in the fishery, factored by year, management area, and specific vessel (to account for relative experience levels).

CPUE for both the directed fishery and the IPHC survey was initially calculated as the ratio of catch to standardized effort for each reported set for a given vessel, for each management area in a given year. The results were not normally distributed and were problematic to model fitting. Following Quinn and Deriso (1999), catch for the commercial fishery and bycatch from the IPHC survey were transformed by implementation of the Box-Cox transformation

$$T(U) = \frac{U^{\alpha} - 1}{\alpha}$$

to describe an underlying normal distribution where U = the untransformed catch values, T = the transformed values, and α = the transformation parameter. For the commercial fishery, α was set to 0.33 for all management areas to obtain a cube root transform (Fig. 3). For the IPHC longline survey, it was necessary to assign different α values to each area to obtain normality (CSEO = 0.33; EYKT = 0.2; SSEO = 0.5) (Fig. 3). Median catch C for each year y and management area a was calculated and back transformed as

$$C_{y,a} = S(T) = (\alpha\hat{\mu}_{y,a} + 1)^{(1/\alpha)}$$

where $\hat{\mu}$ is the median of the transformed values.

Model years and management areas
The model covers the years from 1985 – 2013.

Data set		*Years available*
Directed DSR total annual fishery catch:	CSEO	1985-2004, 2012, 2013
	SSEO	1985- 2004, 2008 – 2012, 2013
	EYKT	1985, 1987-2001, 2004-2005, 2008-2009, 2012, 2013
Directed DSR fishery age composition:	CSEO	1988, 1992 – 2004, 2012, 2013
	SSEO	1991 – 2005, 2009 – 2013
	EYKT	1992 – 2001, 2004 – 2005, 2008 – 2009, 2012, 2013
Halibut longline fishery total annual bycatch		1985 – 2013 for all management areas
Halibut bycatch fishery age composition:	CSEO	2008 - 2011
	SSEO	None
	EYKT	2010 - 2011
Directed DSR fishery CPUE		As for total annual catch
IPHC survey CPUE		1998 – 2013 for all management areas
Sport fishery total annual catch		2006 - 2013

Submarine/ROV survey density:	CSEO	1995, 1997, 2003, 2007, 2012
	SSEO	1999, 2005, 2013
	EYKT	1995,1997, 1999, 2003, 2009

Each management area (EYKT, CSEO, SSEO) was considered a distinct population, with recruitment, mortality, fishery removals, halibut longline fishery incidental catch, survey density estimates, and estimates of suitable rockfish habitat specific to each area. Length-weight-age keys and maturity-at-age were assumed the same for all areas, estimated external to the model, and input. Natural mortality and selectivity-at-age were estimated for each area. Males and females were not separated except in the calculation of female spawning biomass and female maturity-at-age.

Analytic approach

Model structure

Standard age-structured population dynamics equations (Quinn and Deriso 1999) were used to model yelloweye rockfish in SEO waters from 1985 – 2013 using AD Model Builder (Fournier et al. 2011) (BOX 1). Modeled age classes ran from 8 – 97, with 8 being the age of recruitment (the youngest age observed in commercial fisheries data), and 97 being a plus class. Recruitment was estimated from 1903 – 2013 to populate the first year of the age-structured (1992). Model estimates included spawning biomass, recruitment, natural mortality, abundance-at-age, commercial catch, incidental catch in the commercial longline halibut fishery, sport catch, CPUE for both the commercial fishery and the IPHC halibut longline survey, and density (number of individual per square kilometer) for each management area.

Density

Although the line transect surveys count all observed yelloweye, density calculations are completed in DISTANCE 6.0 only for adults and sub-adults, omitting juveniles. The distinction between juvenile and sub-adult classification is based on assessment of changes in coloring and morphology that occur as a fish ages. The ROV surveys in 2012 and 2013 provided length-classification data, allowing for construction of a classification-at-age curve which was used to scale model estimates of total abundance to model estimates of adult and sub-adult density. Estimates of maturity-at-age and suitable rockfish habitat for each management area in square kilometers were assumed known without error.

As survey density scales model estimates of absolute abundance, catchability for the submarine and ROV line transects was set to 1.

Catch-at-age

Catch-at-age for each management area was a function of the Baranov catch equation, with fishing mortality-at-age a in year y $F_{y,a}$ the product of an asymptotically increasing selectivity-at-age f_a and a full-recruitment fishing mortality term F_y (BOX 1). Both the sport fishery and bycatch in the halibut longline fishery were modeled as separate fisheries, but selectivity-at-age f_a was assumed the same as for the yelloweye directed fishery.

Spawning biomass

For each management area, female spawning biomass for a given year y was estimated under the assumption of equal male/female proportions (BOX 2). Yelloweye have internal fertilization and potentially extended periods of parturition; for convenience, it was assumed that parturition occurs in May, following O'Connell (1987).

CPUE

For each year *y* and management area, median catch *C* was modeled as

$$C_y = q_{iphc} E_y^{\alpha+1} N_y^{\beta+1} \qquad \text{IPHC survey}$$
$$C_y = q E_y^{\alpha+1} B_y^{\beta+1} \qquad \text{Directed fishery}$$

where *C* = median catch (pounds for the directed fishery, numbers for the IPHC survey), *q* = catchability for the commercial fishery, q_{iphc} = catchability for the IPHC longline survey, *E* = median effort (total hooks), *N* = abundance (millions of individuals), *B* = biomass (metric tons), and α and β are model parameters defining the relationship between catch and abundance.

Selectivity-at-age

Within SSEO, selectivity-at-age f_a is assumed the same for the directed yelloweye commercial longline fishery, the commercial halibut longline fishery, and the sport fishery. CSEO and EYKT contain age-composition data for halibut longline fishery bycatch, and a separate selectivity-at-age vector for bycatch was estimated. Selectivity vectors were estimated for each management area to potentially aid in identifying differences in age-structure. Selectivity-at-age was estimated as

$$f_a = \frac{1}{1 + \exp(-slope * (age - sel_{50\%}))}$$

for which $sel_{50\%}$ is the age at which 50% of the population is selected into the fishery, *slope* is the slope of the sigmoid curve at the $sel_{50\%}$ point.

Parameter estimation

Model parameters were estimated by minimizing a penalized negative log-likelihood objective function (BOX 3). Log-normal likelihoods were assumed for total annual catch, total annual halibut longline fishery incidental catch, sport catch, and density for each management area. Multinomial likelihoods were assumed for age composition data. Penalties were implemented in the objective function to facilitate scaling and parameter estimation. Natural mortality *Z*, full-recruitment fishing mortality *F*, catchability in the directed commercial fishery *q*, catchability in the IPHC longline survey q_{iphc}, and recruitment variability σ_r were constrained by minimizing deviations from assumed log-normal prior probability distributions. Fishing mortality-at-age for both the commercial DSR fishery and incidental catch in the halibut longline fishery was constrained by minimizing annual fluctuations (BOX 3). Irregularities in recruitment were also constrained (BOX 3).

Yelloweye are managed as a Tier 4 species, with the assumption $F = M = 0.02$. The prior for *F* was set to 0.02 as per the Tier 4 management criteria, but with a variance sufficiently large to allow for parameter flexibility. The prior for total mortality *Z* (for years prior to 1985) was similarly set to 0.02 primarily for stability in the estimation process. The prior for total mortality *Z* (1985 – 2013) was set to the catch-curve estimate of *Z* and heavily weighted.

Priors, starting values, and assumed variances

Parameter	Prior value	Variance	Estimation phase
Z (pre-1985)	0.02	0.4	4
Z (1985 – 2013)	0.0564	0.1	4
Mean F	0.02	0.4	1
Recruitment deviations σ_r	0.5	0.5	5
Commercial catchability q	1	0.5	1
IPHC survey catchability q	1	0.5	1

Objective components and weights for each management area

Component	Weight		
	CSEO	EYKT	SSEO
Density	30	30	30
Commercial annual catch	70	70	70
IFQ halibut annual bycatch	50	50	50
Total annual sport catch	25	25	25
Commercial catch-age composition	5	5	5
Halibut bycatch age-composition	20	20	n/a
Commercial CPUE	0.5	0.5	0.5
IPHC bycatch CPUE	0.5	0.5	0.5
F regularity	0.01	0.01	0.01
PRIORS			
Z (1985 – 2013)	50,000	50,000	50,000
Z (pre-1985)	1	1	1
Mean F	1	1	1
Recruitment deviations σ_r	1	1	1
Commercial catchability q	1	1	1
IPHC survey catchability q	1	1	1

Total estimated parameters for each management area

Parameter	Number
1) mean full-recruitment fishing mortality F	1
2) mean recruitment	1
3) natural mortality (pre-1985, post-1984)	2
4) annual fishing mortality deviations for yelloweye fishery	29
5) annual fishing mortality deviations for IFQ halibut bycatch	29
6) annual fishing mortality deviations for sport catch	8
7) annual recruitment deviation	118
8) recruitment variability	1
9) Selectivity and CPUE parameters (CSEO, EYKT / SSEO)[1]	10 / 8
Total (CSEO, EYKT / SSEO)	197 / 195

[1]As there are no halibut bycatch age-composition data for SSEO, no selectivity-at-age curve is estimated for SSEO for that fishery.

Externally estimated parameters

Life history attributes were estimated externally from data collected through port sampling of commercial fisheries catches from 1992 - 2013. These were assumed constant over all areas and years, and include:

- Weight-at-age
- Maturity-at-age
- Age-error matrix

Weight-at-age (kilograms)

Mean weight-at-age W was estimated by fitting observed weights-at-age to the equation

$$W_t = W_\infty [1 - e^{-k(t-t_0)}]$$

for which W_t = weight at time t (age), W_∞ = asymptotic weight, t_0 = the time (age) at which an individual is considered to have weight 0, and k = growth rate. Mean weight-at-age was assumed consistent across all management areas and equivalent between males and females (Fig. 4).

W_∞	$\boldsymbol{k}$	$\boldsymbol{t_0}$
6.027	0.039	-10.13

Maturity-at-age

Proportions mature-at-age m_a were calculated for females only, fitting observed maturity-at-age to the equation:

$$m_a = \frac{mat_\infty}{1 + \exp(-slope * (age - mat_{50\%}))}$$

for which $mat_{50\%}$ is the age at which 50% of the population is reproductively mature, *slope* is the slope of the sigmoid curve at the $mat_{50\%}$ point, and mat_∞ = asymptotic maturity.

slope	$\boldsymbol{mat_{50\%}}$
-0.341	17.634

Age-error matrix

An age-error matrix, defining the probability of correctly aging a fish based on otolith analysis, was constructed by Dana Hanselman (Auke Bay Lab, National Marine Fisheries Service) for earlier model work in 2010. This matrix is preserved in the current model iteration. The matrix is implemented in the calculation of predicted catch-at-age proportions for the directed yelloweye commercial fishery (BOX 1 & 2). This matrix, however, reflects the uncertainty of age readers for NMFS, not the age readers from the ADF&G Age Determination Unit. An age-error matrix was constructed from ADU data but improvements in the analysis of ADU data are needed before it is considered sufficiently robust for model integration.

Model Results

Objective function values are presented in Table 5.

Model fits to DISTANCE 6.0 estimates of region-specific yelloweye rockfish per square kilometer are presented in Fig. 5. Following Plan Team comments, these data points scale model estimates of abundance and provide general population trends, as opposed to requiring a precise fit to each point.

Fits to directed commercial total annual catch (Fig. 6), commercial halibut longline fishery annual bycatch (Fig. 7) and annual sport catch (Fig. 8) were good. Estimates of full-recruitment fishing mortality *F* for the directed commercial fishery were generally below the Tier 4 assumption that $F = 0.02$ (Fig. 9, Table 7), although when combined with IFQ halibut bycatch fishing mortality, total *F* levels often exceeded 0.02.

Estimates of natural mortality *M* (1985 – 2013) exceeded the Tier 4 assumption that $M = 0.02$ for all areas, but only slightly (Table 6). Total mortality *Z* (1985 – 2013) exceeded the Tier 4 assumption that $Z = 0.04$ for all management areas, and estimates for each area fell within 10% of the specified prior for *Z* derived from the catch-curve analysis (Fig. 10).

Annual recruitment is presented in Fig. 11 along with period-specific estimates of *Z* (1896 – 1984) and *M* (1985 – 2013). Estimates of total mortality for 1896 – 1984 were roughly twice that of natural mortality for 1985 – 2013.

Spawning biomass in CSEO and EYKT appeared relatively steady, while spawning biomass in SSEO declined over model years. Projected spawning biomass (2014 – 2018) for all areas showed a decrease (Fig 12).

Selectivity-at-age curves for all areas were similar (Fig. 13), with age at 50% selectivity ranging from 20.6 to 23.9. Maturity-at-age, calculated external to the model, appears to occur prior to recruitment into the commercial fishery for all areas.

Fits to CPUE data were variable (Figs. 14 and 15). Catchability values for commercial CPUE remained close to 1, while catchability for the IPHC longline survey varied markedly between management areas.

	CSEO	EYKT	SSEO
Q (commercial fisheries)	1.1262	1.0744	0.7823
Q (iphc survey)	0.9942	0.4156	0.8670

Age-composition fits to observed commercial fisheries age data are presented in Figs. 16 -18. EYKT shows strong recruitment events in recent years, which may account for the relative stability of abundance, while both CSEO and SSEO have weaker recruitments. All three areas show decline of older cohorts over time.

Mean recruitment was estimated as the average recruitment from 1987 – 2005 (Table 7). Estimates of female spawning biomass in the terminal model year (2013) for each area fell between $F_{spr\,40\%}$ and $F_{spr\,55\%}$. A comparison of the current management F levels with model estimates of fishing mortality (Table 8) suggests that F_{ABC} lies closer to $F_{55\%}$ than $F_{45\%}$.

Discussion

Density

It can be seen in Fig. 5 that while density data scale model estimates of absolute abundance, fitting to individual estimates was often poor. As discussed above, model estimates of density are not fitted directly to observed survey data, but to estimates of density derived from survey data by the DISTANCE software package (Thomas et al. 2006) as

$$\hat{D}_{distance} = \frac{nf(0)}{L}$$

for which n = number of adult and sub-adult yelloweye observed, $f(0)$ probability of detection as a function of distance from the transect line, and L = total line length (meters). The probability detection function assumes that detection on the line = 1 (Burnham et al. 1980).

Model estimates of density assume the following:

- Estimates of rockfish habitat (km^2) are without error;
- The physical appearance of adults and sub-adults counted in the survey can be represented by the maturity-at-age curve without error;
- Estimates of density and variance from DISTANCE 6.0 are correct, including the assumption that detection on the line = 1.

If assumptions #1 and/or #2 above are relaxed, the model would likely require extremely tight constraints on parameter estimation to allow model convergence. The author is also uncomfortable with an arbitrary *ad hoc* approach to weighting density objective function components, especially when it results in different weights for different areas based on the number of years for which surveys were completed. Although it is logical to change weights relative to available data, the current structure implements the same weight for density estimates over all management areas because a formal approach for weighting density objective function components relative to the years of available data has not yet been developed.

CPUE

Estimates of CPUE and the model functions for fitting to these data remain problematic, and additional work is needed to improve the signal to noise ratio in the data.

Mortality and Fishing Pressure

Use of catch-curve-derived total mortality Z as a prior for model estimates of Z to obtain reasonable values for M appeared to work well, although the statistical implications of using catch-age data both within the model and to calculate the prior for Z are unclear to the author. O'Connell and Brylinksy (2003) applied catch-curve analysis to "lightly fished" 1984 SSEO commercial longline data and estimated M = 0.017 (under the assumption that Z was roughly equal to M under conditions of little fishing pressure), while alternative methods produced estimates ranging from 0.02 to 0.056 (O'Connell and Brylinksy 2003, Table 3). The estimate from O'Connel and Brylinksy (2003) of Z = 0.056 was from commercial fisheries data in CSEO from 2000 – 2002, which is virtually identical to the current catch-curve estimate for CSEO of 0.0564 (Fig. 10).

While slight modifications to the assumption that F_{ABC} = 0.02 may move towards sustainable fisheries removals, model outputs suggest that 0.02 should be understood as representing a somewhat smaller reduction of unfished spawning biomass than the commonly assumed $F_{ABC} = F_{45\%}$ (Table 8). Relative F levels were calculated ranging from $F_{30\%}$ to $F_{70\%}$ for each region, suggesting that F_{OFL} begins roughly at $F_{45\%}$ instead of $F_{35\%}$, and F_{ABC} lies closer to $F_{55\%}$ instead of $F_{45\%}$. If accurate, the implication is that yelloweye are highly sensitive to fisheries removals. The current management assessment set an ABC of 274 metric tons for 2014 (Green et al. 2014). When compared with projected catch levels for 2014 under varying F levels from the ASA model, 274 metric tons represented a removal at roughly $F_{45\%}$. This corresponds to an F level of 0.032, which under current management regulations is classified as the OFL threshold (Table 8).

Biological reference points and unfished spawning biomass

Model estimates of unfished spawning biomass appear reasonable in that current spawning biomass levels are all below $SB_{100\%}$, and the current stock levels fall between $SB_{40\%}$ and $SB_{55\%}$. The implication is that while the Tier 4 assumptions regarding F levels will likely need some minor adjustments to adequately ensure sustainable stock numbers and catch levels, they have, up to the present, been largely adequate for management of yelloweye populations. The author is very interested in comments from the Plan Team and the SSC as to whether the current model structure is considered sufficiently robust to move yelloweye from Tier 4 to a Tier 3 species.

Predation mortality is generally disproportionately higher for younger ages in non-apex species (Gaichas et al. 2010, Van Kirk et al. 2012). One approach to improving estimates of recruitment, natural mortality, and SPR rates might be to construct predation profiles for yelloweye rockfish predators in the Gulf of Alaska, and either actively model predation mortality for younger ages or, alternatively, estimate a separate natural mortality for each age below a given limit, depending on available predation data. Increased mortality for younger ages through predation produces increased recruitment but at the same time prevents the increased biomass from being passed into older cohorts and then requiring unrealistic levels of natural mortality to maintain cohort structure. This, in turn, may aid in estimating realistic values for unfished spawning biomass.

Unified model

The current model estimates the population dynamics of each management area separately, but there may be an advantage to modeling the entire geography of the Southeast Outside water as a single population. Following parturition, yelloweye larvae experience dispersal through passive transport until capable of independent mobility, eventually settling into benthic habitat and thereafter exhibiting only local movement. This early dispersal is unlikely to follow management divisions, may account for differences in relative abundance and natural mortality for each area, and would serve to link adult populations that are largely sedentary and isolated but are treated as a single stock for management purposes.

Data Gaps and Research Priorities

1. Aging methods and data from the ADFG Age Determination Unit need to be better analyzed to allow for construction of a valid age-error matrix that reflects the uncertainty of the ADFG age data instead of using the NMFS age-error matrix. This is of critical importance, as the age-structure of the model has a large effect on estimates of *M* and *F* as well as selectivity-at-age;
2. Alternate methods of estimating recruitment should be explored in the hopes of moving yelloweye rockfish from Tier 4 to Tier 3 management status;
3. CPUE data should be further examined to determine whether the information contained there is able to be extracted with a better signal-to-noise ratio.

The author looks forward to comments and suggestions from the Plan Team and SSC regarding these points and any other suggestions or recommendations for improving model performance.

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Table 1. Total annual directed commercial yelloweye catch (t) for each management district for all modeled years

Year	CSEO	SSEO	EYKT	Total
1985	215.38	26.85	5.15	247.38
1986	204.82	77.74	0.00	282.56
1987	171.75	288.66	64.79	525.2
1988	127.19	211.13	39.17	377.49
1989	118.65	112.16	35.56	266.37
1990	70.22	86.02	15.69	171.93
1991	76.61	87.31	173.08	337
1992	101.11	131.41	46.92	279.44
1993	122.17	62.72	87.48	272.37
1994	128.32	72.57	110.38	311.27
1995	73.61	22.69	46.12	142.42
1996	162.25	62.94	95.86	321.05
1997	136.15	49.62	63.51	249.28
1998	110.44	50.17	64.44	225.05
1999	97.78	57.46	72.55	227.79
2000	58.74	58.94	55.59	173.27
2001	58.94	56.52	48.91	164.37
2002	70.89	57.02	0.00	127.91
2003	57.99	36.33	0.00	94.32
2004	55.51	23.71	86.88	166.1
2005	0.00	0.00	41.90	41.9
2006	0.00	0.00	0.00	0
2007	0.00	0.00	0.00	0
2008	0.00	19.70	21.72	41.42
2009	0.00	29.28	44.40	73.68
2010	0.00	28.49	0.00	28.49
2011	0.00	21.39	0.00	21.39
2012	31.05	31.99	35.99	99.03
2013	35.69	5.27	36.64	77.6

Table 2. Total annual yelloweye incidental catch (t) in the commercial longline halibut fishery for each management district for all modeled years

Year	CSEO	SSEO	EYKT	Total
1985	7.61	0.67	1.49	9.77
1986	4.28	0.92	0.27	5.47
1987	4.52	2.14	1.33	7.99
1988	1.57	3.09	0.11	4.77
1989	22.65	23.59	5.73	51.97
1990	13.01	29.97	5.08	48.06
1991	24.65	11.97	17.59	54.21
1992	43.81	22.30	16.48	82.59
1993	73.91	36.19	11.21	121.31
1994	103.13	44.80	14.61	162.54
1995	34.32	6.68	11.03	52.03
1996	28.18	8.63	14.09	50.9
1997	45.95	6.86	22.79	75.6
1998	49.54	10.20	35.26	95
1999	44.97	13.97	33.40	92.34
2000	40.20	14.37	24.61	79.18
2001	55.73	23.92	34.00	113.65
2002	56.06	23.10	34.97	114.13
2003	56.61	27.09	47.12	130.82
2004	47.17	32.72	45.76	125.65
2005	59.02	47.42	53.14	159.58
2006	67.03	54.17	39.16	160.36
2007	66.42	43.05	54.39	163.86
2008	48.61	26.08	46.73	121.42
2009	41.08	27.08	52.82	120.98
2010	32.54	23.32	57.02	112.88
2011	24.86	7.34	44.24	76.44
2012	20.18	9.96	33.69	63.83
2013	26.23	10.09	33.56	69.88

Table 3. Total annual yelloweye sport and subsistence catch (t) for each management district for 2006 - present

Year	CSEO	SSEO	EYKT	Total
2006	36.973	21.859	0.804	59.636
2007	50.687	18.484	0.270	69.441
2008	34.829	12.313	0.399	47.541
2009	7.825	7.406	0.002	15.233
2010	28.605	9.666	0.004	38.275
2011	16.160	5.820	0.004	21.984
2012	20.665	7.707	0.011	28.383
2013	14.147	7.135	0.001	21.283

Table 4. Submersible (1995, 1997, 1999, 2003, 2005, 2007, 2009) and ROV (2012–2013) yelloweye rockfish density estimates with 95% confidence intervals (CI) and coefficient of variations (CV) by year and management area. The number of transects, yelloweye rockfish (YE), and meters surveyed included in each model are shown, along with the encounter rate of yelloweye rockfish. Values in bold were used for this stock assessment. (Table adapted from Green at al. 2014)

Area	Year	Area (km^2)	# YE[b]	Meters surveyed	Encounter rate (YE/m)	Density (YE/km^2)	Lower CI (YE/km^2)	Upper CI (YE/km^2)	CV
EYKT[a]	1995	744	330	22,896	0.014	2711	1776	4141	0.20
	1997		350	19,240	0.018	2576	1459	4549	0.28
	1999		236	25,198	0.009	1584	1092	2298	0.18
	2003		335	17,878	0.019	3825	2702	5415	0.17
	2009		**215**	**29,890**	**0.007**	**1930**	**1389**	**2682**	**0.17**
CSEO	1995	1404	235	39,368	0.006	2929			0.19
	1997		260	29,273	0.009	1631	1224	2173	0.14
	2003		726	91,285	0.008	1853	1516	2264	0.10
	2007		301	55,640	0.005	1050	830	1327	0.12
	2012		**118**	**38,590**	**0.003**	**752**	**586**	**966**	**0.13**
SSEO	1999	732	360	41,333	0.009	2376	1615	3494	0.20
	2005		276	28,931	0.010	2357	1634	3401	0.18
	2013		118	30,439	0.004	986	641	1517	0.22

[a] Estimates for EYKT management area include only the Fairweather grounds, which is composed of a west and an east bank. In 1997, only 2 of 20 transects and in 1999, no transects were performed on the east bank that were used in the model. In other years, transects performed on both the east and west bank were used in the model.

[b] Subadult and adult yelloweye rockfish were included in the analyses to estimate density. A few small subadult yelloweye rockfish were excluded from the 2012 model based on size; length data were only available for the ROV surveys. Data were truncated at large distances for some models; as a consequence, the number of yelloweye rockfish included in the model does not necessarily equal the total number of yelloweye rockfish observed on the transects.

Table 5. Objective function values

Component	Objective function values		
	CSEO	EYKT	SSEO
Density	246.37	211.54	71.45
Annual commercial catch	10.22	5.36	6.22
Annual commercial longline halibut bycatch	1.84	0.14	0.18
Annual sport catch	0.44	0.00	0.03
Directed commercial catch age composition	4988.49	5157.63	10,428.5
Commercial longline halibut bycatch age composition	3986.83	1529.65	n/a
Directed commercial fishery CPUE	13.17	13.69	29.06
IPHC survey bycatch CPUE	2.65	1705.76	6.02
F regularity	28.26	25.63	14.47
PRIORS			
Z (1985 – 2013)	18.78	0.26	2.04
Z (pre-1985)	0.003	0.002	0.001
Mean *F*	16.33	13.34	11.49
Recruitment deviations σ_r	1.64	1.01	1.12
Commercial catchability *q*	0.02	0.005	0.02
IPHC survey catchability *q*	0.00	0.81	0.06

Table 6. Natural mortality M, mean full-recruitment fishing mortality F, mean total mortality Z, (1985 – 2013)

	CSEO	EYKT	SSEO	Mean
Nat. mortality M	0.0299	0.0287	0.0342	0.0307[1]
F commercial	0.0481	0.0273	0.0215	0.0359[1]
F IFQ hal. bycatch	0.0187	0.0125	0.0074	0.0142[1]
F sport	0.0132	0.0000	0.0044	0.0075[1]
Tot. mortality Z	0.0601[2]	0.0559[2]	0.0575[2]	0.0583[1,2]

[1]Mean over all management areas scaled by relative area (km^2)

[2]Mean over all age classes, including unfished cohorts

Table 7. Mean recruitment, F_{spr} values, and model female spawning biomass

	CSEO	EYKT	SSEO
Avg. Recr. (1000s) (1987 – 2005)	74.99	68.61	57.25
Area (km^2)	1,404	744	732
Female spawning biomass under F_{spr} rates			
$F_{spr\ 100\%}$	2,609	3,437	2,234
$F_{spr\ 45\%}$	1,677	1,547	1,005
$F_{spr\ 40\%}$	1,491	1,375	894
$F_{spr\ 35\%}$	1,305	1,203	782
Female spawning biomass, terminal year (2013)	1,944	1,422	1,385

Table 8. ASA model F levels and ASA model projected catch for all management areas, compared with F levels and 2014 allowable catch from current management approach.

	CSEO	EYKT	SSEO		Current management levels
Estimated commercial F levels				Mean[1]	
$F_{70\%}$	0.0108	0.0112	0.0127	0.0114	
$F_{65\%}$	0.0135	0.0141	0.0159	0.0143	
$F_{60\%}$	0.0167	0.0174	0.0197	0.0176	
$F_{55\%}$	0.0203	0.0214	0.0241	0.0216	$F_{ABC} = 0.02$
$F_{50\%}$	0.0247	0.0262	0.0294	0.0263	Max F_{ABC} (max = $F_{40\%}$) = 0.026
$F_{45\%}$	0.0300	0.0321	0.0359	0.0320	$F_{OFL} = F_{35\%} = 0.032$
$F_{40\%}$	0.0366	0.0396	0.0440	0.0393	
$F_{35\%}$	0.0452	0.0495	0.0546	0.0487	
$F_{30\%}$	0.0566	0.0633	0.0689	0.0615	
Projected commercial catch for 2014 (m. tons)				Total	TAC for 2014
Catch - $F_{70\%}$	39	26	32	97	
Catch - $F_{65\%}$	49	33	40	121	
Catch - $F_{60\%}$	60	40	49	149	
Catch - $F_{55\%}$	73	49	60	182	182 metric tons
Catch - $F_{50\%}$	88	60	73	222	
Catch - $F_{45\%}$	107	74	89	270	274 metric tons
Catch - $F_{40\%}$	130	91	108	330	
Catch - $F_{35\%}$	160	113	134	407	
Catch - $F_{30\%}$	200	144	168	511	

[1] Calculated as a weighted mean relative to the km2 of rockfish habitat per management area.

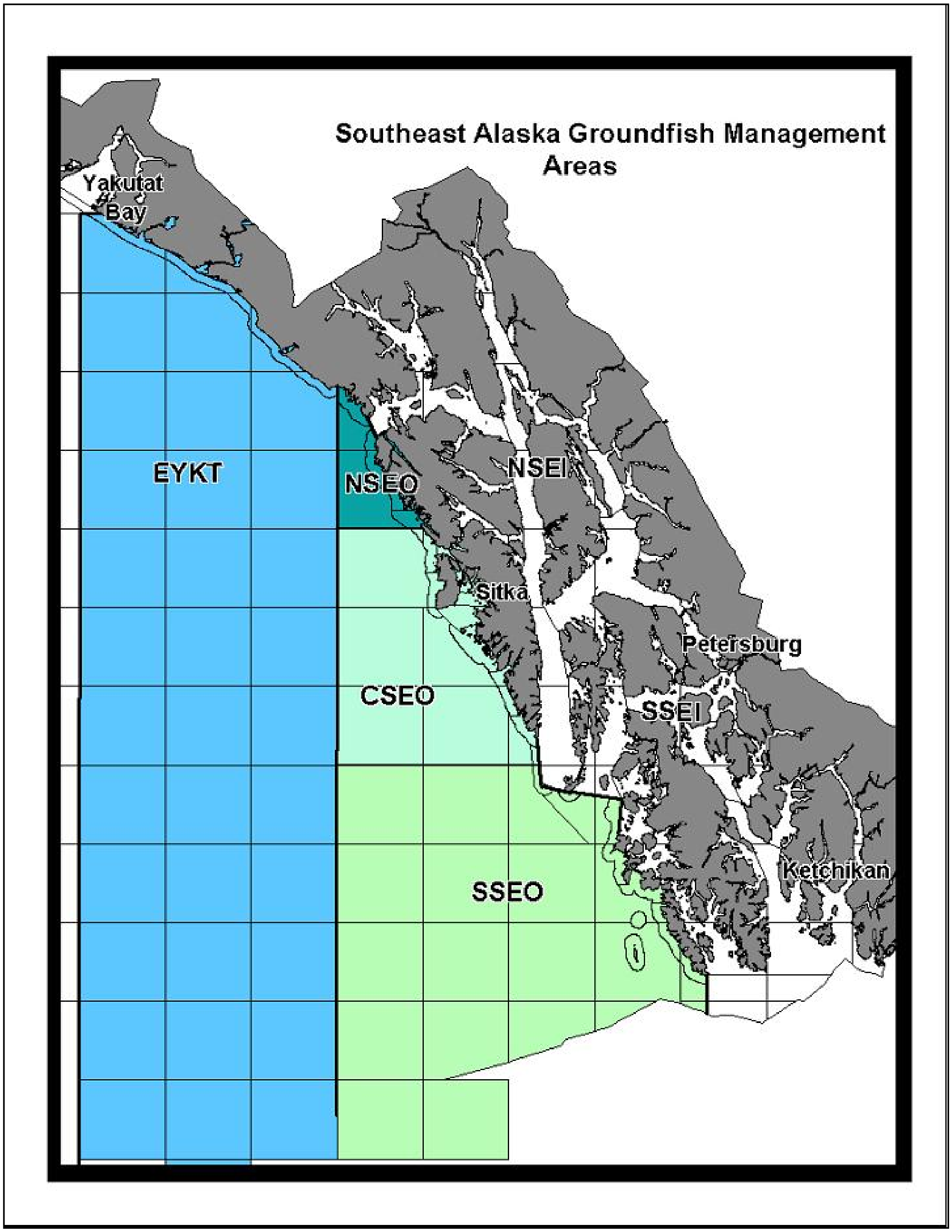

Figure 1. Southeast Alaska Outside Waters (Eastern Gulf of Alaska) with the Alaska Department of Fish and Game groundfish management areas; EYKT, CSEO, NSEO, and SSEO.

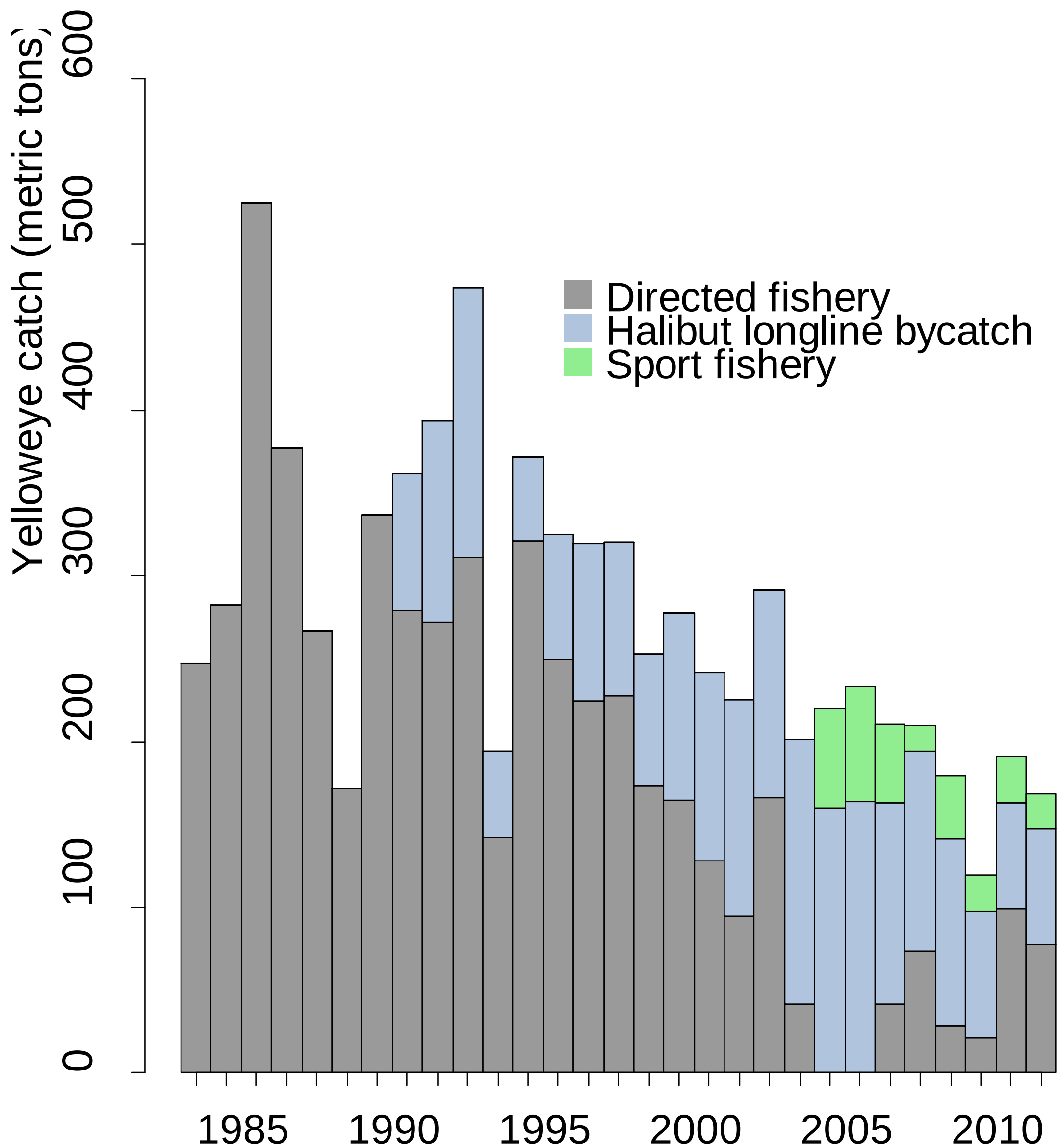

Figure 2. Total annual catch from SEO (CSEO,EYKT,SSEO) waters from the directed DSR commercial fishery, the commercial longline halibut fishery, and sport removals as used in the ASA model.

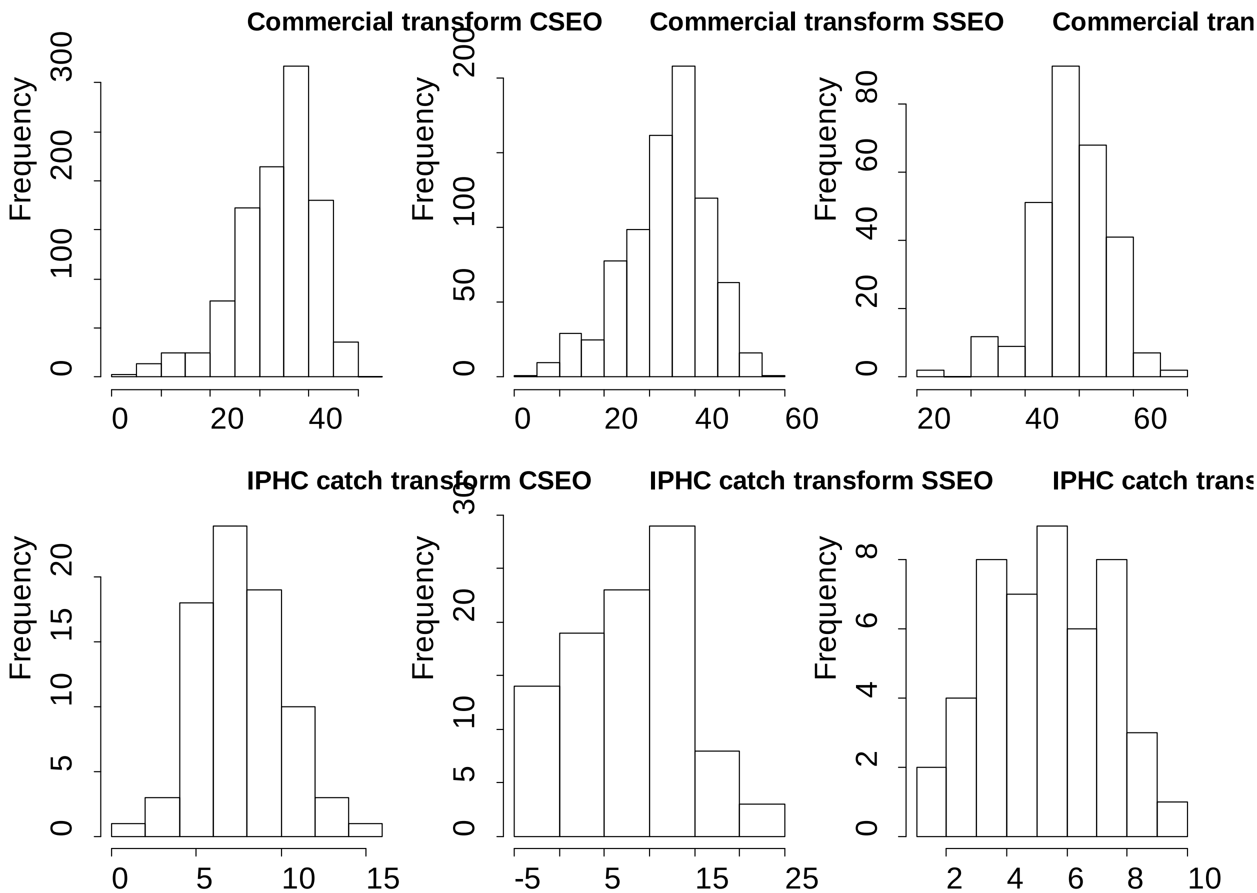

Figure 3. Transformed catch data and transformed catch data from the directed commercial fishery (top row), and the IPHC longline survey (bottom row) for estimating CPUE.

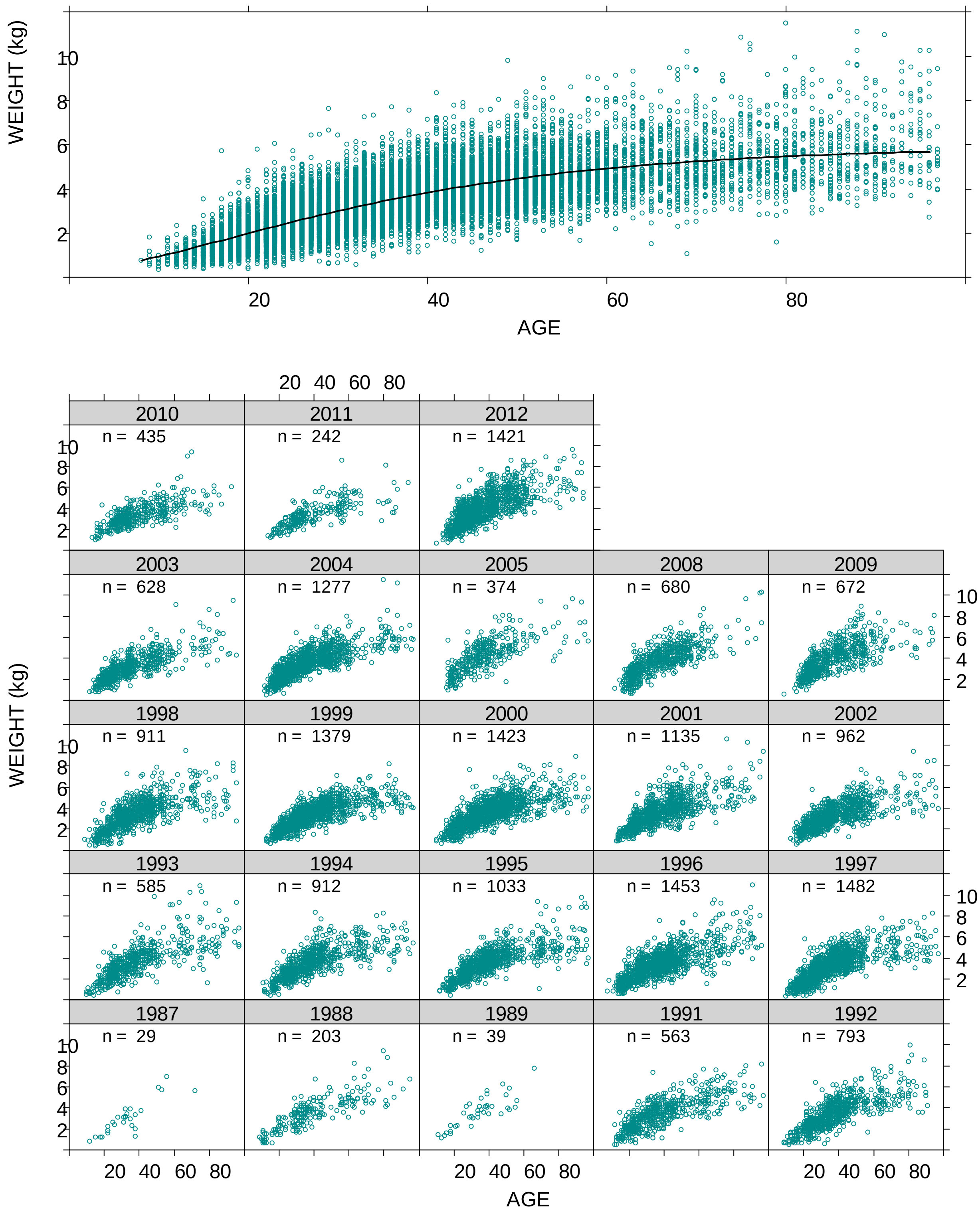

Figure 4. Mean weight-at-age (top) fit to aged samples from 1985 – 2013, with relative distributions and sample size per year (bottom)

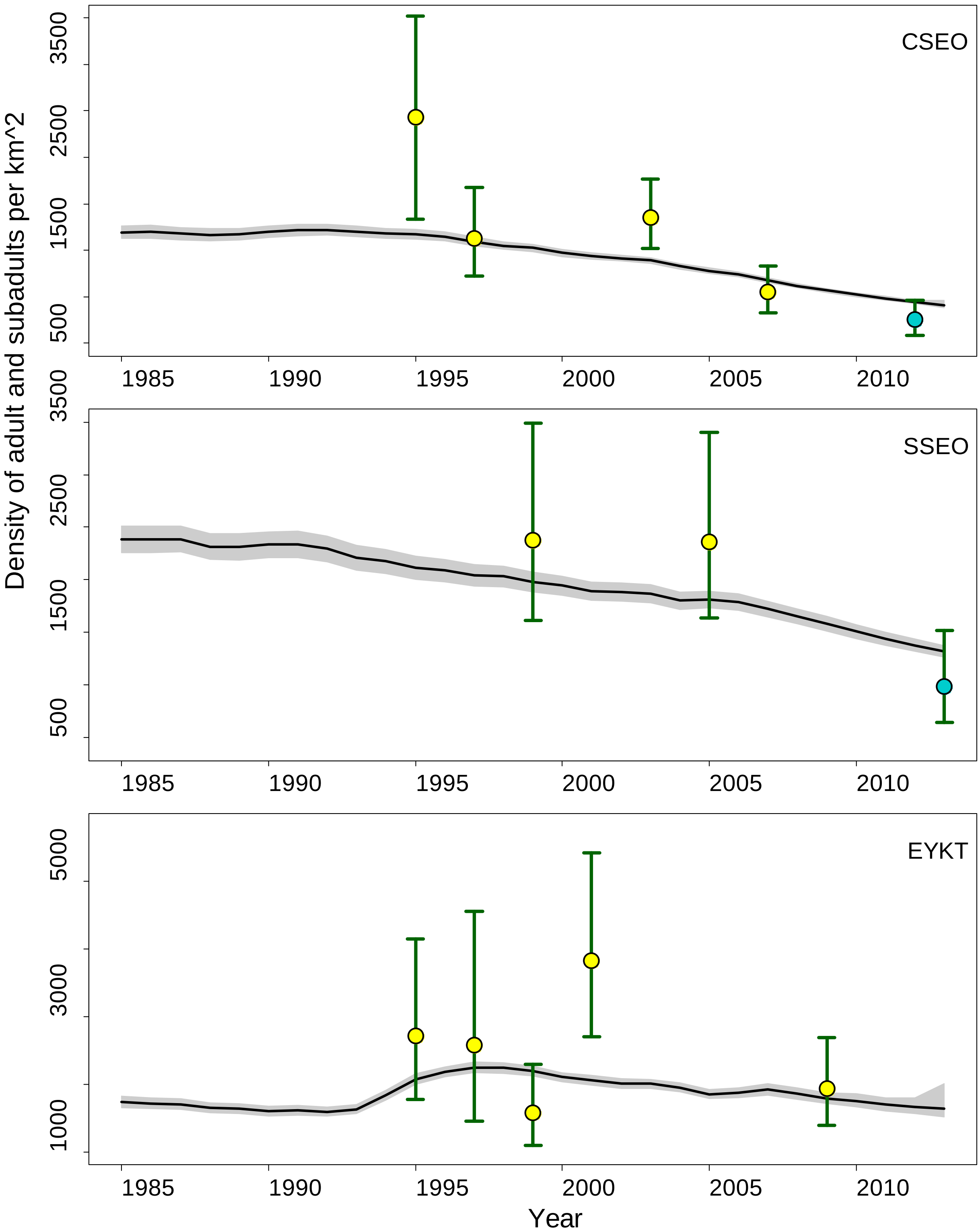

Figure 5. Estimates of yelloweye adult and sub-adult density from ADF&G submarine/ROV surveys +/- two standard deviations and model estimates of density with 95% credible intervals from 2,000,000 MCMC iterations.

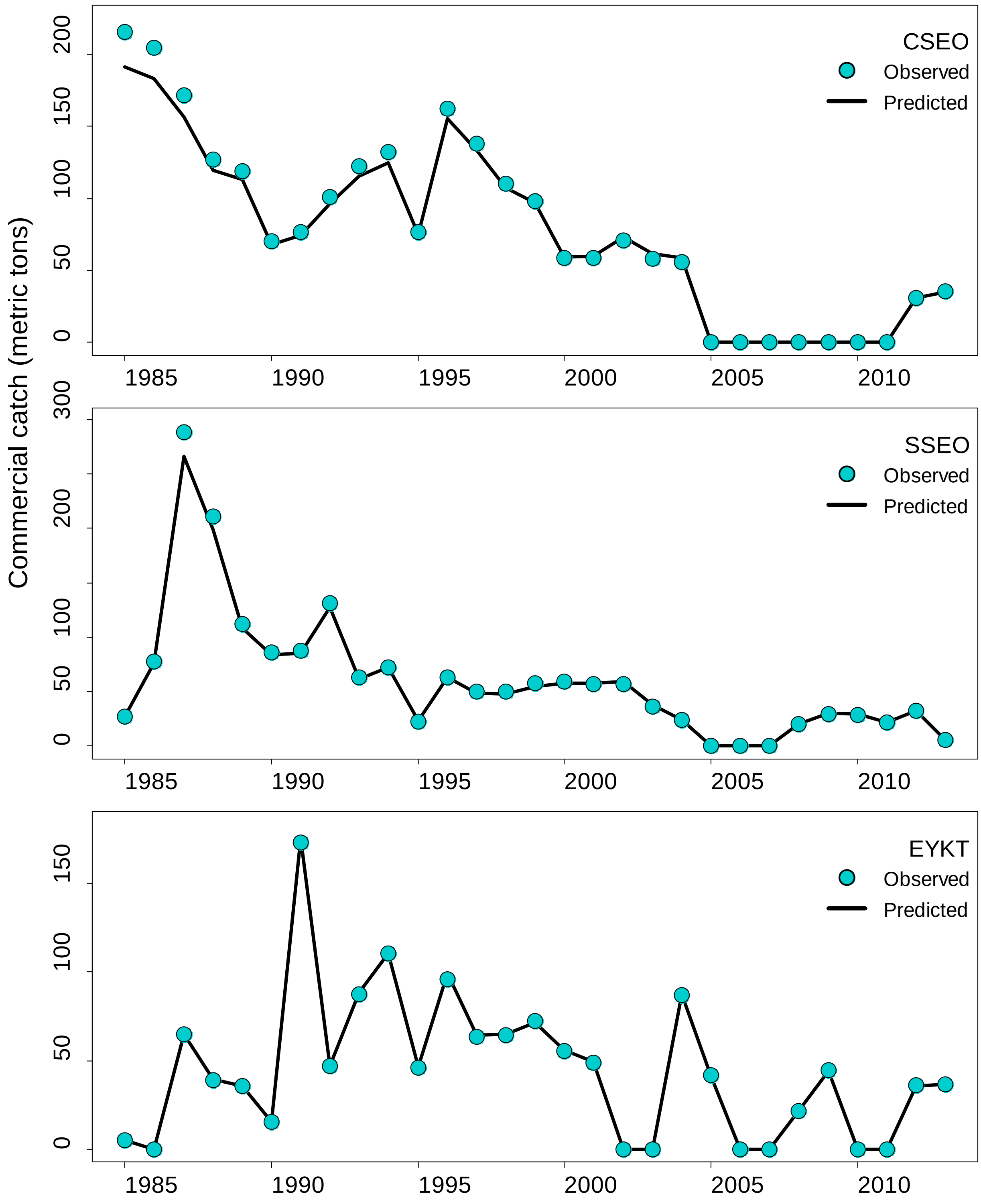

Figure 6. Observed and predicted total annual yelloweye catch from the directed DSR commercial fishery, 1992 - 2013

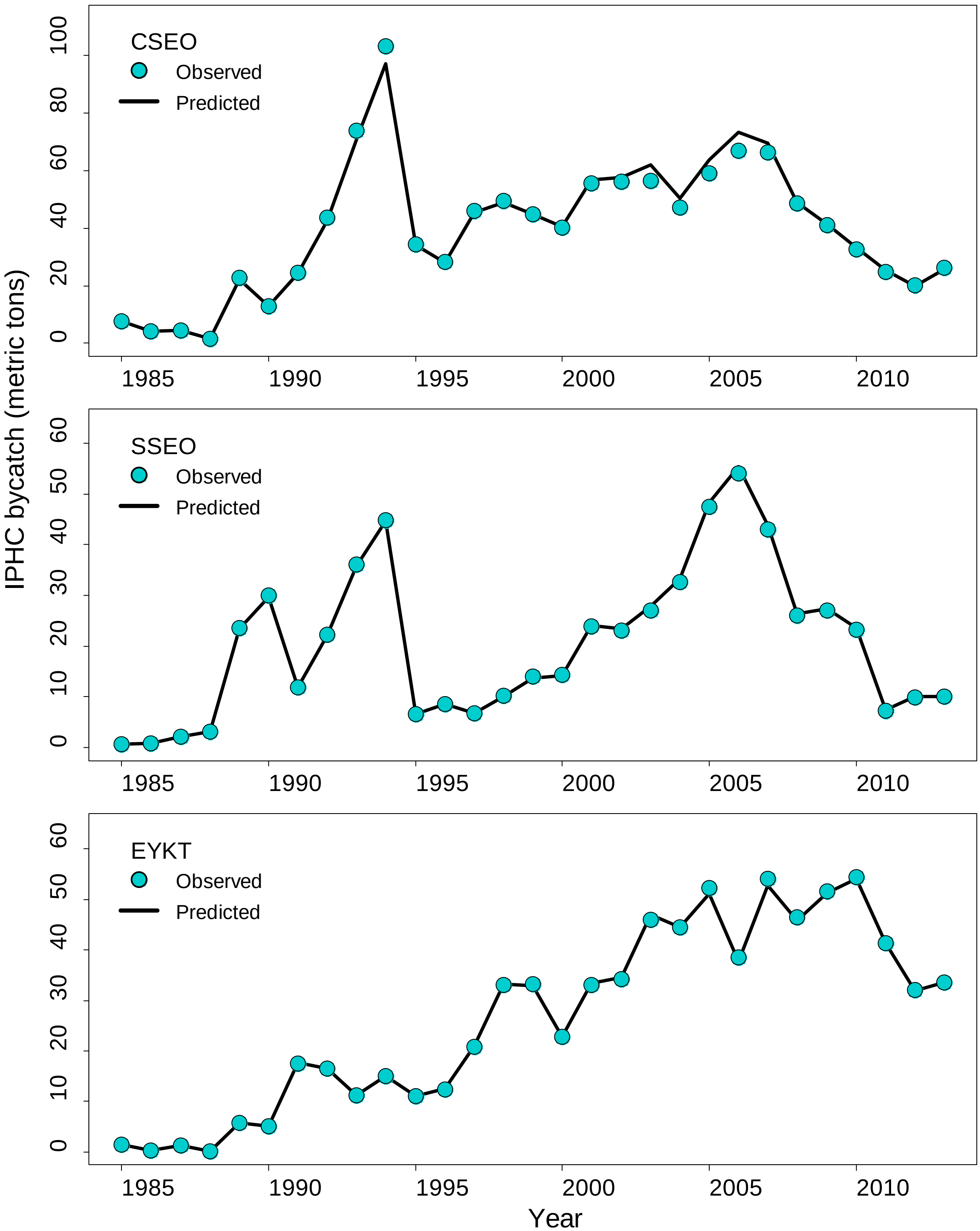

Figure 7. Observed and predicted total annual yelloweye incidental bycatch from the commercial longline halibut fishery, 1992 - 2013

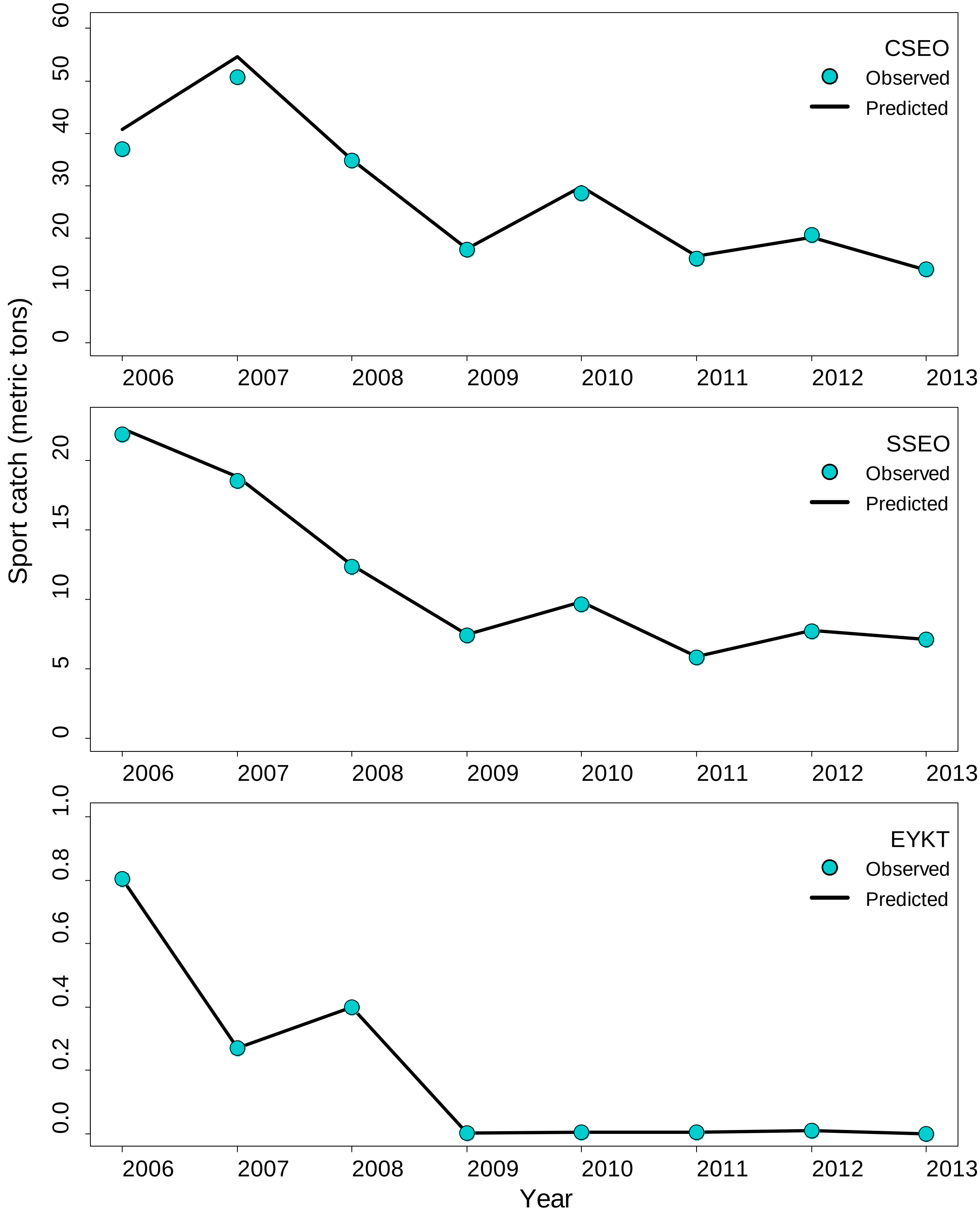

Figure 8. Observed and predicted total annual yelloweye catch from the sport fishery, 1992 - 2013

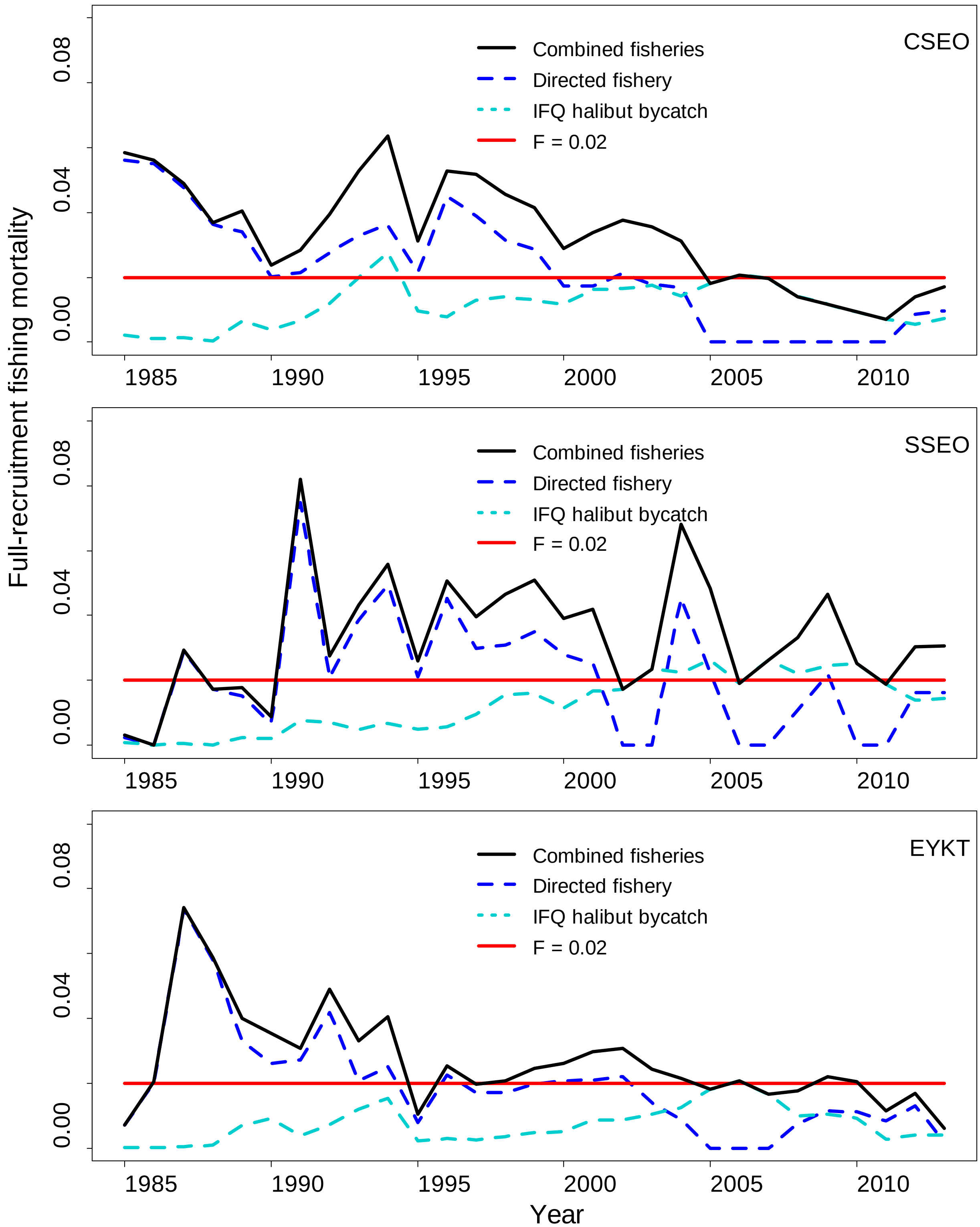

Figure 9. Relative full-recruitment fishing mortality *F* levels from the directed DSR fishery, the commercial halibut longline fishery, combined *F* levels, and a reference *F* = 0.02 value from Tier 4 management guidelines.

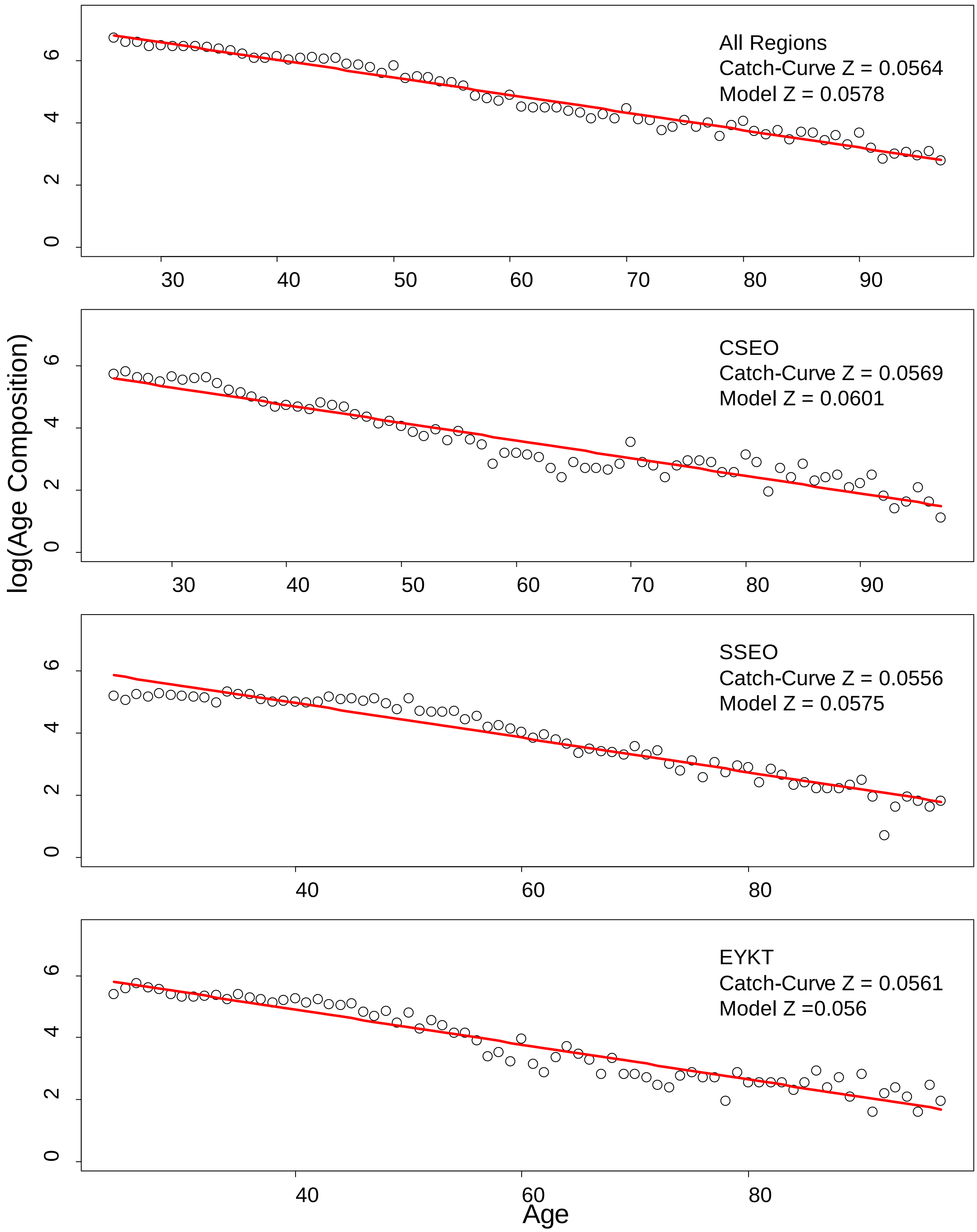

Figure 10. Catch-curve calculations of total mortality *Z* (ages 26 – 90+) compared to model-estimates of total mortality *Z* over all ages for all management areas combined (top panel) and each area individually (lower panels)

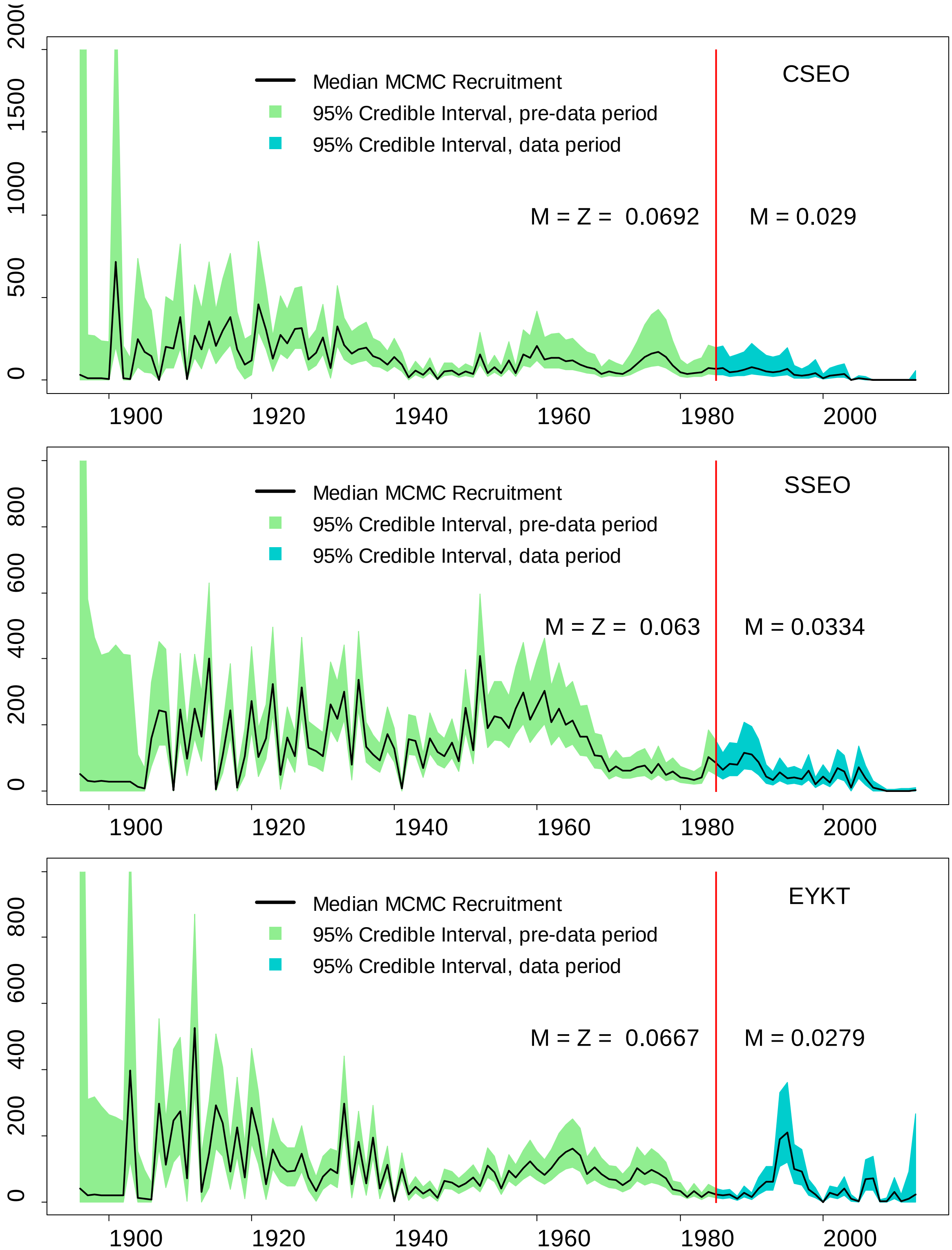

Figure 11. Median recruitment from 1903 – 2013 from 2,000,000 MCMC iterations with 95% credible intervals.

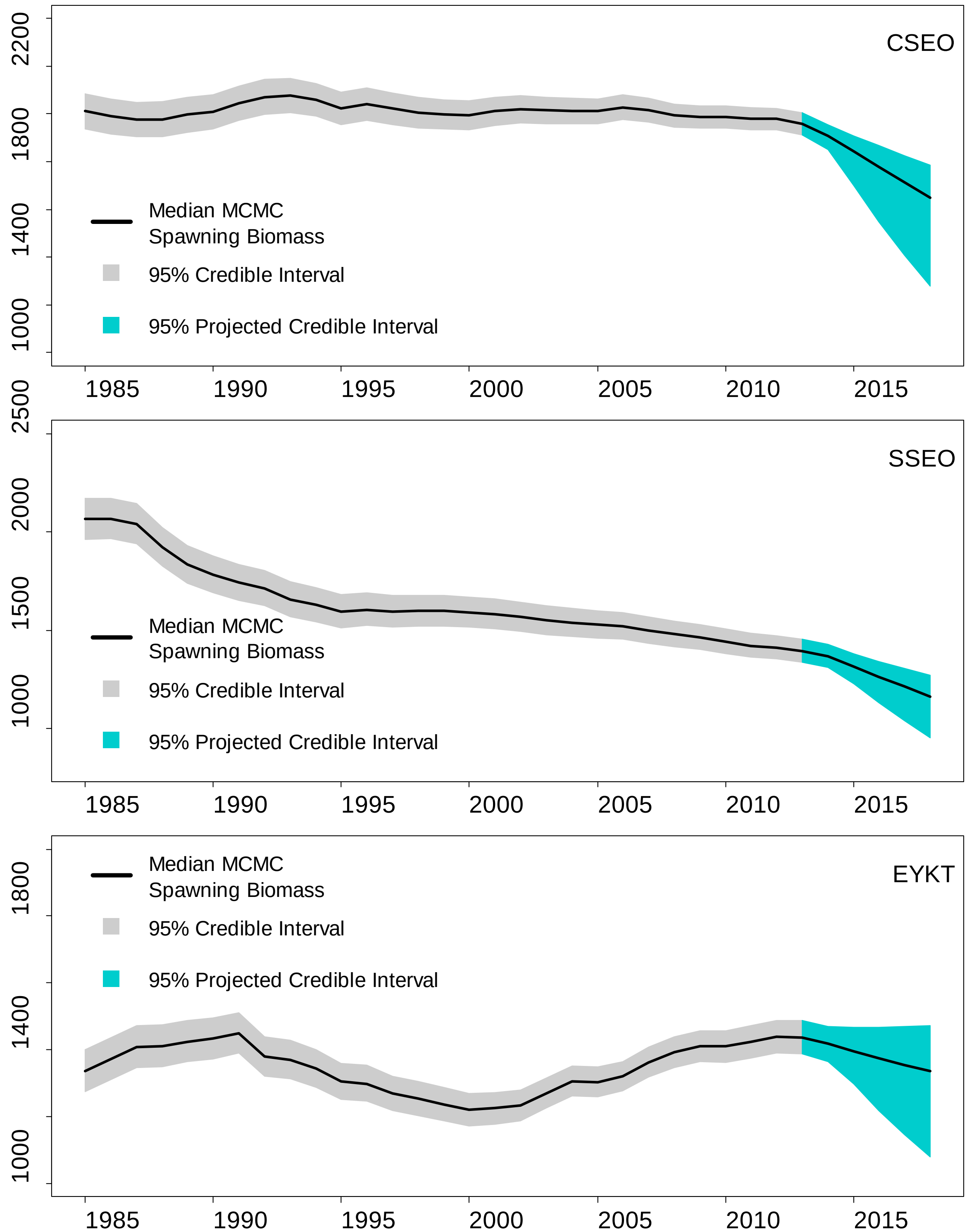

Figure 12. Median spawning biomass 1992 – 2013 and projected to 2018 from 2,000,000 MCMC iterations with 95% credible intervals.

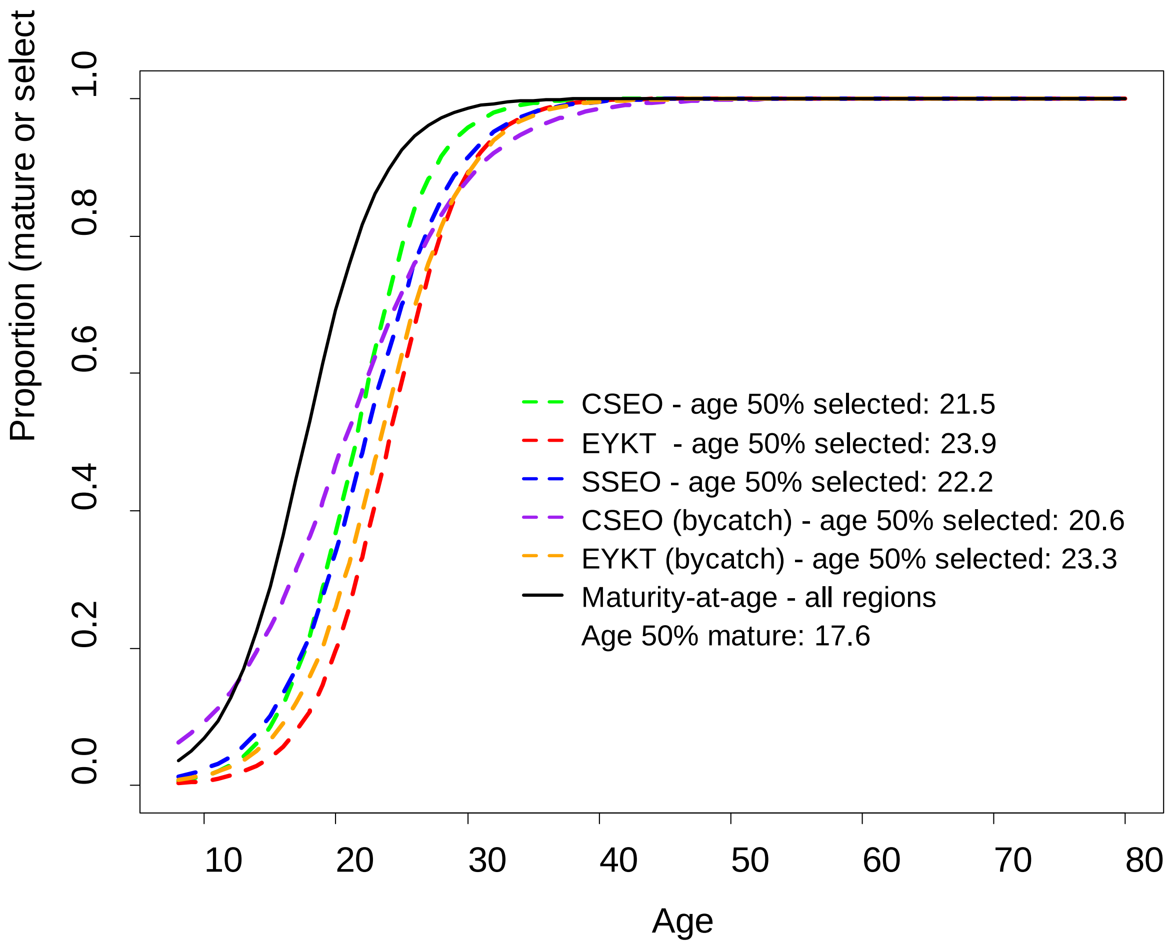

Figure 13. Maturity-at-age relative to selectivity-at-age for all management regions.

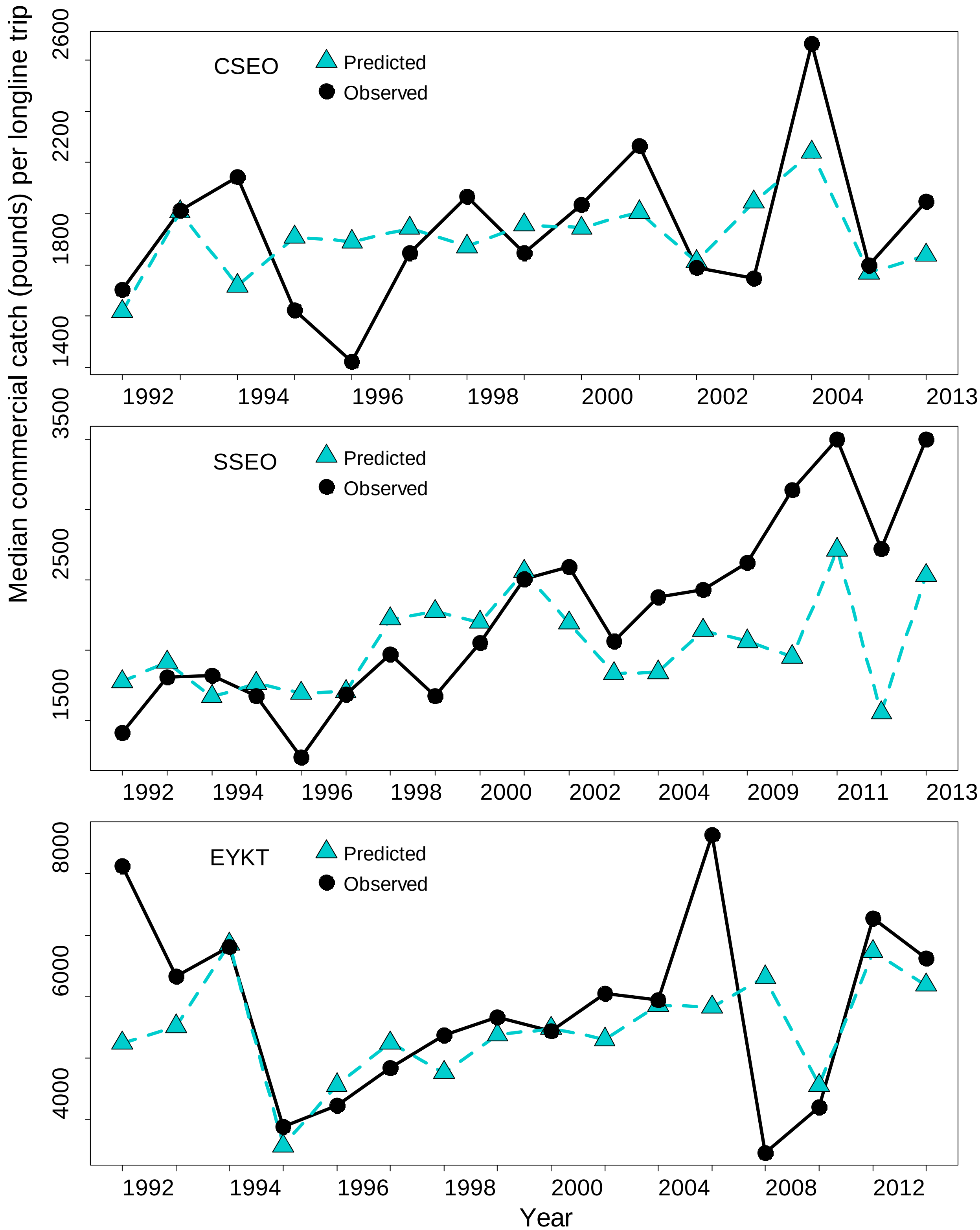

Figure 14. Observed and predicted catch-per-unit-effort for the directed commercial DSR fishery.

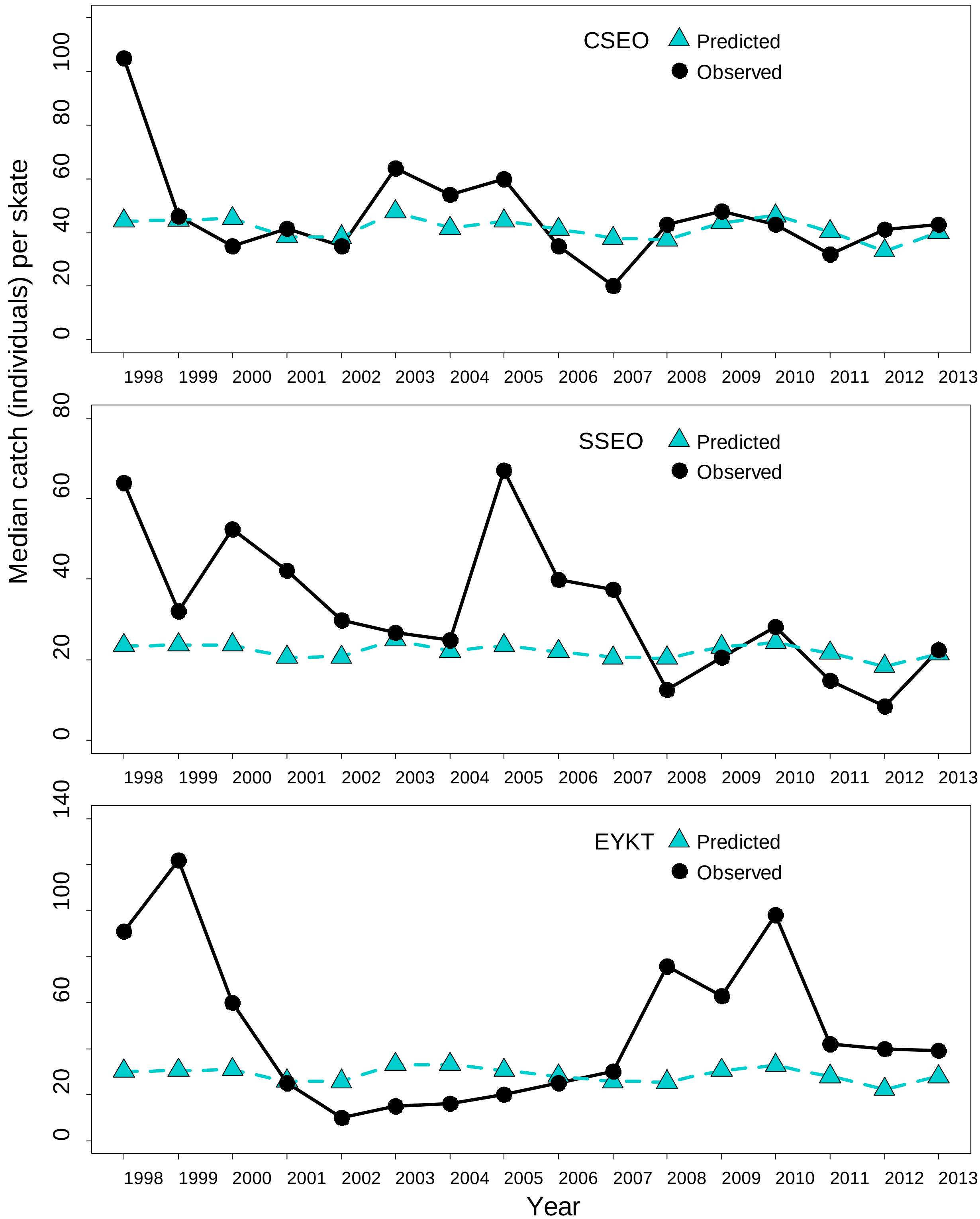

Figure 15. Observed and predicted catch-per-unit-effort from the IPHC longline survey.

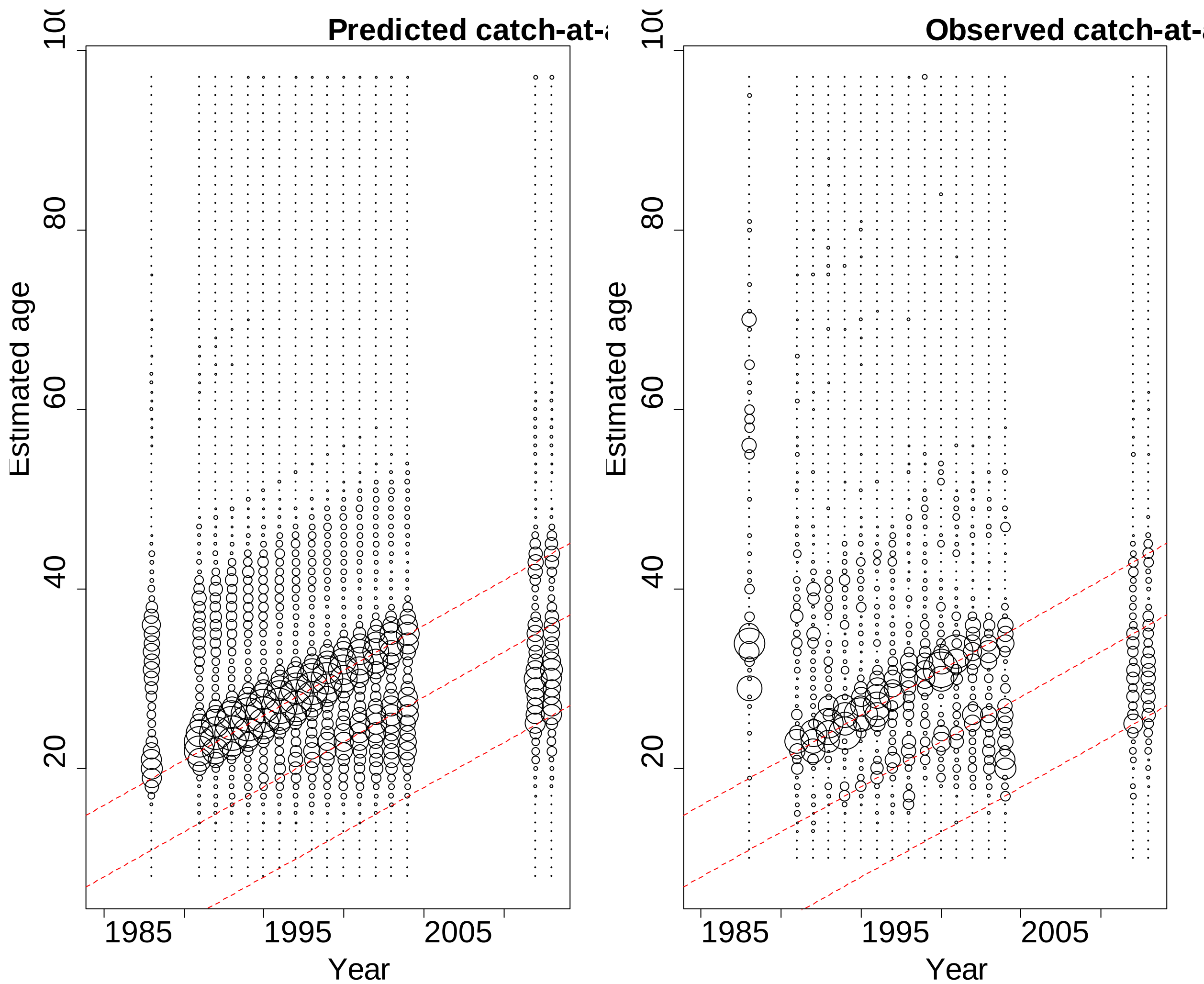

Figure 16. Observed and predicted catch-at-age for the directed commercial DSR fishery in CSEO.

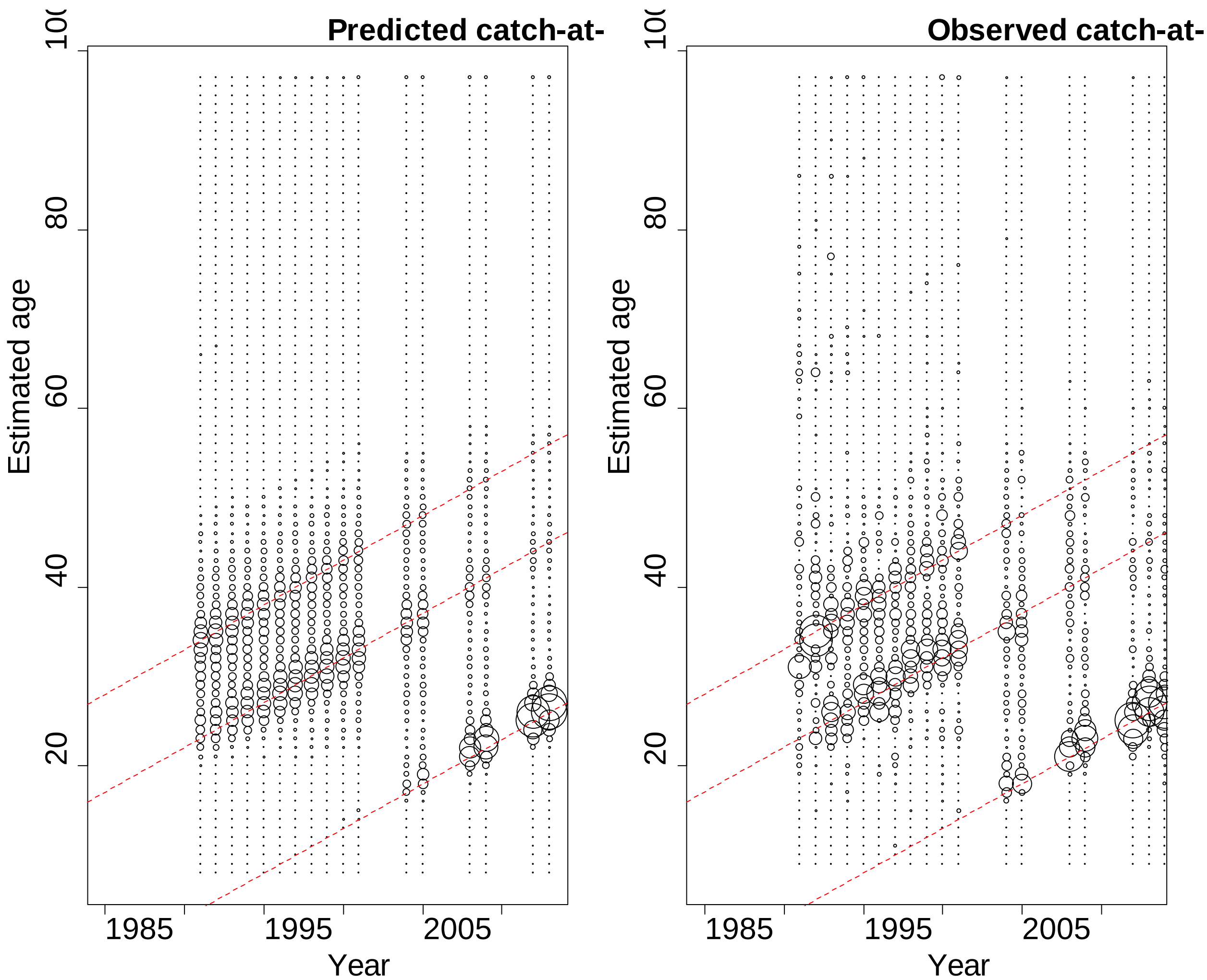

Figure 17. Observed and predicted catch-at-age from the directed commercial DSR fishery in EYKT.

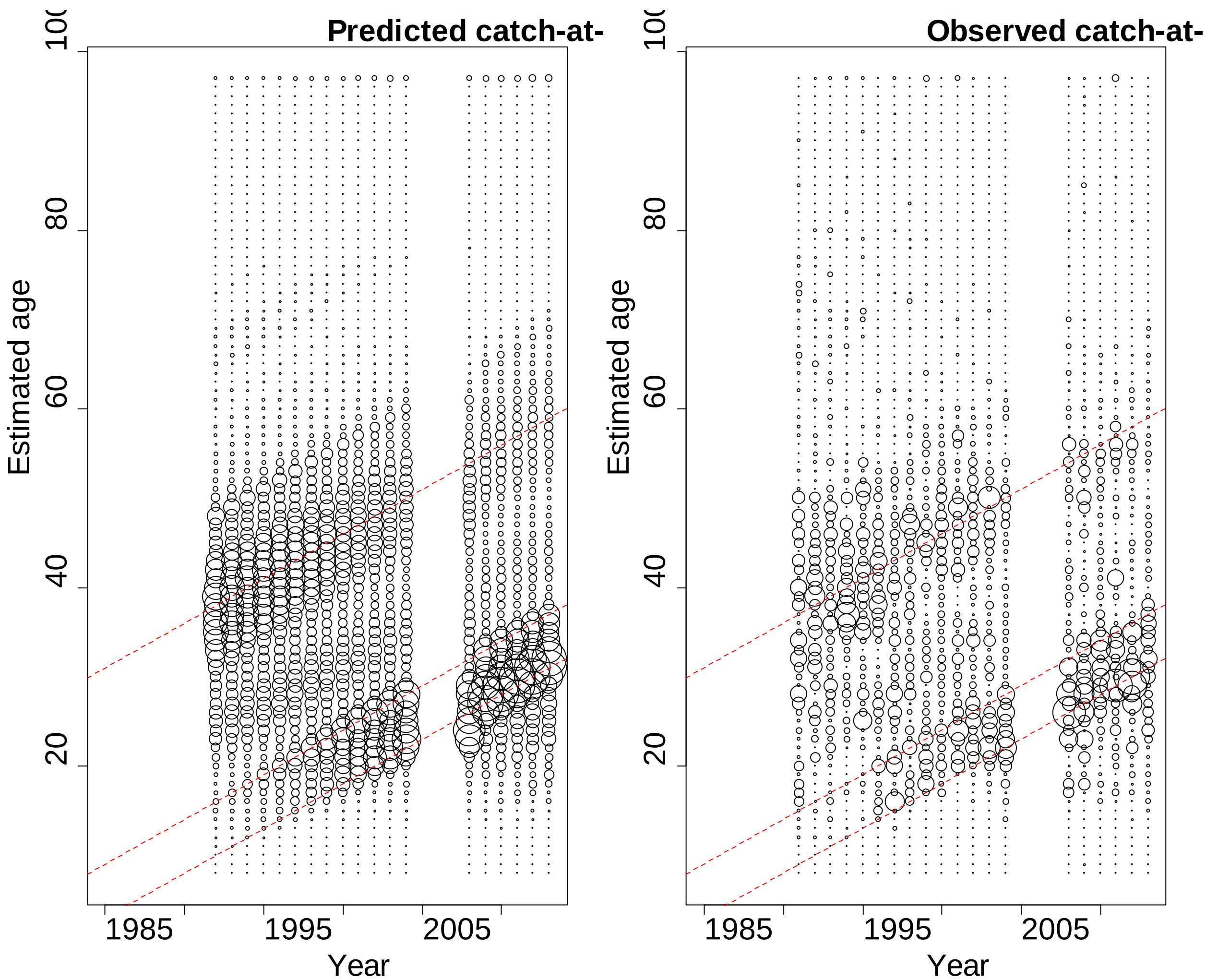

Figure 18. Observed and predicted catch-at-age from the directed commercial DSR fishery in SSEO.

BOX 1: Model parameters and quantities

y	Year
a	Age classes
w_a	Vector of estimated weight-at-age, $a_0 \to a_+$; model input
mat_a	Vector of estimated maturity-at-age, $a_0 \to a_+$; model input
a_0	Age at model recruitment (8)
a_+	Plus class (ages 97+)
μ_r	Mean annual recruitment
μ_f	Mean annual full-recruitment fishing mortality (log)
ϕf_y	Annual fishing mortality deviation for directed DSR fishery
ϕb_y	Annual fishing mortality deviation for commercial halibut incidental catch
ϕs_y	Annual fishing mortality deviation for sport removals
τ_y	Annual recruitment deviation ~ (0, σ_r)
σ_r	Recruitment standard deviation
fs_a	Vector of selectivities-at-age for all fishery removals, $a_0 \to a_+$;
M_a	Natural mortality (1896 – 1984)
M_b	Natural mortality (1985 - 2013)
$F_{y,a}$	Fishing mortality by year y and age a $F_{y,a} = fs_a e^{(\mu_f + \phi f_y + \phi b_y + \phi s_y)}$
$Z_{y,a}$	Total mortality by year y and age a ($Z_{y,a} = F_{y,a} + M$)
$s_{y,a}^{m\_s}$	Survival by year and age at the month m_s of the submarine/ROV survey
$s_{y,a}^{m\_sp}$	Survival by year and age at the spawning month m_sp
$T_{a,a'}$	Aging-error matrix
Z_{1prior}	Prior mean for total mortality 1896 - 1984
Z_{2prior}	Prior mean for total mortality 1985 - 2013
$\mu_{f\ prior}$	Prior mean for mean annual full-recruitment fishing mortality
$\sigma_{r(prior)}$	Prior mean for recruitment variance
$q_{(prior)}$	Prior mean for directed fishery catchability
$q_{iphc(prior)}$	Prior mean for IPHC longline survey catchability
σ^2_{Z1}	Prior CV for total mortality 1896 - 1984
σ^2_{Z2}	Prior CV for total mortality 1985 - 2013
σ^2_r	Prior CV recruitment deviations
σ^2_f	Prior CV for fishing mortality
σ^2_q	Prior CV for directed fishery catchability
$\sigma^2_{q\_iphc}$	Prior CV for IPHC longline survey catchability

BOX 2: Population Dynamics

$\hat{C}_y = \sum_a \frac{N_{y,a} * F_{y,a} * (1 - e^{-Z_{y,a}})}{Z_{y,a}} * w_a$	Catch equation (directed DSR fishery, commercial longline halibut incidental catch, and sport removals)
$\hat{D}_y = \sum_a \frac{N_{y,a} * s_{t,a}^{m\_s} * mat_a}{km^2}$	Survey density (numbers of adults and sub-adults per km^2)
$\hat{P}_{y,a} = \sum_a \left(\frac{\hat{C}_{y,a}}{\sum_a \hat{C}_{y,a}} \right) * T_{a,a'}$	Fishery age composition
$C_y = qE_y^{\alpha+1} N_y^{\beta+1}$	CPUE for the directed DSR fishery, where C = median catch over all sets
$C_{ipch\_y} = q_{iphc} E_{iphc\_y}^{\alpha+1} N_y^{\beta+1}$	CPUE for the IPHC longline survey, where C = median catch over all sets
Start year	
$N_a = \begin{cases} e^{(\mu_r + \tau_{styr})}, & a = a_0 \\ e^{(\mu_r + \tau_{styr+a_0-a})} e^{-(a-a_0)M}, & a_0 < a < a_+ \\ \frac{e^{\mu_r} e^{-(a-a_0)M}}{1-e^{-M}}, & a = a_+ \end{cases}$	Number at age of recruitment (8) Number at ages between recruitment and plus class Number in plus class (97+)
Subsequent years	
$N_a = \begin{cases} e^{(\mu_r + \tau_y)}, & a = a_0 \\ N_{y-1,a-1} * e^{-Z_{y-1,a-1}}, & a_0 < a < a_+ \\ N_{y-1,a-1} * e^{-Z_{y-1,a-1}} + N_{y-1,a} * e^{-Z_{y-1,a}} & a = a_+ \end{cases}$	Number at age of recruitment (8) Number at ages between recruitment and plus class Number in plus class (97+)
$SB_y = \sum_{a=a_0}^{a+} N_{y,a} s_{y,a}^{m\_sp} mat_a w_a / 2$	Annual female spawning biomass

BOX 3: Likelihood components

$L_1 = \lambda_1 \sum_y \left(\ln(C_y + 0.00001) - \ln(\hat{C}_y + 0.0001)\right)^2$	Commercial catch
$L_2 = \lambda_2 \sum_y \left(\ln(C_y + 0.00001) - \ln(\hat{C}_y + 0.0001)\right)^2$	IPHC bycatch
$L_3 = \lambda_3 \sum_y \left(\ln(C_y + 0.00001) - \ln(\hat{C}_y + 0.0001)\right)^2$	Sport catch
$L_4 = \lambda_4 \sum_y \frac{\left(\ln(D_y) - \ln\left(\hat{D}_y\right)\right)^2}{2 * \sigma^2(D_y)}$	Density
$L_5 = \lambda_5 \sum_y \frac{\left(\ln(C_y) - \ln\left(\hat{C}_y\right)\right)^2}{2 * \sigma^2(C_y)}$	Commercial CPUE, where $\hat{C}$ = median catch over all sets
$L_6 = \lambda_6 \sum_y \frac{\left(\ln(C_y) - \ln\left(\hat{C}_y\right)\right)^2}{2 * \sigma^2(C_y)}$	IPHC longline survey CPUE, where $\hat{C}$ = median catch over all sets
$L_7 = \lambda_7 \sum_{styr}^{endyr} - n_y \sum_{a_0}^{a+} \left(P_{y,a} + 0.0001\right) * \ln\left(\hat{P}_{y,a} + 0.0001\right)$	Fishery age composition (n_y = sample size)
$L_8 = \frac{1}{2\sigma_M^2}\left(\ln\left(M / M_{prior}\right)\right)^2$	Penalty on deviation from log-normal prior probability distribution of natural mortality (1896 – 1984)
$L_9 = \frac{1}{2\sigma_M^2}\left(\ln\left(Z / Z_{prior}\right)\right)^2$	Penalty on deviation from log-normal prior probability distribution of total mortality (1985 – 2013)
$L_{10} = \frac{1}{2\sigma_q^2}\left(\ln\left(q / q_{prior}\right)\right)^2$	Penalty on deviation from log-normal prior probability distribution of recruitment deviations
$L_{11} = \frac{1}{2\sigma_{q_{iphc}}^2}\left(\ln\left(q_{iphc} / q_{iphc\ prior}\right)\right)^2$	Penalty on deviation from log-normal prior probability distribution of recruitment deviations
$L_{12} = \frac{1}{2\sigma_F^2}\left(\ln\left(F / F_{prior}\right)\right)^2$	Penalty on deviation from log-normal prior probability distribution of full-recruitment fishing mortality F
$L_{13} = \left(\tau_y / 2\sigma_r^2\right)^2 + \left(n_y * \ln(\sigma_r)\right)$	Penalty on recruitment deviations
$L_{14} = \lambda_{12} \sum_y \varepsilon_y^2$	Fishing mortality regularity penalty
$L_{total} = \sum_{i=1}^{13} L_i$	Total objective function value