Understanding Fish Bycatch Discard And Escapee Mortality

By

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Introduction

One of the most significant issues affecting marine fisheries management today is the mortality of fish that are discarded after capture or that escape from fishing gear. Fish are released after capture (bycatch) because of harvest restrictions: number, size or sex limits, or incidental catch as nontarget species. Fish escape from gear as a result of gear modifications causing unwanted fish to be excluded or released prior to landing. Mortality rates of bycatch and escapees are generally unknown and constitute a large source of uncertainty in estimates of overall fishing mortality. Measurements of bycatch amounts and bycatch mortality rates for individual fisheries are necessary for improvements in present management schemes. Total discarded bycatch has been estimated to be approximately one-quarter of the worldwide fisheries catch, while the amount of fish escaping from fishing gear is unknown. Development of quantitative methods to measure discard and escapee mortality rates in the field requires fundamental knowledge of why fish die after being discarded or escaping and how to measure this endpoint under a wide range of realistic fishing conditions. This article summarizes systematic bycatch research over the past 10 years performed in the laboratory of the Fisheries Behavioral Ecology Group of the Alaska Fisheries Science Center's Resource Assessment and Conservation Engineering (RACE) Division.

Fishing is conducted under social and economic constraints with gear traditionally designed to modify fish behavior in ways to facilitate capture. Fixed gear (hook and line, pots, traps) relies on fish being attracted to gear by baits. Towed gear relies on avoidance responses to herd fish into net codends. Seines also use avoidance behavior to herd fish. Gill nets act as passive capture devices that are generally not detected by fish before capture. Solutions to the bycatch problem have focused on decreasing bycatch by avoiding fishing areas containing unwanted fish and modifying fishing gears to allow unwanted fish to escape through rings in traps, grids, panels, or increased mesh sizes in trawls. Although progress has been made in reducing discards through improvements in fishing gear selectivity, there remain the problems of 1) measuring mortality of fish that are discarded after landing and 2) quantifying the number and mortality of fish that are caught and escape. Little attention has been paid to the role that biology, ecology, and behavior of fish might play in reducing the mortality rate of fish encountering gear.

Because of the seemingly unlimited variety of fishing conditions in the field, members of the Fisheries Behavioral Ecology Group determined it prudent and efficient to uncover patterns of stress and mortality in the laboratory. Results could be used to better understand principles controlling bycatch and escapee mortality and then to correlate innovative behavioral and physiological measures of capture stress and mortality with potential mortality in the laboratory. Such mortality assays could then be used in situ under a wide range of fishing conditions to predict mortality and evaluate new fishing methods designed to reduce bycatch and decrease mortality rates. Investigated principles of bycatch included physical injury from capture and effects of gear; increased mortality caused by interactions of stressors; environmental factors (light conditions, temperature, air exposure, anoxia, sea conditions, and pressure changes); species- and size-related differences in sensitivity to stress; and delayed mortality.

Physical Injury: Capture and Gear Effects

Past bycatch discard research has focused on understanding capture and gear effects. All major fishing gear types involve some degree of injury to discarded fish by internal and external wounding, crushing, scale loss, and hydrostatic effects, with severity of injury dependant on gear type. Contact among fish varies widely, as does fish contact with gear. Effects of gear deployed near the surface, such as gill nets, do not include effects associated with depth, including differences in pressure, temperature, light conditions, and sea conditions. Susceptibility to injury varies with species and stressor type, as well as mix of species in nets (hard vs. soft parts for wounding). Fishes with gas bladders or organs which inflate with changes in pressure, such as rockfish, become trapped near the surface and generally experience 100% mortality. On the other hand, fishes without organ inflation, such as sablefish, have variable and sometimes low mortality and are excellent candidates for a variety of measures that could reduce discard mortality.

Interacting Factors

Stress and mortality in discarded fish from towed- or fixed-gear fisheries result from several classes of stressors (Fig. 1). Interactions of stressors often cause increased stress in fish and must be considered as a primary factor in any assessment of bycatch processes. Classes of bycatch stressors include capture (net entrainment, mesh passage, crushing and wounding, sustained swimming until exhaustion, changes in pressure, catch composition); fishing conditions (towing time, light conditions, water and air temperatures, anoxia, sea conditions, time on deck, handling procedures); and biological attributes (behavior, fish size, species).

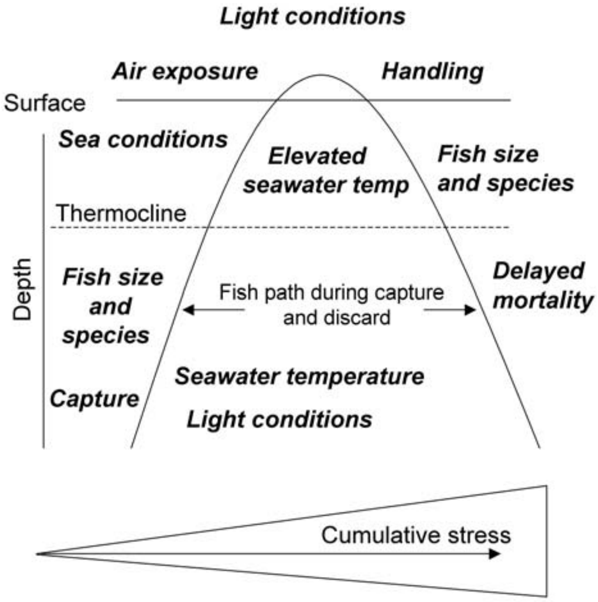

Figure 1. Conceptual diagram of interacting factors in discard mortality for fish caught with deepwater gear (trawl, trap, hook and line). Fish caught with surface gear (seine, hook and line, gill net) would not be subjected to temperature and pressure changes associated with depth. The curved line indicates fish path at depth and the surface during capture and discard. Selected key factors are indicated in bold italic letters. Increasing stress level is indicated at the bottom of the diagram as interaction of factors increases initial capture stress.

Field studies of stressor interactions conducted in the United States and Europe over the past 15 years have been limited and generally uncontrolled. Mortality has been estimated in the field by holding fish in cages, net pens, or tanks or by tag and recapture methods. Confidence in applying generalized discard mortality rates from these field studies to a wide range of fishing conditions is lacking until the effects of factor variation and stressor interaction on mortality are understood. In contrast, a wide range of stressors and their interactions can be studied in the laboratory. Although laboratory bycatch studies can be criticized for lack of realism, they allow for a systematic determination of general behavioral, biological, and physiological principles of stress response up to mortality that is not possible in the field.

Our laboratory bycatch studies conducted over the past 10 years have examined the in-

Figure 2a. Fisheries Behavioral Ecology staff inserting sablefish into a net to be towed to simulate capture in a trawl codend.

Figure 2b. Circular tank and net-towing apparatus for simulation of fish towed in a trawl cod end. Sablefish, Pacific halibut, lingcod, and walleye pollock are towed up to 1.1m/s in two nets attached to arms which are rotated by a 5 hp motor and speed controller. In the tank, light (darkness to low light) and seawater temperature (1° to 14°C) are controlled.

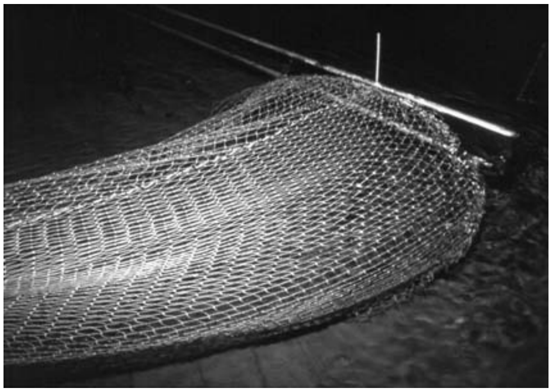

Figure 2c. Sablefish being towed in a net in the net-towing tank to simulate capture in a trawl codend.

teracting capture stressors (towing in a net and hooking), light conditions, temperature, and exposure to air in walleye pollock, sablefish, Pacific halibut, and lingcod using changes in behavior, blood physiology, and mortality as measures of stress. We exposed fish to bycatch stressors by various means. Fish were towed under light or darkness for 4 hours in nets attached to two rotating arms in a tank (4.5 m diameter, 1 m depth) to simulate capture in a codend (Fig. 2). Fish were hooked on lines and held in darkness for 2 - 24 hours to simulate capture by longline. After exposure to capture stressors, fish were placed in lighted tanks with controlled seawater temperature for 15 - 60 minutes to simulate exposure to increased temperature associated with thermoclines. Fish were placed in lighted tanks without water in temperature controlled rooms for 15 - 60 minutes to simulate exposure to air at increased temperature.

In these studies, stress, measured as deficits in feeding, orientation, predator evasion increased with increasing stressor intensity up to the point of observed mortality. Physiological measures (plasma cortisol, lactate, potassium) were not indicators of mortality, as they initially increased with increasing stressor intensity, but maximum concentrations did not differ among fish exposed to sublethal and lethal stressors (Fig. 3).

Light Conditions

Using a circular tow tank and simulated diel light conditions, our laboratory experiments with walleye pollock have shown that fish can swim for up to 3 hours in a net in light without mortality, whereas fish in dark conditions were not able to orient and swim in a net and had 100% mortality after 6 days (Fig. 4). Further laboratory experimentation demonstrated that juvenile walleye pollock collided with an approaching net more frequently in the dark than in the light, supporting the idea that the fish likely experience greater injury and concomitant mortality in darkness. From these studies, we predicted that walleye pollock would not be able to orient to a trawl in the field under dark conditions. A subsequent field study conducted by the RACE Bycatch/Gear Group in 1996 used infrared illumination and underwater cameras attached to the net to film walleye pollock in trawls. We analyzed tapes from this field study and confirmed our prediction of loss of orientation and demonstrated the usefulness of linking laboratory and field bycatch experiments and conclusions. As fishing is often conducted at night or under dark conditions at depth, developing effective gear modifications to reduce discards and improve escape for fish that are volitionally guided out of nets requires a clear understanding of how fish react to gear under conditions when vision is limited or not operative.

Figure 3. Fisheries Behavioral Ecology staff drawing blood from a sablefish that was towed 4 hours in a net at 8°C, exposed to seawater with increased temperature (16°C) for 30 minutes to simulate passage through a thermocline, and exposed to air for 15 minutes to simulate time on deck of a fishing vessel. Plasma is isolated from the blood sample and analyzed for cortisol, lactate, glucose, and potassium to measure stress induced by capture.

Temperature

The additional stress and mortality resulting from the interaction of capture and exposure to increased temperatures may be a widespread condition in fisheries conducted during warmer seasons of the year or in tropical areas where fish are caught in cooler deep water. Exposure to warmer temperatures occurs during retrieval from depth through thermoclines and during air exposure on deck. This exposure results in increased body core temperature, with smaller fish warming at a more rapid rate, and in physiological in-

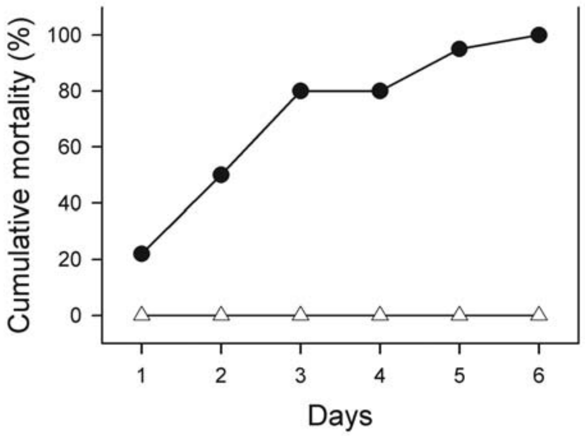

Figure 4. Walleye pollock had higher cumulative mortality (%) after towing 3 hours in a net in darkness (●) than in light (△).

jury and behavioral deficits that can lead to eventual mortality. Our laboratory studies with walleye pollock, sablefish, Pacific halibut, and lingcod after exposure to 4 hours of towing, followed by increased seawater temperature for 30 minutes and exposure to air for 15 minutes showed increased stress and mortality resulting from exposure to increased temperature, alone or in combination with capture and air stressors (Fig. 5).

Low water temperature has been found to reduce fish swimming speeds and endurance in studies conducted in many laboratories. These behavioral deficits would influence the herding of fish by sweeps and the ability of fish to maintain position in trawl mouths and may result in increased mortality. We have observed that low water temperature reduced activity and feeding responses to bait in sablefish and Pacific halibut, thus altering fixed-gear selectivity and catchability, which may result in increased bycatch in longline and trap fisheries conducted at low temperatures. Freezing temperatures on deck may also contribute to discard mortality.

Air Exposure

Exposure to air is an integral part of fish capture and increases any stress and mortality resulting from capture. Exposure times are a function of handling times on deck and can range from a few minutes when catches are small (longline, traps, short trawl tows) to greater than 60 minutes when catches are large (long trawl tows, purse seines). We observed mortality and behavioral deficits in sablefish, Pacific halibut, and lingcod that were exposed to air for various times in tanks without water in controlled temperature rooms (Fig. 6). Resistance to air exposure varied with fish species and size, with small fish having greater mortality than large fish and sablefish and halibut being more sensitive to air than lingcod. For fish that had not encountered lethal stressors already (e.g., pressure changes with organ inflation, mortal wounding, lethal physiological damage from increased temperature), any changes in fishing practices that reduce handling times and exposure to air (e.g., reduced towing time, catch sorting time and time to release from hooks, traps, or gill nets) would reduce discard stress and mortality.

Fish Size

Size-related mortality of discards, with smaller fish showing greater mortality, is an important principle to consider in models of recruitment and yield. Fisheries management strategies often rely on minimum-size rules for harvest, with the assumption that release of under-sized fish may contribute to future recruitment and yield. Target species

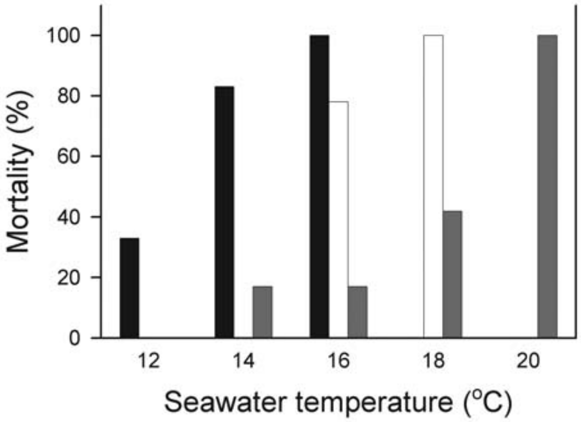

Figure 5. Mortality (%) in sablefish (solid bar), Pacific halibut (open bar), and lingcod (shaded bar) after exposure to 4 hours towing in a net followed by increased seawater temperature (°C) for 30 minutes and air for 15 minutes.

may also be subjected to 'highgrading' in which smaller fish are discarded for economic reasons while larger fish are retained. Our laboratory studies have shown that smaller sablefish, Pacific halibut, and lingcod were more sensitive than larger fish to bycatch stressors and showed greater discard mortality when towed in a net and exposed to increased temperature and air or when exposed to air alone (Fig. 6). When smaller fish have higher mortality, current management assumptions that bycatch mortality does not vary with size are not valid.

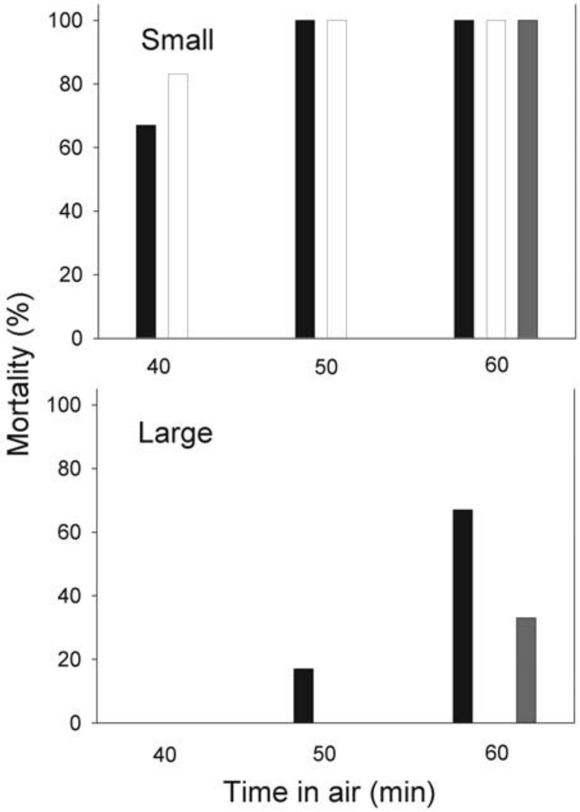

Figure 6. Exposure to air (minutes) resulted in mortality (%) for sablefish (solid bar), Pacific halibut (open bar), and lingcod (shaded bar). Two classes of fish size were used; small (30 - 49 cm) and large (50 - 70 cm). Small sablefish, Pacific halibut, and lingcod were exposed to air (18°C) for 40, 50 and 60 minutes. Small lingcod did not show mortality after 40 and 50 minutes in air. Large sablefish and lingcod were exposed to air (18°C) for 40, 50, and 60 minutes. Large sablefish and lingcod did not show mortality after 40 minutes in air and lingcod after 50 minutes in air.

Anoxia

Lack of oxygen in fish in towed gear, purse seine sets, and piles of fish, slime, and mucus on deck may lead to conditions of anoxia and fish mortality. The interaction of other stressors with anoxia may also be significant. This subject has not been researched. Experiments with anoxia in bycatch would probably best be done under field conditions.

Sea Conditions

Few studies of bycatch discard mortality have accounted for possible effects of sea state and current regimens. In the presence of strong currents or as sea conditions become rougher during the passage of storms, changes would be expected in both towed- and fixed-gear fish. Direct interactions with gear would result in increased injury and mortality. Gear selectivity and the effectiveness of bycatch exclusion devices would probably change, resulting in increased mortality.

The Fate of Escapees

Due to pressure on fisheries to reduce bycatch and discarding, trawl fishers have responded by utilizing a mixture of bycatch reduction devices, such as bird's eye escape holes, Nordmore grates, escape panels, and larger or square mesh codends. These devices have been moderately successful in some fisheries at reducing the number of unwanted and under-sized fish that reach the deck. However, as the observed bycatch and rate of discard decline, the question remains: Do fish escaping trawls via bycatch reduction devices actually survive? Studies in Europe have utilized cages that surround the codend and retain escaping fish, thereby allowing monitoring of their survival over time. These studies have indicated that survival can be highly variable among species, with direct mortalities of 10% - 30% being common for escaping fish. For fragile species such as herring, mortality can be as high as 70%. Arguably, these fish should be considered part of an unobserved bycatch. Studies of

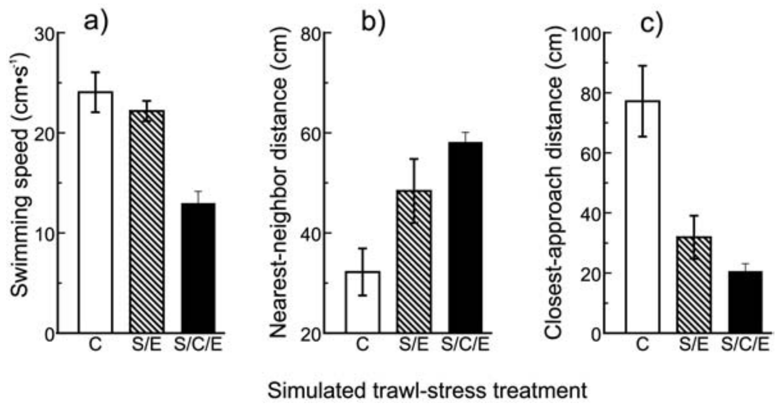

Figure 7. Behavioral impairments and recovery of juvenile walleye pollock after exposure to control, swim/escape and swim/crowd/escape treatments. a) Mean swimming speed (± SE) of walleye pollock. b) Mean nearest-neighbor distance (± SE) between walleye pollock; lower nearest-neighbor distances are indicative of more cohesive shoaling. c) Mean closest approach (± SE) between each walleye pollock and the predator during a 2-minute period. Behavioral measures were made immediately after the fish "escaped" into an arena containing a 3-year-old sablefish predator.

walleye pollock, conducted in conjunction with the RACE Division, indicate that mortality of walleye pollock escaping through a 93-mm square mesh overhead escape panel ranged from 40% to 80%, depending on whether fish exited the net in the codend or in the intermediate (the section of net in front of the codend). As in the European studies, fish escaping the trawl were retained in a cage which was detached and moored after the tow, then monitored for mortality over 14 days. An unintentional consequence of this methodology is that the caged fish are protected from the natural rigors of life in the sea, most notably predation. As such, these numbers likely underestimate true unobserved bycatch, as they do not include fish which become behaviorally impaired and succumb to predation in hours or days after escape.

Because field studies of the effect of trawl-passage upon vulnerability to predation are logistically impossible, we addressed this issue in a series of laboratory experiments. Age-0 walleye pollock (17.1 - 21.6 cm total length) were sequentially subjected to stressors simulating those experienced during trawl passage; sustained swimming, crowding, and escape through codend meshes. The fish escaped into a tank containing a larger sablefish (48 - 53 cm), where the pollock anti-predator behavior could be quantified. Having undergone simulated trawl passage, the pollock exhibited significant impairment in anti-predator behavior compared to control fish; they swam slower, shoaled less cohesively, and allowed the predator to get closer (Fig. 7).

Importantly, behavioral impairment was correlated to the magnitude of the stress, as fish exposed to swimming, followed by escape, were less impaired than fish that also experience crowding. Behavioral impairment lasted at least 2 hours, with fish recovering within 24 hours. In subsequent experiments, when trawl-stressed walleye pollock, along with control fish, were exposed to predation by a lingcod (48 - 60 cm), the trawl-stressed fish were consumed in greater numbers (Fig. 8). We have conducted these identical experiments with juvenile sablefish. From prior experiments we know that sablefish are more "durable" (i.e., more robust), being able to survive physical stressors that typically kill walleye pollock. Nonetheless, sablefish still showed the identical behavioral impairments resulting from sublethal stressors simulating entrainment and subsequent trawl escape. This suggests that behavioral impairment from stress may be a ubiquitous effect, influencing the survival of both durable and fragile fish species. Perhaps more importantly, this work suggests that the fact that bycatch does

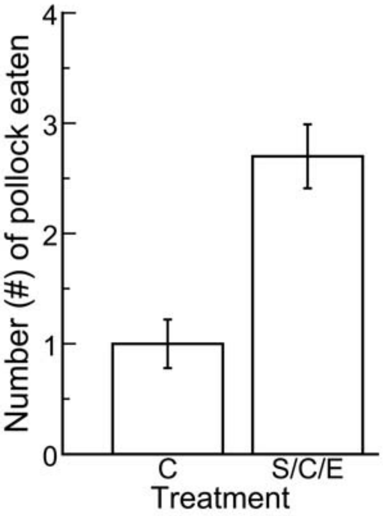

Figure 8. Mean consumption (± SE) of control and trawl-stressed (swim/crowd/escape) by lingcod. Five trawl-stressed walleye pollock were mixed with an equal number of control fish prior to predation in each of seven trials.

not appear on deck, does not mean that those fish have been released from the gear unimpaired and are capable of surviving. While a laboratory study cannot predict the number of fish consumed by predators after escaping trawls, it does suggest that reducing the time nontarget fish spend in the gear and hence the cumulative stress they incur, will minimize both direct and predation-mediated mortality.

Delayed Mortality

Delayed mortality of discards may be common and can occur over an extended period of time after capture and release. This can result from 1) physical injury and wounding associated with capture, 2) physiological injury associated with environmental factors, and 3) indirect mortality resulting from predation and disease. Delayed mortality is difficult to measure in the field because of the logistical problems of holding fish for long periods of time in cages, net pens, or tanks. Tag and recapture studies measure delayed mortality, but give no information about the time course of mortality. To investigate the principle of delayed mortality associated with bycatch, we held fishes in the laboratory under controlled conditions for up to 60 days after exposure to bycatch stressors and found delayed mortality (100%) in Pacific halibut and sablefish after 30 days, walleye pollock after 14 days, and lingcod after1 day. Delayed discard mortality indicates the presence of sublethal effects of bycatch stressors that may eventually result in indirect mortality from predation, physiological stress, or disease. We also observed behavioral deficits in orientation, startle responses, swimming ability, phototaxis, feeding, schooling, social interactions, and predator evasion in walleye pollock, sablefish, Pacific halibut, and lingcod exposed to bycatch stressors. These behavioral deficits ultimately resulted in increased mortality caused by fish predators in our laboratory. Although laboratory experiments are not necessarily comparable to field conditions, it is intuitively obvious that capture-impaired fish have a reduced ability to avoid predation.

Summary

Past efforts at understanding and reducing bycatch mortality have focused on modifying fishing gear to avoid capture of potential bycatch and to reduce physical injury to fish that are caught in fishing gear. Fish experience stress from physiological injury and behavioral deficits that may not be readily apparent to human observers, but may result in significant direct or indirect mortality in discards and escapees. Bycatch mortality is linked to environmental (light conditions, temperature, air exposure) and biological (behavior, fish size and species) factors and their interactions which have not been previously investigated in any detail. Research in a laboratory setting under controlled conditions allows for a systematic investigation of bycatch stressors and furthers our understanding of key principles of bycatch mortality.

This article is based on "Key principles for understanding fish bycatch discard mortality" by Michael W. Davis, which appeared in the November 2002 issue of Canadian Journal of Fisheries and Aquatic Sciences.

Relevant Papers From the Fisheries Behavioral Ecology Group:

Davis, M.W. 2002. Key principles for understanding fish bycatch discard mortality. Can. J. Fish. Aquat. Sci. 59: 1834-1843.

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