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ABSTRACT

An experimental bottom longline survey was conducted at depths > 1,000 m in the western Gulf of Alaska in August 2008. The objective was to investigate the abundance and biological characteristics of giant grenadier (*Albatrossia pectoralis*) and sablefish (*Anoplopoma fimbria*) in deep waters of the Gulf of Alaska that have not been previously sampled in fishery surveys. Several difficulties were encountered during fishing operations highlighting the unique challenges that may occur when fishing longlines at these depths, including substantial gear drift after setting and hang-ups on the bottom that caused the longline to break. Catch rates of giant grenadier were relatively high, although not as large as those in nearby longline survey stations in depths < 1,000 m. Female giant grenadier were much larger in size at the deep-water stations, and their weight averaged 69% greater than females at depths < 1,000 m. Males, which make up a low percentage of the catch in shallower water, were caught in much higher numbers at the deep-water stations. Catch rates for sablefish at the deep-water stations were extremely low, and it appears that the abundance of sablefish is negligible in the western Gulf of Alaska at depths > 1,000 m. Pacific grenadier (*Coryphaenoides acrolepis*) were caught in substantial numbers at depths > 1,000 m, but were not caught at depths < 1,000 m.

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INTRODUCTION

Since 1988, the Alaska Fisheries Science Center (AFSC) of the National Marine Fisheries Service (NMFS) has conducted an annual bottom longline survey of the upper continental slope of the Gulf of Alaska (GOA), which was extended to the Aleutian Islands in 1996 and to the eastern Bering Sea in 1997. Similar surveys were conducted cooperatively between Japan and the United States from 1979 to 1994. These surveys have systematically sampled fixed stations at depths of approximately 200-1,000 m and are primarily directed at sablefish, *Anoplopoma fimbria*, one of the most commercially valuable groundfish species in Alaska. The other main species caught in these surveys is giant grenadier, *Albatrossia pectoralis*. Although the longline surveys in the GOA have comprehensively sampled depths from 200 to 1,000 m, waters deeper than 1,000 m have not been sampled by trawl or longline surveys and very little is known regarding distributions of fish below this depth. Bottom trawl surveys in the GOA also have not extended deeper than 1,000 m.

Although surveys in the GOA have not sampled depths > 1,000 m, there is evidence to suggest that the distributions of giant grenadier and sablefish extend into deeper water. In particular, the population of giant grenadier in deeper water may be substantial. For example, in all but one of the AFSC longline surveys in the GOA from 2002 to 2006, the deepest stratum (801-1,000 m) contained the highest relative biomass of giant grenadier (Clausen 2008). In a 2009 trawl survey in the GOA, the deepest stratum sampled (701-1,000 m) had by far the largest biomass estimate for giant grenadier (von Szalay et al. 2010). Similar GOA trawl surveys in 1999, 2005, and 2007 also indicated a relatively large biomass in this stratum, although in these surveys the greatest biomass of giant grenadier was in the 500-700 m stratum (Clausen 2008, von Szalay et al. 2008). For sablefish, the general pattern in the GOA longline surveys is for relative biomass to be highest at the 401-600 m and 601-800 m strata and for abundance to decrease in the 801-1,000 m stratum[1]. However, in some areas and years the abundance of sablefish in the 801-1,000 m stratum can be considerable; that is, in 2003, in the vicinity of Kodiak Island in the Central Gulf of Alaska (Fig. 1), sablefish in this stratum made up 23% of the total relative biomass for all depths surveyed. Thus, based on past survey results, a reasonable hypothesis is that relatively large numbers of giant grenadier and to a lesser extent sablefish may occur in the GOA at depths >1,000 m that have not been surveyed, and that current survey methods may not accurately inventory these species at the deep end of their distribution.

More complete information on the distribution and abundance of giant grenadier in the GOA is particularly needed at this time. Interest in giant grenadier in Alaska has increased in recent years for a number of reasons: 1) Presently, grenadiers in Alaska are not included in the fishery management plans of the North Pacific Fishery Management Council (NPFMC), which set groundfish quotas in Federal waters in Alaska. Therefore, there are no limitations on catch or retention of grenadiers, no reporting requirements,

[1] C. J. Rodgveller, Unpublished data, Oct. 2008. Alaska Fisheries Science Center, Auke Bay Laboratories, 17109 Point Lena Loop Rd., Juneau, AK 99801.

and no official tracking of catch by management. However, the NPFMC is examining options that would modify NPFMC fishery managements plans to include grenadiers as species that "are in the fishery". If this option is adopted, better information on abundance of giant grenadier will be required to determine appropriate levels of catch and to ensure that overfishing does not occur. 2) Giant grenadier is so abundant on the continental slope of Alaska that it is an extremely important component of the ecosystem in this habitat (Clausen 2008). Given the recent emphasis on using an "ecosystem approach" to fishery management, rather than the traditional single-species approach, increased knowledge of giant grenadier has become more important. 3) Although there is little or no targeted or retained catch of giant grenadier in the GOA, the amount of giant grenadier taken as bycatch in this region is substantial. For example, in the GOA in 2010, the estimated catch of giant grenadier of 5,419 metric tons (t) was exceeded for only five groundfish species: walleye pollock (*Theragra chalcogramma*), Pacific cod (*Gadus macrocephalus*), arrowtooth flounder (*Atheresthes stomias*), Pacific ocean perch (*Sebastes alutus*), and sablefish (Rodgveller and Clausen, 2012; Plan Team for the Groundfish Fisheries of the Gulf of Alaska 2011). Most of the giant grenadier bycatch in the GOA is from the sablefish longline fishery, and nearly all is discarded at sea with a likely mortality rate of 100%. (4) There have only been a few minor attempts to commercially utilize giant grenadier in Alaska. However, because giant grenadier is so abundant and there is limited opportunity for expansion of other groundfish fisheries in Alaska (most are currently fully utilized), it is likely that efforts to develop marketable products from these fish will continue.

To investigate the abundance and distribution of giant grenadier and sablefish in waters deeper than 1,000 m in the GOA, the AFSC's Auke Bay Laboratories conducted an experimental longline survey of these depths in August 2008. The experiment covered a relatively small area over a short time; rather than being a comprehensive study, the experiment provided an indication of what the abundance of the fish may be at these depths. This report summarizes the results of the study.

METHODS

Vessel and Gear

A commercial longlining vessel, the FV *Beauty Bay*, was chartered for the study. The *Beauty Bay* is 37.8 m (124 ft) length overall, with a beam of 9.1 m (30 ft) and a draft of 3.0 m (9.9 ft). The vessel's two engines had a total horsepower of 1,248, and it was equipped with standard longline hauling equipment and a Furuno FCV 1200 3 kW color video sounder, which was needed for depth readings in the relatively deep-water that would be sampled.

The groundline gear, hooks, and bait were identical to that used in the AFSC longline survey and were provided by the AFSC. However, a smaller amount of gear was fished per day in the deep water experiment compared to standard survey stations. The groundline consisted of 45 units of gear ("skates"), each 100 m long (55 fathoms), with

45 hooks per skate spaced 2 m apart. Thus, a total of 2,025 hooks were fished per day, and effective distance fished along the bottom by the hooks was 4.5 km (2.4 nautical miles (nmi)). In comparison, the AFSC longline survey fishes 7,200 hooks per day along a groundline 16 km (8.6 nmi) long. Hooks were 13/0 circle hooks, and were attached to the groundline by 0.38 m (15 inch) gangions. All hooks were hand baited with chopped Atlantic *Illex* squid. Each skate was weighted at the end with a detachable 3.2 kg (7 lb) lead ball to ensure the groundline remained on the bottom. The groundline at each end was attached by a 365.8 m (200 fathom) "running" line to a 36.3 kg (80 lb) halibut anchor. A buoyline attached each anchor to a flagpole and buoy array at the surface. The vessel provided the running lines, anchors, buoylines, flagpoles, and buoy arrays. The standard anchors in the AFSC longline survey are 27.2 kg (60 lb), and heavier 36.3 kg (80 lb) anchors were used in the deep-water experimental survey to reduce possible drifting of the gear due to the increased drag of the long buoylines needed in deeper water.

Study Area and Stations

We originally intended to conduct the deep-water longline experimental survey in waters offshore Kodiak Island in the central GOA because relatively high catch rates of both giant grenadier and sablefish had been found there in the deepest stratum (801-1,000 m) fished in the AFSC longline survey (Fig. 1). Also, we wanted to do the deep-water survey in August because this corresponded to when the AFSC longline survey samples this area. Conducting the deep-water survey at a similar time as the AFSC longline survey would allow a more direct comparison between the two surveys by eliminating possible effects of timing differences on the results. However, we were forced to change our study area to the western Gulf of Alaska because we were only able to find an appropriate charter vessel based out of the port of Dutch Harbor in the western GOA. Although giant grenadier are known to be very abundant in the western GOA (Clausen 2008), this area was not considered ideal concerning sablefish for the deep-water experimental survey. The AFSC longline survey results showed low sablefish catch rates here in its deepest stratum of 801-1,000 m, implying a very low abundance in even deeper water.

Standard AFSC survey stations 65-68 were selected based on their proximity to Dutch Harbor, high catch of giant grenadier in the AFSC longline survey, and generally low historic rates of killer whale (*Orcinus orca*) depredation upon the longline catches. If present, killer whales can have a marked effect on longline catch rates (Dahlheim 1988).

Fishing Operations and Sampling Procedures

One station, consisting of one continuous longline, was fished per day. The vessel's captain was given the ending (i.e., deeper set position) position of each particular station in the AFSC longline survey and instructed to proceed seaward from this point and set the gear so that the first anchor would end up at a depth of approximately 1,000 m. The plan called for setting the gear perpendicular to the isobaths into progressively deeper water so that a range of depths > 1,000 m would be fished. The gear was set starting at about 0830 hr AST and retrieved at about 1230 hr. Gear retrieval for the various stations ended at between 1545 hr and 2100 hr and varied due to the depth fished, gear hang-ups on the bottom, and whether the groundline parted during retrieval. Electronic time-depth recorders were attached to the groundline at the end of first skate and at the beginning of the last skate to determine how long it took for the gear to sink to the bottom and the actual fishing time of the gear on the bottom.

Five stations were sampled 46-50 days after the corresponding stations in shallower water had been fished in the standard AFSC longline survey. However, the first station fished (Station 65a) was not valid for the purpose of our experiment because all the groundline was inadvertently set in depths < 1,000 m that were much shallower than we intended. This problem arose because the vessel's fathometer was not functioning properly on the first day of fishing. Therefore, on this day a bathymetric chart was used to determine the depth to set the gear, which ultimately proved to be very inaccurate. For information only, some of the results for Station 65a are presented in Tables 1-3. This station was later re-fished 4 days later in deeper water as Station 65b. After the first day, the vessel's fathometer worked correctly at the remaining stations.

During retrieval of the longline, one scientist was stationed at the vessel's rail to tally the species catch on a hook-by-hook basis using an electronic data logger ("Polycorder"). For hooks that did not catch fish, hook condition was tallied as "baited", "unbaited" (bare hook), or "missing, bent, broken, or tangled". This is the same system used in the AFSC longline survey. At the beginning of every fifth skate (skates 1, 5, 10, etc.), the captain provided the bottom depth to the scientist doing the recording so that the approximate depth of the catch could be determined.

All giant grenadier, Pacific grenadier (*Coryphaenoides acrolepis*), sablefish, and Pacific flatnose (*Antimora microlepis*) caught were brought aboard for sampling by the scientific party. The only exception was that sablefish caught at non-target depths < 1,000 m were released live at the rail to enhance their survival. For sampling, the fish were kept separate by 100 m depth strata (1,001-1,100 m, 1,101-1,200 m, etc.) to allow determination of possible differences by depth. Sex was determined for giant grenadier and sablefish only, and all four species were measured for length using an electronic barcode measuring board. Length measurement for grenadiers was to the nearest 1.0 cm pre-anal fin length (PAFL), from the tip of the snout to the beginning of the anal fin, whereas length measurement for sablefish and Pacific flatnose was to the nearest 1.0 cm fork length (FL). When giant or Pacific grenadier were especially common in the catch for a depth stratum, a random subsample was selected for the sex determinations/length measurements, and the remaining fish were discarded without sampling. A random subsample of giant grenadier was also selected at each station for age sampling. Individual weight was determined for each of the fish sampled for ageing using a Marel motion-compensating electronic scale, and the fish were measured for length, sexed, and otolith pairs were extracted and preserved in 50% ethanol. Age results are not available for inclusion in this report.

Analytic Methods

To determine differences between giant grenadier populations in deep- and shallow-water, catch rates, length distributions, and sex ratios of giant grenadier in depths > 1,000 m at the deep-water stations were compared with those at the corresponding stations in shallower water in the 2008 AFSC longline survey. Catch rates per skate of gear (45 hooks) were calculated by dividing the catch by the number of effective hooks. Like the AFSC annual longline survey, an effective hook was defined to be a hook that was not missing, bent, broken, or tangled. Skates of gear that had 10 or more ineffective hooks were omitted from the analysis because it was believed that this many ineffective hooks might be an indication that the entire skate was fishing incorrectly. An analysis of variance (ANOVA) was used to test for statistical differences in catch rates at deep and shallow depths at all stations, where depth category (AFSC longline survey < 1,000 m or experimental deep-water survey > 1,000 m) and station (65, 66, 67, or 68) were factors. For the comparison of catch rates, we only included data for depths 401-1,000 m from the AFSC longline survey because catch rates for giant grenadier diminish greatly in water < 401 m. Including these relatively shallow depths < 401 m would bias the comparison. Catch rates of Pacific grenadier could not be compared because none were caught on the AFSC longline survey at these stations.

For a comparison of lengths between deep and shallow-water for female and male giant grenadier, we pooled the length data for all four stations. This was necessary because there were not sufficient lengths taken by sex and station to analyze the station effect. A two-sample *t*-test was used to test for differences in mean lengths between fish sampled in shallow and deep depths for each sex. Before the *t*-tests were performed, an *F*-test was used to determine equality of variance for each data set. The sex ratios of grenadier giant were examined by depth and station.

A similar analysis was done to compare length distributions of Pacific grenadier in deep-water. However, because no Pacific grenadier were caught at stations 65, 66, 67, and 68 in the 2008 AFSC longline survey, a direct comparison for only these stations could not be done. Instead, all the Pacific grenadier sampled for length at stations in the western and central GOA in the AFSC survey were used for the comparison with the four stations in the deep-water experimental survey. Also, sex was not determined for Pacific grenadier on either survey, so a comparison was done for both sexes combined. An *F*-test was used to determine equality of variance between the two data sets and a two-sample *t*-test were used to determine the statistical significance of differences.

Data collected from the giant grenadier sampled for age were used to determine length-weight relationships for males, females, and sexes combined for depths > 1,000 m. The length-weight relationships were based on a non-linear, exponential regression equation:

$$W = aL^b,$$

where W is weight in g, L is PAFL in cm, and a and b are computed constants. This relationship was used to convert all the female lengths to weights so that average female weight could be calculated. For comparison, an average weight was also computed for females at stations 65-68 in the 2008 AFSC survey using a relationship determined for female giant grenadier at depths < 1,000 m (based on equation in Clausen 2008). This relationship is: $W = 0.527(PAFL^{2.597})$.

RESULTS

Five stations were fished from 6 to 10 August 2008 (Table 1; Figs. 1 and 2). The first station fished (65a) was inadvertently set in depths < 1,000 m so 4 days later station 65b was fished to sample in deeper water. Due to hang-ups, 17 skates were lost at station 65b and only 11 effective skates were hauled (Table 2). At the other deep-water stations, 41 or 44 skates were hauled. This was fewer skates than were set from 400 to 1,000 m at the corresponding AFSC longline survey stations (35-77 skates, Table 2). Depths sampled by the AFSC longline survey did not extend to 1,000 m at most station; two stations only sampled depths down to 435 and 574 m.

Complications with Fishing in Deep-water

Several problems were encountered in the deep-water survey which may be an indication of particular difficulties that can be experienced when longline gear is fished on the deep slope at depths greater than normally fished in Alaska: 1) At three of the four valid stations, the gear ended up at a position 1.4 - 1.7 nmi from where it was set, indicating a considerable drift. At only one station (68) did the gear show a shorter drift of 0.7 nmi. The drift was likely related to the drag in the water by the long buoylines. Also, it took the gear a relatively long time to sink to the bottom at these depths (Table 3), which increased the potential time it could be exposed to currents. Although we set the gear across the depth contours in an attempt to sample a range of depth strata, the longlines at each station ended up somewhat parallel to the contours. The most extreme case was Station 68, where the longline settled in a narrow depth range of only 1,400-1,495 m. 2) At two of the stations in deep-water (65b and 66), the gear experienced severe hang-ups on the bottom, which caused the longline to part. At one of these (65b), 17 skates and a time-depth recorder were lost as a result. This may be an indication of especially difficult fishing conditions on the deep slope; in the standard AFSC longline survey on the upper slope, gear hangs-up are not this frequent, and loss of gear is a relatively rare event. 3) At Station 66, data from the time-depth recorders indicated the gear began to drag along the bottom into deeper water about 30 minutes after the first time-depth recorder reached bottom. The second time-depth recorder never did stabilize at a depth after reaching bottom, which indicated the anchor at this end of the groundline was continually dragging along the bottom. Compared with the AFSC longline survey, this was highly unusual. It suggests the existence of strong currents that were enough to move the gear despite the 80 lb anchors at each end of the groundline.

The time-depth recorder data indicated that the sink rate of the gear varied considerably among stations and ranged from 12.0 to 21.9 m/minute (Table 3). However, the slowest sink rate of 12.0 m/minute may not be correct because it was based on data from the second time-depth recorder for Station 66. As noted previously, this time-depth recorder never stabilized at a depth and indicated the gear may have been dragging along the bottom, which made determination of an exact sink time difficult.

Catch Rates

Giant grenadier catch rates at the deep-water stations were significantly lower than those at corresponding shallower stations in the AFSC longline survey (two-factor ANOVA, $F(364, 4) = 47.09$, $p < 0.0001$; for both station and depth effects $p < 0.0001$). The effect of depth on catch rates did not depend on the station (i.e., the interaction term was not significant ($p = 0.544$)). The percentage of hooks in deep-water that caught giant grenadier was approximately half of that in shallow water (Table 2). For example, at station 66 the mean of hooks with giant grenadier was 15.7% in the deep-water survey and 37.3% in the AFSC longline survey. When the two stations where the AFSC longline survey (65 and 66) did not sample near 1,000 m were excluded, the results were consistent with the model that included all four stations (i.e, the ANOVA was still significant ($F(220, 2) = 40.13$, $p < 0.0001$, and both effects were significant, $p < 0.0001$).

The catch of Pacific grenadier was high at three stations (Table 2). This was particularly true for station 68, where Pacific grenadier were caught on 56% of the hooks, which indicates an extremely high abundance at this location. Pacific grenadier were not caught at corresponding stations in the AFSC longline survey (Table 2). Sablefish catch rates were moderate at the AFSC longline survey stations, but the catches dropped to near trace amounts at the deep-water stations. Pacific flatnose were rare in deep-water (0.2-3% of hooks at all stations) and non-existent at the AFSC longline survey stations.

Lengths

On average, female giant grenadier were larger than males at both the deep-water (Fig. 3) and shallow-water stations (Fig. 4). Both females and males were on average larger at the deep-water stations than at the AFSC survey stations in shallower water (Fig. 3, Table 4). This was especially true for females, which averaged 34.6 cm PAFL at the deep-water stations and only 28.7 cm PAFL at the AFSC longline survey stations. Very few females were longer than 35 cm in the AFSC longline survey stations, whereas many fish in this length category were caught in the deep-water survey. Similarly, relatively few females were < 30 cm PAFL in the deep-water survey, while females in this size category were common in the AFSC longline survey. This substantial difference in female size between deep and shallower water was consistent at each individual station (Fig. 5).

Similar to giant grenadier, lengths of Pacific grenadier were greater in the deep-water longline survey when compared with those sampled at the shallower depths of the AFSC longline survey (Fig. 6, Table 4). Sex was not documented for Pacific grenadier because the survey was not directed at studying this species, so comparisons are for both sexes combined. Pacific grenadier in deep-water (> 1,000 m) had a mean PAFL of 21.9 cm, while those in shallow-water averaged 19.9 cm. Very few Pacific grenadier <17 cm PAFL were found in the deep-water survey or the AFSC longline survey, which indicates that either small fish were not inhabiting the area sampled in the surveys or that the longline hooks are too large to catch smaller fish. The latter explanation seems most reasonable because Pacific grenadier as small as 8 cm PAFL have been frequently caught at depths 700-1,000 m in Gulf of Alaska trawl surveys[2].

The length distribution for Pacific flatnose in the deep-water longline survey may be the first available for the Gulf of Alaska, as this species is rarely caught at depths < 1,000 m. The largest fish measured in this study, 68 cm (Fig. 7), exceeds the maximum of 66 cm reported for this species in the most comprehensive guide to Alaskan fishes (Mecklenburg et al. 2002). However, another general guide to fishes of the northeast Pacific lists a maximum length of 75 cm for Pacific flatnose (Eschmeyer et al. 1983).

Very few sablefish (38 females and 10 males) were measured for length on the deep-water survey. This preliminary data indicates that female sablefish caught in deep-water were larger than those in shallow water (mean of 76.8 cm vs. 67.6 cm; Fig. 8). In the deep-water survey 37% of the female sablefish were ≥ 80 cm, whereas only 7% of the female sablefish caught on the survey were in this size range (Fig. 8). Data from the AFSC longline survey support this trend; large sablefish tend to be caught deeper than smaller fish in waters < 1,000 m (Hanselman et al. 2012).

Sex Ratios

Although female giant grenadier predominated at the deep-water stations, the percentage of males at these stations was much higher than at the corresponding shallower stations in the AFSC longline survey (Table 5). For example, at station 67 in the AFSC longline survey, where the maximum depth was 838 m, males made up only 2.5% of the giant grenadier catch. In contrast, at station 67 in the deep-water survey, with a depth range of 1,142-1,325 m, males comprised 19.2% of the catch. The highest percentage of males at any of these stations was 42.1% at station 68 in the deep-water survey, where all the groundline was at a depth of 1,400 m or greater.

Giant Grenadier Growth Curves

Length-weight relationships for giant grenadier in the deep-water experimental survey are shown in Figure 9 for male, female, and sexes combined. The overall mean female weight at the deep-water stations was 5.76 kg, and at the corresponding AFSC longline survey stations it was 3.41 kg. Thus, average weight of females at the deep-water stations was 69% higher than the average at the shallower stations of the AFSC longline survey.

[2] Unpublished data in the National Marine Fisheries Service, Alaska Fisheries Science Center's "RACEBASE" trawl survey data base, April 2010. Alaska Fisheries Science Center, Resource Assessment and Conservation Engineering Division, 7600 Sand Point Way NE, Seattle, WA 98115.

DISCUSSION

The relatively large catch rates of giant grenadier at each of the deep-water stations support our initial hypothesis that giant grenadier reside in depths > 1,000 m in the Gulf of Alaska. Although the catch rates were fairly high, they were all considerably lower than the comparable catch rates for giant grenadier at the corresponding stations in depths < 1,000 m in the 2008 AFSC longline survey. Therefore, our results suggest that peak density for giant grenadier may be at depths < 1,000 m, although catch rates were also substantial in deeper water. Pacific grenadier catch was high at these deeper depths (up to 56% of hooks at one station) and nil at depths < 1,000 m at corresponding stations in the AFSC longline survey.

One unexpected result of the study was the very large size of female giant grenadier at each of the deep-water stations. These females were significantly larger than those in shallower water at the corresponding stations in the AFSC longline survey. Additionally, Pacific grenadier and female sablefish were larger in the deep-water survey. These results are contrary to the only published information for Alaska on size of giant grenadier by depth (Clausen 2008), which was based on results of bottom trawl surveys in the GOA and the eastern Bering Sea. The trawl surveys generally showed a progressive decline in female size from shallow to deep-water. Thus, the results of our study, in contrast to Clausen (2008), agree with the so-called “bigger-deeper” trend for groundfish, which is also called “Heinke’s Law” after the early 20th century biologist who first noted that larger and older European plaice occur mostly in deeper water. The “bigger-deeper” trend appears to hold true for many deep-water fish (Merrett and Haedrich 1997). The reasons for the discrepancy in female size by depth between the data in our deep-water study and the trawl data are unknown, and further investigation is needed. However, it is likely not related to maturity because females in all stages of ovarian development were found at depths < 1,000 m in AFSC longline surveys in the Gulf of Alaska during the summers of 2004 and 2006 (Rodgveller et al. 2010).

Using the growth curve we estimated for female giant grenadier, the size difference in female giant grenadier between the deep-water stations and the corresponding stations in the AFSC longline survey is even larger when lengths are converted to weights, with deep-water females averaging 69% more in weight. This striking size difference may indicate a fundamental difference in the spatial population structure of female giant grenadier. A greater proportion of larger, more fecund females may resided below fishing depths in Alaska. Again, more experimental fishing in depths > 1,000 m is needed to confirm this hypothesis.

Results from the NMFS longline surveys at depths <1,000 m show that male giant grenadier make up a progressively larger percentage of the sex ratio with increasing depth, although females still greatly predominate overall (Rodgveller and Clausen 2012). Bottom trawl surveys in Alaska and trawl data from Russia have also shown greater numbers of males with depth (Novikov 1970, Clausen 2008). Our deep-water survey indicated the trend of increasing numbers of males with depth continued into waters deeper than 1,000 m, with males making up as much as 42% of the giant grenadier catch at one station. This latter percentage was greater than that at any of the individual stations sampled in the entire 2008 NMFS longline survey, and was even greater than the percentage for any particular depth stratum within these stations. Rodgveller and Clausen (2012) speculated that much of the male population of giant grenadier resides in depths > 1,000 m, at least during the summer when most surveys have occurred, and the results of our deep-water experimental survey support this hypothesis.

The giant grenadier abundance index, calculated using catch rates from the AFSC longline survey for depths < 1,000 m, may not adequately describe fluctuations of the entire grenadier population. The AFSC survey samples a portion of the population, but it does not sample as many male or large females as were seen at depths > 1,000 m. This should be considered when using this index for management or conservation purposes. Additionally, even though the catch rates at the deep-water stations were lower than those in the AFSC longline survey, because fish at the deeper depths were larger, the difference in biomass between shallow and deep may not be so great. Also, catch rates were considerably high at depths > 1,000 m, even though they were not as great as at depths < 1,000 m. An unknown factor in any speculation regarding abundance of giant grenadier, or other species in water deeper than 1,000 m in Alaska, is the area size of these depths. To evaluate potential abundance of giant grenadier in deep-water in Alaska, estimates of the bottom area for these depths need to be calculated.

From the limited data on sablefish lengths collected during the deep-water survey, female sablefish may be larger at depths > 1,000 m than depths < 1,000 m. In the western GOA, where the deep-water survey occurred, there were very few sablefish encountered deeper than 800 m in the AFSC and deep-water surveys. However, if sablefish are more abundant at depths > 1,000 m in other areas, biomass may be more substantial, especially if the fish at these depths are larger.

Because the deep-water survey occurred 47-50 days after the AFSC longline survey, it is possible that the results may reflect a change in their distribution or behavior during this period. However, it is likely that this temporal difference did not have a substantial effect on the results. The comparable stations in each survey were fished during the summer period, when most groundfish species off Alaska are believed to have a relatively stable distribution. A comparison of sablefish catch rates between the AFSC longline survey and the Japan-U.S. Cooperative Longline Survey found no significant difference due to timing of the surveys, even when the same stations were fished as much as 26 days apart in the same year (Zenger 1997). To investigate temporal differences in giant grenadier catch rates during the summer, we examined longline catch rates for giant grenadier from the sablefish commercial fishery in the western GOA for June versus July 2005-2011[3] (there was not enough data for August to include in the comparisons). The data were highly variable, and we found no significant difference in catch rates between months.

Extremely low catch rates for sablefish were found at each of the deep-water stations. These results were predictable because very low sablefish catch rates had been found at

[3] Based on data in the Alaska Fisheries Science Center's (AFSC) Fishery Monitoring and Analysis (FMA) Observer Database, July 2012. AFSC, FMA, 7600 Sand Point Way NE, Seattle, WA 98115.

the deepest stratum (801-1,000 m) sampled at western GOA stations in previous years of the AFSC longline survey. Thus, results of both the deep-water survey and the AFSC longline survey indicate biomass of sablefish is likely inconsequential at depths > 1,000 m in the western GOA. For future studies of giant grenadier and sablefish distribution in deep-water, we recommend sampling stations in the central GOA where sablefish may be more numerous at these depths.

Although this study sampled just four locations in the western Gulf of Alaska within the 1,000-1,600 m depth range, the results obtained were very consistent among stations. Giant grenadier catch rates declined with depth, but fish size increased. Additionally, Pacific grenadier were non-existent at the corresponding AFSC longline survey stations at depths < 1,000 m, but were abundant in deep-water. The results of this study are important because they provide data that was previously lacking in the literature about a suite of poorly understood deep-water species.

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Table 1. -- Haul positions of stations fished in the deep-water longline experimental survey in the western Gulf of Alaska, August 2008. Station numbers refer to standard stations fished in the AFSC longline survey in the same general vicinity, but in shallower water. Station 65a was inadvertently set in depths that were too shallow for this experiment, and it was subsequently re-fished in deeper water as Station 65b. Depth range refers to the absolute range of depths along the bottom for the portion of longline that contained hooks. Due to problems with the vessel's plotter, positions are estimated for Station 65b and for end longitude of Station 67.

		Start				End				Depth range (m)	
		Lat.	Lat.	Long.	Long.	Lat.	Lat.	Long.	Long.		
Station	Date	deg.	min.	deg.	min.	deg.	min.	deg.	min.	shallow	deep
65a	6-Aug-08	53	28.48	165	46.58	53	27.67	165	43.29	322	719
65b	10-Aug-08	53	31.27	165	27.31	53	28.83	165	28.79	795	1300
66	9-Aug-08	53	32.96	164	40.85	53	31.69	164	44.64	1445	1620
67	7-Aug-08	53	50.18	163	24.63	53	48.22	163	25.73	1142	1325
68	8-Aug-08	53	55.18	161	57.02	53	53.62	161	59.38	1400	1495

Table 2. -- Percentage of effective hooks with catch in a deep-water longline experimental survey in the western Gulf of Alaska, August 2008. For comparison, catch is also listed for depths 401-1,000 m at corresponding stations in the 2008 AFSC longline survey. Only effective skates, skates with fewer than 10 ineffective hooks, were included in the analysis.

			Catch rate (% of effective hooks with catch)				
Station	Effective skates	Depth range (m)	Giant grenadier	Pacific grenadier	Sablefish	Pacific flatnose	Other species[a]
			Deep-water Survey at Target Depths of > 1,000 m				
65b	11	1001-1300	27.3%	1.6%	0.2%	0.2%	0.2%
66	41	1445-1620	15.7%	20.7%	0.1%	1.7%	0.5%
67	44	1142-1325	24.0%	14.6%	2.0%	1.0%	0.3%
68	44	1400-1495	12.7%	56.1%	0.3%	3.0%	0.3%
			Deep-water Survey at Non-target Depths of <1,000 m				
65a	40	332-719	50.0%	0.0%	7.5%	0.0%	2.2%
65b	41	795-1000	25.9%	9.1%	0.7%	0.0%	0.8%
			AFSC Longline Survey at Depths 401-1,000 m				
65	35	401-435	49.5%	0.0%	15.1%	0.0%	n.a.[b]
66	62	401-574	37.3%	0.0%	20.8%	0.0%	n.a.[b]
67	77	401-838	41.7%	0.0%	6.8%	0.0%	n.a.[b]
68	58	401-945	37.3%	0.0%	8.0%	0.0%	n.a.[b]

[a]Other species in depths > 1,000 m included: shortspine thornyhead (*Sebastolobus alascanus*), arrowtooth flounder (*Atheresthes stomias*), skate unidentified (genus *Raja or Bathyraja*), coho salmon (*Oncorhynchus kisutch*), scarlet king crab (*Lithodes couesi*), *Chionoecetes* crab unidentified, and sea anemone unidentified.
[b]n.a. = not available.

Table 3. -- Time-depth recorder (TDR) data for the deep-water longline experimental survey in the western Gulf of Alaska, August 2008, showing the time it took for the TDR to reach bottom (sink time), the depth at which it reached bottom, the sink rate, and the total time on bottom. TDR location 1 indicates a TDR attached after skate 1 as the gear was set, and TDR location 2 indicates a TDR attached after skate 44 as the gear was set.

Station	TDR location	Sink time hr:mm:ss	Depth (m)	Sink rate (m/minute)	Time on bottom hr:mm:ss
65a	1	0:16:40	323	19.4	4:06:30
65b	2	0:59:00	868	14.7	3:32:20
66	1	1:17:40	1320	17.0	6:47:00[a]
66	2	2:09:30[b]	1554[b]	12.0[b]	5:58:20[b]
67	1	1:24:40	1173	13.9	2:58:10
68	1	1:06:40	1445	21.7	3:49:00
68	2	1:04:00	1400	21.9	4:34:30

[a]At this station, the groundline parted during initial retrieval, and it was then retrieved a second time. The result was that this TDR was on bottom for an initial period of time, came off bottom during the first retrieval, and then sank to the bottom again for a second period when the line parted. The time on bottom for this TDR is the sum of these two periods on bottom.

[b]The sink time, depth, sink rate, and time on bottom could not be precisely determined for this TDR because the gear appeared to be dragging down a slope. The values listed are best estimates.

Table 4. -- T-test results used to test for significant differences between lengths of male or female giant or Pacific grenadier from deep (> 1,000 m) and shallow-water (400-1,000 m) at five stations in the western Gulf of Alaska, 2008. The * denotes that the F-test was significant, variances between the deep- and shallow-water lengths are not equal, and a t-test assuming unequal variances is used. The ** denotes a statistically significant t-test statistic at $\alpha = 0.05$ for a two-tailed test.

species	sex	*t-value*	*df*	*p*	t-test
giant	Male	2.262	172	0.025**	equal variance
giant	Female	22.053	610	<0.001**	unequal variance
Pacific	both	14.974	932	<0.001**	unequal variance

		F-value	*df* shallow	*df* deep	*p*
giant	Male	1.462	21	151	0.156
giant	Female	2.890	766	435	<0.001*
Pacific	both	1.922	489	512	<0.001*

Table 5. -- Sex ratios of giant grenadier sampled in the deep-water longline experimental survey in the western Gulf of Alaska, August 2008. For comparison, sex ratios of giant grenadier are also listed for corresponding stations in the 2008 AFSC longline survey.

Station	Depth range (m)	Number sampled	% male giant gren.	% female giant gren.
Deep-water Survey at Target Depths of > 1,000 m				
65b	1001-1300	102	11.8%	88.2%
66	1445-1620	171	24.6%	75.4%
67	1142-1325	151	19.2%	80.8%
68	1400-1495	164	42.1%	57.9%
Deep-water Survey at Non-target Depths of < 1,000 m				
65a	332-719	54	0.0%	100.0%
65b	795-1000	133	20.3%	79.7%
AFSC Longline Survey				
65	122-435	197	6.6%	93.4%
66	138-574	206	1.9%	98.1%
67	78-838	201	2.5%	97.5%
68	136-945	185	0.0%	100.0%

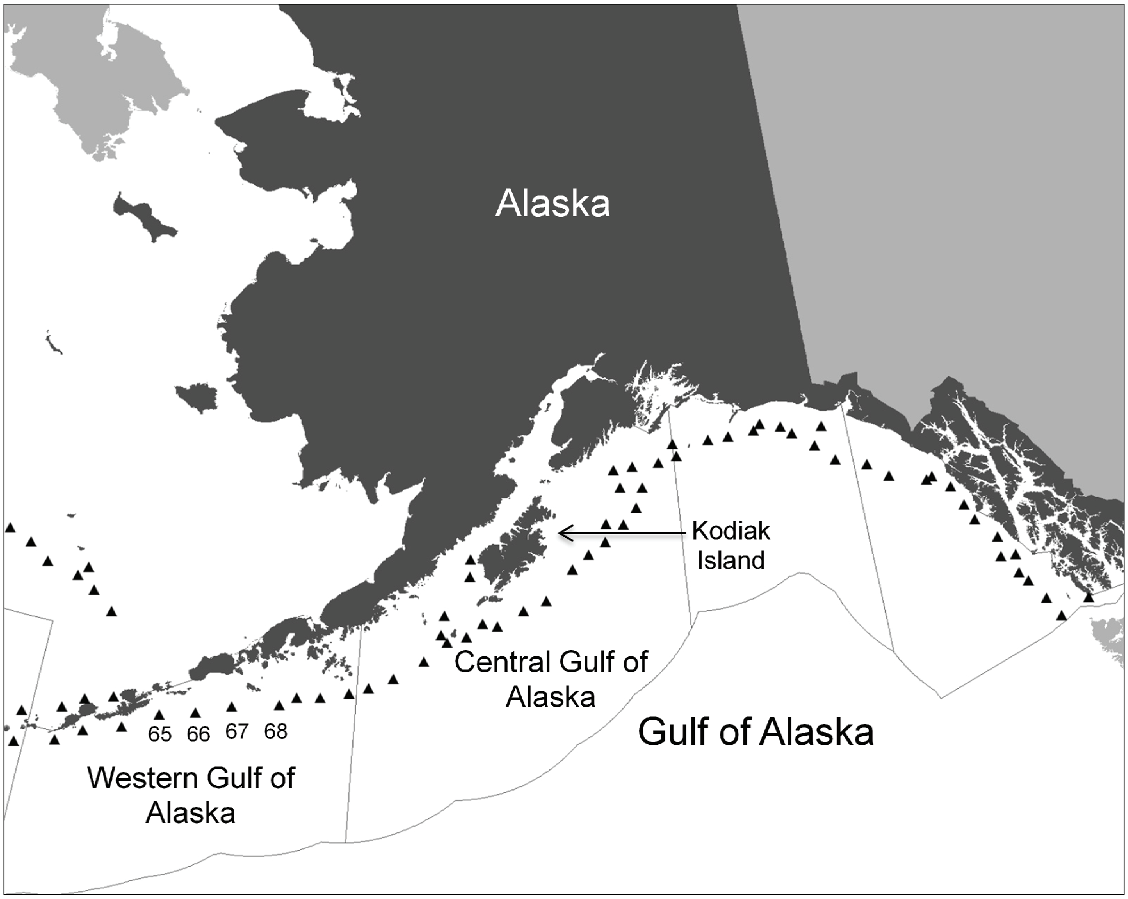

Figure 1. -- Fixed stations sampled annually by the Alaska Fisheries Science Center (AFSC) longline survey. Stations 65-58 were fished in the deep-water experimental longline survey. The AFSC survey stations also extend farther into the Bering Sea and Aleutian Islands.

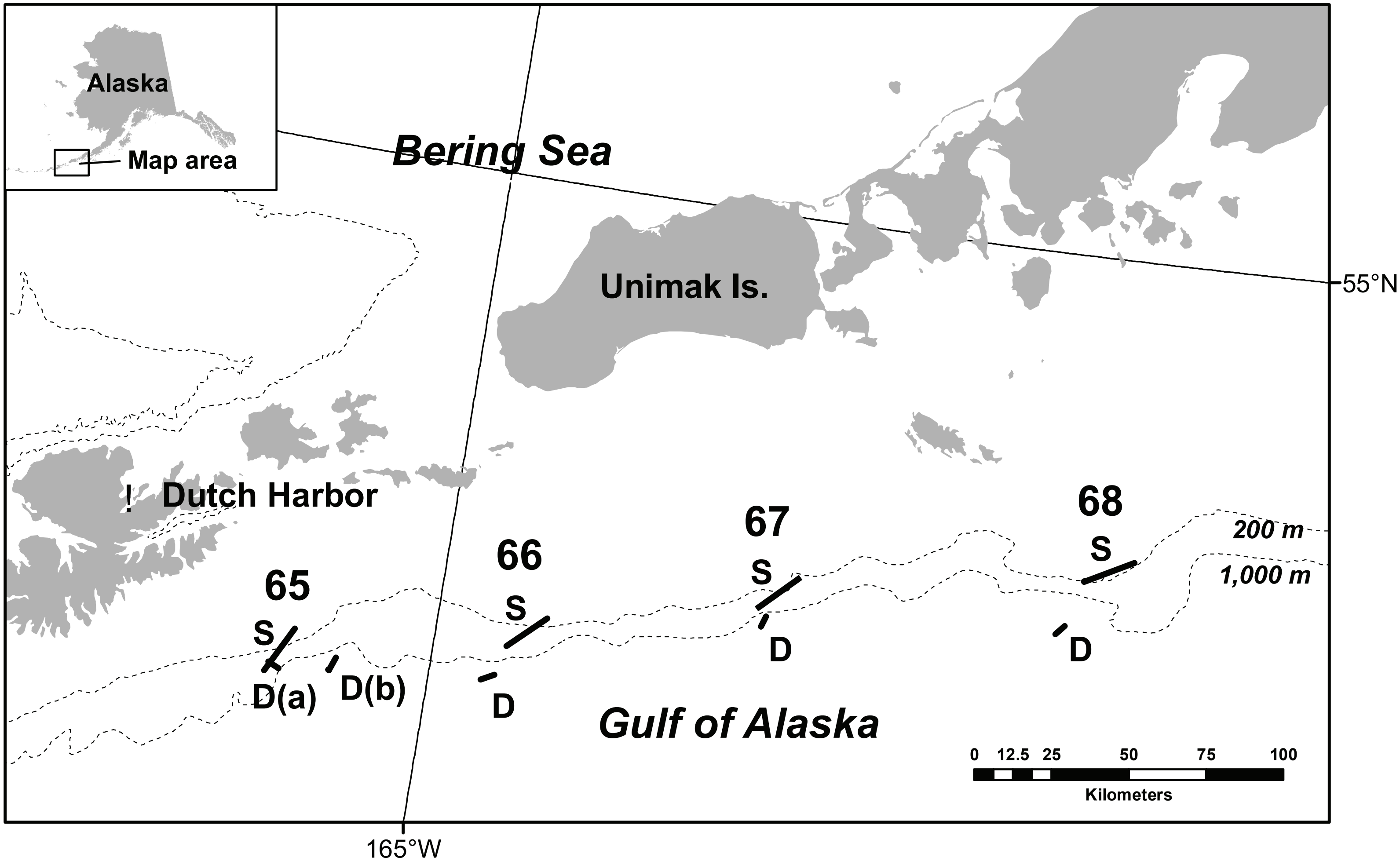

Figure 2. -- Location of stations fished in the deep-water longline experimental survey in the western Gulf of Alaska, August 2008. Deep-water stations are denoted by a “D”. Corresponding stations fished in the AFSC longline survey in 2008 are denoted by an “S”. Station 65 was fished twice in the deep-water survey. The first time, Station 65 was inadvertently set in water that was too shallow and is denoted “D(a)”. This station was later repeated at the proper depth in deep-water and is denoted “D(b)”.

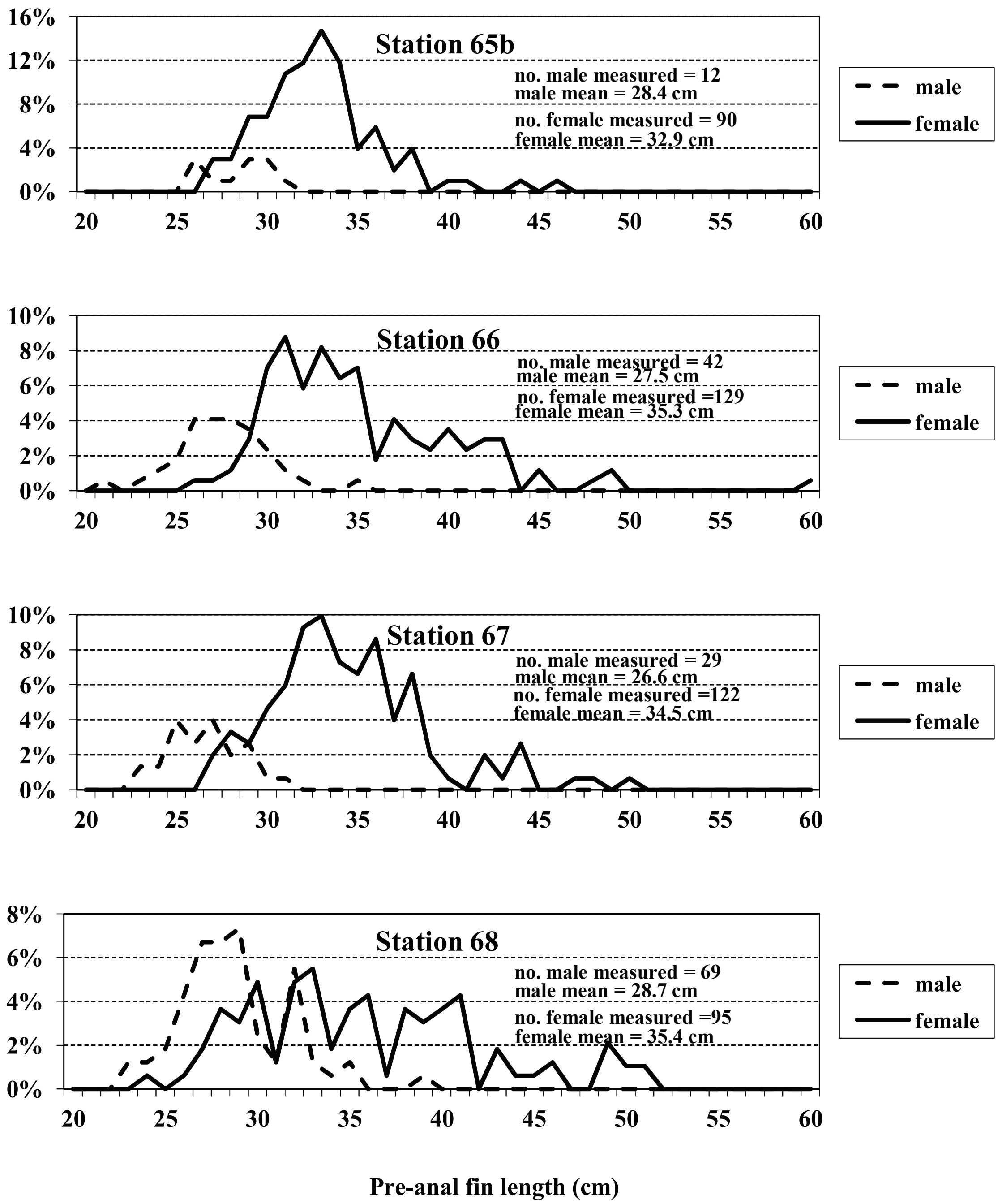

Figure 3. -- Length frequency distribution of male and female giant grenadier, by station, in the deep-water longline experimental survey in the western Gulf of Alaska, August 2008. Distributions shown are only for depths > 1,000 m.

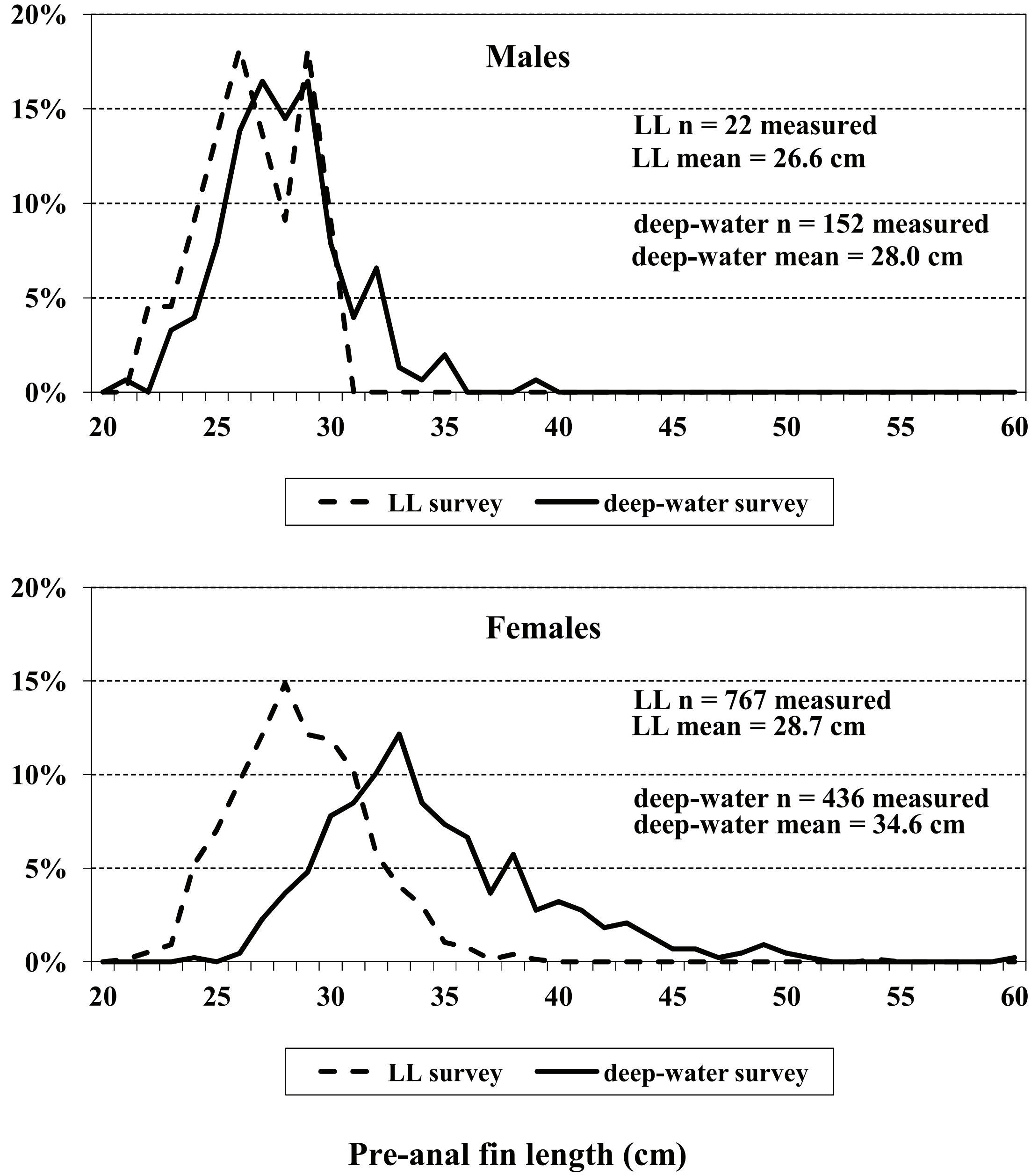

Figure 4. -- Comparison of length frequency distributions for giant grenadier between the 2008 AFSC longline survey (LL; depths <1,000 m) and the 2008 deep-water longline experimental survey (depths > 1,000 m) for stations 65, 66, 67, and 68 combined.

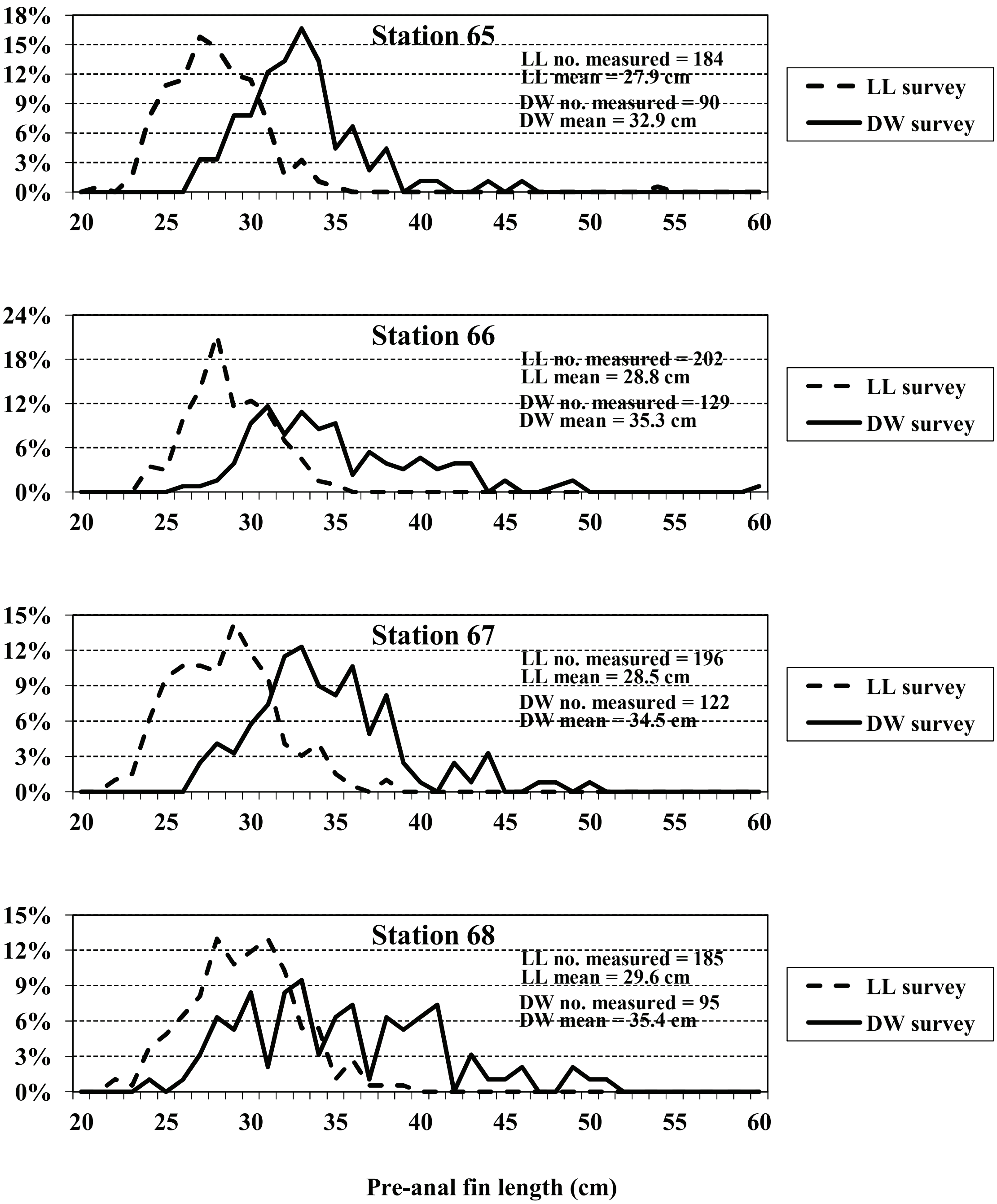

Figure 5. -- Comparison of length frequency distributions for female giant grenadier between the 2008 AFSC longline survey (depths <1,000 m) and the 2008 deep-water longline experimental survey (depths > 1,000 m) for stations 65, 66, 67, and 68. (LL = AFSC longline survey and DW = deep-water experimental longline survey).

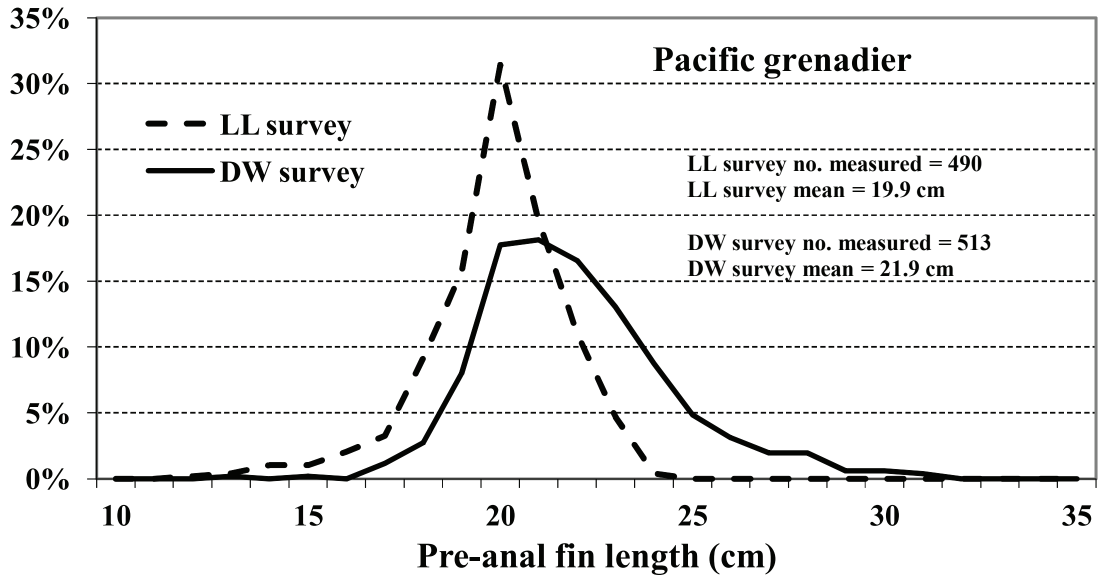

Figure 6. -- Comparison of length-frequency distributions for Pacific grenadier (sex not determined) between the 2008 AFSC longline survey (LL; depths <1,000 m) and the 2008 deep-water longline experimental survey (DW; depths > 1,000 m). Lengths for the AFSC longline survey are those measured at stations in the western and central Gulf of Alaska, and lengths for the deep-water survey are at stations 65, 66, 67, and 68 in the western Gulf of Alaska.

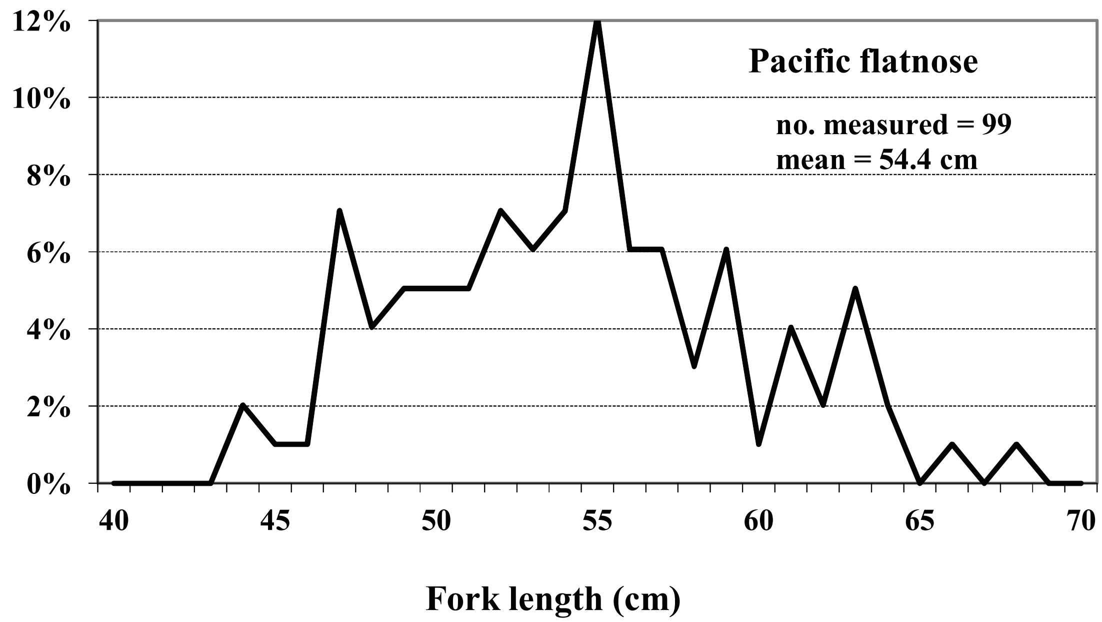

Figure 7. -- Length frequency distribution of Pacific flatnose in the 2008 deep-water longline experimental survey at depths > 1,000 m in the western Gulf of Alaska.

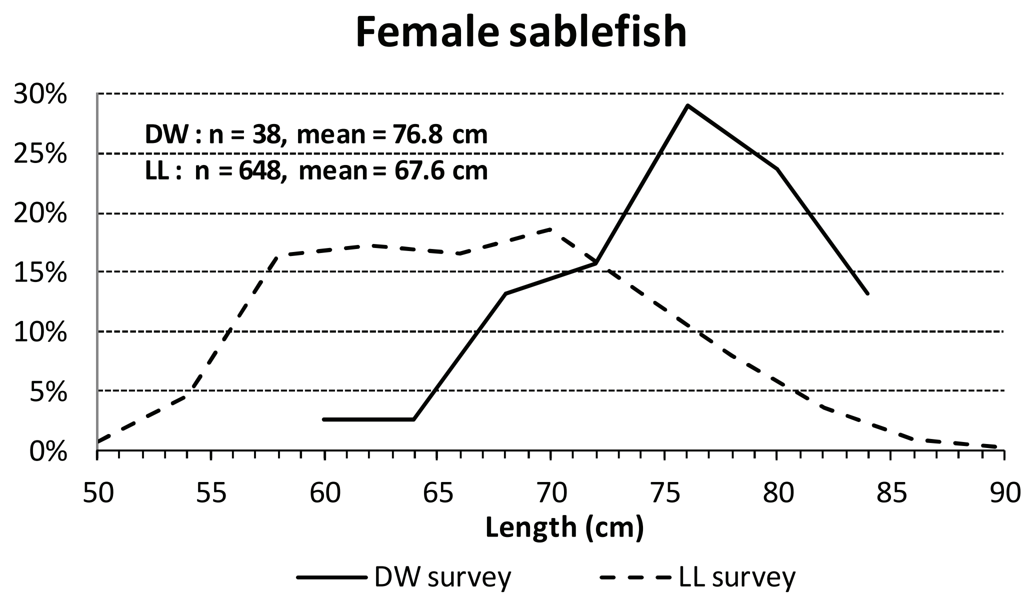

Figure 8. -- Comparison of length-frequency distributions for female sablefish between the 2008 AFSC longline survey (LL; depths <1,000 m) and the 2008 deep-water longline experimental survey (DW; depths > 1,000 m).

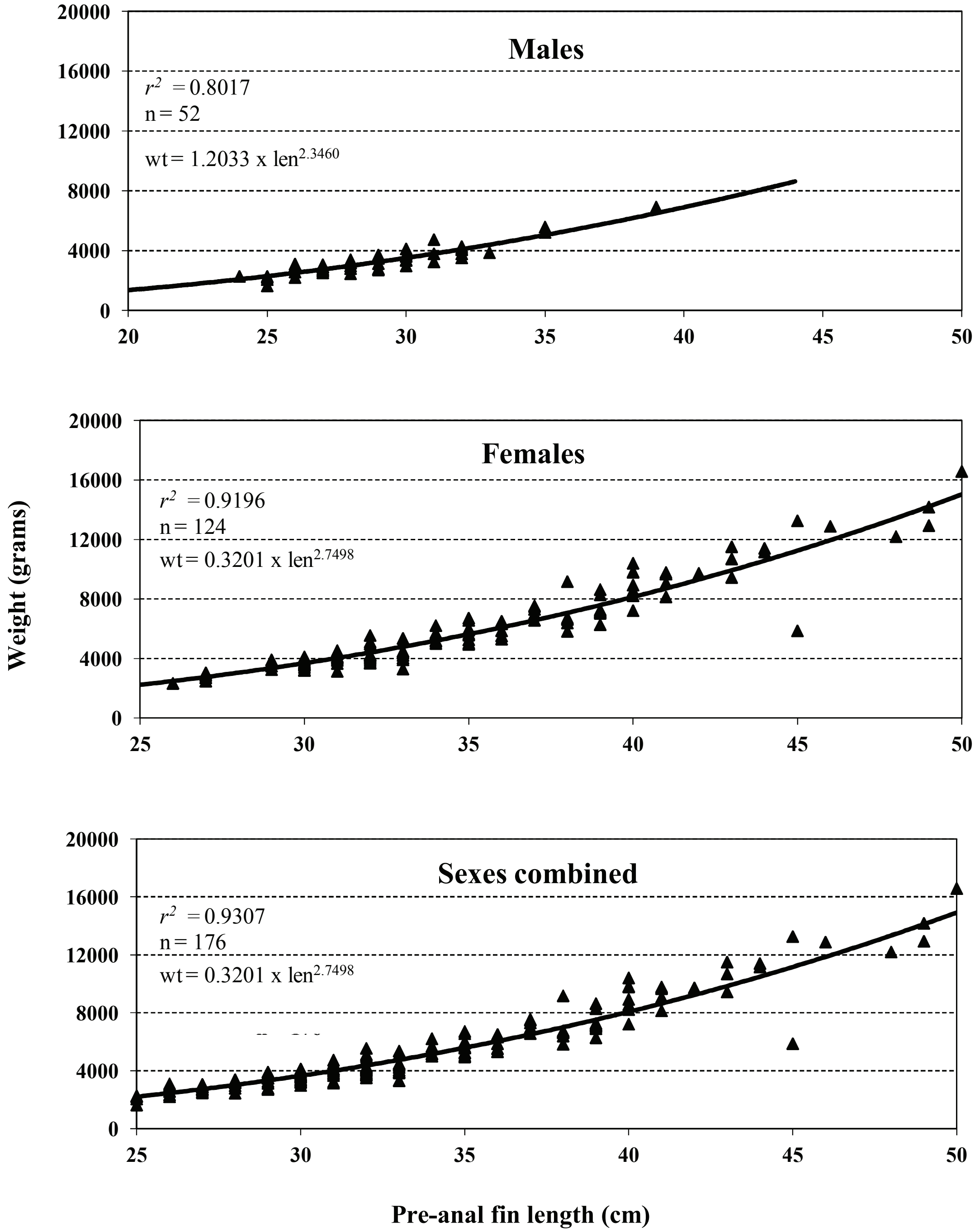

Figure 9. -- Length-weight relationships for giant grenadier sampled in the 2008 deep-water longline experimental survey in the western Gulf of Alaska. Only fish sampled in depths > 1,000 m are included. The non-linear least squares regression lines and equations are shown, as well as the observed values (triangles) for individual fish. (Note: one large female 65 cm pre-anal fin length was included in the regression calculations but is not shown on the plots.)

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