Appendix 1 – Gulf of Alaska and Bering Sea/Aleutian Islands SAFE Reports

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

by
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EXECUTIVE SUMMARY

Grenadiers are presently considered "nonspecified" by the NPFMC, which means they are technically not part of the NPFMC management process and are not assigned values for overfishing levels (OFL), acceptable biological catch (ABC), or total allowable catch (TAC). Therefore, there are no limitations on catch or retention, no reporting requirements, and no official tracking of grenadier catch by management. However, for the last several years there have been proposals to change the management status of grenadiers. Full assessment reports were prepared for this group in 2006, 2008, and 2010, along with the present report. Because grenadiers are "nonspecified", all these reports are considered unofficial, and they have been included as appendices in the standard SAFE reports.

Summary of Changes in the Assessment Inputs

Changes in the input data: Last year an executive summary was presented and not a full assessment. This year 2011 and 2012 data have been updated. New data available for this assessment include: 1) updated catch estimates for 2003-2012; 2) trawl survey results for the eastern Bering Sea (EBS) slope in 2012; 3) a time series of Aleutian Island (AI) biomass and variance estimates using a new estimation method for 1996-2012; 4) NMFS longline survey results for 2011 and 2012; and 5) observer data on giant grenadier length and sex in the commercial fishery for 2011 and 2012.

Changes in assessment methodology: A new method for determining AI biomass and variance estimates is presented in this assessment. This new method utilizes available biomass estimates from AFSC trawl surveys in the AI that only extend from 1-500 m. A ratio of "shallow" biomass estimates from the trawl survey (1-500 m) to "shallow" relative population weights (RPWs) from the AFSC longline survey (1-500 m) is used to extrapolate total biomass from longline survey RPWs for 1-1000 m.

Summary of Results

The tier 5 computations have been based on giant grenadier only and have excluded the other grenadier species because virtually none of the other species are caught in the commercial fishery and relatively few are taken in fish surveys. Therefore, in the tier 5 determinations, giant grenadier are serving as a proxy for the entire grenadier group. The parameters required for tier 5 are reliable estimates of current biomass (*B*), we use the average of the last three trawl surveys, and a reliable estimate of the natural mortality rate (*M*).

No trawl surveys in the Aleutian Islands (AI) have sampled depths >500 m since 1986, so an indirect method was used to determine biomass of giant grenadier in this region (Clausen and Rodgveller 2008, Clausen and Rodgveller 2010). This year a new method was used to estimate Aleutian Island biomass. Details of this method are in Appendix 1A and under the section in this report on survey data.

The best current estimate of the natural mortality rate for giant grenadier is 0.078, which we presented and used for the first time in the 2008 assessment. This estimate is based on a maximum of age of 58 years that was determined for giant grenadier (Rodgveller et al. 2010).

Tier 5 computations for giant grenadier OFL and ABC are summarized as follows (AI = Aleutian Islands, EBS = Eastern Bering Sea, GOA = Gulf of Alaska; biomass, OFL, and ABC are in mt) for 2013:

BSAI and GOA grenadiers

Area	Biomass	Natural mortality *M*	OFL definition	OFL	ABC definition	ABC
EBS	553,557	0.078	biom x *M*	43,177	OFL x 0.75	32,383
AI	598,727	0.078	biom x *M*	46,700	OFL x 0.75	35,026
BSAI total	1,152,284			89,878		67,409
GOA	597,884	0.078	biom x *M*	46,635	OFL x 0.75	34,976
Grand total	1,750,168			136,513		102,385

For the 2013 fishery in the GOA, we recommend the maximum allowable ABC of 34,976 t and OFL of 46,635 for grenadiers. The ABC and OFL are the same as 2011 because the GOA AFSC trawl survey for 2011 only extended to 700 m and therefore did not provide a good estimate of giant grenadier biomass. For the 2013 fishery in the BSAI, we recommend the maximum allowable ABC of 67,409 t and OFL of 89,878 t. The recommended ABC and OFL for the BSAI include the new method to estimate AI giant grenadier biomass, which results in a 34% decrease from the last assessment's ABC. Catches are not approaching OFLs.

Gulf of Alaska Grenadiers

	Last year[a]		**This year**	
Quantity/Status	2012	2013	**2013**	2014
M (natural mortality)	0.078	0.078	**0.078**	0.078
Specified/recommended Tier	5	5	**5**	5
Biomass	597,884	597,884	**597,884**	597,884
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
Specified/recommended F_{ABC}	0.0585	0.0585	**0.0585**	0.0585
Specified/recommended OFL (t)	46,635	46,635	**46,635**	46,635
Specified/recommended ABC (t)	34,976	34,976	**34,976**	34,976
Is the stock being subjected to overfishing?	n/a	n/a	n/a	n/a

[a]The values for biomass, OFL, and ABC in these two columns are based on an interim Executive Summary SAFE report for grenadiers that was prepared in November 2011 (Clausen and Rodgveller 2011). No new biomass estimates were available in 2011 so values of OFL and ABC remain constant.

Bering Sea and Aleutian Islands Grenadiers

Quantity/Status	Last year[a] 2012	2013	This year **2013**	2014
M (natural mortality)	0.078	0.078	**0.078**	0.078
Specified/recommended Tier	5	5	**5**	5
Biomass	1,733,797	1,733,797	**1,152,284**	1,152,284
F_{OFL} (F=M)	0.078	0.078	**0.078**	0.078
$maxF_{ABC}$ (maximum allowable = 0.75x F_{OFL})	0.0585	0.0585	**0.0585**	0.0585
Specified/recommended F_{ABC}	0.0585	0.0585	**0.0585**	0.0585
Specified/recommended OFL (t)	135,236	135,236	**89,878**	89,878
Specified/recommended ABC (t)	101,427	101,427	**67,409**	67,409
Is the stock being subjected to overfishing?	n/a	n/a	n/a	n/a

[a]The values for biomass, OFL, and ABC in these two columns are based on an interim Executive Summary SAFE report for grenadiers that was prepared in November 2011 (Clausen and Rodgveller 2011). Aleutian Islands biomass was updated this year using a new method; however, the data presented for "last year" is what was reported in Clausen and Rodgveller 2011.

Response to SSC Comments Regarding Assessments in general

Regarding obtaining a good estimate of biomass for use in Tier 5 calculations using either the Kalman filter (KF) or random effects (RE) models as alternatives to unweighted or weighted averaging techniques: *The SSC concurs with the Team that stock assessment authors for Tier 5 stocks should continue to use status quo methods for survey averaging, and that they should also calculate alternate RE estimates, so that experience can be gained over time in how similar or different the estimates are from the two approaches."*

This year we applied a Kalman filter model to the GOA AFSC trawl survey biomass estimates for comparison with the status quo method (the average of the last three complete trawl surveys). This analysis is presented at the end of the "Tier 5 OFL and ABC Determinations" section in this report. In the next full assessment we will also apply the Kalman filter to the BS and AI trawl survey biomass estimates for comparison with the BSAI status quo results.

Response to SSC Comments Regarding the Grenadier Assessment

Concerning this assessment, the SSC commented at their December 2010 meeting that, *"The authors provided information for estimation of biological reference points for the BSAI and GOA if the NPFMC elects to manage this complex in the fishery. The SSC agrees with the proposed methods for estimation of reference points in the GOA and BS. However, the estimation method proposed for the AI requires further work. The SSC requests that the author considers the uncertainty associated with the proposed Tier 5 expansion method for the AI."*

This year a new method was used to estimate AI biomass and variance. The new method uses available biomass data from the AI trawl survey and AI RPWs from the longline survey instead of data from the EBS and GOA, which the previous method used (Clausen and Rodgveller, 2010).

At their June 2012 meeting in Appendix A titled "SSC's Five-Year Research Priorities: 2012 through 2016 (as proposed in June 2012)", under "Ongoing Needs", the SSC recommended that assessment authors "Acquire basic life history information needed for stock assessment and bycatch/PSC management of data-poor stocks, such as scallops, sharks, skates, sculpins, octopus, grenadiers, squid, and blue king crab (Bering Sea), golden king crabs (Aleutian Islands), and red king crab (Norton Sound). Specifically, information is needed on natural mortality, growth, size at maturity, and other basic indicators of stock production/productivity)…"

Although continuing research on giant grenadier is warranted, giant grenadiers should not be categorized as a "data-poor species" since we have significant information on their biomass, length

composition, natural mortality, age at maturity, and distribution. The quantity of available data is one contributing argument to adding grenadiers to the FMPs.

INTRODUCTION

Grenadiers (family Macrouridae) are deep-sea fishes related to hakes and cods that occur world-wide in all oceans (Eschmeyer et al. 1983). 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 apparent biomass, and hence is by far the most frequently caught grenadier in Alaska. Because of this importance, this report will emphasize giant grenadier, but it will also discuss the other two species.

Management: All species of grenadier in Alaska are presently considered “nonspecified species” by the North Pacific Fishery Management Council (NPFMC), which means they are not part of the NPFMC management process. Therefore, there are no limitations on catch or retention, no reporting requirements, and no official tracking of grenadier catch by management. However, in 2005 a joint management plan amendment for “other species” was proposed which included an option to change grenadiers to a “specified” status, in which case they would be included as managed groundfish species in the FMPs. In response to this possibility, an unofficial full assessment of grenadiers in Alaska was prepared for the first time as an appendix to the 2006 SAFE report (Clausen 2006), and revised SAFE reports for grenadiers were also prepared in 2008 and 2010 (Clausen and Rodgveller 2008, 2010).

In June 2009, work started on a new amendment package by the NPFMC that superseded the 2005 proposed amendments. The new amendments were in response to guidelines on “Annual Catch Limits” (ACLs) developed by NMFS to comply with the reauthorized version of the Magnuson-Stevens Fishery Conservation and Management Act. Alternatives considered in the new amendments included listing grenadiers in the FMPs as either “in the fishery” or as members of an “ecosystem component” category (North Pacific Management Council 2010). However, alternatives involving grenadiers were not carried forward when the final amendments were approved in September 2010 (Amendment 87 to the Gulf of Alaska FMP and Amendment 96 to the Bering Sea/Aleutian Islands FMP). In 2012, the topic of grenadier management was again addressed. At the June 2012 meeting of the NPFMC, a discussion paper[1] was reviewed that described four alternatives for moving grenadiers into the FMPs. The Council motion at this meeting included a purpose and need statement for moving grenadiers into the FMPs and the four alternatives. One of the alternatives is status quo while the other three would put grenadier into at least one FMP as “in the fishery” or as an “ecosystem component”. For details see the “Other Considerations” section later in this report.

If grenadiers are categorized as “in the fishery” in future FMP amendments, the NPFMC would then need to establish overfishing levels (OFL), acceptable biological catch (ABC), and total allowable catch (TAC) for grenadiers in Federal waters of Alaska. If grenadier became an “ecosystem component” catch would be required to be tracked, but OFL, ABC, and TACs would not be required. Consequently, this SAFE report has been written to prepare for the possible inclusion of grenadiers in the GOA and BSAI

[1] Pearson, T., D. Clausen, and J. DiCosimo. 2012. Discussion paper: Inclusion of grenadiers in the Fishery Management Plans for the Bering Sea and Aleutian Islands and/or the Gulf of Alaska. Unpubl. doc, 32 p. Available from North Pacific Fishery Management Council, 605 W 4th Ave., Suite 306, Anchorage AK 99501.

groundfish management plans, although the recommendations in this report for OFL and ABC are not binding at present.

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. These fish are the largest in size of the world's grenadier species (Iwamoto and Stein 1974); maximum weight of one individual in a Bering Sea trawl survey was 41.8 kg[2].

Speciation: 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 as three very different patterns of otolith morphology. Recent DNA genetic analysis of tissue samples from the two morphs showed no evidence of any differentiation[3], which appears to refute the hypothesis that giant grenadier is comprised of two distinct species. However, tissues for the previous genetic analyses may have been contaminated, and the sample size was small. New tissue and otoliths samples will be collected on the AFSC longline survey in 2013 for a more definitive analysis of speciation, stock structure, and otoliths morphometrics.

Biology: There is some known biological information on adult giant grenadier, but data on larvae and juvenile grenadiers is nonexistent. The spawning period is thought to be protracted and may even extend throughout the year (Novikov 1970; Rodgveller et al. 2010). Two papers provide purported descriptions of larvae of giant grenadier in the North Pacific (Endo et al. 1993; Ambrose 1996), but Busby (2004) points out that these descriptions appear so different that they probably represent separate species. At any rate, no larvae have ever been collected in Alaska that correspond to either of these descriptions or to the description of a third form (Busby 2004) that is also giant grenadier-like[4]. 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 2003, 2005, and 2007), 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). Bottom trawl studies indicate that females and males have different depth distributions, with females inhabiting shallower depths than males. For example, both Novikov (1970) in Russian waters and Clausen (2008) in Alaskan waters found that nearly all fish <600 m depth were female, and the Novikov study was based on trawl sampling throughout the year. Presumably, some vertical migration of one or both sexes must occur for spawning purposes; Novikov (1970) speculates that females move to deeper water inhabited by males for spawning.

Ecology: The habitat and ecological relationships of giant grenadier are likewise little known and uncertain. Clearly, adults 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 in the water column. Most of the prey items found in the stomachs were meso- or bathypelagic squids and fish, and there was little evidence of benthic feeding. Smaller studies of giant grenadier food habits in the Aleutian Islands (Yang 2003) and Gulf of Alaska (Yang et al. 2006) showed similar results.

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[2] G. Hoff, National Marine Fisheries Service, Alaska Fisheries Science Center, RACE Division, 7600 Sand Point Way NE, Seattle WA 98115. Pers. comm. March 2005.
[3] J. Orr, National Marine Fisheries Service, Alaska Fisheries Science Center, RACE Division, 7600 Sand Point Way NE, Seattle WA 98115. Pers. comm. March 2008.
[4] M. Busby, National Marine Fisheries Service, Alaska Fisheries Science Center, RACE Division, 7600 Sand Point Way NE, Seattle WA 98115. Pers. comm. October 2006.

In the Aleutian Islands, the diet comprised mostly squid and bathypelagic fish (myctophids), whereas in the Gulf of Alaska, squid and pasiphaeid shrimp predominated as prey. The hypothesis regarding the tendency of the fish to feed off bottom is 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[5]. 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[6].

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[7]. 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).

Evidence of Stock Structure: Stock structure and migration patterns of giant grenadier in Alaska are unknown, as no genetics studies have been done (except for brief genetic investigation of the two morphs of this species that was previously mentioned), and the fish cannot be tagged because all individuals die due to barotrauma when brought to the surface. One study in Russian waters, however, used indirect evidence to conclude that seasonal feeding and spawning migrations occur of up "to several hundred miles" (Tuponogov 1997).

FISHERY

Catch History

Estimation methods: As mentioned, fishermen are not required to report catch statistics for grenadiers in Alaska because grenadiers are considered "nonspecified" by the NPFMC. However, catches since 1997 have been estimated for the eastern Bering Sea (EBS), Aleutian Islands (AI), and GOA based largely on data from the Alaska Fishery Science Center's Fishery Monitoring and Analysis program (Table 1-1). 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. They do not appear unreasonable compared to the official catches of

[5] D. Clausen, National Marine Fisheries Service, Alaska Fisheries Science, Auke Bay Laboratories, 17109 Point Lena Loop Rd., Juneau, AK 99801. Pers. observ. October 2004.
[6] C. Lunsford, National Marine Fisheries Service, Alaska Fisheries Science Center, Auke Bay Laboratories, 17109 Point Lena Loop Rd., Juneau, AK 99801. Pers. comm. October 2006.
[7] D. M. Clausen and C. J. Rodgveller, 2010. Deep-water longline experimental survey for giant grenadier and sablefish in the western Gulf of Alaska, August 2008. National Marine Fisheries Service, Alaska Fisheries Science Center, Auke Bay Laboratories, 17109 Point Lena Loop Rd., Juneau, AK 99801. Unpubl. manuscr. 23p.

other species caught along with giant grenadier on the continental slope in Alaska, such as sablefish and Greenland turbot. 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. All the data are presented as "grenadiers, all species combined", because observers were not instructed to identify giant grenadiers until 2005. Even then, the catch data suggest that many observers in the years 2005-2007 did not properly identify giant grenadier to species; some observers in these years were still reporting a sizeable percentage of the grenadier catch as "grenadier unidentified". Although the species breakdown of the grenadier catch is unknown, it can be surmised that giant grenadier comprised by far the majority of the fish caught. The only other grenadier species encountered on the continental slope in Alaska are Pacific and popeye grenadier. Bottom trawl and longline surveys all show that very few Pacific and popeye grenadier are found shallower than 800 m deep, whereas giant grenadier are abundant in these depths (see section 1.3.2.1, "Survey Data"). Although there are no analyses of the depth distribution of commercial fishing effort in Alaska, it is likely that very little effort occurs in depths >800 m. Hence, this indirect evidence can be used to conclude that giant grenadier is the overwhelmingly predominant species in the grenadier catch. This conclusion is supported by the catch data for 2008-2012, when it appears that most observers were properly identifying giant grenadier. The catch data for these years show that giant grenadier comprised greater than 90% of the grenadier catch in Alaska; the remainder were nearly all listed as "grenadier unidentified" and most of these were likely also giant grenadier.

One important caveat is that the catch estimates for the BSAI may be more accurate than those for the GOA. In the catch estimation process, it is assumed that grenadier catch aboard observed vessels is representative of grenadier catch aboard unobserved vessels. This is a possible problem because observer coverage in the BSAI fisheries is considerably higher than those in the GOA. In general, smaller vessels fish in the GOA, especially in longline fisheries, and many of these vessels are not required to have observers, which could introduce a bias into the GOA estimates. This should become less of an issue in 2013, when for the first time the observer program will put observers on small vessels (< 60 ft).

Catches: The estimated annual catches of grenadiers in Alaska for the years 1997-2012 have ranged between ~11,000-21,000 mt, with an average for this period of ~16,000 mt (Table 1-1). Highest catches have consistently been in the GOA, followed generally by the EBS and then the AI. By region, annual catches have ranged between ~6,000-15,000 mt in the GOA, ~2,000-5,000 mt in the EBS, and ~1,000-4,000 mt in the AI. To put these catches in perspective, the total annual sablefish catch in Alaska in the years 1996-2012 ranged from about 12,000 to 17,000 mt (Hanselman et al. 2009). Thus, the amount of grenadier caught in these years was similar to the amount of sablefish taken.

Non-commercial catch: Catch from surveys are presented in Appendix 1B (Table 1B-1). AFSC longline, RACE bottom trawl, and IPHC longline surveys data are available, but data from other sources is not tracked since grenadiers are not in the FMP. Recreational fishing does not occur in the deep-waters inhabited by grenadiers. Both trawl and longline surveys by the AFSC contribute significantly to the research catch. IPHC survey catches are relatively minor because the maximum depth of this survey is 500 m.

<u>Description of the Fishery</u>

Virtually all the catch of grenadiers in Alaska has been taken as bycatch in fisheries directed at other species, particularly sablefish and Greenland turbot. Nearly all the grenadier catch is discarded, and the discard mortality rate is 100% because the pressure difference experienced by the fish when they are brought to the surface invariably causes death. An analysis of catch estimates for 1997-1999 indicated that most of the grenadier catch in the GOA was taken in the sablefish fishery, whereas in the BSAI, it came from both the sablefish and the Greenland turbot fishery (Clausen and Gaichas 2004). The high bycatch of grenadiers in fisheries for sablefish and Greenland turbot is not surprising, as the latter two species inhabit waters of the continental slope where giant grenadier are abundant. For the present report, a similar analysis was done for the years 2003-2012 based on data from the NMFS Alaska Regional Office Catch Accounting System (Table 1-2). It also shows that the grenadier catch in the both the GOA and AI has been taken predominantly in hauls that targeted sablefish, whereas that in the EBS came from hauls that targeted Greenland turbot. Historically, both the sablefish and Greenland turbot fisheries have been predominantly longline, and a previous analysis of grenadier catch showed most grenadiers in both the BSAI and GOA were caught on longlines (Clausen and Gaichas 2005). In recent years, however, many sablefish and Greenland turbot fishermen in the BSAI have switched to using pots to protect their catches from whale depredation. In 2011, 60% of the fixed-gear EBS catch of sablefish was taken in pots (Hanselman et al. 2011), and it is uncertain how this change has affected grenadier catches in this area. However, analysis of sablefish pot catches in the BSAI indicates that giant grenadier is the fourth most abundant bycatch species (Hanselman et al. 2009). Pot fishing for sablefish is currently not allowed in Federal waters of the GOA.

The data in Table 1-2 also show substantial catches of grenadiers are sometimes taken in the Pacific halibut fishery. However, these data should be viewed with great caution because they are based on very low rates of observer coverage in the halibut fishery, which may introduce inaccuracies into the catch estimates. For example, low rates of observer coverage likely explain much of the high variability in the halibut fishery's annual grenadier catches shown in Table 1-2. Alternative estimates of bycatch in the halibut fishery are needed to better determine the actual bycatch of giant grenadier in this fishery. The observer program will have observers on halibut vessels for the first time in 2013, so improved data will be available in the future.

There were also large catches of grenadiers in the "other flatfish" category, especially in the BS and AI since 2009 (table 1-2). Within the "other flatfish" target category, the most common target fishery that caught grenadiers were the arrowtooth and Kamchatka founder trawl fisheries. Catches of grenadiers in the "other flatfish" fisheries in the GOA were less substantial and were found in the arrowtooth and rex sole trawl fisheries.

Attempts to develop a market: Because of the large biomass of giant grenadier on the continental slope, research has been done to develop marketable products from this species (Crapo et al. 1999a and 1999b). There have been several know attempts to develop a fishery in Alaska, and it is likely that Alaskan fishermen will continue their efforts at utilizing this species. The first was an endeavor to process longline-caught giant grenadier for surimi at the port of Kodiak in 1998[8]. This small effort was apparently unsuccessful, as it ended in 1999. The second, also from the port of Kodiak, was an exploratory effort in 2005 using trawls to target giant grenadier and develop a fillet and roe market[9]. This second venture was not continued in 2006. From 2009-2011 a total of approximately 1,400 mt were retained for processing[10]. Personal communications with the industry indicate that at least some of this catch is sold as headed and gutted and tail cut off, and at least some of the grenadier were incidentally caught in other groundfish fisheries and not from a targeted fishery. Because it is such a low value product, it is likely that much of the retained catch was caught incidentally in other target fisheries such as sablefish and Greenland turbot fisheries.

<u>Size, Sex, and Age Composition in the Fishery</u>

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[8] J. Ferdinand, National Marine Fisheries Service, Alaska Fisheries Science Center, REFM Division, 7600 Sand Point Way NE, Seattle WA 98115-0070. Pers. comm. September 2004.
[9] T. Pearson, Kodiak Fisheries Research Center, National Marine Fisheries Service, Sustainable Fisheries, 302 Trident Way, Room 212, Kodiak AK 99615. Pers. comm. October 2005.
[10] J. Keaton, National Marine Fisheries Service, Regional Office, P.O. Box 21668, 709 W. 9th St., Juneau, AK, 99802-1668, Pers. comm. October 2012.

Beginning in 2007, length and sex data for giant grenadier in the commercial sablefish fishery were collected by at-sea observers. The sampling scheme has been to collect these data for a random sample of about five giant grenadier per haul for those hauls in which sablefish was the predominant commercial species (i.e., hauls where a large bycatch of giant grenadier would be likely). All the fish sampled were caught on either longlines or in pots. Results for 2007-2012 showed that giant grenadier in the BSAI were generally larger than those in the GOA (Figures 1-1a and 1-1b), which agrees with results of fishery-independent surveys of the two regions. The length distributions in the BSAI, where giant grenadier are caught by both longline and pot gear, suggest that there is no difference in the size of fish by each gear type, for males and for females.

Female giant grenadier comprised the majority of the fish sampled by observers in all areas and years (Table 1-3). For example, in the GOA, about 80% of the fish were female. While this percentage is relatively high, it is much lower than we expected based on sex compositions found in surveys. In particular, females have comprised >95% of the giant grenadier sampled in GOA longline surveys at depths less than 800 m, where nearly all the commercial fishing effort in Alaska is believed to occur (see Table 1-9). This discrepancy may indicate that observers are misidentifying the sex of some fish. To ensure this does not occur, we plan to provide observers with better guidelines, including photographs, to aid in sex determinations. Photographs were taken on the 2012 longline survey.

Age samples of giant grenadier have not been collected in the commercial fishery.

SURVEY DATA

Trawl Surveys

Issues with sampling depths: There have been many NMFS trawl surveys in the EBS, AI, and GOA since 1979, but relatively few have extended deep enough on the continental slope to yield meaningful biomass estimates for grenadiers. For example, most surveys of the AI and some of the GOA have sampled only to 500 m; thus, they barely entered the abundant depth range of giant grenadier and were well above the depths inhabited by Pacific and popeye grenadier. Prior to the early 1990s, it is believed that survey scientists did not always correctly identify Pacific and popeye grenadier in AI and GOA surveys, so historical biomass estimates for these two species in these surveys have not been included in this report. Also, the earlier Bering Sea surveys (1979-1991) usually identified grenadiers only to the level of family, and it is these combined estimates that are listed in Table 1-4. Giant grenadier biomass estimates for those surveys that have extended to 800 m or deeper are listed in Table 1-4. Because of the difficult trawling conditions encountered in the AI at depths >500 m, sampling these deep waters was dropped from the survey design in this area after 1986.

New biomass estimation in AI: No trawl surveys in the Aleutian Islands (AI) have sampled depths >500 m since 1986, so an indirect method was used to determine biomass of giant grenadier in this region (Clausen and Rodgveller 2008, 2010). This method used a combination of data from other areas and surveys: the GOA and EBS slope trawl surveys and the AFSC longline survey (Clausen and Rodgveller, 2010) and not the AI trawl survey. In 2012, we use a new method was used to estimate AI biomass. The ratio of “shallow” (<500 m) biomass estimates from the trawl survey and the “shallow” RPWs from the longline survey (for years when both surveys occurred: 2000, 2002, 2004, 2006, 2010, and 2012) is multiplied by the longline survey RPW, for the “shallow” and “deep” depths combined, to obtain a total AI biomass estimate (1-1000 m). Whenever there is a longline survey an extrapolated biomass is now available even if the AI trawl survey only sampled to 500 m (every survey since 1986). Details of this method are in Appendix 1A. Overall, the new method provides lower estimates of AI biomass than those from previous SAFEs (executive summary above; Appendix 1A, Table 1A-4, Fig. 1A-4). The trends between the old and proposed methods are similar. This ratio between trawl survey biomass and longline survey RPW will be updated each year as new data become available.

Giant grenadier biomass: The biomass estimates indicate that sizeable populations of giant grenadier are found in each of the three regions surveyed, but the survey time series are too intermittent to show any trends in abundance in the EBS and GOA. Highest estimates of giant grenadier biomass in each region were 667,000 mt in the EBS (2004), 809,260 mt in the AI (2006), and 718,000 mt in the GOA (2009). In the EBS, the biomass estimates for 1979-1991 appear to be unreasonably low compared to the biomass estimates in 2002, 2004, 2008, 2010, and 2012. Given the apparent longevity and slow growth of giant grenadier (see "Age Data" section), it is unlikely that its biomass could have increased nearly six-fold from 74,000 mt in 1991 to 426,000 mt in 2002. The EBS slope surveys since 2002 are considered to be better than their predecessors because they were the only ones specifically designed to sample the continental slope, they trawled deeper water (to 1,200 m) that encompassed more of the depth range of grenadiers, and they had good geographical coverage in all areas[11]. Also, in comparison to the steep and rocky slopes of the GOA and especially the AI, the EBS slope is easier to sample with a bottom trawl, which means a trawl survey in the latter region may yield more reliable results. Therefore, the biomass estimates in the EBS since 2002 may be the most accurate of the surveys in Table 1-4.

One factor that could have a significant effect on the biomass estimates is the extent that giant grenadier move off bottom into the water column. As discussed, there is indirect evidence from feeding studies that giant grenadier may be semi-pelagic when searching for prey. If so, some of the population may be unavailable to the bottom trawl, which would result in an underestimate of biomass.

Species specific composition: Results of the most recent trawl surveys, since 1999, in the EBS and GOA can be examined to determine the comparative biomass of the three grenadier species (Table 1-5). In the GOA in 1999, 2005, 2007, and 2009, giant grenadier was by far the most abundant species and comprised 94%-96% of the aggregate grenadier biomass. Next in abundance was popeye grenadier, followed by Pacific grenadier. In the EBS slope surveys in 2002, 2004, 2008, 2010, and 2012 giant grenadier also greatly predominated, with 89%-93% of the aggregate biomass. Similar to the GOA, popeye grenadier was second in biomass, followed by Pacific grenadier. Popeye grenadier biomass was considerably larger in the EBS surveys than in the GOA survey, which may be partially due to the fact that the EBS surveys sampled deeper water to 1,200 m, whereas the GOA survey only went to a maximum depth of 1,000 m (Figures 1-2 and 1-3).

Variability in biomass: Data from recent GOA and EBS slope trawl surveys can also be used to examine the variability of the biomass estimates for giant grenadier (Table 1-6). Except for the 2009 GOA survey, all the surveys in the GOA and EBS show low values of ~10% for the coefficients of variation for each biomass estimate. This indicates that the estimates are relatively precise for giant grenadier compared with those of many other groundfish species, and also that giant grenadier have a rather even distribution within the strata in which they are caught. The 2009 GOA survey, with a much higher coefficient of variation of 38.4%, appears to be anomalous. We examined the distribution of giant grenadier catches in this survey (Figure 1-4), and an extremely large catch of 8,400 kg in one haul appears to be mostly responsible for the increased variability of giant grenadier biomass in this survey. This catch is much higher than any other giant grenadier catch in previous trawl surveys of the GOA or EBS slope. The large catch may also be largely responsible for the increased biomass of giant grenadier seen in the 2009 GOA survey. The CVs for all the AI biomass estimates were all ~24%. They are the same in all years since

[11] G. Walters, National Marine Fisheries Service, Alaska Fisheries Science Center, RACE Division, 7600 Sand Point Way NE, Seattle WA 98115-0070. Pers. commun. October 2004.

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 in each year.

Depth distribution: The recent trawl surveys provide information on the depth distribution of grenadiers in the GOA and EBS in terms of biomass and catch-per-unit-effort (CPUE; Figures 1-2, 1-3, 1-5, and 1-6). The surveys indicated that in both the EBS and GOA, giant grenadier accounted for nearly all the grenadier biomass at depths less than ~600-700 m, whereas Pacific and popeye grenadier did not become moderately abundant until deeper depths. In the GOA, little biomass of giant grenadier occurs in depths <300 m, but there is no consistent trend in the surveys concerning the distribution of biomass in deeper strata. For example, biomass was fairly equal in the 300-500, 500-700, and 700-1,000 m strata in the 1999 survey, but was distinctly highest in the 501-700 m stratum in 2007 and in the 701-1,000 m stratum in 2009. The haul with the anomalously high catch in the 2009 survey occurred in the 700-1000 m stratum, and this likely explains the large biomass in this stratum in 2009. In terms of CPUE in the GOA, catch rates were distinctly highest in the 500-700 stratum in the 1999, 2005, and 2007 surveys (Figure 1-5). The high GOA CPUE in the 700-1,000 m stratum in 2009 may be biased by the haul with the large catch that occurred there. The 2002, 2004, and 2012 EBS surveys showed giant grenadier biomass peaking somewhat evenly at depths 400-1,000 m, whereas the 2008 and 2010 surveys showed a pronounced peak in biomass in the 600-800 m stratum (Figure 1-3).

Size composition: Population size compositions for giant grenadier from the recent trawl surveys indicate that fish are considerably larger in the EBS than the GOA (Figure 1-7). The mean female PAFL (pre anal fin length) for females in the EBS was 29.5 cm whereas it was 27.1 cm in the GOA. For males in the EBS PAFL was 24.1 cm and in the GOA was 23.1 cm. This difference in size is even greater than would outwardly seem because PAFL is a much shorter measurement relative to the fish's size than standard length measurements such as fork length or total length. The mean lengths translate to a difference in female weight of nearly 25% (see later section "Length-at-Age, and Length-Weight Relationships" for giant grenadier length-weight relationships). In the EBS, a much greater percentage of the population appears to consist of female fish >30 cm in length.

Ecological role: Results of the trawl surveys emphasize the important ecological role of giant grenadier in Alaskan waters. In a ranking of all species caught in the 1999 GOA trawl survey, giant grenadier was the fifth most abundant species in terms of CPUE, after arrowtooth flounder, Pacific ocean perch, walleye pollock, and Pacific halibut (Britt and Martin 2001). It should be noted that this survey covered both the continental shelf and slope; if we consider just the slope deeper than 400 m, giant grenadier had the highest overall CPUE. Similarly, the 2007 GOA trawl survey indicated giant grenadier was third most abundant species in terms of CPUE, and was exceeded only by arrowtooth flounder and Pacific ocean perch (von Szalay et al. 2008). In the EBS slope surveys, giant grenadier is even more important. Among all species caught in the 2002, 2004, 2008, and 2010 surveys in this area, giant grenadier was by far the most abundant in terms of both CPUE and biomass (Hoff and Britt 2003, 2005, 2009, 2011).

<u>Longline Surveys</u>

Survey background: Longline surveys of the continental slope off Alaska have been conducted annually since 1979 (Lunsford and Rodgveller 2011). The primary purpose of the surveys is assessment of sablefish abundance, and the standard depth sampled is 200-1,000 m. An index of relative biomass, called the "relative population weight" (RPW), is computed for all the major species caught in the survey. It should be noted that although RPW is an index of biomass (weight), it is actually a unit-less value. Although the survey time series extends back to 1979, RPWs for giant grenadier are only available for the years since 1990[12]. Other measures of giant grenadier abundance in the surveys have been computed for the years 1979-1989, including CPUE values and an index of abundance by number, called "relative population number". These data for the surveys before 1990 are presented in Sasaki and Teshima (1988) and Zenger and Sigler (1992), but because the data are not in terms of weight (RPW), they will be not be discussed in this report.

In the GOA and AI, the longline gear used in the surveys is able to sample a high proportion of the steep and rocky habitat that characterizes the slope in these regions. This is in contrast to bottom trawls used on the trawl surveys, which are often limited to fishing on relatively smooth substrate. Because of this difference, the longline surveys may do a better job of monitoring abundance of giant grenadier on the slope, although they do not provide estimates of absolute biomass.

The RPWs provide a standardized time series of annual RPWs for giant grenadier in the GOA for the period 1990-2012 and an intermittent series in the AI and EBS (Table 1-7). The survey was expanded from the GOA into the AI in 1996 and to the EBS in 1997, but these latter two regions have only been sampled in alternating years since. Therefore, the time series is less complete for the AI and EBS. In the GOA, definitive trends in RPW are difficult to discern.

Calculation changes for RPWs: In 2012 changes were made to giant grenadier RPW calculations. An updated length-weight relationship from trawl survey data was adopted and used for the whole time series in all areas. This decreased RPWs overall. For example, using the old growth curve relationship, the RPW in 2010 in the GOA was 1,412,304 and using the new growth data it is now 1,236,692. Thus all the RPWs in table 1-7 have been modified from what they were in previous SAFEs. Also starting this year, the ratio used to extrapolate RPWs in the western AI was changed. The western AI have not been sampled by the AFSC longline survey since 1994. Since the first grenadier SAFE in 2006, ratios of sablefish relative population numbers (RPNs) between the northwest AI/northeast AI and the southwest AI/southeast AI from 1985-1994 (when the western AI was sampled by the cooperative Japan-U.S. longline survey) were used for giant grenadier to extrapolate the western AI relative population weights (RPWs) from the eastern RPWs for giant grenadier. Previously, western AI RPN and RPWs for all major groundfish were extrapolated using these sablefish ratios and provided to stock assessment authors. Recently, data from the AFSC longline survey and the cooperative Japan-U.S longline survey have been consolidated into one relational database that enables historic data to be queried and analyzed. Sablefish ratios are no longer used to estimate western AI RPNs and RPWs for other species. The ratio for giant grenadier is much larger than the one previously used and so AI RPNs increased overall. For example, in 2010 the AI RPN was 1,915,769 and using the new extrapolation ratio it is now 3,734,301. Details on these changes can be found in Appendix 1B (Table 1B-1).

RPWs: Generally, RPWs in the GOA were relatively high from 1992-2000 (peak in 1999 of 1,277,141), and diminished to a low of 801,271 in 2004. The RPWs have been moderate since 2001 and in 2012 the RPW in the GOA was just below the mean (Table 1-7). Giant grenadier RPWs are much higher in the AI than in the other regions, even though the area of the slope is much larger in the GOA. Since an anomalous low RPW in the AI in 2008 (~ 2 million), RPWs in 2010 and 2012 have remained high (~3.2-3.7 million).

Distribution: Giant grenadier catch rates in the longline surveys can be used to examine the geographic distribution of abundance in more detail (Table 1-8). Highest catch rates are consistently seen in the eastern AI, and in the western most GOA areas, Shumagin and Chirikof, as well as in EBS areas 3 and 4, which are located NW of the Pribilof Islands. In the GOA, there is a definite decline in catch rates as one

[12] C. Lunsford, National Marine Fisheries Service, Alaska Fisheries Science Center, Auke Bay Laboratories, 17109 Point Lena Loop Rd., Juneau, AK 99801. Pers. comm. July 2004.

progresses from the west (Shumagin area) to the east (Southeast area). The 1999, 2005, 2007, and 2009 GOA trawl surveys also showed a similar trend and found very low catch rates and biomass estimates in the eastern GOA (Britt and Martin 2001; Footnote[13]; von Szalay et al. 2008; von Szalay et al. 2009). One anomaly in Table 1-8 is the extremely low catch rate in EBS area 4 in 2007 (1.1 fish/100 hooks). This meager catch rate was presumably a major factor contributing to the relatively low RPW for the EBS in 2007. In 2012 the AI catch rates and RPW were down from 2010 whereas the GOA CPUEs and RPW increased.

The depth distribution of RPW for giant grenadier in the GOA has been remarkably consistent for all the years of the longline survey that have been examined (Clausen 2008). RPW is relatively high and nearly equal in value for each of the three deepest strata sampled in these surveys: 401-600 m, 601-800 m, and 801-1,000 m (Figure 1-8). These data indicate that additional sampling would be useful at depths >1,000 m to determine where the abundance of giant grenadier begins to decline. The data also suggest that an unknown and perhaps significant portion of the giant grenadier population in the GOA may reside in depths beyond 1,000 m that are not currently surveyed. To investigate this further, a deep-water longline survey was completed in 2008 near Dutch Harbor in the western GOA. This showed that catch rates were relatively high at deeper depths but were less than at 400-1000 m. See section below called “Experimental Deep-Water Longline Survey”.

Compared with the GOA, depth distribution of giant grenadier RPW in the eastern AI was generally similar, but was somewhat different in the EBS (Figure 1-8). The RPW in the AI, as in the GOA, was concentrated in the 401-600, 601-800, and 801-1,000 m depth strata, with fairly equal amounts in each stratum. In the EBS, the biomass was distinctly higher in the 601-800 m stratum. All areas show a relatively high RPW at 801-1,000 m, which also implies the possibility that a considerable biomass may inhabit depths >1,000.

Hook competition: A possible factor that may influence the survey’s catch rates and RPWs for giant grenadier is competition amongst species for baited hooks. Rodgveller et al. (2008) demonstrated that there is a negative relationship between giant grenadier and sablefish catch rates on the longline survey at the depths where grenadier are caught; i.e., when sablefish catches were high, giant grenadier catches were low, and vice-versa. This relationship was also explored in the GOA trawl survey, but a negative relationship was not found, indicating that the negative correlations on the longline survey could be due to competition for hooks. Zenger and Sigler (1992) suggested that giant grenadier may be out-competed on the longline by more energetic fish such as sablefish. If sablefish are more quickly attracted to and caught on the hooks, or are able to drive away giant grenadier when both species are competing for the hooks, the survey’s catch rates for giant grenadier may not be proportional to actual trends in abundance. If competition is occurring between sablefish and giant grenadier, the lower abundance of sablefish in the AI and EBS could contribute to the higher catch rates of giant grenadier in these areas. Similarly, it could also explain the large RPW values for giant grenadier in the deep 801-1,000 m stratum in the GOA surveys and in some of the AI and EBS surveys because the relatively low abundance of sablefish in this stratum may allow more giant grenadier to be caught. To investigate the problem of possible competition for hooks in the longline survey, additional analyses and possibly experimental studies are needed to examine the catch probabilities of giant grenadier.

Lengths: Population length frequency distributions for giant grenadier in the longline surveys indicate size of fish is generally largest in the EBS, intermediate in the eastern AI, and smallest in the GOA (Figures 1-9, 1-10, and 1-11). This difference in size between the EBS and the GOA agrees with that found in the recent trawl surveys of these two regions, which were discussed previously in this report. The length

[13] Unpubl. data for 2005 GOA trawl survey in NMFS Alaska Fisheries Science Center’s “Racebase” trawl survey database, Ocober. 2005. Alaska Fisheries Science Center, RACE Division, 7600 Sand Point Way NE, Seattle WA 98115.

distributions of the longline surveys in the EBS tend to be spread over more lengths and include more large fish >35 cm PAFL (Figure 1-10). Mean length in the GOA since 2000 has been consistently smaller than in the 1990s. Mean length in the eastern AI has also been smaller since 2004 compared to previous years. Further analysis is needed to better understand the reasons for this decrease in size.

A comparison between Figure 1-7 (size compositions for the GOA and EBS trawl surveys) and Figures 1-9 and 1-10 (size compositions for the GOA and EBS longline surveys) reveals that the size distributions were consistently smaller for giant grenadier in the trawl surveys. For example, mean length in the 1999 GOA trawl survey for sexes combined was 24.9 cm, whereas it was 30.4 cm in that year's GOA longline survey. This indicates that there is a substantial difference in the size selectivity between the gear types used in each survey. It appears that the longline surveys are not sampling many of the smaller giant grenadiers less than ~25 cm PAFL that are taken in the trawl surveys.

Sex distribution: Information on sex distribution of giant grenadier caught in the longline survey has only been collected since 2006 (Table 1-9). Results show that females are the overwhelming majority of the survey catch, comprising a remarkably consistent 96-97% of the fish sampled in the GOA, 94-99% in the eastern AI, and 98-99% in the EBS. Females especially predominated in depths <800 m. Because most of the effort in the sablefish longline fishery in Alaska is in depths <800 m, this would indicate that nearly all the commercial catch of giant grenadier is female. However, as discussed in the previous section "Size, Sex, and Age Composition in the Fishery", observer data from the GOA fishery during the past six years indicated females comprised only about 80% of the samples (Table 1-3). Because experienced biologists are doing the sex determinations on the survey, we are confident they are accurate, but (as noted previously) we are concerned that observers could perhaps be misidentifying some females as males. In the longline survey sex distributions, there was a trend toward an increased number of males in progressively deeper strata, but even at the deepest stratum of 800-1,000 m, males were only 6-13% of the catch in the GOA, 7-31% in the eastern AI, and 5-8% in the EBS (Table 1-9). These results imply that much of the male population may reside in depths >1,000 that are not covered by the survey, at least during the summer period when the survey is occurring.

Experimental Deep-Water Longline Survey

Depth coverage in the standard AFSC longline survey of the slope in Alaska extends only to 1,000 m, and (as discussed previously) a substantial but unknown amount of giant grenadier may reside in deeper water. To investigate the abundance of GOA giant grenadier in waters >1,000 m depth, a short experimental longline survey was conducted at these depths in the Shumagin area in 2008[14]. The experiment consisted of fishing survey longline gear in depths 1,000-1,600 m at stations located adjacent to standard survey stations in shallower water. The results showed that although catch rates for giant grenadier were fairly high in these deep waters, they were considerably less than at the corresponding survey stations at depths <1,000 m. This suggests that peak abundance for giant grenadier may be at depths <1,000 that are covered by the standard longline and trawl surveys. One unexpected result of the experimental survey was that female giant grenadier were much larger in size at the deep-water stations; they averaged 69% greater in weight than comparable females in depths <1,000 m. Also, males were much more abundant in deep water and comprised as much as 42% of the giant grenadier catch at one station. Additional survey work needs to be done in depths >1,000 m to better determine the abundance and biological characteristics of giant grenadier in these deep waters.

Age Data

[14] D. M. Clausen and C. J. Rodgveller, 2010. Deep-water longline experimental survey for giant grenadier and sablefish in the western Gulf of Alaska, August 2008. National Marine Fisheries Service, Alaska Fisheries Science Center, Auke Bay Laboratories, 17109 Point Lena Loop Rd., Juneau, AK 99801. Unpubl. manuscr. 23p.

Giant grenadier: Although otolith samples of giant grenadier have been collected in recent trawl surveys, none of these have been aged. The first aging study of giant grenadier to use contemporary aging methods (thin-sectioning of otoliths) was by Burton (1999), and it was based on 357 adult fish from the AI, GOA, and off Oregon and California. Results showed ages ranged between 13 and 56 years, and the 56 year-old came from the GOA. However, the otoliths were reported to be very difficult to age, and von Bertalanffy growth curves yielded an unreasonable fit to the size and age data because there were very few small fish in the samples. No analysis was done to determine if ages differed by geographic area. Radiometric aging methods were also applied to the otoliths, and confirmed that giant grenadier live to at least 32 years.

In the 2008 SAFE report (Clausen and Rodgveller 2008), we discussed results of the first attempt by age readers at the AFSC REFM Division Age and Growth Program to determine ages for giant grenadier. The age samples (otoliths) were collected during the 2004 and 2006 NMFS longline surveys in the GOA for a female age-at-maturity study (Rodgveller et al. 2010). A total of 338 fish were aged (all female), and ages ranged from 14 to 58 years. The maximum age of 58 is very close to the maximum age of 56 that was reported in Burton's 1999 study. This agreement lends credence to the results of both studies.

The REFM aging staff found that an innovative aging procedure that involved two different methods seemed to yield the best results. Each otolith was first aged with the "ground distal surface" method, and if aging was still judged to be unsatisfactory, the otolith was then aged by a second method, "transverse thin-sectioning" (Rodgveller et al. 2010; Hutchinson and Anderl 2012). Using these two techniques, the age-determination process appeared to be somewhat easier and perhaps more reliable than in Burton's study. However, even using REFM's new methods, age determination for giant grenadier is still difficult compared to many other groundfish species, and validation of the new aging methodology is needed. An attempt in 2008 to use carbon 14 to confirm some of the ages determined by REFM staff proved unsuccessful[15], and other means of validation will be necessary before aging of giant grenadier can move from an experimental to a production mode.

The REFM age and growth lab staff found that giant grenadier have three shapes of otoliths, with more than one shape sometimes existing within one fish. Otolith shape within a species usually has very little variation and so this finding is highly unusual. To investigate the possibility of giant grenadier being more than one species or sub-species and to investigate evidence of stock structure between areas and otolith morphology, genetic tissue and otolith samples will be collected on the longline survey in 2013.

Pacific grenadier: No aging studies have been done for Pacific grenadier in Alaska, but Andrews et al. (1999) conducted an aging study for this species off the U.S. west coast. Similar to giant grenadier, the study found that Pacific grenadier otoliths were extremely difficult to age. Both immature and adult fish were sampled, and ages ranged from 1 to 73 years. Radiometric aging was used to confirm the ages in this study, and it verified that Pacific grenadier live to at least 56 years. Another study off California also found that Pacific grenadier are slow-growing and long-lived, and it reported a maximum age of 62 years (Matsui et al. 1990). In contrast to Burton's study for giant grenadier, Andrews et al. (1999) successfully yielded von Bertalanffy growth equations for Pacific grenadier.

Grenadiers in general: Age information for other Macrouridae species suggests that most are quite long-lived. For example, the roundnose grenadier (*Coryphaenoides rupestris)*, an important commercial species in the Atlantic, is thought to live up to 70 years (Merrett and Haedrich 1997). It appears that macrourids, including giant and Pacific grenadier, can be categorized as classic "*K*-selected species", as

[15] C. Hutchinson, National Marine Fisheries Service, Alaska Fisheries Science Center, REFM Division, 7600 Sand Point Way NE, Seattle WA 98115. Pers. comm. Sept. 2008.

they possess the *K*-selected traits of longevity, slow growth, relatively large size, and residence in a stable and unproductive environment (the deep ocean).

ANALYTIC APPROACH

Parameter estimates

Maximum Age: The most recent aging studies for giant grenadiers (Burton 1999 and Rodgveller et al. 2010) found the maximum age to be 56 and 58 years, respectively, based on specimens from the GOA. There have been no aging studies for Pacific grenadier in Alaska, but Andrews et al. (1999) found a maximum age of 73 years for this species off the U.S. west coast.

Natural mortality: In the 2012 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.

Age and length at maturity: Novikov (1970) briefly stated that sexual maturity is reached at about 56 cm total length (14 cm PAFL based on a conversion factor in Burton (1999)), when the fish assume a more benthic existence. However, he gives no data as to how this value was determined or to which sex it applies, and the size seems unreasonably small. Recently, Rodgveller et al. (2010) made both macroscopic observations of fresh ovaries at sea, and microscopic/histological observations of preserved ovarian tissue samples in the laboratory, and aged the majority of samples using the new techniques described in the section "Age Data". The microscopic method of determining maturity, which is considered the most reliable, indicated age-at-50%-maturity was 22.9 years, and size at 50% maturity was 26 cm PAFL. Therefore, female giant grenadier mature at a much older age than most other groundfish.

Length frequency distributions for giant grenadier in the commercial fishery (Figure 1-1) and size composition data for the longline surveys (Figures 1-9, 1-10, and 1-11) show that only fish >20 cm PAFL are taken by longlines and pots, and relatively few fish <25 cm PAFL are caught. If we assume the female size-at-50%-maturity is 26 cm PAFL (see preceding paragraph), it appears that immature fish comprise only a small percentage of the giant grenadier catch.

As part of the recently completed maturity study of giant grenadier in the GOA, fecundity was also examined (Rodgveller et al. 2010). Only ovaries with advanced stage oocytes, based on both macroscopic observations and histology, were included in the analysis. Total fecundity ranged from 35,000-231,000 oocytes, with a mean of 107,000 (n = 34 fish examined).

Length at Age, and Length-Weight Relationships: Length at age information is available for female giant grenadier based on the AFSC REFM Division's aging of 338 individuals from the GOA longline survey. Unlike Burton's (1999) previous aging study of giant grenadier, enough small fish were included in the

REFM age sample to allow the determination of a von Bertalanffy growth curve. The von Bertalanffy parameters are as follows[16] (L_{inf} is in cm):

	female
L_{inf}	54.9
K	0.022
t_0	-7.54

Andrews et al. (1999) reported these von Bertalanffy parameters for Pacific grenadier off the U.S. west coast (L_{inf} is in mm):

	male	female	combined
L_{inf}	372	268	272
K	0.024	0.040	0.041
t_0	-1.79	0.20	0.25

The combined sex length-weight relationship for giant grenadiers is calculated from measurements taken on BS, AI, and GOA trawl surveys. This relationship is used for calculation of RPWs for the longline survey.

W is weight is kg and PAFL is in cm:

$W = 2.883 \times 10^{-4} (PAFL^{2.772})$

n combined (female, male, unknown) = 3,558

n, male = 987

n, female = 2,571

Tier 5 OFL and ABC Determinations

Giant grenadier as a proxy for grenadiers: Similar to the previous grenadier assessments, we have chosen to only include giant grenadier in the tier 5 calculations of OFL and ABC (see Executive Summary). Thus, for tier 5 giant grenadier is serving as a proxy for the entire grenadier group. The reasons for excluding Pacific and popeye grenadier are twofold: (1) at present, nearly all the grenadier catch in Alaska is comprised of giant grenadier, as Pacific and popeye grenadier are largely distributed in waters >800 m depth where very little commercial fishing takes place; and (2) groundfish surveys in Alaska have extended only to 1,000-1,200 m depth, whereas the distribution of Pacific and popeye grenadier extends far deeper. Hence, biomass estimates for these two species are unreliable and are likely much less than their true values.

Parameters used: In the previous stock assessment for grenadiers (Clausen and Rodgveller 2010), the NPFMC's tier 5 approach for determining the OFL and ABC was recommended, and this approach was supported by both the GOA Groundfish Plan Team and the NPFMC's Scientific and Statistical Committee. We again recommend using the tier 5 approach in the present assessment. Tier 5 assumes that a species has reliable estimates of biomass and natural mortality. Credible biomass estimates for giant grenadier are available as well as an estimate of M (0.078) based on a maximum age of 58 determined in recent aging studies for this fish in the GOA (Rodgveller et al. 2010). In future assessments, it may be possible to move giant grenadier into tier 4 because data on female age-at-maturity is now available, as well as new methods for determining age that were recently developed by the AFSC.

[16] Data from C. Rodgveller, Alaska Fisheries Science Center, Auke Bay Laboratories, 17109 Point Lena Loop Rd., Juneau, AK 99801. October 2008.

However, movement to tier 4 will depend on whether validation studies of the new aging methods for giant grenadier are successful.

Methods: Current biomass estimates in this assessment for giant grenadier in the EBS and GOA were calculated based on the average of the three most recent deep-water trawl surveys that sampled down to 1,000 or 1,200 m (Table 1-4). In the EBS, these are now the 2008, 2010, and 2012 surveys. In the GOA, these are in 2005, 2007, and 2009. The 2011 GOA survey only sampled to 700 m so it is not included in the average biomass, since a large portion of grenadier biomass is deeper than 700 m. In the AI a new method was used to calculate biomass down to 1,000 m, even when trawl surveys sampled only to 500 m. A summary of this method follows and more extensive details are in Appendix 1A and the "survey data" section. Estimates of AI biomass used for calculations of ABC and OFL are now based on 2008, 2010, and 2012. This approach of using the three most recent biomass estimates to determine a value for tier 5 biomass has been applied for a number of years to tier 5 rockfish species in the GOA, and we recommend continuing to use this methodology for giant grenadier.

The Aleutian Islands have presented a special problem for biomass estimation because no trawl surveys since 1986 have sampled waters deeper than 500 m, where most giant grenadier biomass is found. In the previous grenadier assessments (Clausen 2006; Clausen and Rodgveller 2008, Clausen and Rodgveller 2010), an indirect method was used to determine a more up-to-date biomass in this region. In 2012, we use a new method to estimate giant grenadier biomass (Appendix 1A and in the "survey data" section). This method depends on a ratio of "shallow" (1-500 m) AFSC trawl survey biomass estimates and AFSC longline survey relative population numbers (RPNs) from previous surveys. For those years when the AFSC longline survey occurs in the AI, an AI biomass estimate is now available.

Results: 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 our discussion above, tier 5 recommendations for OFL and ABC of grenadiers are listed below (biomass, OFL, ABC, and mean catch are in mt).

BSAI and GOA grenadiers

Area	Biomass	Natural mortality M	OFL definition	OFL	ABC definition	ABC
EBS	553,557	0.078	biom x M	43,177	OFL x 0.75	32,383
AI	598,727	0.078	biom x M	46,700	OFL x 0.75	35,026
BSAI total	1,152,284			89,878		67,409
GOA	597,884	0.078	biom x M	46,635	OFL x 0.75	34,976
Grand total	1,750,168			136,513		102,385

Gulf of Alaska Grenadiers

Quantity/Status	Last year[a] 2012	2013	This year **2013**	2014
M (natural mortality)	0.078	0.078	**0.078**	0.078
Specified/recommended Tier	5	5	**5**	5
Biomass	597,884	597,884	**597,884**	597,884
F_{OFL} (F=M)	0.078	0.078	**0.078**	0.078
$maxF_{ABC}$ (maximum allowable = 0.75x F_{OFL})	0.0585	0.0585	**0.0585**	0.0585
Specified/recommended F_{ABC}	0.0585	0.0585	**0.0585**	0.0585
Specified/recommended OFL (t)	46,635	46,635	**46,635**	46,635
Specified/recommended ABC (t)	34,976	34,976	**34,976**	34,976
Is the stock being subjected to overfishing?	n/a	n/a	n/a	n/a

[a]The values for biomass, OFL, and ABC in these two columns are based on an interim Executive Summary SAFE report for grenadiers that was prepared in November 2011 (Clausen and Rodgveller 2011). No new biomass estimates were available in 2011 so values OFL and ABC remain constant.

Bering Sea and Aleutian Islands Grenadiers

Quantity/Status	Last year[a] 2012	2013	This year **2013**	2014
M (natural mortality)	0.078	0.078	**0.078**	0.078
Specified/recommended Tier	5	5	**5**	5
Biomass	1,733,797	1,733,797	**1,152,284**	1,152,284
F_{OFL} (F=M)	0.078	0.078	**0.078**	0.078
$maxF_{ABC}$ (maximum allowable = 0.75x F_{OFL})	0.0585	0.0585	**0.0585**	0.0585
Specified/recommended F_{ABC}	0.0585	0.0585	**0.0585**	0.0585
Specified/recommended OFL (t)	135,236	135,236	**89,878**	89,878
Specified/recommended ABC (t)	101,427	101,427	**67,409**	67,409
Is the stock being subjected to overfishing?	n/a	n/a	n/a	n/a

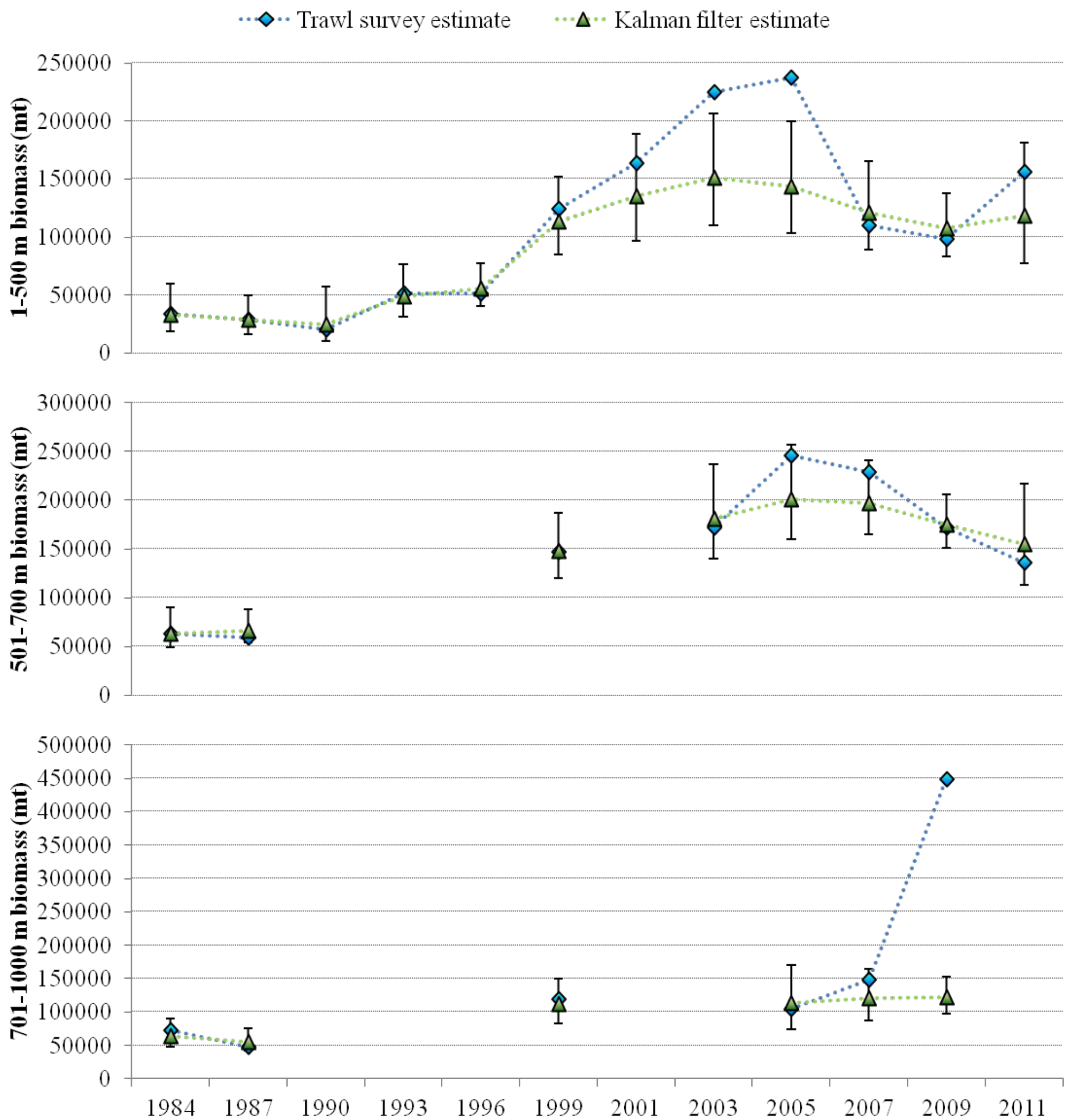
[a]The values for biomass, OFL, and ABC in these two columns are based on an interim Executive Summary SAFE report for grenadiers that was prepared in November 2011 (Clausen and Rodgveller 2011).

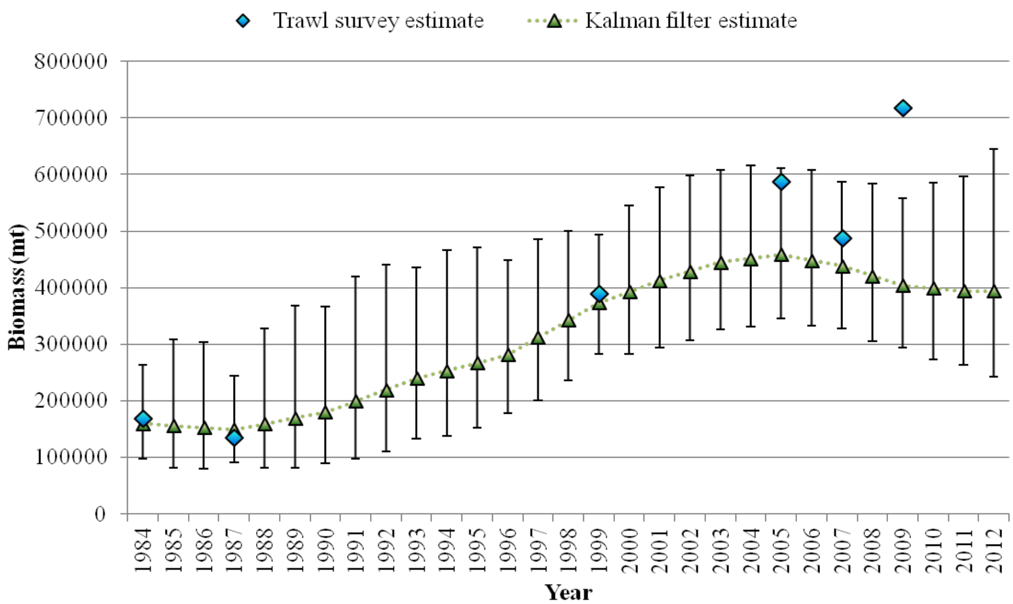
Compared to the 2010 OFL and ABC recommendations from the last full assessment, the OFLs and ABCs for the EBS decreased by ~7%, the AI decreased by ~39%, and the entire BSAI decreased by ~34%. The EBS mean biomass decreased compared to 2012 due to a lower biomass estimate in 2012 than in 2004 (the year that was dropped from the three year average of biomass estimates). AI biomass decreased 38% from the 2010 recommendations because new methods were used to estimate biomass in this assessment. GOA has not changed since there have not been any new trawl surveys that sampled deeper than 700 m since 2009.

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 (see Table 1-1), 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. Therefore, even taking into account the special concerns for giant grenadier in Alaska that could make them particularly vulnerable to overfishing and the decrease in the BSAI ABC and OFL, the recommended OFLs and ABCs appear to be sufficiently conservative to protect the stocks.

Kalman filter to estimate GOA biomass (for information only): The Plan Team and SSC suggested that for tier 5 species a Kalman filter model be presented in this year's assessment for comparison with the status quo method of averaging the most recent three trawl survey biomass estimates. However, they also stated that the status quo method should be retained for determinations of biomass this year. We applied a Kalman filter model to estimate giant grenadier biomass in the GOA as a test case. As mentioned previously, the only GOA trawl surveys that extended to 1000 m include the surveys in 1984, 1987, 1999, 2005, 2007, and 2009. In 1990, 1993, 1996, and 2001 the trawl survey only sampled depths down to 500 m, and in 2003 and 2011 the trawl survey sampled depths up to 700 m. Due to the differences in the depth sampled among the various trawl surveys, and the distribution of giant grenadier biomass across depth strata, we applied the Kalman filter model to biomass estimates for the 1-500 m, 501-700 m, and 701-1000 m depth strata separately. This resulted in three time series of Kalman filter estimates of biomass fit to the trawl survey biomass. The full time series of biomass estimates in the GOA from the Kalman filter were then obtained by summing the biomass estimates across the three depth strata (see figures below).

In all three depth strata, the Kalman filter fits the early trawl survey years' biomass estimates precisely, whereas in recent years there are differences between the Kalman filter and the trawl survey biomass estimates. As discussed previously, there was a haul in the 700-1000 m depth strata in 2009 that was unusually large, owing to the trawl survey biomass estimate being outside the 95% confidence intervals of the Kalman filter model estimates for the 700-1000 m depth strata.
Compared to the six years in which the trawl survey extended to 1000 m (i.e., included all three depth strata modeled, see bottom panel), the Kalman filter estimates contained the trawl survey biomass estimates within the 95% confidence intervals in all years except one, 2009.


Trawl survey estimate
Kalman filter estimate
1-500 m biomass (mt)
501-700 m biomass (mt)
701-1000 m biomass (mt)
250000
200000
150000
100000
50000
0
300000
500000
450000
400000
350000
1984
1987
1990
1993
1996
1999
2001
2003
2005
2007
2009
2011



For the GOA, the Kalman filter forecast of 2012 biomass was 394,585 mt and the resultant OFL was 30,778 mt and ABC was 23,083 mt. The Kalman filter model estimate is 34% lower than the recommended OFL and ABC for the GOA. Even with this decrease in OFL and ABC, the catch is still well below these values. Catch estimates in the GOA have ranged from 5,419 to 14,683 mt and the mean is 9,838 mt (Table 1-1). The CVs of the Kalman filter model estimates of biomass ranged from 8-16% while the CVs of the trawl survey biomass estimates ranged from 10-38% (Table 1-6).

	Biomass	OFL	ABC
Status quo	597,884	46,635	34,976
Kalman flter	394,585	30,778	23,083

In future assessments we will apply Kalman filter methods similar to that performed in the GOA for the BS and AI for comparison with status quo tier 5 specifications.

OTHER CONSIDERATIONS

Discussion of Special Overfishing Concerns for Giant Grenadier

Although the present exploitation rate of giant grenadier appears to be relatively low, a discussion is warranted regarding some unique concerns that may put giant grenadier at greater risk of overharvest than most other groundfish. These concerns could become important if catches were to increase in the future, especially in the GOA where catches have been historically higher and biomass lower than in the BSAI. There are three reasons that grenadier may be at greater risk of overharvest that other groundfish:

a) Nearly all the giant grenadier caught are discarded, and none of these survive because the fish cannot withstand the pressure change caused by retrieval to the surface.

b) Because the sablefish and Greenland turbot fisheries are responsible for most of the giant grenadier catch, and because they operate at depths where female giant grenadier greatly outnumber males, the great majority of the giant grenadier catch is female. Disproportionate removal of females by the fishery clearly reduces the spawning potential of the stocks and could put them at greater risk of overfishing if catches were sufficiently large.

c) There have been several recent studies that indicate deep-sea fish such as grenadiers appear to be especially susceptible to overfishing, which suggests fishery managers need to exercise particular caution when setting catch levels for these fish. One study in the NW Atlantic Ocean examined the relative abundance over a 20 year period of five deep-water species that were taken in target fisheries or as bycatch, and abundance of all five progressively declined to the point that each could be considered "critically endangered" (Devine et al. 2006). Two of these species were grenadiers. The depletion of one of these grenadiers, the roundnose grenadier (*Coryphaenoides rupestris)*, has also been documented by Atkinson (1995). In the early years of the fishery for this species, catches were as high as 75,000 mt, but landings quickly declined in later years even though exploitation was only moderate. Roundnose grenadier stocks appear to have become depleted with little sign of recovery. The particular vulnerability of deep-sea fish, such as grenadiers, to overfishing is likely due to the life history traits they have evolved in response to living in the relatively unproductive environment of the deep ocean. These traits may include longevity, slow growth, low fecundity, late maturation, low metabolic rates, and not spawning in some years (Merrett and Haedrich 1997; Koslow et al. 2000; Drazen 2008). All these characteristics imply that the replenishment rate for these fish could be less than recruitment if they are subject to fishing pressure.

Recommendation to Include Grenadiers in the Fishery Management Plans

Grenadiers are not included in the groundfish FMPs for either the BSAI or GOA. There are no limits on their catch or retention, no reporting requirements, and no official record of their catch. Prior to the ACL (annual catch limits) amendments, grenadiers were considered non-specified species, which were defined as a "residual category of species and species groups of no current or foreseeable economic value or ecological importance, which are taken in the groundfish fishery as accidental bycatch and are in no apparent danger of depletion" and for which "virtually no data exists (that) would allow population assessments" (DiCosimo 2001, Witherell 1997). Based on this definition, Groundfish Plan Teams recommended in 2008 that grenadiers be moved into the groundfish FMPs. Because of their abundance on the continental slope, giant grenadier are of great ecological importance in this habitat, and they also hold economic potential. In addition, there now exists considerable information on giant grenadier. In 2010, the Groundfish Plan Teams reiterated their strong recommendation that the Council (NPFMC) prioritize this for action. They also strongly recommended that grenadier be classified as "in the fishery" in the GOA. The Scientific and Statistical Committee also recommended that the Council consider revising management of grenadiers.

In 2012 a paper on the inclusion of grenadiers in the FMPs was discussed at the June, 2012 NPFMC meeting (Pearson et al., 2012, unpublished document, see previous footnote 1). At this meeting the NPMFC made a motion to initiate and EA/RIR/IRFA and approved a "purpose and needs" statement and four options for moving grenadiers into the FMPs (see below). The NMFS non-target species committee will review the discussion paper and the motion and provide recommendations to the Council. Initial review of grenadier management is tentatively scheduled for the February, 2013 Council meeting, and final review is tentatively scheduled for the April, 2013 meeting.

"Purpose and need:
Grenadiers are not included in the BSAI or GOA groundfish FMPs. There are no limits on their catch or retention, no reporting requirements, and no official record of their catch. However, grenadiers are taken in relatively large amounts as bycatch, especially in longline fisheries; no other Alaska groundfish has such high catches and is not included in the FMPs. Considerable information on giant grenadier exists that can be used for stock assessment (under Tier 5).

Inclusion in the groundfish FMPs would provide for their precautionary management by, at a minimum, recording their harvest and/or placing limits on their harvest.

Alternative 1.No Action.
Alternative 2. Include Grenadiers in the BSAI and GOA FMPs as 'in the fishery'
Alternative 3. Include Grenadiers in the BSAI and GOA FMPs as an 'ecosystem component'
Alternative 4. Include Grenadiers in the BSAI FMP as an 'ecosystem component' and in GOA FMP as 'in the fishery'

The species to be included (applicable to any action alternative):
Option 1. giant grenadier only
Option 2. giant, popeye, and Pacific grenadiers"

Authors' recommendations: The NPFMC is changing how it categorizes species in the FMPs that were formerly in the "other species", "non-specified", and "forage fish" categories. This is to comply with requirements of the reauthorized Magnuson-Stevens Fishery Conservation and Management Act which call for establishment of "Annual Catch Limits". The new categories include "in the fishery", an "ecosystem component" category, and a de facto third category consisting of all remaining species, which would be removed entirely from the FMPs (North Pacific Fishery Management Council 2010). For "ecosystem component" species, catches are required to be reported for monitoring purposes and directed fishing (open status) is prohibited. However, maximum retainable amounts of incidental catch and other management measures could be adopted. For species that are "in the fishery" ACLs, AMs, OFLs, ABCs, and TACs must be established each year in the annual harvest specifications process. In this new classification scheme, we recommend that grenadiers be categorized as "in the fishery" because 1) giant grenadier are taken in such large amounts as bycatch in commercial fisheries, 2) the potential exists for the future development of a targeted fishery on giant grenadier, and 3) because they are slow growing and late to mature, they are vulnerable to overfishing.

Although our preferred option is to classify grenadiers as "in the fishery" in both FMPs, an "ecosystem component" classification for grenadiers in the BSAI may be acceptable from a biological and management standpoint because giant grenadiers are very abundant in this area and catches have been relatively small. Thus, overfishing of grenadiers in the BSAI is unlikely in the foreseeable future. Placing grenadiers in the "ecosystem component" category in the BSAI would mean that their catches would not count toward the OY of 2.0 million mt and would not affect the TACs of other groundfish in this area.

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 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 food preferences.

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[17]. 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 information on predators of these earlier life stages is nil.

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 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.

Fishery Effects on the Ecosystem

Because there has been virtually no directed fishing for grenadiers in Alaska, the reader is referred to the discussion on Fishery Effects in the sablefish SAFE report. The sablefish longline fishery is the main fishery that takes giant grenadier as bycatch, so the Fishery Effects section in 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 grenadiers presently caught in the sablefish and Greenland turbot fisheries are discarded and do not survive, this constitutes a major input of dead organic material to the ecosystem that would not otherwise be there.

DATA GAPS AND RESEARCH PRIORITIES

Many aspects of basic information are lacking for grenadiers in Alaska. Research priorities include,

[17] C. Lunsford, National Marine Fisheries Service, Alaska Fisheries Science Center, Auke Bay Laboratories, 17109 Point Lena Loop Rd., Juneau, AK 99801. Pers. comm. Oct 2006.

1) Validation of the AFSC REFM Division aging methodology for giant grenadier is especially needed, because it would allow giant grenadier to be moved from tier 5 to a higher tier assessment category.
2) Further analysis and study of competition for hooks that may affect giant grenadier catch rates on the AFSC longline survey.
3) Extended survey coverage in waters >1,000 m to investigate the abundance of giant grenadier and other grenadiers in deep depths that have not been sampled in past surveys. A deep-water survey was completed in 2008 in the western GOA, however surveys in other areas would also be useful.
4) Continue a study to examine if the three different shapes of otoliths found in giant grenadier represent separate species or subpopulations. More samples will be collected on the 2013 AFSC longline survey for this cooperative project between the Marine Ecology and Stock Assessment program at Auke Bay Laboratories (ABL), REFM Age and Growth Lab, and the ABL genetics lab.
5) Analysis of the observer data for giant grenadier to determine why the sex composition is different than in the AFSC longline survey. We are working with the observer program to add more details on sex determination of giant grenadier to the observer manual.
6) Because early life history information for giant grenadier is nil, studies are also needed to investigate where larvae and young juveniles reside.
7) Evaluation of the catchability of giant grenadier in the bottom trawl surveys, which would affect the accuracy of subsequent biomass estimates. Studies are needed on whether this fish is a completely benthic species or if individuals sometimes move off-bottom.

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Table 1-1.--Estimated catch (mt) of grenadiers (all species combined) in the eastern Bering Sea, Aleutian Islands, and Gulf of Alaska, 1997-2012.

	Eastern Bering Sea	Aleutian Islands	Gulf of Alaska	Total
1997	2,964	2,887	12,029	17,881
1998	5,011	1,578	14,683	21,272
1999	4,505	2,883	11,388	18,776
2000	4,067	3,254	11,610	18,931
2001	2,294	1,460	9,685	13,439
2002	1,891	2,807	10,479	15,177
2003	2,869	3,558	12,253	18,679
2004	2,223	1,251	11,989	15,463
2005	2,633	1,795	7,251	11,679
2006	2,067	2,195	8,429	12,691
2007	1,631	1,544	9,119	12,294
2008	2,820	2,525	11,333	16,678
2009	2,902	3,739	6,326	12,968
2010	2,799	3,553	5,419	11,772
2011	4,221	2,596	8,216	15,032
2012	2,276	4,383	7,206	13,868
mean	2,948	2,626	9,838	15,413

Sources: 1997-2001, Gaichas (2002); 2002, S. Gaichas, Unpubl. data, Jan. 2005. NMFS Alaska Fisheries Science Center, REFM Division, 7600 Sand Point Way NE, Seattle WA 98115-0070; 2003-2010, NMFS Alaska Region, Sustainable Fisheries Division, P.O. 21668, Juneau, AK 99802. 2011-2012 Catch Accounting System data query accessed through the Alaska Fisheries Information Network (AKFIN), October 2012.

Table 1-2.--Estimated catch (mt) of grenadiers (all species combined) in the eastern Bering Sea, Aleutian Islands, and Gulf of Alaska, by target species/species group, 2003-2011. G. turbot = Greenland turbot; halibut = Pacific halibut; other flat = flatfish species other than Greenland turbot or Pacific halibut; P. cod = Pacific cod; and other sp. = other species. Source: Regional Office Catch Accounting System accessed through the Alaska Fisheries Information Network (AKFIN), October 1, 2012.

	Target species/species group						
Year	Sablefish	G. turbot	Halibut	Other flat	P. cod	Rockfish	Other sp.
			Eastern Bering Sea				
2003	598	1,452	355	150	240	9	65
2004	287	1,315	253	79	240	22	29
2005	108	1,975	143	24	334	32	18
2006	419	1,189	180	125	126	12	16
2007	199	1,070	89	7	179	17	68
2008	113	691	1,579	82	148	3	204
2009	542	1,807	99	238	203	6	7
2010	129	1,854	102	166	416	126	6
2011	254	1,738	58	1,052	1,098	254	2
2012	148	1,085	37	704	297	2	3
			Aleutian Islands				
2003	2,016	113	1,376	0	46	6	0
2004	748	14	414	0	13	60	1
2005	979	161	617	0	2	21	16
2006	1,083	328	170	341	120	154	0
2007	893	342	65	108	40	21	76
2008	656	67	1,044	397	26	59	276
2009	1,393	414	259	1,377	13	200	84
2010	902	175	184	1,653	222	168	205
2011	1,227	83	97	774	18	292	105
2012	982	0	64	2,824	47	39	427
			Gulf of Alaska				
2003	9,500	0	872	1,208	5	613	54
2004	8,568	0	163	420	0	2,830	8
2005	6,371	0	505	109	0	212	54
2006	7,184	0	738	69	22	338	77
2007	8,197	0	524	115	80	198	5
2008	8,206	0	2,529	93	97	165	243
2009	4,392	0	1,431	118	58	301	26
2010	4,099	0	471	292	138	409	11
2011	5,973	0	1,186	343	69	529	115
2012	6,517	0	10	160	9	422	88

Table 1-3.--Sex composition (percent) of giant grenadier sampled by observers in the 2007-2012 commercial sablefish fishery, by gear type and area. See Figure 1-1 for sample sizes. BSAI = eastern Bering Sea and Aleutian Islands; GOA = Gulf of Alaska. Fisheries Monitoring and Analysis database query accessed through the Alaska Fisheries Information Network (AKFIN), October 2012.

	BSAI longline		BSAI pot		GOA longline	
Year	Male	Female	Male	Female	Male	Female
2007	20.8	79.2	20.6	79.4	20.0	80.0
2008	21.2	78.8	13.3	86.7	20.4	79.6
2009	13.1	86.9	8.0	92.0	17.2	82.8
2010	13.5	86.5	18.0	82.0	16.7	83.3
2011	12.9	87.1	37.5	62.5	19.3	80.7
2012	14.9	85.1	17.8	82.2	18.8	81.2

Table 1-4.--Estimated biomass (mt) of giant grenadier in NMFS trawl surveys in Alaska that sampled the upper continental slope to depths of at least 800 m. Aleutian Island (AI) biomass estimates for 1-1000 m from 1996-2012 were estimated from relative population weights from the AFCS longline survey and biomass estimates from the AI trawl survey for 1-500 m, since trawl surveys in those years only sampled to 500 m.

Year	Eastern Bering Sea	Aleutian Islands	Gulf of Alaska
1979	91,500[a]	-	-
1980	-	313,480	-
1981	90,500[a]	-	-
1982	104,700[a]	-	-
1983	-	349,538	-
1984	-	-	169,708
1985	107,600[a]	-	-
1986	-	600,656	-
1987	-	-	135,971
1988	61,400[a]	-	-
1989	-	-	-
1990	-	-	-
1991	73,520[a]	-	-
1992	-	-	-
1993	-	-	-
1994	-	-	-
1995	-	-	-
1996	-	471,483	-
1997	-	-	-
1998	-	468,818	-
1999	-	-	389,908
2000	-	628,046	-
2001	-	-	-
2002	426,397	639,301	-
2003	-	-	-
2004	666,508	645,082	-
2005	-	-	587,346
2006	-	809,260	-

[a]Estimates are for all species of grenadiers combined

Notes and data sources:

a) Eastern Bering Sea: Depths sampled were to 1,000 m in 1979, 1981, 1982, and 1985; to 800 m in 1988 and 1991; and to 1,200 m in 2002, 2004, 2008, 2010, and 2012. Data sources: 1979 to 1988, Bakkala et al. (1992); 1991, Goddard and Zimmermann (1993); 2002, Hoff and Britt (2003); 2004, Hoff and Britt (2005); 2008, 2010, and 2012, data on the Alaska Fisheries Science Center's "Racebase" trawl survey database, October 2012, available from the National Marine Fisheries Service, Alaska Fisheries Science Center, RACE Division, 7600 Sand Point Way NE, Seattle, WA 98115.
b) Aleutian Islands: Depths sampled were to 900 m in surveys from 1980-1986. Data source: Ronholt et al. (1994). Biomass estimates from 1996-2012 are extrapolated from trawl survey biomass estimates from 1-500 m and AFSC longline survey relative population weights from 200-1000m (see section titled "survey data").
c) Gulf of Alaska: Depths sampled were to 1,000 m in each survey. Data sources: 1984, 1987, 1999, 2005, 2007, and 2009 data on the Alaska Fisheries Science Center's "Racebase" trawl survey database, September 2010, available from the National Marine Fisheries Service, Alaska Fisheries Science Center, RACE Division, 7600 Sand Point Way NE, Seattle, WA 98115.

Table 1-4.--(continued from above).

Year	Eastern Bering Sea	Aleutian Islands	Gulf of Alaska
2007	-	-	487,987
2008	449,777	487,573	-
2009	-	-	718,320
2010	660,528	771,605	-
2011	-	-	-
2012	550,366	537,001	-

Table 1-5.--Comparative biomass estimates (mt) for the three common grenadier species in recent NMFS trawl surveys in Alaska that sampled the upper continental slope. Biomass estimates for the Gulf of Alaska include depths to 1,000 m; estimates for the eastern Bering Sea include depths to 1,200 m.

Region	Year	Giant grenadier	Pacific grenadier	Popeye grenadier
Gulf of Alaska	1999	389,908	8,240	16,260
Gulf of Alaska	2005	587,346	2,252	21,297
Gulf of Alaska	2007	487,987	3,046	15,593
Gulf of Alaska	2009	718,320	6,367	24,893
Eastern Bering Sea	2002	426,397	2,461	50,329
Eastern Bering Sea	2004	666,508	4,039	44,361
Eastern Bering Sea	2008	463,429	4,221	50,665
Eastern Bering Sea	2010	660,528	6,582	70,243
Eastern Bering Sea	2012	550,366	3,561	57,772

Table 1-6.--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. The Gulf of Alaska surveys included depths to 1,000 m, whereas the eastern Bering Sea slope surveys included depths to 1,200 m. 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"). No variance is available in 1996 for the Aleutian Islands biomass because detailed longline survey was not available for that year.

			95% Conf. bounds			
Region	Year	Biomass	Lower	Upper	Variance	cv (%)
Gulf of Alaska	1999	389,908	313,786	466,030	1,418,688,152	9.7
Gulf of Alaska	2005	587,346	420,489	754,202	6,503,760,627	13.7
Gulf of Alaska	2007	487,987	346,802	629,173	4,332,366,537	10.6
Gulf of Alaska	2009	718,320	0	1,484,296	76,136,273,860	38.4
Aleutian Islands	1996	471,483	245,525	692,112	-	-
Aleutian Islands	1998	468,818	328,813	927,279	12,978,937,192	24.3
Aleutian Islands	2000	628,046	335,098	943,504	23,308,135,571	24.3
Aleutian Islands	2002	639,301	337,189	952,975	24,088,792,131	24.3
Aleutian Islands	2004	645,082	423,076	1,195,444	24,676,725,626	24.4
Aleutian Islands	2006	809,260	244,155	730,990	38,821,849,183	24.3
Aleutian Islands	2008	487,573	404,357	1,138,854	15,423,809,426	25.5
Aleutian Islands	2010	771,605	279,803	794,200	35,108,126,216	24.3
Aleutian Islands	2012	537,001	245,525	692,112	17,219,645,992	24.4
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

Table 1-7.--Giant grenadier relative population weight, by region, in AFSC longline surveys in Alaska, 1990-2012. 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. NA indicates that length data is not available for calculations of RPWs. AFSC longline survey database query accessed through the Alaska Fisheries Information Network (AKFIN), October 2012.

Year	Eastern Bering Sea	Aleutian Islands	Gulf of Alaska
1990	-	-	NA
1991	-	-	NA
1992	-	-	686,827
1993	-	-	1,041,508
1994	-	-	1,018,292
1995	-	-	1,264,245
1996	-	2,281,815	1,121,058
1997	762,639	-	1,266,800
1998	-	2,268,918	1,066,477
1999	571,852	-	1,277,141
2000	-	3,039,523	1,143,980
2001	398,950	-	1,067,335
2002	-	3,093,994	904,922
2003	538,190	-	1,058,570
2004	-	3,121,973	801,271
2005	694,456	-	826,495
2006	-	3,914,871	857,510
2007	437,268	-	1,242,833
2008	-	1,985,511	919,083
2009	521,179	-	1,063,104
2010	-	3,734,301	1,236,692
2011	574,349	-	829,476
2012		3,230,202	911,728
mean	562,360	2,963,457	944,048

Source: Longline survey database, NMFS Alaska Fisheries Science Center, Auke Bay Laboratories, 17109 Point Lena Loop Rd., Juneau, AK 99801. October 2012.

Table 1-8.--Giant grenadier catch rates (number caught per 100 hooks), by area, in NMFS longline surveys in Alaska, 1990-2010. Dashes indicate years that the eastern Bering Sea or Aleutian Islands were not sampled by the survey.

Year	EBS 4	EBS 3	EBS 2	EBS 1	NE AI	SE AI	Shum	Chir	Kod	W Yak	E Yak	SE
1990	-	-	-	-	-	-	22.1	22.1	10.4	5.8	2.4	1.4
1991	-	-	-	-	-	-	21.8	17.8	8.4	4.3	3.2	1.4
1992	-	-	-	-	-	-	19.4	19.3	6.5	3.6	2.3	1.8
1993	-	-	-	-	-	-	24.2	21.8	7.6	5.9	3.3	1.6
1994	-	-	-	-	-	-	25.5	20.4	10.9	3.9	2.0	1.7
1995	-	-	-	-	-	-	30.1	28.4	13.8	6.0	4.0	2.8
1996	-	-	-	-	12.8	22.8	21.5	27.4	16.1	4.5	4.1	2.4
1997	26.1	27.0	10.7	1.9	-	-	27.9	28.3	16.9	9.8	3.2	2.6
1998	-	-	-	-	11.1	25.3	31.6	17.1	11.7	7.7	4.1	3.6
1999	22.3	23.0	7.7	0.2	-	-	24.4	22.2	17.5	8.8	3.9	5.5
2000	-	-	-	-	17.8	28.2	24.7	21.0	13.4	9.1	3.3	4.3
2001	8.0	14.5	7.0	1.6	-	-	26.5	24.4	13.1	8.7	3.6	5.2
2002	-	-	-	-	21.0	27.9	28.3	15.4	11.6	3.4	4.6	4.8
2003	13.3	26.5	7.2	1.3	-	-	26.6	26.6	15.4	7.6	5.1	3.2
2004	-	-	-	-	25.3	24.6	27.6	16.7	8.2	4.9	3.8	2.6
2005	25.9	28.4	10.2	1.6	-	-	25.4	19.7	14.5	8.3	4.0	3.2
2006	-	-	-	-	34.4	24.8	31.6	17.4	9.2	5.9	3.6	3.8
2007	1.1	30.4	7.5	1.7	-	-	34.7	26.6	20.1	13.2	6.0	4.6
2008	-	-	-	-	17.9	22.5	28.7	20.9	13.4	10.7	3.9	3.9
2009	28.4	26.5	12.2	2.6	-	-	28.1	22.0	20.2	10.4	4.2	5.1
2010	-	-	-	-	35.1	27.5	36.5	34.8	19.8	8.6	6.2	5.2
2011	27.6	29.4	5.7	4.7	-	-	29.8	22.5	14.7	7.1	3.4	4.2
2012	-	-	-	-	23.3	11.2	28.5	23.1	13.9	7.5	5.2	5.0
mean	18.6	25.9	7.5	1.9	22.1	23.9	27.2	22.4	13.4	7.2	3.9	3.5

Areas:
EBS 4 = eastern Bering Sea survey area 4
EBS 3 = eastern Bering Sea survey area 3
EBS 2 = eastern Bering Sea survey area 2
EBS 1 = eastern Bering Sea survey area 1
NE AI = Northeast Aleutian Islands
SE AI = Southeast Aleutian Islands
Shum = Shumagin
Chir = Chirikof
Kod = Kodiak
W Yak = West Yakutat
E Yak = East Yakutat
SE = Southeastern

Note: Data not available for the NW and SW Aleutians.

Table 1-9.--Sex distribution, by depth stratum, of giant grenadier sampled in the 2006-2012 NMFS longline surveys in Alaska. Dashes indicate that a stratum was not sampled. AFSC longline survey query accessed through the Alaska Fisheries Information Network (AKFIN), October 2012.

Depth stratum (m)	No. fish sampled	Percent male	Percent female	No. fish sampled	Percent male	Percent female
			2006 Survey			
	Eastern Aleutian Islands			Gulf of Alaska		
201-300	5	0.0	100.0	176	0.0	100.0
301-400	134	0.0	100.0	1,097	0.5	99.5
401-600	824	1.2	98.8	1,970	1.5	98.5
601-800	684	5.8	94.2	1,876	3.8	96.2
801-1000	278	24.8	75.2	871	10.1	89.9
All depths	1,925	6.2	93.8	5,990	3.2	96.8
			2007 Survey			
	Eastern Bering Sea			Gulf of Alaska		
201-300	220	0.0	100.0	79	0.0	100.0
301-400	415	0.0	100.0	1,013	0.9	99.1
401-600	605	0.3	99.7	2,251	2.0	98.0
601-800	774	1.0	99.0	1,977	5.2	94.8
801-1000	322	6.8	93.2	923	9.9	90.1
All depths	2,336	1.4	98.6	6,243	4.0	96.0
			2008 Survey			
	Eastern Aleutian Islands			Gulf of Alaska		
201-300	57	0.0	100.0	280	1.4	98.6
301-400	263	0.4	99.6	1,242	1.1	98.9
401-600	797	2.1	97.9	2,547	2.8	97.2
601-800	692	3.9	96.1	2,138	3.9	96.1
801-1000	211	7.1	92.9	1,120	7.2	92.8
1,001-1,200	-	-	-	79	29.1	70.9
All depths	2,020	3.0	97.0	7,406	3.7	96.3
			2009 Survey			
	Eastern Bering Sea			Gulf of Alaska		
201-300	219	0.0	100.0	281	0.0	100.0
301-400	481	0.0	100.0	1,365	0.4	99.6
401-600	746	0.1	99.9	2,734	2.4	97.6
601-800	944	1.7	98.3	2,530	4.7	95.3
801-1000	218	5.5	94.5	1,372	6.0	94.0
1,001-1,200	32	28.1	71.9	-	-	-
All depths	2,640	1.4	98.6	8,282	3.3	96.7
			2010 Survey			
	Eastern Aleutian Islands			Gulf of Alaska		
201-300	167	0.0	100.0	393	0.5	99.5
301-400	526	0.0	100.0	1,164	0.4	99.6
401-600	722	1.8	98.2	2,309	1.8	98.2
601-800	612	7.0	93.0	2,136	5.3	94.7
801-1000	173	18.5	81.5	971	12.7	87.3
All depths	2,200	4.0	96.0	6,973	4.1	95.9

Table 1-9.—(continued from above.)

Depth stratum (m)	No. fish sampled	Percent male	Percent female	No. fish sampled	Percent male	Percent female
	2011 Survey					
	Eastern Bering Sea			Gulf of Alaska		
201-300	83	1.2	98.8	274	0.0	100.0
301-400	367	0.0	100.0	1,104	0.8	99.2
401-600	939	0.6	99.4	2,312	1.9	98.1
601-800	731	2.7	97.3	2,329	3.3	96.7
801-1000	236	7.6	92.4	1,103	9.6	90.4
All depths	2,356	1.9	98.1	7,122	3.3	96.7
	2012 Survey					
	Eastern Aleutian Islands			Gulf of Alaska		
201-300	94	0.0	100.0	79	0.0	100.0
301-400	413	0.5	99.5	1,013	0.9	99.1
401-600	619	2.9	97.1	2,251	2.0	98.0
601-800	607	9.1	90.9	1,977	5.2	94.8
801-1000	115	31.3	68.7	923	9.9	90.1
All depths	1,848	1.4	98.6	6,243	4.0	96.0

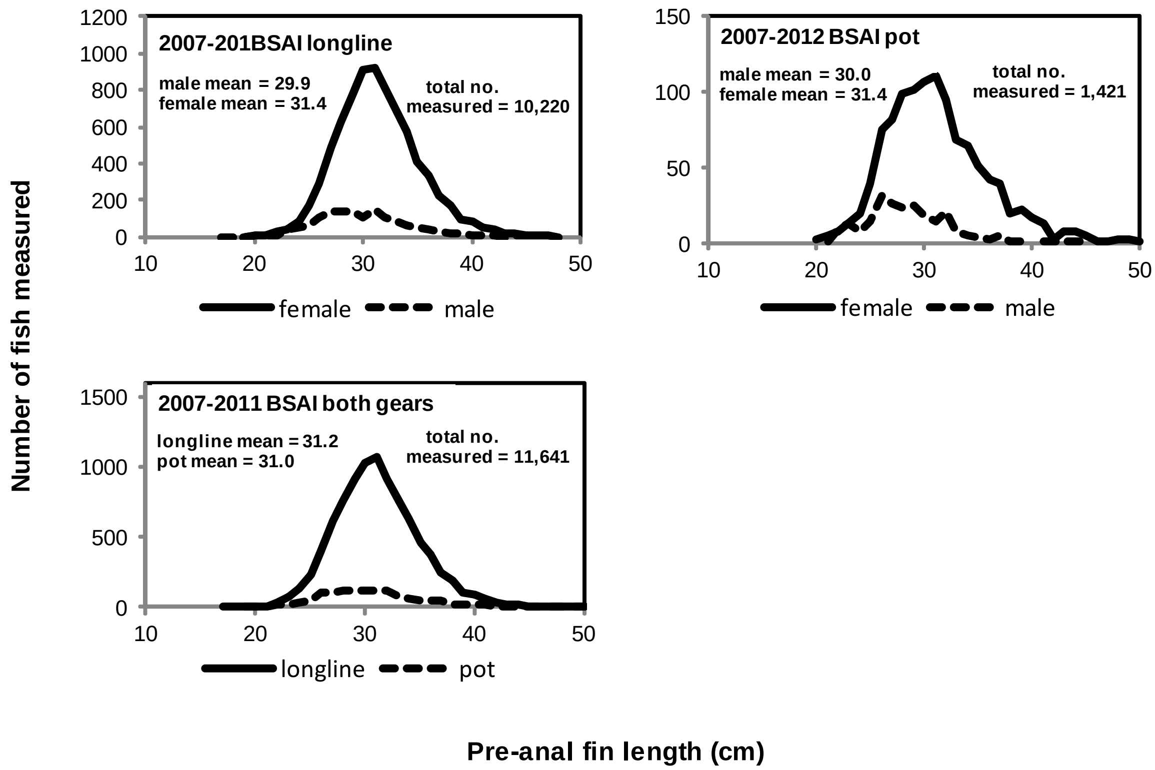

Figure 1-1a.--Raw length frequency distribution of giant grenadiers sampled at sea by observers in the 2007-2011 commercial sablefish fishery in the eastern Bering Sea and Aleutian Islands (BSAI). The distributions are graphed for each of the two major gear types of the fishery, longline and pot. Note that the y-axes differ.

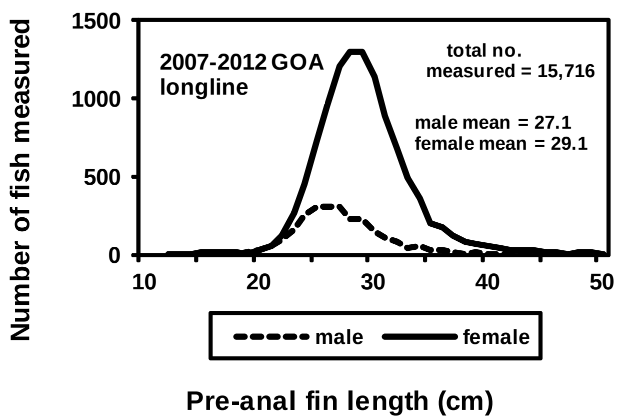

Figure 1-1b.--Raw length frequency distribution of giant grenadiers sampled at sea by observers in the 2007-2011 commercial sablefish fishery in the Gulf of Alaska (GOA). The distributions are graphed for the major gear type of the fishery, longline.

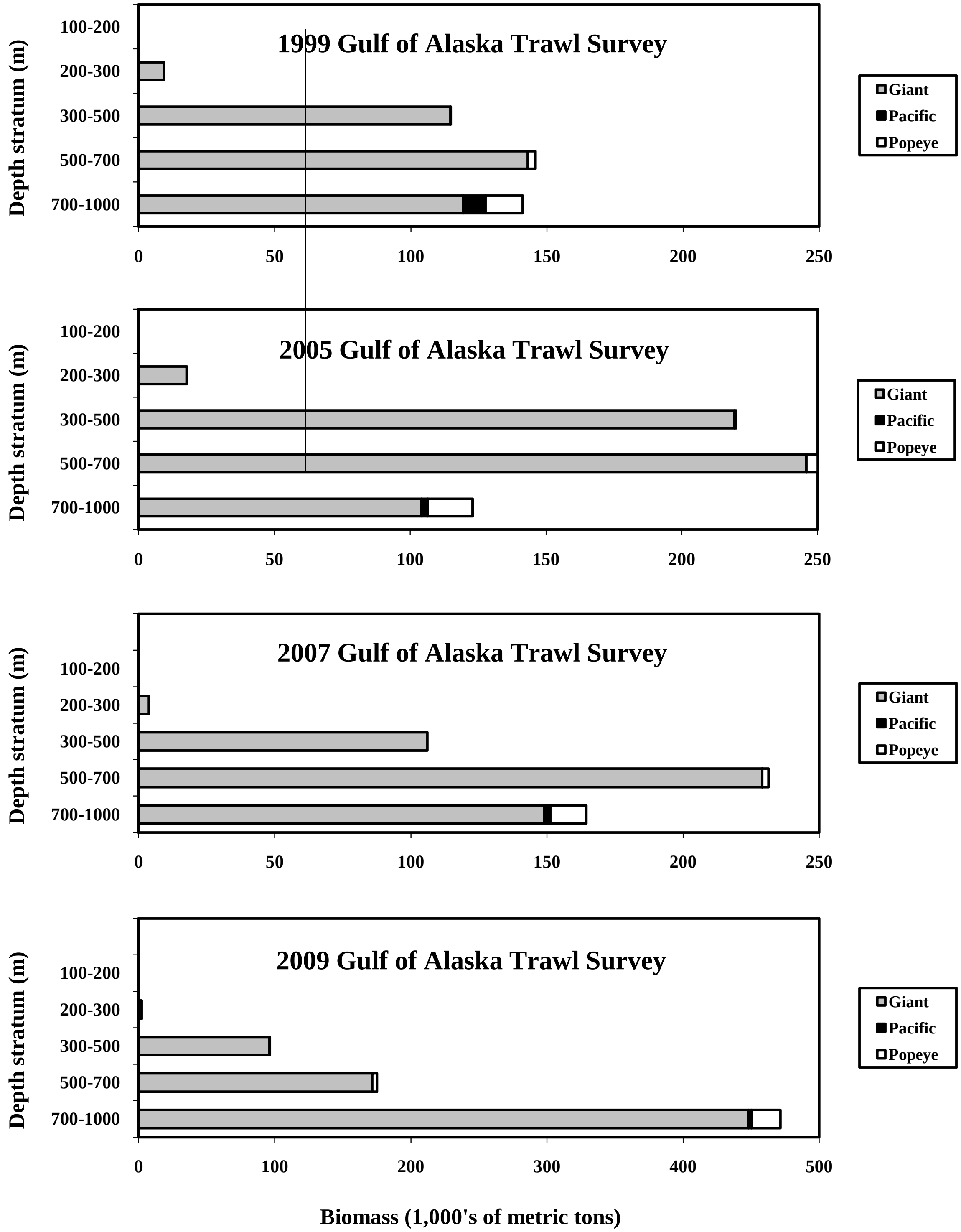

Figure 1-2.--Depth distribution of giant, Pacific, and popeye grenadier biomass estimates in the 1999, 2005, 2007, and 2009 Gulf of Alaska trawl surveys. Note that the x axis (biomass) scale for 2009 is different than that for the other years due to the very large biomass in the 700-1,000 m stratum in 2009. Also, the depth strata shown in this figure are different than those shown in Figure 1-3 for the eastern Bering Sea slope survey because the surveys had different stratification schemes for depth.

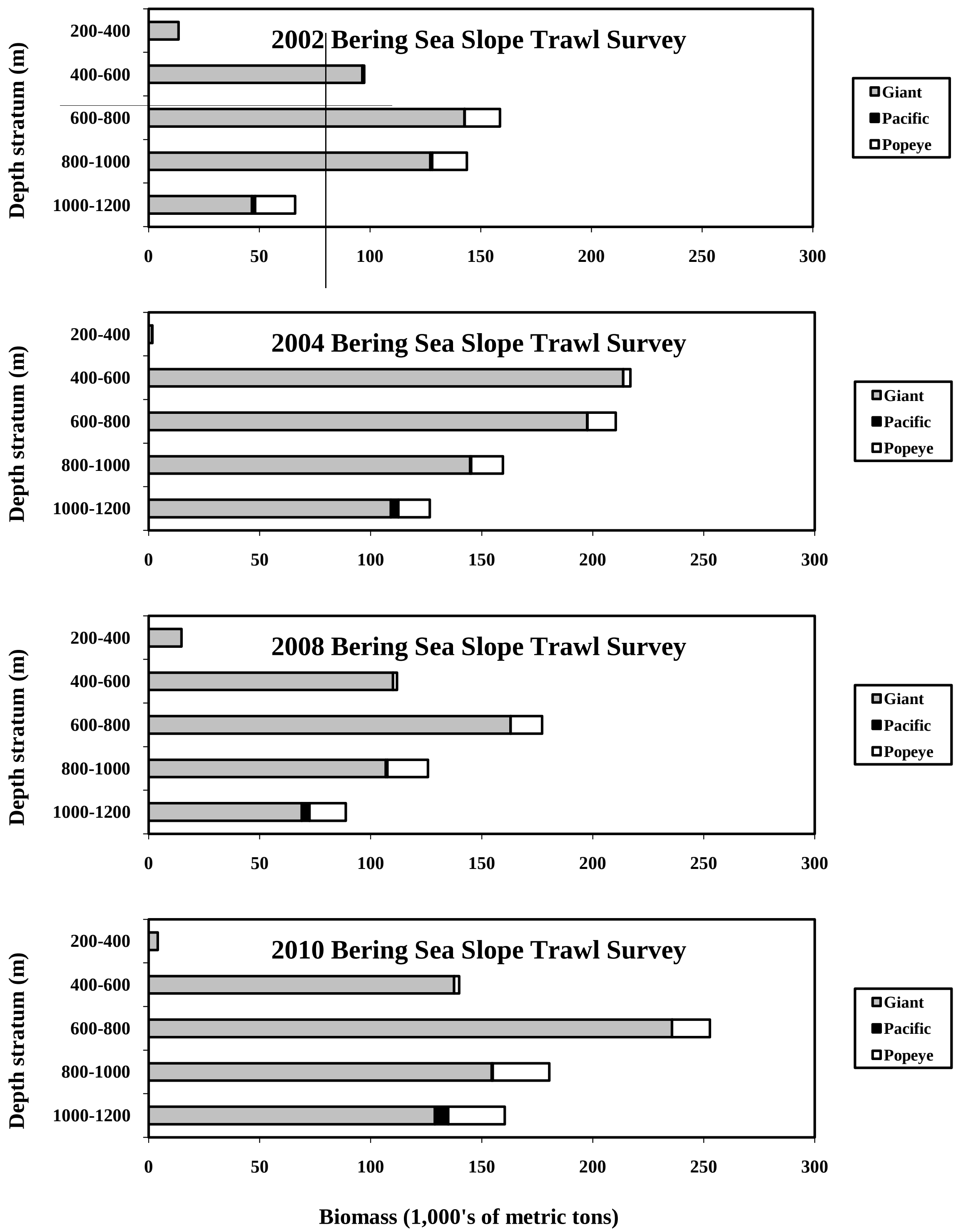

Figure 1-3.--Depth distribution of giant, Pacific, and popeye grenadier biomass estimates in the 2002, 2004, 2008, 2010, and 2012 eastern Bering Sea slope trawl surveys. Note: depth strata shown in this figure for the eastern Bering Sea slope are different than those shown in Figure 1-2 for the Gulf of Alaska survey because the surveys had different stratification schemes for depth.

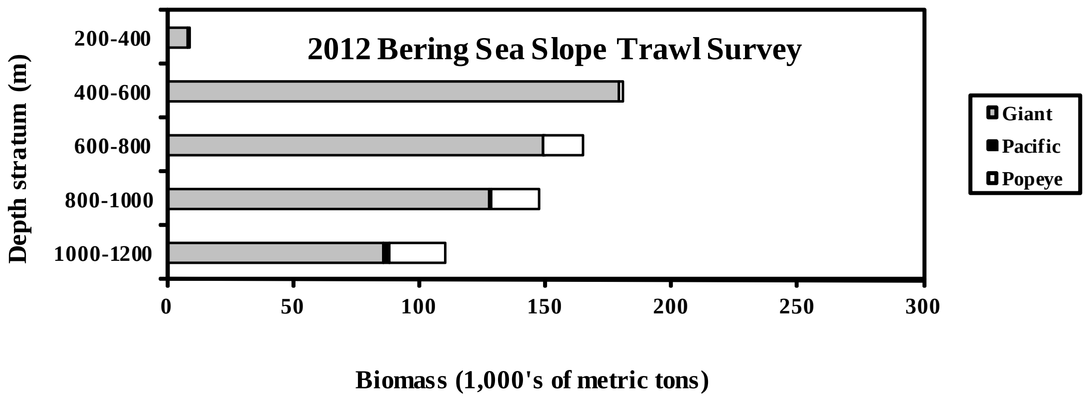

Figure 1-3.-- (continued from preceding page).

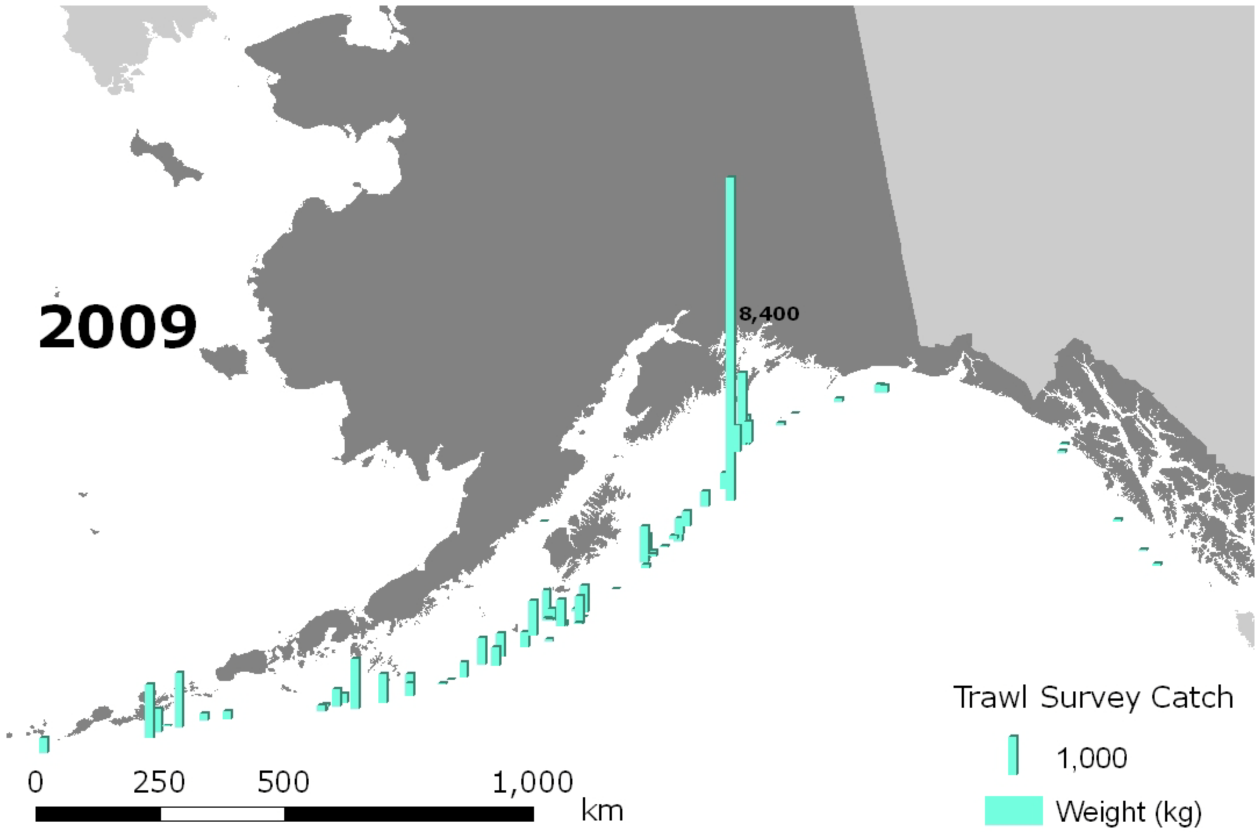

Figure 1-4.--Catch distribution of giant grenadier in the 2009 Gulf of Alaska trawl survey.

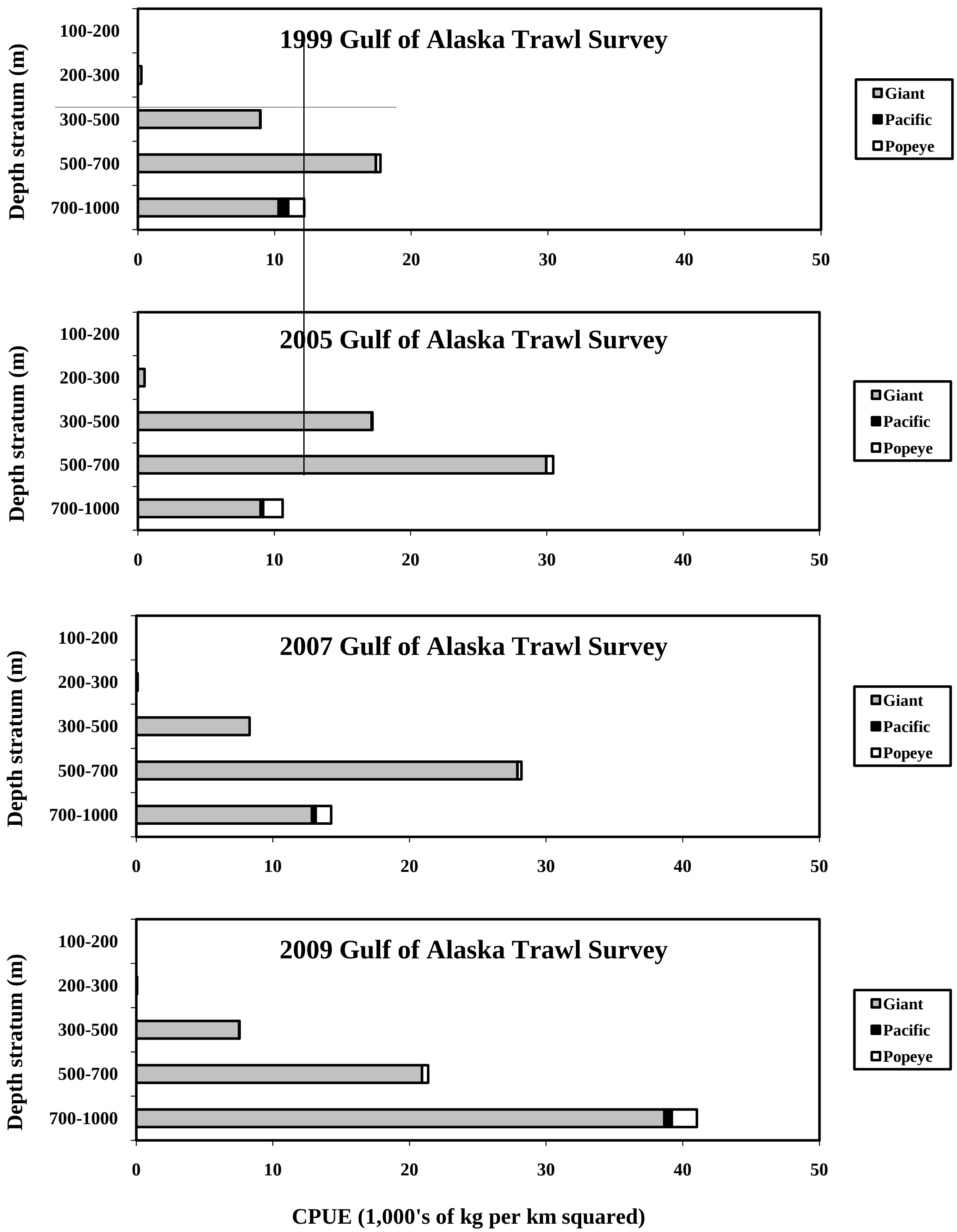

Figure 1-5.-- Depth distribution of giant, Pacific, and popeye grenadier catch per unit effort (CPUE) in the 1999, 2005, 2007, and 2009 Gulf of Alaska trawl surveys. Note: depth strata shown in this figure for the Gulf of Alaska are different than those shown in Figure 1-5 for the eastern Bering Sea slope survey because the surveys had different stratification schemes for depth.

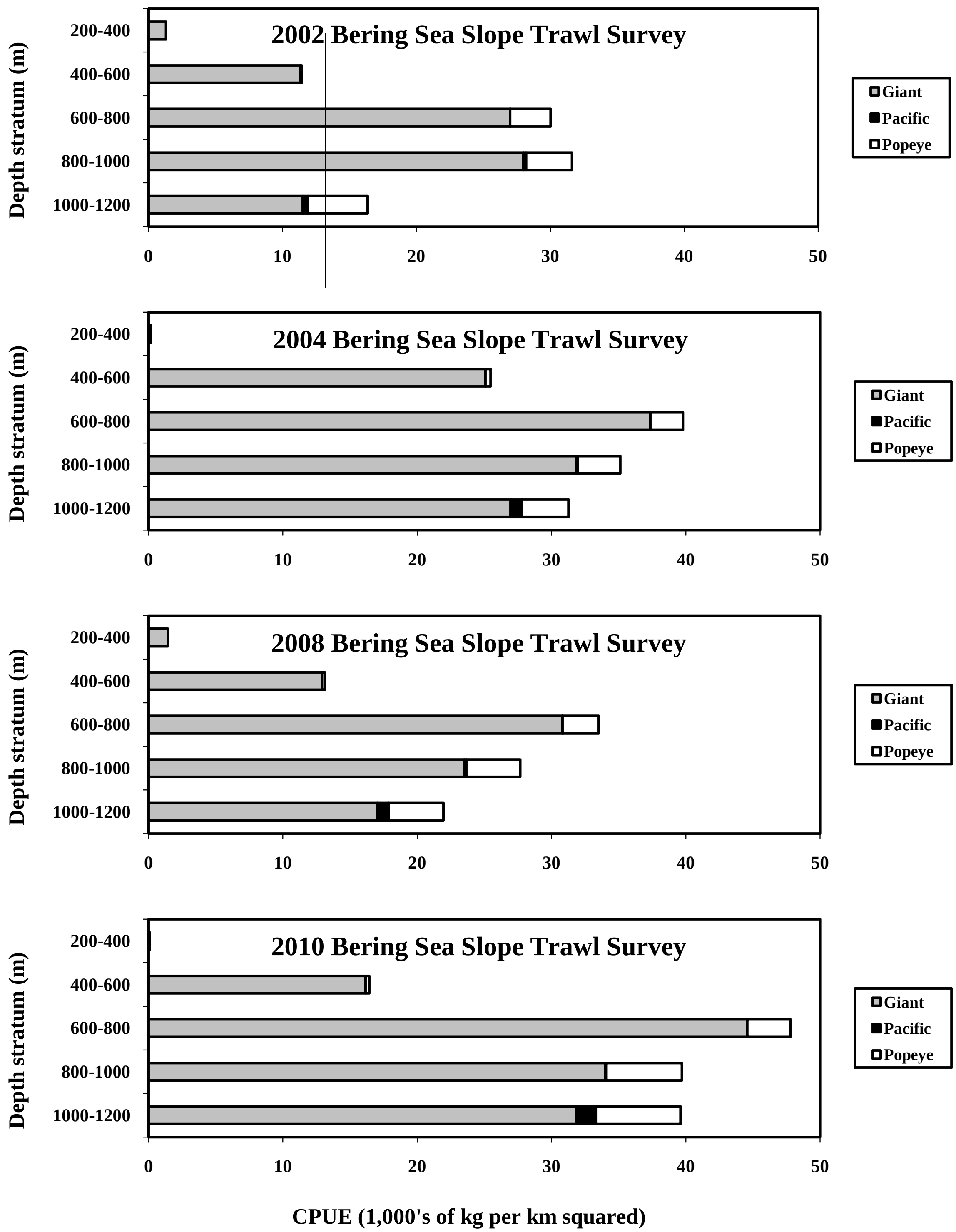

Figure 1-6.--Depth distribution of giant, Pacific, and popeye grenadier catch per unit effort (CPUE) in the 2002, 2004, 2008, 2010, and 2012 eastern Bering Sea slope trawl surveys. Note: depth strata shown in this figure for the eastern Bering Sea slope are different than those shown in Figure 1-4 for the Gulf of Alaska survey because the surveys had different stratification schemes for depth.

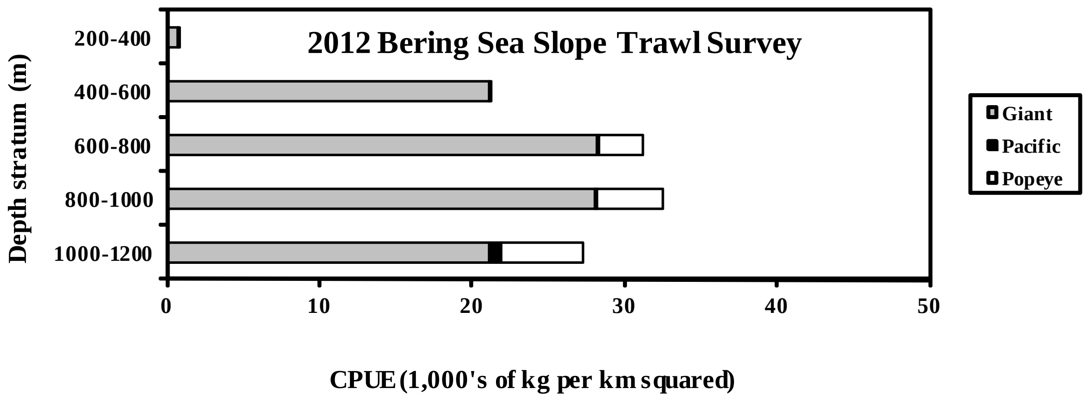

Figure 1-6.--(continued from preceding page).

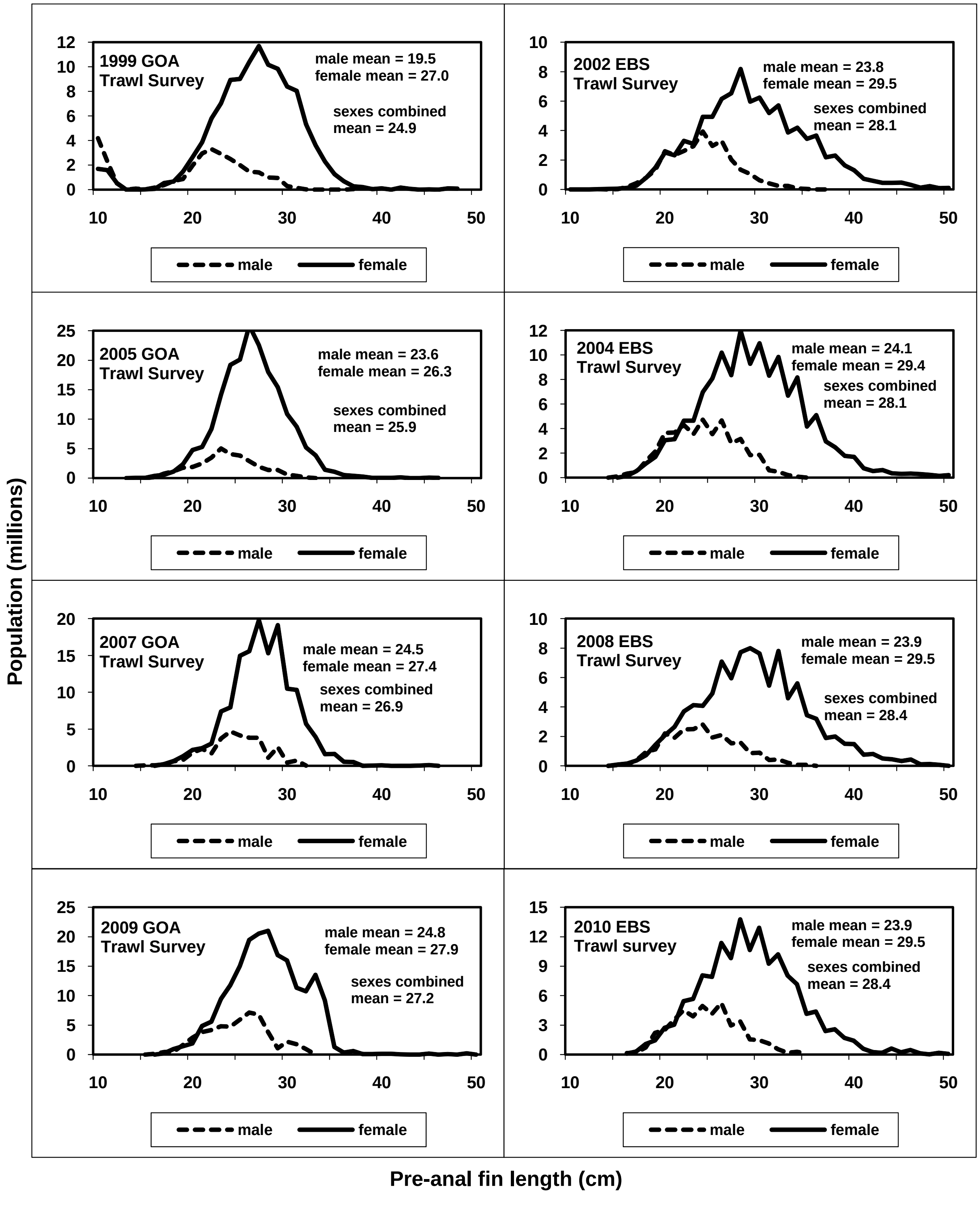

Figure 1-7.--Estimated population size compositions for giant grenadier in recent Alaskan trawl surveys. (GOA = Gulf of Alaska; EBS = eastern Bering Sea slope).

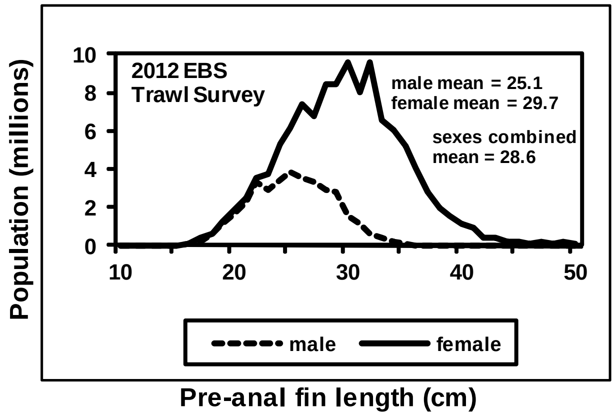

Figure 1-7.-- (continued from preceding page).

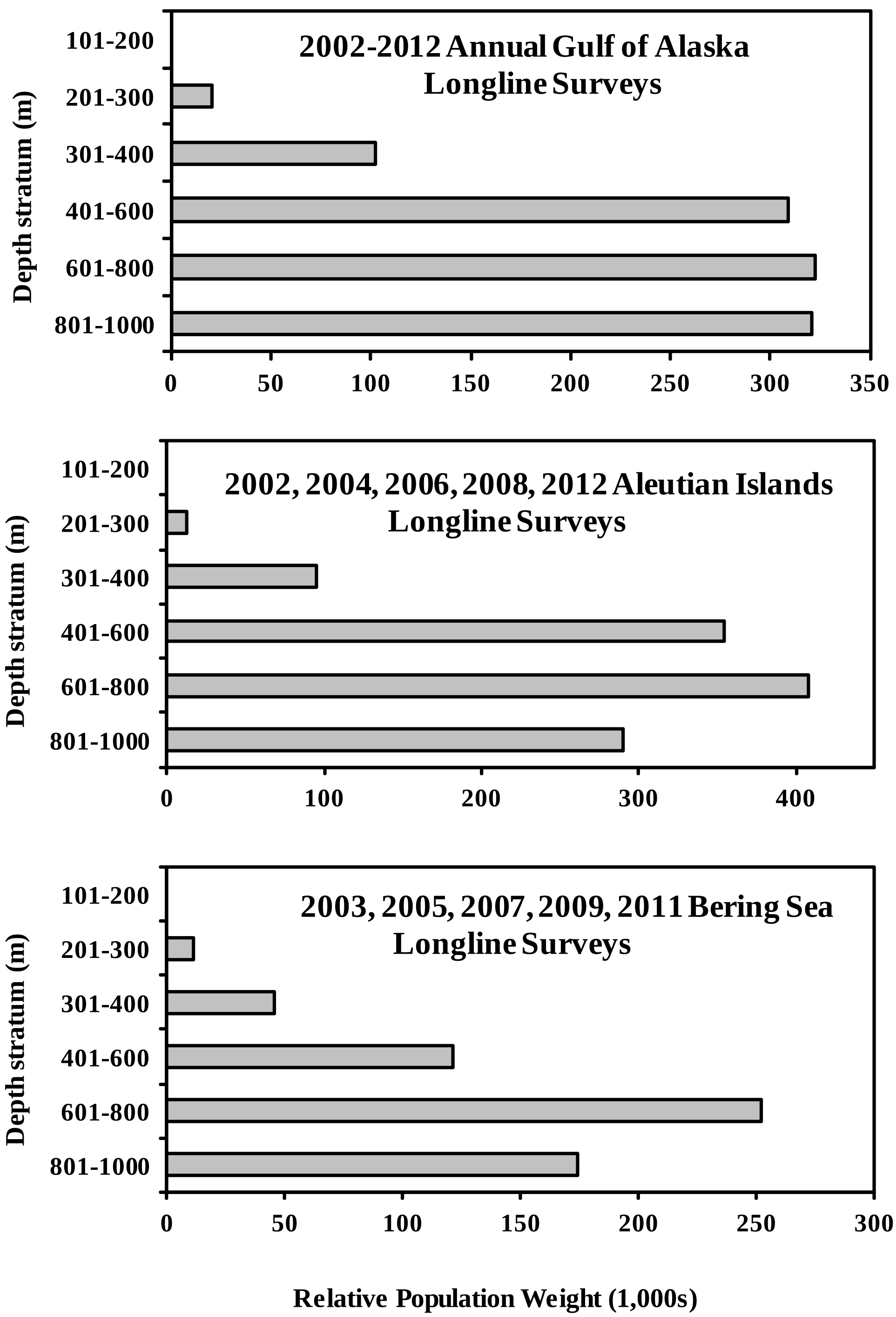

Figure 1-8.--Average depth distribution of giant grenadier relative population weight in longline surveys of the Gulf of Alaska, eastern Aleutian Islands (area of the Aleutian Islands east of 180^{o} w. longitude) , and eastern Bering Sea since 2002. Data on depth distribution are available only for the eastern Aleutian Islands.

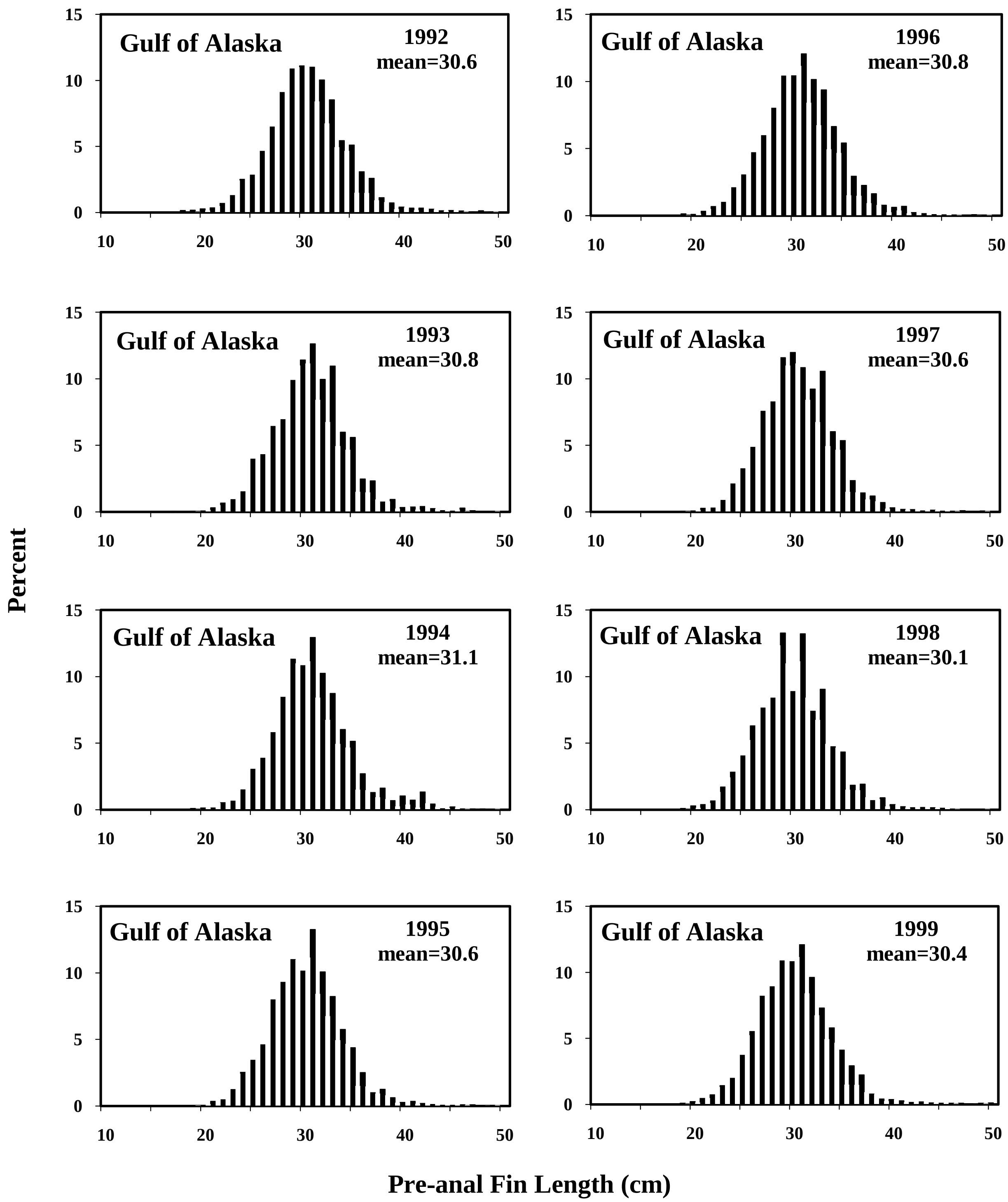

Figure 1-9.--Estimated population size compositions for giant grenadier in the 1992-2012 longline surveys of the Gulf of Alaska. (Figure continued on next two pages).

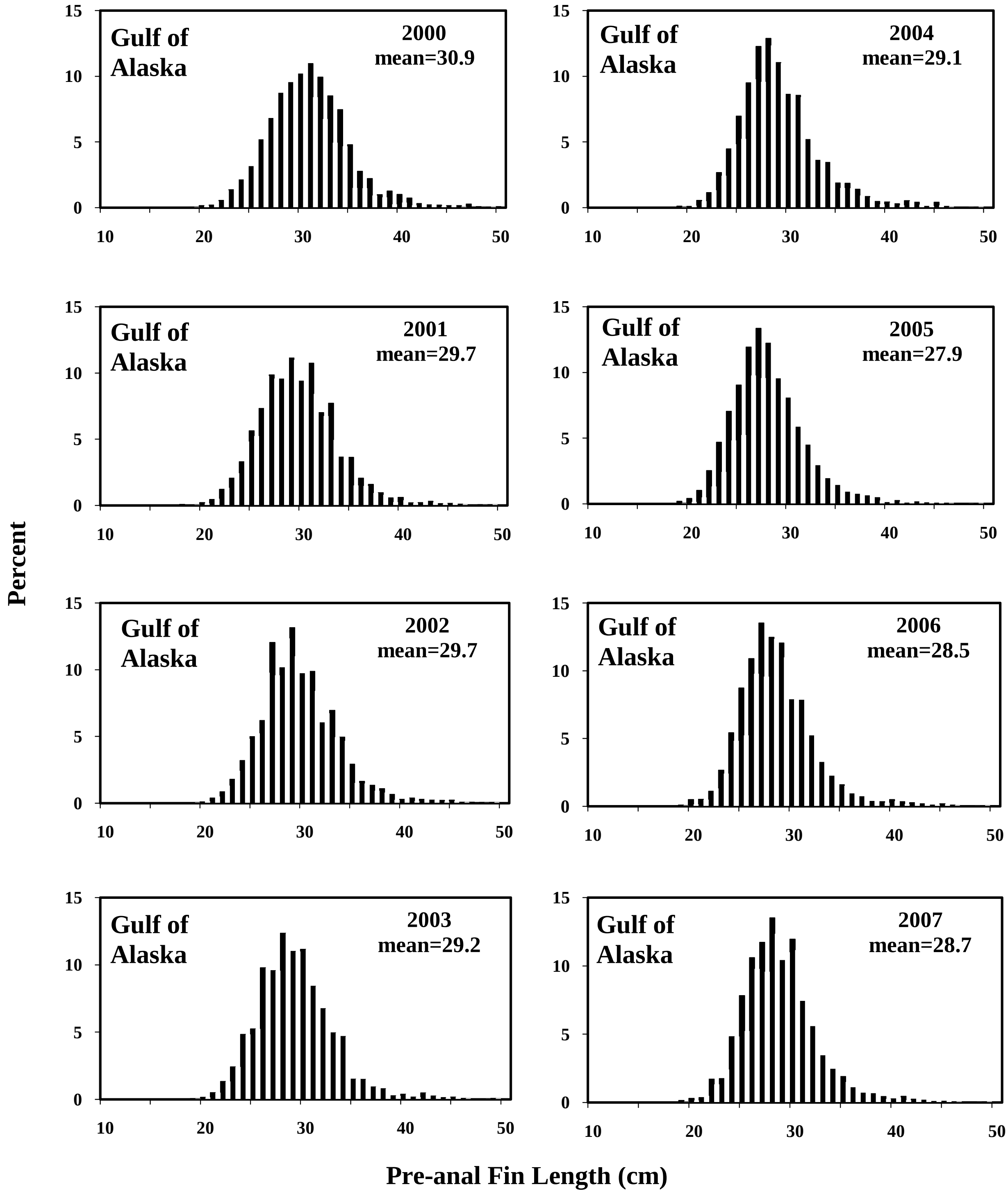

Figure 1-9. (continued from preceding page).

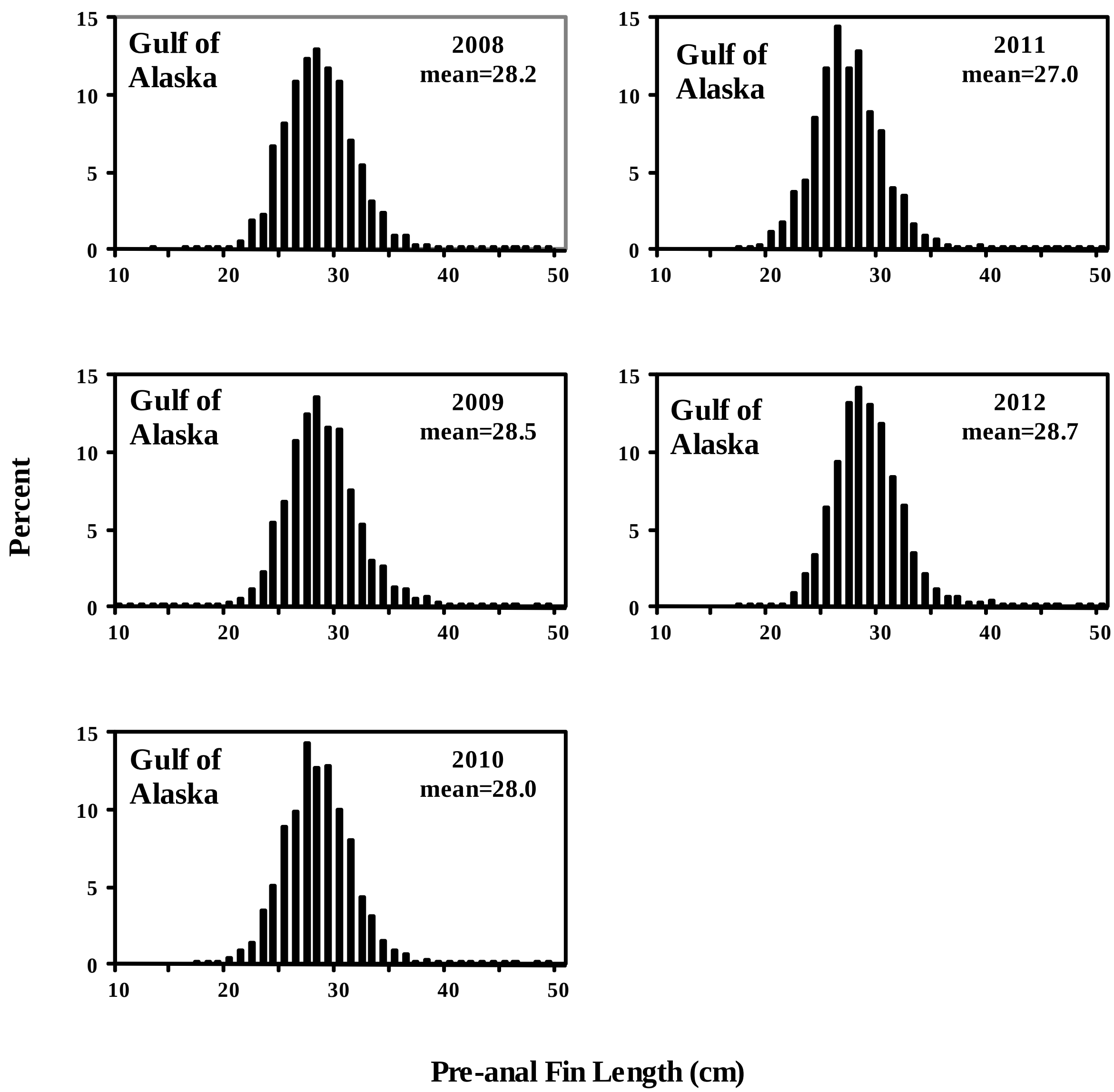

Figure 1-9. (continued from preceding page).

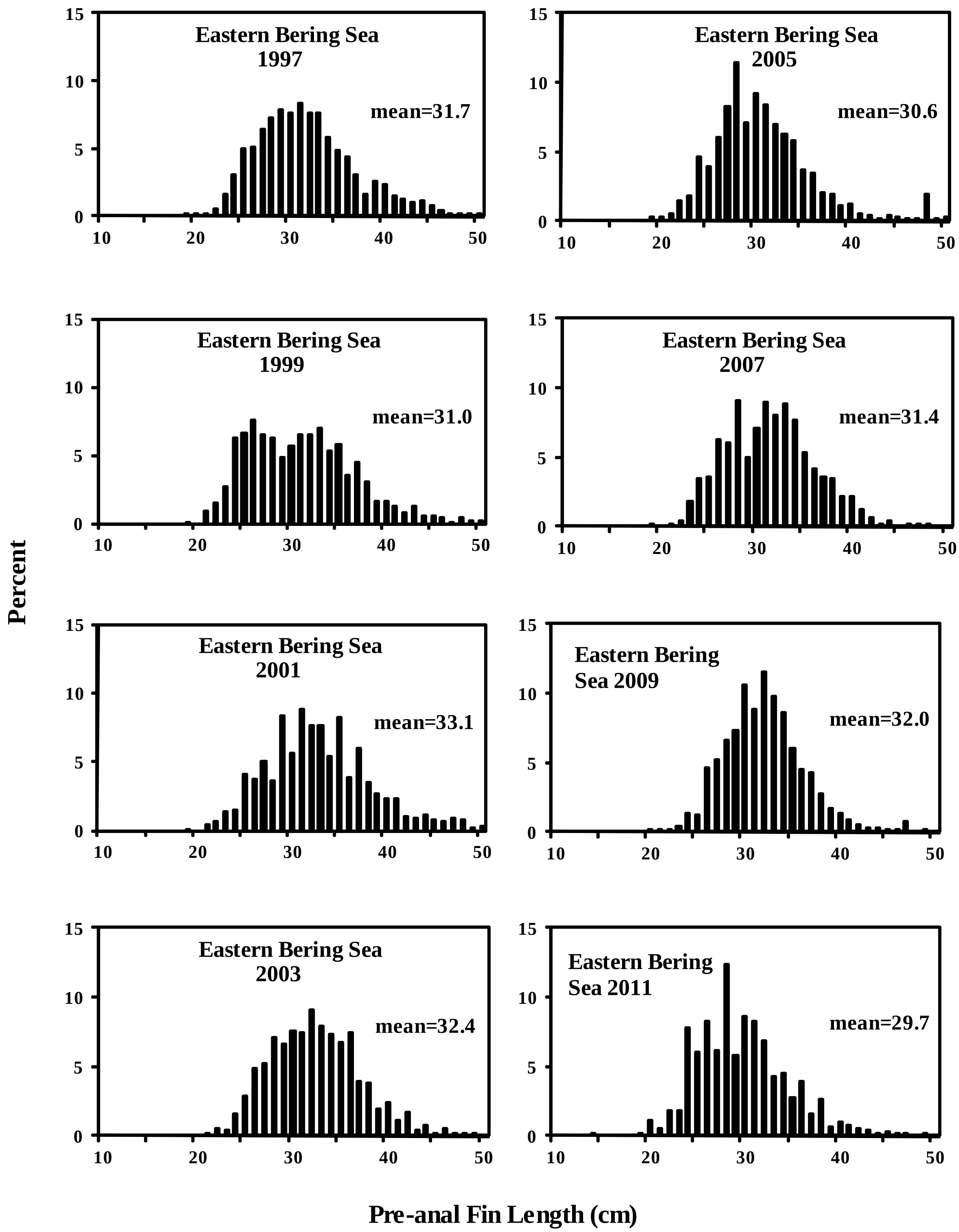

Figure 1-10.--Estimated population size compositions for giant grenadier in the 1997-2011 longline surveys of the eastern Bering Sea.

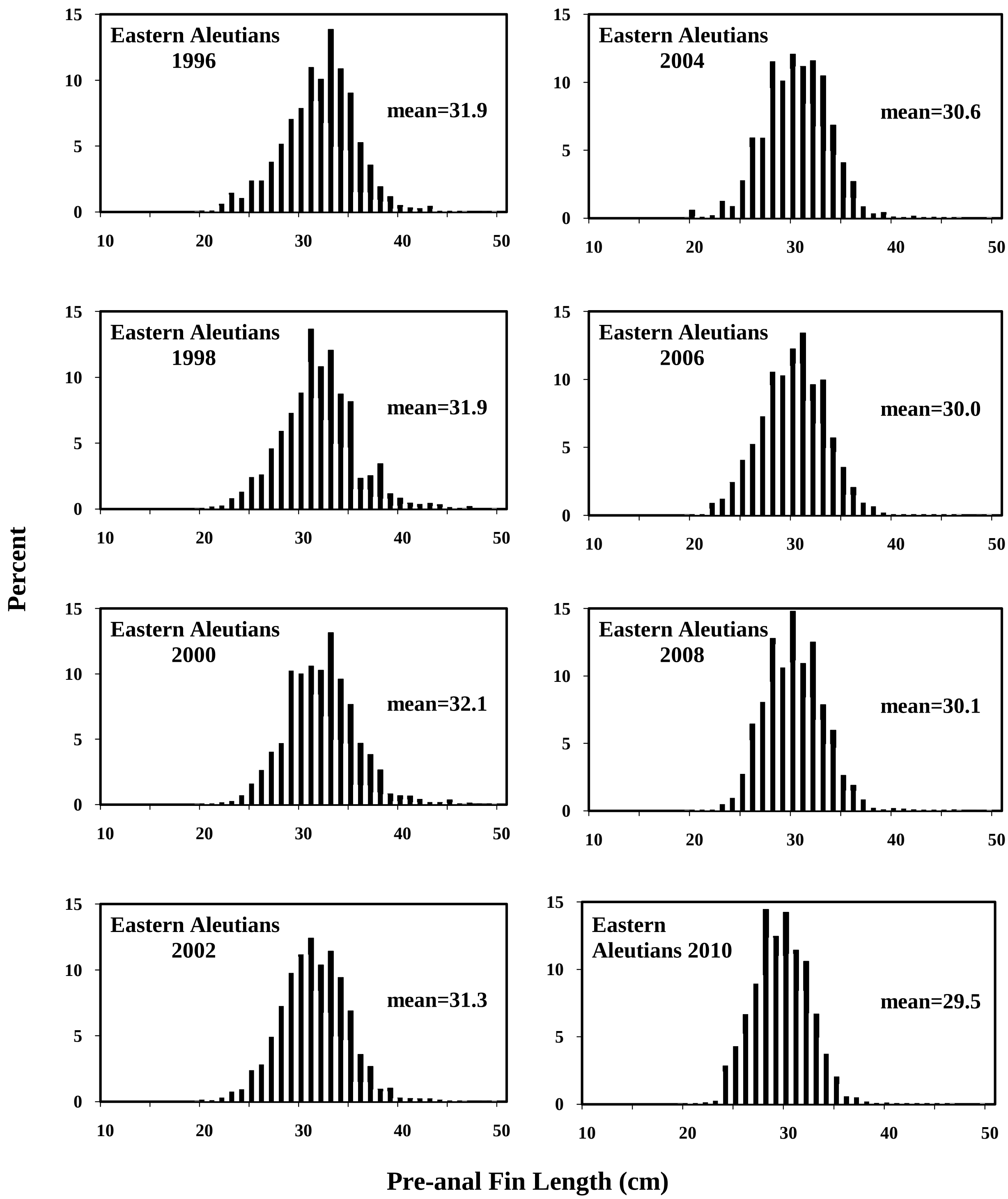

Figure 1-11.--Estimated population size compositions for giant grenadier in the 1996-2012 longline surveys of the eastern Aleutian Islands (area of the Aleutian Islands east of 180° w. longitude). Size composition data are not available for the western Aleutian Islands.

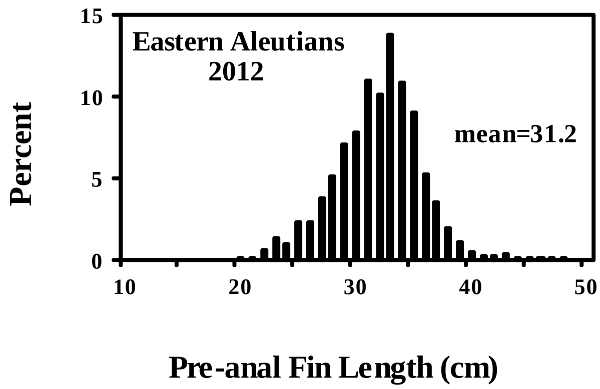

Figure 1-11.--(continued from preceding page).

Appendix 1A.--September 2012 document prepared for the Plan Team on proposed Aleutian Islands biomass and variance estimates for giant grenadier. Note: This document has been updated since September with new 2012 data.

Background

The last full assessment of Alaskan grenadiers was presented as an appendix in the 2010 SAFE report (Clausen and Rodgveller 2010). Concerning this assessment, the SSC commented at their December 2010 meeting that, "The authors provided information for estimation of biological reference points for the BSAI and GOA if the NPFMC elects to manage this complex in the fishery. The SSC agrees with the proposed methods for estimation of reference points in the GOA and BS. However, the estimation method proposed for the AI requires further work. The SSC requests that the author considers the uncertainty associated with the proposed Tier 5 expansion method for the AI."

Giant grenadier are by far the most common grenadier caught in fisheries and surveys in Alaska and are used as a proxy for the grenadier complex in the grenadier assessment. In this document we will 1) present an alternative method to extrapolate western Aleutian Islands (AI) Relative Population Weights (RPWs) for giant grenadier calculated from longline survey catches and fish weights, 2) describe a proposed method to estimate giant grenadier biomass in the AI and, 3) describe a method to estimate variances of AI biomass and RPW.

Western Aleutian Islands relative population weight extrapolation

Previous methodology

The western Aleutian Islands (AI) have not been sampled by the AFSC longline survey since 1994. Since the first grenadier SAFE in 2006, ratios of sablefish relative population numbers (RPNs) between the northwest AI/northeast AI and the southwest AI/southeast AI from 1985-1994 (when the western AI was sampled by the cooperative Japan-U.S. longline survey) were used to extrapolate the western AI relative population weights (RPWs) from the eastern RPWs for giant grenadier. Years previous to 1985 were not included because ineffective hooks were not documented in the earlier years. Previously, western AI RPN and RPWs for all major groundfish were extrapolated using these sablefish ratios and provided to stock assessment authors. Recently, data from the AFSC longline survey and the cooperative Japan-U.S longline survey have been consolidated into one relational database that enables historic data to be queried and analyzed. Sablefish ratios are no longer used to estimate western AI RPNs and RPWs for other species.

Proposed Methodology

For 2012, we use new methods to estimate the northwest and southwest AI RPWs for giant grenadier. Like the old method, two ratios were calculated for the 1985-1994 time period: one for the north and one for the south. However, instead of using sablefish RPN ratios to estimate giant grenadier RPWs in the western AI, we directly estimate giant grenadier RPN ratios as well as ratios for other species caught during the survey.

Western AI giant grenadier RPWs were estimated using the following formula,

$$(1)\quad W_y = r_{NE}W_{NE,y} + r_{SE}W_{SE,y}$$

where W_y is the AI RPW in year y, r_{NE} is the ratio of total northern RPN to northeast RPN (3.46) (using summed RPNs for the period from 1985-1994), $W_{NE,y}$ is the RPW in the NE in year *y*, r_{SE} is the ratio of total southern RPN to southeast RPN (2.17), and $W_{SE,y}$ is the RPW in the SE in year *y*.

For example in the 2010 survey,

$$AI\ RPW = 3{,}732{,}194 = 3.46 \times 793{,}287 + 2.17 \times 455{,}926$$

The new method of extrapolating giant grenadier RPWs from the eastern AI to the western AI is preferable to the previous method because it is based on giant grenadier RPNs and not on sablefish RPNs.

Overall, estimating western AI giant grenadier RPWs using this proposed method resulted in large increases in the estimates of total AI RPWs (Table 1A, Fig. 1A) This new method increases the RPWs in the AI because there appears to be considerably more giant grenadier in the northwest AI than the northeast AI.

AI biomass estimates

Previous Methodology

The AFSC AI trawl survey regularly samples depths from 1-500 m, but has not sampled deeper than 500 m since 1986. This presents a problem for determining total biomass of giant grenadier in the AI because the majority of giant grenadier habitat is deeper than 500 m. An AI biomass for 1-1000 m was estimated in previous grenadier SAFEs by using a combination of data from other areas and surveys: the GOA and EBS slope trawl surveys and the AFSC longline survey (Clausen and Rodgveller, 2010). Note that for this previously used method the western AI longline RPWs were extrapolated using a ratio of sablefish RPNs in the eastern and western areas instead of the proposed extrapolation method described in the previous section. Here AI indicates both western and eastern AI.

The AI biomass was estimated as,

$$(2)\ B_y = (\left(\frac{RPW_{AI}}{RPW_{EBS}}\bar{B}_{ebs}\right) + \left(\frac{RPW_{AI}}{RPW_{GOA}}\bar{B}_{GOA}\right))/2$$

where B_y is the total AI biomass in year *y*, $\frac{RPW_{AI}}{RPW_{EBS}}$ is the average ratio of longline survey AI RPWs to the eastern Bering Sea (EBS) RPWs and $\frac{RPW_{AI}}{RPW_{GOA}}$ is the average ratio of the AI RPWs to the GOA RPWs and in years when the EBS and AI were sampled; EBS was sampled in odd years since 1997 and AI was sampled in even years since 1996. $\bar{B}_{ebs}$ is the average EBS biomass from the previous three bottom trawl surveys and $\bar{B}_{GOA}$ is the average GOA biomass from the previous three surveys. For the 2010 SAFE the most recent surveys in the EBS that sampled to 1,200 m were 2004, 2008, 2010. In the GOA, depths to 1,000 m were sampled in 2005, 2007, and 2009. By using this method, we assumed that the ratios between the AI and the other areas are the same in the longline and trawl survey. Given that this assumption is likely violated, a new method is proposed.

Proposed New Methodology

The new, proposed method for determining biomass of giant grenadier in the AI uses available biomass data from the AI trawl survey and AI RPWs from the longline survey instead of data from the EBS and GOA. The AI trawl survey biomass estimates from the “shallow” depths, which are regularly sampled (1-500 m), 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:

$$(3)\ B_y = \bar{r}W_y$$

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 RPWs in the shallow depth stratum for years when both surveys occurred (2000, 2002, 2004, 2006, 2010, 2012), and W_y is the total RPW in year *y*. $\bar{r}$ of “shallow” biomass to “shallow” RPWs for these years was 0.22.

When ratios were examined individually for each year, 2000, 2002, 2004, and 2006 were similar (0.30, 0.29, 0.31, 0.26, respectively) and 2010 and 2012 were similar and lower (0.06 and 0.10, respectively). Because the 2010 and 2012 ratios were so different than the others, we examined them in more detail. From 2006 to 2010 (no survey in 2008), the shallow longline RPW increased 55% and the shallow trawl biomass decreased 63% (Table 1A-2, Fig. 1A-2). The decrease in trawl biomass in 2010 can be attributed to an 80% drop in the estimated biomass of giant grenadier the 301-500 m stratum in the eastern AI, where giant grenadiers previously had consistently high catch rates. There were fewer trawl stations in this stratum in 2010 and 2012 (down to 6, from 10 in 2006, and down to 4 in 2012), but there were no reports of gear issues or any unusual sampling practices. In 2012 biomass remained low. The "shallow" RPW decreased while "shallow" biomass in all areas in the AI combined had a small increase, so the ratio was slightly higher than in 2010 (1A- 2, Fig. 1A-2). AI biomass CVs in this stratum range from 26-73%, and overall AI CVs range from 33%-68%, so variability among stations is not uncommon. Because there is potential for large fluctuations in the "shallow" biomass estimates, we propose using the average ratio when estimating total giant grenadier biomass in the AI and updating this ratio when new data is available.

The longline survey does not compute RPWs for depths <200, so the "shallow" depths in each survey do not incorporate the same depth range. However, this difference is moot because no grenadiers reside in water <200 m deep. The new method assumes that the ratio of the shallow to deep RPWs in the longline survey is similar to the ratio of shallow to deep biomass estimates in the trawl survey (i.e, there is not a difference in catchability between "shallow" and "deep" in both surveys). Biomass for the AI can be calculated for years when there is an RPW, even if there was no trawl survey in "shallow" waters of the AI.

RPWs are substantially higher in the "deeper" depths than "shallow" depths (Tables 1A-2 and 1A-3; Figs. 1A-2 and 1A-3). Giant grenadier are caught primarily at depths from 400-1000 m on the longline survey in the EBS, the AI, and the GOA. It is logical that "deep" biomass is higher than "shallow" biomass. Although there was a decrease in the "shallow" biomass in 2010 (Table 1A-2, Fig. 1A-2), the "deep" biomass does not exhibit this trend because it is calculated from the sum of "shallow" biomass to "shallow" RPWs for all years and not the annual ratio. In 2010, the "deep" biomass estimate increased because total RPW increased. In 2012 it decreased RPWs decreased even though "shallow" biomass increased slightly.

Overall, the proposed method provides lower estimates of AI biomass than those from previous SAFEs (Table 1A-4, Fig. 1A-4). The trends between the old and proposed methods are similar. The new estimates of AI biomass seem reasonable (i.e., the density of biomass, as biomass/area size, is similar in the AI and the GOA) and are recommended as an alternative to the method used in previous SAFEs.

Summary

The new method proposed here for calculating AI biomass uses trends in the AI RPWs instead of those in the Eastern Bering Sea and Gulf of Alaska to estimate AI biomass. Using the ratio of the sums will keep the calculated total biomass from making drastic swings. This ratio will be updated each year as new data becomes available.

AI biomass variance

RPW calculation

The total and shallow RPW in region *r* and year *y* are estimated as the sum of RPWs over depth strata. RPWs are the product of average weight of the giant grenadier catch in the depth stratum, the area of the depth stratum, and the average catch of giant grenadier per skate in a depth stratum. Here the region-wide RPW (e.g., AI) is estimated as,

$$(4)\quad W_{r,y} = \sum_{d=1}^{D} \overline{w}_{r,d,y} A_{r,d} \overline{CPUE}_{r,d,y}$$

where $W_{r,y}$ is the total RPW for region *r* and year *y*, $\overline{w}_{r,d,y}$ is the average weight (in kg) in region *r*, depth stratum *d*, and year *y*, $A_{r,d}$ is the area (in km^2) in region *r* and depth stratum *d*, and $\overline{CPUE}_{r,d,y}$ is the average catch of grenadier per skate of gear in region *r*, depth stratum *d*, and year *y*. The estimate of average catch per unit effort can be written as:

$$(5)\quad \overline{CPUE}_{r,d,y} = \frac{1}{n_{r,d,y}} \sum_{i=1}^{n_{r,d,y}} C_{i,r,d,y}$$

where $\overline{CPUE}_{r,d,y}$ is the average CPUE for region *r*, depth stratum *d*, and year *y*, $n_{r,d,y}$ is the number of skates and $C_{i,r,d,y}$ is the catch per skate *i* in region *r*, depth stratum *d*, and year *y*.

Aleutian Islands biomass variance estimate

To obtain the variance of the estimate of grenadier biomass in the AI we used the delta method (Quinn and Deriso 1999). Ignoring the covariance terms, the variance of a function of random variables can be approximated with,

$$(6)\quad V[f] \cong \sum_i \left(\frac{\partial f}{\partial X_i}\right)^2 V[X_i]$$

where *f* is some function of random variables X_i. In the case of grenadier biomass in the AI, the random variables include the average ratio of bottom trawl biomass to longline survey RPW ($\bar{r}$) and the total RPW (W_y). Using the delta method the variance of total biomass (equation 1) can be approximated with,

$$(7)\quad V[B_y] = \bar{r}^2 V[W_y] + W_y^2 V[\bar{r}]$$

The variance of the total RPW (equation 3) can be obtained with,

$$(8)\quad V[W_y] = (r_{NE})^2 V[W_{NE,y}] + (r_{SE})^2 V[W_{SE,y}]$$

which can also be used to obtain the variance of the shallow RPW by replacing total RPW in the NE/SE regions with shallow RPW. The variance of the regional RPW can be shown to be,

$$(9)\quad V[W_{NE,y}] = \sum_D \left(\overline{w}_{r,d,y} A_{r,d}\right)^2 \frac{V[C_{r,d,y}]}{n_{r,d,y}}$$

The variance of the ratio estimator (equation 2) is given by the standard variance estimate,

$$(10)\quad V[\bar{r}] \cong \frac{1}{Y\bar{B}_{S,y}^2} \frac{\sum_Y \left(B_{S,y} - \bar{r} W_{S,y}\right)^2}{Y-1}$$

where the variance of the bottom trawl survey biomass is given by $V[B_{S,y}]$, and the variance of shallow depth strata RPW ($V[W_{S,y}]$) can be computed with equations 8 and 9. The variance of total biomass is then obtained by combining equations 7-11.

The variance of the proposed total and shallow AI RPWs are relatively small (Tables 1A-1 and 1A-2) compared to the trawl survey variance. The longline survey tends to produce steady catches of giant grenadiers when it is fishing in the preferred depths, and steady zero catches when not in preferred depths. The estimates of variance for the trawl survey shallow biomass are larger than for the longline survey RPWs because of the random design and because trawl survey stations are short while longline survey stations cover approximately 4.5 miles (Table 1A-2). The coefficient of variation (CV) on total biomass is the same in all years since most of the variance is the ratio of trawl biomass to the longline survey RPW and the same average ratio was used to compute the biomass in each year (Table 1A-4). The estimated variance of the total RPW estimate is smaller than the variance estimate of shallow RPW due to the increase in the sample size of grenadier catches.

Table 1A-1. Total Aleutian Island (AI) Relative Population Weight (RPW) estimates when either 1) a ratio of sablefish Relative Population Numbers of the eastern and western AI was used to extrapolate western AI giant grenadier RPWs (Previous SAFEs) or 2) when a ratio of giant grenadier RPNs was used (Proposed). The standard deviation (SD) and coefficient of variation (CV) are reported for the proposed estimate. No CV is available for 1996 because raw catch data is not available.

Year	Previous SAFEs	Proposed	SD	CV
1996	1,281,800	2,281,816	73,357	
1998	1,348,632	2,268,918	54,915	2.4%
2000	1,743,203	3,039,523	76,045	2.5%
2002	1,760,703	3,093,994	67,337	2.2%
2004	1,565,915	3,121,973	90,207	2.9%
2006	1,991,259	3,914,871	111,698	2.9%
2008	1,162,392	1,985,511	42,715	8.0%
2010	1,915,769	3,732,194	83,717	2.2%
2012		2,598,901	91,813	3.5%

Table 1A-2. Giant grenadier AI biomass estimates (mt) and Relative Population Weights (RPWs) in the “shallow” depth range from AFSC trawl (100-500 m) and longline surveys (200-500 m). RPWs are computed from sampling in the eastern AI and extrapolating the western AI areas using ratios of giant grenadier RPNs in both areas from previous surveys. Shallow biomass is computed in both surveys from sampling in “shallow” depths. The standard deviation (SD) and coefficient of variation (CV) are reported for each estimate. RPWs are not available by stratum in 1996 and there was no trawl survey in 1996.

Year	Shallow biomass*	SD*	CV*	Shallow RPW	SD	CV
1998				471,332	16,060	3.4%
2000	219,693	150,801	69%	727,607	28,835	4.0%
2002	218,147	132,592	61%	745,959	31,362	4.2%
2004	248,136	94,917	38%	807,530	43,555	5.4%
2006	192,640	110,122	57%	749,141	45,101	6.0%
2008				476,527	22,710	4.8%
2010	70,748	23,776	34%	1,157,035	45,843	4.0%
2012	86,556	30,257	35%	824,667	38,023	4.6%

*Note: This document has been updated since September with new 2012 data. Biomass and variance estimates in all years have changed since September due to a change in the ratio used to estimate biomass.

Table 1A-3. Giant grenadier AI biomass estimates (mt) (using the proposed method) and RPWs in the "deep" depth range (501-1000 m) from AFSC trawl and longline surveys, respectively. RPWs are computed from sampling in the eastern AI and extrapolating the western AI areas using ratios of giant grenadier RPNs in both areas from previous surveys. Deep biomass is only available in years when there was a trawl survey.

Year	Deep biomass*	Deep RPW	SD	CV
1996		1,973,519	72,386	3.7%
1998		1,797,587	49,497	2.8%
2000	408,352	2,311,917	64,235	2.8%
2002	421,154	2,348,036	53,280	2.3%
2004	396,923	2,314,442	75,768	3.3%
2006	616,620	3,165,730	98,801	3.1%
2008		1,879,990	31,474	2.1%
2010	700,857	2,575,159	66,065	2.6%
2011	450,446	1,774,234	83,530	4.7%

*Note: This document has been updated since September with new 2012 data. Biomass and variance estimates in all years have changed since September due to a change in the ratio used to estimate biomass.

Table 1A-4. Estimated total biomass (mt) of giant grenadier in the AI for depths 1-1000 m (a combination of "shallow", 1-500 m, and "deep", 501-1000 m, depths) using 1) a previous method, used in the 2006, 2008, and 2010 SAFEs, that extrapolated AI biomass using trawl surveys in the GOA and EBS and the longline survey RPWs and 2) a new method that uses AI trawl survey biomass estimates from "shallow" water (1-500 m) and longline survey RPWs from "shallow" (200-500 m) and "deep" water (501-1000 m). The standard deviation (SD) and coefficient of variation (CV) are reported for the proposed biomass estimate. Total biomass is available in all years when RPWs are available.

	AI Biomass*			
Year	Previous SAFEs	Proposed	SD	CV
1996		471,483		
1998		468,818	113,925	24.3%
2000		628,046	152,670	24.3%
2002		639,301	155,206	24.3%
2004		645,082	157,088	24.4%
2006	1,030,466	809,260	197,033	24.3%
2008	979,256	487,573	124,193	25.5%
2010	1,141,526	771,605	187,372	24.3%
2012		537,001	131,224	24.4%

*Note: This document has been updated since September with new 2012 data. Biomass and variance estimates in all years have changed since September due to a change in the ratio used to estimate biomass.

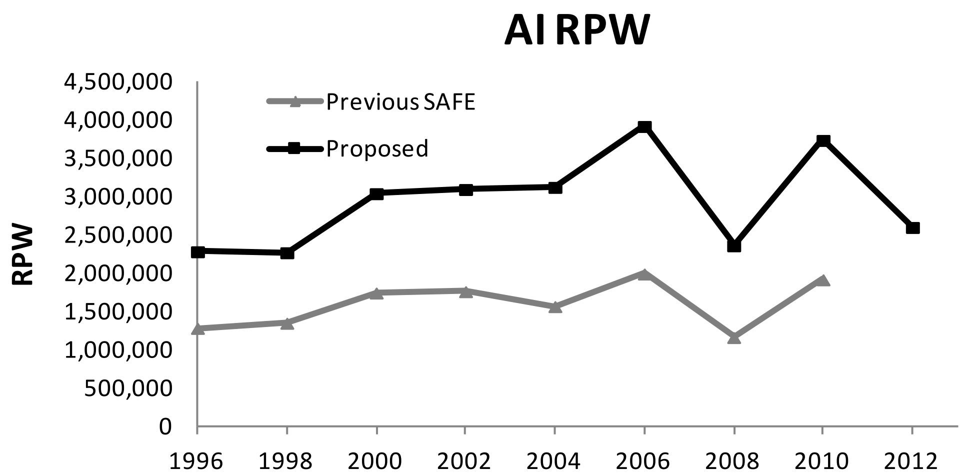

Figure 1A-1. Aleutian Island (AI) relative population weights (RPW) for giant grenadier from previous SAFEs that extrapolated the western AI RPW using a sablefish ratio and using the proposed method that uses giant grenadier ratios. Values are from Table 1.

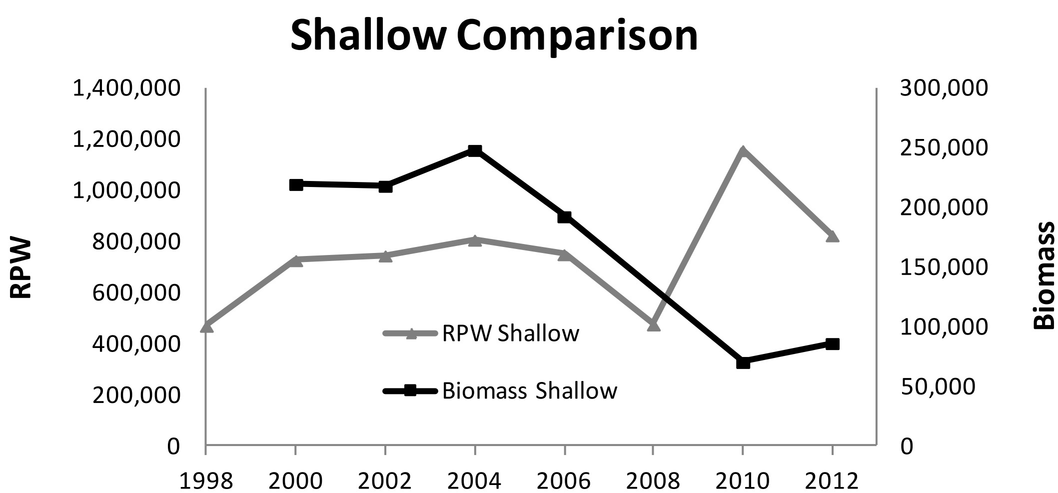

Figure 1A-2. Aleutian Island (AI) relative population weights (RPWs) for the longline survey and biomass estimates from trawl surveys for giant grenadier. There was no trawl survey in 2008. Values are from Table 2.

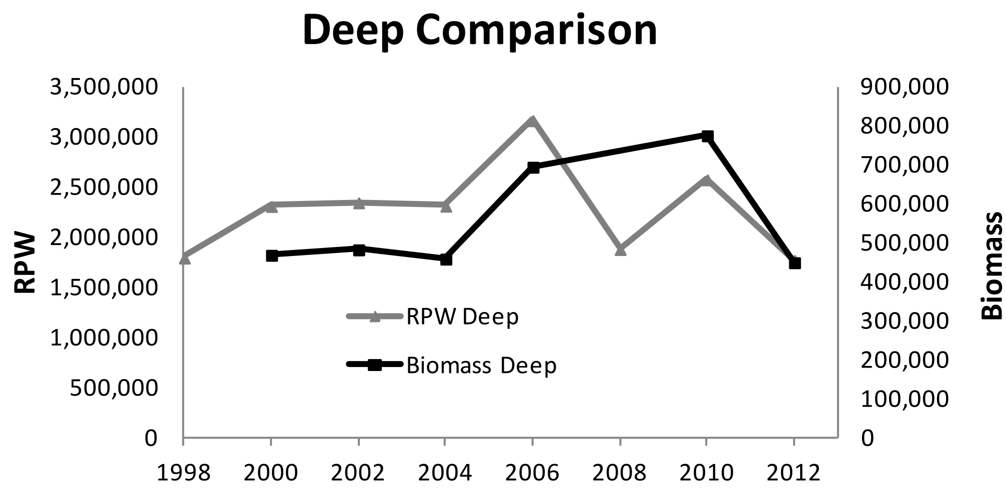

Figure 1A-3. Giant grenadier relative population weights (RPWs) and biomass estimates for “deep” depths (500-1000 m) in the Aleutian Islands (AI). RPWs are from longline surveys. “Deep” depths were not sampled by AI trawl surveys. “Deep” giant grenadier biomass was estimated using data from longline surveys from “shallow” (200-500 m) and “deep” (501-1000 m) depth strata and from “shallow” trawl surveys. There was no trawl survey in 2008. Biomass and RPWs are presented on separate axis for comparison of the relative trends. Values are from Table 3.

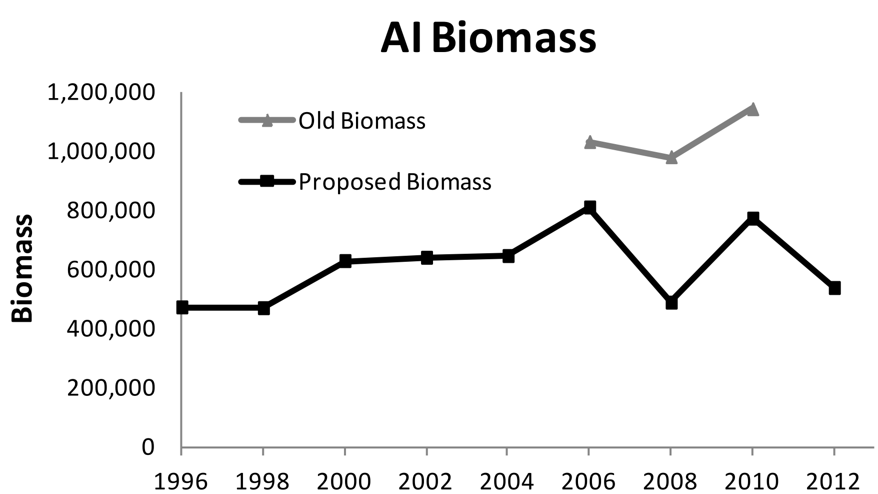

Figure 1A-4. Total Aleutian Islands (AI) biomass from previous SAFEs and using the proposed methodology. Total AI biomass includes estimates from trawl surveys in “shallow” depths and estimates of “deep” biomass using the proposed method. Values are from Table 4.

Citations

Clausen, D. M. and C. J. Rodgveller. 2010. Assessment of grenadier stocks in the Gulf of Alaska, eastern Bering Sea, and Aleutian Islands. In Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska, Appendix 1, p. 797-846. North Pacific Fishery Management Council, 605 W. 4th. Avenue, Suite 306, Anchorage, AK 99501.

Quinn II, T. J., and R. B. Deriso. 1999. Quantitative Fish Dynamics, 542 p. Oxford University Press, New York.

Appendix 1B.--Research catch.

Table 1B-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; 2010 and 2011 catch in weight is available. 0s indicate that there was catch but it is <1 mt.

	BSAI					GOA					
Year	IPHC #s	IPHC wt	AFSC Trawl	AFSC LL	Total BSAI	IPHC #s	IPHC wt	AFSC Trawl	AFSC LL	Total GOA	Total
1976								0		0	0
1977								0		0	0
1978			0		0			0		0	0
1979			33		33			0		0	33
1980			85		85			1		1	86
1981			66		66			3		3	69
1982			124		124			0		0	125
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	128	131	131
1991			10		10				113	113	123
1992									117	117	117
1993								6	135	141	141
1994			6		6				134	134	140
1995									191	191	191
1996				38	38			8	173	181	219
1997	1,184		9	78	87	258			169	169	256
1998	556			59	59	681		12	141	153	212
1999	165		0	57	57	660		47	157	204	261
2000	774		118	88	206	621			160	160	366
2001	1,313			43	43	287		11	161	173	215
2002	987		23	81	104	942			129	129	233
2003	1,792		91	50	141	1,344		27	151	178	320
2004	2,111		196	78	274	1,110			109	109	383
2005	1,404			71	71	1,266		49	120	169	240
2006	941		20	76	96	919			112	112	208
2007	1,224			77	77	849		44	166	209	286
2008	1,331		123	47	170	755			120	120	290
2009	2,710			86	86	785		39	154	193	279
2010	2,451	9	156	66	231	1,265	6		164	170	401
2011	1,808	7		75	82	751	2	20	124	145	227
2012			135	43	177				132	132	310
Total		16.2	1,616	1,111	2,744		7	380	3,259	3,647	6,392

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