Estimation of discard mortality of sablefish (*Anoplopoma fimbria*) in Alaska longline fisheries

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Abstract—Sablefish (*Anoplopoma fimbria*) are often caught incidentally in longline fisheries and discarded, but the extent of mortality after release is unknown, which creates uncertainty for estimates of total mortality. We analyzed data from 10,427 fish that were tagged in research surveys and recovered in surveys and commercial fisheries up to 19 years later and found a decrease in recapture rates for fish originally captured at shallower depths (210–319 m) during the study, sustaining severe hooking injuries, and sustaining amphipod predation injuries. The overall estimated discard mortality rate was 11.71%. This estimate is based on an assumed survival rate of 96.5% for fish with minor hooking injuries and the observed recapture rates for sablefish at each level of severity of hook injury. This estimate may be lower than what actually occurs in commercial fisheries because fish are likely not handled as carefully as those in our study. Comparing our results with data on the relative occurrence of the severity of hooking injuries in longline fisheries may lead to more accurate accounting of total mortality attributable to fishing and to improved management of this species.

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For stock assessment, accurate accounting of discard mortality is important for estimating total mortality attributable to fishing. Studies of sablefish (*Anoplopoma fimbria*) and other fish species show that catch-related injuries can cause delayed mortality after a fish is discarded. For example, sablefish laboratory experiments have shown that the level of physical injury, reflex impairment, and behavior impairment may be useful proxies for delayed mortality (Davis, 2005; Davis and Ottmar, 2006). Pacific halibut (*Hippoglossus stenolepis*) with more severe hook injuries had increased mortality and reduced growth compared to those with less severe injuries (Kaimmer, 1994; Kaimmer and Trumble, 1998) and were visually impaired after exposure to simulated sunlight (Brill et al., 2008). For Atlantic cod (*Gadus morhua* L), injuries to the eyes, gills, and belly were more lethal than injuries to other anatomical parts (Pálsson et al., 2003). After release, Atlantic cod had inhibited activity for 4 days, during which there was potentially increased susceptibility to predation and delayed mortality (Neat et al., 2009).

A first step in estimating discard mortality is to estimate the proportion of fish that die after being discarded. Estimates of sablefish discard mortality rates and the derivation methods for determining these estimates vary regionally and by management agency. In the southeast Alaska sablefish stock assessment conducted by the Alaska Department of Fish and Game for state waters, a 25% discard mortality rate in the Pacific halibut longline fishery is assumed for sablefish (Dressel[1]). For both trawl and longline federal groundfish fisheries in Alaska, 100% mortality is assumed for all sablefish that are discarded (Hanselman et al., 2010). In the federal Pacific Coast sablefish stock assessment a much lower discard mortality rate of 10% is assumed for longline gear (Schirripa, 2008).

Sablefish support one of the most valuable fisheries in Alaska (Hiatt et al., 2010). The fixed gear fishery in

[1] Dressel, S. C. 2009. 2006 northern southeast inside sablefish stock assessment and 2007 forecast and quota. Fishery Data Series 09-50, 78 p. Alaska Dep. Fish Game, Anchorage, AK.

federal waters off Alaska is managed by a catch shares program, where annual individual fishing quota (IFQ) shares are allocated to fishermen, for fish that can be caught anytime during the eight and a half month season. For fishermen with IFQs, full retention of all sablefish caught is required. However, sablefish are often legally discarded in other commercial longline fisheries, primarily in those targeting Pacific halibut and Pacific cod (*Gadus macrocephalus*). In the sablefish fishery, the practice of releasing small sablefish and retaining only the larger fish because of the greater value per pound of larger fish (a technique known as "highgrading" [Davis, 2002]) is illegal. However, because there is an incentive to retain larger fish and not all fishing trips are monitored, highgrading may occur.

Factors affecting discard mortality likely vary by species, gear type, depth, and other environmental factors. Injury location on fish has proven to be an indicator of short and long-term discard mortality (e.g., Bartholomew and Bohnsack, 2005). In Alaska, sablefish inhabit a wide range of depths and are caught primarily on longline gear, which can cause external injuries to different areas of the body. Fish tethered to longline gear for extended periods are subject to predation by parasitic amphipod crustaceans. Also fish size may affect mortality of discarded fish. The objective of our study is to determine if the location and severity of the hook injury, line and roller gear injury, water depth, fish size, and the level of amphipod predation affect the discard mortality rate in Alaskan longline fisheries. To answer these questions, the recapture rates of fish tagged and released in the marine environment were related to each factor. In addition, an absolute discard mortality rate was computed on the basis of the observed severity of hooking injuries.

Materials and methods

Tagging and data collection

In 1989 and 1990, research surveys were conducted by the National Marine Fisheries Service (NMFS), Alaska Fisheries Science Center (AFSC) in Southeast Alaska. In 1989, sablefish were tagged during August and September in Chatham Strait; in 1990, sablefish were tagged during April and May in Clarence Strait (Fig. 1). Longline gear was fished on the bottom at depths from 210 to 419 m with a minimum 3-hour soak time. Gear configuration consisted of size 13/0 circle hooks baited with squid attached to 38-cm gangions that were secured to beckets tied in a 9.5-mm (3/8 in) groundline at 2-m intervals. This gear configuration is similar to that used in the commercial sablefish fishery in Alaska. However, the Pacific halibut fishery typically uses larger hooks (16/0). All sablefish, except those with extremely severe injuries, were tagged with plastic T-bar style anchor tags, and injuries were classified by the following 4 variables: location of hook injury, severity of hook injury, severity of injuries due to amphipod predation, and the presence of injury sustained on fins or body from line and roller gears. Within each variable, a categorical condition code describing the injury was recorded (Table 1). The date of capture, capture location, and depth of capture were also documented. Fish were promptly released after they were measured (fork length, nearest mm) and tagged.

To determine recapture rates of fish within each category, tagged fish were recovered in commercial fisheries and tags were returned to the AFSC for a reward (Maloney[2]). Tags were also recovered during subsequent research studies. Data for fish recaptured from the time of tagging to June 2009 were used in our analysis (up to 19 years at liberty).

Analysis

A logistic regression model was constructed to determine which factors were related to significant differences in recapture rates. The relationship between the binary, dependent variable, Y_i, which represents whether a fish was recaptured or not, and seven independent explanatory variables was estimated with the following full model,

$$Logit(Y_i) = a + bYr_i + cL_i + dD_i + eHL_i + fHS_i + gA_i + hG_i, \quad (1)$$

where a = the intercept, and b to h are estimated model coefficients;
Yr_i = year of tagging (1989, 1990);
L_i = fish length at capture;
D_i = capture depth group (210–269, 270–319, 320–419 m);
HL_i = location of the hook injury (cheek, upper jaw, lower jaw, nose, throat, eye, gill);
HS_i = severity of the hook injury (minor, moderate, severe);
A_i = severity of amphipod predation injury (no injury, ≤10% scale loss, >10% scale loss); and
G_i = type of injury sustained on fins or body from line and roller gears (no injury, fin damage, lacerations) for fish i (Table 1).

Year can also be considered to be the effect of location because in each year fish were tagged at different locations. All independent variables were treated as categorical except for length, which was continuous. Interaction terms were not included in the model because of the small sample sizes available across multiple categorical variables, which resulted in an inability to estimate these interaction parameters.

Forward-stepwise model selection was performed to simplify the model to factors that significantly improved

[2] Maloney, N. E. 2002. Report to industry on the Alaska sablefish tag program, 1972–2001. AFSC Processed Rep. 2002-01, 44 p. Auke Bay Laboratory, NMFS, NOAA, 11305 Glacier Highway, Juneau, AK 99801.

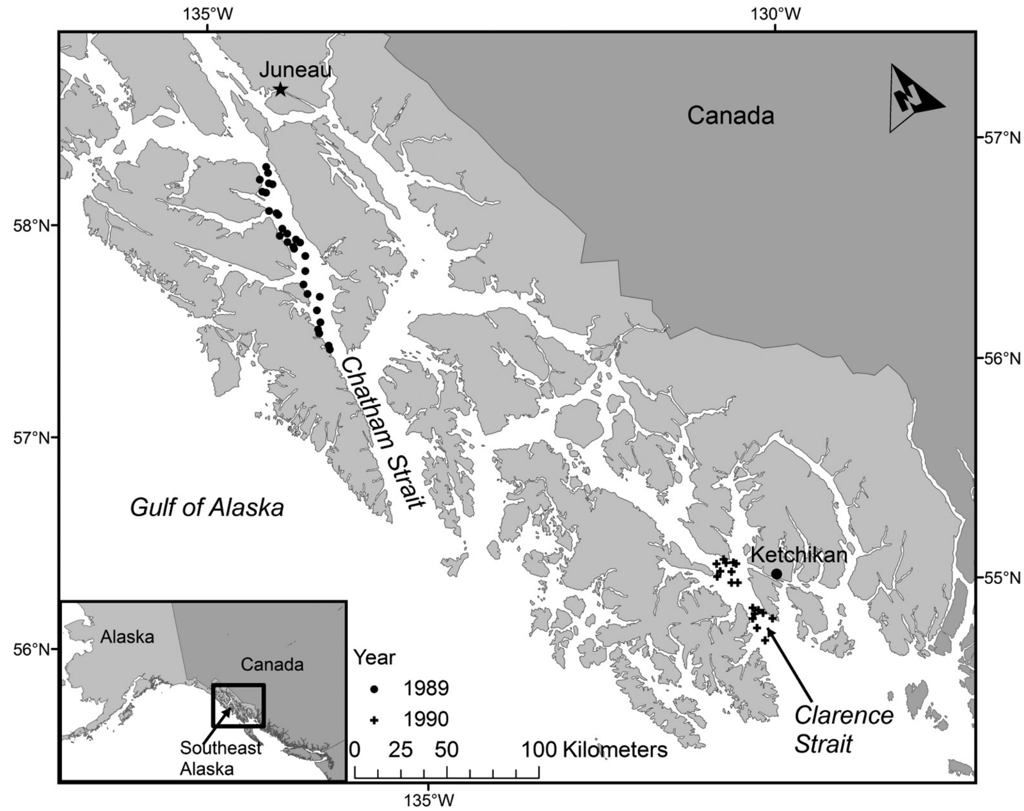

Figure 1

Map of the areas in Southeast Alaska where sablefish (*Anoplopoma fimbria*) were tagged during research surveys in 1989 (●) and 1990 (✦).

model fit. The model with the minimum Akaike information criteria (AIC) value was chosen. A Wald chi-squared test was used to calculate the overall significance of categorical variables with multiple coefficients. All statistical analysis was implemented in R software, vers. 2.11.1 (R Development Core Team, 2010) including use of the aod package, vers. 1.2 (Lsenoff and Lancelot, 2010).

Recapture rates for categories within each variable were calculated by dividing the number of recaptured fish by the number of tagged fish for each category. Absolute survival rates were calculated for each level of hook severity on the basis of observed recapture rates and the survival rate of a Pacific halibut with minor hooking injuries (Kaimmer, 1994; Kaimmer and Trumble, 1998; Trumble et. al., 2000). Previous studies have determined that the expected survival of a properly handled Pacific halibut is in the 95–98% range; a released fish with minor injuries has an estimated 96.5% survival rate (Trumble et al., 2000). We used the Pacific halibut estimate of survival rate as a proxy for that of sablefish for the following reasons: these species do not experience barotrauma as a result of rapid decompression; they co-occur in the same water temperatures, areas, and depths; they are caught with nearly identical gear types; and they are commonly fished by the same fishing vessels and crew. Like Pacific halibut, sablefish are hardy and, when handled appropriately, have high survival rates after capture and discard. Long-term tagging programs for both species provide evidence of their hardiness (Kaimmer, 2000; Maloney[2]). The hardiness of sablefish is also supported by previous research in a laboratory setting where there was 100% survival after 60 days (Davis et al., 2001). Ours is the first dedicated study to estimate sablefish discard mortality. Previous estimates of Pacific halibut survival rates are the best available data to use as a proxy for sablefish.

The average survival rate of fish with different severities of hook injury, i.e., the absolute survival rate, was estimated on the basis of recapture rates and relative frequency of all 3 levels of hook injury (minor, moderate, severe) by using the methods in Kaimmer and Trumble (1998). The overall absolute survival rate (S) of captured fish was calculated with the following formula:

$$S = \frac{\left(\dfrac{R_0 + R_1 + R_2}{T_0 + T_1 + T_2 + NT}\right)}{\dfrac{R_0}{T_0}} \times 0.965, \qquad (2)$$

where T_0, T_1, and T_2 and R_0, R_1, and R_2 are the number of fish tagged (T) and recovered (R) with minor (0), moderate (1) and severe hook injuries (2). Fish that were not

Table 1

Description and assigned injury code for injury types and severities for sablefish (*Anoplopoma fimbria*) caught on longline gear, for an estimation of discard mortality.

Factor	Description
Hook injury location	
0	Hooked in cheek or parts of operculum
1	Hooked in upper jaw: maxilla or premaxilla
2	Hooked in lower jaw: dentary (mandible)
3	Hooked in nose or snout
4	Hooked in throat
5	Hooked in eye
6	Hooked around gill or gill arches
Hook injury severity	
0	Minor: small puncture, flesh not torn, no abrasion
1	Moderate: flesh torn; some abrasion; bones intact, eye orbit not punctured
2	Severe: bones torn at insertion, severed or shattered, gills hooked but no broken gill arches, hooked through palatine into nose capsule, cheek bones shattered, hooked in throat and bleeding but not torn
NT	No tag: gill arches torn or bleeding, hook swallowed with substantial tears in throat; maxillary and premaxillary or dentary torn off; nose or snout smashed
Amphipod predation injury	
0	No injury
1	Moderate scale loss: 10% or less
2	Heavy scale loss: greater than 10%
Line and roller gear injury sustained on fins or body	
0	No injury
1	Fin damage: caudal, pectoral, pelvic, dorsal, or anal fin
2	Lacerations: line markings across body

tagged because of the extreme severity of their injuries were assumed to have 0% survival and are represented in the equation as *NT* (having no tag and they were included in the total number of fish caught when calculating the recovery rate for each injury group). The survival rate of fish in each category was calculated with the following formula:

$$S_x = \frac{\left(\frac{R_x}{T_x}\right)}{\frac{R_0}{T_0}} \times 0.965, \qquad (3)$$

where all variables are the same as in Equation 2 and x represents the severity of the hook injury (0, 1, or 2).

Results

A large number of sablefish were captured (10,940) and tagged (10,508): 8838 fish were tagged during the 1989 survey and 1670 during the 1990 survey. A substantial number of fish were recaptured (1207 fish, 11.49% recapture rate of tagged fish) between 9 days and 19.2 years (mean=3.4 yr, standard deviation=4.5 yr) after tagging. Because some data were lacking for 81 fish, analyses were run with data from 10,427 fish. An additional 432 fish were captured but not tagged because of the extreme injuries from capture or amphipod predation (*NT* in Eq. 2, see *Materials and methods* section).

Logistic regression model

The reduced model was chosen on the basis of the smallest AIC value. Several parameters were found to significantly affect recapture rates: year (which also can be considered to be a location effect), depth, severity of hook injury, and amphipod predation (Table 2, Fig. 2). Fish tagged in 1989 had a lower recapture rate (11.26%) than those tagged in 1990 (12.66%) (Table 3). Fish from the greatest depths (320–419 m) had a greater rate of recapture (14.33%) than fish captured at shallower depths (210–269 m, 10.61%; 270–319 m, 10.43%; Table 3). Severity of hook injury also exhibited a significant effect on the recapture of tagged fish (Table 2). Fish with severe injuries had a lower recapture rate (8.49%) than those with minor (12.05%) or moderate (11.81%) injuries (Table 3). The confidence intervals surrounding the parameters for severity of injury were relatively narrow, with the 95% confidence interval of the odds

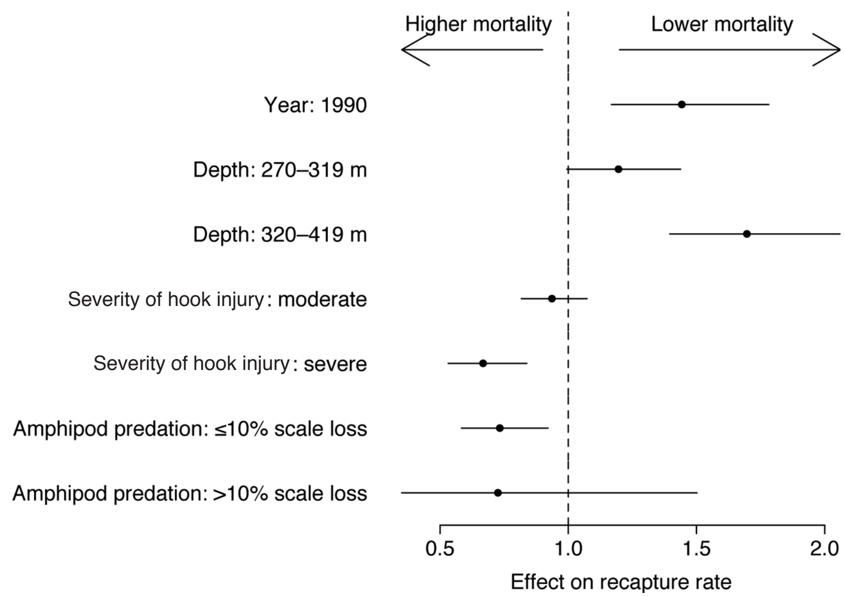

Figure 2

Comparison of the effects of the variables in the final model on the recapture rate of tagged sablefish (*Anoplopoma fimbria*). The effect on recapture (circle) is the exponent of the estimated parameter for the variable in the logistic regression and is the odds ratio: the odds of recapture of a fish in a category compared to the odds of recapture in the initial category of the categorical variable (year: 1989; depth: 210–269 m; severity of hook injury: minor; amphipod predation: no predation). Horizontal lines are 95% confidence intervals for the estimate.

ratio for the effect of severe hooking injuries <1, indicating a significant negative effect on recapture (Fig. 2). Although only a small portion of the fish sampled suffered from amphipod predation, it significantly affected recapture and was included in the final model (Table 2). Fish with no observed amphipod predation had a higher rate of recapture (11.86%) than fish with ≤10% scale loss (8.44%) and fish with >10% scale loss (7.84%) owing to amphipod predation (Table 3). The 95% confidence interval of the odds ratio for the effect of less than or equal to 10% scale loss was less than 1, indicating a significant negative effect on recapture (Fig. 2). However, there was a high amount of variability around the estimated parameter for the effect of >10% scale loss because of a low number of samples (Fig. 2). The majority of fish (51.06%) that were too severely injured to be tagged had suffered from amphipod predation, and only 11.09% of fish that were healthy enough to be tagged had suffered amphipod predation.

In our study location of hook injury, fish length, and type of gear injury did not significantly affect recapture rates. Hook injuries were not in critical locations that would likely cause mortality alone. Most injuries were located on the cheek and upper and lower jaws (95.53%). There were a small number of fish observed that had hook injuries to other areas of the body (nose, throat, eye, gill; 4.47%) (Table 3). A wide range of fish lengths were included in our study, but length did not have a significant effect on recapture rate. Injuries caused by the line and roller gear also did not have a significant effect on recapture rate. This result may be the consequence of low statistical power because few fish (5.58%) sustained injuries caused by gear other than hooks (Table 3).

Table 2

Significant effects included in the reduced logistic regression model, where the response is whether a sablefish (*Anoplopoma fimbria*) was successfully recaptured after tagging. The overall variable significance was calculated by using a Wald chi-squared test.

Variable	χ^2	df	$P(>\chi^2)$
Intercept	571.0	1	<0.001
Year	11.6	1	<0.001
Depth (m)	34.8	2	<0.001
Severity of hook injury	12.4	2	0.002
Amphipod predation	7.7	2	0.021

Survival rates

The absolute survival rate of fish in each category of severity of hook injury was calculated with Equation 3

Table 3

Number of sablefish (*Anoplopoma fimbria*) tagged and recaptured (number and %) by each variable. Length was a continuous variable in the analysis but is categorized here for summary purposes. The estimated absolute survival was estimated for the levels of the severity of hook injury on the basis of an assumed 96.5% survival of fish with minor injuries.

Variable	Tagged	Recaptured	% Recaptured	Estimated absolute survival %
Year				
1989	8768	987	11.26	
1990	1659	210	12.66	
Length (cm)				
<60	1280	152	11.88	
60–69	5250	585	11.14	
70–79	3048	360	11.81	
>80	849	100	11.78	
Depth (m)				
210–269	3354	356	10.61	
270–319	4428	462	10.43	
320–419	2645	379	14.33	
Hook location				
Cheek	3290	396	12.04	
Upper jaw	1759	199	11.31	
Lower jaw	4912	559	11.38	
Nose	123	14	11.38	
Throat	212	17	8.02	
Eye	120	11	9.17	
Gill	11	1	9.09	
Severity of hook injury				
Minor	2963	357	12.05	96.50
Moderate	6204	733	11.81	94.63
Severe	1260	107	8.49	68.01
Extreme	432			0.0
Total	10,859	1197	11.02	88.29
Amphipod predation				
No predation	9271	1100	11.86	
≤10% scale loss	1054	89	8.44	
>10% scale loss	102	8	7.84	
Gear injury				
No injury	9845	1133	11.51	
Fin damage	539	57	10.58	
Lacerations	43	7	16.28	

(Table 3). The overall absolute survival of released sablefish was estimated, with Equation 2, to be 88.29%, or an overall mortality rate of 11.71% (Table 3). The absolute survival of fish with severe injuries (68.01%) was much lower.

Discussion

Our results indicate that the severity of hook injury is related to recapture rates for tagged sablefish. Most injuries were to the cheek and jaw and not to critical areas, such as the gills and brain. The severe injuries that we saw likely resulted in delayed mortality following the tagging event which would explain lower recapture rates. The severity of an injury is likely influenced by the technique for hook removal. Previous studies with Pacific halibut (Kaimmer, 1994; Kaimmer and Trumble, 1998) found that the removal of the hook affects the severity of the hook injury and, as with sablefish, survival decreased with an increase in the severity of hook injury. Severity of hook injury is a logical parameter for estimation of discard mortality because it significantly affects recapture rate.

In our study, the location of hooking injury did not significantly affect recapture rates. However, a large portion of injuries occurred on the cheek and upper and lower jaws—locations that are typically affected by circle hooks. We likely did not have enough samples of fish with injuries in other locations to detect the effects of those injuries. Unlike our results, results from studies of catch-and-release of recreationally caught species have indicated that hooking location was the most significant factor in estimating mortality (reviewed in Bartholomew and Bohnsack, 2005). Deep-hooking injuries in critical locations such as the esophagus, stomach, gills, eyes, and brain significantly increase mortality in many species (e.g., Muoneke and Childress, 1994; Pálsson et al., 2003; Aalbers et al., 2004; Alós et al., 2009). The circle hooks that are used in Alaska longline fisheries usually hook fish in the mouth and injuries in critical locations are not common (reviewed in Trumble et al., 2000). Capture with other hook types or fishing gears, such as trawl gear, would likely produce injuries on other locations of the body.

Depth of capture significantly affected the recapture rate of sablefish, which is common for other fish species. We found a positive relationship between depth of capture and assumed survival (i.e., fish caught at shallow depths were less likely to be recaptured). The sablefish fishery extends to at least 800 m in many areas and so the effect of depth on recapture rates may be even more pronounced at depths greater than 419 m, the maximum sampling depth in our study. The opposite has been observed in physoclistous species due to barotrauma, because of organ damage caused by gas expansion in the body cavity during capture (e.g., Gitschlag and Renaud, 1994; Wilson and Burns, 1996; Collins et al., 1999; St. John and Syers, 2005). Sablefish lack a swim bladder, thus no correlation between mortality and depth of capture was expected. Deeper-dwelling fish can also have increased injuries with greater capture depths, indicating that injuries are inflicted while fish struggle during hauling (Atlantic cod; Pálsson et al., 2003).

There are some potential explanations for why fish caught at shallow depths had lower recapture rates. First, sablefish caught at deeper depths (320–419 m) could be less vigorous because of the longer retrieval time and the increased time spent fighting the line during retrieval and therefore they are less likely to become injured during the landing process when out of the water and onboard the fishing vessel. Differential predation in the depth categories may also affect the mortality of released sablefish, if they return to their previous depths after release. Two major predators of sablefish have greater concentration at shallower depths, Pacific halibut (27–274 m; IPHC, 1998) and Pacific sleeper sharks (*Somniosus pacificus*) (Yano et al., 2007). Second, fishing effort likely differs by depth and therefore may affect depth-related recapture rates of tagged fish. Data on fishing effort by depth were not available from the Pacific halibut fishery or the southeast Alaska state sablefish fishery and therefore a full examination of this supposition was not possible.

In our study, amphipod predation was related to the recapture rate of sablefish and was prevalent for fish that were too severely injured to tag. Similarly, Pacific halibut that were tethered to longlines for extended periods suffered from amphipod predation and had a low survival rate (Trumble et al., 2000). Fishery-specific amphipod predation rates would need to be investigated to accurately assess this effect on the discard mortality of sablefish.

The year of capture significantly affected the recapture rate of sablefish. A greater recapture rate was found for fish tagged in Clarence Strait in 1990 and several factors likely contributed to this difference. First, a greater proportion of fish tagged in 1990 (18.57%) were recaptured within 60 days of tagging compared to those tagged in 1989 (7.42%). This is likely explained by the occurrence of an Alaska Department of Fish and Game sablefish survey and the southern southeast Alaska directed sablefish fishery both occurring within 60 days of the initial tagging effort. Tagging conducted in Chatham Strait in 1989 occurred after both the state survey and fishery period and therefore the grounds were not fished for nearly a year after the tagging effort. A minimum time at liberty was not used in our study because the year or location of tagging was secondary to our primary objective of determining the factors related to discard mortality and estimating absolute discard mortality based on the severity of injuries to sablefish. Second, longline fishing is permitted in the Chatham Strait fishery, and in Clarence Strait both longline and pot gear are allowed. Animals can exhibit varying levels of “trap addiction” (attraction to fishing gear) or “trap shyness” (an aversion to the gear) depending on the gear type (Seber, 1982). Previous tagging analyses have shown that sablefish may be trap shy towards longline gear within the first year after capture, likely because of the stress incurred during the initial capture (Carlile, et al.[3]). Because many of our fish were caught soon after capture in the fishery, some of the difference in recapture rate that we saw may be explained by the differential recapture catch rates between pot and longline gear types. Finally, amphipod predation was significantly higher in 1989 (12.45%) than in 1990 (3.86%) indicating that Chatham Strait may have a higher incidence of amphipods, which we found to be related to a decreased recapture rate.

We calculated an absolute mortality rate for each level of severity of hook injury. The overall mortality rate of 11.71% is substantially lower than the 25% mortality rate assumed for sablefish discarded in the Pacific halibut fishery in state waters (i.e., Chatham

[3] Carlile, D., B. Richardson, M. Cartwright, and V. M. O’Connell. 2002. Southeast Alaska sablefish stock assessment activities 1998–2001. Regional Information Report IJ02-02, 86 p. Alaska Dep. Fish and Game, Douglas, AK.

and Clarence Straits; Dressel[1]), and the assumed 100% mortality of sablefish caught in other target fisheries in federal waters in Alaska (Hanselman et al., 2010). Applying the 11.71% mortality rate to the average catch of sablefish discarded in federally managed hook-and-line fisheries (491 t, 2004–09 average; Hanselman et al., 2010), yields an annual discard mortality of 57.5 tons.

There are two reasons why our estimate of absolute discard mortality may be lower than what occurs in the commercial fishery. First, in our study fish were handled carefully and released, whereas in commercial fisheries we would expect a greater proportion of moderate and severe injuries that would result in a higher discard mortality. Second, commercial fishery discards come from multiple fisheries that use numerous gear types, most notably different hook types and sizes. Larger hooks have been shown to result in higher discard mortality (Trumble et al., 2000). Because the halibut fishery in Alaska uses larger hooks than we used in our study, a higher discard mortality rate for sablefish would be expected in the halibut fishery. Careful hook removal during release of fish could potentially minimize discard mortality rates observed in commercial fisheries.

Conclusion

In this study we examined some of the factors that affect the discard mortality rate of sablefish in Alaskan longline fisheries. We found a decrease in recapture rates for fish originally captured at shallower depths (210–319 m) in our study, sustaining severe hooking injuries, and sustaining amphipod predation injuries. Based on the severity of hook injury, we estimated an overall discard mortality rate of 11.71%. Obtaining data on the relative occurrence of the severity of hook injuries that occur in these fisheries is a logical next step. Such data would allow us to extrapolate our findings more reliably and may lead to a more accurate accounting of total mortality attributable to fishing and to improved management of this species.

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