Assessment of the Grenadier Stock Complex in the Gulf of Alaska, Eastern Bering Sea, and Aleutian Islands

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Executive Summary

In 2015, a final rule was issued adding the grenadier stock complex as an Ecosystem Component to the Gulf of Alaska (GOA) and Bering Sea and Aleutian Islands (BSAI) Fishery Management Plans (FMPs) under Amendments 100/91. Prior to this rule they were not in the FMPs (i.e., "nonspecified"). Under this rule, grenadiers are not allowed to be targeted, but there is an 8% Maximum Retainable Allowance (MRA) (Federal Register, Proposed Rules, Vol. 79, No. 93).

As an Ecosystem Component, conservation, management, and a grenadier stock assessment is not required. There are no ABC or OFL catch limits adopted in the annual groundfish harvest specifications. However, this abbreviated SAFE report, for the BSAI and GOA combined, is presented for tracking trends in abundance and catch and provides unofficial OFL and ABC values based on Tier 5 calculations. Because overfishing is not defined for an Ecosystem Component, these values are not used for management or for determining if overfishing is occurring. Through the SAFE prioritization process, the grenadier assessment is now on a 4-year cycle. The last grenadier SAFE report was completed in 2016.

Summary of Changes in Assessment Inputs

Changes in the input data: New data inputs include: 1) updated catch data through September 22, 2020; 2) 2018 and 2020 Aleutian Island (AI) biomass using the estimation method presented in the 2012 SAFE; 3) NMFS longline survey Relative Population Weights (RPWs) in the Gulf of Alaska (GOA) for 2017-2020, in the Eastern Bering Sea (EBS) for 2017 and 2019, and in the AI for 2018 and 2020, and 4) updated GOA trawl survey biomass time series through 2019 using a random effects model.

Summary of Results

The unofficial maximum allowable ABC for 2021 is 61,738 mt in the BSAI and 21,623 mt in the GOA. Compared to the last SAFE completed in 2016, this is a 12% decrease in the BSAI and a 27% decrease in the GOA. The corresponding reference values for grenadier are summarized in the following tables, with the unofficial ABC and OFL values in bold. Overfishing is not occurring in either the BSAI or GOA. Catches are not approaching unofficial OFLs.

Gulf of Alaska Grenadier

Quantity	As estimated or specified in the *last* SAFE[1] for: 2017	2018	As estimated or recommended *this* year for: 2021	2022
M (natural mortality)	0.078	0.078	0.078	0.078
Specified/recommended Tier	5	5	5	5
Biomass (mt)	507,888	507,888	369,618	369,618
F_{OFL} (F=M)	0.078	0.078	0.078	0.078
$maxF_{ABC}$ (maximum allowable = 0.75*x* F_{OFL})	0.0585	0.0585	0.0585	0.0585
F_{ABC}	0.0585	0.0585	0.0585	0.0585
OFL (mt)	39,615	39,615	**28,830**	28,830
maxABC (mt)	29,711	29,711	**21,623**	21,623
ABC (mt)	29,711	29,711	**21,623**	21,623
Status	As determined in the *last* SAFE for: 2015	2016	As determined *this* year for: 2019	2020
Overfishing	No	n/a	No	n/a

[1]The last SAFE was is 2016.
The grenadier stock complex is an Ecosystem Component and, therefore, ABCs or OFLs are not used for catch specification.

Bering Sea and Aleutian Islands Grenadier

Quantity	As estimated or specified in the *last* SAFE[1] for: 2017	2018	As estimated or recommended *this* year for: 2021	2022
M (natural mortality)	0.078	0.078	0.078	0.078
Specified/recommended Tier	5	5	5	5
Biomass (mt)	1,197,110	1,197,110	1,055,348	1,055,348
F_{OFL} (F=M)	0.078	0.078	0.078	0.078
$maxF_{ABC}$ (maximum allowable = 0.75*x* F_{OFL})	0.0585	0.0585	0.0585	0.0585
F_{ABC}	0.0585	0.0585	0.0585	0.0585
OFL (mt)	93,375	93,375	**82,317**	82,317
maxABC (mt)	70,031	70,031	**61,738**	61,738
ABC (mt)	70,031	70,031	**61,738**	61,738
Status	As determined in the *last* SAFE for: 2015	2016	As determined *this* year for: 2019	2020
Overfishing	No	n/a	No	n/a

[1]The last SAFE was is 2016.
The grenadier stock complex is an Ecosystem Component and, therefore, ABCs or OFLs are not used for catch specification.

Tier 5 computations for grenadier OFL and ABC (mt) are summarized by region (AI = Aleutian Islands, EBS = Eastern Bering Sea, GOA = Gulf of Alaska) for 2021:

BSAI and GOA Grenadiers

Area	Biomass	Natural mortality *M*	OFL definition	OFL	ABC definition	ABC
EBS	564,778	0.078	biom x *M*	44,053	OFL x 0.75	33,040
AI	490,570	0.078	biom x *M*	38,264	OFL x 0.75	28,698
BSAI total	1,055,348			82,317		61,738
GOA	369,618	0.078	biom x *M*	28,830	OFL x 0.75	21,623
Grand total	1,424,966			111,147		83,361

The grenadier stock complex is an Ecosystem Component and, therefore, ABCs or OFLs are not used for catch specification.

Summaries for Plan Team

In the summary table below, the 2019 and 2020 biomass estimates and ABCs are from the last SAFE, which was in 2016, so that 2019 and 2020 catches could be reported.

Complex	Year	BSAI Biomass	BSAI ABC	BSAI Catch[1]	GOA Biomass	GOA ABC	GOA Catch[1]	Total Catch[1]
grenadiers	2019	1,197,110	70,031	2,142	507,888	29,711	4,601	6,743
	2020	1,197,110	70,031	2,016	507,888	29,711	2,213	4,229
	2021	1,055,348	61,738		369,618	21,623		
	2022	1,055,348	61,738		369,618	21,623		

[1]Current as of September 21, 2020. Source: NMFS Alaska Regional Office Catch Accounting System via the Alaska Fisheries Information Network (AKFIN) database (http://www.akfin.org).

SSC and Plan Team Comments on Assessments in General

There were no comments on assessments in general that pertains to this assessment.

SSC and Plan Team Comments Specific to this Assessment

There were no comments for this assessment.

Introduction

Grenadiers (family Macrouridae) are deep-sea fishes related to hakes and cods that occur world-wide in all oceans. Also known as "rattails", they are especially abundant in waters of the continental slope, but some species are found at abyssal depths. At least seven species of grenadier are known to occur in Alaskan waters, but only three are commonly found at depths shallow enough to be encountered in commercial fishing operations or in fish surveys: giant grenadier (*Albatrossia pectoralis*), Pacific grenadier (*Coryphaenoides acrolepis*), and popeye grenadier (*Coryphaenoides cinereus*) (Mecklenburg et al. 2002). Of these, giant grenadier has the shallowest depth distribution and the largest estimated biomass, and hence is by far the most frequently caught grenadier species in Alaska. As such, this report will emphasize giant grenadier.

Distribution: Giant grenadier range from Baja California, Mexico around the arc of the north Pacific Ocean to Japan, including the Bering Sea and the Sea of Okhotsk (Mecklenburg et al. 2002), and they are also found on seamounts in the Gulf of Alaska and on the Emperor Seamount chain in the North Pacific (Clausen 2008). In Alaska, they are especially abundant on the continental slope in waters >400-m depth. The densest giant grenadier catches in Russia occur in temperatures ranging from 1.8 to3.7 ℃. Females and males have different depth distributions, with females inhabiting shallower depths than males. For example, nearly all fish <600-m depth were female in Russian waters (Novikov 1970) and Alaskan waters (Clausen 2008). Presumably, some vertical migration of one or both sexes must occur for spawning purposes. Although the majority of surveys only sample down to 1,000 m, giant grenadier were caught in a deep-water (1,000-1,500 m) experimental survey in the western Gulf of Alaska (Clausen and Rodgveller 2013).

Distribution of Pacific and popeye grenadier: Pacific grenadier have a geographic range nearly identical to that of giant grenadier, i.e., Baja California, Mexico to Japan. Popeye grenadier range from Oregon to Japan. Compared to giant grenadier, both species are much smaller and generally found in deeper water. They appear to be most abundant in waters >1,000 m, which is deeper than virtually all commercial fishing operations and fish surveys in Alaska. For example, in a recent experimental longline haul in the western Gulf of Alaska at a depth of 1400-1500 m, 56% of the hooks caught Pacific grenadier (Clausen and Rodgveller 2013). This indicates that at least in some locations in deep-water, abundance of Pacific grenadier in Alaska can be extremely high. Few popeye grenadier are caught on longline gear, apparently because of the relatively small size of these fish, and most of the information on this species comes from trawling. Food studies off the U.S. West Coast indicate that Pacific grenadier are more benthic in their habitat than are giant grenadier, as the former species fed mostly on bottom organisms such as polychaetes, mysids, and crabs (Drazen et al. 2001).

Speciation and stock structure: Previous publications (Clausen 2006 and 2008) speculated that more than one species of giant grenadier may exist in Alaska because two morphs of the fish have been observed based primarily on the relative size of the eye to the head, as well two different patterns of otolith morphology and associated body growth, with a third of intermediate shape and growth (Rodgveller et al. 2017). Tissue and otoliths samples were collected on the Alaska Fisheries Science Center (AFSC) longline survey in 2013 for a more definitive analysis of speciation and stock structure. COI gene sequence data, regularly used by the Fish Barcode of Life Initiative (FISH-BOL) for species identification, failed to separate samples by otolith shape and had extremely low variation, indicating that there was only one species (Rodgveller et al. 2017). The reasons for the extreme variation in shape are still unknown. They may be related to differences in habitat, but there is no information on grenadier distribution in Alaska prior to when they settle to a demersal life at approximately age 14. There is also no data on movement from tagging studies because all grenadier die when brought to the surface due to barotrauma.

Biology: Giant grenadier are long-lived and late to mature, with an age at 50% maturity of 23 years old. The spawning period is thought to be protracted and may even extend throughout the year (Novikov 1970; Rodgveller et al. 2010); however, no larvae have been collected in Alaska. Small, juvenile fish less than ~15-20 cm pre-anal fin length (PAFL) are virtually absent from bottom trawl catches (Novikov 1970; Ronholt et al. 1994; Hoff and Britt 2009, 2011), and juveniles may be pelagic in their distribution. Because the long tapered tails of grenadiers are frequently broken off when the fish are caught, PAFL is the standard unit of length measurement for these fish. PAFL is defined to be the distance between the tip of the snout and the insertion of the first anal fin ray. Giant grenadier are the largest of the world's grenadier species (Iwamoto and Stein 1974); maximum weight of one individual in a NMFS Bering Sea trawl survey was 41.8 kg.

Ecology: There is little known about the habitat and ecological relationships of giant grenadier. Adult giant grenadier are often found in close association with the bottom, as evidenced by their large catches in bottom trawls and on longlines set on the bottom. However, based on a study of the food habits of giant grenadier off the U.S. west coast, Drazen et al. (2001) concluded that the fish feeds primarily off-bottom in the water column; most of the prey items found in giant grenadier stomachs were meso- or bathypelagic squids and fish, and there was little evidence of benthic feeding. In the Aleutian Islands, the diet was comprised mostly of squid and bathypelagic fish (myctophids) (Yang 2003) and in the Gulf of Alaska the predominant prey items included squid and pasiphaeid shrimp (Yang et al. 2006). The hypothesis regarding the tendency of the fish to feed off bottom is also supported by observations of sablefish longline fishermen, who report that their highest catches of giant grenadier often occur when the line has been inadvertently "clothes-lined" between two pinnacles, rather than set directly on the bottom. Pacific sleeper sharks (*Somniosus pacificus)* and Baird's beaked whales (*Berardius bairdii*) have been documented as predators on giant grenadier (Orlov and Moiseev 1999; Walker et al. 2002). Sperm whales (*Physeter macrocephalus*) are another likely predator, as they are known to dive to depths inhabited by giant grenadier on the continental slope and have been observed in Alaska depredating on longline catches of giant grenadier.

Natural mortality: In this assessment we continue to use the natural mortality estimate (*M*) of 0.078, calculated using Hoenig's (1983) longevity equation with a maximum age of 58 from a study of age at maturity for giant grenadier (Rodgveller et al. 2010). A discussion of the four methods employed by Rodgveller et al. (2010) and the reason for choosing Hoenig's (1983) method can be found in the 2010 grenadier SAFE (Clausen and Rodgveller 2010). Giant grenadier greater than 60 cm PAFL have been caught on the AFSC longline survey, whereas the greatest length in the age samples was 53 cm (Rodgveller et al. 2010). Therefore, it is probable that fish older than 58 exist. An older maximum age would result in a decrease in *M*. Because fish older than 58 years may exist, we suggest revisiting the determination of *M* for giant grenadier if more age samples become available in the future.

Data

Fishery

Catch History

Catches since 1997 have been estimated for the eastern Bering Sea (EBS), Aleutian Islands (AI), and GOA based largely on data from the AFSC Fishery Monitoring and Analysis Division. The estimates for 1997-2002 were determined by simulating the catch estimation algorithm used for target species by the NMFS Alaska Regional Office in what was formerly called their "blend catch estimation system" (Gaichas 2002 and 2003). Although these estimates may not be as accurate as the official catch estimates

determined for managed groundfish species, they are believed to be the best possible based on the data available. The estimates for 2003 and later were computed by the NMFS Alaska Regional Office based on their Catch Accounting System, which replaced the "blend" system in 2003.

Starting in 2015 the grenadier complex was added to both FMPs as an Ecosystem Component. With this change 1) retention is now recorded and 2) total catch is estimated using a combination of observer estimates of retention and from discards and retention records at landing. Retention in the BSAI ranged from 1-11 mt from 2015-2020 and from 10-43 mt in the GOA. This is substantially below the max ABC. Retention mostly occurs in bottom trawl fisheries, where it is not possible to sort fish at-sea. The primary source of retention was in the pollock mid-water fishery (5-36 mt in the GOA from 2015-2020). Most of the retained grenadier is turned into fish meal (10-40 mt), and a small amount of retained grenadier is used for bait (1-6 mt). None was discarded after delivery.

Most grenadiers are caught in deep-water bottom trawl and longline fisheries. In the BSAI, since observer restructuring in 2013, catch estimates have decreased; the average catch in the BSAI from 2003-2012 was 6,401 mt and from 2013-2019 it was 3,078 mt (Table 1). Catches peaked over a short period from 2010-2012 and afterwards catches dropped and remained low (Table 1, Figure 1). In the EBS there was a 69% decrease in average catch between these two time periods (2010-2012 and 2013-2019) and in the AI there was a 75% decrease (Table 1, Figure 1). Catches in 2019 and 2020 were similar to those in recent years. The lower catch in recent years appears in most of the fisheries that encounter grenadier. In the EBS the majority of grenadier are caught in the Greenland turbot (*Reinhardtius hippoglossoides*) fishery (Table 2). The catch of grenadier in this fishery was cut in half in 2018 and was again low in 2019 (1,589 in 2017 and 775 mt in 2018).

In the AI, catch is predominately in the Pacific halibut (*Hippoglossus stenolepis*), Kamchatka flounder (*Atheresthes evermanni)*, and sablefish (*Anoplopoma fimbria*) fisheries (Table 3). The sablefish fishery historically caught the majority of grenadier in the AI, but catch in the sablefish fishery decreased dramatically in 2015 (Table 3); shifting from an average annual catch of 1,365 mt from 2003-2014 to an average catch if 447 mt from 2015-2019. This does not align with observer restructuring in 2013. The Pacific halibut fishery is no longer a significant source of grenadier catch; since 2017 catch has been <60 mt, whereas previously it was 296 mt on average (Table 3). Catch in the Kamchatka flounder fishery appeared in 2011. Since then the average catch has been 541 mt (208 mt when removing an outlier in 2012). So far in 2020 catch in the Kamchatka flounder fishery is up from 178 to 666 mt.

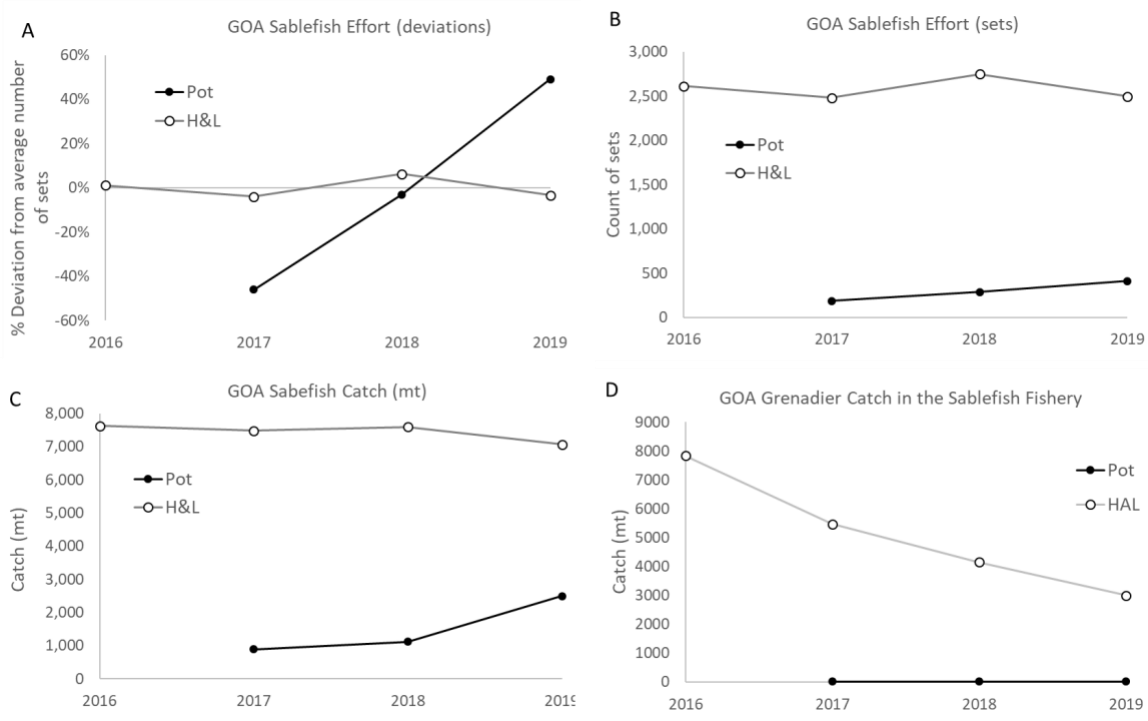
Total catch in 2019 was the lowest in the GOA time series, and so far it is much lower in 2020 than in 2019 (4,601 in 2019 vs. 2,213 mt in 2020) (Table 1, Figure 1). There was a peak catch of 20,539 mt in 2013, which is the first year of restructuring and is an outlier for the time series (Table 1, Figure 1). From 2016-2020 there has been a downward trend; catches ranged from 2,213-7,426 mt from 2017-2020. In the GOA, grenadier are caught in the Pacific halibut and rockfish fisheries (*Sebastes spp*.), but the majority of catch is in the sablefish fishery (Table 4). In rockfish fisheries there have been high catches recently (1,054 mt in 2017 and 1,696 in 2018); however, in the past two years it dropped substantially to 791 mt and then to 301 mt (Table 4). The average catch in the Pacific halibut fishery was similar prior to and after observer restructuring in 2013 (time series average is 557 mt), but it decreased to 12 mt in 2020. In the sablefish fishery, catch was among the highest in the time series in 2016, which was the last assessment (8,484 mt) and then declined each year; in 2019 it had declined to 3,348 mt. So far in 2020 the catch in the sablefish fishery is 1,795 mt.

In summary, catches of grenadier in the BSAI have been below average since 2014 and catch in the GOA has been in decline since 2016, with the lowest catch in 2019 (Figure 1). Declines in catch are primarily in the hook and line Greenland turbot fishery in the EBS and the hook and line sablefish fishery in the AI

and the GOA. In Alaska, catch is down 22% from 2018 to 2019 and down 36% from 2015 to 2019 (2015 was the last year with a complete record of catch in the 2016 SAFE, which was the most recent).

Pot gear has been allowed in the GOA since 2017 and the transition to this gear may reduce catch of grenadier and other bycatch species. Pot sets and sablefish catch have increased annually, particularly from 2018 to 2019 (Figure below: A, B, C). However, hook and line (H&L) effort in the sablefish target fishery has not declined (A), H&L sablefish catch has remained high (C), and at the same time grenadier catch has been declining in the H&L fishery (D). Therefore, although there was an increase in pot gear, there was consistent H&L effort and so a shift in gear is not the reason for a decrease in grenadier catch. It is still possible that future transitions to pot gear may lead to decreases in grenadier catch and should continue to be monitored.

Figure.–Sablefish pot and hook and line (H&L) effort (sets in the sablefish fishery) and sablefish and grenadier catch in the GOA sablefish fishery. A) is the percent deviation from average effort; B) is the sablefish effort measured as the count of sets; C) is the sablefish catch; D) is the grenadier catch in the sablefish fishery (Alaska Regional Office Catch Accounting System, accessed via AKFIN).



Survey

Trawl Surveys

Biomass in the GOA: In the GOA, trawl surveys sampled depths to 500, 700, or 1,000 m throughout the time series. Giant grenadier are most prevalent at depths deeper than 500 m and the majority of the biomass is deeper than 700 m. The trends in grenadier biomass are very difficult to ascertain because of the difference in sampling depths through the years. The last two biomass estimates in surveys down to

1,000 m were 718 thousand mt in 2009 and 538 thousand mt in 2015 (Table 5). The value in 2015 is not the lowest in the 1,000 m survey time series (Table 5, Figure 2).

Biomass in the AI: Trawl surveys in the AI sample down do 500 m and do not descend into the depths of peak grenadier abundance. The raw biomass estimates are not used to track biomass, instead an alternative method is used to extrapolate biomass down to 1,000 m (see Modeling Approach).

Biomass in the EBS: The last EBS slope trawl survey was in 2016. Biomass point estimates have ranged from 426-666 thousand mt between 2002 and 2016 (Table 6). Biomass in 2016 was 483,440 mt, which is 10% below average and 12% lower than the last survey in 2012 (Table 6, Figure 3).

Longline Surveys

RPWs in the GOA: Relative population weight (RPW) of giant grenadier in the GOA have ranged from 800 thousand to 1,200 thousand (Table 7). In 2020 it dropped 47% from 2019 and it was down 43% from 2016, the value in the last SAFE. RPWs were consistently high from 1993-2003 and then were generally lower from 2004-2020, with the exceptions of a few higher RPWs in 2007, 2010, and 2015. There may be competition for hooks with sablefish and so some fluctuations may be related to sablefish abundance; however, this does not hold true in all years. The inconsistent pattern may be because competition is better reflected on a smaller scale. For example, in 2019 sablefish RPWs increased and grenadier RPWs decreased in the central and western GOA (unpublished data); however, grenadier overall GOA RPWs were up in 2019.

RPWs in the EBS: RPWs are available in odd years since 1997. There was a 40% decrease from 2017 to 2019 and from 2015 to 2019 there was a 26% decrease; 2015 is the last RPW value in the 2016 SAFE. The 2017 RPW was only 5% lower than the overall peak, but the 2019 RPW was the second lowest in the time series, which explains why there was such a steep decline from 2017 to 2019. There may be competition for hooks with sablefish and so some fluctuations may be related to sablefish abundance.

RPWs in the AI: The eastern AI is sampled in even years. RPWs of giant grenadier in the AI are larger than in other areas, due to the large population estimated for the western Aleutians. This area is not currently sampled, but a ratio of eastern to western areas from previous surveys is used to extrapolate RPWs in these areas. Like in the GOA, there was a decrease in RPWs in 2020 (Table 7). The RPWs in the AI were irregular until 2014 and then declined gradually through 2020. The RPW in 2020 was 20% lower than in 2018 and was 46% lower than in 2016, which is the value in the last SAFE (Table). The RPW in 2020 is the second lowest in the time series, with the lowest in 1996. There may be competition for hooks between sablefish and grenadier. The RPW trends between sablefish and grenadier in 2018 and 2020 are divergent; however, the trend is not strong over the time series (unpublished data). This irregular relationship may be because so much of the grenadier RPW in the AI is estimated using a ratio and does not come from direct measurements.

Competition for hooks on longline survey: In an evaluation of catch rates by management area at depths of high grenadier abundance, sablefish catch per unit effort (CPUEs) were negatively correlated with giant grenadier CPUEs in all management areas (Rodgveller et al. 2008). Sablefish are fast moving and able to quickly find baited hooks even when they are sparse (Sigler 2000), so it is likely that they would outcompete grenadier and some other species. Sigler (2000) described the arrival time, catch probability, and required soak time for sablefish; however, this data is lacking for other species caught on the longline survey. Information on giant grenadier capture time and catch rates in relation to baited hook availability would aid in strategies for adjusting CPUE of grenadier.

Analytic Approach

Modeling Approach

Biomass in the GOA: In the GOA, trawl surveys sampled depths to 1,000 m in 1984, 1987, 1999, 2005, 2007, 2009, and 2015. In 1990, 1993, 1996, and 2001 the trawl survey only sampled depths down to 500 m, and in 2003, 2011, 2013, 2017, and 2019 the trawl survey sampled depths to 700 m. Since 2014 we have used a random effects model to estimate exploitable biomass from trawl survey data (Table 5) (Rodgveller and Hulson 2014). A single estimate of exploitable biomass from the most recent year with a trawl survey is used for Tier 5 calculations. This method is preferable to averaging the last three trawl surveys that sampled depths to 1,000 m because sampling to 1,000 m is not completed on a regular basis. The random effects model biomass estimate used in this assessment is the most recent estimate of the time series, which was 2019, when there was a GOA trawl survey.

Due to the differences in surveyed depths among trawl surveys, we applied a random effects model to three depth strata (1-500 m, 501-700 m, and 701-1000 m) (Rodgveller et al. 2012; Rodgveller and Hulson 2014). This resulted in three time series of biomass estimates with one time series for each depth stratum. The full time series of biomass estimates in the GOA from the random effects model were then obtained by summing the biomass estimates across the three depth strata (Figure 2). Exploitable biomass computations have been based only on giant grenadier because virtually none of the other species are caught in the commercial fishery or surveys.

Estimates of biomass increased steadily from the late 1980's through 2005 (Table 5, Figure 2). For the remainder of the time series there was a slow downward trend, but the biomass is still much higher than in the 1980s and 1990's. The time series low of 158,542 mt was in 1987. It steadily rose to a peak of 544,881 in 2005, and then had an overall decreasing trend. The biomass in 2019 was 369,618 mt (Figure 2, Table 5). Note that the time series is recalculated using the random effects model whenever there is a trawl survey; therefore, the estimates in Table 5 will not be identical to those in the previous SAFE. Surveys down to 1,000 m are not common and so random effects models will be consistent in their estimates of abundance in deep water until there are new surveys to this depth.

Biomass in the AI: In the AI the trawl survey regularly samples from 1-500 m, but not in "deep" water from 501-1,000 m. The AI trawl survey biomass estimates from the "shallow" depths and AI longline survey RPWs from "shallow" (200-500 m) and "deep" depths (501-1000 m) are used to estimate the total AI biomass using the following equation (Rodgveller et al. 2012; Appendix 1A). :

(1) $B_y = \bar{r} W_y$

where B_y is the total biomass in year y, $\bar{r}$ is the ratio of the sum of bottom trawl survey biomass estimates to the sum of longline survey RPWs in the shallow depth stratum for years when both surveys occurred (2000, 2002, 2004, 2006, 2010, 2012, 2014, 2016, and 2018), and W_y is the total RPW in year y. The ratio used in the 2016 SAFE was 0.188. In 2020 the ratio was recalculated using all years when both surveys occurred and it was nearly identical (0.189). The time series of biomass was updated this year using this ratio (Table 4). To estimate exploitable biomass in the AI, we continue to use an average of the three most recent biomass estimates using the method described here, which are 2016, 2018, and 2020.

Biomass estimates decreased 20% in 2020 from 2018 and 46% from 2016 to 2020 (the most recent value in the last SAFE was for 2016). The 2020 biomass estimate is the lowest in the time series. The CVs for all AI biomass estimates were all ~20% (Table 6, Figure 3). They are the same in all years because most

of the variance is from the ratio of trawl biomass to the longline survey RPW, and the same average ratio was used to compute the biomass for all years in the time series.

Biomass in the EBS: To estimate exploitable biomass in the EBS we continue to use an average of the three most recent trawl surveys. For the BS that is still 2010, 2012, and 2016.

Parameter Estimates

Maximum Age: Based on otolith ageing, giant grenadier maximum age in the GOA is 56 or 58 years, respectively (Burton 1999 and Rodgveller et al. 2010). There have been no ageing studies for Pacific grenadier in Alaska, but specimen off the U.S. west coast had a maximum age of 73 years (Andrews et al. 1999).

Natural mortality: In this assessment we continue to use the natural mortality estimate (*M*) of 0.078, calculated using Hoenig's (1983) longevity equation with a maximum age of 58 from a study of age at maturity for giant grenadier; an discussion of a variety of methods is presented in Rodgveller et al. 2010.

Results

Harvest Recommendations

As an Ecosystem Component in FMPs, a grenadier stock assessment is not required. There are no ABC or OFL catch limits adopted in the annual groundfish harvest specifications. However, this abbreviated SAFE report is presented for tracking trends in abundance and catch and provides unofficial OFL and ABC values based on Tier 5 calculations. Because overfishing is not defined for an Ecosystem Component, these values are not used for management or for determining if overfishing is occurring.

Amendment 56 Reference Points
The NPFMC's Tier 5 definitions for OFL and ABC are: OFL = *M* x *Biomass*, where *M* is the estimated natural mortality rate, and ABC is $\leq$ (0.75 x OFL). Based on the discussion above, unofficial OFLs and ABCs for of grenadiers are listed below (biomass, OFL, ABC, and mean catch are in mt). Catches are not approaching unofficial OFLs.

Specification of OFL and Maximum Permissible ABC

BSAI and GOA Grenadiers

Area	Biomass	Natural mortality *M*	OFL definition	OFL	ABC definition	ABC
EBS	564,778	0.078	biom x *M*	44,053	OFL x 0.75	33,040
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GOA	369,618	0.078	biom x *M*	28,830	OFL x 0.75	21,623

Grand total	1,424,966	111,147	83,361

The grenadier stock complex is an Ecosystem Component and, therefore, ABCs or OFLs are not used for catch specification.

Not subject to over fishing: The recommended OFLs and ABCs in the above tables are much larger than the mean catches for grenadiers and also much larger than the catch in any single year, which indicates catches could increase without endangering the stocks. This is especially true for the EBS and AI, where the exploitation rate appears to be quite low.

Ecosystem Considerations

A determination of ecosystem considerations for grenadiers in Alaska is hampered by the extreme lack of biological and habitat information for these species and by limited knowledge in general on the deep slope environment inhabited by these fish.

Ecosystem Effects on the Stocks

Prey availability/abundance trends: The only food studies on grenadiers in the northeast Pacific Ocean have been on adults. One study of giant grenadier off the U.S. west coast concluded that the fish fed primarily off-bottom on bathy- and mesopelagic food items that included gonatid squids, viperfish, deep-sea smelts, and myctophids (Drazen et al. 2001). Smaller studies of giant grenadier food habits in Alaska showed generally similar results. In the Aleutian Islands, the diet comprised mostly squid and myctophids (Yang 2003), whereas in the Gulf of Alaska, squid and pasiphaeid shrimp predominated as prey (Yang et al. 2006). Research on these deep-sea prey organisms in Alaska has been virtually non-existent, so information on prey availability or possible variations in abundance of prey are unknown. Very few juvenile giant grenadier have ever been caught, so nothing is known about their diet.

In contrast to giant grenadier, a study of Pacific grenadier food habits off the U.S. west coast found a much higher consumption of benthic food items such as polychaetes, cumaceans, mysids, and juvenile Tanner crabs (*Chionoecetes* sp.), especially in smaller individuals (Drazen et al. 2001). Carrion also contributed to its diet, and larger individuals consumed some pelagic prey including squids, fish, and bathypelagic mysids.

Predator population trends: The only documented predators of giant grenadier are Pacific sleeper sharks (Orlov and Moiseev 1999) and Baird's beaked whales (Walker et al. 2002). According to Orlov's and Moiseev's study, giant grenadier was ranked third in relative importance as a food item in the diet of these sharks. Sperm whales are another potential predator, as they are known to dive to depths inhabited by giant grenadier on the slope and have been observed depredating on longline catches of giant grenadier[1]. Giant grenadier is a relatively large animal that is considered an apex predator in its environment on the deep slope (Drazen et al. 2001), so it may have relatively few predators as an adult. Predation on larval and juvenile giant grenadiers would likely have a much greater influence on the ultimate size of the adult population size, but there is no information on predators of these earlier life stages.

Changes in habitat quality: Little or no environmental information has been collected in Alaska for the deep slope habitat in which grenadiers live. This habitat is likely more stable oceanographically than

[1] C. Lunsford, National Marine Fisheries Service, Alaska Fisheries Science Center, Auke Bay Laboratories, 17109 Point Lena Loop Rd., Juneau, AK 99801. Pers. comm. Oct 2012.

shallower waters of the upper slope or continental shelf. Regime shifts on the continental shelf and slope in Alaska in recent decades have been well documented, but it is unknown if these shifts also extend to the deep slope. Regime shifts could have a pronounced effect on giant grenadier if their larvae or post-larvae inhabited upper portions of the water column. However, no larvae or post-larvae for this species have ever been collected in Alaska. The absence of larvae or post-larvae giant grenadier in larval surveys in Alaska, which have nearly all been conducted in upper parts of the water column, implies that larval giant grenadier may reside in deeper water, where they may be less affected by regime shifts since water temperatures in deep water tend to be more stable. Productivity of adults may be affected by the availability of resources that sink from surface waters to deep-water; however, linkages to this effect are difficult to quantify and monitor.

Fishery Effects on the Ecosystem

Because there has been virtually no directed fishing for grenadiers in Alaska, the reader is referred to the Ecosystem and Socioeconomic Profile in the sablefish SAFE report. The sablefish longline fishery is the main fishery that takes giant grenadier as bycatch, so the sablefish report is applicable to giant grenadier and is an indication of what the effects might be if a directed fishery for giant grenadier were to develop. It should be noted that because all caught grenadiers do not survive, this contributes dead, organic material into the ecosystem that would not otherwise be there.

Data Gaps and Research Priorities

Research priorities

1) Locate where larvae and juveniles (<15 years old) reside.
2) Determine the fraction of time giant grenadiers are off-bottom. Studies are needed on whether grenadiers are a benthic species or if individuals sometimes move off-bottom. This information could be used in an evaluation of the catchability of giant grenadier in the bottom trawl surveys, which would affect the accuracy of biomass estimates.
3) Evaluate how competition for hooks affects giant grenadier catch rates on the AFSC longline survey.
4) Better understand the depth distribution of female and male grenadiers below 1,000 m, differences in size with depth, and the portion of the population deeper than 1,000 m.
5) Investigate methods to estimate EBS biomass on the slope.

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Table 1.—Updated catch data (mt) for giant grenadier as of September 21, 2020. The estimates for 2003-2012 were computed by the NMFS Alaska Regional Office based on their Catch Accounting System, which replaced the "blend" system in 2003. Catch is updated from 2003-2020 only. Observer restructuring began in 2013 so the mean catch from 2003-2012 is presented for comparison to the mean from 2013-2019.

	BSAI	Eastern Bering Sea	Aleutian Islands	Gulf of Alaska	Total
1997	5,851	2,964	2,887	12,029	17,880
1998	6,589	5,011	1,578	14,683	21,272
1999	7,388	4,505	2,883	11,388	18,776
2000	7,321	4,067	3,254	11,610	18,931
2001	3,754	2,294	1,460	9,685	13,439
2002	4,698	1,891	2,807	10,479	15,177
2003	5,681	2,647	3,034	10,843	16,523
2004	3,430	2,202	1,228	10,315	13,745
2005	4,425	2,641	1,784	6,606	11,031
2006	4,291	2,067	2,224	8,500	12,791
2007	3,217	1,641	1,576	9,366	12,583
2008	3,488	1,687	1,800	11,113	14,600
2009	6,662	2,983	3,679	6,660	13,322
2010	13,516	6,234	7,282	7,303	20,819
2011	9,518	5,627	3,891	8,595	18,113
2012	9,777	4,136	5,641	8,404	18,180
2013	5,430	2,093	3,337	20,539	25,969
2014	3,510	1,147	2,363	7,123	10,633
2015	2,681	1,668	1,014	7,903	10,585
2016	3,018	2,064	954	10,893	13,911
2017	2,875	2,096	779	7,426	10,301
2018	1,889	1,110	779	6,760	8,649
2019	2,142	1,489	653	4,601	6,743
2020	2,016	1,093	923	2,213	4,229
Avg. 2003-2012	6,401	3,186	3,214	8,770	15,171
Avg. 2013-2019	3,078	1,667	1,411	9,321	12,399

Updated catch for 2003-2020 are from NMFS Alaska Regional Office Catch Accounting System via the Alaska Fisheries Information Network (AKFIN) database, http://www.akfin.org.

Table 2.—Estimated catch (mt) of giant grenadier in the Eastern Bering Sea by target species/species group, 2003-2020. Arrow = arrowtooth flounder; Atka = Atka mackeral; DW flat = deep-water flatfish; GT = Greenland turbot; halibut = Pacific halibut; Kam = Kamchatka flounder; cod = Pacific cod; rex = rex sole; sable = sablefish. Other = all other target species/groups combined (including yellowfin sole, rock sole, shallow-water flatfish, "other flatfish", flathead sole, pollock, all other species).

Year	Arrow	DW flat	Atka	GT	Halibut	Kam	Cod	Rex	Rockfish	Sable	Other
2003	38		0	1,460	355		245		9	370	165
2004	24			1,312	290		237		23	233	82
2005	26		0	1,974	148		344		9	108	31
2006	125		0	1,189	181		127		12	417	15
2007	2		10	1,073	88		179		17	211	56
2008	69			708	392		163		3	127	226
2009	242		2	1,823			212		6	692	5
2010	528			3,877	201		781		322	515	5
2011	874			2,356	290	245	1,34		19	494	2
2012	675		1	1,686	889	6	632		3	222	23
2013	272		0	504	790	14	261		38	211	2
2014	121			473	206	10	162		2	163	10
2015	112			1,034	279	3	137		4	87	12
2016	48		2	1,195	402	18	318		14	57	11
2017	31			1,589	38	62	230		9	107	30
2018	8			775	42	16	166		43	39	22
2019	128		0	888	44	127	152		40	39	72
2020	59			536	43	316	51		22	38	29

Updated catch for 2003-2020 are from NMFS Alaska Regional Office Catch Accounting System via the Alaska Fisheries Information Network (AKFIN) database, http://www.akfin.org.

Table 3.— Estimated catch (mt) of giant grenadier in the Aleutian Islands by target species/species group, 2003-2020. Arrow = arrowtooth flounder; Atka = Atka mackeral; DW flat = deep-water flatfish; GT = Greenland turbot; halibut = Pacific halibut; Kam = Kamchatka flounder; cod = Pacific cod; rex = rex sole; sable = sablefish. Other = all other target species/groups combined (including yellowfin sole, rock sole, shallow-water flatfish, "other flatfish", flathead sole, pollock, all other species).

Year	Arrow	DW flat	Atka	GT	Halibut	Kam	Cod	Rex	Rockfish	Sable	Other
2003				113	1,374		46		6	1,494	0
2004				14	424		13		61	716	1
2005			14	161	606		2		21	978	2
2006	341		0	328	175		121		154	1,105	0
2007	108		36	343	70		41		21	918	40
2008	397		274	67	229		26		59	746	2
2009	1,377		84	413			12		151	1,642	0
2010	3,434		430	453	194		481		334	1,957	0
2011	63		113	82	460	723	1		284	2,163	0
2012	264		424		783	2,566	43		44	1,517	0
2013	278		210	41	352	406	3		298	1,747	1
2014	254		61		109	295	23		221	1,400	0
2015	2		45		158	169	3		66	572	0
2016	27		95		213	61			94	464	0
2017			60		21	240	0		20	438	0
2018			65		46	109	2		84	474	0
2019	0		107		4	178	0		79	285	0
2020	3		67		56	666	1		98	32	0

Updated catch for 2003-2020 are from NMFS Alaska Regional Office Catch Accounting System via the Alaska Fisheries Information Network (AKFIN) database, http://www.akfin.org.

Table 4.—Estimated catch (mt) of giant grenadier (all species combined) in the Gulf of Alaska by target species/species group, 2003-2020. Arrow = arrowtooth flounder; Atka = Atka mackeral; DW flat = deep-water flatfish; GT = Greenland turbot; halibut = Pacific halibut; Kam = Kamchatka flounder; cod = Pacific cod; rex = rex sole; sable = sablefish; other = all other target species/groups combined (including yellowfin sole, rock sole, shallow-water flatfish, "other flatfish", flathead sole, Pollock, all other species).

Year	Arrow	DW flat	Atka	GT	Halibut	Kam Fl	Cod	Rex	Rockfish	Sable	Other
2003	27	474			710		5	325	613	8,464	223
2004	171	178			156		0	5	2,231	7,501	72
2005	103				488			4	212	5,743	54
2006	18				766		22	4	338	7,228	120
2007	90	20			530		79	5	198	8,439	5
2008	3				1,918		97	89	164	8,597	244
2009					1,430		79	102	227	4,779	29
2010	41	62			372		171	360	463	5,616	186
2011	123	1			203		60	291	618	7,185	112
2012	209				42		228	2	416	7,375	133
2013	672	5,713			656		132	7	1,006	12,284	69
2014	439				360		176	7	555	5,545	40
2015	37				479		93		951	6,330	13
2016	135				829		86		456	8,484	903
2017	97				442		14	1	1,054	5,753	14
2018	1				237		1		1,696	4,796	29
2019	15				401		0		791	3,348	47
2020	87				12				301	1,795	19

Updated catch for 2003-2020 are from NMFS Alaska Regional Office Catch Accounting System via the Alaska Fisheries Information Network (AKFIN) database, http://www.akfin.org.

Table 5.—Biomass estimates for giant grenadier in the Gulf of Alaska. Left: estimates of biomass from 1-1,000 m using a random effects model. Right: biomass estimates from NMFS trawl surveys that sampled either down to 1,000 m (**), 700 m (1), or 500 m (2).

	Random Effects			Surveys down to 1,000 m		
Year	Biomass	L 95% CI	U 95% CI	Biomass	U 95% CI	L 95% CI
1984	161,491	123,792	210,671	169,708**	228,015	111,401
1985	160,431	118,712	216,810			
1986	159,443	116,714	217,815			
1987	158,542	117,623	213,696	135,971**	188,211	83,731
1988	167,199	117,200	238,528			
1989	176,369	118,832	261,765			
1990	186,079	122,058	283,679	20,194[2]	44,802	-4,414
1991	199,652	129,113	308,728			
1992	214,387	138,297	332,344			
1993	230,490	150,067	354,013	51,411[2]	76,559	26,364
1994	244,324	159,935	373,241			
1995	259,083	172,758	388,544			
1996	274,789	189,530	398,403	51,356[2]	70,935	31,777
1997	302,341	217,600	420,082			
1998	335,156	255,521	439,610			
1999	378,362	318,530	449,432	389,908**	466,030	313,786
2000	406,381	313,133	527,398			
2001	437,789	335,944	570,509	163,761[2]	110,605	53,126
2002	468,320	355,223	617,425			
2003	502,243	402,551	626,624	396,900[1]	530,521	263,278
2004	521,395	402,602	675,240			
2005	544,881	447,226	663,860	587,346**	754,202	420,489
2006	511,029	400,881	651,441			
2007	486,582	402,186	588,687	487,987**	629,173	346,802
2008	462,944	363,331	589,867			
2009	442,948	352,286	556,942	718,320**	1,270,176	275,928
2010	444,999	343,521	576,455			
2011	450,894	355,362	572,109	292,142[1]	403,820	180,464
2012	465,277	358,097	604,535			
2013	482,859	385,270	605,169	545,563[1]	465,458	225,668
2014	473,463	373,225	600,622			
2015	472,004	387,137	575,475	538,450**	659,114	417,786
2016	408,558	321,333	519,459			
2017	360,154	276,562	469,014	153,690[1]	209,568	97,812
2018	364,659	271,055	490,587			
2019	369,618	274,573	497,564	216,537[1]	270,796	162,278

Table 6.—Biomass estimates (mt) and associated 95% confidence bounds (mt), variances, and coefficients of variation (cv) for giant grenadier in recent NMFS surveys in Alaska that sampled the upper continental slope. Aleutian Islands biomass was estimated from trawl survey biomass estimates from 1-500 m and AFSC longline survey relative population weights from 200-1000m (see section titled "survey data").

			95% Conf. bounds			
Region	Year	Biomass	Lower	Upper	Variance	cv (%)
Aleutian Islands	1998	428,152	263,193	593,111	7,083,336,594	19.7
Aleutian Islands	2000	573,568	352,468	794,667	12,725,126,089	19.7
Aleutian Islands	2002	583,846	359,228	808,464	13,133,398,100	19.6
Aleutian Islands	2004	589,126	361,417	816,835	13,497,357,576	19.7
Aleutian Islands	2006	739,057	453,475	1,024,639	21,229,923,336	19.7
Aleutian Islands	2008	444,711	261,071	628,350	8,778,474,877	21.1
Aleutian Islands	2010	704,674	433,469	975,879	19,146,197,484	19.6
Aleutian Islands	2012	490,421	299,859	680,983	9,452,784,245	19.8
Aleutian Islands	2014	750,672	461,691	1,039,653	21,738,361,188	19.6
Aleutian Islands	2016	661,190	406,825	915,555	16,842,375,693	19.6
Aleutian Islands	2018	450,420	275,732	625,107	7,943,466,302	19.8
Aleutian Islands	2020	360,099	220,291	499,907	5,088,053,079	19.8
Eastern Bering Sea	2002	426,397	344,922	507,871	1,659,519,194	9.6
Eastern Bering Sea	2004	666,508	527,524	805,491	4,829,084,657	10.4
Eastern Bering Sea	2008	449,777	353,902	545,652	2,298,003,647	10.7
Eastern Bering Sea	2010	660,528	521,035	800,021	4,864,588,623	10.6
Eastern Bering Sea	2012	550,366	433,097	667,635	3,437,997,235	10.6
Eastern Bering Sea	2014	-	-	-	-	-
Eastern Bering Sea	2016	483,440	390,014	576,867	2,182,132,716	9.7
Eastern Bering Sea	2018	-	-	-	-	-
Eastern Bering Sea	2020	-	-	-	-	-

Table 7.—Giant grenadier relative population weight, by region, in AFSC longline surveys in Alaska, 1990-2020. Dashes indicate years that the eastern Bering Sea or Aleutian Islands were not sampled by the survey. Gulf of Alaska values include data only for the upper continental slope at depths 201-1,000 m and do not include continental shelf gullies sampled in the surveys. Note: relative population weight, although an index of biomass (weight), is a unit-less value.

Year	Eastern Bering Sea	Aleutian Islands	Gulf of Alaska
1992	-	-	686,827
1993	-	-	1,041,508
1994	-	-	1,018,292
1995	-	-	1,264,245
1996	-	1,568,662	1,121,058
1997	762,639	-	1,266,800
1998	-	2,268,851	1,066,477
1999	571,852	-	1,277,141
2000	-	3,039,421	1,143,980
2001	398,950	-	1,067,335
2002	-	3,093,887	904,922
2003	538,190	-	1,058,570
2004	-	3,121,848	801,271
2005	694,456	-	826,495
2006	-	3,914,703	857,510
2007	437,268	-	1,242,833
2008	-	1,985,445	919,083
2009	521,179	-	1,063,104
2010	-	3,734,142	1,236,692
2011	574,349	-	829,476
2012	-	2,598,777	911,728
2013	605,727	-	896,776
2014	-	3,977,880	848,321
2015	584,723	-	1,235,344
2016	-	3,503,718	852,816
2017	727,514	-	921,175
2018	-	2,386,827	788,178
2019	434,460	-	919,782
2020	-	1,908,200	489,271
Avg.	570,942	2,854,028	984,724

Figure 1.— Catch and average catch (dotted line) of giant grenadier in the eastern Bering Sea, Aleutian Islands, Eastern Bering Sea and Aleutian Islands combined, or the Gulf of Alaska. Updated catch for 2003-2020 are from NMFS Alaska Regional Office Catch Accounting System via the Alaska Fisheries Information Network (AKFIN) database, http://www.akfin.org.

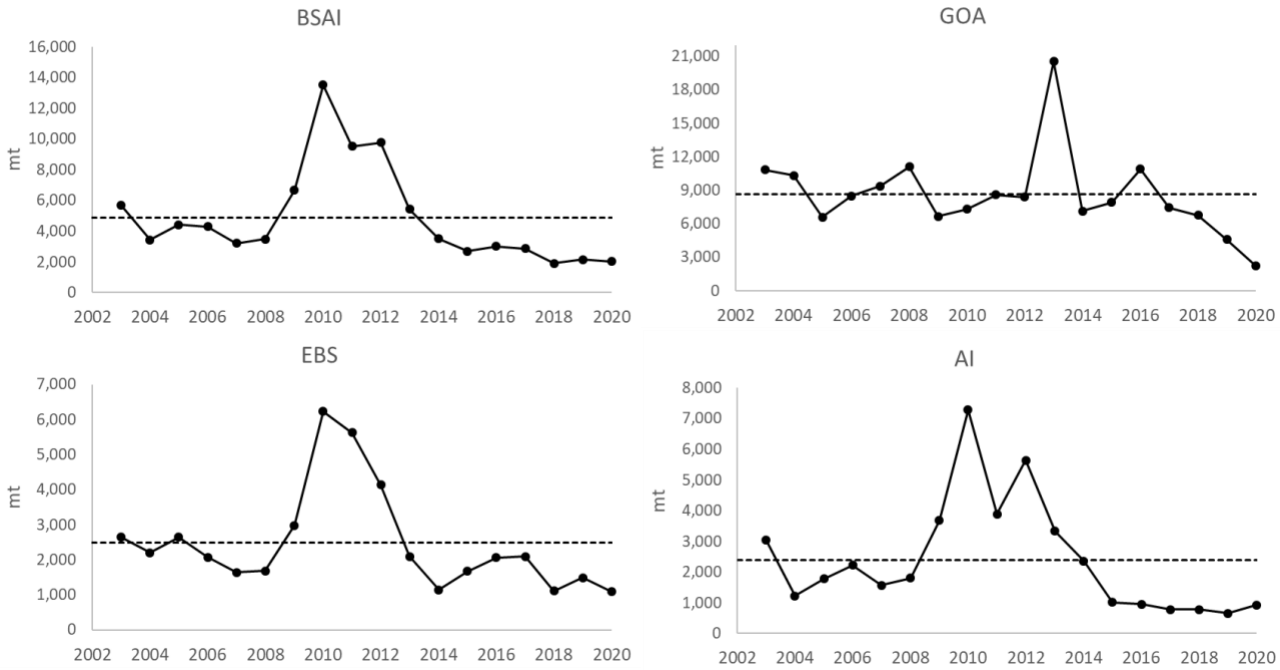


Figure 2.—Biomass estimates of giant grenadier for the Gulf of Alaska from NMFS bottom trawl surveys and from a random effects model that utilizes trawl survey biomass estimates from all years (with 95% confidence intervals).

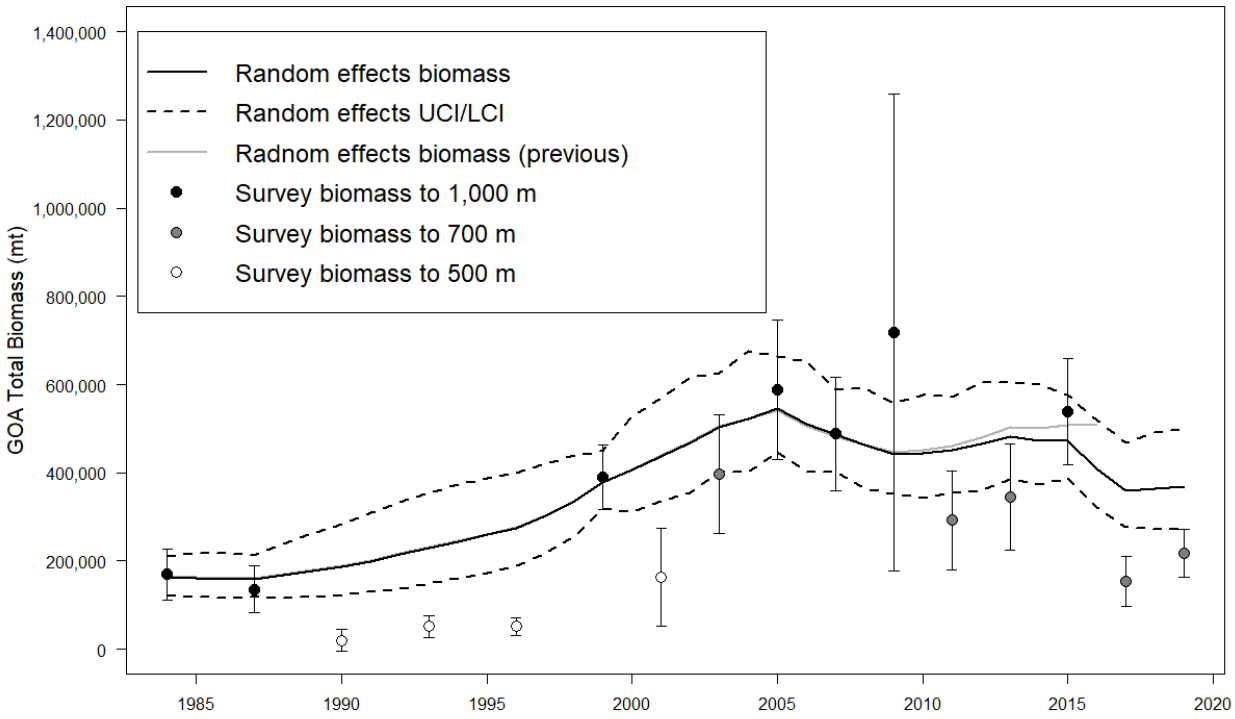
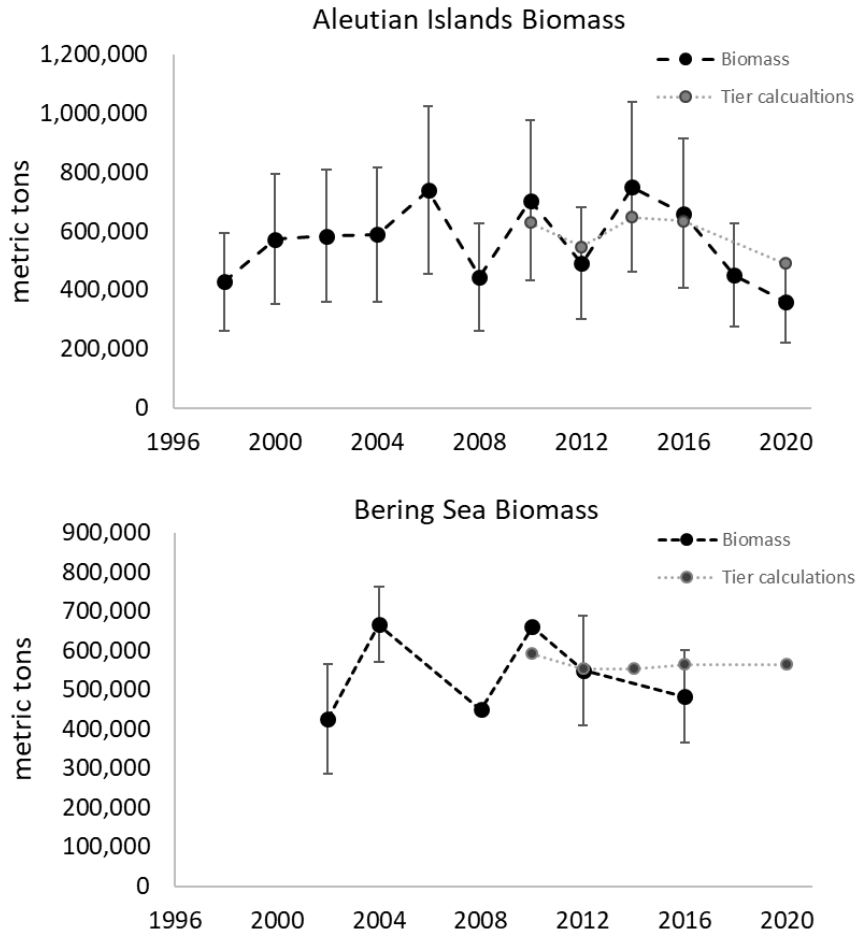


Figure 3.—Biomass estimates of giant grenadier for the Aleutian Islands and Bering Sea with 95% confidence intervals (black) and biomass estimates used in Tier 5 calculations in each SAFE (the average biomass estimates from the three most recent trawl surveys) (gray). The Aleutian Islands biomass is estimated using a combination of NMFS longline and bottom trawl survey data and Bering Sea biomass is estimated from NMFS slope bottom trawl surveys. Dotted lines are used to indicate that estimates are not annual.



Appendix A

Table 1A-1.—Research catch (mt) of grenadier (giant, popeye, and pacific grenadier, but primarily giant grenadier) in AFSC trawl and longline (LL) surveys and the International Pacific Halibut Commission (IPHC) longline survey. Only numbers are available from the IPHC survey through 2009. 0s indicate that there was catch but it is <1 mt. Accessed through the Alaska Fisheries Information Network (AKFIN) on October 20, 2020.

	BSAI					GOA					
Year	IPHC #s	IPHC wt	AFSC Trawl	AFSC LL	Total BSAI	IPHC #s	IPHC wt	AFSC Trawl	AFSC LL	Total GOA	Total
1979			33		33			0		0	33
1980			85		85			1		1	86
1981			66		66			3		3	69
1982			124		124			0		0	124
1983			136		136			0		0	136
1984								59		59	59
1985			165		165			9		9	174
1986			90		90			0		0	90
1987			0		0			42		42	42
1988			30		30						30
1989											
1990								3	133	136	136
1991			10		10				110	110	120
1992									100	100	100
1993								6	122	128	128
1994			6		6				133	133	139
1995									198	198	198
1996				38	38			8	175	183	221
1997	1,184		9	79	88	258			162	162	250
1998	556			67	67	681		12	146	158	225
1999	165		0	57	57	660		47	159	206	263
2000	774		118	89	207	621			163	163	370
2001	1,313			42	42	287		11	164	175	217
2002	987		23	83	106	942			131	131	237
2003	1,792		91	50	141	1,344		27	153	180	321
2004	2,111		196	78	274	1,110			111	111	385
2005	1,404			71	71	1,266		49	122	171	242
2006	941		20	77	97	919			114	114	211
2007	1,224			79	79	849		44	167	211	290
2008	1,331		123	46	169	755			121	121	290
2009	2,710			88	88	785		39	156	195	283
2010	2,451	9	156	67	232	1,265	6		167	173	405
2011	1,808	7		75	82	751	2	20	125	147	229
2012		5	135	42	182		2		134	136	318
2013		5		87	92		2	20	134	156	248
2014		16	79	75	170		2		130	132	302
2015		6		82	88		5	34	157	196	284
2016		9	293	70	72		2		132	134	206
2017		22		92	114		1	7	139	147	261
2018		2	101	45	148		3		104	107	255
2019		6		71	77		5	11	131	147	224