15. Assessment of the Thornyhead stock complex in the Gulf of Alaska

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November 2018 Plan Team Draft

Executive Summary

Rockfish have historically been assessed on a biennial stock assessment schedule to coincide with the availability of new trawl survey data (odd years). In 2017, the Alaska Fisheries Science Center (AFSC) participated in a stock assessment prioritization process. It was recommended that the Gulf of Alaska (GOA) thornyhead complex remain on a biennial stock assessment schedule with a full stock assessment produced in even years and no stock assessment produced in odd years. However, we performed a partial stock assessment in 2017 because the allowable biological catch (ABC) has been exceeded in the past in the western GOA, and because the biomass estimates provided by the GOA trawl surveys have at times displayed extreme variability between surveys. We followed the recommendation of the Science and Statistical Committee (SSC) and the GOA Groundfish Plan Team that "partial assessments for Tiers 4-5 should be an expanded version of the current off-year executive summaries, including catch/biomass ratios for all species in addition to re-running the random effects model" (SSC minutes – February 2017).

For this on-cycle year, we incorporate Relative Population Weights (RPWs) from the 1992 - 2018 longline surveys, and update auxiliary data sources.

This stock is classified as a Tier 5 stock. We continue to use a random effects (RE) model fit to survey data to estimate exploitable biomass and determine the recommended ABC, but we present a new method of combining the AFSC longline survey Relative Population Weight (RPW) index (1992 - 2018) with the AFSC bottom trawl survey biomass index (1984 – 2017) within the random effects model. The RE model was fit to the time series of trawl survey biomass values and estimates of uncertainty by region and depth strata and regional RPW indices from the AFSC longline survey (with associated estimates of uncertainty). These regional biomass estimates from the RE model were then summed to obtain Gulfwide biomass.

Summary of Changes in Assessment Inputs

Changes in the input data:

1. Total catch was updated with partial 2018 data through 10 October 2018.
2. Length compositions from the 2016, 2017, and 2018 longline and trawl fisheries were added.
3. Length compositions from the 2017 GOA bottom trawl survey data were added.
4. Relative Population Numbers (RPNs), RPWs, and size compositions from the 2016, 2017, and 2018 AFSC annual longline surveys were updated.
5. RPWs from the 1992 – 2018 GOA longline survey were updated for use in the random effects model.

Changes in assessment methodology:

The methodology used to estimate exploitable biomass to calculate ABC and OFL values for the 2019 fishery has changed. This year, a random effects model, utilizing the bottom trawl survey biomass index from 1984 - 2017 and the AFSC longline survey RPW index from 1992 – 2018, is used. This new

methodology has been requested for Tier 5 species that are assessed with a random effects model that fits estimates of biomass from the AFSC bottom trawl survey and are also sampled by the longline survey.

Summary of Results

For the 2019 fishery, we recommend the maximum allowable ABC of 2,016 t for thornyhead rockfish. This ABC is a decrease of 1.1% from the 2018 ABC of 2,038 t. The OFL is 2,688 t. Reference values for thornyhead rockfish are summarized in the following table, with the recommended ABC and OFL values in bold. The stock was not being subjected to overfishing last year.

Quantity	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
	2018	2019	2019	2020
M (natural mortality rate)	0.03	0.03	0.03	0.03
Tier	5	5	5	5
Biomass (t)	90,570	90,570	89,609	89,609
F_{OFL}	$F=M=0.03$	$F=M=0.03$	$F=M=0.03$	$F=M=0.03$
$maxF_{ABC}$	$0.75M=0.0225$	$0.75M=0.0225$	$0.75M=0.0225$	$0.75M=0.0225$
F_{ABC}	0.0225	0.0225	0.0225	0.0225
OFL (t)	2,717	2,717	**2,688**	2,688
maxABC (t)	2,038	2,038	2,016	2,016
ABC (t)	2,038	2,038	**2,016**	2,016
Status	As determined *last* year for:		As determined *this* year for:	
	2016	2017	2017	2018
Overfishing	No	n/a	No	n/a

Updated catch data (t) for thornyhead rockfish in the GOA as of October 10, 2018 (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	Western	Central	Eastern	Gulfwide Total	Gulfwide ABC	Gulfwide TAC
2017	155	617	250	1,021	1,961	1,961
2018	156	643	310	1,109	2,038	2,038

Area Apportionment

For apportionment of ABC/OFL, the random effects model was fit to area-specific biomass and subsequent proportions of biomass by area were calculated. The following table shows the recommended apportionment, estimated biomass, and ABC value by regulatory area for 2019.

	Regulatory area			
	Western	Central	Eastern	Total
Area Apportionment	16.2%	45.2%	38.6%	
Estimated Area Biomass (t)	14,504	40,481	34,624	89,609
Area ABC (t)	326	911	779	2,016
OFL (t)				2,688

Summaries for Plan Team

All values are in metric tons.

Species	Year	Biomass[1]	OFL	ABC	TAC	Catch[2]
Thornyhead rockfish	2017	87,155	2,615	1,961	1,961	1,021
	2018	90,570	2,717	2,038	2,038	1,109
	2019	89,609	2,688	2,016		
	2020	89,609	2,688	2,016		

Stock/ Assemblage	Area	2018				2019		2020	
		OFL	ABC	TAC	Catch[2]	OFL	ABC	OFL	ABC
Thornyhead rockfish	W		344	344	156		326		326
	C		921	921	643		911		911
	E		773	773	310		779		779
	Total	2,717	2,038	2,038	1,109	2,688	2,016	2,688	2,016

[1] Biomass for 2017 and 2018 was calculated with the random effects model utilizing bottom trawl biomass indices. Biomass for 2019 was calculated with the random effects model utilizing the bottom trawl biomass and the longline survey RPW indices.
[2]Catches updated through October 10, 2018: National Marine Fisheries Service, Alaska Region, Catch Accounting System, accessed via the Alaska Fishery Information Network (AKFIN).

Responses to SSC and Plan Team Comments on Assessments in General

"Secondly, a few assessments incorporate multiple indices that could also be used for apportionment. The Team recommends an evaluation on how best to tailor the RE model to accommodate multiple indices." (Plan Team, November 2015).

In this year's assessment we present and recommend a random effects model that incorporates both the AFSC bottom trawl survey biomass index and the AFSC longline survey RPW index to estimate exploitable biomass and recommend management quantities.

"The Team recommends that a workgoup or subset of authors investigate applying the geostatistical approach to selected stocks." (Plan Team, November 2015)

A working group is currently investigating the geostatistical approach and the results of this evaluation will be applied to the thornyhead complex as appropriate.

"In an effort to improve record keeping as assessment authors formulate various stock status evaluation models, the Plan Team has recommended a systematic cataloging convention. Any new model that diverges substantial from the currently accepted model will be marked with the two-digit year and a "0" version designation (e.g., 16.0 for a model from 2016). Variants that incorporate major changes are then distinguished by incremental increases in the version integer (e.g., 16.1 then 16.2), and minor changes

are identified by the addition of a letter designation (e.g., 16.1a). The SSC recommends this method of model naming and notes that it should reduce confusion and simplify issues associated with tracking model development over time." (SSC December 2016)

Authors have incorporated recommended model naming.

"The SSC recommends that, for those sets of environmental and fisheries observations that support the inference of an impending severe decline in stock biomass, the issue of concern be brought to the SSC, with an integrated analysis of the indices in future stock assessment cycles. To be of greatest value, to the extent possible, this information should be presented at the October Council meeting so that there is sufficient time for the Plan Teams and industry to react to the possible reduction in fishing opportunity." (SSC, October 2017)

To facilitate a coordinated response to this request, the co-chairs and coordinators of the BSAI and GOA Groundfish Plan Teams, with concurrence from stock assessment program leadership at the AFSC, have suggested that authors address it by using the previous year's Ecosystem Status Report (ESR) as follows:

> **"No later than the summer of each year, the lead author of each assessment should review the previous year's ESR and determine whether any factor or set of factors described in that ESR implies an impending severe decline in stock/complex biomass, where "severe decline" means a decline of at least 20% (or any alternative value that may be established by the SSC), and where biomass is measured as spawning biomass for Tiers 1-3 and survey biomass as smoothed by the standard Tier 5 random effects model for Tiers 4-5. If an author determines that an impending severe decline is likely and if that decline was not anticipated in the most recent stock assessment, he or she should summarize that evidence in a document that will be reviewed by the respective Team in September of that year and by the SSC in October of that year, including a description of at least one plausible mechanism linking the factor or set of factors to an impending severe decline in biomass, and also including an estimate or range of estimates regarding likely impacts on ABC. In the event that new survey or relevant ESR data become available after the document is produced but prior to the October Council meeting of that year, the document should be amended to include those data prior to its review by the SSC, and the degree to which they corroborate or refute the predicted severe decline should be noted, with the estimate or range of estimates regarding likely impacts on ABC modified in light of the new data as necessary."**

This suggestion was followed. Authors examined the ESR for evidence of big declines and did not find evidence of any impending severe decline in stock biomass.

"…The SSC also recommends explicit consideration and documentation of ecosystem and stock assessment status for each stock, perhaps following the framework suggested below, during the December Council meeting to aid in identifying areas of concern." (SSC October 2017)

This recommendation was subsequently clarified in the minutes of the December 2017 SSC meeting and then re-clarified in the minutes of the June 2018 SSC meeting. In the interest of efficiency, the clarification from the December 2017 minutes is not included here. The relevant portion of the clarification from the June 2018 minutes reads as follows:

"This request was recently clarified by the SSC by replacing the terms 'ecosystem status' and 'stock assessment status' with 'Ecosystem Status Report information' and 'Stock Assessment Information,'

where the potential determinations for each will consist of 'Okay' and 'Not Okay,' and by issuing the following guidance:

• The SSC clarifies that 'stock assessment status' is a fundamental requirement of the SAFEs and is not really very useful to this exercise, because virtually all stocks are never overfished nor is overfishing occurring.
• Rather the SSC suggests that recent trends in recruitment and stock abundance could indicate warning signs well before a critical official status determination is reached. It may also be useful to consider some sort of ratio of how close a stock is to a limit or target reference point (e.g., B/B35). Thus, additional results for the stock assessments will need to be considered to make the 'Okay' or 'Not Okay' determinations.
• The SSC retracts its previous request for development of an ecosystem status for each stock/complex. Instead, while considering ecosystem status report information, it may be useful to attempt to develop thresholds for action concerning broad-scale ecosystem changes that are likely to impact multiple stocks/complexes.
• Implementation of these stock and ecosystem determinations will be an iterative process and will require a dialogue between the stock assessment authors, Plan Teams, ecosystem modelers, ESR editors, and the SSC."

"The SSC recognized that because formal criteria for these categorizations have not been developed by the PT, they will not be presented in December 2018." (SSC October 2018)

The iterative process described in the final bullet above was scheduled to begin at this year's September meeting of the Joint BSAI and GOA Plan Teams. However, no formal criteria for these categorizations were developed by the Plan Teams. We will provide determinations for the thornyhead complex when these formal criteria are established.

"Stock assessment authors are encouraged to work with ESR analysts to identify a small subset of indicators prior to analysis, and preferably based on mechanistic hypotheses." (SSC October 2018)

No indicators were presented in the GOA 2017 Ecosystem Status Report concerning thornyhead species. Observations from 2017 surveys targeting YOY fish in the EGOA and inside archipelago waters of northern southeast Alaska indicated low productivity of groundfish. Authors will further examine this in the next full assessment.

Responses to SSC and Plan Team Comments Specific to this Assessment

"The PT noted the high discard rates for thornyheads over the last four years and requested the author investigate these. The PT also recommended that the author examine the tagging data. The SSC concurs with these suggestions." (SSC, December 2015)

Discard rates for thornyheads are examined in the Catch History-Discard section. A review of the thornyhead rockfish tagging data was included as an appendix to the 2017 Executive Summary and published in Echave (2017).

"*High rates of discards appear to have occurred in some recent years (e.g., 41% in 2013). The Team requests the authors investigate the reasons for these high discard rates* (GOA Plan Team, November 2015)."

Discard rates for thornyheads are examined in the Catch History-Discard section.

"The SSC supports the author's plan to explore the feasibility of incorporating longline survey abundance indices for use in estimating biological reference points and possibly area apportionments. If the longline survey is added to the assessment, the SSC and the PT notes that methods will need to be developed to estimate area apportionments for assessments that utilize more than one survey." (SSC, December 2015)

In this year's assessment we present and recommend a random effects model that incorporates both the AFSC bottom trawl survey biomass index and the AFSC longline survey RPW index to estimate exploitable biomass and recommend management quantities. We also incorporate the longline survey index to be used with the trawl survey biomass index in such a manner that it is directly influential on apportionment. This method can be easily extended to other Tier 5 species as well as Tier 3 species that use multiple population indices.

"The assessor presented a new method to combine the AFSC longline survey Relative Population Weight (RPW) index with the AFSC bottom trawl survey biomass index within the random effects model. Preliminary results based on this method appear promising and therefore, the SSC agrees with the CPT that the combined index should be brought forward for consideration in this assessment cycle. Additionally, it was noted that while observers have been collecting otoliths from as many as 500 thornyheads annually in the GOA, reading these otoliths has not been a priority. The SSC supports the PT's recommendation to process these otoliths in a timely manner such that an age-structured model can be incorporated into future assessments." (SSC, October 2018)

In this year's assessment we present and recommend a random effects model that incorporates both the AFSC bottom trawl survey biomass index and the AFSC longline survey RPW index to estimate exploitable biomass and recommend management quantities. Authors agree that ageing thornyheads is a high priority, however, ageing this species has not been possible to date. The Alaska Department of Fish and Game has been making progress on thornyhead ageing and has ages for the central region of Alaska as well as bomb carbon specimens to do a Prince William Sound validation. We will continue to monitor this process and pursue an age-structured model once accurate age data is available.

Introduction

Thornyheads (*Sebastolobus* species) are groundfish belonging to the family Scorpaenidae, which contains the rockfishes. The family Scorpaenidae is characterized morphologically within the order by venomous dorsal, anal, and pelvic spines, numerous spines in general, and internal fertilization of eggs. While thornyheads are considered rockfish, they are distinguished from the "true" rockfish in the genus *Sebaste*s primarily by reproductive biology; all *Sebastes* rockfish are live-bearing (ovoviviparous) fish, while thornyheads are oviparous, releasing fertilized eggs in floating gelatinous masses. Thornyheads are also differentiated from *Sebastes* in that they lack a swim bladder. There are three species in the genus *Sebastolobus*, including the shortspine thornyhead *Sebastolobus alascanus*, the longspine thornyhead *Sebastolobus altivelis*, and the broadfin thornyhead *Sebastolobus macrochir* (Eschmeyer *et al.* 1983, Love *et al.* 2002).

General Distribution

Thornyheads are distributed in deep water habitats throughout the north Pacific, although juveniles can be found in shallower habitats. The range of the shortspine thornyhead extends from 17 to 1,524 m in depth and along the Pacific Rim from the Seas of Okhotsk and Japan in the western north Pacific, throughout the Aleutian Islands, Bering Sea, Gulf of Alaska, and south to Baja California in the eastern north Pacific (Love *et al.* 2005). Shortspine thornyheads are considered most abundant from the Northern Kuril Islands to southern California. They are concentrated between 150 and 450 m depth in cooler northern waters, and are generally found in deeper habitats up to 1,000 m in the warmer waters of this range (Love *et al.* 2002).

The longspine thornyhead is found only in the eastern north Pacific, where it ranges from the Shumagin Islands in the Gulf of Alaska south to Baja California. Longspine thornyheads are generally found in deeper habitats ranging from 201-1,756 m (Love *et al.* 2005). They are most commonly found below 500 m throughout their range. Off the California coast, longspine thornyheads are a dominant species in the 500-1,000 m depth range, which is also a zone of minimal oxygen (Love *et al.* 2002).

The broadfin thornyhead is found almost entirely in the western north Pacific, ranging from the Seas of Okhotsk and Japan into the Aleutian Islands and eastern Bering Sea. The depth range of the broadfin thornyhead, 100-1,504 m, is similar to that of the shortspine thornyhead. The broadfin thornyhead is relatively uncommon in the eastern north Pacific, and some researchers believe that historical records of this species from the Bering Sea may have been misidentified shortspine thornyheads.

Life History Information

Shortspine thornyhead spawning takes place in the late spring and early summer, between April and July in the Gulf of Alaska and between December and May along the U.S. west coast. It is unknown when longspine thornyheads spawn in the Alaskan portion of their range, although they are reported to spawn between January and April on the U.S. West coast (Pearson and Gunderson 2003). Unlike rockfish in the genus *Sebastes*, which retain fertilized eggs internally and release hatched, fully developed larvae, thornyheads spawn a bi-lobed mass of fertilized eggs which floats in the water column (Love *et al.* 2002). Once the pelagic egg masses hatch, larval and juvenile thornyheads spend far more time in a pelagic life stage than the young of year rockfish in the genus *Sebastes* (Love *et al.* 2002). Shortspine thornyhead juveniles spend 14-15 months in a pelagic phase, and longspine thornyhead juveniles are pelagic even longer, with up to 20 months passing before they settle into benthic habitat. While shortspine thornyhead juveniles tend to settle into relatively shallow benthic habitats between 100 and 600 m and then migrate deeper as they grow, longspine thornyhead juveniles settle out into adult longspine habitat depths of 600 to 1,200 m.

Once in benthic habitats, both shortspine and longspine thornyheads associate with muddy/hard substrates, sometimes near rocks or gravel, and distribute themselves relatively evenly across this habitat, appearing to prefer minimal interactions with individuals of the same species. Research focusing on non-trawlable habitats found rockfish species often associate with biogenic structure (seafloor relief; Du Preez and Tunnicliffe 2011, Laman *et al.* 2015), and that thornyhead rockfish are often found in both trawlable and untrawlable habitats (Rooper and Martin 2012, Rooper *et al*. 2012). Several of these studies are notable as results indicate adult thornyhead biomass may be underestimated by traditional bottom trawl surveys because of issues with extrapolating survey catch estimates to untrawlable habitat (Jones *et al*. 2012; Rooper *et al.* 2012). Mean abundance of shortspine thornyheads estimated in submersible surveys were several times higher than those estimated from trawl surveys (Else *et al.* 2002). They have very sedentary habits and are most often observed resting on the bottom in small depressions, especially longspine thornyheads, which occupy a zone of minimal oxygen at their preferred depths (Love *et al.* 2002).

Like all rockfish, thornyheads are generally longer lived than most other commercially exploited groundfish. Both shortspine and longspine thornyheads are long-lived, relatively slow-growing fishes, but shortspines appear to have the greater longevity. Shortspine thornyheads may live 80-100 years with the larger-growing females reaching sizes up to 80 cm fork length (Love *et al*. 2002). Longspine thornyheads are generally smaller, reaching maximum sizes less than 40 cm and maximum ages of at least 45 years (Love *et al*. 2002).

Prey and Predators

Diets of shortspine thornyheads are derived from food habits collections taken in conjunction with Gulf of Alaska (GOA) trawl surveys. Over 70% of adult shortspine thornyhead diet measured in the early 1990s was shrimp, including both commercial (Pandalid) shrimp and non-commercial (NP or Non-Pandalid shrimp) in equal proportions. Other important prey of shortspine thornyheads include crabs, zooplankton, amphipods, and other benthic invertebrates. Juvenile thornyheads have diets similar to adults, but in general prey more on invertebrates.

Shortspine thornyheads are consumed by a variety of piscivores, including arrowtooth flounder, sablefish, “toothed whales” (sperm whales), and sharks. Although, thornyheads are not a common prey item for these predators and make up less than 2% of their diets in the GOA. Juvenile shortspine thornyheads are thought to be consumed almost exclusively by adult thornyheads.

Evidence of Stock Structure

Population structure of longspine thornyheads has not been studied in Alaska. Longspine thornyheads are not the target of a directed fishery in the GOA but are the target of directed fisheries off the U.S. west coast where they are managed separately from shortspine thornyheads (e.g., Fay 2005). They have not been explicitly managed in the GOA to date.

Population genetics, phylogeography, and systematics of thornyheads were discussed by Stepien *et al.* (2000). Genetic variation using mtDNA was analyzed for shortspine thornyheads from seven sites off the west coast, but only included one Alaska site off Seward. Longspine thornyheads were sampled from five sites off the Washington-Oregon-California coast, and a single site off Abashiri, Japan was sampled for broadfin thornyheads. Significant population structure was found in this study that was previously undetected with allozymes (Siebenaller 1978). Gene flow was substantial among some locations and diverged significantly in other locations. Significant genetic differences among some sampling sites for shortspine and longspine thornyheads indicated barriers to gene flow. Genetic divergences among sampling sites for shortspine thornyheads indicated an isolation-by-geographic-distance pattern. In contrast, population genetic divergences of longspine thornyheads were unrelated to geographic distances and suggested larval retention in currents and gyres (Pearcy *et al.* 1977, Stepien *et al.* 2000). Differences in geographic genetic patterns between the species are attributed to movement patterns as juveniles and adults. While not a part of this complex, another *Sebastolobus* species, the broadbanded thornyhead, was part of an age and population genetic structure study in North Japan (Sakaguchi *et al.* 2014). While significant differences in body size (growth) was detected between certain year classes off the Pacific coast of Tohoku and off Abashiri, the Sea of Okhotsk, Japan, it appears that broadbanded do not migrate extensively after settlement and subsist on food within the settled environment. At the same time, no genetic isolation was observed between the populations at the two sites. Sakaguchi *et al.* (2014) concluded that it was highly likely that its pelagic eggs, larvae and juveniles widely disperse and migrate before settlement.

The National Marine Fisheries Service (NMFS) Auke Bay Laboratory (ABL) has released 15,512 tagged shortspine thornyhead in Alaska waters since 1992, and 265 of those fish have been recovered by members of the fishing industry (to date). A review of this tagging data show that the majority of tagged shortspines show little to no movement: 19% traveled < 2 nautical miles (nm) between tagging and recovery location, 36% traveled 2 – 5 nm, 18% traveled 6 - 10 nm, 12% traveled 11 – 50 nm, 4% traveled 51 – 100 nm, and 11% traveled >100 nm (Echave 2017). The amount of movement varied by tagging location, as did the direction of movement. However, there was no significant difference in movement by fish size and all fish included in the analysis were assumed mature. The majority of fish that moved generally traveled east/southeast, and fish that were tagged and released in the Eastern GOA were more inclined to move than fish from other areas. These regional differences in recapture patterns may highlight an actual propensity for movement from the Eastern GOA, or reflect geographic differences in fishing effort, particularly at depth. Shortspine thornyhead released in the Eastern GOA displayed the most movement. Of the 102 recoveries that were released in the Eastern GOA, 76% remained within the Eastern GOA, 18% were recovered in British Columbia, Canada (BC), 5% were recovered in the Central GOA, and 1% were recovered on the West Coast (WC). Overall, the majority of recovered shortspine thornyhead remained within their management area of release, and very near their actual release location. While a small percentage of tagged shortspine thornyhead traveled large distances, at times crossing management and international boundaries, the low movement rate coupled with an isolation-by-geographic-distance pattern (Siebenaller 1978), indicate that the current scale of management of using at least sub-areas in Alaska is appropriate. When defining the stock structure of shortspine thornyhead in Alaska waters, one may conclude that this species displays little movement, but that large movements are possible (Echave 2017).

Fishery

Fishery History

Shortspine thornyheads are abundant throughout the GOA and are commonly taken by bottom trawls and longline gear. In the past, this species was seldom the target of a directed fishery. Thornyheads have probably been caught in the northeastern Pacific Ocean since the late 19th century, when commercial trawling by U.S. and Canadian fishermen began. In the mid-1960s Soviet fleets arrived in the eastern GOA (Chitwood 1969), where they were soon joined by vessels from Japan and the Republic of Korea. These fleets represented the first directed exploitation of GOA rockfish resources, primarily Pacific ocean perch (*Sebastes alutus*), and likely resulted in the first substantial catches of thornyheads as well. Today, thornyheads are one of the most valuable of the rockfish species, with most of the domestic harvest exported to Japan. Despite their high value, they are still managed as a “bycatch only” fishery in the GOA because they are nearly always taken in fisheries directed at sablefish (*Anoplopma fimbria*) and other rockfish (*Sebastes spp*.). The incidental catch of shortspine thornyheads in these fisheries has been sufficient to capture a substantial portion of the thornyhead quota established in recent years, so directed fishing on shortspine thornyheads exclusively is not permitted. Although the thornyhead fishery is managed operationally as a “bycatch” fishery, the high value and desirability of shortspine thornyheads means they are still considered a “target” species for the purposes of management.

In 2007, the Central Gulf of Alaska Rockfish Pilot Program was implemented to enhance resource conservation and improve economic efficiency for harvesters and processors who participate in the Central GOA rockfish fishery. In 2012 this pilot program was permanently put in to place as the Central Gulf of Alaska Rockfish Program. This is a rationalization program that established cooperatives among trawl vessels and processors which receive exclusive harvest privileges for rockfish species. The primary rockfish management groups are northern, Pacific ocean perch, and dusky rockfish. Thornyhead rockfish are a secondary species that has an allocation of quota share which can be caught while fishing for the primary management groups. Effects of this program on the primary rockfish groups include: 1) extended fishing season lasting from May 1 – November 15, 2) changes in spatial distribution of fishing effort within the Central GOA, 3) improved at-sea and plant observer coverage for vessels participating in the rockfish fishery, and 4) a greater potential to harvest 100% of the TAC in the Central GOA region. Many of the effects on the primary rockfish groups will also affect the secondary species groups. Future analyses regarding the Rockfish Program and the effects on thornyhead will be possible as more data become available.

Management Measures and History

After passage of the Fishery Conservation and Management Act (FCMA) in 1977, thornyheads were placed in the rockfish management group which contained all species of rockfish except Pacific ocean perch (Berger *et al.* 1986). In 1979, thornyhead rockfish were removed from the rockfish group and placed in the "other fish" group. Thornyhead rockfish became a reported species group in 1980. For the Gulf of Alaska, the "thornyheads" management unit is currently a species complex which includes shortspine thornyhead, longspine thornyhead and broadfin thornyhead. The broadfin thornyhead is currently believed to be extremely unlikely to stray into the Gulf of Alaska and is very uncommon even in the Aleutian Islands and eastern Bering Sea. Therefore, it would be reasonable for management to exclude the broadfin thornyhead from consideration within the Gulf of Alaska thornyhead species complex. Longspine thornyheads do occur in the Gulf of Alaska but are much less common than the shortspine thornyheads and are found much deeper. Because longspine thornyheads are infrequently encountered in the GOA trawl surveys and fisheries, and the GOA thornyheads assemblage is overwhelmingly dominated in biomass and catch by the shortspine thornyhead, the historical single species focus of this assessment and harvest recommendations have been for shortspine thornyheads. However, since 1995, the assessment has provided information on longspine thornyheads from GOA trawl surveys and fishery sampling to help determine whether they should be explicitly considered along with shortspine thornyheads for harvest recommendations in future assessments. The rest of this document will refer to either shortspine or longspine thornyheads explicitly and will ignore broadfin thornyheads because they do not occur in the Gulf of Alaska.

All shortspine thornyheads in the Gulf of Alaska have been managed as a single stock since 1980 (Ianelli and Ito 1995, Ianelli *et al.*1997). In practice, the NPFMC apportions the ABCs and TACs for thornyhead rockfish in the GOA into three geographic management areas: the Western, Central, and Eastern Gulf of Alaska. This apportionment is to disperse the catch across the Gulf and prevent possible depletion in one area. Separate management has been applied to shortspine thornyheads on the U.S. west coast (e.g., Hamel 2005), and Bering Sea and Aleutian Islands (BSAI) shortspine thornyheads are managed as a separate stock from GOA thornyheads. In the BSAI FMP, all thornyhead species are managed within the "Other rockfish" species complex (Reuter and Spencer 2006).

A timeline of management measures that have affected thornyhead rockfish, along with the corresponding gulfwide annual catch and ABC/TAC levels are listed Table 15-1.

Catch History

The earliest available records of thornyhead catch begin in 1967, as published in French *et al.* (1977). Rockfish catch peaked in 1965 when foreign fleets occupied Alaska waters, with nearly 350,000 metric tons removed (Ito 1982). However, records of catch and bycatch from this fishery were insufficient for precise estimation of historical catch for thornyheads. Active data collection began as part of the U.S. Foreign Fisheries Observer Program in 1977, when the thornyhead catch in the GOA was estimated at 1,317 t. Catch estimates from 1977-1980 are based on the following reports: Wall *et al.* (1978, 1979, 1980, and 1981). Beginning in 1983, the observer program also estimated the catches of thornyheads in joint venture fisheries where U.S. catcher vessels delivered catch to foreign processor vessels, and beginning in 1984, thornyheads were identified as a separate entity in the U.S. domestic catch statistics. Data from 1981 to 1989 are based on reported domestic landings extracted from the Pacific Fishery Information Network (PacFIN) database and the reported foreign catch from the NMFS Observer Program. Catches for the years 1990-2002 are based on "blended" fishery observer and industry sources using an algorithm developed by the NMFS Alaska Regional Office (AKRO). Catches for 2003-2018 were provided by NMFS Regional Office Catch Accounting System (CAS) and accessed through the Alaska Fishery Information Network (AKFIN) database. Previous catch and discard estimates for 2003-2009 included catches and discards from fisheries prosecuted in state of Alaska waters (Lowe and Ianelli 2009). These data were removed from the thornyhead rockfish assessment in 2011 and are no longer included in the reported catch estimates.

Catch trends for GOA thornyheads appear to result mainly from management actions rather than from thornyhead stock fluctuations. Thornyhead catches averaged 1,090 tons between 1977 and 1983 in the GOA (Table 15-1). The greatest foreign-reported harvest activities for thornyheads in the GOA occurred during the period 1979-83. The catches of thornyheads in the GOA declined markedly in 1984 and 1985, primarily due to restrictions on foreign fisheries imposed by U.S. management policies. In 1985, the U.S. domestic catch surpassed the foreign catch for the first time. U.S. catches of thornyheads continued to increase, reaching a peak in 1989 with a total removal of 2,616 t. Catches averaged about 1,220 t for the period 1990 through 2003. Thornyhead catch over time indicates most is retained (83% since 2005) and since the late 1980s the distribution of catch being mostly from trawlers has shifted to mostly longline gear (61% for 2005-2018; Table 15-2). Recent catches (2013 to the present) have averaged around 1,095 tons (Table 15-1). This increase appears to be due to an increase in thornyhead catches in the sablefish, rockfish, and Other (primarily Pollock) fisheries (Table 15-3).

Historically, except for the years 1992 to 1994, thornyhead total catch has been less than the Allowable Biological Catch (ABC) and Total Allowable Catch (TAC, Table 15-1). The high (relative to the TAC) thornyhead catches in 1992 to1994 are attributed to high discards in the sablefish longline fishery during the years preceding the implementation of IFQs for sablefish in 1995. From 1980 to 1990, the ABCs and TACs were set at the estimate of maximum sustainable yield for thornyheads which was determined to be 3.8% of the 1987 estimated GOA biomass. The drop in ABC/TAC in 1991 was in response to a large decrease in estimated biomass from the GOA trawl survey. Since 2000, the NPFMC has set relatively low TACs for GOA thornyheads due to uncertainty in assessment model results which suggested that higher quotas would be sustainable. The assessment model uncertainty resulted from inadequate age and growth information and low levels of biological sampling from the fisheries. Therefore in 2003, the use of the assessment model was suspended. The Tier 5 biomass-based approach to calculating ABC and OFL, which was initiated in 2003, results in more conservative ABCs and OFLs. Even with this relative conservatism in recent thornyhead management, fisheries do not appear to be constrained by small TACs for thornyheads.

Catches by management area for 2005-2018 are given in Table 15-1. Over this time period, about 50% of the total Gulf thornyhead catch comes from the Central Gulf, 25% from the Western Gulf, and 25% from the Eastern Gulf. The distribution of thornyhead catches ranges broadly throughout the GOA and is consistent over recent years for the different gear types (Figure 15-1, Lowe and Ianelli 2009).

Survey research catches of all thornyhead species are a very small component of overall removals and recreational and other catches are assumed negligible. Estimates of non-commercial catches (research and sport) are given in Appendix 15A.

Discards

For this assessment, thornyhead retained and discarded catch by gear type (Table 15-2) has been derived from a variety sources that are described above in the fishery data section. Thornyhead discards before 1990 are unknown. We assumed that the reported catches before 1990 included both retained and discarded catch. Discard rates have increased slightly in recent years (~19% average discard rate since 2010) but are still less than the “Other rockfish” management category or shortraker rockfish, which reached a Gulfwide historical high of 51.2% in 2016 (see chapters in this SAFE report for Pacific ocean perch, northern rockfish, dusky rockfish, other rockfish, and shortraker rockfish). In addition, discard rates have become more disproportionate between gear types. In recent years, the sablefish fishery has accounted for nearly 90% of thornyhead discards (Table 15-4).

Why thornyhead discard rates are increasing, particularly in the hook and line sablefish fishery is not completely understood. However, the Maximum Retainable Amount (MRA) rate for hook and line boats still lends to overage concerns for vessels. Possible explanations for the reportedly high discard rate in the sablefish fishery include the following: 1) potentially biased discard values among the fishery catch data, and 2) regulatory discards due to low sablefish catch onboard. Logbook and observer data have shown seasonal variation in depths fished during the IFQ season: boats that target sablefish fish at shallower depths in the spring (March – May) and move deeper as the season progresses. When vessels fish the upper slope edge during the early season (~190 – 250 fm), they are more likely to catch a greater number of rockfish and are therefore forced to discard early in the trip as there are often not enough sablefish on board for retention of thornyhead (D. Falvey, ALFA, pers. comm.). The same explanation could apply during times of heavy whale depredation. When a first set is heavily depredated by whales, the vessel will move and likely catch enough sablefish on subsequent sets to accommodate the amount of bycatch of the first set. However, the rockfish caught on the first set would have been discarded under current regulation (D. Falvey, L. Behnken, ALFA, pers. comm.). While observer data is incredibly useful, it is important to keep in mind that the estimate of the amount of catch that is discarded at sea for each species encountered in the haul is based on the observer’s best professional judgment and is challenging because it can occur at many places in a fishing and processing operation (Cahalan et al. 2010). These estimates are then applied to the unobserved fleet, and if data is limited or based on a small number of hauls with large catch, these numbers have the potential of being extrapolated to inaccurate values. Future work looking at electronic monitoring (EM) data may help answer potential extrapolation bias questions. In short, industry representatives state that the market for thornyhead rockfish is good and that there are no processor restrictions. The practice of discarding bycatch species exist because of enforcement concerns. Gulfwide discard rates[1] (% of the total catch discarded within a management category) of thornyhead rockfish are listed below for the years 1991-2018:

Year	Thornyhead rockfish
1991	7.4%
1992	24.0%
1993	35.2%
1994	40.3%
1995	23.5%
1996	26.1%
1997	24.6%
1998	14.0%
1999	21.5%
2000	14.8%
2001	8.9%
2002	13.0%
2003	9.3%
2004	12.8%
2005	9.9%
2006	12.5%
2007	10.7%
2008	15.3%
2009	15.2%
2010	11.8%
2011	15.0%
2012	23.9%
2013	28.4%
2014	14.0%
2015	16.5%
2016	18.5%
2017	17.8%
2018*	23.2%

[1]1991-2018: National Marine Fisheries Service, Alaska Region, Catch Accounting System, accessed via the Alaska Fishery Information Network (AKFIN). *Updated through October 9, 2018.

Data

Fishery data

Catch

Detailed catch information for thornyhead rockfish is listed in Table 15-1.

Size and Age Composition

Length frequency data from the 2015-2018 trawl and longline fisheries are shown in Figure 15-2; in general, longline fisheries capture larger thornyheads than trawl fisheries (average length of 39 cm versus 29 cm), perhaps because they operate in deeper waters and hook selectivity tends to select for larger fish. Few age samples for this species have been collected from the fishery, and none have been aged.

Survey Data

Longline Surveys in the Gulf of Alaska

Two longline surveys of the continental slope in the Gulf of Alaska provide data on the relative abundance of thornyhead rockfish in this region: the earlier Japan-U.S. cooperative longline survey, and the ongoing Alaska Fisheries Science Center (AFSC) domestic longline survey. These surveys compute relative population numbers (RPNs) and relative population weights (RPWs) for fish on the continental slope as indices of stock abundance. The surveys are primarily directed at sablefish, but also catch considerable numbers of thornyhead rockfish. Results for both surveys concerning rockfish, however, should be viewed with some caution, as the RPNs and RPWs do not take into account possible effects of competition for hooks with other species caught on the longline, especially sablefish. For example, Sigler and Zenger (1994) found that thornyhead catch increased in areas where sablefish abundance decreased. They suggested that the increase in thornyhead catch rates between 1988 and 1989 (their data) might be partly due to the decline in sablefish abundance. They reasoned that availability of baited hooks to thornyheads may have increased. Further research is needed on the effect of hook competition between slow, low metabolism species such as shortspine thornyheads and faster, more actively feeding sablefish. Rodgveller et al. (2008) found evidence of competition for hooks in the longline surveys between sablefish and giant grenadiers (*Albatrosia pectoralis*), and between sablefish and shortraker (*Sebastes borealis*) and rougheye rockfish (*Sebastes aleutianus*).

The cooperative longline survey was conducted annually during 1979-94, but RPNs for rockfish are only available for the years 1979-87 (Sasaki and Teshima 1988).

The AFSC domestic longline survey has been conducted annually since 1988, and RPNs and RPWs have been computed for each year (Table 15-5). For thornyhead rockfish, Gulfwide RPNs have ranged from a low of approximately 45,000 in 2004 to a high of approximately 98,000 in 2013. Although there has been an overall increasing trend in RPNs, there is still a considerable amount of fluctuation between adjacent years: (the RPN in 2016 of 69,262 increased to 95,369 in 2017 and then decreased to 77,915 in 2018). Some of the fluctuations may be related to changes in the abundance of sablefish, as discussed above, regarding competition for hooks among species. The domestic survey results show that abundance of thornyhead rockfish is highest in the central Gulf of Alaska: the Kodiak and Chirikof areas have consistently had the greatest RPN and RPW values for thornyhead rockfish (Table 15-5).

Longline Survey Size Compositions

Length frequency data from the 2016-2018 longline surveys are shown in Figure 15-3. The longline survey length data are very consistent with distinct modes at 34-36 cm.

AFSC Trawl Survey Biomass Estimates

Bottom trawl surveys were conducted on a triennial basis in the Gulf of Alaska from 1984 through 1999, and these surveys became biennial starting in 2001. This survey employs standard NMFS Poly-Nor'eastern bottom trawl gear and provided biomass estimates using an "area-swept" methodology described in Wakabayashi *et al.* (1985). The trawl surveys have covered all areas of the GOA out to a depth of 500 m (in some surveys to 1,000 m), but the 2001 survey did not sample the eastern GOA. Also, in 1984 a different, non-standard survey design was used in the eastern Gulf of Alaska; furthermore, much of the survey effort in the western and central Gulf of Alaska in 1984 and 1987 was by Japanese vessels that used a very different net design than what has been the standard used by U.S. vessels throughout the surveys. To deal with this latter problem, fishing power comparisons of rockfish catches have been conducted for the various vessels used in the surveys (for a discussion see Heifetz *et al*. 1994). The reader should be aware that an element of uncertainty exists as to the standardization of the 1984 and 1987 surveys.

The bottom trawl surveys provide much information on thornyhead rockfish, including estimates of absolute abundance (biomass, Table 15-6) and population length compositions, however, in assessing the relative abundance of GOA thornyheads, it is important to consider the extent to which an individual survey covers the full depth and geographic range of the species. The 1996 and 2001 surveys did not survey the depths >500 m, and the 2003, 2011, 2013, and 2017 surveys did not survey depths >700 m. It is evident from trawl survey results that a significant portion of the biomass of shortspine thornyheads exists at depths greater than 500 m (Table 15-6), and that all of the biomass of longspine thornyheads exists at depths greater than 500 m and mostly in the eastern Gulf. In addition, the 2001 survey did not sample the eastern GOA, and a comparison of survey biomass estimates by management area shows that shortspine thornyheads are most abundant in the Eastern and Central Gulf. In 1999, 2005, 2007, 2009, and 2015, the surveys had the most extensive survey coverage of the primary thornyhead habitat (all depths sampled to 1,000 m).

Gulfwide biomass estimates for thornyhead rockfish have sometimes shown rather large fluctuations between surveys (Figure 15-4); for example, the 2015 estimated survey shortspine biomass of 89,241 t is a 24% increase from the 2013 survey estimate. This follows biomass decreases of 7%, 16%, 22%, and 38% in 2005, 2007, 2009, and 2011 from the 2003 estimate. The 2017 GOA biomass estimate decreased by 10% from the 2015 estimate but is well above the long-term mean (Figure 15-4). Trawl survey estimates by area (Table 15-6) were down in the CGOA, but up slightly in the WGOA and EGOA areas.

Spatial distribution of catches of thornyhead rockfish in the last three GOA trawl surveys indicate the fish are rather evenly spread along an offshore band along the continental slope (Figure 15-5).

Compared with many other rockfish species, the biomass estimates for thornyhead rockfish have historically shown relatively moderate confidence intervals and low CVs (compare CVs for thornyhead in Table 15-6 versus those for sharpchin, redstripe, harelequin, and silvergray rockfish in the “Other Rockfish” chapter of this SAFE report). The low CVs are an indication of the generally even distribution of thornyhead rockfish.

Despite the relatively precise biomass estimates historically observed, assessment authors have been uncertain whether the trawl surveys are accurately assessing abundance of thornyhead rockfish. Nearly all the catch of these fish is found on the upper continental slope at depths of 300-700 m. A considerable portion of this area in the GOA is not trawlable by the survey’s gear because of the area’s steep and rocky bottom, except for gully entrances where the bottom is more gradual. In addition, these depths have not always been sampled by the trawl survey. For these reasons, and because thornyhead rockfish are sampled by the annual longline survey, we present and recommend a random effects model that incorporates both the AFSC bottom trawl survey biomass index and the AFSC longline survey RPW index to estimate exploitable biomass and recommend management quantities. This is further discussed in the ‘modeling’ section.

Trawl Survey Size Compositions

Size compositions for thornyhead rockfish from the 2013, 2015, and 2017 trawl surveys were consistently unimodal with modes at 24-27 cm (Figure 15-6). These are substantially lower than the mode for the longline survey (Figure 15-3), suggesting that the two surveys may capture different parts of thornyhead population.

Analytic Approach

Modeling Structure

Due to difficulties in ageing thornyheads and issues raised with previous age-based methods using length composition data, recent assessments have all used a biomass-based approach based on trawl survey data to calculate ABCs. We continue to use this approach through the use of a random effects model (RE). The process errors (step changes) from one year to the next are the random effects to be integrated over and the process error variance is the free parameter. The observations can be irregularly spaced; therefore, this model can be applied to datasets with missing data. Large observation errors increase errors predicted by the model, which can provide a way to weight predicted estimates of biomass. Estimates were made using the 1984-2017 GOA trawl survey time series for biomass and estimates of uncertainty. The RE model was fit separately by region and depth strata to account for missing survey data, and then summed to obtain Gulfwide biomass.

Thornyhead in the GOA are managed under Tier 5, where OFL = M * estimated exploitable biomass, where M represents natural mortality, and F_{ABC} is estimated by 0.75 * M. The acceptable biological catch (ABC) is obtained by multiplying F_{ABC} by the estimated exploitable biomass, ABC ≤ 0.75 * M * biomass. M is assumed equal to 0.03 and is discussed in the 'Parameter estimates' section.

Modeling Selection

In total, two changes were made to the input data and model configuration in this year's assessment compared to the 2015 assessment. We present these changes in a step-wise manner, building upon each previous model change to arrive at the recommended model for this year's assessment. The following table provides the model case name and description of the changes made to the model.

Model case	Description
15.1	2015 model with data updated through 2018
15.1a	15.1 with bottom trawl biomass estimates summed for the 0-500 m depth strata within each region
18.1	15.1a with AFSC longline survey RPWs from 1992-2018 included as an additional population index

A brief description of each model case is provided below.

15.1a – Alternate bottom trawl survey depth strata

Several alternatives of fitting the random effects model to bottom trawl biomass indices by region and depth strata were presented to the NPFMC GOA Groundfish Plan Team in September 2018. Here we present the most promising combination of data and process error scenarios that were investigated. In 15.1a we sum the bottom trawl survey biomass index across depth strata that range from 0 m to 500 m (three depth strata), which has been sampled in each year of the bottom trawl survey in the GOA since 1984. Thus, for each region there are three total depth strata fit, 0-500 m, 501-700 m, and 701-1,000 m. This is an alternative to 15.1, in which each region fit six depth strata, that include 0-100 m, 101-200 m, 201-300 m, 301-500 m, 501-700 m, and 701-1,000 m depth strata.

18.1 – Including the longline survey RPW index

In model 18.1, the AFSC longline survey RPW index is added to the random effects model by estimating a catchability coefficient parameter that scales the random effects biomass estimates to the longline survey RPWs. The longline survey RPW index is available with associated uncertainty at the regional scale. To estimate the regional RPW index we sum the random effects parameters by depth strata within each region (thus, providing a regional estimate of biomass) prior to scaling by the catchability coefficient. The estimate of the longline survey RPW index by region is then given by:

$$\hat{I}^{L}_{y,r} = q \sum_{S} e^{\hat{\theta}_{y,r,s}}$$

where the superscript L in $\hat{I}^{L}_{y,r}$ denotes that the index is for the longline survey and q is the catchability coefficient parameter. An additional observation error component is then added to the objective function, which is the negative log-likelihood of the model fit to the longline survey RPWs, given by:

$$-lnL^{L}_{O} = \sum_{Y} \frac{1}{2}\left[ln\left(2\pi\sigma^{2}_{L,y,r}\right) + \frac{1}{\sigma^{2}_{L,y,r}}\left(ln\left(q\sum_{S} e^{\hat{\theta}_{y,r,s}}\right) - lnI^{L}_{y,r}\right)^{2}\right]$$

where $\sigma^{2}_{L,y,r}$ is the regional variance of the longline RPW index and $I^{L}_{y,r}$ is the observed longline RPW index. Thus, the model has three likelihood components: 1) the process error component (which represents the amount of variation across time of the random effect parameters), 2) the bottom trawl survey biomass index observation error component, and 3) the longline survey RPW index observation error component. It is through the addition of the observation error component of the longline survey index to the total likelihood that the biomass estimates from the random effects model are sensitive to both the bottom trawl biomass and longline RPW indices.

Parameter Estimates

Age and growth, maximum age, and natural mortality (M):

Despite a general knowledge of the life history of thornyheads throughout their range, precise information on age, growth, and natural mortality *(M)* remains elusive for shortspine thornyheads in Alaska and is unknown for longspine thornyheads. Miller (1985) estimated shortspine thornyhead natural mortality by the Ricker (1975) procedure to be 0.07. The oldest shortspine thornyhead found was 62 years old in that study. On the U.S. continental west coast, at least one large individual was estimated to have a maximum age of about 150 years (Jacobson 1990). Another study of west coast shortspine thornyheads found a 115-year-old individual using conventional ageing methods (Kline 1996). Kline (1996) also used radiochemical aging techniques to estimate a maximum age of about 100 years. These maximum ages would suggest natural mortality rates ranging from 0.027 to 0.036 if we apply the relationship developed by Hoenig (1983). Recent radiometric analyses suggest that the maximum age is between 50-100 years (Kastelle *et al.* 2000, Cailliet *et al.* 2001), but these have high-variance estimates due to sample pooling and other methodological issues. A recent analysis of reproductive information for Alaska and west coast populations also indicates that shortspine thornyheads are very long-lived (Pearson and Gunderson 2003). The longevity estimate was based on an empirically derived relationship between gonadosomatic index (GSI) and natural mortality (Gunderson 1997) and suggested much lower natural mortality rates (0.013-0.015) and therefore much higher maximum ages (250-313 years) than had ever been previously reported using any direct ageing method.

A contracted age study was completed in August 2009 (Black 2009). Results were limited as shortspine thornyheads are extremely difficult to age. Out of the 428 otoliths included in this study, an age was obtained for just over half of the samples. Approximately a quarter of the total number of otoliths (109 out of 428) were of a high enough clarity for ages to be considered reliable. Ageing confidence was found to decrease with fish age, compounding the difficulty in establishing a reasonable range of maximum ages. Maximum ages in this study were approximately 85 years, with the possibility of 100 years. These maximum ages are in agreement with other studies, including those that employed radiometric validation. All the samples for this study were from specimens >20 cm selected to obtain older aged individuals. The AFSC Age and Growth Lab will continue aging work on smaller specimens, which can be surface read, to compliment the older ages so that a more complete length-at-age data set can be compiled. It is hoped that a full range of ages could provide improved age and growth information specific to the Gulf of Alaska.

Although shortspine thornyheads are extremely difficult to age, studies seem to indicate that Miller's (1985) estimate of maximum age of 62 is low and an estimate of *M* of 0.07 based on this would be high. Conversely, the maximum ages implied by Pearson and Gunderson (2003, 250-313 years) may be high and infer natural mortality rates that may be inappropriately low. The maximum ages from Kline (1996) and Jacobson (1990) are 115 and 150 years, respectively. The average natural mortality rate from these studies is 0.030. Preliminary results from Black's (2009) work are in line with this estimate of *M*. Assuming *M*=0.03 implies a longevity in the range of 125 years, which is bracketed by estimates derived from Jacobson (1990) and Kline (1996). Until we gather more information on shortspine thornyhead productivity, age, and growth in the GOA, we will continue to assume *M*=0.03 is a reasonable and best available estimate of *M*.

A summary of the estimates of mortality and maximum age for thornyhead rockfish are listed as follows:

Mortality rate	Maximum age	Ageing Method	Species	Area	References
0.07	62	-	shortspine	AK	1
~0.03	150	-	shortspine	WC	2
0.027	115	conv	shortspine	WC	3
0.036	100	radio	shortspine	WC	3
-	50-100	radio	shortspine	-	4,5
0.013-0.015	250-313	GSI	shortspine	AK, WC	6
	85-100	conv	shortspine	-	7

Area indicates location of study: West Coast of U.S. (WC), Alaska (AK)
Conv: conventional ageing method; radio: radiochemical aging technique; GSI: gonadosomatic index
References: 1) Miller 1985; 2) Jacobson 1990; 3) Kline 1996; 4) Kastelle et al. 2000; 5) Cailliet et al. 2001; 6) Pearson and Gunderson 2003; 7) Black 2009.

Fecundity and maturity at length:

Fecundity at length has been estimated by Miller (1985) and Cooper *et al.* (2005) for shortspine thornyheads in Alaska. Cooper *et al.* (2005) found no significant difference in fecundity at length between Alaskan and West Coast shortspine thornyheads. It appeared that fecundity at length in the more recent study was somewhat lower than that found in Miller (1985), but it was unclear whether the difference was attributable to different methodology or to a decrease in stock fecundity over time. Longspine thornyhead fecundity at length was estimated by Wakefield (1990) and Cooper *et al.* (2005) for the West Coast stocks; it is unknown whether this information is applicable to longspine thornyheads in Alaska.

Size at maturity varies by species as well. The size-at-maturity schedule estimated in Ianelli and Ito (1995) for shortspine thornyheads off the coast of Oregon, suggests that female shortspine thornyheads appear to be 50% mature at about 22 cm. More recent data analyzed in Pearson and Gunderson (2003) confirmed this, estimating length at maturity for Alaska shortspine thornyheads at 21.5 cm (although length at maturity for west coast fish was revised downward to about 18 cm). Male shortspine thornyheads mature at a smaller size than females off Alaska (Love *et al.* 2002). Longspine thornyheads reach maturity between 13 and 15 cm off the U.S. west coast; it is unknown whether this information applies in the Alaskan portion of the longspine thornyheads range.

Estimates of age- and size-at-50% maturity for thornyhead rockfish are listed below:

Age at Maturity	Size at Maturity	Species	Sex	Area	References
-	22 cm	shortspine	female	O	1
-	21.5 cm	shortspine	female	AK	2
-	13-15 cm	longspine	male	WC	3
12	-	shortspine	male/female	AK	4

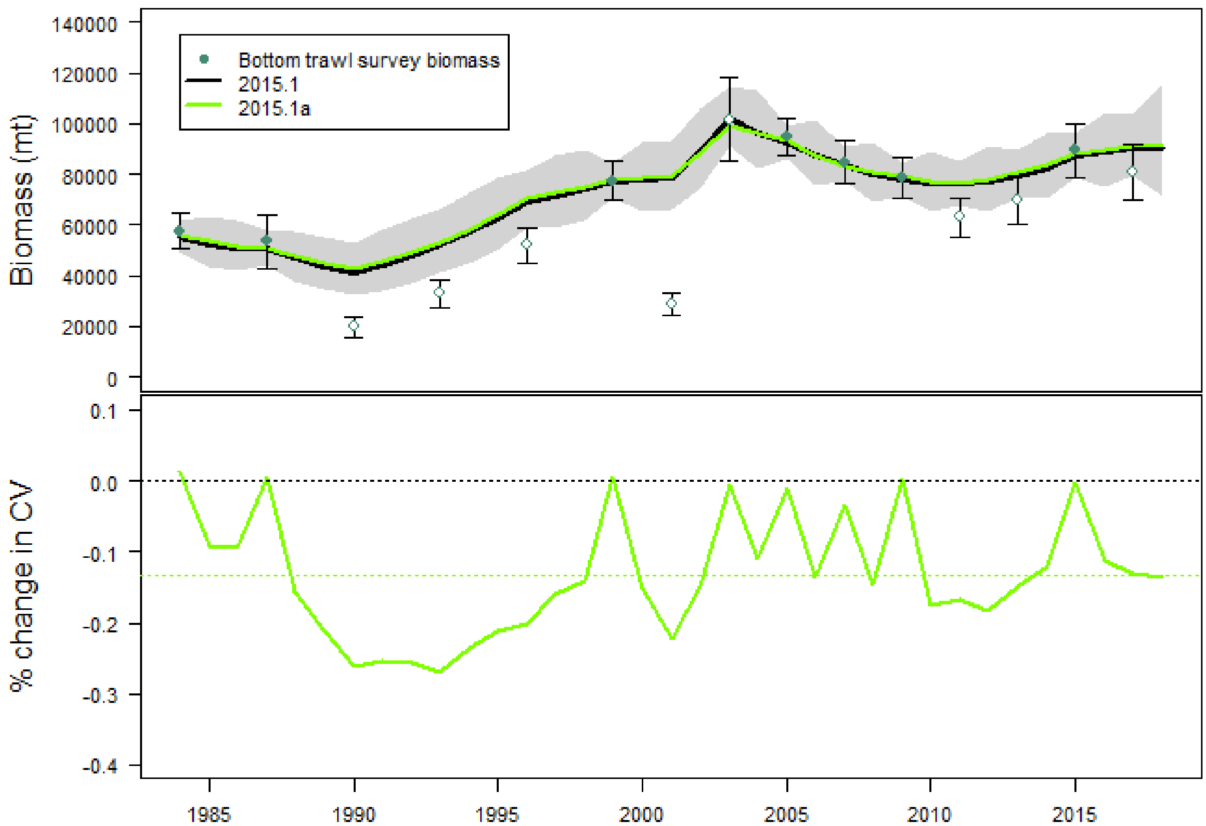
Area indicates location of study: Oregon (O); West Coast of U.S. (WC), Alaska (AK)
References: 1) Ianelli and Ito 1995; 2) Pearson and Gunderson 2003; 3) Love *et al*. 2002; 4) Miller 1985.

Results

Model Evaluation

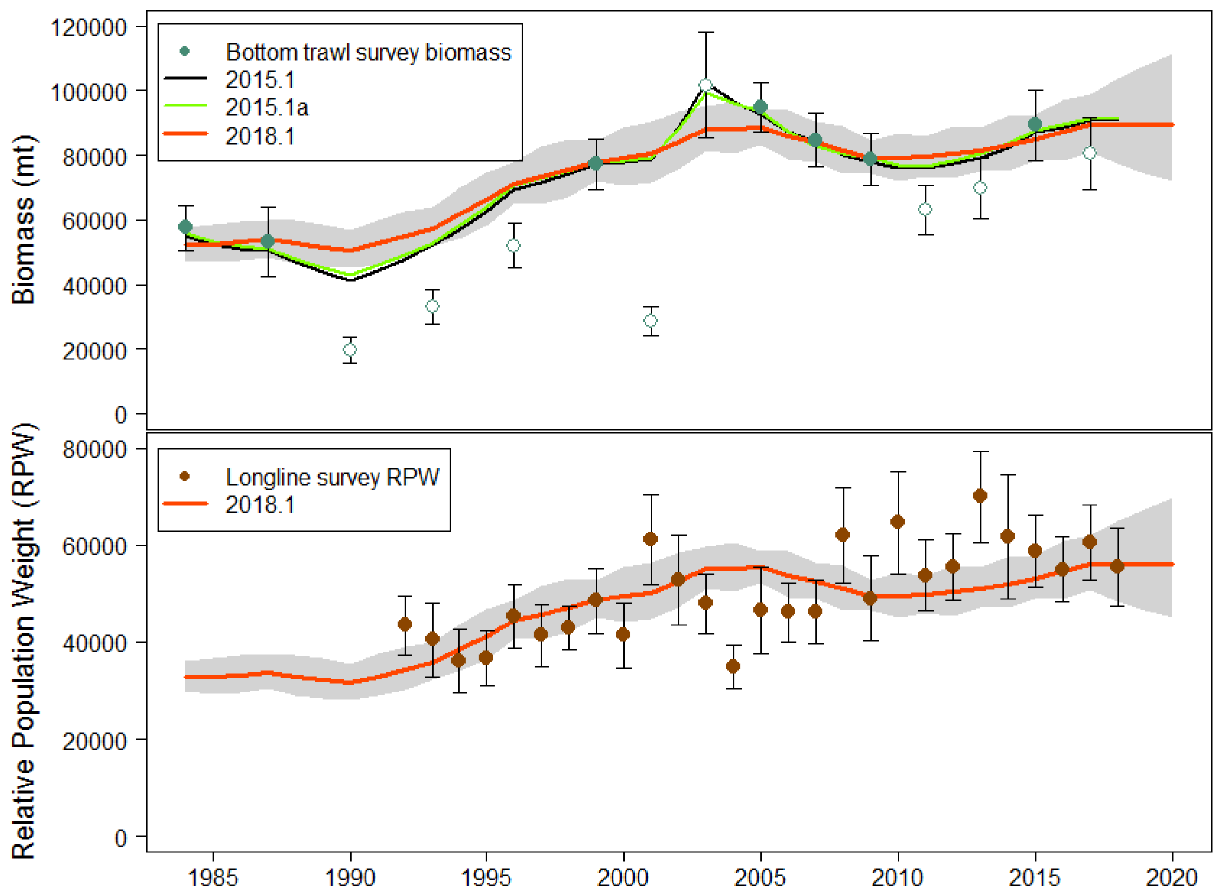
In this year's assessment we recommend two changes to the random effects model used to estimate the biomass of shortspine thornyhead: (1) how the bottom trawl survey biomass data is structured, and (2) including the longline survey RPW index as an additional index to the bottom trawl survey.

The following figure compares the random effects model fit to the bottom trawl survey (top panel) and the percent change in the coefficient of variation (CV) of the random effects model's biomass estimates between models 15.1 and 15.1a (bottom panel).



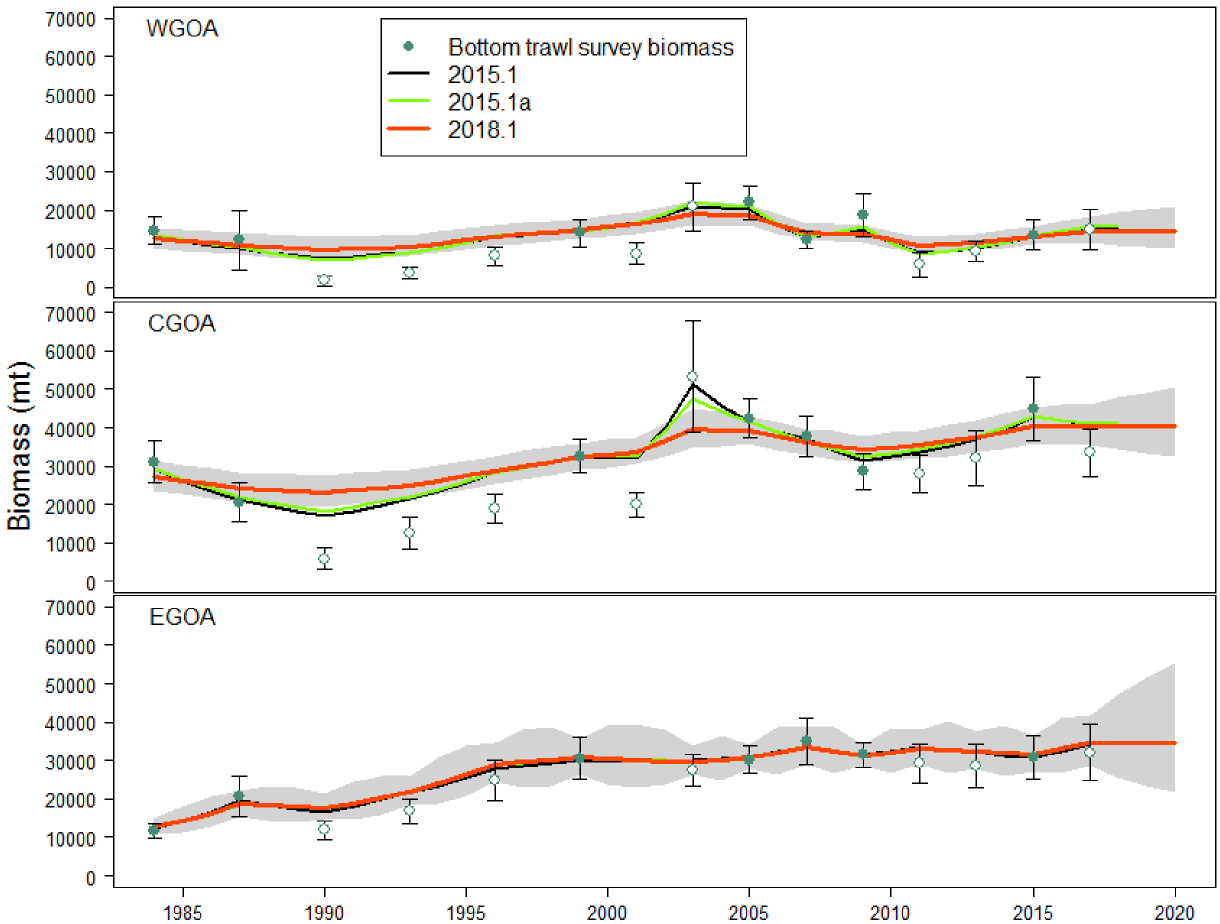
Combining the bottom trawl survey biomass across strata from 0 to 500 m in model 15.1a resulted in biomass estimates that were similar to model 15.1 (top panel). However, on average the CV in estimated biomass from model 15.1a was over 10% smaller than model 15.1 (bottom panel). The bottom trawl survey has sampled the depth strata within 0 to 500 m every year, but not the depth strata 501-700 m and 701-1,000 m (in years denoted by open points in the figure below). This results in nine fewer time-series of bottom trawl survey biomass indices fit in model 15.1a compared to 15.1. We recommend that the data structure of 15.1a be used in the assessment of shortspine thornyhead biomass because of the reduction of random effects parameters and the decrease in uncertainty of biomass estimates from the random effects model.

Comparison of fit to the GOA-wide AFSC bottom trawl survey biomass between models 15.1, 15.1a, and 18.1 is shown in the top panel of the figure below. The bottom panel shows the fit of the random effects model to the longline RPW index.



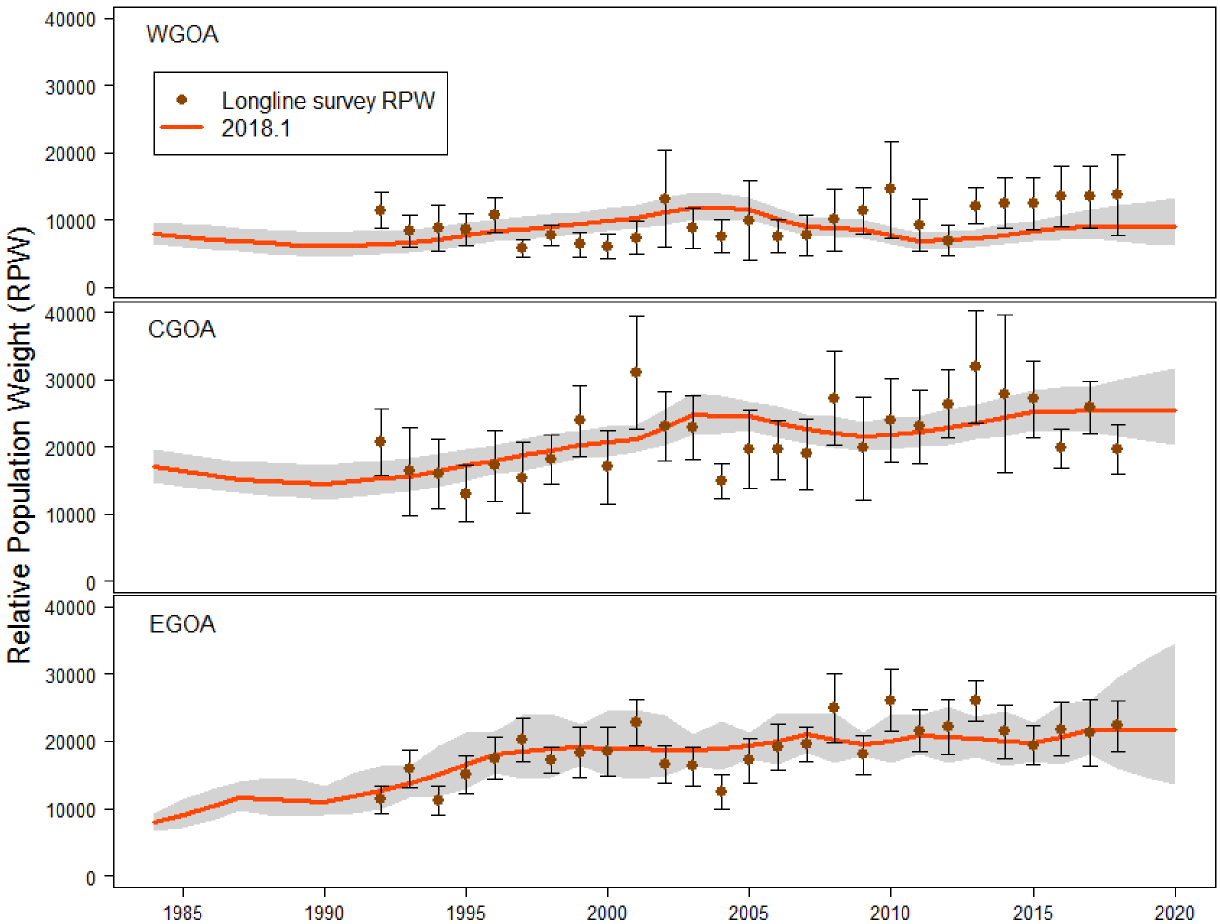
In general, model 18.1 provides estimates of AFSC bottom trawl survey biomass index that are not as precisely fit to the index as compared to 15.1 and 15.1a. This is particularly true for the 1990 and 2003 bottom trawl survey biomass values for which 15.1 and 15.1a are more sensitive to those years than 18.1. It is also interesting that the fit to the 1990 bottom trawl survey biomass is influenced by the longline RPW index when there is no RPW data in that year. It appears that to balance the process error component of the likelihood the combined model smooths this data point in order to fit the start of the RPW index time-series. Model 18.1 fits the longline survey RPW index well in most years (bottom panel). There are some time periods in which the trajectories of the trawl survey biomass index and the longline RPW index observations do not agree, in particular in the period between 2000 and 2005 and the period between 2010 and 2015, exposing differences between these time-series that are accounted for more specifically in 18.1 compared to 15.1 or 15.1a.

The following figure presents the fit from 15.1, 15.1a, and 18.1 to the regional bottom trawl survey biomass indices.

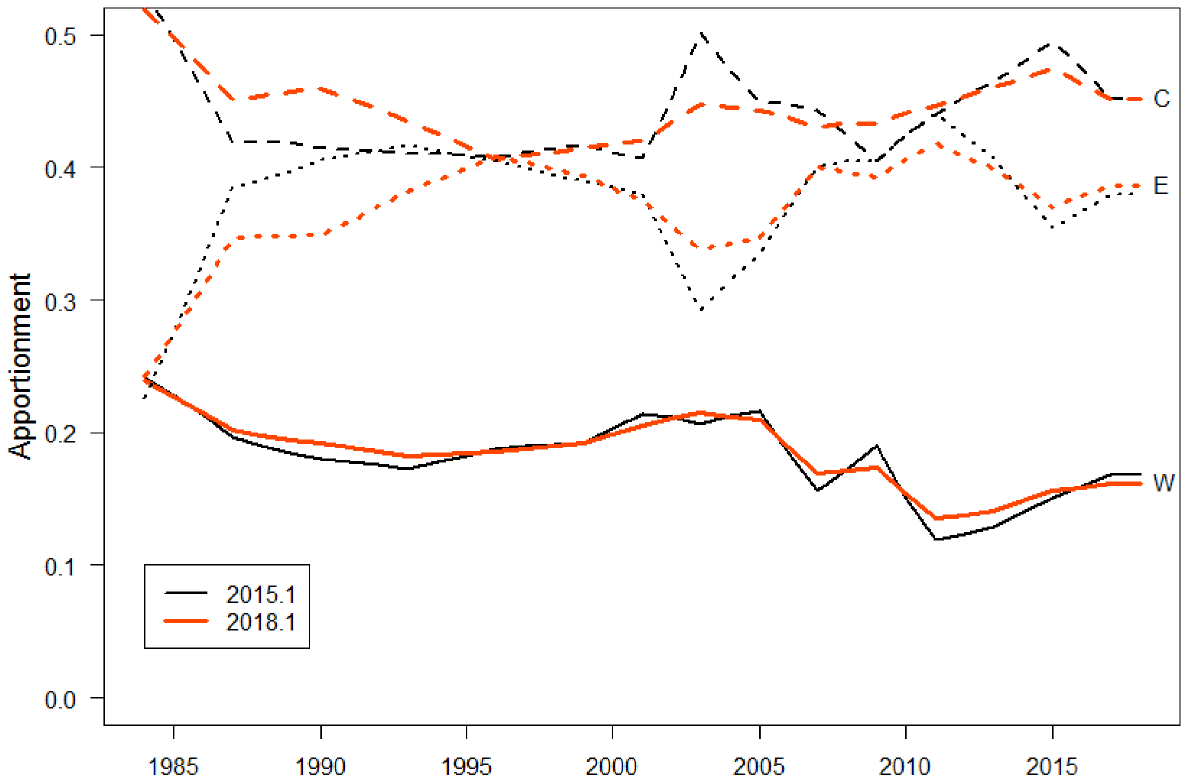


The general result of dampening the response of the random effects model to the bottom trawl survey biomass index with 18.1 compared to 15.1 or 15.1a also held for the WGOA and CGOA regional estimates, while the EGOA estimates of biomass were similar between the two model structures.

The following figure shows the fit to the regional longline survey RPW index by model 18.1. Regional fit to the longline index by 18.1 was generally precise, with the exception of recent years in the WGOA in which the combined model fit resulted in estimated RPWs that were smaller than the observed index.



Because we fit the longline survey RPW index by region, model 18.1 provides a straight-forward way to estimate apportionment that is responsive to both the bottom trawl survey biomass index and the longline survey RPW index. As would be expected from the results of the fit to regional indices, the regional apportionment from the combined model was more stable across time than the apportionment estimated by the current model (figure below).



The estimate of catchability for the longline survey RPW index from the combined model was 0.627.

The method presented in model 18.1 is a simple and straight-forward approach for including additional population indices in the random effects model used to assess Tier 5 species at AFSC. The general result shown here was an increase in the stability of biomass estimates across time, reduced tendency for the random effects model to over-fit bottom trawl survey biomass values in some years, and more consistent regional apportionment across time. Further, this model exposed data differences between the bottom trawl survey biomass index and the longline survey RPW index over time for shortspine thornyheads that can now be integrated into the estimation of management quantities for the thornyhead complex. For these reasons, we recommend that model 18.1 be used for the assessment of shortspine thornyheads within the GOA thornyhead complex.

It should be noted that this method could easily be extended to assess other Tier 5 species that are sampled by longline gear as well as aid in the estimation of apportionment for Tier 3 species that include multiple population indices within the assessment. However, while the general method shown here can be used for the assessment of other species, considerations should be made by the individual stock assessment authors on how best to apply this method.

Harvest Recommendations

Since broadfin thornyheads do not range into the GOA they should not be considered within the GOA thornyheads assemblage.

At present, we do not attempt to estimate natural mortality or apply Tier 5 assessment methods to longspine thornyheads (*S. altivelis*) in the GOA. Our fishery sampling indicates that this species is rarely encountered in fisheries (likely because most fisheries operate at depths shallower than 500 m in the GOA), and surveys suggest that it is uncommon relative to shortspine thornyheads in Alaska, even in its preferred depths from 500 to 1,000 m. The center of longspine thornyhead abundance appears to be off the U.S. West Coast, not in Alaska. Furthermore, the TAC established based on the biomass and natural mortality of shortspine thornyheads has not been fully exploited since 1994, suggesting that fishing pressure on thornyheads in general is relatively light. Therefore, additional management measures specific to longspine thornyheads in the GOA are not recommended at this time. In the future, if fisheries shift to deeper depths along the continental slope, and/or the catch of shortspine thornyheads increases dramatically, specific management measures for longspine thornyheads should be considered. Therefore, the historical single species focus of this assessment on shortspines seems appropriate, and we continue to make harvest recommendations specific to shortspine thornyheads in the GOA.

We recommend keeping thornyhead rockfish as "Tier 5" in the NPFMC definitions for ABC and Overfishing Level (OFL) based on Amendment 56 to the Gulf of Alaska FMP. The population dynamics information available for Tier 5 species consists of reliable estimates of biomass and natural mortality M, and the definition states that for these species, the fishing rate that determines ABC (i.e., F_{ABC}) is $\leq 0.75M$. Thus, the recommended F_{ABC} for thornyhead rockfish is 0.0225 (i.e., 0.75 x M, where $M = 0.03$).

As described in the previous section, the recommended RE model was fit to the 1984-2017 GOA trawl survey time-series of biomass values and estimates of uncertainty by region and depth strata (to account for missing survey data) and regional RPW indices from the AFSC longline survey (with associated estimates of uncertainty). These regional biomass estimates from the RE model were then summed to obtain Gulfwide biomass (Figure 15-7). Applying the F_{ABC} to the estimate of current exploitable biomass (using the new random effects methodology) of 89,609 t (+/- 95% CI of 77,225 and 103,980) for thornyhead rockfish results in a Gulfwide ABC of 2,016 t and OFL of 2,688 t for the 2019 fishery.

Area Allocation of Harvests

The Gulfwide ABC for thornyhead rockfish was apportioned using the most recent biomass estimate from the recommended random effects model. The fit of the recommended random effects model to the AFSC bottom trawl survey biomass by region is shown in Figure 15-8 and to the AFSC longline survey RPW index by region is shown in Figure 15-9. From the recommended random effects model, the apportionment of ABC by region is responsive to both the bottom trawl and longline survey indices. Apportionment is determined by dividing the estimated biomass in each region by the total biomass, providing estimates of the proportion of biomass within each region. For the 2019 fishery, the percent distribution of exploitable biomass for shortspine thornyhead rockfish biomass in the GOA based on the random effects model is: Western Area, 16.2%; Central Area, 45.2%, and Eastern Area, 38.6%. Applying these percentages to the recommended Gulfwide ABC of 2,016 t yields the following apportionments for the GOA in 2019: Western area, 326 t; Central area, 911 t; and Eastern area, 779 t.

GOA Area	2019 Biomass (t)	Percent of Total Biomass	Area ABC Apportionment (t)
Western	14,504	16.2%	326
Central	40,481	45.2%	911
Eastern	34,624	38.6%	779
Gulfwide Total	89,609	100%	2,016

Overfishing Level

Based on Amendment 56 of the Gulf of Alaska FMP, overfishing for Tier 5 species such as thornyhead rockfish is defined to occur at a harvest rate of $F=M$. Therefore, applying the estimate of M for thornyhead rockfish (0.03) to the estimate of current exploitable biomass (89,609 t) yields an overfishing catch limit of 2,688 t for 2019. This stock is not being subjected to overfishing.

Summary

A summary of tier, current exploitable biomass, values of F, and recommended ABC (Gulfwide yield and allocated by area) and OFL using the random effects for thornyhead rockfish is listed below for 2019 (biomass and yield are in t):

	Exploit.	ABC		Overfishing	
Tier	biomass	F	Yield	F	Yield
5	89,609	$F = 0.75M = 0.0225$	2,016	$F = M = 0.030$	2,688
		Harvest Allocation			
		WGOA	326		
		CGOA	911		
		EGOA	779		

The ABC and OFL values are calculated using the random effects (RE) model. The RE model was fit separately by area, and then summed to obtain Gulfwide biomass. WGOA = Western Gulf of Alaska, CGOA = Central Gulf of Alaska, and EGOA = Eastern Gulf of Alaska.

Ecosystem Considerations

This section focuses on shortspine thornyheads exclusively, because they overwhelmingly dominate the thornyhead biomass in the GOA. Shortspine thornyheads occupy different positions within the GOA food web depending upon life stage. Adults are generally more piscivorous and are also available to fisheries (Figure 15-10, upper panel) whereas juveniles prey more on invertebrates and are therefore at a lower trophic level (Figure 15-10, lower panel). These food webs were derived from mass balance ecosystem models assembling information on the food habits, biomass, productivity and consumption for all major living components in each system (Aydin *et al.* 2007). See the 2011 Ecosystem Assessment's ecosystem modeling results section for a description of the methodology for constructing the food web.

Ecosystem Effects on GOA Shortspine Thornyheads

Predators

One simple way to evaluate ecosystem effects relative to fishing effects is to measure the proportions of overall mortality attributable to each source. Apportionment of shortspine thornyhead mortality between fishing, predation, and unexplained mortality from mass balance ecosystem modeling based on information from 1990-1994, indicates that adult shortspine thornyheads experience more fishing mortality than predation mortality, while juvenile thornyheads only experience predation mortality (Figure 15-11). During these years, approximately 52% of adult GOA shortspine thornyhead exploitation rate was due to the fishery, 22% due to predation, and 26% "unexplained". Adult and juvenile groups were not modeled separately in the EBS and AI, so the upper panel of Figure 15-11 includes all thornyheads in those two ecosystems. Combining adults and juveniles with different sources of mortality could account for the apparent differences between the GOA and BSAI in the overall dominance of fishing versus predation mortality. However, since shortspine thornyheads are retained at higher levels in the GOA fisheries relative to the BSAI, it is likely that fishing mortality is a more important component of total mortality for GOA thornyheads than for those populations in the AI and EBS.

In terms of annual tons removed, it is clear that fisheries were annually removing 1,300 tons of thornyheads from the GOA on average during the early 1990s (see Fishery section above). While estimates of predator consumption of thornyheads are more uncertain than catch estimates, the ecosystem models incorporate uncertainty in partitioning estimated consumption of shortspine thornyheads between their major predators in each system. Of the 22% of mortality due to predation, 36% (8% of total) is due to arrowtooth flounder, 24% (5.4% of total) due to "toothed whales" (sperm whales), 14% (3% of total) due to sharks, and 6% (1.4% of total) due to sablefish. If converted to tonnages, this translates to between 100 and 300 metric tons of thornyheads consumed annually by arrowtooth flounder during the early 1990's in that ecosystem, followed by "toothed whales" (sperm whales), which consume a similar range of thornyheads annually (Figure 15-12, lower panel). Sharks consumed between 50 and 200 tons of shortspine thornyheads annually, and sablefish were estimated to consume less than 75 tons of adult thornyheads. Juvenile shortspine thornyheads are consumed almost exclusively by adult thornyheads, according to these models (Figure 15-13). Thornyheads are an uncommon prey in the GOA, as they generally make up less than 2% of even their primary predators' diets.

Prey

Diets of shortspine thornyheads are derived from food habits collections taken in conjunction with GOA trawl surveys. Over 70% of adult shortspine thornyhead diet measured in the early 1990s was shrimp, including both commercial (Pandalid) shrimp and non-commercial (NP or Non-Pandalid shrimp) in equal measures (Figure 15-14, upper panel). This preference for shrimp in the adult thornyhead diet combined with consumption rates estimated from stock assessment parameters and biomass estimated from the trawl survey, results in an annual consumption estimate ranging from 2,000 to 10,000 tons of shrimp (Figure 15-14, lower panel). Other important prey of shortspine thornyheads include crabs, zooplankton, amphipods, and other benthic invertebrates. Thornyheads are estimated to consume up to an additional 1,000 metric tons of each of these prey annually in the GOA (Figure 15-14). Juvenile thornyheads have diets similar to adults, but they are estimated to consume far less prey overall than adults, as might be expected when a relatively small proportion of the population is in the juvenile stage at any given time (Figure 15-15).

Changes in habitat quality

The physical habitat requirements for thornyheads are relatively unknown, and changes in deepwater habitats have not been measured in the GOA. Furthermore, the ecosystem models employed in this analysis are not designed to incorporate habitat relationships or any effects that human activities might have on habitat.

Fishery Effects on the Ecosystem

Fishery contribution to bycatch

While it is difficult to evaluate the ecosystem effects of a "thornyhead fishery" since there are no directed thornyhead fisheries in the GOA, we can examine the ecosystem effects of the primary target fisheries which catch thornyheads. According to Alverson *et al.* (1964), groundfish species commonly associated with thornyheads include: arrowtooth flounder (*Atheresthes stomias*), Pacific ocean perch (*Sebastes alutus*), sablefish (*Anoplopoma fimbria*), rex sole (*Glyptocephalus zachirus*), Dover sole (*Microstomus pacificus*), shortraker rockfish (*Sebastes borealis*), rougheye rockfish (*Sebastes aleutianus*), and grenadiers (family Macrouridae). As described above, most thornyhead catch comes from fisheries directed at sablefish, rockfish, and flatfish in the GOA. Discussions of the ecosystem effects of these fisheries can be found in their respective stock assessments. The GOA sablefish fishery removes, as bycatch, the highest weight of nontarget species of any GOA fishery. Most of this bycatch is grenadiers. Fisheries for Pacific halibut also catch thornyheads and other rockfish, as well as skates and sharks.

Fishery concentration in time and space

Fisheries which catch thornyheads are widespread throughout the GOA, as is the distribution of thornyheads.

Fishery effects on amount of large size thornyheads

Poor length sampling of thornyheads from other target fisheries makes it difficult to evaluate the effects of the fishery on large size thornyheads. It is noted that in general, longline fisheries capture larger thornyheads than trawl fisheries, perhaps because they operate in deeper waters and due to hook selectivity, which tends to select for larger fish.

Fishery contribution to discards and offal production

Most of the bycatch in the GOA sablefish fishery is grenadiers which are discarded. The bycatch of halibut fisheries are estimated to have high bycatch (and potentially discards) of sharks.

Fishery effects on age-at maturity and fecundity

The effects of fisheries on the age-at-maturity and fecundity of thornyheads are unknown. Cooper *et al.* (2005) found a slightly lower fecundity at length for GOA shortspine thornyheads than had been estimated in an earlier study by Miller (1985). Further studies would be needed to determine whether this difference was due to different methodology or to a real decrease in fecundity at length over time, and whether changes could be attributed to the fisheries.

Summary of Ecosystem Effects on GOA Thornyheads and Fisheries Effects on the Ecosystem

Examining the trophic relationships of shortspine thornyheads suggests that the direct effects of fishing on the population which are evaluated with standard stock assessment techniques are likely to be the major ecosystem factors to monitor for this species, because fishing is the dominant source of mortality for shortspine thornyheads in the GOA, and there are currently no major fisheries affecting their primary prey. However, if fisheries on the major prey of thornyheads—shrimp and to a lesser extent deepwater crabs—were to be re-established in the GOA, any potential indirect effects on thornyheads should be considered.

Ecosystem considerations for GOA thornyheads are summarized in Table 15-7. The observation column represents the best attempt to summarize the past, present, and foreseeable future trends. The interpretation column provides details on how ecosystem trends might affect the stock (ecosystem effects on the stock) or how some aspects of fisheries for other targets which catch thornyheads may affect the ecosystem. The evaluation column indicates whether the trend is of: *no concern, probably no concern, possible concern, definite concern,* or *unknown.*

Data Gaps and Research Priorities

Because fishing mortality appears to be a larger proportion of adult thornyhead mortality in the GOA than predation mortality, highest priority research should continue to focus on direct fishing effects on shortspine thornyhead populations. The most important component of this research is to fully evaluate the age and growth characteristics of GOA thornyhead to re-institute the age-structured population dynamics model with adequate information. Additionally, mark recapture studies should continue since in the long-term this may provide insight on mortality and growth rates.

Acknowledgements

We thank Sarah Gaichas, Sandra Lowe, and Jim Ianelli for having developed the background information presented in this assessment.

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Tables

Table 15-1.--Comparison of Gulf of Alaska thornyhead catches (t) by management area and total gulfwide, Allowable Biological Catch (ABC), Total Allowable Catch (TAC), and management measures.

		Area		Gulfwide	Gulfwide	Gulfwide	
Year	Western	Central	Eastern	Total	ABC	TAC	Management Measure
1977				1,317			After passage of the Fishery Conservation and Management Act (FCMA), thornyheads were placed in the rockfish management group which contained all species of rockfish except Pacific ocean perch.
1978							
1979							Thornyheads were removed from the rockfish category and placed in the "other fish" category. TAC is set gulfwide.
1980				1,485	3,750	3,750	Thornyheads became a reported species group and are managed as a single stock.
1981				1,340	3,750	3,750	
1982				787	3,750	3,750	
1983				729	3,750	3,750	
1984				208	3,750	3,750	
1985				82	3,750	3,750	
1986				714	3,750	3,750	
1987				1,877	3,750	3,750	
1988				2,181	3,750	3,750	
1989				2,616	3,800	3,800	
1990				1,576	3,800	3,800	
1991	689	596	250	1,535	1,798	1,398	
1992	249	1015	761	2,025	1,798	1,798	
1993	110	849	378	1,337	1,180	1,062	
1994	162	733	341	1,236	1,180	1,180	The NPFMC apportions the ABC and TAC into three geographic management areas: the Western, Central, and Eastern Gulf of Alaska.
1995	158	603	267	1,027	1,900	1,900	
1996	177	595	241	1,013	1,560	1,248	
1997	148	716	244	1,109	1,700	1,700	
1998	238	716	195	1,149	2,000	2,000	
1999	283	583	247	1,113	1,990	1,990	Trawling is prohibited in the Eastern Gulf east of 140 degrees W longitude. Eastern Gulf trawl closure becomes permanent with the implementation of FMP Amendments 41 and 58 in 2000 and 2001, respectively.

Table 15-1. cont.

	Area			Gulfwide	Gulfwide	Gulfwide	
Year	Western	Central	Eastern	Total	ABC	TAC	Management Measure
2000	340	551	244	1,134	2,360	2,360	
2001	276	523	196	995	2,310	2,310	
2002	372	505	169	1,046	1,990	1,990	
2003	317	715	101	1,133	2,000	2,000	
2004	276	409	138	823	1,940	1,940	
2005	190	391	140	720	1,940	1,940	
2006	197	400	184	781	2,209	2,209	
2007	342	258	197	798	2,209	2,209	Amendment 68 creates the Central Gulf Rockfish Pilot Program, which affects trawl catches of rockfish in this area.
2008	270	299	167	736	1,910	1,910	
2009	235	276	154	665	1,910	1,910	
2010	140	278	151	569	1,770	1,770	
2011	159	302	166	627	1,770	1,770	
2012	172	345	223	741	1,665	1,665	The Central Gulf Rockfish Program is permanently put into place.
2013	305	541	309	1,156	1,665	1,665	
2014	244	668	219	1,131	1,841	1,841	
2015	234	588	214	1,035	1,841	1,841	
2016	209	690	223	1,121	1,961	1,961	
2017	155	617	250	1,021	1,961	1,961	
2018[a]	156	643	310	1,109	2,038	2,038	

[a] 2018 catch estimate is reported catch as of October 10, 2018

Catch Sources: 1977-1980 catches based on estimates extracted from NMFS observer reports (e.g., Wall et al. l978) 1981-1989 based on PACFIN and NMFS observer data; 1990-2002 based on blended NMFS observer data and weekly processor reports; 2003-present from the NMFS Alaska Regional Office (AKRO) Catch Accounting System (CAS), accessed with the AKFIN database.

Table 15-2.--Estimated retained catch and discard of GOA thornyheads (tons) by gear type[1], 1977-2018.

	Trawl gear			Longline gear		
Year	**Retained**	**Discarded**	**Total**	**Retained**	**Discarded**	**Total**
1977	1,163	-	1,163	234	-	234
1978	442	-	442	344	-	344
1979	645	-	645	454	-	454
1980	1,158	-	1,158	327	-	327
1981	1,139	-	1,139	201	-	201
1982	669	-	669	118	-	118
1983	620	-	620	109	-	109
1984	177	-	177	31	-	31
1985	70	-	70	12	-	12
1986	607	-	607	107	-	107
1987	1,863	-	1,863	14	-	14
1988	2,132	-	2,132	49	-	49
1989	2,547	-	2,547	69	-	69
1990	1,233	38	1,271	284	20	304
1991	1,188	60	1,248	228	53	281
1992	1,041	129	1,169	499	356	855
1993	489	173	662	297	377	674
1994	488	222	710	250	277	257
1995	471	165	636	307	77	384
1996	435	170	605	306	94	400
1997	567	224	791	398	61	459
1998	625	112	737	363	49	411
1999	597	197	794	277	42	320
2000	557	92	649	397	75	472
2001	479	52	532	424	37	461
2002	500	89	589	404	46	450
2003	705	70	775	321	36	357
2004	414	66	480	314	30	344
2005	333	27	360	319	41	360
2006	297	60	357	387	37	424
2007	368	11	379	370	49	419
2008	318	29	347	330	59	390
2009	252	25	277	320	69	388
2010	179	15	194	315	60	375
2011	214	30	245	305	41	346
2012	141	56	197	425	117	542
2013	199	17	216	485	453	938
2014	461	16	477	469	185	654
2015	317	28	345	476	215	691
2016	410	67	477	463	181	644
2017	379	23	402	456	163	618
2018*	412	30	442	459	207	666

[1] Prior to 1990, retained catch was assumed to equal retained and discarded catch combined. Catches by gear type from 1981-1986 were estimated by apportioning 85% of the total catch to trawl and 15% to longline gear.
Sources: 1977-1980 based on estimates extracted from NMFS observer reports (e.g., Wall et al. l978) 1981-1989 based on PACFIN and NMFS observer data; 1990-2002 based on blended NMFS observer data and weekly processor reports; 2003-present from the NMFS Alaska Regional Office Catch Accounting System (CAS), accessed through the AKFIN database system.
*The 2018 catch is incomplete, representing catch reported through October 10, 2018.

Table 15-3.--Estimated catch (%) of thornyhead rockfish in the Gulf of Alaska by target fishery, 2005-2018.

	Target Fishery				
Year	Rockfish	Sablefish	Flatfish	Other[1]	Total[2]
2005	46	48	5	1	100
2006	42	51	7	0	100
2007	40	53	7	1	101
2008	35	55	9	1	100
2009	28	59	11	1	99
2010	20	69	11	1	101
2011	27	63	9	2	101
2012	18	75	6	0	99
2013	9	84	6	1	100
2014	22	59	13	6	100
2015	22	69	6	3	100
2016	31	59	2	8	100
2017	36	58	2	4	100
2018*	33	62	5	1	101

Source: National Marine Fisheries Service, Alaska Region, Catch Accounting System, accessed via the Alaska Fishery Information Network (AKFIN). *Updated through October 10, 2018.

[1]The Other category includes catch from Pollock, Pacific Cod, and Other target fisheries.

[2]Values may not add to 100 due to rounding.

Table 15-4.-- Gulf of Alaska thornyhead discards (t) by target fishery, 2005-2018; approximate percentage of total discards in parentheses. 2005-2018: National Marine Fisheries Service, Alaska Region, Catch Accounting System, accessed via the Alaska Fishery Information Network (AKFIN). Updated through October 10, 2018.

	Fishery			
Year	Flatfish	Rockfish	Sablefish	Other
2005	5 (7%)	23 (34%)	38 (57%)	<1 (<1%)
2006	4 (4%)	56 (58%)	36 (37%)	<1 (<1%)
2007	16 (27%)	4 (7%)	40 (67%)	<1 (<1%)
2008	8 (9%)	16 (18%)	63 (72%)	1 (1%)
2009	11 (12%)	18 (19%)	64 (68%)	1 (1%)
2010	6 (8%)	7 (10%)	58 (82%)	1 (1%)
2011	7 (8%)	20 (22%)	61 (68%)	1 (1%)
2012	31 (18%)	21 (12%)	121 (70%)	<1 (<1%)
2013	12 (3%)	5 (1%)	448 (96%)	5 (1%)
2014	10 (5%)	10 (5%)	179 (89%)	3 (1%)
2015	18 (7%)	11 (5%)	209 (86%)	5 (2%)
2016	7 (3%)	7 (3%)	185 (75%)	49 (20%)
2017	10 (5%)	19 (10%)	146 (78%)	11 (6%)
2018	11 (5%)	17 (7%)	209 (88%)	1 (<1%)

Table 15-5.--Relative population number (RPN) and relative population weight (RPW) for Gulf of Alaska thornyhead rockfish in the Alaska Fishery Science Center longline survey, 1992-2018. Data are for the upper continental slope only, 201-1,000 m depth (gullies are not included).

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Thornyhead RPN:												
Shumagin	25,908	18,602	22,004	12,044	15,475	7,842	9,796	8,345	8,511	10,654	17,017	13,691
Chirikof	25,767	19,204	18,830	7,887	11,706	7,964	12,357	14,036	13,384	22,152	20,456	17,287
Kodiak	17,202	20,890	16,347	9,951	9,089	14,330	13,187	13,067	9,887	18,437	13,890	13,292
Yakutat	9,062	11,085	11,620	9,042	6,545	9,035	7,204	10,102	7,786	13,234	7,705	10,579
Southeastern	8,070	9,949	9,204	6,644	6,535	6,937	6,850	8,682	10,464	7,405	6,257	5,058
Total	**86,009**	**79,732**	**78,005**	**45,568**	**49,350**	**46,109**	**49,394**	**54,232**	**50,033**	**71,883**	**65,325**	**59,906**
Thornyhead RPW:												
Shumagin	12,305	8,144	9,138	8,676	10,867	5,852	7,849	6,737	6,147	7,327	12,489	8,978
Chirikof	14,893	8,421	10,022	7,000	11,312	6,594	10,715	14,992	10,724	19,398	15,184	14,346
Kodiak	6,346	8,650	5,842	6,817	6,778	10,047	8,419	8,339	6,621	12,411	9,724	9,446
Yakutat	3,891	4,609	4,799	5,353	4,215	6,450	4,320	5,983	5,055	8,192	4,781	6,385
Southeastern	3,880	4,864	3,176	3,980	4,616	4,300	5,607	5,727	6,445	5,914	4,886	3,943
Total	**41,314**	**34,688**	**32,979**	**31,827**	**37,788**	**33,243**	**36,909**	**41,779**	**34,991**	**53,242**	**47,064**	**43,098**

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Thornyhead RPN:												
Shumagin	11,208	10,910	12,330	13,116	17,281	20,581	23,546	15,333	12,792	21,107	17,557	20,689
Chirikof	10,012	13,726	12,533	15,243	21,373	15,951	18,120	17,465	18,160	23,882	21,233	15,460
Kodiak	11,061	14,275	13,352	11,640	18,070	14,592	18,801	19,130	21,513	24,201	18,006	25,368
Yakutat	8,000	11,700	11,133	9,802	14,943	9,408	15,654	14,540	15,943	17,525	10,875	10,247
Southeastern	4,336	8,011	8,233	10,245	10,883	9,630	11,119	11,911	8,172	10,530	12,006	8,515
Total	**44,617**	**58,622**	**57,582**	**60,045**	**82,550**	**70,162**	**87,240**	**78,379**	**76,579**	**97,245**	**79,676**	**80,279**
Thornyhead RPW:												
Shumagin	7,625	8,972	7,770	7,436	10,501	11,391	14,319	8,942	7,262	12,910	13,088	13,027
Chirikof	7,905	11,036	9,690	10,949	17,153	11,320	13,223	11,986	13,782	18,012	16,668	12,344
Kodiak	7,623	8,934	9,953	7,718	11,398	8,700	11,699	12,300	13,646	14,667	11,861	15,981
Yakutat	4,623	6,901	7,337	6,011	9,119	5,470	9,245	7,988	10,183	10,028	7,308	6,720
Southeastern	3,130	5,041	5,851	7,215	7,059	6,484	6,746	7,572	5,521	7,117	6,200	5,968
Total	**30,906**	**40,883**	**40,600**	**39,330**	**55,229**	**43,366**	**55,232**	**48,787**	**50,394**	**62,734**	**55,124**	**54,040**

	2016	2017	2018
Thornyhead RPN:			
Shumagin	21,896	21,507	20,458
Chirikof	14,403	15,846	14,204
Kodiak	14,130	24,216	18,747
Yakutat	11,294	22,998	16,041
Southeastern	7,538	10,802	8,464
Total	**69,262**	**95,369**	**77,915**
Thornyhead RPW:			
Shumagin	14,467	14,332	13,416
Chirikof	10,979	12,471	9,770
Kodiak	9,293	14,274	10,642
Yakutat	7,120	7,834	9,580
Southeastern	5,339	6,917	5,211
Total	**47,198**	**55,829**	**48,619**

Source: 1992-2018: AFSC longline survey database accessed via the Alaska Fishery Information Network (AKFIN)

Table 15-6.--Shortspine (top two panels) and longspine (bottom two panels) thornyhead biomass (t), and the percentage distribution by management area from the bottom trawl surveys in the Gulf of Alaska, 1996-2017. The 1996 and 2001 surveys did not survey depths >500 m, and the 2003, 2011, 2013, and 2017 surveys did not survey depths >700 m. In addition, the 2001 survey did not survey the Eastern Gulf of Alaska.

		Shortspine Thornyhead Biomass (t)										
Area	Depth (m)	1996	1999	2001	2003	2005	2007	2009	2011	2013	2015	2017
	1-100	0	116	46	54	180	212	85	17	0	37	153
	101-200	6,625	4,446	1,776	3,988	5,682	4,742	3,002	5,400	9,077	7,664	9,965
Gulf of	201-300	21,968	23,418	13,619	39,156	28,252	21,330	26,494	20,473	26,659	31,171	27,459
Alaska	301-500	23,390	27,872	13,220	37,017	28,394	28,063	22,415	23,800	19,639	26,549	31,030
(all areas)	501-700	--	14,952	--	21,360	18,213	16,409	17,790	13,491	14,503	11,774	11,885
	701-1000	--	6,531	--	--	13,947	13,920	9,009	--	--	12,047	--
	Total	**51,984**	**77,336**	**28,661**	**101,576**	**94,668**	**84,676**	**78,795**	**63,180**	**69,878**	**89,241**	**80,492**
	CV	7%	5%	8%	8%	4%	5%	5%	6%	7%	6%	7%
	Lower 95% CI	44,611	69,406	24,249	84,5499	86,893	76,132	70,445	55,313	60,049	77,916	69,254
	Upper 95% CI	59,356	85,265	33,074	118,602	102,444	93,220	87,146	71,046	79,707	100,567	91,730

Area	Depth (m)	1996	1999	2001	2003	2005	2007	2009	2011	2013	2015	2017
	1-100	0	4	0	0	63	0	0	17	0	0	17
	101-200	313	37	0	500	1,108	7	84	202	62	329	269
	201-300	3,115	2,248	3,981	6,017	5,550	2,910	7,094	1,082	4,012	4,578	5,680
Western	301-500	4,615	4,739	4,771	8,519	5,630	4,702	5,286	2,245	2,402	4,746	6,230
Gulf	501-700	--	5,389	--	5,887	6,377	2,590	5,605	2,272	2,739	2,733	2,740
	701-1000	--	1,679	--	--	3,277	1,943	719	--	--	1,147	--
	Total	**8,043**	**14,097**	**8,753**	**20,922**	**22,005**	**12,152**	**18,789**	**58,18**	**9,215**	**13,533**	**14,936**
	% of total biomass	15%	18%	31%	21%	23%	14%	24%	9%	13%	15%	19%
	1-100	0	2	46	54	103	131	13	0	0	37	86
	101-200	309	690	1,776	1,317	3,000	1,465	559	3,136	5,862	3,380	3,384
	201-300	10,456	10,605	9,638	25,386	13,545	8,190	11,880	9,239	10,000	18,635	15,524
Central	301-500	8,266	11,638	8,449	16,031	10,780	11,124	7,270	8,797	8,006	10,973	9,597
Gulf	501-700	--	6,725	--	10,463	6,728	8,962	5,365	6,885	8,196	4,666	4,845
	701-1000	--	2,930	--	--	8,262	7,736	3,469	--	--	7,214	--
	Total	**19,030**	**32,590**	**19,908**	**53,250**	**42,419**	**37,607**	**28,556**	**28,057**	**32,064**	**44,906**	**33,436**
	% of total biomass	37%	42%	69%	52%	45%	44%	36%	44%	46%	50%	42%
	1-100	0	111	--	0	14	81	73	0	0	0	51
	101-200	6,003	3,719	--	2,172	1,574	3,271	2,358	2,061	3,153	3,955	6,312
	201-300	8,398	10,565	--	7,753	9,157	10,230	7,520	10,152	12,646	7,958	6,255
Eastern	301-500	10,510	11,495	--	12,468	11,984	12,237	9,859	12,758	9,231	10,830	15,203
Gulf	501-700	--	2,838	--	5,011	5,108	4,858	6,820	4,334	3,569	4,374	4,301
	701-1000	--	1,922	--	--	2,408	4,241	4,821	--	--	3,686	--
	Total	**24,911**	**30,649**	**--**	**27,404**	**30,244**	**34,918**	**31,451**	**29,305**	**28,600**	**30,803**	**32,121**
	% of total biomass	48%	40%	--	27%	32%	41%	40%	46%	41%	35%	40%

Table 15-6. cont.

Area	Depth (m)	Longspine Thornyhead Biomass (t)										
		1996	1999	2001	2003	2005	2007	2009	2011	2013	2015	2017
Gulf of	1-100	0	0	0	0	0	0	0	0	0	0	0
Alaska (all areas)	101-200	0	0	0	0	0	0	0	0	0	0	0
	201-300	0	0	0	0	0	0	0	0	0	0	0
	301-500	0	0	0	0	0	0	2.3	0	0	0	0
	501-700	--	1,652	--	1,394	1,537	1,390	969	1,142	394	802	1,581
	701-1000	--	2,950	--	--	1,989	2,993	3,144	--	--	4,744	--
	Total	**0**	**4,602**	**0**	**1,394**	**3,526**	**4,383**	**4,116**	**1,142**	**394**	**5,546**	**1,581**
	CV	--	11%	--	11%	14%	12%	21%	27%	67%	19%	1%
	Lower 95% CI	--	3,515	--	950	2,390	2,903	1,726	177	0	2,610	1,543
	Upper 95% CI	--	5,689	--	1,838	4,661	5,863	6,505	2,107	1,526	8,483	1,618

Area	Depth (m)	Longspine Thornyhead Biomass (t)										
		1996	1999	2001	2003	2005	2007	2009	2011	2013	2015	2017
Western Gulf	1-100	0	0	0	0	0	0	0	0	0	0	0
	101-200	0	0	0	0	0	0	0	0	0	0	0
	201-300	0	0	0	0	0	0	0	0	0	0	0
	301-500	0	0	0	0	0	0	0	0	0	0	0
	501-700	--	10	--	31	0	0	0	0	0	0	0
	701-1000	--	285	--	--	0	0	0	--	--	0	--
	Total	0	295	0	31	0	0	0	0	0	0	0
	% of total biomass	--	6%	--	2%	--	--	--	--	--	--	--
Central Gulf	1-100	0	0	0	0	0	0	0	0	0	0	0
	101-200	0	0	0	0	0	0	0	0	0	0	0
	201-300	0	0	0	0	0	0	0	0	0	0	0
	301-500	0	0	0	0	0	0	0	0	0	0	0
	501-700	--	289	--	10	385	0	41	0	0	0	0
	701-1000	--	1,646	--	--	779	2,205	2,119	--	--	3,378	0
	Total	0	1,936	0	10	1,164	2,205	2,160	0	0	3,378	0
	% of total biomass	--	42%	--	1%	33%	50%	52%	--	--	61%	--
Eastern Gulf	1-100	0	0	--	0	0	0	0	0	0	0	0
	101-200	0	0	--	0	0	0	0	0	0	0	0
	201-300	0	0	--	0	0	0	0	0	0	0	0
	301-500	0	0	--	0	0	0	2.3	0	0	0	0
	501-700	--	1,353	--	1,353	1,152	1,390	928	1,142	394	802	1,581
	701-1000	--	1,019	--	--	1,210	787	1,025	--	--	1,366	--
	Total	0	2,372	--	1,353	2,362	2,177	1,955	1,142	394	2,169	1,581
	% of total biomass	--	52%	--	97%	67%	50%	48%	100%	100%	39%	100%

Table 15-7.--Shortspine thornyhead ecosystem considerations.

Ecosystem effects on GOA Thornyheads (evaluating level of concern for thornyhead populations)

Indicator	Observation	Interpretation	Evaluation
Prey availability or abundance trends			
Shrimp Benthic invertebrates Pelagic zooplankton	Trends are not currently measured directly Gulfwide. Shrimp biomass in isolated nearshore habitats may have declined since 1977, but it is unclear if all biomass declined, especially in deeper habitats occupied by thornyheads. Only short time series of food habits data exist for potential retrospective measurement	Unknown	Unknown
Predator population trends			
Arrowtooth flounder	Increasing since 1960's, leveling recently	Possibly higher mortality on thornyheads, but still small relative to fishing mortality	Probably no concern
Toothed whales	Unknown population trend	Predation mortality is small relative to fishing mortality	Probably no concern
Sharks	Unknown population trend	Predation mortality is small relative to fishing mortality	Probably no concern
Shortspine thornyheads	Adults prey on juveniles, but population biomass is apparently stable	Stable mortality on juvenile thornyheads	No concern
Changes in habitat quality			
Benthic slope habitats	Physical habitat requirements for thornyheads are unknown, and changes in deepwater habitats have not been measured in the Gulf of Alaska.	Unknown	Unknown
Fishery contribution to bycatch			
Sablefish fishery	GOA sablefish removes the highest weight of nontarget species bycatch of any GOA fishery, mostly grenadiers	Possible effects on grenadier populations, deep slope food webs	Possible concern
Rockfish fishery	Small bycatch of skates, grenadiers and other non-specified demersal fish	Catch of skates small relative to other fisheries	Probably no concern
Non-halibut flatfish fisheries	Small bycatch of skates, sculpins, and grenadiers, moderate bycatch of halibut	Catch of skates moderate relative to other fisheries	Probably no concern
Halibut fisheries	Bycatch unmonitored, high estimated bycatch of skates, moderate estimated bycatch of sharks, flatfish and rockfish	Catch of skates estimated high relative to all groundfish fisheries	Possible concern
Fishery concentration in space and time	Fisheries are widespread throughout the GOA, as are thornyheads	Unlikely impact	No concern
Fishery effects on amount of large size target fish	Poor length sampling of thornyheads from fisheries makes this difficult to evaluate	Unknown	Unknown
Fishery contribution to discards and offal production	High discard of grenadiers in sablefish fishery, lower offal production in all	Dead grenadiers affect energy flow?	Unknown
Fishery effects on age-at-maturity and fecundity	Lower thornyhead fecundity-at-length in 2005 than 1985 study could be methodology or real difference	Requires more investigation	Unknown

Figures

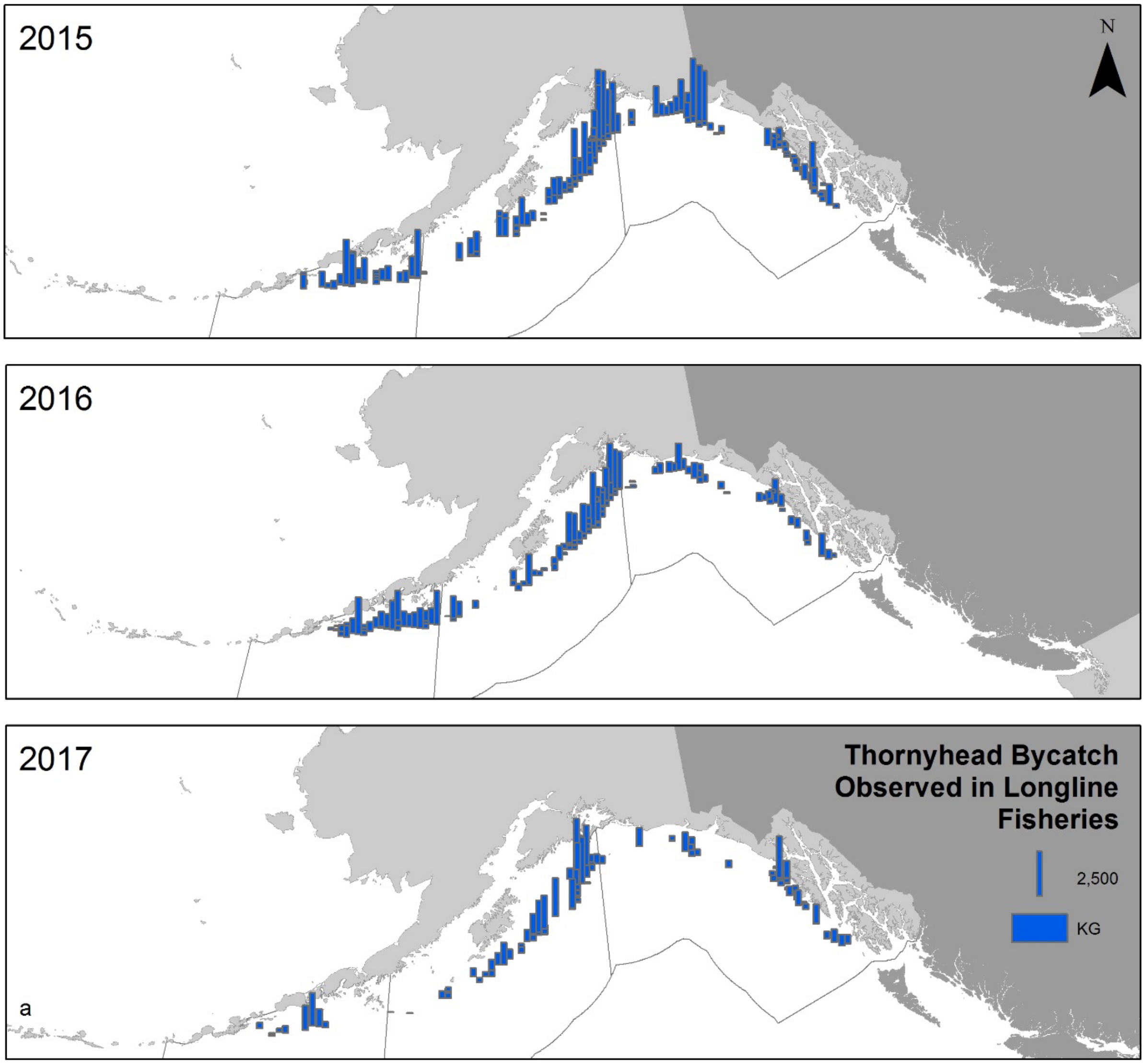

Figure 15-1.- Spatial distribution of observed thornyhead rockfish catch in the longline fisheries (top panel a) and in the trawl fisheries (bottom panel b) in the GOA from 2015 - 2017. Height of the bar represents the catch in kilograms. Each bar represents non-confidential catch data summarized into 400km^2 grids. Note that catch within the inside waters of Southeast are not within federal waters. Grid blocks with zero catch were not included for clarity. Data provided by the Fisheries Monitoring and Analysis division website, queried October 10, 2018 (http://www.afsc.noaa.gov/FMA/spatial_data.htm).

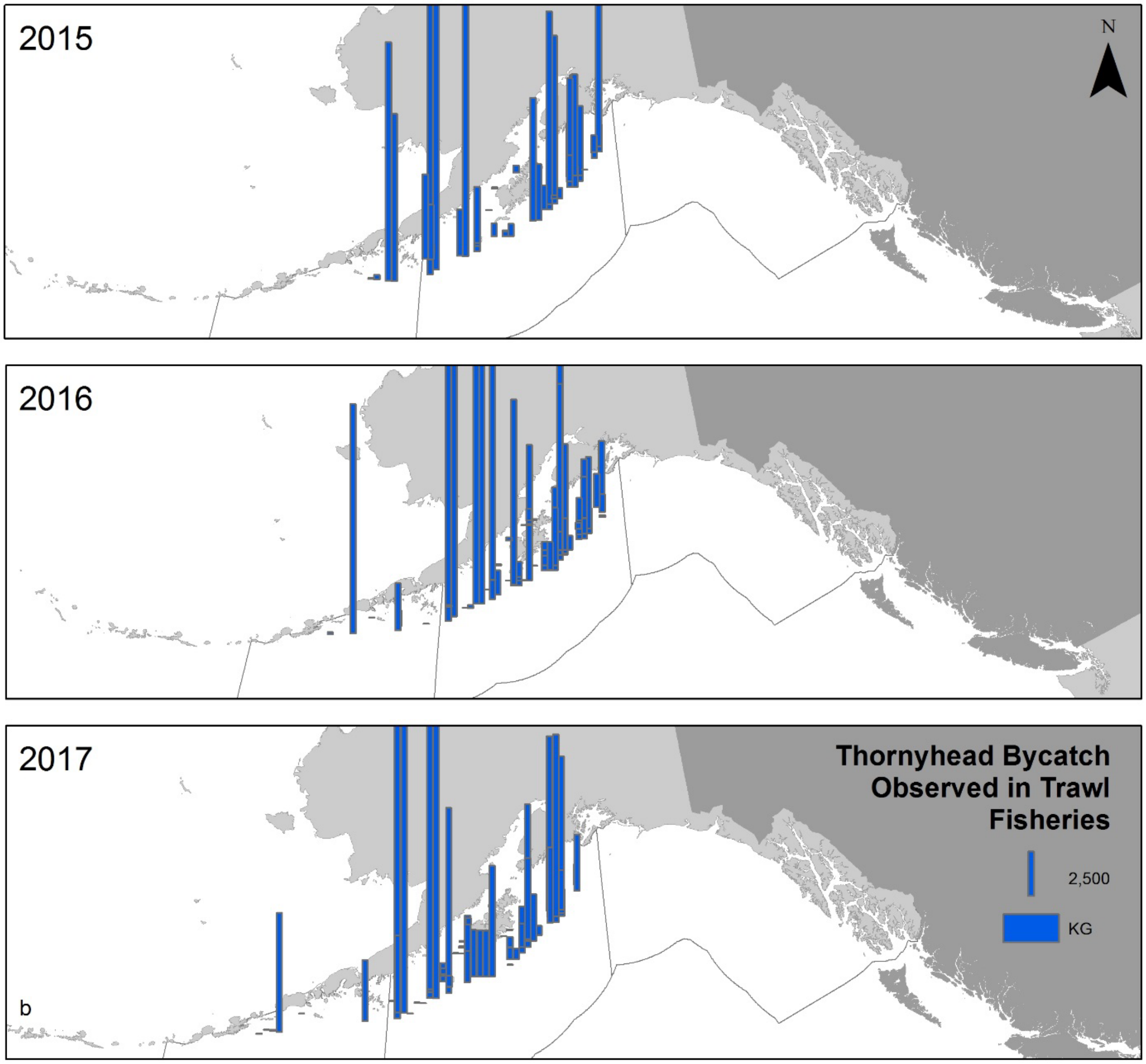

Figure 15-1.- -cont.

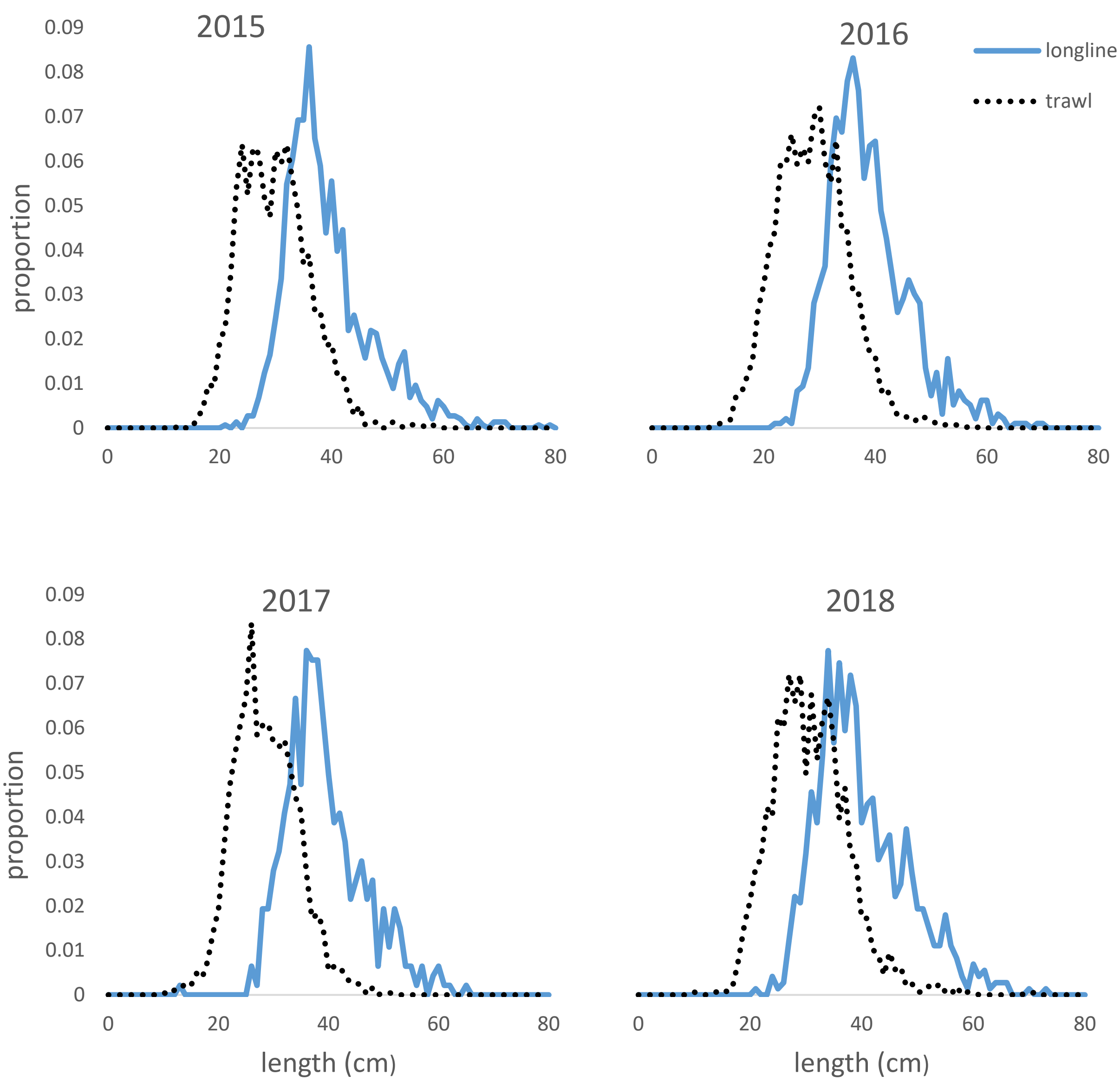

Figure 15-2.--Shortspine thornyhead lengths measured in trawl and longline fisheries, 2015-2018.

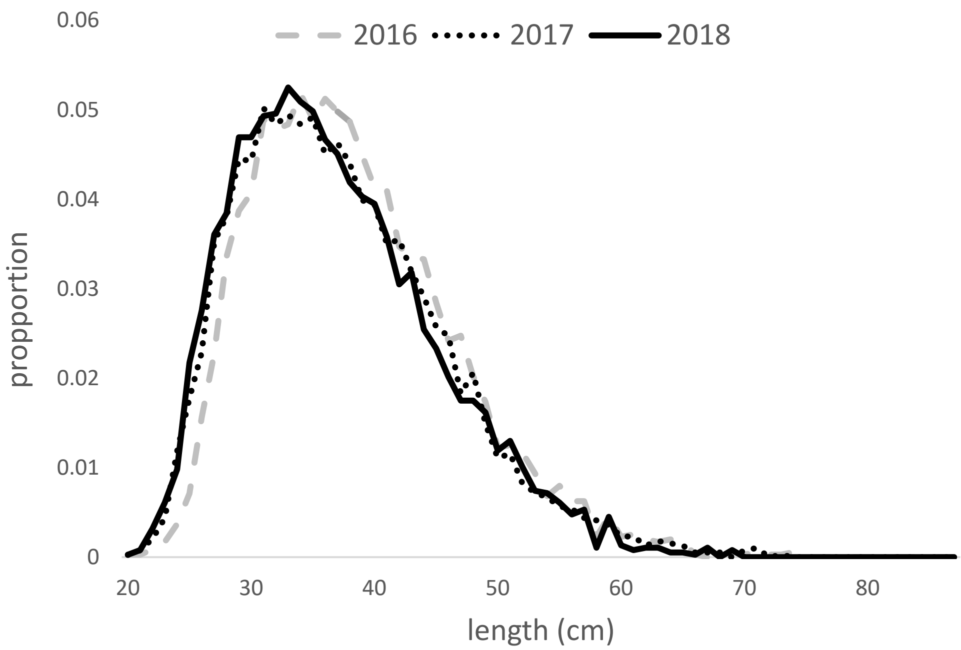

Figure 15-3.--Shortspine thornyhead length frequencies from the NMFS longline survey, 2016-2018.

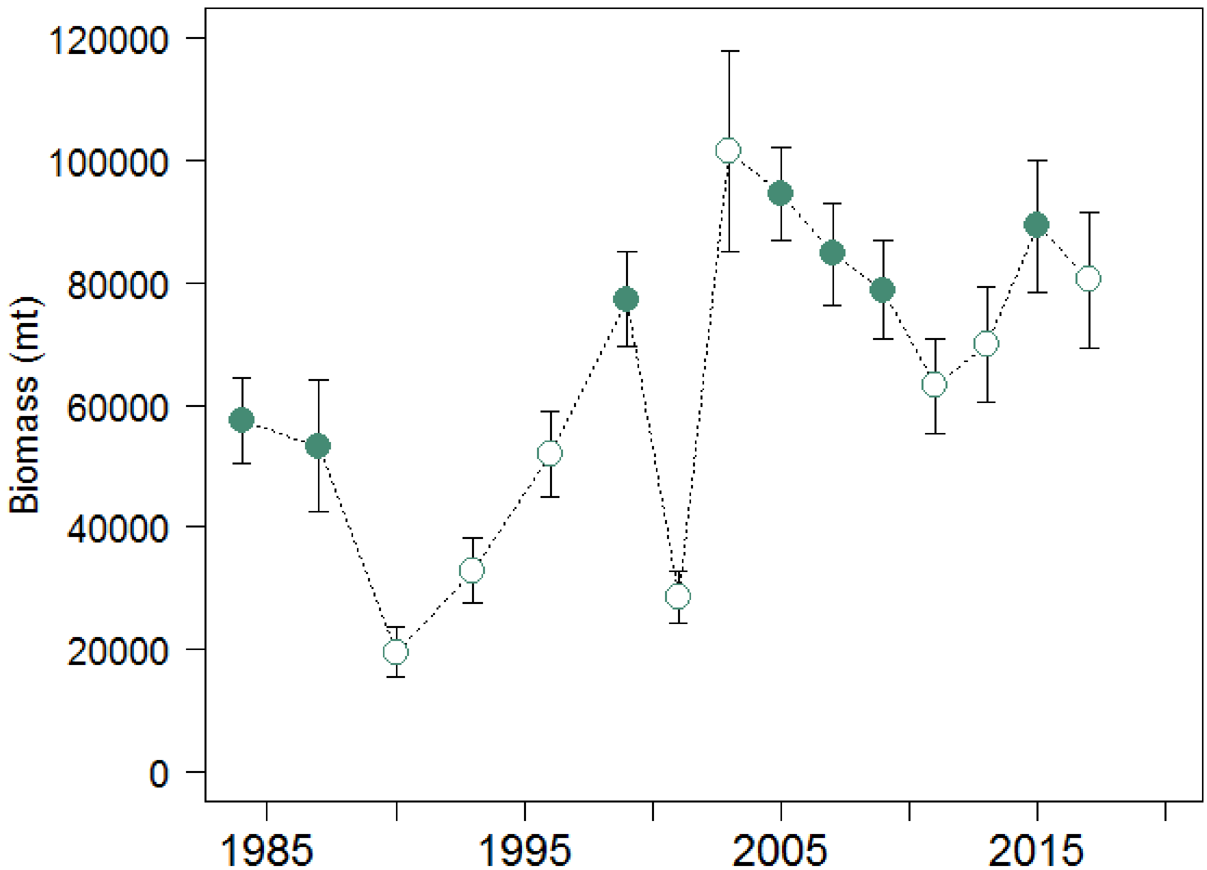

Figure 15-4.--Trawl survey biomass estimates for Gulf of Alaska (GOA) thornyhead rockfish. The 1990, 1993, 1996, and 2001 surveys did not survey depths >500 m. The 2003, 2011, 2013, and 2017 surveys did not survey depths >700 m. The 2001 survey also did not survey the Eastern GOA. The years with missing depth strata or regions are denoted by open circles.

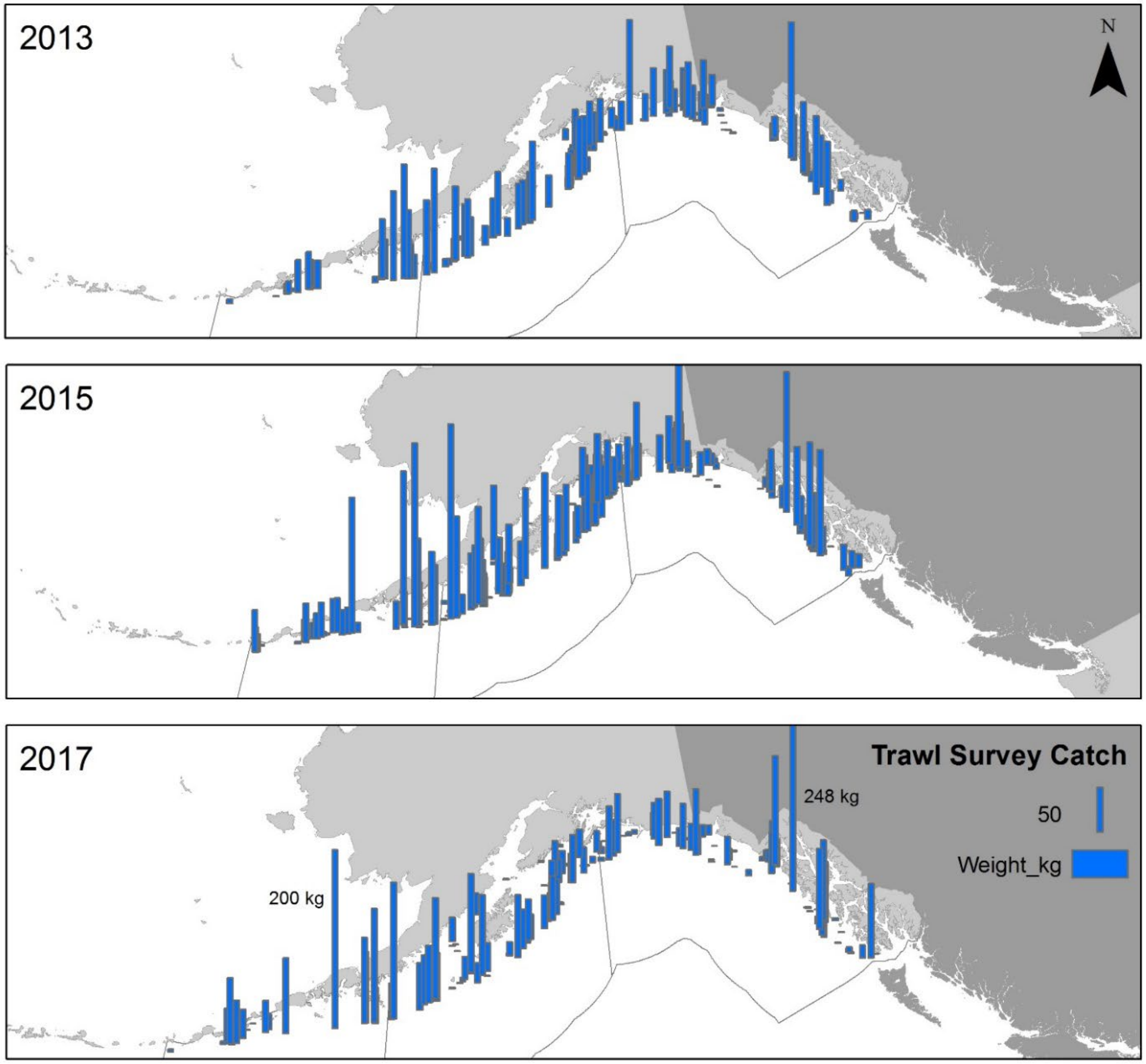

Figure 15-5.--Spatial distribution of thornyhead rockfish catches in the Gulf of Alaska 2013, 2015, and 2017 NMFS bottom trawl surveys.

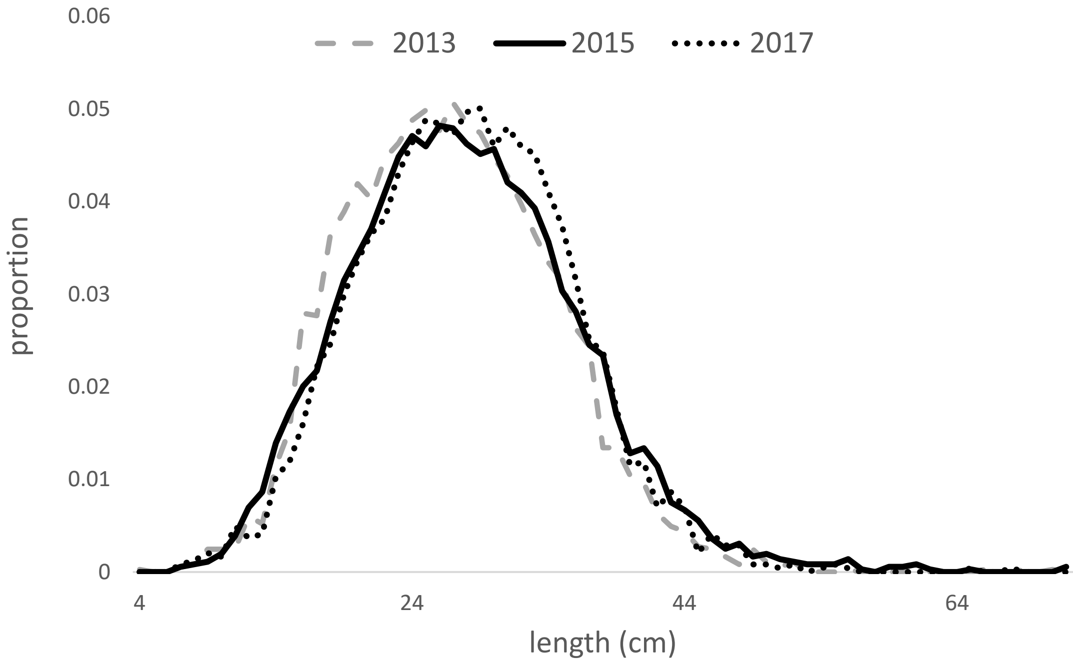

Figure 15-6.--Shortspine thornyhead length frequencies from the 2013, 2015, and 2017 trawl surveys.

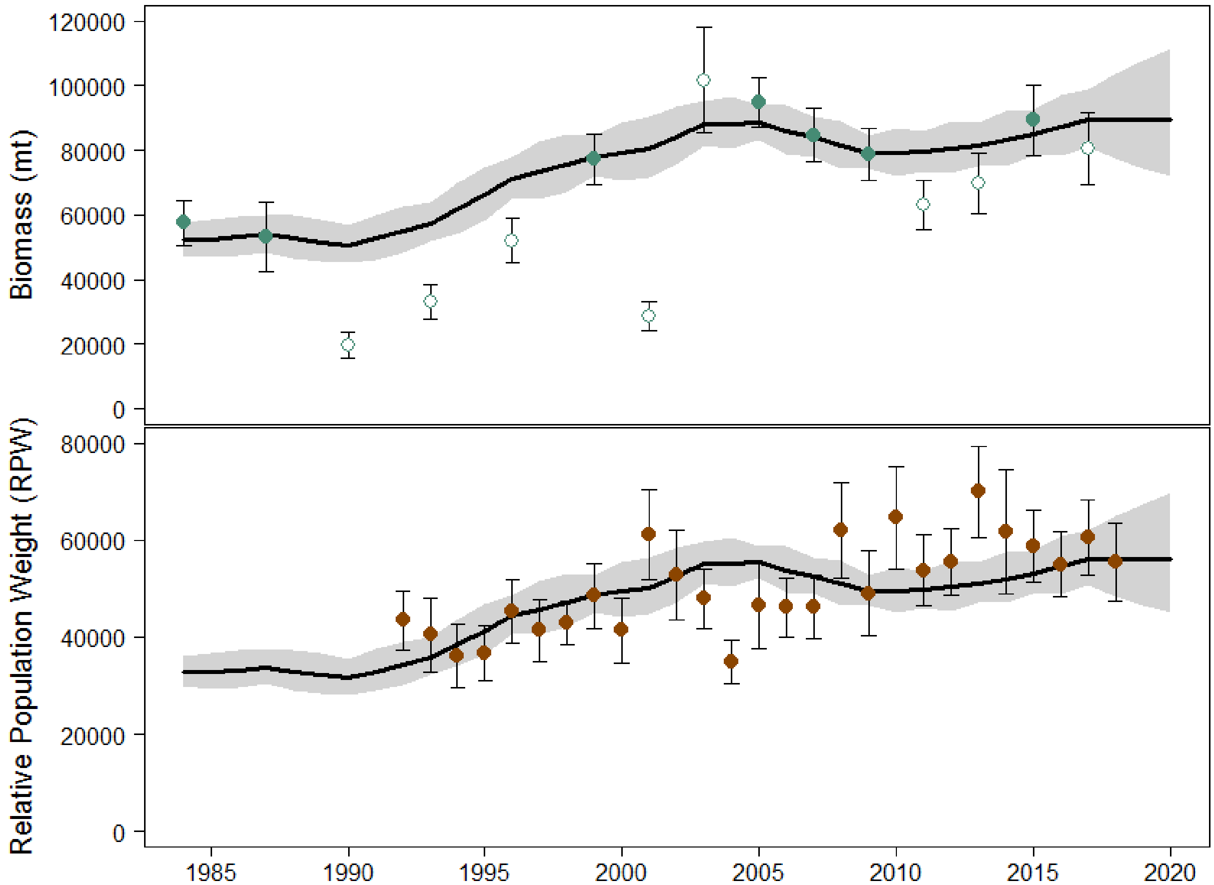

Figure 15-7.--Biomass estimates (t, top panel) of thornyhead rockfish from the random effects model (solid black line with 95% confidence interval in grey shaded region) for the AFSC bottom trawl survey (filled circle with error bars for 95% confidence intervals, open circles denotes years with missing regional/depth strata data), and Relative Population Weight estimates (RPW, lower panel) from the random effects model (solid black line with 95% confidence interval in grey shaded region) for the AFSC longline survey (filled circle with error bars for 95% confidence intervals).

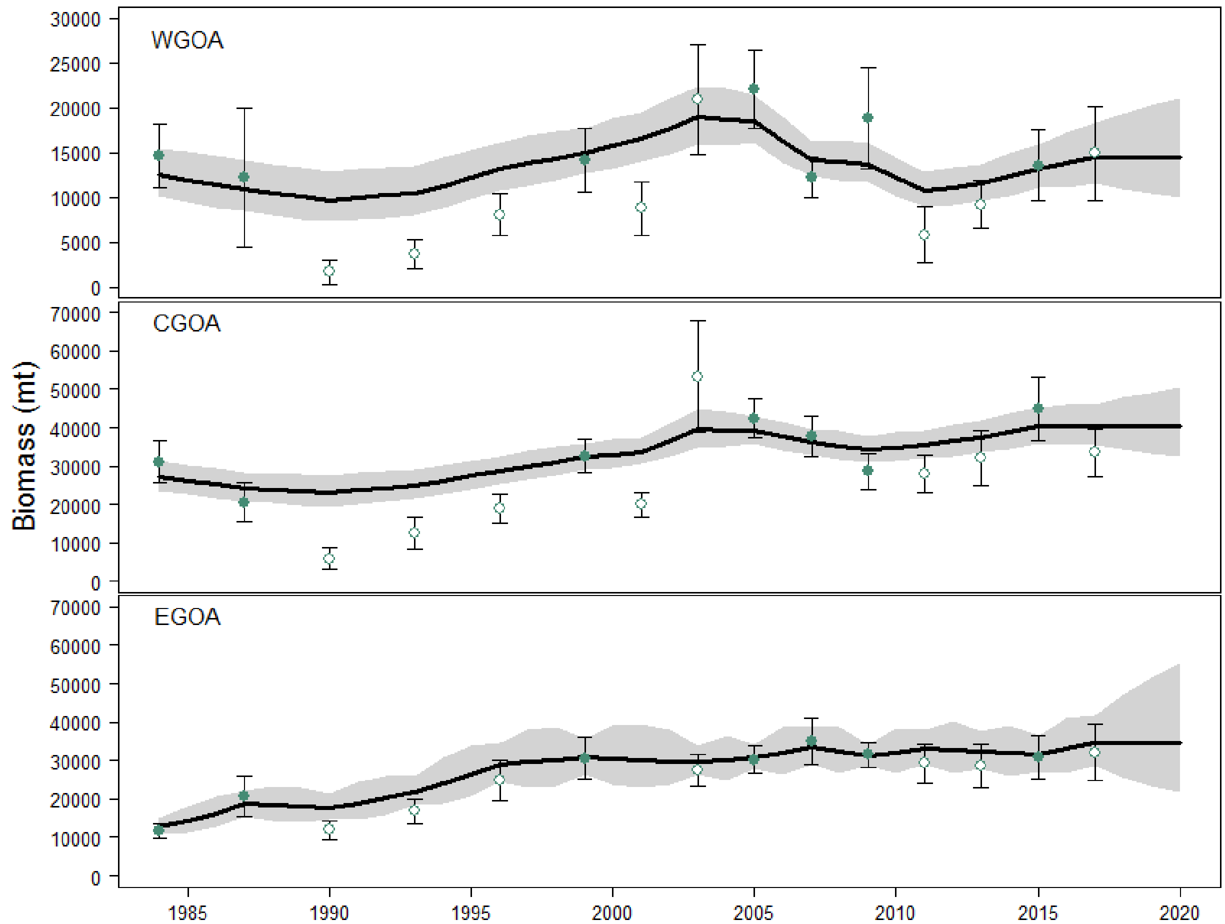

Figure 15-8.-- Biomass estimates (t) of thornyhead by area from NMFS bottom trawl surveys (filled circle with error bars for the 95% confidence intervals) fit to the recommended random effects model (solid black line with 95% confidence intervals shown in grey shaded region). Open circle points in the figure denote years with missing depth strata data. Top panel is the Western Gulf of Alaska (WGOA) area, middle panel is the Central Gulf of Alaska (CGOA) area, and bottom panel is the Eastern Gulf of Alaska (EGOA) area. Please note the different scales between panels on the y-axis.

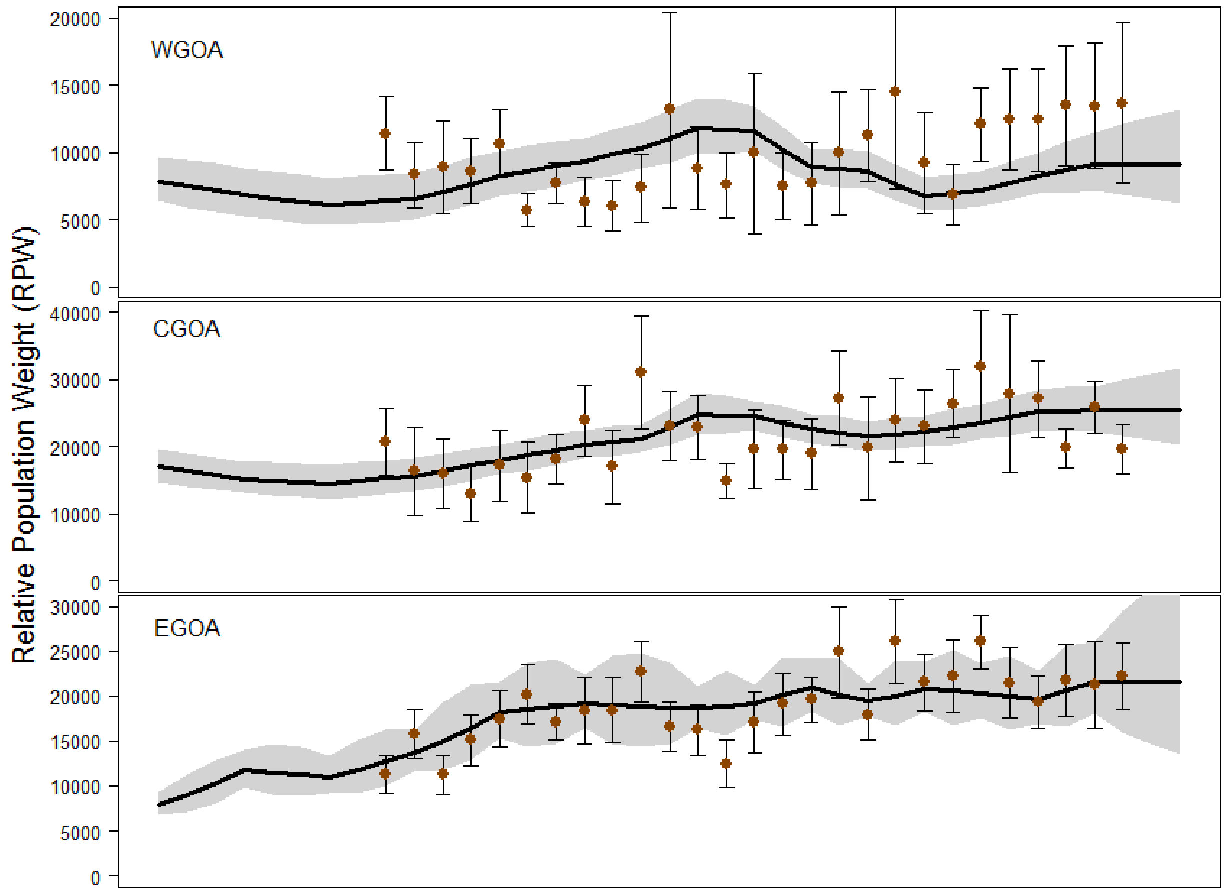

Figure 15-9.- - Relative Population Weight (RPW) of thornyhead by area from AFSC longline surveys (filled circle with error bars for the 95% confidence intervals) fit to the recommended random effects model (solid black line with 95% confidence intervals shown in grey shaded region). Please note the different scales between panels on the y-axis.

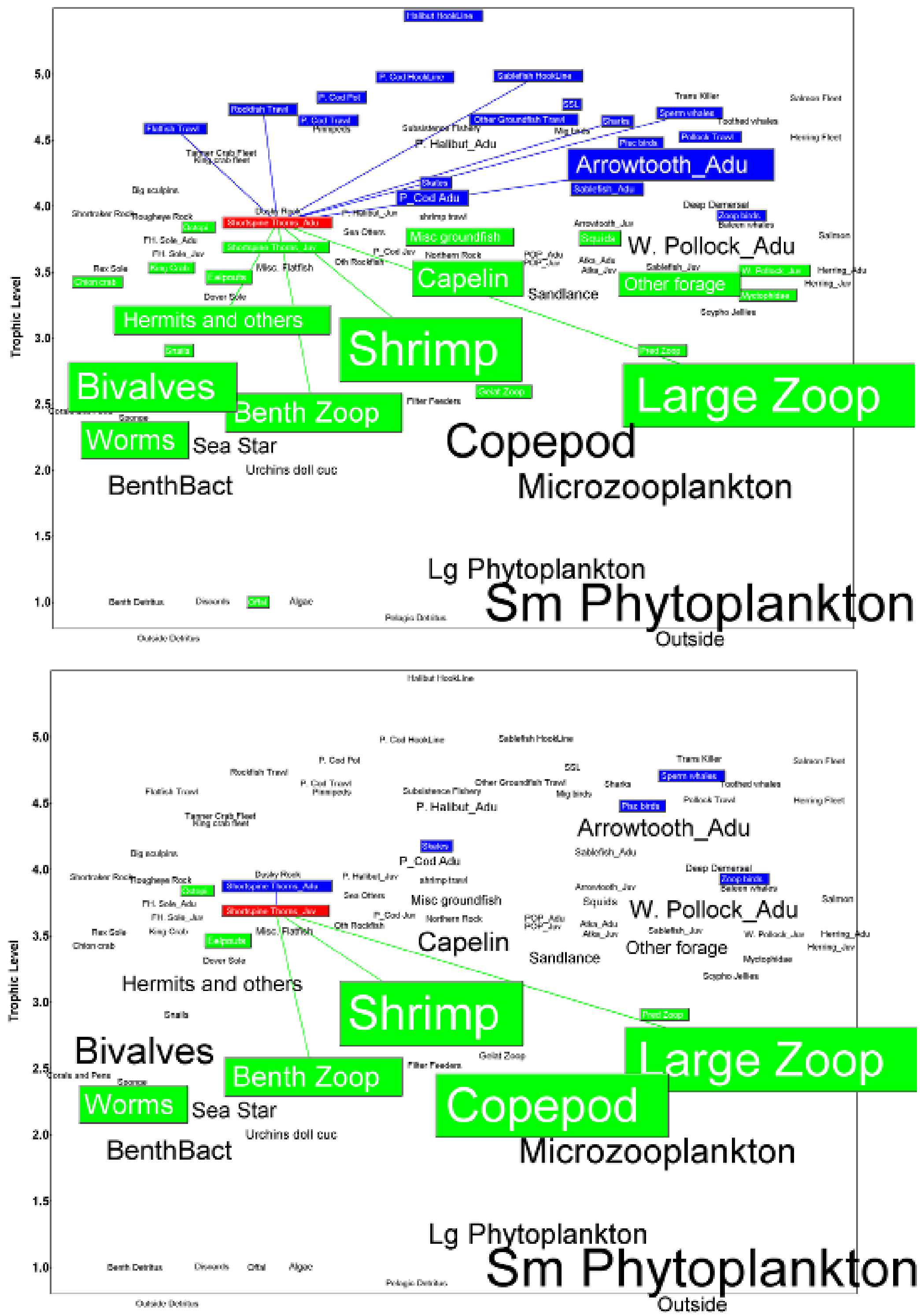

Figure 15-10.--Position of shortspine thornyheads within GOA food webs: adults (marked red in upper panel) and juveniles (marked red in lower panel). Groups shaded blue are predators of shortspine thornyheads, and groups shaded green are prey. Similar information for longspine thornyheads is not available.

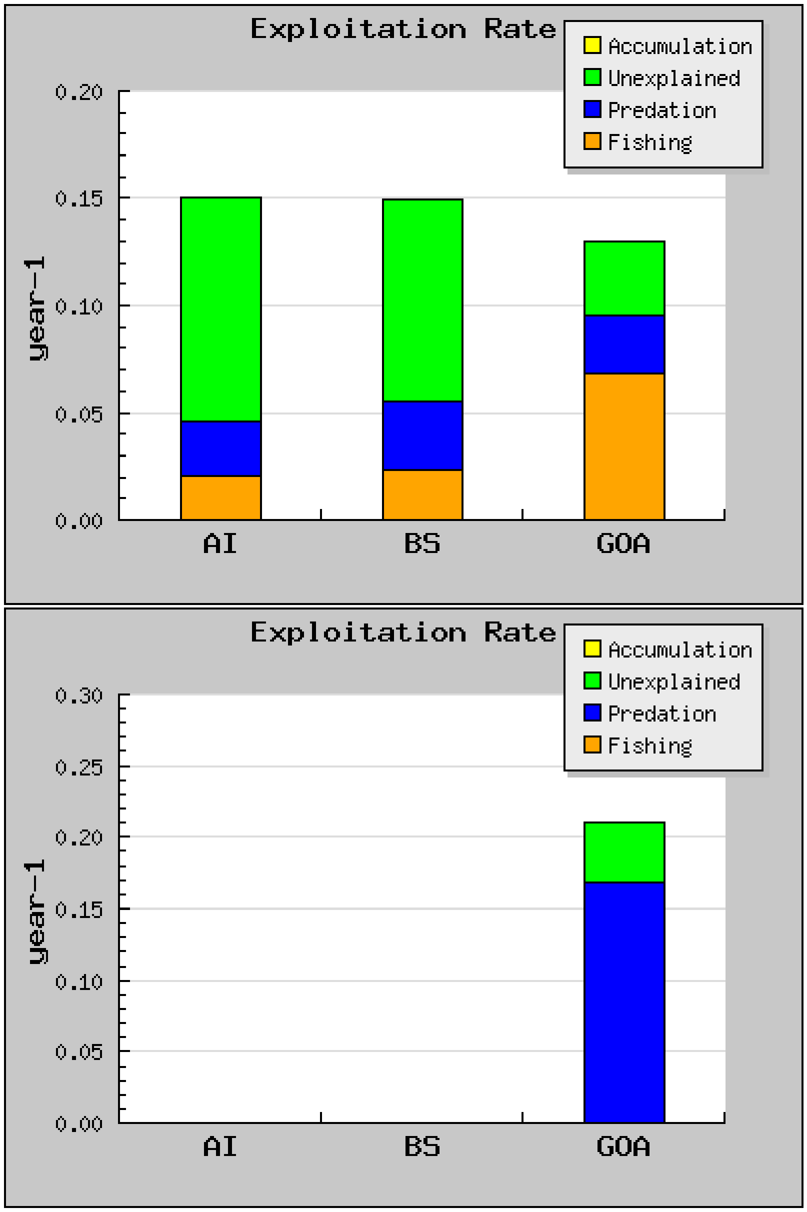

Figure 15-11.--Comparison of exploitation rates for shortspine thornyheads across Alaskan ecosystems. Adult shortspine thornyheads (upper panel) have higher predation than fishing mortality in the AI and EBS, but higher fishing mortality in the GOA. Juvenile shortspine thornyheads (lower panel) were only modeled in the GOA, where they do not experience fishing mortality but do experience substantial predation mortality. Because juvenile thornyheads were not explicitly modeled in AI and EBS ecosystem models, juvenile mortality is included along with adult mortality in the top panel for AI and EBS, which exaggerates the differences between predation and fishing mortality between the two systems.

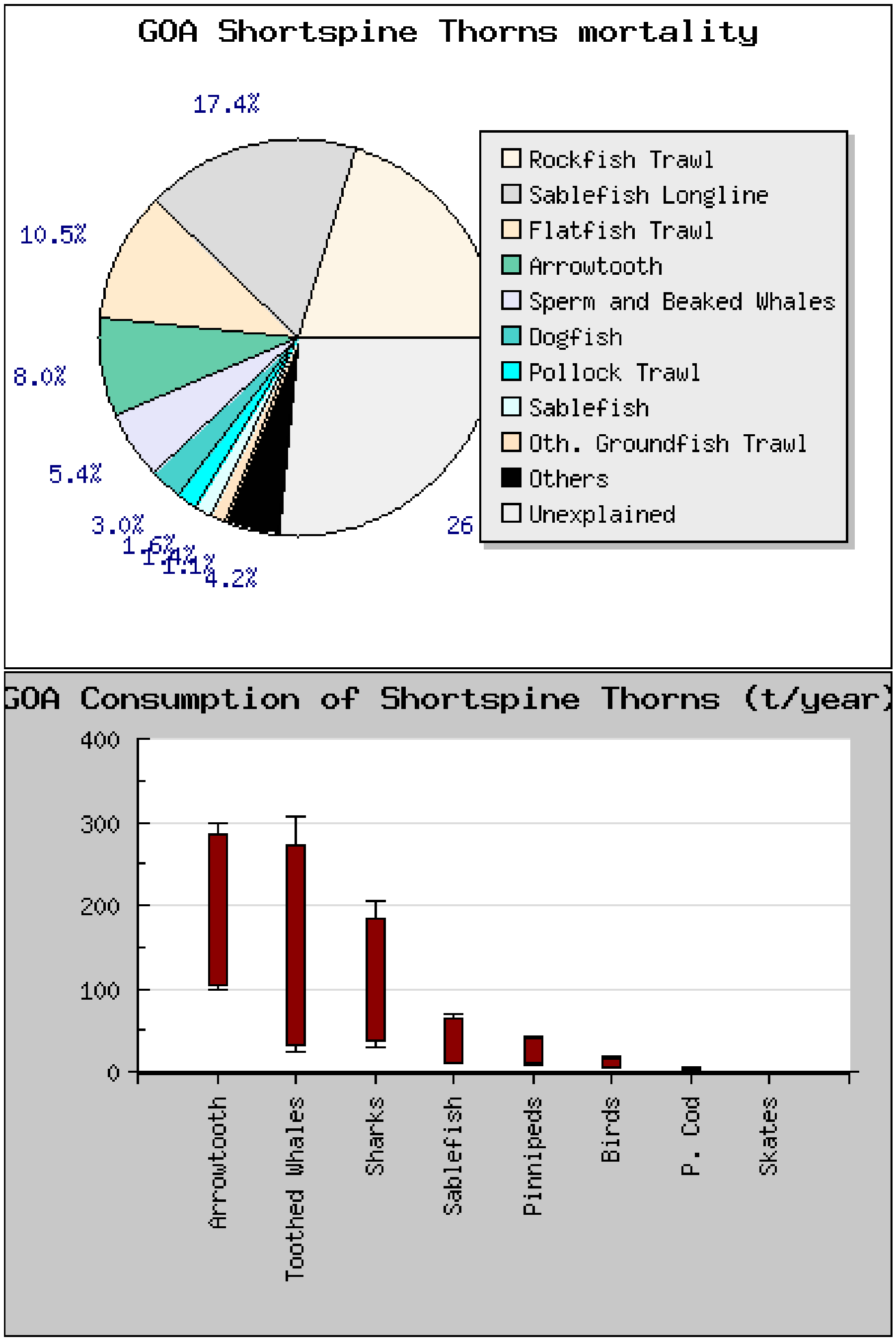

Figure 15-12.--Mortality sources (upper panel) and annual consumption in tons (lower panel) by predators of adult shortspine thornyheads in the GOA. Fisheries for rockfish, sablefish, and flatfish account for nearly 50% of total adult shortspine thornyhead mortality, while all predators combined account for about 25% of total mortality.

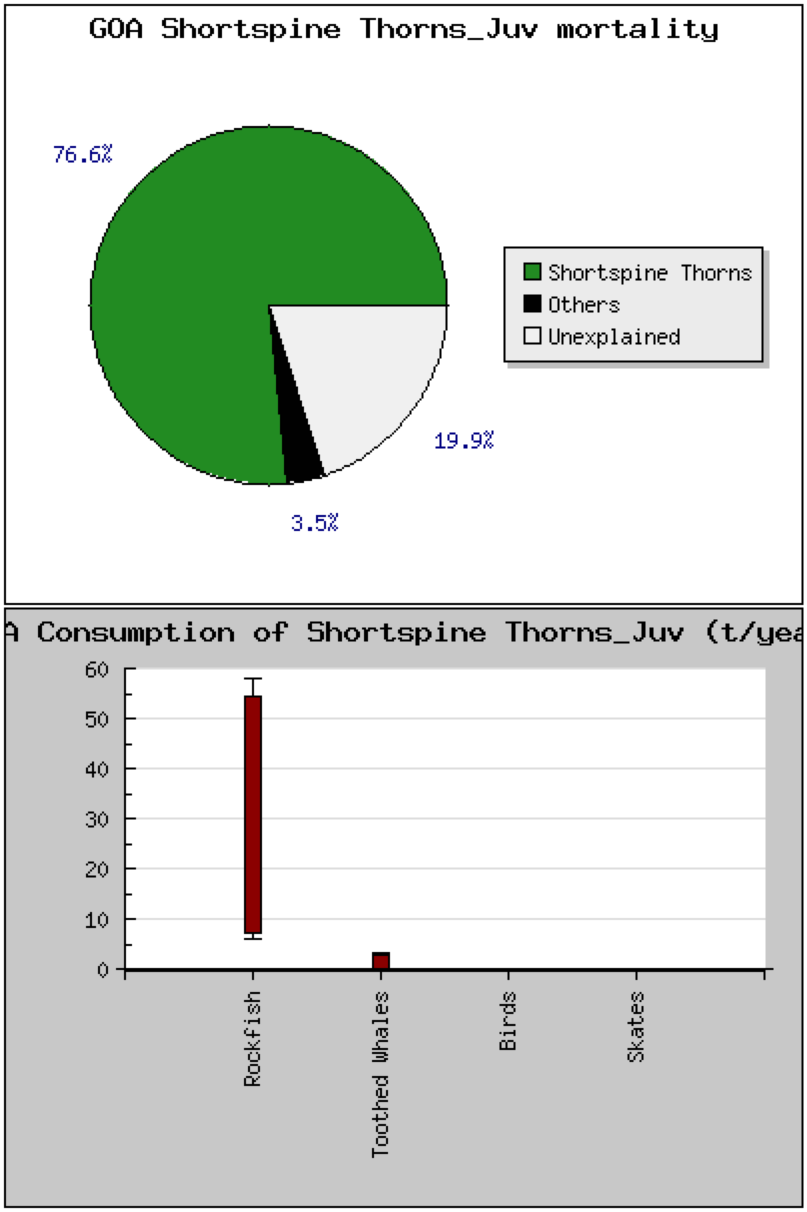

Figure 15-13.--Mortality sources (upper panel) and annual consumption in tons (lower panel) by predators of juvenile shortspine thornyheads in the GOA. “Rockfish” in the lower panel refers to adult thornyheads, which account for more than 75% of juvenile thornyhead mortality via cannibalism.

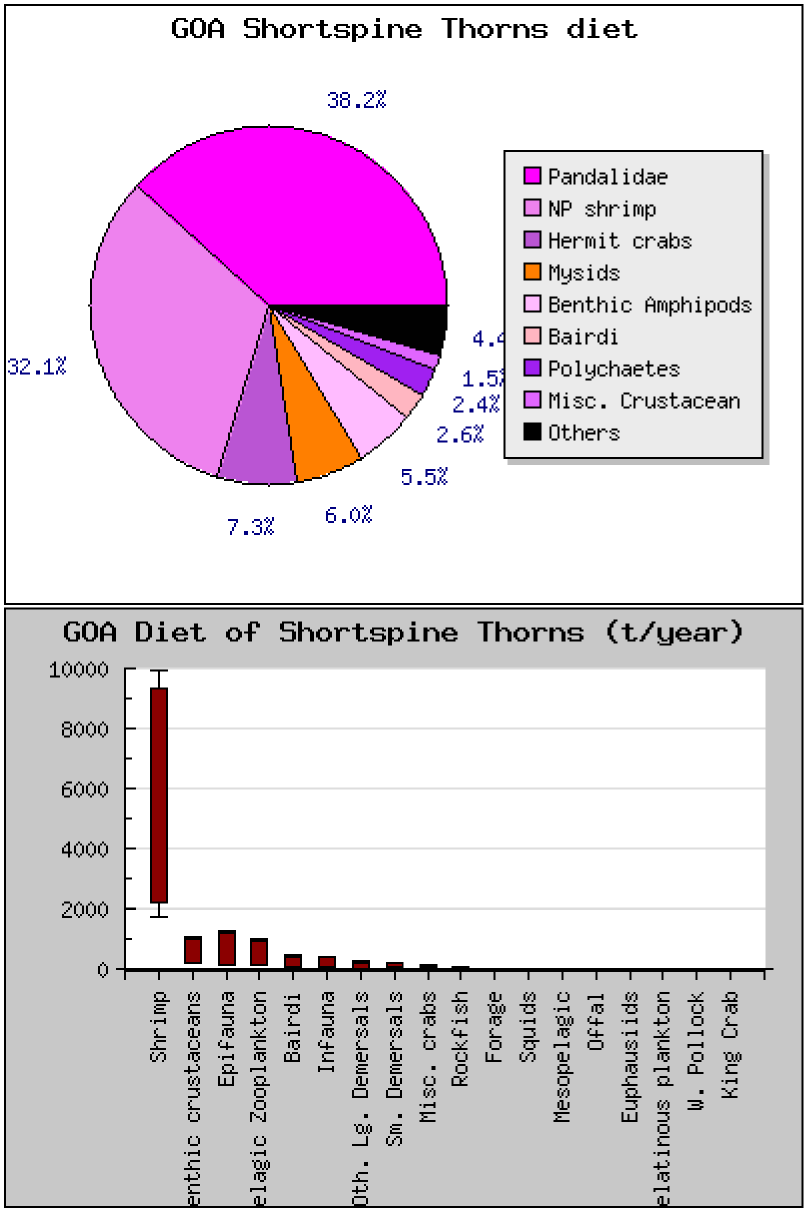

Figure 15-14.--Diet composition (upper panel) and annual consumption of prey in tons (lower panel) by adult shortspine thornyheads in the GOA.

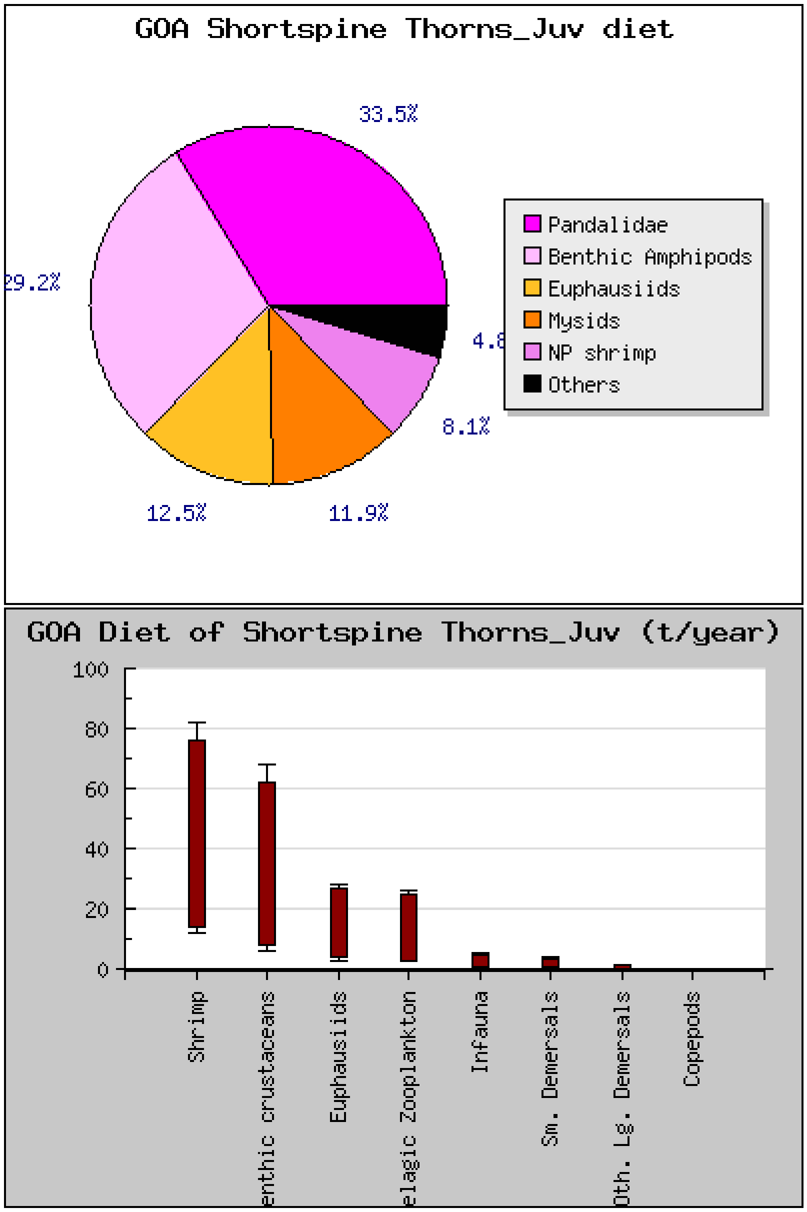

Figure 15-15.--Diet composition (upper panel) and annual consumption of prey in tons (lower panel) by juvenile shortspine thornyheads in the GOA.

Appendix 15A – Supplemental catch data

In order to comply with the Annual Catch Limit (ACL) requirements, non-commercial removals in the Gulf of Alaska (GOA) are presented. Non-commercial removals are estimated total removals that do not occur during directed groundfish fishing activities (Table 15A-1). This includes removals incurred during research, subsistence, personal use, recreational, and exempted fishing permit activities, but does not include removals taken in fisheries other than those managed under the groundfish FMP. These estimates represent additional sources of removals to the existing Catch Accounting System estimates.

Research catches of thornyhead rockfish for the years 1977-2017 are listed in Table 15A-1. Although data are not available for a complete accounting of all research catches, the values in the table indicate that generally these catches have been modest. The majority of research removals of thornyhead rockfish are taken by the Alaska Fisheries Science Center's (AFSC) annual longline survey. Other research activities that harvest minor amounts of thornyhead rockfish include other trawl research activities conducted by the AFSC and the Alaska Department of Fish and Game (ADFG), and the International Pacific Halibut Commission's (IPHC) longline survey. There are no records of recreational harvest or harvest that was non-research related. The non-commercial removals show that a total of almost 16 t of thornyhead rockfish was taken in 2017 during research cruises (Table 15A-1). This total is approximately 1.5% of the reported commercial catch of 1,021 t for thornyhead rockfish in 2017 (see Table 15-1 in the main document). Therefore, this presents no risk to the stock especially because commercial catches in recent years have been much less than ABCs.

Table 15A-1.--Research catches of GOA thornyheads (t), 1977-2017. Estimates from IPHC survey and "other" sources only available since 2010.

Year	Domestic Longline Survey	Trawl Survey	Japan US Longline Survey	IPHC Survey	Other	Total research catch
1977		1				1
1978		1				1
1979		5	3			8
1980		1	5			6
1981		10	5			14
1982		6	4			10
1983		1	4			5
1984		24	3			27
1985		12	4			16
1986		2	4			5
1987		17	4			20
1988	2	0	5			7
1989	3	0	5			8
1990	3	4	4			11
1991	4		3			7
1992	5		4			9
1993	5	5	4			14
1994	4		5			9
1995	5					5
1996	6	6				12
1997	6					6
1998	6	9				15
1999	6	23				29
2000	5					5
2001	7	2				9
2002	5					5
2003	5	7				12
2004	4					4
2005	5	9				14
2006	5					5
2007	5	9				14
2008	7					7
2009	6	7				13
2010	9	<1		<1	<1	9
2011	10	4		<1	<1	14
2012	9			<1	<1	9
2013	13	4		<1	<1	17
2014	10			<1	<1	10
2015	10	8		0.5		18.5
2016	9			<1		9
2017	11	5		<1		16