SARC 53 Gulf of Maine Atlantic Cod Data Working Group

Working Paper 1. A review of factors affecting the survival of Gulf of Maine Atlantic cod (*Gadus morhua*) discarded at-sea

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Abstract

Previous assessments of the Gulf of Maine Atlantic cod (*Gadus morhua*) stock have included estimates of discards from the commercial fishery. These estimates have assumed that there was no survival of fish discarded at sea. There is a growing body of literature suggesting that there may be some survival of fish discarded at sea with the survival contingent on multiple factors including gear type, fish size, depth, season, soak duration and overall handling care. Incorporating the results from experimental studies into absolute estimates of fisheries removals is difficult do to the number of factors, the high degree of interactions effects and the uncertainty in the general population. This paper provides an overview of the scientific literature relevant to the survival of Atlantic cod discarded in the commercial fishery.

Introduction

The magnitude of fishery discards, both commercial and recreational, can represent a considerable fraction of overall fishery removals. In the most current assessment of the Gulf of Maine Atlantic cod (*Gadus morhua*) stock, commercial discards accounted for up to 65.5% of the total catch in any given year, though typically, in the vicinity of 10-20% (Mayo et al. 2009). Incorrect assumptions about the fate of fishery discards can lead to biases in the stock assessment and yield projections (Mesnil 1996, Breen and Cook 2002).There is a growing body of literature suggesting that there may be some survival of fish discarded at sea, including work specific to Atlantic cod.

There are numerous factors that can affect the survival of discarded fish. These can be broadly categorized into three areas: biotic effects, capture and gear effects and interaction effects (Davis 2002, Fig. 1). Biotic effects include the fish species, its behavior in the net and the fish size. Capture and gear effects include net entrainment, physical injury, pressure changes and sustained exhaustion (e.g., tow duration). Interacting effects include environmental temperature, sunlight exposure, handling time and care, post-release predation and behavioral impairment. A thorough summary of the contributing factors is provided in Davis (2002) and summarized as they relate to northeast groundfish by Hendrickson and Nies (2007).

Specific to Atlantic cod, these factors can include fishing gear type and characteristics, tow/soak duration, fishing depth, handling care and time on deck, fish size, volume and composition of the catch (for trawls), predation rates of injured individuals (particularly by avian predation), and environmental conditions (Suuronen 2005). Because of the interaction of these numerous factors, it is important that discard survival rate studies reflect commercial fishing conditions. Limited data are available with which to assess the mortality rate of cod in the Gulf of Maine, since only a few studies have been conducted that address the above factors. Those that exist have produced conflicting results. Some of the high variability in survival rates for the experiments may be attributed to a lack of information on how fish condition is affected by the various fishing stressors and the type and severity of physical damage received (Chopin and Arimoto 1995). Additionally, there is evidence that over 50% of capture-induced mortality occurs > 72 hours post release (Sangster et al. 1996). Much of the research work done on survival has focused on the short-term survival (≤ 72 hours) though there is evidence that short-term survival studies may underestimate long-term survival by as great as 50% (Sangster et al. 1996). Confounding the interpretation of these mortality studies is the fate of post-release fish. Some research has suggested that post-release mortality due to predation is in the vicinity of 50% (Milliken et al., 1999).

Comparative gear work

Much of the literature reviewed here assessed the effects of fishing gear type on discard mortality. Benoit and Hurlbut (2010) showed that fish condition, based on vitality score, was poorest for gillnet-caught cod, and best for handline. Vitality scores for longline-caught fish fell in between (Table 4). Overall short-term survival was estimated at 64% for handline caught fish, 59% for longline and 38% for gillnet. The work of Benoit et al. (2010) extended the Benoit and Hurlbut (2010) work to trawl gear based on observer coding. Milliken et al. (2009) reported longline survival in the range of 45-83% contingent on handling care and environmental conditions. Jean (1963) estimated average short-term survival of 8%, leading to a conclusion that "…the majority of cod and plaice discarded at sea…are dead when thrown overboard". The survival rates of trawl caught cod estimated by Robinson and Carr (1993) were somewhat higher, ranging from 13-51%.

Handling methods

The handling methods for cod once they are caught and the time spent on deck are also major factors that affect mortality. Carr et al. (1995) found that cod showed differential survival according to both tow duration and deck treatment. Cod showing the highest survival were kept in dry trays, and the lowest survival rate was seen by the cod kept in wet trays. Jean (1963) also showed that survival decreased with increasing deck exposure and air temperature. As for releasing the fish from the gear, gangion cutting for Pacific halibut resulted in far fewer severe injuries than careful shaking and hook straightening (Kammer and Trumble 1998). The longline discard survival studies that have been conducted indicate that discard mortality is largely dependent on the de-hooking method and the ability of a species to quickly swim below the surface upon release so as to avoid avian predation. The “crucifier” method of de-hooking which is commonly used in the Northeast longline fisheries is associated with fairly high rates of mortality for cod (Milliken et al. 1999), especially when post-release avian predation mortality is considered, and haddock (Huse and Soldal 2002). The survival rate for cod encountering a crucifer was only half that of jigged cod (Farrington et al. 1998). Palsson et al. (2003) showed that short-term mortality from recorded injuries ranged from 20% to 50%, though the injuries were thought to be likely to impede post-release feeding and lead to even higher long-term mortality.

Fish size

Fish species, size, and age also affect mortality rates for discarded cod. The work of Jean (1963) suggest that smaller cod experienced lower survival than larger cod. Similar size-dependent mortality among longline-caught fish was reported in the work of Milliken et al. (1999). In the work of Sangster et al. (1996) survival of fish <20 cm was near zero and the survival of fish >25 cm was generally more than 90%. Such findings are consistent with those of Soldal et al. (1991) which suggests that smaller cod are more susceptible to gear damage than larger cod. Conversely, the work of Farrington et al. (2003) suggests that mortalities of fish held after being captured by demersal longline and hook and line had mortalities in the same length range as surviving fish.

The effects of size on the post-release survival of cod is variable, though there is a general trend for increased survival among larger fish; particularly those > 25 cm. Overall, accounting for size-specific differences in discard and escape mortality is important since this will have a direct impact on estimates of catch at age (Breen and Cook 2002).

Survival of cod-end escapees

Much of the work reviewed has focused on the post-release survival of fish discarded at sea. Though not directly related to post-release survival, a discussion of unaccounted mortality should include some consideration of the survival of undersized fish that escape from the cod-ends of mobile fishing gear. Increases in minimum codend mesh size and other gear selectivity measures are often implemented to reduce fishing mortality rates on immature fish. This assumption is based on the thought that fish escaping from the mesh are not seriously injured and post-escapement survival is high. Field and laboratory studies have shown that this assumption is not always valid. The work of Carr et al. (1995) suggested approximately 83% short-term survival (<24 hours) of Atlantic cod, though other studies have indicated survival to be closer to 100% (Ingolfsson et al. 2002, 2007). Though the Sangster et al. (1996) work did not directly examine cod, their work did suggested survival on the order of 48-86% (haddock and whiting) with higher survival of fish when passing through larger sized mesh.

Post-release fitness

The blood biochemistry of cod has been shown to change significantly after being captured in fishing gear (Farrington et al. 1998). This may also have a seasonal and/or environmental component. This was noted by Robinson and Carr (1993); the blood biochemistry of fish caught in June were more stressed than those caught in April. Acute injuries sustained during capture may not be fatal, but may impact the post-release behavior of the fish. For example, Kaimer (1994) found that halibut of fish surviving releases with after sustaining severe injuries experienced slower growth than those sustaining less severe injuries. The causal factor for decreased growth is unknown, but interference with normal feeding is a hypothesis. Work summarized in Davis and Ryer (2003) suggest that fish surviving discard or trawl cod-end escapement may swim slower, school less cohesively and overall be less responsive to predators. The overall conclusion is that fish surviving capture in the fishery are likely to experience an overall decrease in the relative fitness.

Below some specific summaries are provided for the relevant literature:

Benoit, H.P. and T. Hurlbut (2010): Study area occurred in the Gulf of St. Lawrence. Examined the short-term survival of fish caught in trawl gear towed 1-2 hr at 2.75 knots using typical commercial trawl gear (286 Rock-hopper). On capture fish were assigned vitality scores ranging from 1-4 (Table 1) and then placed in a holding tank for 48->72 hours. On completion of the experiment, short-term survivals by vitality score were then determined (Table 2).

Fish discarded from three fixed gear fisheries (gillnet, longline and handline) were assigned vitality scores by trained observers prior to release. For Atlantic cod, the overall discard vitality was poorest for gillnet gear and best for handline (Table 3). If one assumes that post-discard survival is more a function of the vitality score at discard rather than the gear type associated with the capture it is possible to estimate an expected short-term survival from these results. By applying the short-term survival rates from the controlled experiment to the observer-determined vitality scores an overall gear-specific survival can be estimated. These estimates suggest that the short-term survival by gear type is approximately: 38.1% for gillnet, 58.9% for longline and 63.7% for handline.

The short-term survival estimates are likely underestimates for several reasons:

1. Participating fishers were knowledgeable of the study objectives and it is possible that fish were handled with more care than typical of unobserved trips.
2. The controlled survival experiments likely provide underestimates of total mortality because of the elimination of post-release predation.

Even in the absence of post-release predation, short-term survival may account for <60% of the total post-discard mortality (Ryer, 2002)

Benoit, H.P., Hurlbut, T. and J. Chasse (2010): Proposes the use of a mixed-effects multinomial proportional-odds model, which is appropriate for modelling ordinal vitality data and is a useful approach for addressing observer scoring subjectivity.

Two-part study during 2005 and 2006 fishing seasons in the southern Gulf of St. Lawrence. The first part was based on data collected by at-sea observers, using all gear types (gillnets, demersal longlines, handlines, and mobile gear), where they rated captured fish based on vitality. The second was based on experiments where fish were captured using a bottom trawl commonly used by local commercial fish harvesters at 2.75 knots for 1–2 h. Fish were kept in tanks with temperatures set to the bottom temperatures where the capture occurred for at least 48 h (though often >72 h) to assess short term survival.

At-sea observers collected vitality data on over 13,000 fish (all taxa). Fish of all taxa tended to be in overall better condition (i.e., higher proportion of individuals with lower vitality code scores) in hook and line fisheries compared to mobile gear fisheries. For cod, vitality scores were also higher for the handline-caught fish. For all taxa captured by more than one gear type, the difference between gear types was statistically significant, as was the random effect. Survival of cod in the holding experiment ranged from 65% for cod with the highest vitality score to only 1.9% of cod in the lowest vitality category.

Breen, M. and R. Cook (2002): Proposes a method for calculating a mortality rate and applies it to North Sea haddock assessments.

The relative importance of the escape mortality component decreases with increasing age. Moreover, the proportion of fish dying on encountering the gear increases with age to a maximum (1.0) at age 5. Accounting for discard and escape mortality has an impact on fishing mortality pattern by age. This is likely to affect the calculation of equilibrium yield and related biological reference points.

Shows that exclusion of discard mortality would lead to very significant biases in all aspects of the stock assessment process, as well as the benefits of including escape mortality estimates in stock assessments. Historically, escape mortality appears to have contributed little to total fishing mortality, F, (even assuming all escaping fish die), for anything other than the very youngest fish (<age 2). Although, in recent years the relative importance of escape mortality has increased, as the trend for using more selective gears has continued. Furthermore, inclusion of escape mortality in predictive models was shown to have significant impact on estimates, even at reasonably low escape mortalities ($s_e = 0.75$). This was particularly true for the calculation of equilibrium yield and comparing the effects of different gear selectivities.

Carr, H.A., Farrington, M., Harris J. and M. Lutcavage (1995): Juvenile groundfish deck discards and codend escapees were collected during normal fishing operations during the summers of 1993 and 1994. Tow durations were 1 or 3 hrs. Fish were placed in one of three deck treatments (wet, spray, or dry bins) for a set period of time. Survival rates were calculated by placing the fish in cages and returning them to the tow depth for about 72 hrs. Codend escapee survival was determined by releasing a codend cover/cage approximately 20 minutes into the tow and returning then to depth for a period of 24 or 72 hours.

Deck discarded was the only species to show differential survival according to both tow duration and deck treatment. Cod showing the highest survival (25%) were from one hour tow - dry trays. Cod showing the worst survival were from the one hour tow – wet trays (0%). For codend escapees, during the first cruise cod had high 24 hour survival (83%). After these survivors were held for an additional 72 hours, 94% of the cod survived

Chopin, F.S. and T. Arimoto (1995): Reviews literature on condition of gear escapees and concludes that immediate and delayed mortalities can occur in fish escaping from fishing gears, and that the high variation in mortality rates within experiments is associated with a lack of information on how fish condition is affected by various fishing stressors and the type and severity of physical damage received. Improving selectivity without reducing damage or stress incurred during capture and escape may not be the most appropriate way of protecting immature fish.

Davis, M. (2002): Argues that studies of discard mortality in the field have generally not addressed the importance of environmental factors and interactions of stressors in determining potential mortality rates. Suggests that the combination of laboratory and field experiments is crucial to success and that prediction of discard mortality in a wide range of fisheries requires fundamental knowledge of why discarded fish die and the relationships between mortality, bycatch stressors, and fish stress physiology and behaviour.

Resolving the discard mortality issues should come from a combination of social, economical, engineering and biological solutions. More attention should be paid to the interaction of fishing and environmental conditions (light, temperature, air exposure, anoxia, sea conditions, pressure changes) and biological factors (fish size and species, behavior, physiology, and potential mortality). Fish with organs that inflate due to pressure changes usually experience complete mortality. These fish would not be considered for reduction of discard mortality unless it is from gear avoidance and/or escape measures before landing on deck or in shallow waters. Mortality is lower in the fish that do not have organs that inflate after capture.

Discard mortality is difficult to assess because there are various stressors and interactions are not easy to study at sea. However, it is also difficult to assess discard mortality in the laboratory because it's difficult to simulate by catch stressors. Mortality increased as stressor intensity increased.

Exposure to warmer temperatures (whether air or water temperatures) increase physiological stress and mortality. Sea conditions can also be a problem. Increased injury and mortality can happen from the rough seas and longer handling time on deck. Measurable mortality in various fish species was 15-60 minutes of air exposure, depending on the species. It hasn't been separated from increased temperature and is noted that it should be investigated. Fish size is extremely important in measuring discard mortality. Smaller fish tend to show greater mortality and should be considered in models of yield and recruitment. When smaller fish are discarded so larger fish can be landed, it disproportionally increases discard mortality because smaller fish have higher mortality rates. There could be crushing and other injuries in the net, less oxygen, etc.

Farrington, M., Carr, A., Pol, M. and M. Szymanksi (2003): (East of Cape Cod around Great South Channel—juvenile cod) Fish were captured using demersal longlines and hooks removed by hauling gear ("snub") or backing the fish off hook ("flip"). Then they were assessed for damage and placed in holding tanks. They were checked for mortality after 72 hours. Mortalities had same length range as surviving fish.

This is contradictory to other studies.

Farrington, M., Milliken, H., Lent, E., Carr, H.A (1998?): Juvenile cod were collected during experimental longline fishing operations during 1996 and 1997. Fish were removed from fishing gear either mechanically (Wounded) or gently by hand (TLC). Survival rates were determined by placing the juvenile fish into large cages and returning them to the depth at which they were caught for a period of about 72 hours. The lowest survival figures were found for fish that were wounded by the mechanical dehooking device. The results from the study showed that there was high mortality associated with capture using the 11/0 circle hook when the cod were damaged from the process of having their jaws broken or torn after passing through the crucifier. Mortality increased when predation by herring gulls was considered.

The longline caught 658 sub-legal cod (less than 49 cm). All fish were tagged, measured and the location and severity of their wounds recorded. During the third cruise, 129 cod were caught by hand jigging. Survival of cod for all three cruises ranged from 22-47% for cod passing through the crucifier and 38-63% for cod that were carefully removed and did not pass through the crucifier. The third cruise, which had the least significant problems and the most complete data set, established that the 72 hour survival rate for cod encountering the crucifier was 22% , cod gently removed was 38% and jigged cod was 44%.

Blood biochemical analyses were conducted on fish caught during experimental longline operations in part 2 of the study. These analyses revealed that these cod showed significant ($p<0.0001$) changes in their blood profiles after being removed from longline fishing gear. With the exception of potassium ion concentration all parameters that were measured immediately after cod v/ere removed from longline gear (protein, lactate, sodium ion and chloride ion concentrations and hematocrit and osmolality) were elevated when compared to normal values.

Hendrickson, L.C. and T. Nies (2007): Provides a summary of discard and gear escapement survival rates for some of the Northeast groundfish species. See Table 8 for summary of information for cod.

There are several factors that dictate the survival of discarded fish such as: species and size, volume and composition of the catch, predation rate of injured individuals, and environmental conditions. Survival rates seem to be lower for species that have swim bladders or other organs that are sensitive to pressure. For trawl caught gadids such as cod and haddock, discard mortality seemed size dependent, where large fish had a higher discard survival rate than smaller fish. In studies of longline discard survival rates, it indicates that discard mortality is highly dependent on the unhooking method and ability of the fish to swim below the surface to avoid bird predation. It is also size dependent for cod specifically in the longline fishery.

When gear selectivities are implemented (such as increased minimum cod end), the discard mortality on immature fish decreases. It is based on the assumption that escaped fish survive, however they may still die. The escape from trawl mortality rates are the highest 2-3 days after the escape then decreases after 1-2 weeks. One way to incorporate discard survival rates into a model is by using a VPA. This allows testing for significance of discard survival rates despite the high levels of variability.

Ingolfsson, O., Soldal, A.V., and I. Huse (2002): Mortality and injury rates of cod were studied after codend and grid escapement in two full scale trials in August 2000 and 2001 in the Barents Sea (around 70 hauls were made each year and 94 cod were caught in total). The escaped fish were sampled using small meshed cages. Trawl caught controls were sampled by removing the codend and attaching the cage directly to the codend extension. In the 2001 trial, control fish were sampled in fish traps in addition. Survival rates of cod and saithe escaping through codend and sorting grid were 100%.

Cod had significantly less skin and fin injuries than haddock, and in general, frequency of skin injuries increased towards the tail. Grid escaped gadoids had significantly less skin and fin damages than the mesh and control groups.

Ingolfsson, O.A., Soldal, A.V., Huse, I. and M. Breen (2007): Investigated the survival of gadoid fish in the Barents Sea escaping from a demersal trawl during commercial fishing conditions, with and without a sorting grid, at high and low levels of fishing intensity. Two experiments were conducted out of Varanger Peninsula in Norway at depths of 45–90 m during the periods 16 April–5 May 2004, and 28 March–18 April 2005. The trawler towed for ~0.5 h at a speed of 3.5-4 knots with the cage open at the rear, allowing all fish to pass through it. The observation period was 6 d, which showed peak mortality on day 1, followed by a gradual decrease in mortality over the next few days, after which secondary infections, thought to be caused by captivity, started to appear after ~1 week.

Conclude that the mortality of cod following their escape from either the codend or selection grid of a demersal trawl is negligible. Also, mortality was not affected by fishing intensity.

Jean, Y. (1963): Assessed the survival of undersized cod discarded from commercial trawlers operating in northern New Brunswick as a function of fish size, time on deck and ambient temperature. Generally smaller cod (< 40 cm) experienced lower survival than larger cod (40 cm – 59 cm). Survival decreased with increasing deck exposure and air temperature. Survival ranged from an average of 8% to 81% per experiment depending on the air temperature and cull time. After 45 minutes on deck at low air temperatures (-1.1º to 0.6ºC), average survival was 8%, with no survival of fish smaller than 40 cm. At higher temperatures (4.4º to 7.8ºC), even with a decreased cull time of 30 minutes, average survival dropped to 6%; again with no survival of fish smaller than 40 cm (Table 6). It is unknown how the cull times reported in the article compare to the cull times experienced on commercial draggers operating in the Gulf of Maine. The results of the survival experiment led the researcher to conclude that the majority of cod discarded by northern New Brunswick draggers are discarded dead.

Kaimmer, S.M, and R.J. Trumble (1998): Observers in the Pacific halibut longline fishery subsample the released halibut for fish condition, and condition codes are used to track cumulative bycatch mortality in these fisheries. Tag return rates of halibut released from longline gear near Kodiak Island, Alaska, are used to estimate relative and absolute mortalities of fish by release method, hook removal injury, and condition code. Generally, the proper application of the careful release techniques results in only minor hook removal injuries. Survival rates of moderately and severely injured halibut are 1.5-2 times higher than previously assumed. One result of our study is the finding that not all fish judged at tagging as likely to die actually die.

12,851 fish were sampled in total using 4 release methods. The fork length of tagged fish ranged from 34 to 191 cm, with an average length of 77 cm. The smallest proportion of severe injuries was observed in fish that were released by gangion cutting (leaving hook embedded in the jaw or the mouth) In the few minutes between gangion cutting and our inspection and tagging, almost 15% of the then unattached hooks had fallen from the fish' mouths. Careful shaking and hook straightening had higher proportions of fish with more severe injuries. Injuries were far more severe with fish removed by the hook stripper, less than 25% exhibited minor hook removal injuries. Small but significant differences were found between the severities of injuries resulting from all of the release methods from the two hook styles. When the removal technique involved stressing (hook stripping) or deforming (hook straightening) the hook, injuries were more severe for removal from the stronger circle hooks compared to removal from the weaker autoline hooks.

No short-term mortality was observed over periods of 4 or 10 days, even for fish with severe injuries. This observation is conservative, since small tank sizes and rough weather during the tank holding could be expected to increase stress conditions during holding. Tag recovery rates, by either class of hook removal injury or condition code, showed significant differences. From these tag returns, the survival of poor condition halibut is estimated at 73%, while the survival of dead halibut is estimated as 26%.

From the perspective of mortality, the mortality of poor fish is almost eight times as great (27% vs. 3.5%), while the mortality of dead fish is over 21 times greater than that of excellent fish (74% vs. 3.5%). These numbers agree with those currently used for the management in direction, but not in magnitude, and suggest that poor and dead condition fish survive at higher rates than currently assumed.

Kaimmer, S.M (1994): Type of injury and subsequent survival was assessed for halibut that were removed from longline gear using either the manual method (a gaff is used to invert and then shake the hook) or the automated method (closely spaced pipes or rollers located between rail and line hauler tear the hook from the fish mouth; hook strippers are popularly known as "crucifiers"). Study site was 20 km east of Kodiak Island off Alaska at shallow depth (<100m), from 1-3 September 1986. Haul back occurred after 4 hours of soak time. 95% of hooking through side wall of mouth, more often on the left (blind) side; smaller fish (<82 cm) were hooked in places other than jaw a significantly higher proportion of the time. A highly significant difference was found in distribution of hook removal injuries, with automatic method resulting in greater occurrence of more severe injuries (torn jaw and cheek, torn face); smaller fish suffered the more severe injuries more often than larger fish. No significant difference was found in injury by fish size with the manual method. Automated removal of hooks increases the severity of hooking injury, decreases survival of released fish, and of the released fish that survive, their growth rate is decreased (presumably because the torn jaw/cheek/face limits their ability to feed).

Kaiser, M.J. and B.E. Spencer (1995): Investigated the survival of animals caught by a 4 m beam trawl fitted with a chain matrix and a sole net with an 80 mm diamond mesh cod end. Trawling was undertaken by the RV 'Corystes' at a site 34 m deep (chart datum) off Dulas Bay, Anglesey, North Wales, UK in March and August 1992, April 1993, and April and October 1994. The trawl was towed for ca 30 min at a mean speed of 4 knots (it was not possible to tow for commercial durations).

Did not include cod; all fish caught had high mortality rates. Dragonets *Callionymus lyra* continued to die throughout the experiments, and had a final mortality of 68-97%. Initially, none of the cuckoo rays *Raja naevus* were dead, but after 5 d 41 % had died. Plaice *Pleur-onectes platessa* and dab *Limanda limanda* had the highest initial mortality of the fish examined, and their total mortality increased to 61% and 76% respectively. Lesser-spotted dogfish *Scyliorhinus canicula* were extremely resilient as 90% had survived after 6 d.

Mesnil, B (1996): Examines the effects on estimates obtained by VPA when discards are allowed to survive, and validates a procedure for deriving partial fishing mortalities in multiple-fleet fisheries where discarding and survival rates are fleet specific.

The main objective of this paper was to examine how VPA results are altered when survival of discarded fish is taken into account. As expected, this results in lower fishing mortalities, since fewer fish are effectively killed. Perhaps more counterintuitive is the finding that this also results in smaller estimates of the population number and biomass for the ages concerned.

Milliken, H.O., Farrington, M., Carr, H.A., E. Lent (1999): Study was conducted to determine the survival rate of sub-legal cod caught in the longline fishery using 11/0 circle hooks. The focus of the research was to assess the rate of mortality of sub-legal catch after the cod were placed in cages for 72 hours. The results of the study showed that there was high mortality (69%) associated with capture using the 11/0 circle hook when the fish were injured by the process of having the hooks removed from their mouths by the crucifier. Furthermore, sublegal cod that had wounds from the dehooking process and were under 39 cm were statistically more likely to die as compared to cod between 38 and 49 cm. An ancillary set of observations on the predation by sea birds of released sublegal cod was included. Despite low numbers, the findings from these observations show that sea bird predation should be included when estimating the survival of fish caught by a longline.

Milliken, H.O., Farrington, M., Rudolph, T. and M. Sanderson (2009): The survival of sublegal Atlantic cod caught in the Georges Bank longline fishery was assessed. The work was primarily focused on examining the short-term (≤72 hours) survival of 'snubbed' fish relative to 'un-snubbed' fish. Fish caught concurrently using electric jigs were used as a control. The handling procedure used for the control group utilized the same procedures developed for the Northeast Regional Cod Tagging Program (Tallack et al. ????). Additionally, only healthy-looking fish with no major injuries were selected for the control. These two facts severely limit the applicability of control-group survival rates to commercial handline gear.

Survival of longline caught fish ranged from 45.2 to 82.8% dependent on whether the fish were 'snubbed' or 'un-snubbed', sea surface temperature and fishing depth. Generally survival was greater among the unsnubbed fish caught in shallower water at lower sea surface temperatures (i.e., those factors which limited physical injury and thermal and hydrostatic stress). Given the work of Sangster et al. (1996), these estimates may be high because of the probability of additional post-release mortality from injuries sustained during capture. Sangster et al. (1996) suggests that an additional 25 to 55% mortality may occur after 72 hour observation period. This estimate would not account for predation mortality and longer-term mortality.

Palsson, O.H., Einarsson, A. and H. Bjornsson (2003): Study examined survival of undersized cod in the Icelandic handline fishery. Fishing depths ranged from 100-200 m (most sites < 100 m). Similar length distribution to commercial longline and recreational discards. Recorded injury types which show that injuries to the jaws, tongue, vomer and eyes are the most common. The short-term mortality from these types of injuries ranged from approximately 20% to 50%, though injuries to these area may impede post-release feeding and lead to long-term mortality. Kaimmer (1994) found that longline-caught halibut with severe injuries have exhibited decreased growth rates. Overall, higher acute mortality was associated with less prevalent injuries such as those to the gills and belly. The authors noted an overall difference in the vitality of the control fish compared to the discarded fish. They wondered "whether fish in such condition, injured and exhausted by fishing gear and eventual following treatment [handling on deck], might be subject to increased risk of predation, in addition to other types of "escape mortality"."

The control fish experienced zero mortality where as the handline caught fish experienced 43% mortality. This would suggest that observed mortalities were related to the capture event and not cage-induced mortality. Mortality was greatest in deep water (75-122 m, 54% mortality) compared to shallow water stations (19-53 m, 32% mortality).

Richards, L.J., Fargo, J., and J.T. Schnute (1995): All measured factors, including physical condition, time spent on vessel deck, halibut length, total weight of catch, tow depth, and tow duration, influence the survival of discarded Pacific halibut. Significant reductions in bycatch mortality can be achieved with shorter handling times.

Robinson, W.E., and H.A Carr (1993): Two cruises on a bottom trawler operating on Stellwagen Bank at depths of 37-90 m were used to evaluate the effect of tow length, deck handling, stress level (via blood biochemistry), and subsequent survival after being returned to water in a cage. The cage was held for 24 hours at depth. Cruises took place in April 1992 and June 1991. Tows were one or two hours long. Handling on deck was considered normal operating procedures with the exception that no fish picks were used. Survival was estimated to be 13% and 51% survival on June and April cruises, respectively. Based on blood biochemistry, June fish were more stressed than April caught fish. This was thought to be due to differences in climate: April was cold and damp with little to no thermocline; June was warmer and a thermocline prevailed. Cod survival was influenced by air temperature, decktime, fish length, tow duration, and tow weight. Blood samples did not vary by length of tow. Control group fish were held in an aquarium for 10-87 days so that baseline blood biochemistry could be compared to stressed fish.

Rochet, M.-J. and V.M. Trenkel (2005):
Conclusions:
(*i*) the assumptions most commonly used for estimating discards, namely that discards are proportional to catch or to effort, are generally not supported by the available evidence,
(*ii*) both environmental conditions and fishing methods influence the amounts and composition of discards, but because of the huge variability, sampling stratification according to these factors might not result in any improvement of the precision of discard estimates, and
(*iii*) many intricate factors can play a role in determining discards in a particular fishery.

Sample from French trawler fleet operating in the Celtic Sea. As a whole, this fleet discarded an estimated 30,000 t in 1997 while landing around 63 000 t. The fleet consists of three métiers, which discarded from around 25% for benthic and gadoid trawlers to 55% for *N. norvegicus* trawlers. These estimates are based on a sample of 462 hauls from 26 trips

Ryer, C.H (2002): The goal of this study was to simulate in the laboratory the stressors associated with trawl passage and determine if they degrade the behavioral capabilities of juvenile walleye pollock to avoid predation. In the first of 2 experiments, groups of Age 1 yr+ walleye pollock were subjected to 3 treatments: (1) controls: no stressor; (2) swim/escape: forced swimming for 90 min at 0.33 m s–1 in a towed net, followed by escape through 8 cm square mesh; (3) swim/crowd/escape: forced swimming followed by 3 min of crowding, followed by escape. To evaluate the effect of these treatments on pollock behavior, a sablefish *Anoplopoma fimbria* (48 to 53 cm) was placed in an observation arena with the group and pollock anti-predator behavior was quantified. Beginning immediately after simulated trawling and for up to 24 h afterwards, pollock exposed to both trawl-stressor treatments were less likely to avoid the predator than controls, allowing it to approach closer. They were also less able to form a cohesive shoal, and in the case of the swim/crowd/escape treatment, swam more slowly than control fish. To determine if trawl-stressed fish are more vulnerable to predation, in a second experiment I mixed control and swim/crowd/escape pollock together and then subjected them to predation by a 48 to 60 cm lingcod *Ophiodon elongatus*, observing the behavior and enumerating the number of pollock consumed in each treatment. Lingcod concentrated attacks upon solitary individuals or those straggling behind the shoal, were more likely to lunge at pollock that did not move away when approached, and were more successful the closer the pollock at lunge initiation. As a result, trawl-stressed pollock were consumed in greater numbers than controls.

On the basis of these results, it is reasonable to expect that juvenile walleye pollock passing through trawls suffer behavioral deficits, subjecting them to elevated predation risk. If this is a generic effect, these results suggest that there may be a significant bycatch associated with many commercial trawl fisheries which is generally unrecognized, unmeasured, and unaccounted for in current stock-assessment models.

Sangster, G.I., Lehmann. K. and M. Breen (1996): This work focused on the survival of haddock and whiting escaping from the trawl cod-ends during the course of the haul. Survival ranged from 48 – 89% dependent on species and mesh size, with survival generally greater at larger mesh sizes (110 mm). Escapee survival was worse for smaller fish relative to the larger fish for both species examined. Regardless of mesh size and species, the survival of fish < 20 cm was near zero and survival of fish > 25 cm was high (generally > 90%). While these results are not directly comparable to Atlantic cod, they do suggest that there is some unaccounted mortality that occurs among fish escaping through the cod-end mesh during the fishing operation that would be above and beyond any observed mortality of the fish brought on deck. This mortality could be somewhere in the order of 10-50% but would be highly contingent on the length distribution of the fish encountered. The length distribution of these fish is unknown.

Additionally, the results of their cageing studies suggested that short-term mortality studies with observation periods < 8 days may underestimate the overall mortality associated with fishery interactions. Of fish that died, mortality ranged from approximately 45 to 75% within the first three days, with most subsequent death occurring from days 3 to 8 (Figure 1). These results are cited in subsequent literature (e.g., Milliken et al. 2009) as support for establishing the observation period of short-term mortality experiments.

Soldal, A.V., Isaksen, B., Marteinsson, J.E. and A. Engas (1991): Study to determine scale damage in fish passing through mesh cod end or metal grid on a demersal trawl fishery operating in northern Norway waters at 30-60 m depth. Fish passing through gear were caught in a cage behind the codend, then towed to a fjord, where the cage was deposited and observed by ROV for 12-16 days. Dead fish were counted and skin injuries enumerated. Haddock lose scales more easily (particularly haddock < 40 cm) than cod when passing through cod end mesh or metal grid sorting devices. Nearly all fish with skin damage had developed heavy infections at the end of the observation period. Cod appeared to be highly resistant to gear damage, though smaller cod seemed more vulnerable than larger cod. It was suspected that the collection apparatus (cage) and subsequent towing might have imposed damage beyond that due to fish passing through codend. Despite flaws with study methodology, controlling minimum size via mesh size appears to be a reasonable approach given low observed mortality of fish passing through codends and grates in this study.

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Tables

Table 1 – Description of the scores used to qualify the vitality of captured fishes during commercial and Sentinel survey fishing trips (from Benoit and Hurlbut 2010).

Vitality	Vitality score	Vitality description
Exceleent	1	Vigours body movement; no or minor external injuries only
Good/Fair	2	Week body movement; responds to touching/prodding; minor external injuries
Poor	3	No body movement but fish can move operculum; minor or major external injuries
Moribund	4	No body or opercular movements; no response to touching or prodding

Table 2 – Description of the codes used to qualify the degree of injury of captured fishes during commercial and Sentinel survey fishing trips (from Benoit and Hurlbut 2010).

Injury	Code	Description
None	1	No bleeding, torn operculum or noticeable loss of scales
Minor	2	Minor bleeding or minor tear of mouthparts or operculum or moderate loss of scales (i.e., bare patch)
Major	3	Major bleeding or major tear of mouthparts or operculum or everted stomach or bloated swim bladder

Table 3 – Summary of the vitality scores of Atlantic cod (*Gadus morhua*) collected during short-term survival experiments using standard trawl gear. Surival experiment results are presented as the percentage of fish surviving at least 48 hours post capture as a function of vitality code attributed to fish prior to placement in holding tanks (from Benoit and Hurlbut 2010).

Vitality code	Short-term survival
1	65.1%
2	39.4%
3	14.8%
4	1.9%

Table 4 – Summary of the vitality scores collected by at-sea observers during commercial and Sentinel survey fishing trips (from Benoit and Hurlbut 2010).

		Discarded fish by vitality score (%)			
Gear	**Sample size**	**1**	**2**	**3**	**4**
Gillnet	519	32.9%	33.7%	21.4%	11.9%
Longline	3869	84.1%	9.0%	3.4%	3.5%
Handline	450	97.1%	0.2%	2.7%	0.0%

Table 5 – Total short-term survival (<48 hours) of fish captured in fixed gear fisheries as estimated from Benoit and Hurlbut (2010) experimental results (Table 3) and fixed-gear specific vitality scores (Benoit and Hurlbut 2010, Table 4).

		Short-term survival (%)				
Gear	**Sample size**	**1**	**2**	**3**	**4**	**Total survival**
Gillnet	519	21.4%	13.3%	3.2%	0.2%	38.1%
Longline	3869	54.7%	3.5%	0.5%	0.1%	58.9%
Handline	450	63.2%	0.1%	0.4%	0.0%	63.7%

Table 6 – Survival of trawl cod after exposure on deck for varying periods of time; for air temperature, high = 4.4° to 7.8°C and low = -1.1° to 0.6°C (from Jean 1963).

Exposure, *minutes:*	<5	5		15		30		45
	Series 1	Series 1	Series 2	Series 1	Series 2	Series 1	Series 2	Series 2
Air temperature	High	High	Low	High	Low	High	Low	Low
Tank temp., °*C*	11.4	11.5	6.6	11.6	6.7	11.6	6.5	6.4
Bottom temp., °*C*	1.9	3.8	3.6	10.6	2.0	4.4	1.1	1.0
Size groups *cm*	Survival, %							
20 – 29	20	10	70	20	60	0	20	0
30 – 39	50	60	78	40	40	0	20	0
40 – 49	50	70	90	70	90	10	50	10
50 – 59	100	67	87	50	90	13	80	20
All sizes	51	50	81	45	70	6	43	8

Table 7 – Observed survival (%) of snubbed and unsnubbed sublegal-size Atlantic cod when data are grouped by broad cold (≤9.0ºC) and warm (>9.0ºC) sea surface temperatures and observed survival plus the mortality experienced by jigged fish. Midpoints are also shown (from Milliken et al 2009).

	Cold			Warm		
Survival measure	37 m	55 m	73 m	37 m	55 m	73 m
Unsnubbed						
Survival + jigged cage mortality	92.1	92.1	88.0	91.8	100.0	98.3
Observed survival	82.8	79.1	78.2	79.2	74.3	56.7
Midpoint	87.4	85.6	83.1	85.5	87.1	77.5
Snubbed						
Survival + jigged cage mortality	81.5	79.8	83.5	76.7	92.0	86.8
Observed survival	72.1	66.8	73.7	64.2	50.0	45.2
Midpoint	76.8	73.3	78.6	70.5	71.0	66.0

Table 8- Summary of discard survival rates and codend escapement survival rates (from Hendrickson and Nies, 2007)

Reference	Type of study	Gear type	Survival percentage (%)
Palsson et al., 2003	Discard	Automatic jigging machines	57%
Benoit and Hurlbut, 2010	Discard	Handline	63.7%
Milliken et al., 1999	Discard	Longline	22-63%, 50% avian predation post release
Milliken et al., 2009	Discard	Longline	45.2-82.8%
Benoit and Hurlbut, 2010	Discard	Longline	58.9%
Benoit and Hurlbut, 2010	Discard	Gillnet	38.1%
Robinson and Carr, 1993	Discard	Otter trawl	summer=13%, spring=51%
Carr et al., 1995	Discard	Otter trawl	0-25%
Jean, 1963	Discard	Otter trawl	6-81%
Soldal et al., 1993	Escapement	Otter trawl	100%
Carr et al., 1995	Escapement	Otter trawl	94% (year 1), 96% (year 2)
Ingolfsson et al., 2007	Escapement	Otter trawl	99.70%

Table 9. Summary of mortality rates currently applied to the stocks in the Northeast Multispecies fishery.

		Discards									Recreational
Species	Stock	Large mesh otter trawl	Small mesh otter trawl	Large mesh gillnet	Extra large mesh gillnet	Longline	Handline	Otter trawl, midwater	Shrimp trawl	Scallop dredge	B2
Cod	GOM	100%*		100%*					100%		0%
	GB	100%		100%						100%	0%
Haddock	GOM	100%	100%	100%		100%		100%			0%
	GB	100%*		100%		100%**				100%	
Winter flounder	GOM	50%		50%*					50%		15%
	GB	100%	100%							100%	
	SNEMA	50%								50%	15%
Yellowtail flounder	CCGOM	100%	100%	100%*						100%	
	GB	100%	100%							100%	
	SNEMA	100%	100%							100%	
Windowpane flounder	NOR	100%	100%							100%	
Windowpane flounder	SOU	100%	100%							100%	
American plaice	UNIT	100%							100%		
Witch flounder	UNIT	100%	100%						100%		
Atlantic halibut	UNIT	100%***		100%***							
Pollock	UNIT	100%	100%	100%	100%						100%
White hake	UNIT	100%*		100%*							
Redfish	UNIT	100%*		100%*		100%					
Ocean pout	UNIT	100%	100%	100%*						100%	

*didn't specify mesh categories
**unknown if hool/line includes handline or longline only
***run using all mesh categories combined

Figures

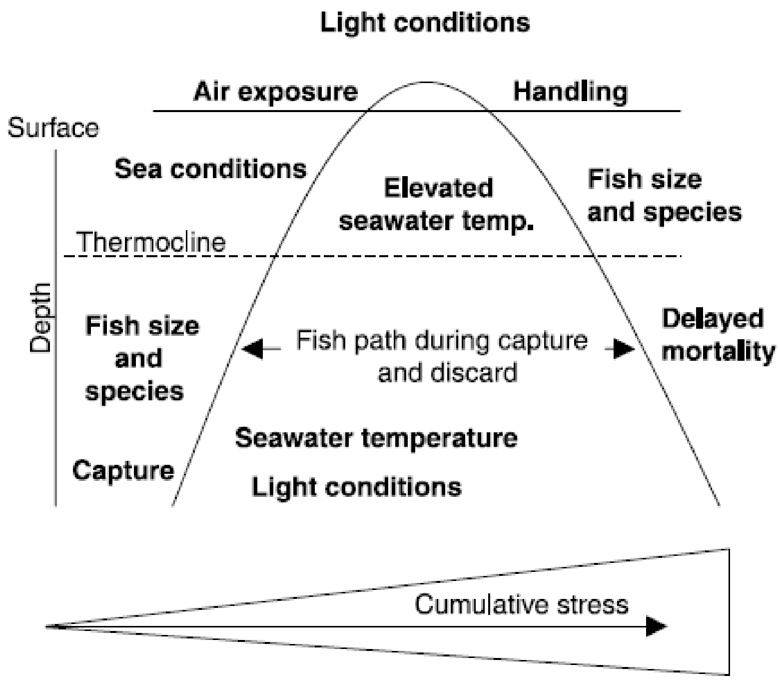

Figure 1. Conceptual diagram of interacting factors in discard mortality for fish caught with deepwater gear (trawl, trap, hook and line). Fish caught with surface fishing gear (seine, hook and line, gill net) would not be subjected to the temperature and pressure changes associated with depth. The curved line indicates fish path at depth and the surface during capture and discard. Selected key factors are indicated in bold letters. Increasing stress level is indicated at the bottom of the diagram as interaction of factors increases initial capture stress. (from Davis 2002).

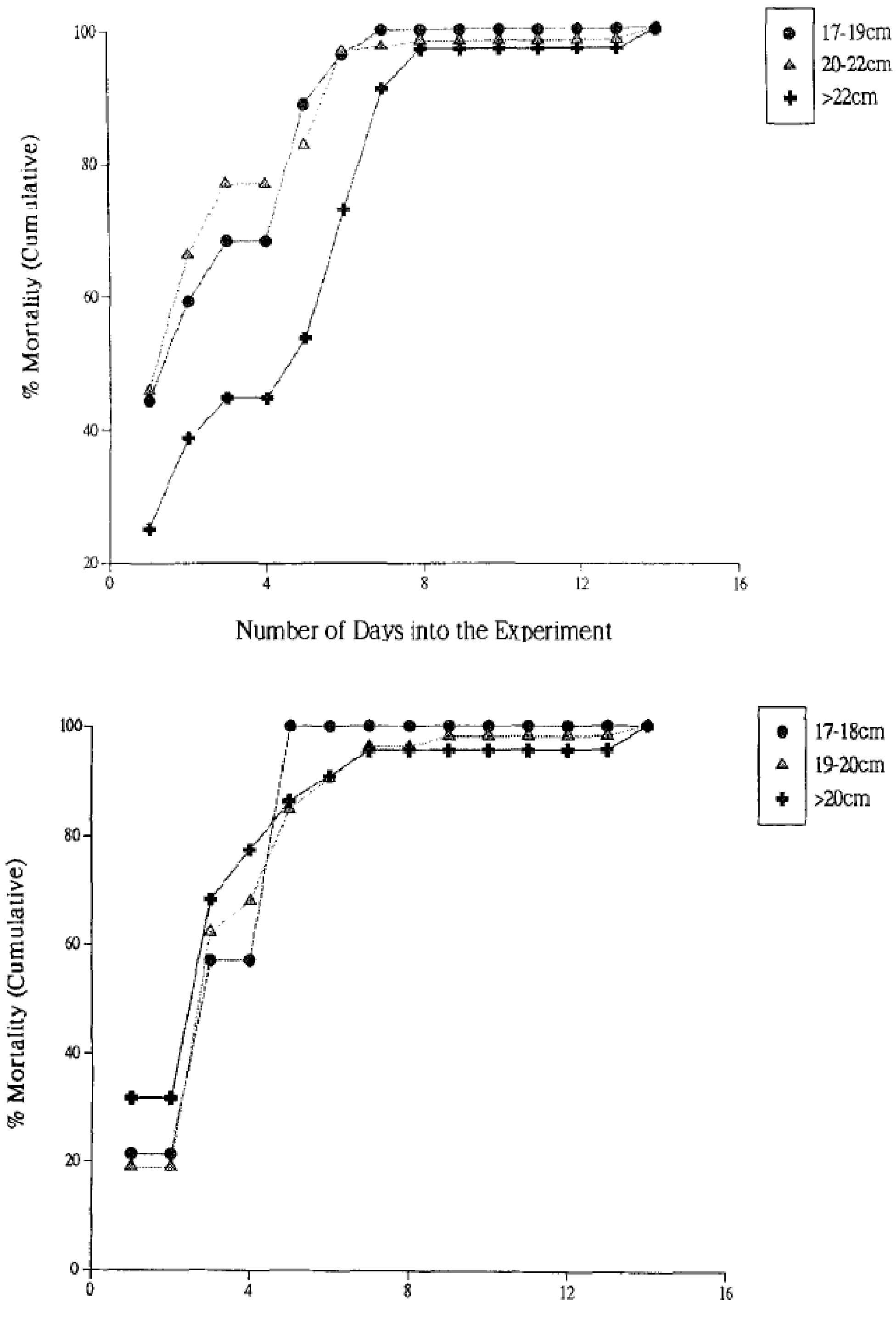

Figure 2. Mortality change over time for different lengths and mesh sizes from two different cages (from Sangster et al. 1996).

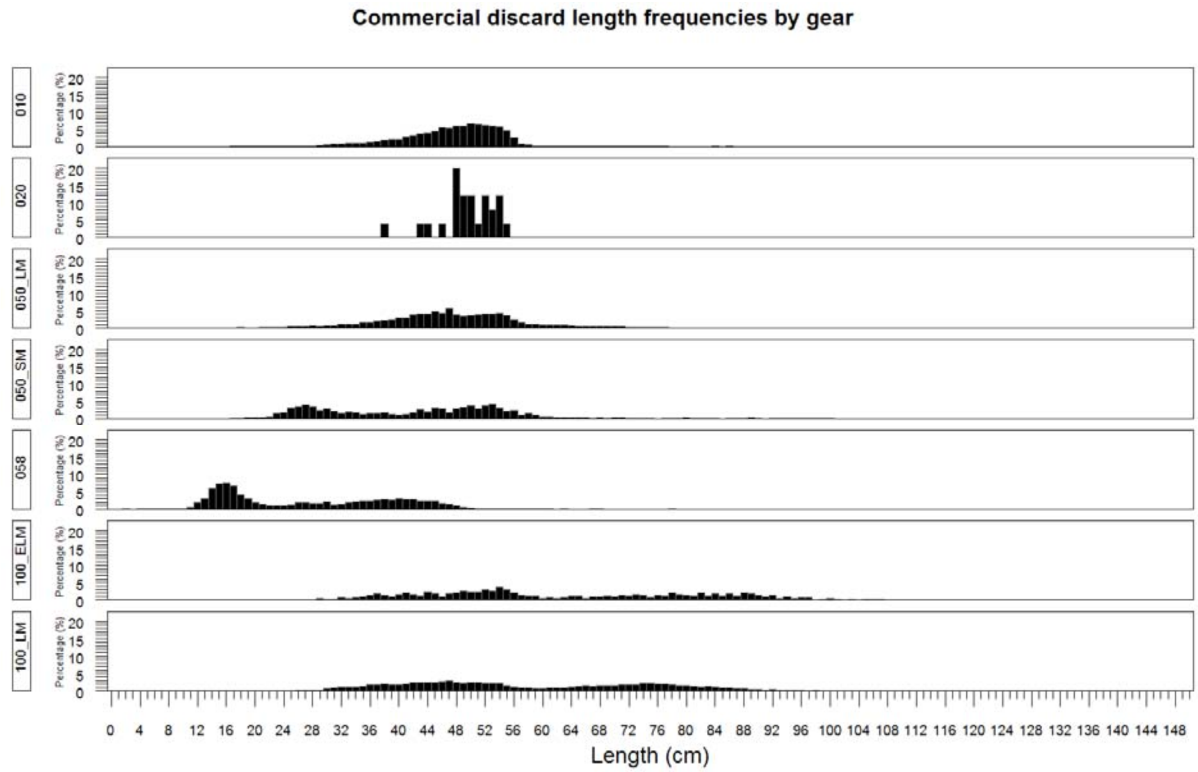

Figure 2. Distributions observed discards of Gulf of Maine Atlantic cod (*Gadus morhua*) by fork length and gear type between 1989 and 2010. Gear types are as follows: longline (010), small mesh trawl (050_SM), large mesh trawl (050_LM), shrimp trawl (058), large mesh gillnet (100_LM) and extra large mesh gillnet (100_ELM). There was insufficient sampling of handline gear (020) to adequately characterize the length frequency distribution.

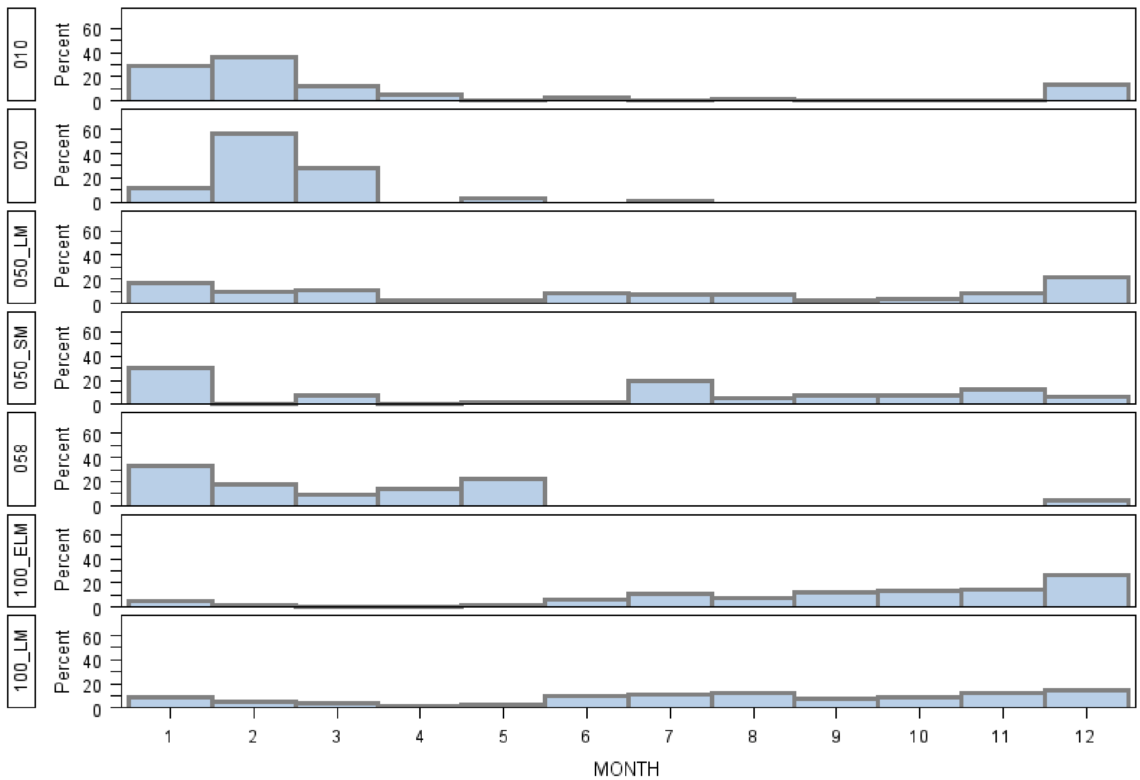

Figure 3. Distributions observed discards of Gulf of Maine Atlantic cod (*Gadus morhua*) by month and gear type between 1989 and 2010. Gear types are as follows: longline (010), handline (020), small mesh trawl (050_SM), large mesh trawl (050_LM), shrimp trawl (058), large mesh gillnet (100_LM) and extra large mesh gillnet (100_ELM).

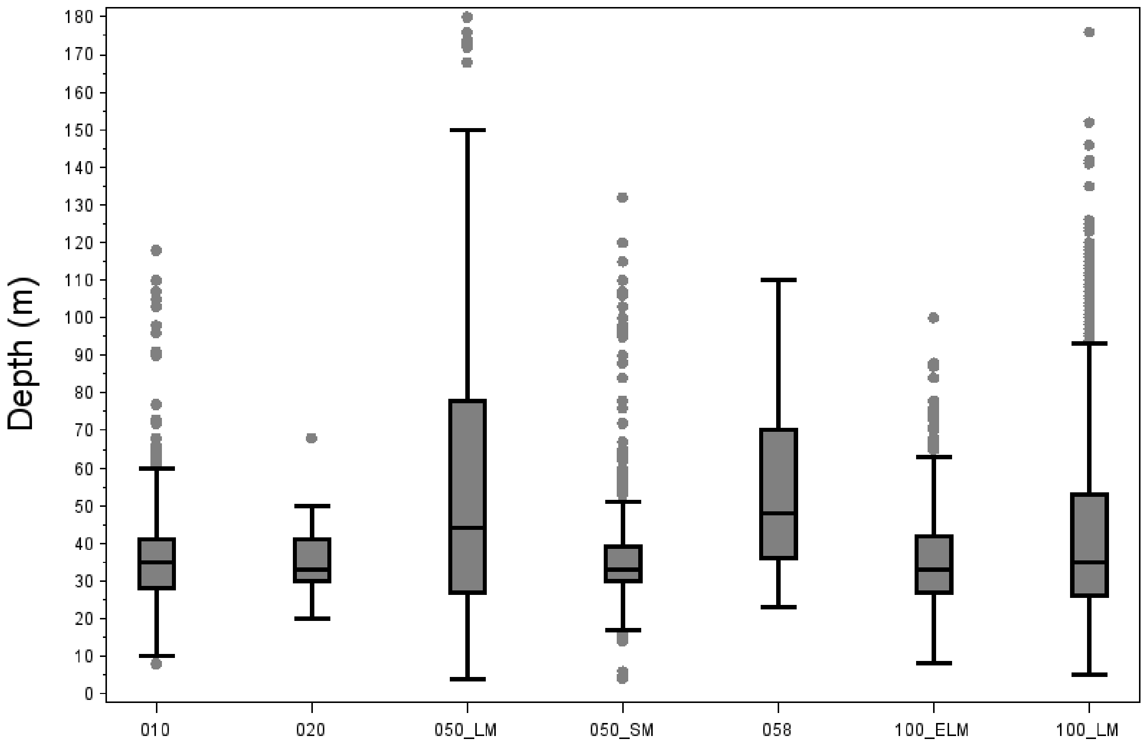

Figure 4. Depth distributions of gears responsible for the discards of Gulf of Maine Atlantic cod (*Gadus morhua*) between 1989 and 2010. Gear types are as follows: longline (010), handline (020), small mesh trawl (050_SM), large mesh trawl (050_LM), shrimp trawl (058), large mesh gillnet (100_LM) and extra large mesh gillnet (100_ELM).

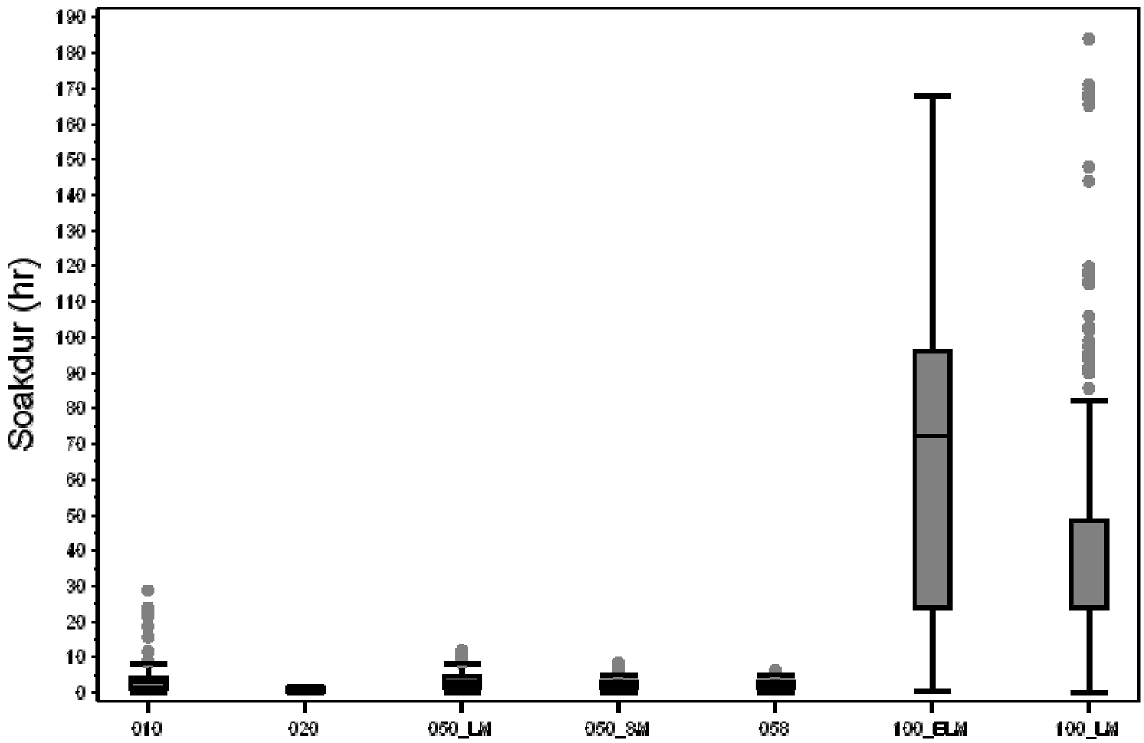

Figure 5. Distributions of soak/tow duration by gears responsible for discards of Gulf of Maine Atlantic cod (*Gadus morhua*) between 1989 and 2010. Gear types are as follows: longline (010), handline (020), small mesh trawl (050_SM), large mesh trawl (050_LM), shrimp trawl (058), large mesh gillnet (100_LM) and extra large mesh gillnet (100_ELM).