Evidence of hook competition in longline surveys

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Abstract—Catch rates from surveys are used as indices of abundance for many fish species. Relative abundance estimates from surveys with longline gear do not usually account for possible effects of gear saturation, which potentially creates competition among fish for baited hooks and misrepresentations of abundance trends. We examined correlations between catch rates of sablefish *(Anoplopoma fimbria)* and giant grenadier (*Albatrossia pectoralis*) and between sablefish and shortraker (*Sebastes borealis*) and rougheye rockfish (*Sebastes aleutianus*) from 25 years of longline surveys in Alaska waters for evidence of competition for hooks. Sablefish catch rates were negatively correlated with giant grenadier catch rates in all management areas in Alaskan waters, and sablefish and rockfish were negatively correlated in five of the six areas, indicating that there is likely competition for hooks during longline surveys. Comparative analyses were done for trawl survey catch rates, and no negative correlations were observed, indicating that the negative correlations on the longline surveys are not due to differing habitat preferences or direct competition. Available adjustments for gear saturation may be biased if the probability of capture does not decrease linearly with baited hooks. A better understanding of each fish species' catch probabilities on longline gear are needed before adjustments for hook competition can be made.

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Catches from longline surveys are used to estimate relative fish abundance for many benthic and pelagic fish species around the world, including: sablefish (*Anoplopoma fimbria,* Hanselman et al., 2006), Pacific halibut (*Hippoglossus stenolepsis,* Clark and Hare, 2006), Greenland halibut (*Reinhardtius hippoglossoides*, Woll et al., 2001; Murua and Cardenas, 2005), sharks (class Elasmobranchia, e.g., Musick et al., 1993; Kohler et al., 1998; Simfendorfer et al., 2002), red snapper (*Lutjanus campechanus*) and yellowedge grouper (*Epinephelus flavolimbatus*) (Cook, 2007), roughhead grenadier (*Macrourus berglax,* Murua and Cardenas, 2005), and many demersal fish species off the Azores Archipelago in the mid-Atlantic (Menezes et al., 2006). In these surveys, it is assumed that catch rate is proportional to abundance, and the probability of catching a fish remains constant even as the number of baited hooks decreases. However, several factors may affect this relationship. Water temperature (Sogard and Olla, 1998a, 1998b; Stoner and Strum, 2004) and feeding history (Løkkeborg et al., 1995; Stoner and Strum, 2004) affect the activity level and feeding behavior of sablefish. The area and strength of the scent plume surrounding bait can also affect the probability of capturing a fish (Løkkeborg et al., 1995). Additionally, in some cases longline gear may become saturated with fish, which potentially creates competition among fish for baited hooks (Murphy, 1960; Rothschild, 1967). Hook competition may reduce the probability of catching a fish as the number of baited hooks decrease, and factors such as temperature and feeding behavior may affect the rate of gear saturation and the intensity of competition for baited hooks.

The National Marine Fisheries Service (NMFS) Alaska Fisheries Science Center (AFSC) conducts annual longline surveys to estimate the relative abundance of major groundfish species in the eastern Bering Sea, Aleutian Islands, and the Gulf of Alaska (Sigler, 2000). The survey is primarily designed to assess sablefish and indices of abundance have been computed since 1979. Recently, catch rates of other groundfish species, such as giant grenadier (*Albatrossia pectoralis*) (hereafter grenadier), and shortraker (*Sebastes borealis,* Clausen, 2006a, 2006b) and rougheye rockfish (*Sebastes aleutianus*, Shotwell et al., 2006), have also been used to assess population levels. Sablefish are the dominant species caught on the longline surveys and most reside in the ~200–1000 m depth range (Sigler, 2000). Sablefish depth range overlaps those of the grenadier (>300 m) and shortraker and rougheye rockfish (~250–500 m), indicating that these species could potentially be competing with sablefish for longline hooks. Also, experimental evidence indicates that sablefish are adept at finding baited hooks on the longline surveys, even when few

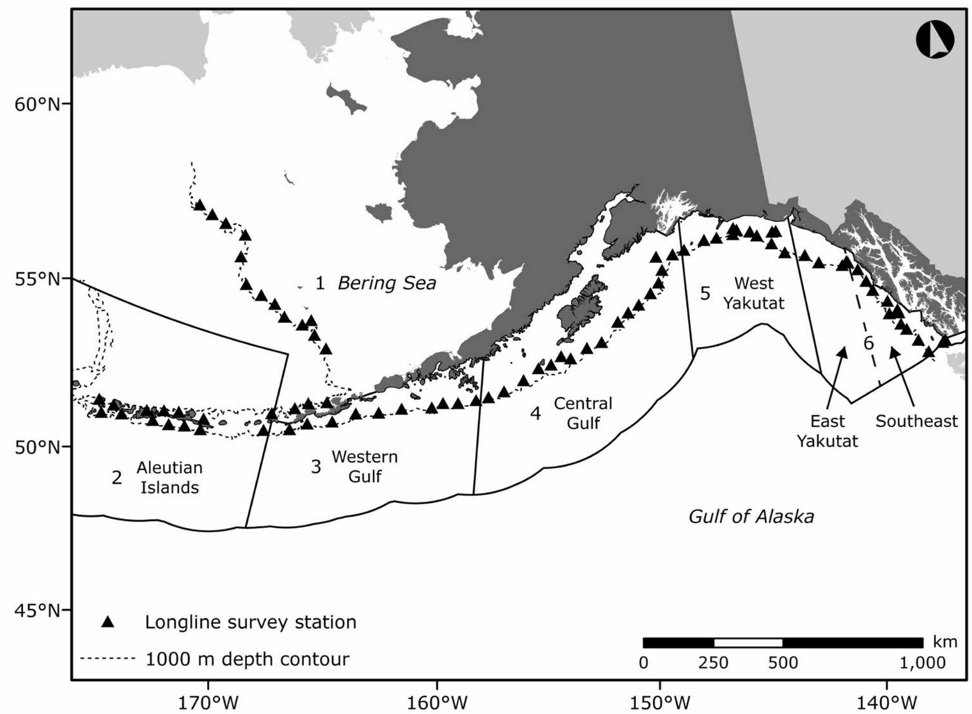

Figure 1

Stations sampled (▲) during the annual National Oceanic and Atmospheric Administration Alaska Fisheries Science Center (AFSC) sablefish (*Anoplopoma fimbria*) longline surveys, 1979–2003 within the six sablefish management areas (1–Bering Sea, 2–Aleutian Islands, 3–Western Gulf of Alaska, 4–Central Gulf of Alaska, 5–West Yakutat, and 6–East Yakutat and Southeast [Alaska]). The AFSC Gulf of Alaska slope trawl survey stations (not shown) are also located along the continental slope above the 1000-m isobath.

remain (Sigler, 2000). Therefore, it is more likely that sablefish are outcompeting grenadier and shortraker and rougheye rockfish for hooks.

Negative correlations between catch rates of two species could be evidence of gear saturation, or could be caused by other factors such as differing habitat preferences or direct competition between species. If the cause of negative correlations is competition for hooks, catch rate trends or depth distribution shifts could be confounded. Additionally, it may not be possible to evaluate the effects of factors such as habitat and other environmental variables until competition effects are taken into account. For this study, we examined the correlations between sablefish and grenadier and between sablefish and shortraker and rougheye rockfish to identify any negative relationships on the longline surveys. We also compared correlations of catch rates from the longline surveys to correlations of catch rates from the AFSC bottom trawl surveys in the Gulf of Alaska to investigate the cause of the relationships on the longline surveys (Britt and Martin, 2001). Because trawl survey catches are not generally susceptible to gear saturation, catches are a reflection of natural fish densities and therefore a good control to compare to longline catch rates (Gunderson, 1993). Although feeding history, water temperature, and other variables could affect the strength of competition between sablefish and grenadier and between sablefish and shortraker and rougheye rockfish, we were unable to control for these variables in this analysis.

Materials and methods

Sampling

AFSC longline surveys The continental slope throughout the eastern Bering Sea, the eastern Aleutian Islands, and the Gulf of Alaska have been systematically sampled each summer since 1979 during the annual AFSC longline surveys. The survey is divided among six sablefish management areas: 1) Bering Sea; 2) Aleutian Islands; 3) Western Gulf of Alaska; 4) Central Gulf of Alaska; 5) West Yakutat; and 6) East Yakutat and Southeast (Alaska). Stations are placed 30–50 km apart and at each station depths from 150 to 1000 m are sampled (Fig. 1). Catches are pooled by management area and an abundance index is computed (Sigler, 2000). The gear on the survey closely resembles gear used by the sablefish fishery in Alaska. The basic unit of gear is a skate; each skate consists of 45 hooks, baited with squid, spaced 2 m apart. At the end of each skate a 3-kg lead ball is attached to ensure the gear is fished on the bottom. Each station consists of 160 skates set across depth contours from 150 to 1000 m. At each station there are 7200 hooks set over 16 km. The objective of the setting pattern is to evenly distribute sampling effort over the depths that sablefish inhabit. Gear retrieval begins after the gear has soaked for 3 hours, and fish and baited hooks are counted as they are brought aboard. Catch rates are tabulated as the number of fish of each species per skate of gear (no. fish/45 hooks). Bottom depth is recorded every five skates as the gear is hauled. Interpolated depths are assigned to skates that do not have a recorded depth.

Shortraker and rougheye rockfish catches were pooled for this analysis because they are not distinguished from one another during gear retrieval. These species are very similar in appearance and difficult to distinguish, share the same habitat on the upper continental slope, and often are found in fishery hauls (Clausen and Fujioka, 2005). In this article we will refer to both species as rockfish.

AFSC trawl surveys The AFSC groundfish trawl surveys sample the continental shelf and upper continental slope of the Gulf of Alaska at depths to 500 m, and in some years as deep as 1000 m, during the summer (Britt and Martin, 2001; Fig. 1). The surveys follow a stratified random sampling pattern with 49 strata that are categorized by depth, geological area (e.g., gully, slope), and management area (i.e., latitude and longitude). Trawls are hauled at a vessel speed of 3 knots for 15 minutes, or in some years, for 30 minutes, and tows are conducted along a constant bottom depth. An average depth is assigned to each trawl haul. All fish caught on the surveys are enumerated and a catch rate is calculated by dividing the number of fish caught by the area swept by the net (no. fish/km^2).

Analysis

Longline correlations Average catch rates from the 1979–2003 annual longline surveys were calculated by 50-m depth increments to determine the preferred depth range for grenadier and rockfish in each sablefish management area. Analyses were done separately by management area because preferred depth ranges and catch rates have differed in each area for each fish species. The preferred depth ranges of grenadier and rockfish in each area were defined as the range where the average catch rate, in all years, was at least 20% of the highest catch rate. This method resulted in disregarding depths where the catch rate was less that 20% of the average peak catch rate. Our intention was to consider only depths where grenadier or rockfish were prevalent. An average catch rate was then calculated for the preferred depth range for grenadier and rockfish in each management area in each year at each longline survey station. Catch rates were also calculated for sablefish in the grenadier and rockfish preferred depth ranges so that sablefish catch rates could be compared to grenadier and rockfish catch rates. Preferred depth ranges were calculated from longline survey catch rates instead of trawl survey catch rates because there is little fishing effort below 500 m on the trawl surveys. In addition to calculating the average catch rate for the whole preferred depth range, we also calculated the average catch rate by 50-m increments within the preferred depth range in order to make more fine-scale species comparisons.

Before tests for statistical significance, catch rates were transformed by using natural logarithm, square root, or fourth root transformations to help meet assumptions of normality. Pearson's correlation coefficients and tests of significance were calculated. Catch rates calculated as catch per skate did not meet the assumptions of normality due to a prevalence of zeros. Therefore, average catch rates of the preferred depth range by station were used to calculate correlation coefficients.

Longline versus trawl correlations Because longline and trawl data are collected at the same time, areas, depths, and from the same habitats, trawl correlations are a good comparison for longline correlations. In the trawl data, a positive or zero correlation indicates that species do not have differing habitat preferences and that the species do not directly compete with each other. A negative correlation on longline gear and a positive or zero correlation in trawl gear would indicate that the negative correlations in longline gear could be caused by hook competition and not by these other factors.

Trawl catch rates were computed for each haul for each species in each year the trawl surveys occurred (1984, 1987, 1990, 1993, 1996, 1999, 2001, 2003, and 2005). Because depth ranges varied throughout the Gulf of Alaska, the entire depth distribution of grenadier and rockfish throughout the Gulf of Alaska was included in this analysis. The depth distribution was rounded to the nearest 50 m because longline survey catches were already summarized by 50 m increments. For grenadier the range was 300–700 m and for rockfish the depth range was 250–550 m. Catches deeper than 700 m were not included because of the limited trawl survey effort below this depth. Trawl catch rates were also transformed to help meet the assumptions of normality. In one case, namely for the rockfish trawl data, the data could not be transformed to fit a normal distribution, but the transformation was retained because it aided in the visual analysis of the data. In this instance, nonparametric correlation tests, Spearman's ρ and Kendall's τ, were used to calculate correlation coefficients and to test for significance. Longline catch rates were summarized to be comparable with trawl catch rates; average catch rates were computed for the same depth ranges and years at each station.

Results

Longline catch rates by area

Preferred depths of grenadier and rockfish differed by management area (Table 1). Peak catch rates also dif-

Table 1

Preferred depth ranges (m) and average peak number of fish caught per 45 hooks (one skate of gear) for giant grenadier (*Albatrossia pectoralis*) (grenadier) and rockfish (shortraker [*Sebastes borealis*] and rougheye [*Sebastes aleutianus*] rockfish) caught during the National Oceanic and Atmospheric Administration Alaska Fisheries Science Center annual longline surveys in the six management areas, 1979–2003. Preferred depth range is defined as the range in which the catch rate was at least 20% of the average peak catch rate (peak catch).

	Grenadier		Rockfish	
Area	Preferred depth (m)	Peak catch	Preferred depth (m)	Peak catch
Bering Sea	350–1000	5.3	250–550	1.0
Aleutian Islands	400–1000	9.8	250–500	4.1
Western Gulf	400–1000	14.4	250–450	2.8
Central Gulf	350–1000	8.8	300–500	1.8
West Yakutat	350–1000	5.5	250–500	4.2
East Yakutat and Southeast	550–1000	3.5	300–600	4.8

Table 2

Average number of giant grenadier (*Albatrossia pectoralis*) (grenadier) and rockfish (shortraker [*Sebastes borealis*] and rougheye [*Sebastes aleutianus*] rockfish) caught per 45 hooks (one skate of gear) in their preferred depth range in each management area during the National Oceanic and Atmospheric Administration Alaska Fisheries Science Center annual longline surveys, 1979–2003. Preferred depth range is defined as the range in which the catch rate was at least 20% of the average peak catch rate. The average sablefish (*Anoplopoma fimbria*) catches (SB catch) and the average number of baited hooks retrieved in the preferred depth ranges are also shown. Total catch is the sum of the average number of grenadier and sablefish caught per skate or the sum of the average number of sablefish and rockfish caught per skate. Catches and baited hooks are an average from 1995 through 2003 because baited hooks were not counted before 1995.

	Grenadier				Rockfish			
Area	Grenadier catch	SB catch	Baited hooks	Total catch	Rockfish catch	SB catch	Baited hooks	Total catch
Bering Sea	6.6	3.9	14.9	10.5	3.5	8.6	18.9	12.1
Aleutian Islands	15.2	5.0	7.9	20.2	4.3	3.0	9.0	7.3
Western Gulf	18.1	6.4	7.2	24.5	3.0	9.2	4.0	12.2
Central Gulf	9.1	10.5	9.1	19.6	1.4	8.4	10.2	9.8
West Yakutat	3.8	10.6	15.3	14.4	4.3	5.5	19.8	9.8
East Yakutat and Southeast	3.1	11.3	17.9	14.4	3.3	9.5	16.4	12.8

fered substantially by species in each area. For example, in the East Yakutat and Southeast area the preferred rockfish depth range was 300–600 m and the peak catch rate was 4.8 fish/45 hooks, but in the Western Gulf area it was 250–450 m and the peak catch rate was 2.8 fish/45 hooks. The highest grenadier catch rates occurred in the Western Gulf area and were also relatively high in the Central Gulf and the Aleutian Islands areas. The highest rockfish catch rates were in the East Yakutat and Southeast area, West Yakutat, and the Aleutian Islands areas (Table 1).

The number of baited hooks retrieved was similar at grenadier and rockfish preferred depths in each area; however, in the Aleutian Islands, Western Gulf, and Central Gulf areas, the total number of sablefish and rockfish caught at rockfish preferred depths was less than the number of sablefish and grenadier caught at grenadier preferred depths (Table 2). This finding indicates that there were many fish species other than sablefish and rockfish caught at rockfish preferred depths than at grenadier preferred depths.

Longline correlations

In 11 out of 12 cases, there were significant negative correlations between sablefish and grenadier and between sablefish and rockfish catch rates. The correlations between sablefish and grenadier catch rates were negative in all six management areas. Correlations between sablefish and rockfish catch rates were negative in five of the six management areas (Table 3). Sample sizes varied between grenadier and rockfish in some areas because,

Table 3

Correlations between longline catch rates of giant grenadier (*Albatrossia pectoralis*) (grenadier), sablefish (*Anoplopoma fimbria*), and rockfish (shortraker [*Sebastes borealis*] and rougheye rockfish [*Sebastes aleutianus*] combined) caught during the National Oceanic and Atmospheric Administration Alaska Fisheries Science Center annual longline surveys in the six management areas, 1979–2003. The Pearson's correlation coefficient (r) and the P-value associated with the significance of the correlation (P) is shown as well as the sample size (n).

	Grenadier-Sablefish			Rockfish-Sablefish		
Area	*r*	*P*	*n*	*r*	*P*	*n*
Bering Sea	–0.23	0.0006	243	–0.31	<0.0001	243
Aleutian Islands	–0.37	<0.0001	264	0.03	0.6626	264
Western Gulf	–0.38	<0.0001	243	–0.27	<0.0001	243
Central Gulf	–0.36	<0.0001	375	–0.22	<0.0001	368
West Yakutat	–0.38	<0.0001	200	–0.28	<0.0001	200
East Yakutat and Southeast	–0.46	<0.0001	269	–0.43	<0.0001	400

Table 4

Strongest correlations between giant grenadier (*Albatrossia pectoralis*) (grenadier) and sablefish (*Anoplopoma fimbria*) catch rates and between rockfish (shortraker [*Sebastes borealis*] and rougheye [*Sebastes aleutianus*] combined) and sablefish catch rates by 50-m depth increments. Data were collected during the National Oceanic and Atmospheric Administration Alaska Fisheries Science Center annual longline surveys, 1979–2003. The Pearson's correlation coefficient (r), the P-value associated with the significance of the correlation (P), and the sample size (n) are reported. n is often larger for rockfish because in some years the deeper areas, where grenadier reside, were not sampled at each station. Catch rates from the Bering Sea for giant grenadier and sablefish could not be transformed to fit a normal distribution; therefore, no data are presented.

	Grenadier-Sablefish				Rockfish-Sablefish			
Area	Depth (m)	*r*	*P*	*n*	Depth (m)	*r*	*P*	*n*
Bering Sea					350–400	–0.35	<0.0001	199
Aleutian Islands	750–800	–0.44	<0.0001	218	400–450	–0.09	0.1751	218
Western Gulf	450–500	–0.51	<0.0001	239	250–300	–0.31	<0.0001	244
Central Gulf	600–650	–0.51	<0.0001	356	300–350	–0.40	<0.0001	366
West Yakutat	700–750	–0.50	<0.0001	187	350–400	–0.35	<0.0001	199
East Yakutat and Southeast	600–650	–0.44	<0.0001	341	400–450	–0.53	<0.0001	393

at some stations in some years, gear was not set in the preferred depth range for grenadier or rockfish. For example, in the East Yakutat and Southeast area there were 269 station/year combinations for grenadier and 400 for rockfish because gear was not set deep enough for the preferred grenadier depth range at some stations in some years. At certain 50-m depth intervals, within the preferred depth range, correlations were more strongly negative than catch rate correlations for the entire preferred depth range (Table 4).

When sablefish catch rates were high, grenadier and rockfish catch rates were low, and vice versa on the longline surveys. To illustrate an example of these negative correlations, we plotted the transformed catch rates in the East Yakutat and Southeast area (Fig. 2). The 90% density ellipses demonstrated that the trend in the data was negative in both the sablefish and grenadier and sablefish and rockfish scatter plots. Raw, untransformed catch rates also illustrated that the trend between the catch rates was negative. As an example, grenadier and rockfish catch rates were plotted against sablefish catch rates in the East Yakutat and Southeast area (Fig. 3). In both figures, sablefish catch rates were high when grenadier or rockfish were low and vice versa.

When the catch rates of all the stations were averaged within a management area, the negative correlation was evident in the time series. For example, the time series of the average catch rates in the East Yakutat and Southeast area showed that grenadier and rockfish catch rates were higher than average when sablefish catch rates were lower than average and vice versa (Fig. 4). This trend was evident in all areas where there was a negative correlation.

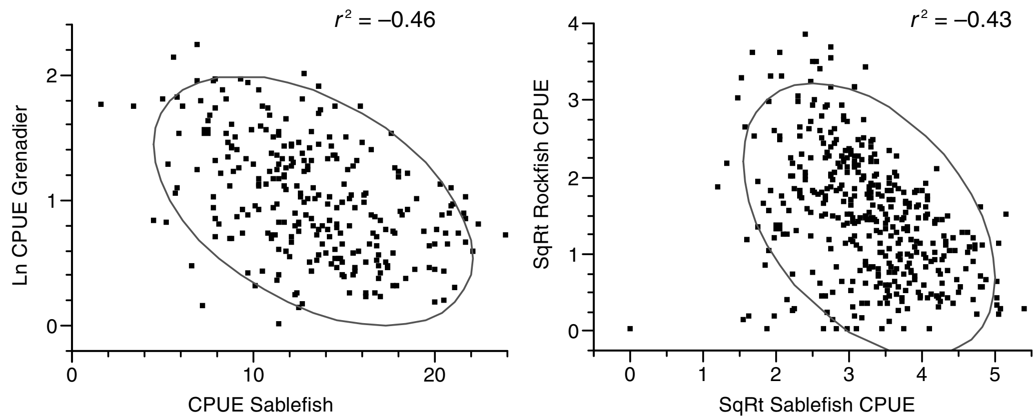

Figure 2

Scatterplots of grenadier (giant grenadier [*Albatrossia pectoralis*]) versus sablefish (*Anoplopoma fimbria*) catch rates and rockfish (shortraker [*Sebastes borealis*] and rougheye [*Sebastes aleutianus*] rockfish) versus sablefish catch rates from the National Oceanic and Atmospheric Administration Alaska Fisheries Science Center annual longline surveys, 1979–2003. Only data from the East Yakutat and Southeast management area are shown as an example. Each data point represents the average number of fish caught per 45 hooks (one skate of gear) at preferred depths at each station per year. Ninety percent density ellipses are included to demonstrate the trend of the relationship. Catch per unit of effort is abbreviated as CPUE. Data transformations are also abbreviated: square root (SqRt) and natural logarithm (Ln).

Table 5

Correlation coefficients (coefficient) between giant grenadier (*Albatrossia pectoralis*) (grenadier) and sablefish (*Anoplopoma fimbria*) catch rates and between rockfish (shortraker [*Sebastes borealis*] and rougheye [*Sebastes aleutianus*] combined) and sablefish catch rates in the Gulf of Alaska. Data were collected during the National Oceanic and Atmospheric Administration Alaska Fisheries Science Center Alaska longline and trawl surveys (1984, 1987, 1990, 1993, 1996, 1999, 2001, 2003, and 2005). The Pearson's correlation coefficient of the relationship between sablefish and either grenadier or rockfish is listed. The coefficients for nonparametric tests (Spearman's ρ and Kendall's τ) are listed for the rockfish and sablefish comparison in the trawl data because these data were not normally distributed. The *P*-value associated with the significance of the correlation tests are shown as well as the sample size (n). The sampling gear is specified as either longline (LL) or trawl (Trawl).

		Grenadier–Sablefish			Rockfish–Sablefish		
Gear	Test	Coefficient	*P*	*n*	Coefficient	*P*	*n*
LL	Pearson's	–0.45	<0.0001	327	–0.24	<0.0001	355
Trawl	Pearson's	0.51	<0.0001	249			
Trawl	Spearman's ρ				–0.08	0.1070	419
Trawl	Kendall's τ				–0.05	0.1102	419

Longline versus trawl correlations

When longline data were summarized in the same way as the trawl data, the correlations between sablefish and grenadier and sablefish and rockfish catch rates were significantly negative (Table 5), just as they were in the analyses that were stratified by sablefish management area. Scatter plots of the joint catch rates of sablefish and grenadier (Fig. 5A) and sablefish and rockfish (Fig. 5B) showed that when catch rates were low for grenadier and rockfish, they were high for sablefish, and vice versa. The 90% density ellipses illustrated the negative trend in the joint catch rates.

Correlation coefficients between sablefish and grenadier catch rates from the Gulf of Alaska trawl surveys were significantly positive and the correlations between sablefish and rockfish catch rates were not significantly different from zero. Because sablefish and rockfish catch rates within the rockfish preferred depth range could not be transformed to fit a normal distribution, nonparametric methods and tests of significances were used. Both the Spearman's ρ and Kendall's τ had the same result of no significance (Table 5).

Correlations between sablefish and grenadier or rockfish catch rates in trawl gear were either positive or not different from zero. A scatter plot of sablefish and grenadier catch rates showed that there were very few hauls when no sablefish or no grenadier were caught (Fig. 5C). It also demonstrated that when sablefish catch rates were relatively high, grenadier catch rates were high as well. The positive trend in the data is illustrated by the 90% density ellipse. However, the scatter plot of sablefish and rockfish catch rates (Fig. 5D) showed that there were three distinct groups of data: one where there were very few sablefish and many rockfish, one where there were few rockfish and many sablefish, and one where there were high catch rates of both species. The 90% density ellipse showed that the overall trend was neutral. The data for the sablefish and rockfish comparison in trawl gear did not conform to a normal distribution after the data were transformed, although the transformation was retained for ease in viewing the data.

Lengths of sablefish, grenadier, shortraker, and rougheye rockfish were similar in trawl and longline gear. Because large fish were caught by both types of gear, we can assume that both gears are catching adult cohorts of fish. Neither gear appears to be selecting only small juveniles (Fig. 6).

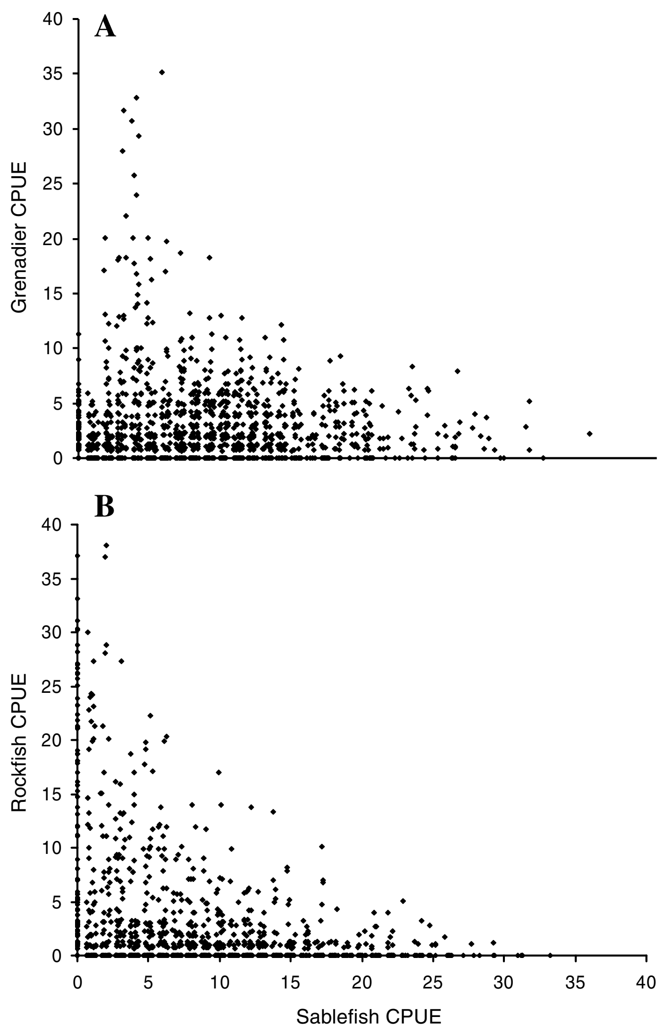

Figure 3

Untransformed catch rates, in number of fish caught per 45 hooks (one skate of gear), for (**A**) grenadier (giant grenadier [*Albatrossia pectoralis*]) versus sablefish (*Anoplopoma fimbria*) and (**B**) rockfish (shortraker [*Sebastes borealis*] and rougheye [*Sebastes aleutianus*] rockfish) versus sablefish caught during the National Oceanic and Atmospheric Administration Alaska Fisheries Science Center annual longline surveys from 1979–2003. Catch per unit of effort is abbreviated as CPUE. Because multiple data points coincide, a random number was added to each point so that they could be spread slightly to illustrate data point frequency. Only catches from the East Yakutat and Southeast management area from 2003 are shown as an example. Only preferred depths were included for grenadier (550–1000 m) and rockfish (300–600 m).

Discussion

Negative correlations on the longline surveys indicated that there was likely competition for hooks between sablefish and grenadier and also possibly between sablefish and rockfish. The catch rate correlations on longline gear between these species were negative in all six of the management areas, with the exception of the correlations for sablefish and rockfish in the Aleutian Islands. The comparison of longline and trawl catch rates in the Gulf of Alaska demonstrated that, in the same areas, depths, and habitats, the relationship between sablefish and grenadier and sablefish and rockfish catch rates on longline gear were negative, but positive for sablefish and grenadier, and neutral for sablefish and rockfish caught in trawl gear. The lack of negative correlations for trawl gear and the presence of negative correlations for longline gear indicated that longline gear was not catching these species in proportion to their abundance. The trawl comparison is important because trawl gear is thought to catch fish in proportion to their abundance, even if the gear may be size selective (Gunderson, 1993). Therefore, hook competition is likely the cause of the negative correlations between sablefish and grenadier catch rates and is also likely one of the factors causing negative correlations between sablefish and rockfish catch rates.

If the cause of the negative correlations on longline gear was due to differing habitat preferences or direct competition, the trawl correlations would also have been negative. In the trawl data, there were very few hauls when zero sablefish or grenadier were caught, demonstrating that sablefish and grenadier are found in the same habitats consistently. Additionally, the correlation between catch rates of these species in the trawl gear was positive, also indicating they both use the same habitats. Because catch rates from multiple fixed stations, where the same habitats are sampled each year in several geographic areas for 25 years, consistently show negative correlations, it is unlikely that the negative relationship is due to differing habitat preferences. For example, the time series of catch rates at all stations in the East Yakutat and Southeast area shows that grenadier and rockfish densities are above average when sablefish densities are below average and vice versa (Fig. 4). This result cannot be explained by differing habitat preferences because the same habitats were sampled each year.

Sablefish and rockfish catch rate correlations in the trawl gear showed that there may be three distinct habitat types at rockfish preferred depths, and that negative correlations on the longline surveys may be partially influenced by habitat preferences of sablefish and rockfish at these depths. However, although there appeared to be some different habitat preferences, relatively large numbers of both species were caught in most hauls. Also, nonparametric correlations of trawl catch rates were not significantly different from zero, indicating that any differences in habitat preferences were not great enough to cause negative correlations for the longline gear. Additionally, just as with sablefish and grenadier catch rate trends for longline gear, the rockfish catch rates were above average in years when sablefish were below average, and vice versa, even when the same habitats were sampled each year.

It is also unlikely that sablefish are directly competing with grenadier and rockfish, causing negative correlations. If this were true there would be negative correlations for the trawl gear as well as the longline gear. Also, if sablefish were pushing grenadier or rockfish out of their preferred depth range, grenadier and rockfish catch rates would increase at other depths when sablefish catch rates increased; however, this has not been observed. Or, if their population numbers were actually being depressed because of competition, it would likely take longer time periods for adult populations of long-lived fish species like grenadier and rockfish to rebound.

Although selective differences between longline and trawl gear for species and size have been reported for the Atlantic Ocean (e.g., Hovgard and Riget, 1992; Huse et al., 2000), both gear types caught adult cohorts in these studies. Although gear selectivity of longline and trawl gear in Alaska has not been compared in field studies, all four of the species analyzed in this article were caught in longline and trawl gear in significant numbers. Very few small fish are caught, indicating that both gears catch adult fish (Fig. 6). Moreover, this finding indicates that the same cohorts are being selected by both gear types. Therefore, correlation coefficients between these species in these gear types can be compared fairly.

Some environmental and fish specific variables, such as feeding history (e.g., Løkkeborg et al., 1995; Stoner and Strum, 2004) may affect the strength of the effect of competition for hooks; however, we could not address these variables. It is possible, however, that at warmer water temperatures fish would have greater metabolic demands and increased hunger, causing more intense competition if prey availability was similar in each scenario (i.e., at colder and warmer temperatures). It is likely that the ability of fish to locate bait and their hunger affects catch rates. To assess the effects of these variables on competition, more laboratory studies of fish behavior would be needed.

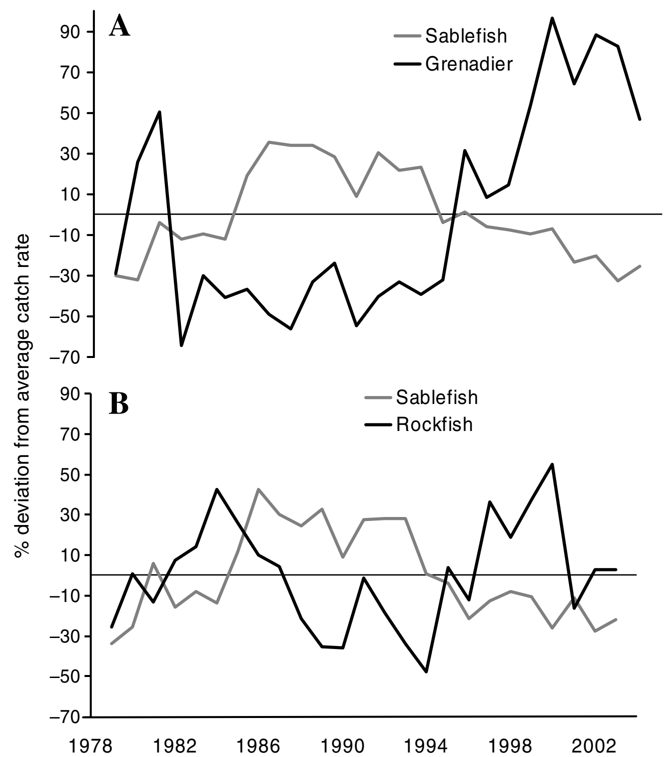

Figure 4

Percent deviation from the average catch rate of the time series for grenadier (giant grenadier [*Albatrossia pectoralis*]), rockfish (shortraker [*Sebastes borealis*] and rougheye [*Sebastes aleutianus*] rockfish), and sablefish (*Anoplopoma fimbria*) caught during the National Oceanic and Atmospheric Administration Alaska Fisheries Science Center annual sablefish longline surveys from 1979 to 2003. (**A**) includes only the grenadier preferred depths and (**B**) includes only the preferred rockfish depths. Data from the East Yakutat and Southeast management area are presented as an example. The lines that intersect the y-axis at 0 indicate the average catch rate; anything below this line is lower than average and anything above is higher than average.

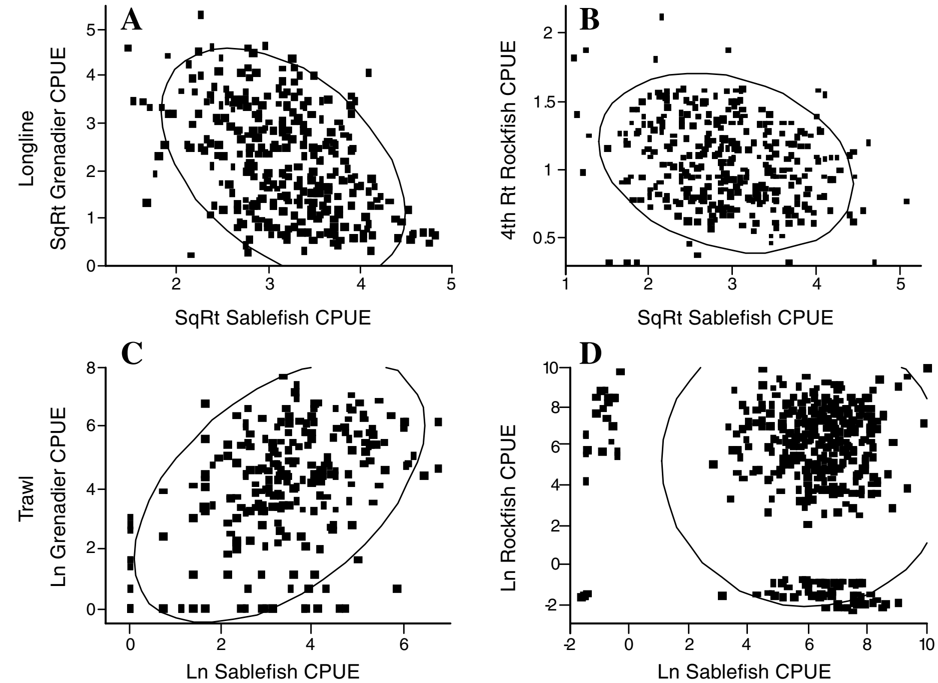

Figure 5

Scatterplots of catch rates from the National Oceanic and Atmospheric Administration Alaska Fisheries Science Center Gulf of Alaska longline and trawl surveys (1984, 1987, 1990, 1993, 1996, 1999, 2001, 2003, and 2005). (**A**) Plot of grenadier (giant grenadier [*Albatrossia pectoralis*]) and sablefish (*Anoplopoma fimbria*) catch rates on longline gear; (**B**) rockfish (shortraker [*Sebastes borealis*] and rougheye [*Sebastes aleutianus*] rockfish) and sablefish catch rates on longline gear; (**C**) catch rates of grenadier and sablefish from the trawl surveys; (**D**) rockfish and sablefish catch rates from the trawl surveys. Ninety percent density ellipses are included to demonstrate the trend. Catch per unit of effort is abbreviated as CPUE. Data transformations are also abbreviated: square root (SQRT), fourth root (4^{th} rt), and natural logarithm (LN).

Effects of competition on grenadier and rockfish catch rates will vary by area because of spatial abundance differences of these species and other groundfish. Negative correlations between sablefish and grenadier catch rates on longline gear varied with the density of sablefish, and the strongest negative relationships were found in the West Yakutat area and East Yakutat and Southeast area where sablefish catch rates and abundances were highest (Hanselman et al., 2006). Negative correlations between sablefish and rockfish catch rates were weaker than the correlations between sablefish and grenadier catch rates. Correlations between sablefish and rockfish catch rates were likely weaker because there were a variety of species caught in relatively large numbers in rockfish preferred depths, such as Pacific halibut (*Hippoglossus stenolepsis*), arrowtooth flounder (*Atheresthes stomias*), and Pacific cod (*Gadus macrocephalus*). In areas where there were many other species caught at preferred rockfish depths (Aleutian Islands, Western Gulf, and Central Gulf areas), the relationship between sablefish and rockfish catch rates was weaker than in other areas. Hence, sablefish and rockfish may compete with multiple species for hooks at rockfish preferred depths and dampen the direct competition with each other. The negative correlations at specific depths where grenadier or rockfish catch rates were highest were even greater than the negative correlations of the entire preferred depth ranges. This finding also shows that hook competition will vary depending on the depth, area, and possibly the abundance of the species of interest as well as other species.

As our data and data from other studies indicate, aggressive predators may out-compete other species for hooks on longline gear (e.g., Skud, 1978; Zenger and Sigler, 1992). For example, the proportion of Pacific halibut caught increased as hook spacing increased because when hooks were widely spaced and less abundant, Pacific halibut out-competed other species for baited hooks (Skud 1978). This experiment also indicates that halibut are caught in proportion to their abundance, while other less aggressive species may not be. Similarly, Zenger and Sigler (1992) and Sigler and Zenger (1994) reported that catches of shortspine thornyhead (*Sebastolobus alascanus*) and grenadier were low in areas where sablefish catches were high, and vice versa, during the AFSC sablefish longline surveys. They concluded that because sablefish are more mobile and aggressive, they are likely out-competing other species for baited hooks. If competition between less aggressive groundfish and more energetic predators like sablefish is occurring on the AFSC longline surveys, as our data indicate, catch rate trends may not be proportional to actual trends in fish densities.

Directed sablefish experiments have shown that the decrease in probability of catching a sablefish as the number of baited hooks decreases is not linear. However, in existing models where longline catch rates are adjusted for competition, this decrease is assumed to be linear (Murphy, 1960; Rothschild, 1967). In these models, when the number of recovered baited hooks is high, the magnitude of competition is low and model adjustments to catch rates are minimal. Conversely, as fewer baited hooks remain, competition increases, resulting in a greater need for model adjustments. Sigler (2000) documented the time until capture of sablefish on a hook-by-hook basis on longline gear and observed a nonlinear relationship between hooking probability and the number of baited hooks. The probability of hooking a fish remained constant until approximately half of the baited hooks were left; it then decreased steeply toward zero. This indicates that hook competition does not affect sablefish catch rates until fewer than 50% of the baited hooks remain, and that the decrease in hooking probability with a decrease in baited hooks is not linear. In another experiment, Sigler (2000) examined 12- to 42-m hook spacings that represented a condition of only 17% and 5% baited hooks remaining, respectively, and found that sablefish catch per hook decreased only 8%. The hook-spacing experiment showed that there is little decrease in catch probability, indicating that competition affects sablefish catch rates very little and also indicates that the decrease in catch probability does not decrease linearly to zero as the number of baited hooks decreases; it may decrease very slowly until very few baited hooks remain and then drop off quickly. If the effect of baited hooks on catch probability is not linear, as Sigler (2000) showed, results from the Murphy (1960) and Rothschild (1967) competition models used to adjust catch rates would be biased. Assuming a linear relationship, when it is in fact nonlinear, will underestimate relative abundance when fish densities are high, and will overestimate relative abundance when fish densities are low.

Competition for hooks likely occurs during the AFSC longline surveys. Both Skud (1978) and Sigler (2000) found that groundfish catch rates can be affected by hook competition; therefore it is likely that the catch rates of more docile groundfish, such as grenadier and rockfish, would also be affected. Currently gear saturation effects are not taken into account when relative population sizes of groundfish are calculated. Hook timing studies, such as Sigler's (2000), have not been directed at other species caught during the longline surveys. To accurately assess competition effects on grenadier and rockfish, directed experiments on hook spacing or with hook timers would be needed to develop alternate models of the relationship between catch probability and number of baited hooks.

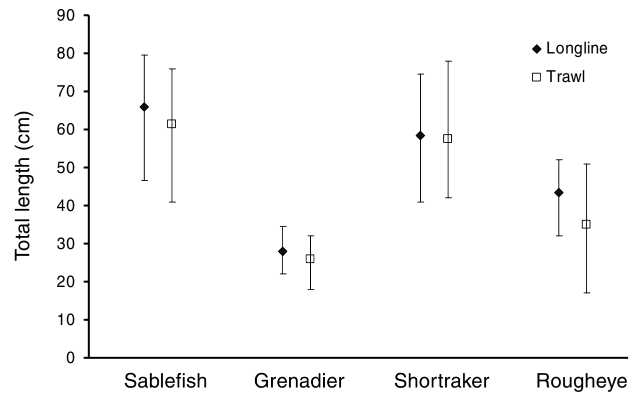

Figure 6

Average total length (cm) and associated 95% confidence intervals for sablefish (*Anoplopoma fimbria*), giant grenadier (*Albatrossia pectoralis*), shortraker rockfish (*Sebastes borealis*), and rougheye rockfish (*Sebastes aleutianus*) caught during the National Oceanic and Atmospheric Administration Alaska Fisheries Science Center longline and trawl surveys in 2003.

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