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Fish Size and Exposure to Air: Potential Effects on Behavioral Impairment and Mortality Rates in Discarded Sablefish

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Abstract.—Fisheries models often assume that discarded undersized fish and target species will survive and contribute to future recruitment and yield. If smaller fish are more susceptible to capture stressors than larger fish, then the assumption that smaller discards would contribute to recruitment may not be true. We tested the hypothesis that small sablefish *Anoplopoma fimbria* show more behavioral impairment and mortality than large fish when exposed to air (10–60 min) at various temperatures (10–18°C). Sablefish captured by trawl, longline, or trap are commonly exposed to these conditions during warmer seasons when brought up on deck and sorted. Two size-classes of fish (small: 32–49 cm total length [TL]; large: 50–67 cm TL) were used in the experiments. Behavior was measured as upright orientation and startle responses to visual and mechanical stimuli 1, 2, 3, and 24 h after air exposure; mortality was measured through 7 d after air exposure. Small fish mortality increased as air time increased and was at higher levels than in large fish. Only 10 min of air exposure caused behavioral impairment in small and large fish, which could lead to increased predation on discarded fish. At 24 h after air exposure, normal behavior had not generally resumed and small fish had more behavioral impairment than large fish.

Size-related mortality and its causes in discarded fish, with smaller fish showing greater mortality than larger fish, is an important factor to consider in models of fisheries recruitment and yield. Fisheries management often relies on minimum size rules for harvest, with the assumption that discarding of undersized fish will contribute to future recruitment and yield (Halliday and Pinhorn 2002). Target species may also be subjected to ‘‘highgrading’’ in which smaller fish are discarded for economic reasons. If mortality rates of discarded smaller fish are high, the benefits in future growth or reproductive potential are thwarted (Pinhorn and Halliday 2001). While size-related mortality has not been investigated in sablefish *Anoplopoma fimbria*, smaller fish of other species have been observed to have higher discard mortality rates than larger fish under field conditions (Neilson et al. 1989; Richards et al. 1995; Milliken et al. 1999; Parker et al. 2003) and laboratory conditions (Davis and Olla 2002). Size-related behavioral impairment in discards, in which normal behavior is decreased or completely inhibited, has not been studied in any detail and may result in predation becoming a significant source of delayed mortality.

Sablefish is a highly valued species that is subjected to an intense commercial fishery off Alaska, British Columbia, Washington, Oregon, and California, with landings of 26,240 metric tons (mt) in 2000, worth an estimated US$82 million ex-vessel (FAO 2002). The current discard rate of sablefish in trawl fisheries off the U.S. West Coast is estimated to be 21% of total sablefish catch by weight and 85% by number (Schirripa and Methot 2001). Mortality of sablefish discards from trawl fisheries is assumed to be 100%, while no mortality is assumed for discard from longline and trap fisheries (Schirripa and Methot 2001). Studies of capture-related stressor effects have indicated that these mortality assumptions are not realistic. In warmer months of the year, there is a high probability that during fixed-gear retrieval and landing on deck, sablefish discards would be subjected to abrupt increases in water and air temperature which would be expected to produce a range of discard sablefish behavioral impairment and mortality rates in fixed-gear fisheries (Davis et al. 2001; Davis 2002). The assumption of 100% mortality in trawl fisheries may not be realistic given the relative hardiness of sablefish to capture in nets

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during cooler seasons (Davis et al. 2001; Davis 2002).

Sablefish move to deeper waters as they age (Methot 1992), so the size composition of sablefish catch is related to the depth of the fishery. In addition, sablefish are discarded in trap, longline, and bottom trawl fisheries for other species because of size or catch limits, or minimum market size (Ackley and Heifetz 2001; PFMC 2002). In 2002, the size limit for sablefish captured in trawl fisheries off California was 56 cm (PFMC 2002). The estimated size at 50% selection is approximately 40 cm for trawl gear and 50 cm for trap and longline gears (Schirripa and Methot 2001). In Washington, Oregon, and California trawl fisheries, all estimated discards were less than 48 cm, with an average total weight of 566 and 547 metric tons in 2000 and 2001, respectively. For landed catch, prices paid for sablefish depend on the size of the fish. This price structure creates an incentive to retain larger fish and discard smaller fish (Schirripa and Methot 2001) and to capture even more fish and discards than necessary in the process. The seasonality of fisheries (occurring mainly in summer months), minimum size limits, and economic incentives to select for larger fish can result in smaller fish being discarded at high rates in most fisheries and, consequently, in high discard mortality rates.

The aim of this laboratory study was to test the hypothesis that small sablefish have more behavioral impairment and mortality than large fish as a result of exposure to air for various times and temperatures which are often present in trawl, longline, and pot fisheries when fish are brought on deck and sorted. Stress responses to air conditions are a conservative estimate of stress in discarded fish because stressors associated with other factors—including physical injury from capture, pressure changes, and hypoxia in piles of fish on board—are not included (Davis et al. 2001; Davis 2002). Such additional capture stressors would be expected to increase stress responses and mortality, but not to alter the basic principles of stress response related to size.

Methods

Juvenile age-0 sablefish (20–40 mm total length [TL]) were captured in the spring from the neuston offshore from Newport, Oregon, and reared in the laboratory for up to 2 years prior to experiments. For the first year of rearing, fish were held in circular tanks (2.0 m diameter, 0.8 m depth, 3,140 L volume) supplied with seawater (10 L/min, 10–13°C, 30–32 g/L salinity, $O_2 > 90\%$ saturation) and fed 6% body weight on chopped dead market squid *Loligo opalescens* three times per week. For the remaining time, fish were reared in circular tanks (4.5 m diameter, 1.0 m depth, 15,904 L volume) supplied with seawater (20 L/min, 7.5–8.5°C, 30–32 g/L salinity, $O_2 > 90\%$ saturation) and fed 6% body weight on whole dead squid twice per week. A total of 108 (32–49 cm TL) age-1 juvenile fish and 108 (50–67 cm TL) age-2 juvenile fish were used once in experiments (Figure 1). Fish age was determined by holding age-0 fish for a known period of time. All fish lengths were measured after conducting air exposure experiments.

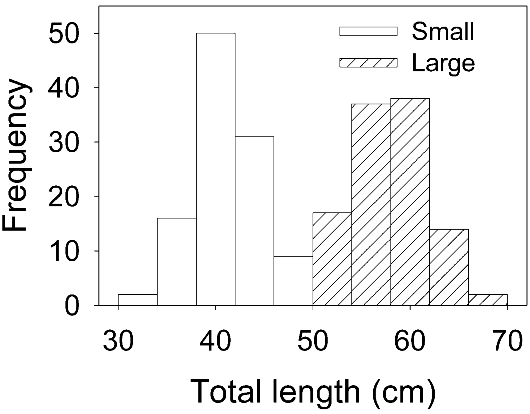

FIGURE 1.—Length frequency of sablefish in two size-classes (small [<50 cm]: $N = 108$; and large [≥50 cm]: $N = 108$) used in air time and temperature experiments.

Air exposure.—Sablefish were exposed to air at three temperatures for various periods of time, similar to the exposure that would occur on the deck of a fishing vessel. For sablefish, air exposure is a function of handling time on deck and can range from a few minutes when catches are small (hook and line, trap, and trawl) to greater than 60 min when catches are large (trawl), while air temperature on deck in the summer can range up to 25°C. The fish were transferred by dip net from a holding tank into empty rectangular tanks (90 × 60 × 30 cm) in temperature-controlled rooms. Two age-classes (size-classes) were exposed to air at 10, 14 and 18°C for 10, 20, 30, 40, 50, and 60 min. A total of 18 treatments (3 air temperatures × 6 air times) were administered using six fish per treatment, held together in a rectangular tank. After a stressor treatment, the six treatment fish were transferred to a 3,140-L circular tank (2.0 m diameter, 0.8 m depth) supplied with seawater (10

TABLE 1.—Mortality in age-1 (small fish) and age-2 (large fish) sablefish through 7 d after air exposure (air time) for 10–60 min at 10, 14, and 18°C (air temperature). The value for each treatment is the proportion of fish that died in a group of six fish.

Air time (min)	Small fish 10°C	Small fish 14°C	Small fish 18°C	Large fish 10°C	Large fish 14°C	Large fish 18°C
10	0	0	0	0	0	0
20	0	0	0	0	0	0
30	0	0	0	0	0	0
40	0.17	0.33	0.67	0.17	0	0
50	0	1	1	0.17	0.33	0.17
60	0.50	1	1	0	0.33	0.67

L/min, 7.5–8.5°C, 30–32 g/L salinity, $O_2 > 90\%$ saturation) and held for 7 d.

Behavior was noted at 1, 2, 3, and 24 h after air treatment. Visual observations were made from above the tank for (1) the presence or absence of upright orientation in individual fish and (2) startle responses to a uniform visual stimulus (lifting the tank cover), followed by a uniform mechanical stimulus (striking the side of the tank three times in succession). These behaviors are innate orientation and startle responses that are critical for swimming and evasion of predators. Deficiencies in these behaviors increase predation on stressed fish (Olla and Davis 1989; Schreck et al. 1997; Ryer et al. 2004). An index for behavior at each observation time in each treatment was calculated by adding the number of fish observed to be upright and showing a startle response to visual and mechanical stimuli. Fish not exposed to stressors always showed full responsiveness (with a total score of $6 + 6 + 6 = 18$). Scores for individual treatments were divided by 18 to calculate the behavior index as the proportion of full responsiveness. Behavioral impairment was defined as a decrease or complete inhibition of normal behavior. Dead fish had no behavior, were removed from the tank and were not included in the behavior index. If there was mortality in a treatment, then the behavior index was calculated by totaling observed scores and dividing by the maximum score possible for the number of living fish. Mortality as evidenced by lack of movement and sustained flaring of opercula was noted through 7 d after stressor treatment. The proportion of mortality in each treatment was calculated by dividing the observed mortality by six.

Statistical analysis.—The proportion of mortality through 7 d and behavior index at 1, 2, 3, and 24 h after stressor treatment was calculated for each treatment as described above and used as individual nonreplicated data points in statistical testing. Nonparametric tests were used throughout, as data and transformed data did not fit a standard distribution and variances were not homogeneous. Tests were calculated with Statistix 7 software. Statistical significance was assumed at P equal to 0.050. Effects of fish size on mortality and behavior index were tested with Wilcoxon's signed rank test by matching measures in corresponding treatments among two size-classes. Effects of air exposure time and air temperature on mortality and behavior index were tested with Friedman two-way analysis of variance (ANOVA) in two size-classes of fish separately. Changes in behavior index (recovery) between 1, 2, 3, and 24 h after air exposure were tested with ANOVA in two size-classes of fish separately.

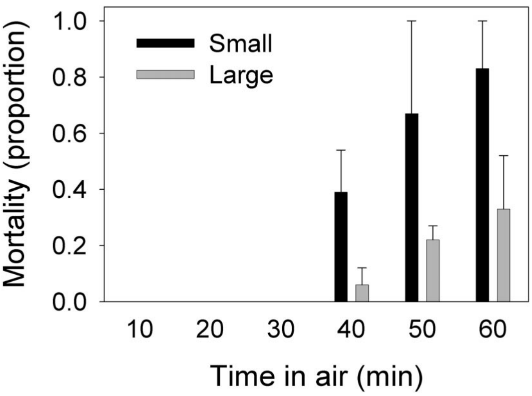

FIGURE 2.—Small sablefish had higher mortality compared with that of large fish after air exposure. Proportion of mortality (1.0 = 100% mortality) was expressed for small and large fish exposed to air (10–60 min). Bars are mean ± 1 SE ($N = 3$; calculated from exposure to air at 10, 14 and 18°C) for mortality observed after each air exposure time. No mortality was observed at 10, 20, and 30 min in air.

Results

Mortality.—Mortality was higher in small sablefish than in large sablefish (Wilcoxon, $P = 0.021$; Table 1; Figure 2). Mortality was not observed in small or large fish until after 30 min of air exposure. In small fish, there was a significant rise in mortality between 30 and 50 min (ANOVA; Tables 1, 2; Figure 2). In large fish, a more gradual increase in mortality was apparent but not significant because of high variability (ANOVA; Tables 1, 2; Figure 2). Higher air temperature may have increased small fish mortality ($P = 0.061$), but

TABLE 2.—Effects of air exposure time (air time) and air temperature on mortality and behavior index in age-1 (small fish) and age-2 (large fish) sablefish. Friedman analysis of variance (ANOVA) F-scores with degrees of freedom (F_{df}) and probabilities (P) are reported for mortality at 7 d after air exposure and the behavior index 1, 2, 3, and 24 h after air exposure.

	Small fish				Large fish			
	Air time (min)		Air temperature (°C)		Air time (min)		Air temperature (°C)	
Item	F_5	P	F_2	P	F_5	P	F_2	P
Mortality	12.4	0.030	5.60	0.061	9.52	0.090	0.20	0.905
Behavior								
1 h	7.93[a]	0.048	0.80	0.670	10.9	0.054	1.53	0.466
2 h	8.79[a]	0.032	0.20	0.905	10.0	0.074	2.82	0.244
3 h	8.79[a]	0.032	2.00	0.368	9.78	0.082	2.57	0.277
24 h	3.00[a]	0.392	2.00	0.368	12.3	0.030	2.92	0.232

[a] F_3.

there was no apparent temperature effect on large fish mortality (ANOVA; Tables 1, 2).

Behavior index.—Only 10 min of air exposure caused behavioral impairment in sablefish. Behavior index for small fish decreased as air exposure time increased at 1, 2, and 3 h after exposure (ANOVA; Tables 2, 3), while behavior index for large fish was related to air time only at 24 h after exposure. Behavior index was lower in small fish than in large fish at 24 h after air exposure (Wilcoxon, $P = 0.002$; Figure 3; Table 3). No difference was detected among small and large fish at 1 h ($P = 0.969$), 2 h ($P = 0.929$), and 3 h ($P = 0.081$) after air exposure. Partial recovery of sablefish behavior (increased behavior index) occurred by 24 h after air exposure in small (ANOVA; $F_3 = 25.44$, $P < 0.001$; Figure 3; Table 3) and large fish (ANOVA; $F_3 = 44.94$, $P < 0.001$; Figure 3; Table 3). Behavior index was not related to increased air temperature in small and large sablefish (ANOVA; Table 2).

Discussion

Sablefish orientation and startle behavior was impaired by exposure to air for only 10 min and this impairment continued for at least 24 h. Behavioral impairment was not dependant on fish size for the first 3 h after air exposure, suggesting that the effect was produced by a basic change in physiology not linked to body size. However, small fish behavior did recover at a slower rate, indicating a body size effect on recovery. Although the effects of many environmental factors on behavior have been studied, little is known about how air exposure alters fish behavior and its recovery (Schreck et al. 1997). In light of the dynamics of sablefish behavior recovery, discard mortality from predation would be expected to be higher in smaller fish than in larger fish exposed to 10 min of air or more and adds further concern for the accurate measurement of discard mortality. For discarded fish in the ocean that are able to sink

TABLE 3.—Behavior index in age-1 (small fish) and age-2 (large fish) sablefish measured 1, 2, 3, and 24 h after exposure to air (air time) for 10–60 min. Data are means ±SEs ($N = 3$; calculated from exposure to air at 10, 14, and 18°C). When small fish were exposed to air for 50 and 60 min, only fish at 10°C survived and their behavior index was measured. Since behavior could not be measured for small fish that died when exposed to air for 50 and 60 min at 14°C and 18°C, no standard error was calculated (nd).

Air time (min)	Small fish				Large fish			
	1 h	2 h	3 h	24 h	1 h	2 h	3 h	24 h
10	0.74 (0.13)	0.76 (0.12)	0.78 (0.11)	0.78 (0.11)	0.58 (0.05)	0.63 (0.05)	0.58 (0.02)	1.00 (0.00)
20	0.66 (0.07)	0.58 (0.02)	0.67 (0.07)	0.67 (0.00)	0.39 (0.00)	0.46 (0.02)	0.52 (0.02)	1.00 (0.00)
30	0.33 (0.00)	0.42 (0.02)	0.56 (0.00)	0.67 (0.00)	0.40 (0.04)	0.48 (0.08)	0.50 (0.10)	0.89 (0.11)
40	0.22 (0.11)	0.33 (0.00)	0.41 (0.05)	0.67 (0.00)	0.35 (0.02)	0.45 (0.06)	0.43 (0.07)	0.89 (0.11)
50	0.00 (nd)	0.33 (nd)	0.39 (nd)	0.67 (nd)	0.39 (0.06)	0.41 (0.05)	0.39 (0.06)	0.73 (0.10)
60	0.00 (nd)	0.33 (nd)	0.33 (nd)	0.67 (nd)	0.25 (0.05)	0.36 (0.03)	0.38 (0.03)	0.61 (0.06)

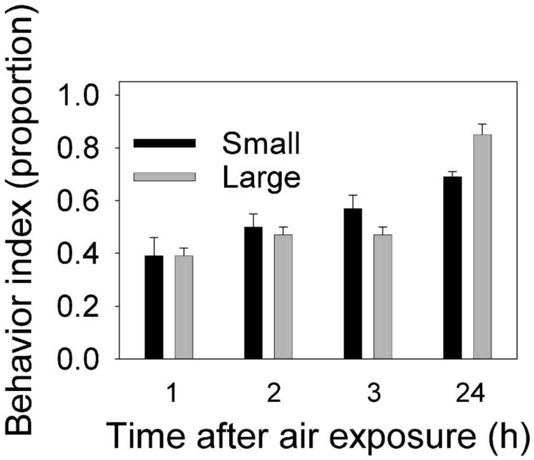

FIGURE 3.—Partial recovery of sablefish behavior occurred in small and large fish 24 h after exposure to air. Small fish had lower behavior index than large fish at 24 h after air exposure, but no differences were apparent at 1, 2, and 3 h. Bars are mean ± 1 SE for behavior index (small fish $N = 14$, large fish $N = 18$ at all four times); data were pooled for small and large fish from all air times and temperatures tested.

(no inflated gas bladders) but have impaired orientation and startle responses, swimming is often not possible and they drop rapidly in a catatonic state to the bottom, showing few responses to predators in the water column and on the bottom. Fish with behavioral impairments often have a reduced ability to evade predators (Olla et al. 1995; Ryer 2002, Ryer et al. 2004).

In contrast to behavioral measures, sablefish could be considered relatively resistant to air on the basis of mortality, which did not occur until after 30 min of air exposure. Other studies in the laboratory have shown that mortality was caused by air exposure ranging from 7 min in walleye pollock *Theragra chalcogramma* to 45 min in lingcod *Ophiodon elongatus* (Olla et al. 1997; Davis and Olla 2002). Comparison with past field studies of air exposure in other species is difficult because they did not control for fish size, temperature, or capture injury. Relative resistance to air exposure after trawl capture was noted in winter flounder *Pleuronectes americanus* and lingcod, which did not show measurable mortality until after 45 min on deck (Ross and Hokenson 1997; Parker et al. 2003). Other discard species were more sensitive to air, with mortality occurring after 15 min in air for Pacific halibut *Hippoglossus stenolepis*, witch flounder *Glyptocephalus cynoglossus*, American plaice *Hippoglossoides platessoides*, and pollock (known in Europe as saithe) *Pollachius virens* (Hoag 1975; Richards et al. 1995; Ross and Hokenson 1997).

Our results confirm the widely held idea that smaller fish are more sensitive to capture stressors than larger fish. Small sablefish mortality appeared and increased abruptly between 30 and 50 min, indicating a threshold-type response. In large fish an apparent increase in mortality after 30 min was gradual and variable. Large sablefish were able to absorb the effects of stress to a greater extent and this ability was also observed in lingcod that were towed in a net and exposed to air (Davis and Olla 2002). Small fish were more susceptible to trawl capture and exposure to air than large fish for lingcod, Atlantic halibut *Hippoglossus hippoglossus*, and Pacific halibut, while size effects were also evident in longline discards of Atlantic halibut and Atlantic cod *Gadus morhua* (Neilson et al. 1989; Richards et al. 1995; Milliken et al. 1999; Parker et al. 2003). Size effects have also been obtained in field studies of escapees from trawls in haddock *Melanogrammus aeglefinus*, European whiting *Merlangius merlangus*, vendance *Coregonus albula*, and Atlantic herring *Clupea harengus* (Suuronen et al. 1995, 1996a,b; Sangster et al. 1996).

The lack of air temperature effects on sablefish behavior and mortality in this study was not expected. Previous sablefish studies showed a marked increase in mortality when fish were exposed to increased seawater temperature for 30 min, followed by 15 min in air (Olla et al. 1998; Davis et al. 2001). An explanation of this difference may be that the warming of sablefish is not as efficient in air as it is in seawater and that body core temperatures were lower during air exposure in the present study. This warming efficiency could be tested in the laboratory and emphasizes the importance of measuring body core temperature and knowing the relationship between body temperature, behavioral impairment, and mortality when predicting potential discard mortality (Davis and Olla 2001; Davis et al. 2001; Davis 2002).

Studies of discarded fish in the laboratory may be considered artificial because all possible stressors are not included (e.g., crushing in a net, pressure changes, damage from other fish and invertebrates, and hypoxic piles of fish). At the same time, field studies suffer from a lack of controls and hypothesis testing and are generally conducted under a limited set of conditions making generalization difficult. In this context, the role of laboratory hypothesis testing is to identify the key factors that control discard behavior and mortality.

With this knowledge, we can sample and predict discard mortality in the field using a rational model based on the established relationships between fishing practices, environmental conditions, fish biology, and mortality. Measures of discard mortality are key for the management of specific fisheries. A rational approach to obtaining mortality data would include a measurement of (1) discard quantity, (2) the proportion of discards that immediately die, and (3) the proportion of discards showing delayed mortality. Delayed mortality may be measured using a condition index based on physical injury, behavior, or physiology. The condition index must have a defined response curve to sublethal stress and mortality and must include the appropriate range of key factors that are important in specific fisheries. While the role of capture injury is obvious, studies have shown that other key factors which are often ignored in the assessment of discard mortality include environmental variables, fish size, behavioral impairment leading to predation, immune suppression leading to disease, and factor combinations (Davis 2002). Mark–recapture studies are useful for developing condition indices if they include an appropriate range of fishing, environmental, and biological conditions.

The effects of air exposure and fish size observed in this study are not expected to impact fixed-gear fisheries which discard fish in less than 10 min, while trawl fisheries would certainly be impacted. It is clear from previous studies that combinations of stressors during warmer seasons in fixed-gear fisheries would increase discard mortality and behavioral impairment (i.e., hooking or trapping followed by increased seawater temperature and air exposure experienced during fish passage from the bottom to the surface and back to the bottom; Davis 2002). While sablefish are robust by some fish standards, discard mortality can be minimized through changes in fishing gear and practices and the development of appropriate economic incentives. For example, although mandatory in Canada, a growing use of traps equipped with escape rings off Alaska and the U.S. West Coast will help to reduce the capture and handling of smaller sablefish in the trap fishery (Department of Fisheries and Oceans Canada Pacific Region 1999; K. Matteson, Oregon Department of Fish and Wildlife, personal communication). Similar escape devices in trawls have not been tested for sablefish, where increased mesh size, grates, and other discard reduction devices may help to reduce the quantities landed of smaller fish. Other modifications of fishing practices could include avoiding areas in which smaller fish are abundant and reducing trawling times to produce smaller catch per set and shorter handling times. As these methods are developed and implemented, the potential delayed mortality of discards and escapees from predation and disease should be estimated. Utilizing smaller fish that are more likely to die from capture is a more difficult issue and requires the development of a market and a price structure that provides the appropriate incentives for fishers. A management and market system that encouraged the retention of all sablefish until the quota was met would minimize total mortality and fishing effort. However, full retention requirements without changes in price structure are not enforceable.

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