North American Journal of Fisheries Management

Mortality of Lingcod Towed in a Net as Related to Fish Length, Seawater Temperature, and Air Exposure: A Laboratory Bycatch Study

Michael W. Davis a & Bori L. Olla b

a Alaska Fisheries Science Center, National Marine Fisheries Service, Hatfield Marine Science Center, Newport, Oregon, 97365, USA

b Oregon State University, Hatfield Marine Science Center, Newport, Oregon, 97365, USA

Available online: 08 Jan 2011

To cite this article: Michael W. Davis & Bori L. Olla (2002): Mortality of Lingcod Towed in a Net as Related to Fish Length, Seawater Temperature, and Air Exposure: A Laboratory Bycatch Study, North American Journal of Fisheries Management, 22:4, 1095-1104

To link to this article: http://dx.doi.org/10.1577/1548-8675(2002)022<1095:MOLTIA>2.0.CO;2

PLEASE SCROLL DOWN FOR ARTICLE

Full terms and conditions of use: http://www.tandfonline.com/page/terms-and-conditions

This article may be used for research, teaching and private study purposes. Any substantial or systematic reproduction, re-distribution, re-selling, loan, sub-licensing, systematic supply or distribution in any form to anyone is expressly forbidden.

The publisher does not give any warranty express or implied or make any representation that the contents will be complete or accurate or up to date. The accuracy of any instructions, formulae and drug doses should be independently verified with primary sources. The publisher shall not be liable for any loss, actions, claims, proceedings, demand or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of this material.
Mortality of Lingcod Towed in a Net as Related to Fish Length, Seawater Temperature, and Air Exposure: A Laboratory Bycatch Study

MICHAEL W. DAVIS*
Alaska Fisheries Science Center, National Marine Fisheries Service, Hatfield Marine Science Center, Newport, Oregon 97365, USA

BORI L. OLLA
Oregon State University, Hatfield Marine Science Center, Newport, Oregon 97365, USA

Abstract.—The mortality of discarded bycatch is a critical problem in the management of fisheries worldwide. Little is known about the key principles involved in the mortality of discarded bycatch. These principles are best elaborated under controlled conditions in the laboratory where the actions and interactions of stressors found in fishing practices can be investigated independently. The goal of this study was to investigate the principles involved in the mortality of lingcod Ophiodon elongatus by testing hypotheses concerning the factors that may control trawl bycatch mortality. Lingcod were towed in a net and exposed to increased seawater temperature and to air, two stressors that occur during the processes of trawl capture, retrieval through a thermocline, and landing on deck. Mortality occurred after exposure to more than 45 min in air, after exposure to 4 h towing in a net followed by more than 30 min in air, or after 4 h towing followed by exposure to seawater above 16.0°C for 30 min and air for 15 min. In treatments of equal stressor intensity, smaller fish (41–51 cm total length) had higher rates of mortality than larger fish (52–67 cm). The effects of net towing and air—as well as of towing, increased seawater temperature, and air—were additive. Lingcod bycatch mortality may be reduced by decreasing trawling times and exposure to increased seawater and air temperatures during warmer seasons or by restricting fisheries that produce bycatch to seasons of cooler temperatures. The sorting, handling, and release of bycatch on deck after capture may be conducted in a manner that would probably enhance survival if fish are released within 30 min of capture. Because smaller lingcod had higher rates of mortality, further information about the mortality rates of relevant size-classes of fish is needed to validate the assumptions of management rules for released, undersized bycatch that are designed to enhance recruitment.
elongatus as an example to develop an understanding of bycatch mortality. Lingcod is important in marine food webs and comprises valuable recreational hook and line and commercial trawl and hook and line fisheries, as well as incidental bycatch in other directed fisheries along the west coast of the USA and Canada. The total catch of lingcod in the USA and Canada was 7,412 metric tons in 1993, falling to 2,628 metric tons by 1999; the total estimated exvessel value was US$6.2 million in 1993 and $4.6 million in 1999 (FAO 2001; PacFIN 2001). Because of declining stocks and catches, conservation is a concern for lingcod in the USA and Canada. In 1999 the Pacific Fishery Management Council designated lingcod as an overfished species in California, Oregon, and Washington, and imposed regulations for minimum size and trip limits on the directed fishery and on other fisheries that produce lingcod bycatch. These restrictions have led to an increased discarding of smaller lingcod and the early closure of fisheries with excess lingcod bycatch. In Canada, fishing for lingcod has been restricted because of depressed stocks, and some areas of the Strait of Georgia have been closed since 1990. Lingcod is a potential candidate for the reduction of bycatch mortality rates because it does not have a gas bladder and is relatively resistant to the effects of capture and handling, with little scale loss or damage to skin. Mortality is very high in discarded fish with a gas bladder or organs which inflate after capture, while mortality may be variable and sometimes quite low in fish that do not have a gas bladder, or have a gas bladder that does not inflate after capture (Alverson et al. 1994). While the mortality of discarded lingcod from trawl fisheries has been hypothesized, estimates of this mortality are not available (Jagielo 1999).

The intent of this work was not to precisely duplicate widely varying fishing conditions and estimate bycatch mortality rates. That task is best performed in future studies in the field using physiological measures of fish condition and mortality that have been correlated with key principles of bycatch mortality. The goal of this study was to investigate the principles involved in lingcod mortality by using tested hypotheses concerning the classes of stressors that may control bycatch mortality. These stressors, including towing in a net and exposure to increased temperature and to air, have been found in the processes of capture, retrieval through a thermoline, and landing on deck. Fish from two size-classes (41–51 cm and 52–67 cm total length [TL]) were exposed to stressors and then held for 60 d after stress induction to assess delayed mortality. The results of this study—along with previous laboratory studies of stress and mortality in walleye pollock Theragra chalcogramma, sablefish Anoplopoma fimbria, and Pacific halibut Hippoglossus stenolepis—can be used to elaborate the general principles of bycatch mortality and to suggest improvements in the design of field bycatch experiments (Olla et al. 1997, 1998, 2000; Davis and Olla 2001; Davis et al. 2001).

Methods

Preliminary laboratory experiments with stress in lingcod indicated that there may be a size effect in the induction of stress. Therefore, efforts were made to capture fish in a range of sizes for this study. Eighty nonreproductive lingcod (41–67 cm TL) were captured in May 2000 by trawling with four 30-min tows at 1.2 m/s, using a commercial bottom trawl in the Pacific Ocean (44°45’N, 124°27’W) offshore from Depoe Bay, Oregon. The tow depth was 150 m, the tow depth temperature was 7.5°C, and the surface water temperature was 13.0°C. Fish were released from the cod end onto the deck after each tow, and all fish appeared to be in excellent condition. Forty fish less than 52 cm TL (small fish) and 40 fish equal to or greater than 52 cm TL (large fish) were sorted into eight, 450-L totes (106 × 92 × 46 cm) within 2 min of landing on the deck. Each tote contained 10 fish of a size-class and was supplied with seawater pumped from depth (7.5°C, 32.5 g/L salinity). The fish were transported within 4 h to the laboratory at the Hatfield Marine Science Center, Newport, Oregon. Small and large lingcod were held separately at a density of 20 fish per tank in 15,904-L circular tanks (4.5 m diameter, 1.0 m depth) and supplied with seawater (20 L/min, 7.0–8.0°C, 30–32 g/L salinity, O2 > 90% saturation). The tanks were in low light conditions (daylight fluorescent, 5,000 K) at 0.5 μmol photons·m–2·s–1 with a photoperiod of 12 h light: 12 h darkness. Fish were initially fed every other day with one live surf smelt Hypomesus pretiosus per fish until all fish had begun feeding and later were fed ad libitum twice per week with frozen Pacific herring Clupea pallasi. Large lingcod began feeding after capture and transport to the laboratory within 2 d, while small lingcod began feeding within 8 d. The resumption of feeding was the criterion for recovery from stress imposed by capture, transport to the laboratory, and laboratory stressors. Experiments were begun 45 d after the fish had been brought
Fish from the two size-classes that died as a result of experimental treatments were measured (N = 27 small, 27 large; Figure 1). The two size-classes probably represented different age-classes, although this was not confirmed by aging techniques.

Air exposure.—Lingcod were exposed to air for various periods of time, similar to the exposure that would occur on the deck of a boat (Figure 2). The fish were transferred by dip net from a holding tank into an empty rectangular tank (90 × 60 × 30 cm). Thirty fish were used in the air experiments (12 small and 18 large fish). Small fish (N = 6 replicate fish for each time period) were held in air (20.0°C) for 45 and 60 min, while large fish (N = 6 replicate fish for each time period) were held in air for 45, 60, and 75 min. After stressor treatment, fish were transferred to 3,140-L circular tanks (2.0-m diameter, 0.8-m depth) supplied with seawater (10 L/min, 7.0–8.0°C, 30–32 g/L salinity, O₂ > 90% saturation) and mortality was noted for up to 60 d after exposure to the stressors.

Net towing and air exposure.—Lingcod were towed in a net for 4 h and then exposed to air, which is similar to the conditions found in trawling (Figure 2). Thirty-six fish were used in the net towing and air experiments (12 small and 24 large fish; N = 6 replicate fish per period of air exposure and fish size). The fish were transferred by dip net from a holding tank into towing nets, located in a tank, as previously described (Olla et al. 1997, 1998). In brief, the apparatus had two nets suspended at the ends of two rotating arms in a tank (4.5-m diameter, 1-m depth). The nets were cylindrical (1.2 m length, 0.7 m diameter) and constructed with nylon, single-knot 2.5-cm diamond mesh (single strand twine, 0.11-cm diameter). Nets were towed for 4 h at 8.0 ± 0.2°C (mean ± 1 SE) in lighted conditions (1.0-μmol photons·m⁻²·s⁻¹) at 1.1 m/s. At this speed, lingcod did not swim and remained pressed against the mesh of the net. Comparisons between the laboratory current speed and current speeds inside commercial trawls was not possible, since the current speeds in trawls have not been measured and may be quite low when the trawls are filled with fish that block water flow. After being towed for 4 h, fish were transferred to the air tank (20.0°C) as previously described and small fish were held for 30 and 45 min, while large fish were held for 30, 45, 60, and 75 min. After stressor treatment, the fish were transferred to 3,140-L circular tanks (2.0-m diameter, 0.8-m depth) supplied with seawater (10 L/min, 7.0–8.0°C, 30–32 g/L salinity, O₂ > 90% saturation), and mortality was noted for up to 60 d after exposure to stressors.
Lingcod stressor treatments

Net towing, increased temperature, and air exposure.—Lingcod were towed in a net for a 4-h period, followed by an abrupt exposure to increased seawater temperature and then exposure to air (Figure 2). During retrieval onboard a fishing vessel while trawling in the warmer seasons, fish may be exposed to 45–60 min of increased temperature (either from seawater or air) which will warm them. These conditions can be found if fish are exposed to (1) a slow passage through thermoclines, (2) time in the surface water before hauling aboard, (3) time in the warm air on deck, and (4) time in the surface water after discarding. The fish were towed as previously described, and 72 fish were used (36 small fish and 36 fish large) with $N$ equal to 6 replicate fish per temperature tested (except at 18.0°C when $N = 12$ replicate fish used). After towing, the fish were exposed to control (8.0°C) or increased seawater temperatures (14.0, 16.0, 18.0, or 20.0°C) for 30 min in a circular tank (3.0-m diameter, 1.0-m depth), followed by 15 min in air (16.8 ± 0.2°C) in an empty rectangular tank (90 × 60 × 30 cm). After stressor treatments, the fish were transferred to 3,140-L circular tanks (2.0-m diameter, 0.8-m depth) supplied with seawater (10 L/min, 7.0–8.0°C, 30–32
NET-TOWED LINGCOD MORTALITY

Figure 3.—Mortality of lingcod subjected to air exposure only or to both net towing and air exposure. Small fish (<52 cm) were exposed to air at 20.0°C for 45 or 60 min (air only treatment) or subjected to 4 h of towing in 8.0°C seawater followed by exposure to air at 20.0°C for 30 or 45 min (towing plus air treatment). Large fish (≥52 cm) were exposed to air at 20.0°C for 45, 60, or 75 min (air only) or subjected to 4 h of towing in 8.0°C seawater followed by exposure to air at 20.0°C for 30, 45, 60, or 75 min (towing plus air). No mortality is indicated by 0; no data is indicated by nd (i.e., the experimental treatment was not performed because 100% mortality was already reached at lower stress).

Results

When lingcod were exposed to air (20.0°C) for 45 min, no mortality resulted in either small or large fish (N = 6, 6; Figure 3). In contrast, lingcod exposed to air for 60 min resulted in significantly higher mortality in small fish (100%) than in large fish (33%; N = 6, 6; one-tailed sign test, P < 0.016; Figure 3). The exposure of large lingcod to air for 75 min resulted in 100% mortality (N = 6; Figure 3). All mortality occurred within 1 d of exposure to air, with sustained flaring of opercula as an indication of mortality.

When lingcod were towed in a net for 4 h at 8.0°C and then abruptly exposed to air (20.0°C), no mortality was observed in small or large fish after 30 min of air exposure, while after 45 min of air exposure, mortality was significantly higher in small fish (100%) than in large fish (33%; N = 6, 6; one-tailed sign test, P < 0.016; Figure 3). After 4 h of towing, mortality in large fish continued to increase as time in air increased after towing, with 66% mortality after 60 min and 100% after 75 min (N = 6, 6; Figure 3). All mortality (with sustained flaring of opercula) occurred within 1 d of exposure to towing and air.

When lingcod were towed in a net for 4 h at 8.0°C and then to air (16.8°C) for 15 min, no mortality resulted in either small or large fish (N = 6, 6; Figure 4). Towed lingcod exposed to 14.0°C and then to air showed 17% mortality in small fish and 0% in large fish (N = 6, 6; Figure 4), while exposure to 16.0°C and then to air resulted in a mortality of 17% in small and large fish (N = 6, 6; 100% salinity, O2 > 90% saturation), and mortality was noted for up to 60 d after exposure to stressors.

Statistical analysis.—In these studies, individual fish used for the three stressor treatments were considered independent replicates and analyzed with the sign test. The assumption of fish replicate independence was reasonable because towing conditions were uniform among all trials, temperatures were controlled, and conditions did not vary among holding tanks for fish after stress induction. Statistical analysis for significant mortality associated with stress treatment was made using the one-tailed sign test which required a minimum of N equal to 5 to demonstrate a 100% mortality effect (at P = 0.05). A one-tailed test was used because the untreated fish were not expected to experience mortality (based on previous experience). The results were reported in percent mortality for clarity of presentation, although statistical analysis was not performed on values for percent mortality. The survivors from initial trials in which fish were towed and exposed to increased temperature and to air were reused 90 d later for trials with exposure to air and exposure to towing and air. As animal care and ethical considerations in studies with mortality as an endpoint required that the study use minimum numbers of fish, surviving fish were reused in additional experiments.
FIGURE 4.—Mortality of lingcod exposed to net towing, increased temperature, and air. Small and large fish were exposed to 4 h of towing in 8.0°C seawater, 30 min in seawater at 8.0, 14.0, 16.0, 18.0, or 20.0°C, and then air at 16.8°C for 15 min. No mortality is indicated by 0.

Figure 4). Exposing towed lingcod to 18.0°C and then to air, resulted in a significantly higher mortality in small fish (42%) than in large fish (0%; N = 12, 12; one-tailed sign test, P < 0.031; Figure 4). Exposure of towed lingcod to 20.0°C and then to air resulted in a mortality of 100% in small and large fish (N = 6, 6; Figure 4). All mortality (with sustained flaring of opercula) occurred within 1 d of exposure to towing, temperature, and air.

Discussion

The mortality in lingcod exposed to bycatch processes was magnified by combinations of increased temperature and exposure to air and towing. The exposure of lingcod to increased temperature after 4 h of towing in a net caused mortality to increase as temperature increased between 16.0°C and 20.0°C. Similarly, while exposure to air without previous towing caused mortality to increase as time in air increased from 45 to 75 min, after 4 h of towing the effects of exposure to air were magnified, causing a reduction in the time of air exposure that led to 100% mortality.

The stress and mortality induced in fish as a result of bycatch processes often result from a combination of several stressors, including capture, environmental factors, and handling. The magnification of stress caused by the interactions of stressors is probably a common occurrence (Wedemeyer et al. 1990; Barton and Iwama 1991). Previous studies with walleye pollock, sablefish, and Pacific halibut in the laboratory demonstrated that the interactions of capture stressors, temperature, and handling caused significant increases in stress as measured by changes in behavior, blood physiology, and mortality (Olla et al. 1997, 1998; Davis and Olla 2001; Davis et al. 2001). Field studies of bycatch mortality related to trawling have shown that significant factors which control mortality rates often include net entrainment, mesh passage, crushing and wounding, sustained swimming until exhaustion, changes in pressure, towing time and depth, time on deck, surface water and air temperatures, and the mean size of fish (Neilson et al. 1989; Chopin and Arimoto 1995; Richards et al. 1995; Ross and Hokenson 1997). Interacting stressors in the field may also degrade the potential for liberated fish to evade predators in the short term and disrupt reproductive activity in the long term (Schreck et al. 1997, 2001). Laboratory studies have shown that predator evasion was diminished in walleye pollock, sablefish, and Pacific halibut after towing in a net (Olla et al. 1997; C. Ryer, Alaska Fisheries Science Center, personal communication). Because conditions are highly variable and uncontrolled in field studies, it has not been possible to quantify the relative strength for the induction of stress and mortality by stressors and their interactions.

Lingcod was relatively resistant to air exposure, with or without towing for 4 h prior to air exposure. A similar resistance to the effects of air after capture by trawl was noted in winter flounder Pleuronectes americanus, which did not show measurable mortality until after 45 min on deck (Ross and Hokenson 1997). In contrast, other studies of bycatch in the field have shown that mortality induced by exposure to air may occur rapidly, with exposure to air for 15 min being sufficient to induce mortality in Pacific halibut, witch flounder Glyptocephalus cynoglossus, American plaice Hippoglossoides platessoides, and pollock Pollachius virens (Hoag 1975; Richards et al. 1995; Trumble et al. 1995; Ross and Hokenson 1997). In a field experiment with lingcod captured by trawl, deck time was more stressful than towing. As deck time was increased from 10 to 60 min, the mortality in fish (55–75 cm TL) rose from 0% to 94% (50% mortality at 30 min), while increased towing time from 1 and 5 h prior to time on deck did not increase mortality (S. Parker, Oregon Department of Fish and Wildlife, personal communication). With lingcod, the laboratory and field results suggested that the sorting, handling, and release of bycatch on deck after capture may be conducted...
in a manner that would probably enhance survival if fish are released within 30 min of capture. Of course, the possibility of reducing bycatch mortality by the rapid liberation of fish depends on the type of handling they receive. If fish are discarded using a gaff or other tools which cause external or internal injury, then mortality rates will be greatly increased.

Sensitivity to towing in a net in the laboratory differed among species. Lingcod, sablefish and Pacific halibut did not experience mortality when towed in a net for 4 h at a speed at which they did not swim (1.1 m/s), followed by exposure to 8.0°C seawater for 30 min and air for 15 min (Olla et al. 1998; Davis and Olla 2001; Davis et al. 2001). However, walleye pollock appeared to be more sensitive as 100% mortality occurred 14 d after towing in a net for 15 min at 0.85 m/s, a speed at which the fish did not swim (Olla et al. 1997). The speeds at which these species were towed and did not swim appeared to be similar to the observed maximum sustained swimming speeds (1.1–1.2 m/s) for a variety of marine species (He 1993). The towing speeds and current speeds were the same in our laboratory nets. The current speeds inside our laboratory nets cannot be compared with the speeds inside commercial trawls since the latter have not been measured and are probably lower than the actual trawl towing speeds because of trapped water and fish.

Lingcod mortality increased with increasing temperature after net towing, and the exposure to increased temperature after capture has generally been found to be a significant source of stress and mortality for fish in both laboratory studies (Olla et al. 1998; Davis and Olla 2001; Davis et al. 2001) and field studies (Plumb et al. 1988; Barton and Iwama 1991; Muoneke and Childress 1994; Schisler and Bergersen 1996; Ross and Hokenson 1997). Seasonal increases in temperature associated with thermoclines and deck conditions would probably increase the mortality of bycatch that might otherwise survive capture and release in cooler seasons. In fisheries observer programs, it would be useful to record water and deck temperatures and body core temperatures, in addition to recording the characteristics of capture and handling processes as well as fish condition and length. Realistic estimates of bycatch mortality related to temperature could be made for various fisheries by combining such observer information with field measurements of the relationship between fish body core temperature, stress, and mortality.

Comparing the results of experiments performed in the laboratory with results obtained in the field must be done with caution. The experiments in this study were generally conservative in their effects relative to field capture conditions and did not attempt to duplicate highly variable field conditions. There were some minor stressors that were unavoidably present in these laboratory experiments, and these were considered part of the overall stressor treatments (including dipnetting and transfer to tanks between treatments). The capture of lingcod by trawl would also include exposure to the effects of depth and pressure changes, crushing and wounding, changes in temperature that are generally less rapid than those simulated in the laboratory, handling on deck during discard of bycatch, the presence of predators, and exposure to thermocline conditions after discarding from the deck. The conclusions from the present study emphasize the principles of stressor action in bycatch mortality. Ongoing work in our laboratory seeks to combine the principles of bycatch mortality with the physiological measures of stress in an effort to develop portable measures of fish condition (Davis et al. 2001). Once the principles of bycatch mortality are correlated with the physiological measures of fish condition, then appropriate field experiments can be designed to estimate bycatch mortality by measuring the condition of fish that are captured in various fisheries.

Delayed mortality is an important factor to consider in the design of bycatch experiments. When lingcod were exposed to capture stressors, there was no delayed mortality after 1 d. Delayed mortality in laboratory studies has been observed after capture for up to 3 d in sablefish, up to 14 d in walleye pollock, and up to 30 d in Pacific halibut (Olla et al. 1997, 1998; Davis and Olla 2001). In the field, delayed mortality has been observed for Atlantic mackerel Scomber scombrus, plaice Pleuronectes platessa, sole Solea solea (also known as Solea vulgaris), Atlantic herring Clupea harengus, and lingcod (Lockwood et al. 1983; Van Beek et al. 1990; Suuronen et al. 1996a, 1996b; Albin and Karpov 1998). Although our results suggest that holding lingcod for 1 d after capture is sufficient to evaluate potential mortality, delayed mortality has been observed for lingcod up to 12 d after capture by hook and line; therefore experiments with lingcod bycatch mortality should include a 12-d period of observation for delayed mortality (Albin and Karpov 1998).

Lingcod mortality resulting from towing and air exposure was greater in small fish (41–51 cm TL) than in large fish (52–67 cm TL). In a previous
field study, a similar effect of size was hypothesized for lingcod captured by hook and line, although this could not be confirmed because of small sample sizes (Albin and Karpov 1998). The relationship between fish size and rates of mortality induced by capture processes has been observed previously in field studies of fish that were captured and passed through trawl gear into a net pen for observation of potential delayed mortality. Under these conditions, species in which smaller fish showed greater mortality included haddock *Melanogrammus aeglefinus*, European whiting *Merlangius merlangus*, vendace *Coregonus albula*, and Atlantic herring (Sueur et al. 1995, 1996a, 1996b; Sangster et al. 1996). This size effect was generally attributed to fatigue in smaller fish from swimming as they passed down the net and to greater injury from abrasion as they passed along and through the net mesh. Studies of trawl-caught Atlantic halibut and Pacific halibut that were held in tanks after capture also found that injury and mortality were greater in the smaller fish (Neilson et al. 1989; Richards et al. 1995). The smaller lingcod were more sensitive to increased temperature after net towing, and similar size effects were also suggested in laboratory studies on sablefish and Pacific halibut as the body core temperature warmed faster in smaller fish than in larger fish (Olla et al. 1998; Davis and Olla 2001; Davis et al. 2001). Size differences in fish sensitivity to increased temperature would be expected in general, based on the observed inverse relationship between the rate of body core temperature increase and fish size (Spigarelli et al. 1977).

Fisheries management strategies often rely on minimum size rules to enhance recruitment and yield, with the assumption that the release of undersized fish may contribute to future recruitment. Unless there is a significant avoidance of undersized bycatch in the fishery, the consequences of differential fishing mortality among size-classes are dependent on the mortality rates of released undersized bycatch. The mortality rates of relevant size-classes of fish are needed to validate the assumptions of management rules for released, undersized bycatch (Wilson and Burns 1996; Bettoli and Osborne 1998).

Minimum size regulations have been applied widely to lingcod fisheries. A limit of 61 cm TL was imposed on all recreational and commercial fisheries for lingcod in California, Oregon, and Washington in 1998. Canadian commercial and sport fisheries are subject to a minimum size regulation of 65 cm TL for lingcod. Our results showed that while the mortality of released lingcod larger than 52 cm may be low enough to support increased yields, the mortality of fish smaller than 52 cm exposed to temperatures greater than 16.0°C or to air for periods longer than 30 min may be too high for the size rule to result in effective fishery management. High-grading (the practice of discarding smaller fish and landing larger ones for economic reasons) would not be recommended when smaller fish have higher mortality rates, as this would disproportionately increase bycatch mortality. To confirm potential size effects, research must be performed in the field to determine how capture processes and seasonal conditions may affect the mortality of undersized lingcod bycatch that are released.

The management of lingcod stocks off Washington, Oregon, and California in 2001 allowed a total catch of 611 metric tons, with retention of lingcod only during May–October for trawl gear, fixed gear and open access, trip limits of 182 kg/month for each gear type, and 1–2 fish bag limit in sport fisheries (depending on the season and state of jurisdiction). In Canada, the management of lingcod in 2001 relied on a combination of closed areas for protection, trip limits (which were higher than in U.S. fisheries), and a total catch of 950 metric tons. Trip limits were 6,818 kg/month for trawl during January–December (with various closed areas and measures to reduce towing time and to avoid the capture of bycatch), 6,818 kg/month per month for hook and line during April–November, and 1–3 fish bag(s) in sportfishing during June–September or April–November, depending on the jurisdictional zone.

Unfortunately under present management scenarios, discarded bycatch and mortality continue to increase as trip limits are reduced and bycatch limits are reached sooner, and as efforts shift to those species with remaining quotas to be fished. For example, under the present management for trawling, the increased fishing mortality associated with lingcod bycatch would eventually result in a severe depression of stocks and the closure of other fisheries that impact lingcod. One radical alternative would be to retain all fish caught, close seasons during periods of warmer weather and water temperatures, and close seasons once bycatch limits have been reached. This alternative is not acceptable to fish processors and fishermen because it would reduce the duration of fishing seasons, make fish unavailable during warmer parts of the year, require the use of expensive observer programs, and produce a larger quantity of smaller,
lower value fish. Sport fishermen would be excluded from the summer months when recreation has its highest value. The most politically and economically feasible management alternatives appear to be the avoidance of areas with lingcod, the reduction of trawling times to 1–3 h, and the implementation of shorter handling times (<30 min) of discarded bycatch on deck as a result of smaller catches per tow.

Acknowledgments

We thank Steve Parker and Polly Rankin for the collection and transport of lingcod to the laboratory. Michele Ottmar, Mara Spencer, Erick Sturm, and Rich Titgen provided excellent technical assistance during rearing and experimentation. The protocols used in this research conform to the guidelines for the ethical treatment of experimental animals prescribed by Oregon State University.

References


Olla, B. L., M. W. Davis, and C. Rose. 2000. Differences in orientation and swimming of walleye pollock Theragra chalcogramma in a trawl net under light and dark conditions: concordance between field and laboratory observations. Fisheries Research 44:261–266.


