Cod Discard Mortality Working Group. Working Paper 1.

[NOT A CITABLE DOCUMENT]

A review of factors affecting the mortality of discarded Atlantic cod (*Gadus morhua*).

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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 and recreational fisheries. These estimates have assumed that there was no survival of fish discarded at sea. The topic of discard mortality and evaluation of appropriate mortality rates was included as a term of reference for the most recent Gulf of Maine cod assessment (NEFSC, 2012). Ultimately, the assessment concluded "…*that the published studies probably overestimated survival, although it was difficult to characterize the extent of the bias. The discard mortality rates to be used in SARC53 for Gulf of Maine cod are 100% for all gears.*"

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 due 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. While recreational catch is an important component of total catches of cod in United States waters, no known information exists on the survival of cod discarded in the recreational fishery.

Introduction

The magnitude of fishery discards, both commercial and recreational, can represent a considerable fraction of overall fishery removals. In the most recent assessment of the Gulf of Maine Atlantic cod (*Gadus morhua*) stock, commercial discards accounted for up to 44% of the total catch in any given year, averaging approximately 25% over the past decade (NEFSC 2012). 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). However, the extent of the bias is contingent on multiple factors including the relative magnitude of fleet discards (e.g., if longline discards comprise <5% of the total discards, the discard mortality estimate for this gear will have little impact), the relative magnitude of discards to the overall fishery removals, and the magnitude of discards to the population size. Sensitivity analyses performed on the Georges Bank yellowtail flounder (Barkley et al. 2010) and Gulf of Maine cod assessments (Palmer, unpublished) demonstrated that alternate assumptions of discard mortality (0% compared to 100%) had insubstantial impacts on the assessment results. Comparatively, sensitivity analyses on the Southern New England/Mid-Atlantic yellowtail flounder assessment found the assessment to be more sensitive to alternate assumptions of discard mortality (Barkley 2011).

There is a growing body of literature that shows that there may be some survival of fish discarded at sea, including work specific to Atlantic cod. Extending the work on discard mortality into stock assessments has proven difficult, largely because of the large range of factors and interactions that need to be considered to accurately estimate the true discard mortality. Despite the difficulties, it is important to evaluate the information available on discard mortality as well as evaluate the sensitivity of an individual assessment to the discard mortality assumptions.

The issue of discard mortality is more complicated than the fate of the observed discards. Accurately quantifying the magnitude and mortality/survival of the observed discards can still represent only a fraction of the mortality on non-retained fish; mortality can also occur as result of escapement from the fishing gear pre-capture (Fig. 1, Suuronen 2005). Mortality of non-retained fish results from physical injuries or stress incurred as direct result of interacting with the fishing gear or from post-interaction predation due to decreased fitness. There are numerous factors that can affect the survival of fish that encounter the fishing gear, but are not retained (Fig. 2). 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). The factors and their degree of influence vary throughout the duration of the fishing process (Fig. 3, Suuronen 2005).

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 of haddock and whiting occurs more than 72 hours post release (Sangster et al. 1996, Fig. 4). 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).

For some gears such as trawl, escapement mortality, while small, may not be negligible. For example, the work of Suuronen et al. (2005) found escape mortality of Baltic Sea cod to be low (<3%) in water temperatures less than 10 ^{o}C, but substantially higher (up to 75%) when water temperatures exceeded 15 ^{o}C. The work of Carr et al. (1995), which was conducted off New England, suggested approximately 83% short-term survival (<24 hours) of Atlantic cod. In general, escapement mortality is likely to be less than captured discard mortality and subject to many variable including water temperature and mesh size (Sangster et al. 1996). Generally escapement mortality is not considered when estimating total discard mortality because it cannot be observed. However, it should be recognized that quantification of only the discard mortality of captured fish represents an underestimation of total discard mortality, particularly for mobile gears such as trawls.

The topic of discard mortality and evaluation of appropriate mortality rates was included as a term of reference for the most recent Gulf of Maine cod assessment (NEFSC, 2012). After a review of the relevant research and scientific literature the assessment working group concluded that the available scientific information was insufficient to reliably estimate discard survival for any of the considered fisheries. The discard mortality rates used in SARC53 assessment were assumed to be 100% for all gears. The same assumption is made for many of the assessed groundfish stocks in the northeast United States due to the lack of definitive research results (Table 1). The 100% assumption captures the upper bound of possible discard mortality, and for most gear types/species, is likely closer to the true discard mortality than the lower bound (0%).

The [SARC 53 data] working group discussed all gears for which discards were estimated in the updated SAW 53 assessment, with each gear being evaluated separately based on the gear-specific information available from the literature. While each study provided an estimate of survival, no single study could address every factor implicated in mortality. Important factors in determining discard survival from the available scientific literature include: water and air temperature, sunlight exposure, depth of capture, time of handling, type of handling, length of time on deck, short term and long term survival (one study estimated that only about 50% of mortality occurred in first few days—the length of most observation periods), impacts on growth due to reduced feeding ability, whether predator avoidance was compromised or predator exposure was increased at release time (birds, mammals, other fish predators), whether fish were held on deck in tanks or in an aquarium or held in a cage at depth. Each gear was evaluated with respect to available studies with survival estimates, what factors had been accounted for, what factors had not been accounted for, and whether it was possible to determine what conditions were likely to have existed for unobserved trips. Because it is not possible to characterize the temperature/depth/season for all unobserved trips, a single, annual discard mortality rate is required. The working group was consistent in how it *approached the evaluation of each gear, first by reviewing the available studies, discussing what factors were and were not controlled for, and whether the estimates in the literature were likely to be biased high or low. In the end, the working group did agree that the published studies probably overestimated survival, although it was difficult to characterize the extent of the bias. The discard mortality rates to be used in SARC53 for Gulf of Maine cod are 100% for all gears (NEFSC 2012).*

In January 2012, the New England Fisheries Management Council's Science and Statistical Committee (SSC) met to discuss aspects of the 2011 assessment that may affect the interpretation of the assessment results. One of the issues identified by the SSC was the assumption of 100% discard mortality used in the assessment. The SSC formulated a work plan to address this issue. Specifically, the work plan included the following two tasks:

1. Identify studies summarized in Palmer et al. (2011) that may be most appropriate to the TOR; studies relevant for gears and studies most likely to be transferrable to cod.

2. Identify any other known sources such as grey literature or cooperative research studies that were not included in Palmer et al. (2011).

This working paper is an update to the Palmer et al. 2011 paper. It summarizes the available information on discard mortality with a focus on work specific to Atlantic cod and similar gadoid species. Additionally, a summary is provided on the range of mortality factors likely to be experienced by Atlantic cod discarded in the fisheries of the northeastern United States. To the author's knowledge there is no new additional information that was not included in the Palmer et al. (2011) paper.

Factors influencing discard mortality

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. Trawl captured fish were assigned vitality scores ranging from 1-4 (Table 2) and then placed in a holding tank for 48->72 hours and the resulting mortality assessed (Table 3). For Atlantic cod, the overall discard vitality was poorest for gillnet gear and best for handline (Table 4). Overall short-term survival was estimated at 64% for handline caught fish, 59% for longline and 38% for gillnet (Table 5). Benoit et al. (2010) found that trawl caught cod scored with a vitality score of 4 experienced mortality in excess of 98% compared to 34.9% mortality among fish scored with a vitality score of 1. Approximately 75% of the cod caught in the study were scored with a vitality score of 4. Milliken et al. (2009) reported longline survival in the range of 45-83% contingent on handling care and environmental conditions. Jean (1963) found trawl survival to be variable across a range of factors, with high mortality when deck exposure exceeded 30 minutes (Table 6). The findings lead to the 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

Once they are caught, the handling methods and the time spent on deck are also major factors that affect mortality of cod. 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. Milliken et al. (2009) estimated snubbed mortality (damaged due to de-hooking device) ranging from 8% to 54.8% and un-snubbed mortality ranging from 0% to 43.3% (Table 7). Mortality generally increased with temperature and fishing depth. The survival rate for cod encountering a crucifer was only half that of jigged cod (Farrington et al. 2003). 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

The size, and age also affect mortality rates for discarded cod. The work of Jean (1963, Table 6) suggest that smaller cod experienced higher mortality compared to larger cod. Similar size-dependent mortality among of longline-caught cod 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).

Other factors affecting mortality of discarded fish

As discussed in the introduction and covered in the study summaries contained in Appendix 1, the mortality of discarded fish is more complicated than gear type, handling practices and fish size. Other factors include ambient temperature (both water temperature and air temperature) and haul duration. Generally, survival decreases with increasing temperature (e.g., Jean 1963, Robinson and Carr 1993, Davis 2002, Suuronen et al. 2005), though this is not always the case. Colder temperatures may negatively impact the swimming speeds and endurance (Davis 2002), and thus increase the likelihood of injury during the capture process. Additionally, prolonged exposure to sub-freezing temperatures on deck is likely to be lethal. Similarly, longer haul durations are likely to increase the stress induced on the fish and the likelihood of injury (Richards et al. 1995). Physical injuries could occur from either contact with the gear, or crushing in the net under the presumption that longer hauls will produce larger catches. The catch composition of the particular haul can also be important. Physical injury of fish caught in tows containing a large amount of species such as spiny dogfish *Squalus acanthias* are likely to incur greater physical damage compared to those tows containing species such as Atlantic herring *Clupea harengus*.

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 suggest survival on the order of 48-86% (haddock and whiting) with fish survival positively correlated with fish size and mesh size. Suuronen et al. (2005) found escape mortality of Baltic Sea cod to be low (<3%) in water temperatures less than 10 ^{o}C, but substantially higher (up to 75%) when water temperatures exceeded 15 ^{o}C. Suuronen et al. (2005) also investigated the influence of fish size and codend fullness and found no clear relationship to cod mortality. They did note that their results in these areas were not conclusive and that more work was needed in this area.

The previous studies were primarily concerned with mortality associated with stress and physical injury in the absence of predation. Ryer (2002) found that walleye pollock *Theragra chalcogramma* exposed to trawl-induced forced swimming were less likely to exhibit predatory avoidance behavior up to 24 hours after the trawl event. Additionally, these fish were less likely to form cohesive schools and swam more slowly than fish not exposed to the trawl treatment. The results of this study suggest that the fish that have escaped capture, but do suffer behavioral deficits as result of the escapement, will be subjected to an elevated risk of predation that is not reflected in the escapement studies mentioned above.

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 indicated that fish 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 for halibut surviving release 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 relative fitness.

Barotrauma incurred during forced rapid decompression can produce both acute and long-term effects, particularly for fish that possess a swim bladder (e.g., Davis 2002, Suuronen 2005). However, Midling et al. (2012) found that while Atlantic cod captured at depths between 130 and 200 m, experienced a high incidence of ruptured swim bladders (100% of sampled fish), the ruptures had "…acute but reversible effects on function and welfare." While effects may be reversible, during the recuperation period fish may be subject to lower fitness due to the need to occupy suboptimal habitat (i.e., shallower depths; Fig. 5). In Pacific cod (*Gadus macrocephalus*), the recuperation period ranged from 1.6 – 16.7 days with the recuperation period positively correlated with fish size and capture depth (Nichol and Chilton 2006). Additionally, diving behavior immediately following release was shown to be a poor indicator of the degree of barotrauma.

Summary of discard mortality factors for Atlantic cod in Northeast United States waters

A summary of some of the factors that influence the mortality of cod discarded in the commercial fishery are present in Figures 6-12. These figures provide a summary of the length, season, capture depth, water and air temperatures experienced by discarded cod from both the Gulf of Maine and Georges Bank cod stocks. Summaries are broken down by stock and gear when possible. There is virtually no shrimp trawl fishery on Georges Bank which explains the lack of information on this fishery in the Georges Bank summaries. It should be noted that the source of much of the information contained in these summaries comes from trips observed by at-sea observers. The commercial handline fishery is poorly sampled by observers due to a combination of regulatory exemptions and small vessel size, thus the characterization of discard factors from this fishery is incomplete.

Generally, fish discarded in the US fishery are below the minimum retention size (Fig. 6). Minimum retention sizes have varied over time in response to management actions, but i have varied between 43-56 cm (17-22 inches) in the commercial fishery and 38-61 cm (15-24 inches) in the recreational fishery since 1982 for both stocks.. The sole exception to this is gillnet gear where a non-trivial amount of discards of legal size fish occur. These discards reflect the discarding of legal-size unmarketable fish (LUMF). Reason for LUMF discards include fish damaged by sand fleas, and seal or shark predation. This type of damage is not uncommon in gillnet gear where the gear is left to soak for prolonged periods of time, occasionally in excess of 48 hours (Fig. 7). LUMF discards are either dead or of such poor fitness that survival should be considered to be negligible.

With the exception of sink gillnet gear, the soak/haul duration of most commercial gears is less than five hours (Fig. 7). Median haul durations for otter trawl gear range from 2-4 hours, with tow durations tending to be slightly longer in the Georges Bank fishery.

On both Georges Bank and in the Gulf of Maine the period of highest gillnet discards occurs during the summer months (May to October), though discard patterns are variable and do occur year round (Fig. 8). Discard patterns for the longline fishery suggest slightly higher discarding during the winter months (December to March), though like gillnet discards, are highly variable. The trawl discard patterns are different between Georges Bank and the Gulf of Maine fisheries, with Georges Bank discards being most predominant between February and June and Gulf of Maine discards peaking between November and March. The shrimp trawl fishery is primarily a winter fishery which explains the lack of discards from June through November.

Both the Georges Bank and Gulf of Maine fisheries occur in water depths generally less than 100 m (Fig. 9). The handline fishery tends to occur in the shallowest depths with the median fishing depth below 50 m. The median fishing depth of the gillnet fishery trawl fishery is also less than 50 m, though there is considerable variability in the fishing depths of both the Georges Bank and Gulf of Maine trawl fishery. The Georges Bank longline fishery tends to occur in deeper waters than the Gulf of Maine fishery. Compared to all other Gulf of Maine fisheries, the shrimp trawl fishery occurs at greatest depth.

A range of water temperatures at fishing depth was achieved through an examination of temperature-depth probe data collected by the Northeast Fisheries Science Center's

Cooperative Research Program from participating commercial fishing vessels. These data come primarily from trawl vessels active in both the Gulf of Maine and Georges Bank regions. The general patterns in the temperature-depth data show the lowest water temperatures occurring between February and April, following by a seasonal warming pattern with water temperatures peaking between August and October (Fig. 10). The peak temperatures occur earlier on Georges Bank compared to the Gulf of Maine. Generally the temperatures at fishing depth range from 4-16 ^{o}C with average fishing depth temperatures of approximately 7 ^{o}C and 10 ^{o}C for the Gulf of Maine and Georges Bank respectively.

Region-wide air temperatures were characterized from National Buoy Center (http://www.ndbc.noaa.gov) oceanographic station data collected from two buoys; one in the central Gulf of Maine (44005) and one on the southeastern flank of Georges Bank (44011; Fig. 11). These summaries are only intended to provide a general description of seasonal trends in both regions to put the regions in context of the some of the studies reviewed in this paper. Seasonal air temperatures in both regions are similar, with summertime highs near 20 ^{o}C and winter time lows between 0-5^{o}C (Fig. 12). Summertime air temperatures are similar between regions, but wintertime air temperatures are slightly colder in the Gulf of Maine region.

Conclusions

The factors effecting the mortality and survival of fish discarded by both commercial and recreational fisheries are numerous and complex. Many of the studies published on discard mortality have utilized short-term studies to estimate the impacts in very controlled environments. Mortality estimates range from near 0 to 100%, with a mean in the range of 40-80% depending on gear type and study (Table 8). Application of these study results for the purposes of stock assessments is difficult because each study only accounts for a handful of the potentially influential factors. Additionally, the work of Sangster et al. (1996) suggests that estimates of mortality from short-term survival studies may underestimate long-term survival by as great as 50%. Additionally, capture-related injuries may contribute to additional mortality beyond the longer-term observation windows such as those used in the Sangster et al. study (e.g., Kaimmer 1994, Nichol and Chilton 2005). The longer-term Sangster et al. study, like many of the short-term studies was a cage study. 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).

The discards incorporated into stock assessments only account for the observed discards brought on deck. There is some additional and un-quantified mortality associated with fish that escape the capture process. While this fraction is likely small, it is an additional component that if not considered will result in negatively biased estimates of discard mortality.

There is undoubtedly some survival of fish that do encounter fishing gear, however, an accurate quantification of that percentage is difficult. Sole reliance on the results of the available literature is likely to bias the discard estimates low both because of the impacts of long-term post-release mortality as well as unobserved escapement mortality.

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Note: Highlighted references have not been summarized in Appendix 1.

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Tables

Table 1. Summary of mortality rates currently applied to the stocks in the Northeast Multispecies fishery.

Species	Stock	Commercial									Recreational
		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%	100%	100%			100%		100%
	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	90%	90%							90%	
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%	

*Mesh categories were not specified in the assessment document.
**It is unknown if hook/line includes handline or longline only.
***Discards were estimated using all mesh categories combined.

Table 2. 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
Excellent	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 3. Summary of the vitality scores of Atlantic cod (*Gadus morhua*) collected during short-term survival experiments using standard trawl gear. Survival 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 2) and fixed-gear specific vitality scores (Benoit and Hurlbut 2010, Table 3).

		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	Series		Series		Series		Series
	1	1	2	1	2	1	2	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				Survival, %				
cm								
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 (modified 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)
Suuronen et al., 2005	Escapement	Otter trawl	25-97%
Ingolfsson et al., 2007	Escapement	Otter trawl	99.70%

Figures

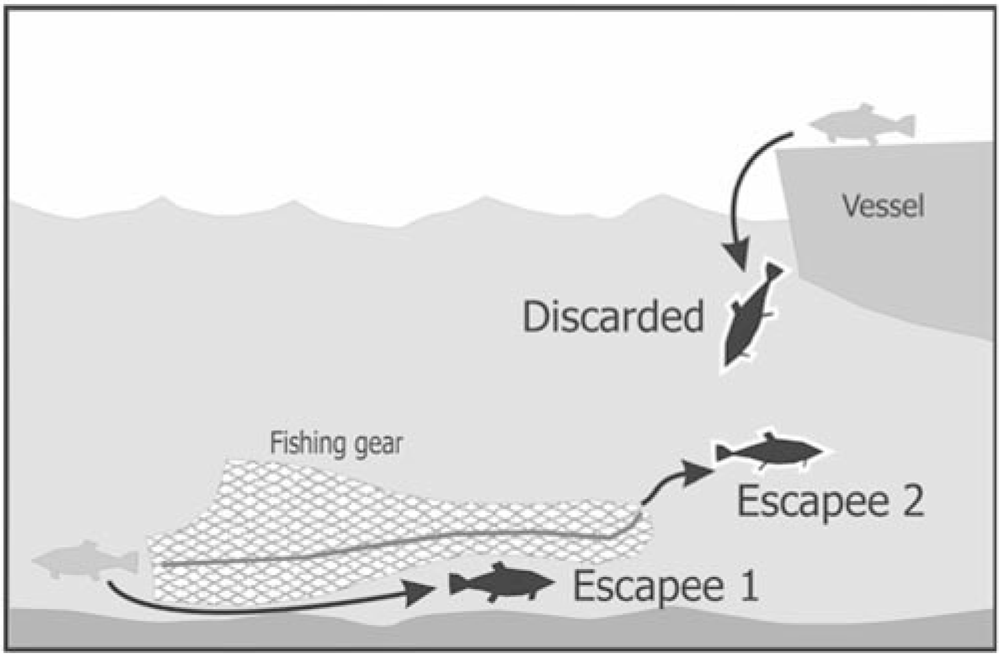


Figure 1. Fish may escape a towed fishing gear for instance by diving below the ground gear (Escapee 1) or by swimming through the mesh (Escapee 2). Fish that are retained by a fishing gear may be discarded from the deck of the vessel after the gear has been retrieved and the catch sorted. At each of these stages, the environmental and physical conditions that the fish are exposed to may vary considerably (from Suuronen 2005).

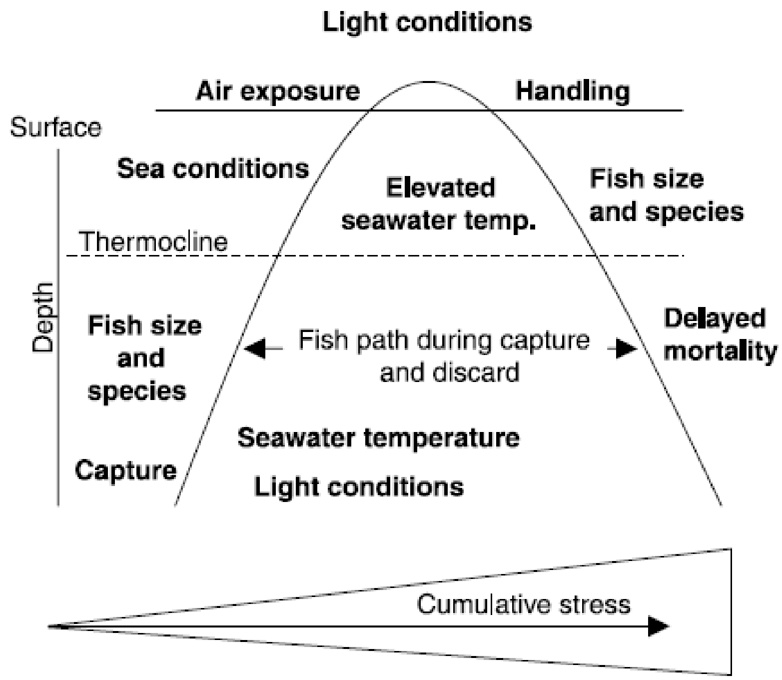


Figure 2. Conceptual diagram of interacting factors in discard mortality for fish caught with deepwater gear (trawl, trap, gillnet, hook and line). The curved line indicates fish path at depth and the surface during capture and discard. Selected key factors are indicated in bold letters. Increasing stress level is indicated at the bottom of the diagram as interaction of factors increases initial capture stress. (from Davis 2002).

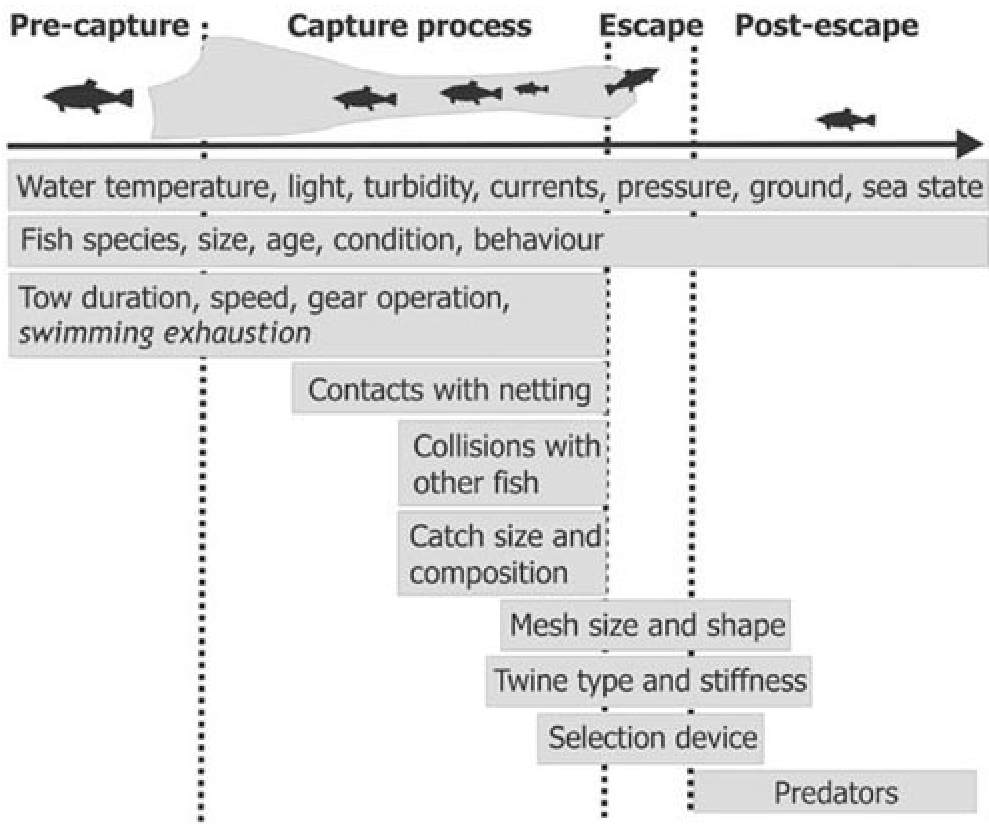


Figure 3. A schematic description of potential factors that may affect fish behavior, endurance, stress and injury during the capture and escape process. The effects of these factors may be cumulative (from Suuronen 2005).

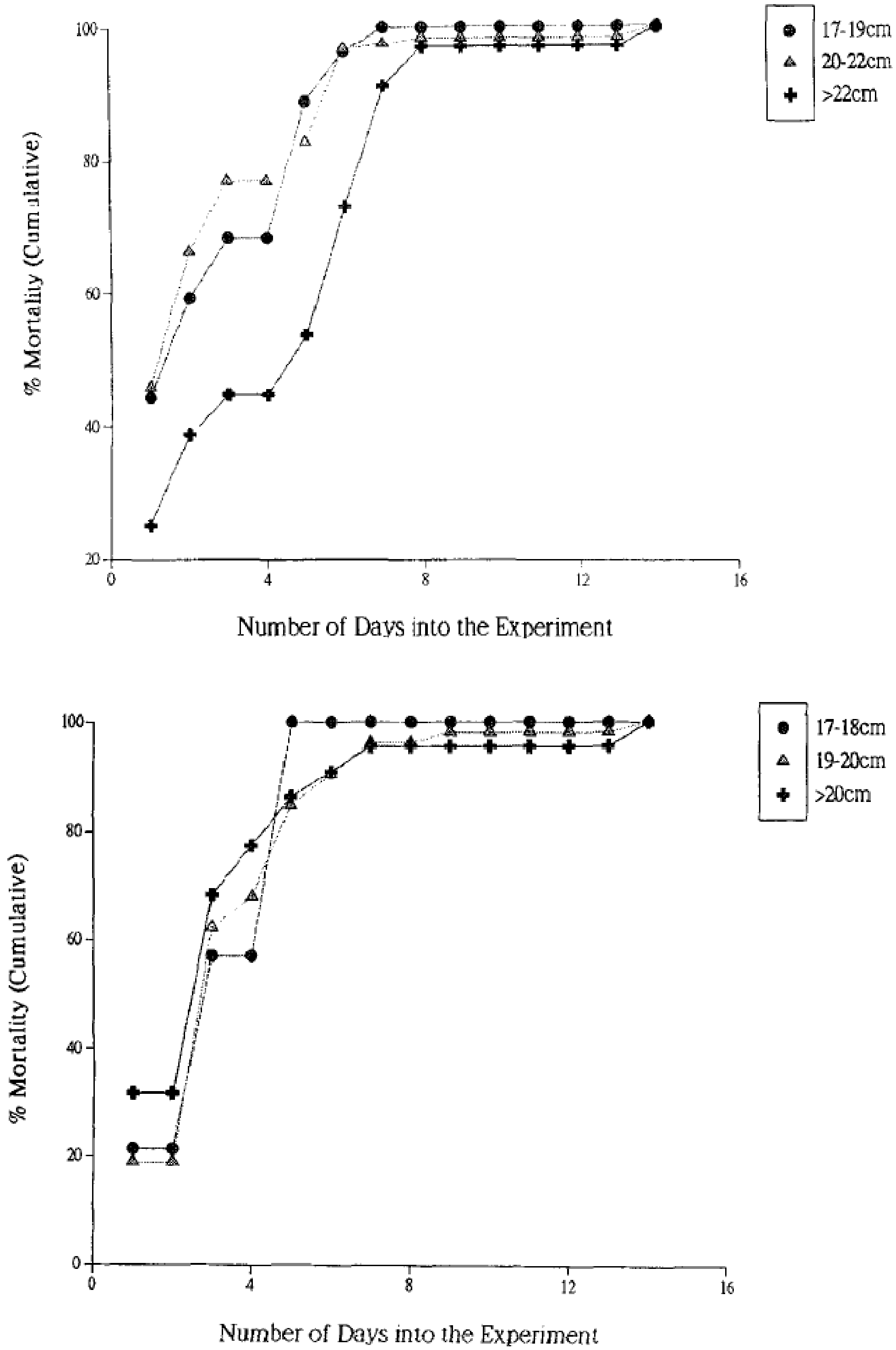


Figure 4. Mortality change over time for different lengths and mesh sizes from two different cages (from Sangster et al. 1996).

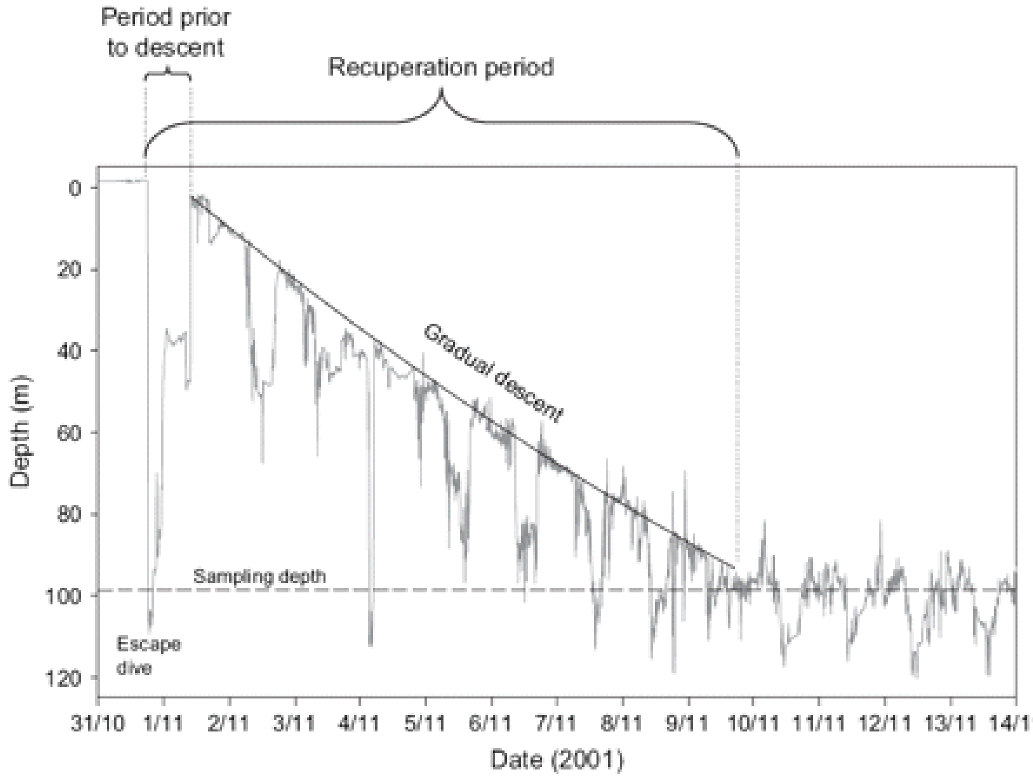


Figure 5. The recuperation period (RP), defined as the period between fish release and the recuperation-end date. Times, depths, and temperatures at common "events" such as escape dives, the shallow-water point prior to descents, and the point at which a cod's descent stopped were examined. The period prior to descent (PP) was also examined. The curve indicates the fitted quadratic equation to the gradual descent (from Nichol and Chilton 2005).

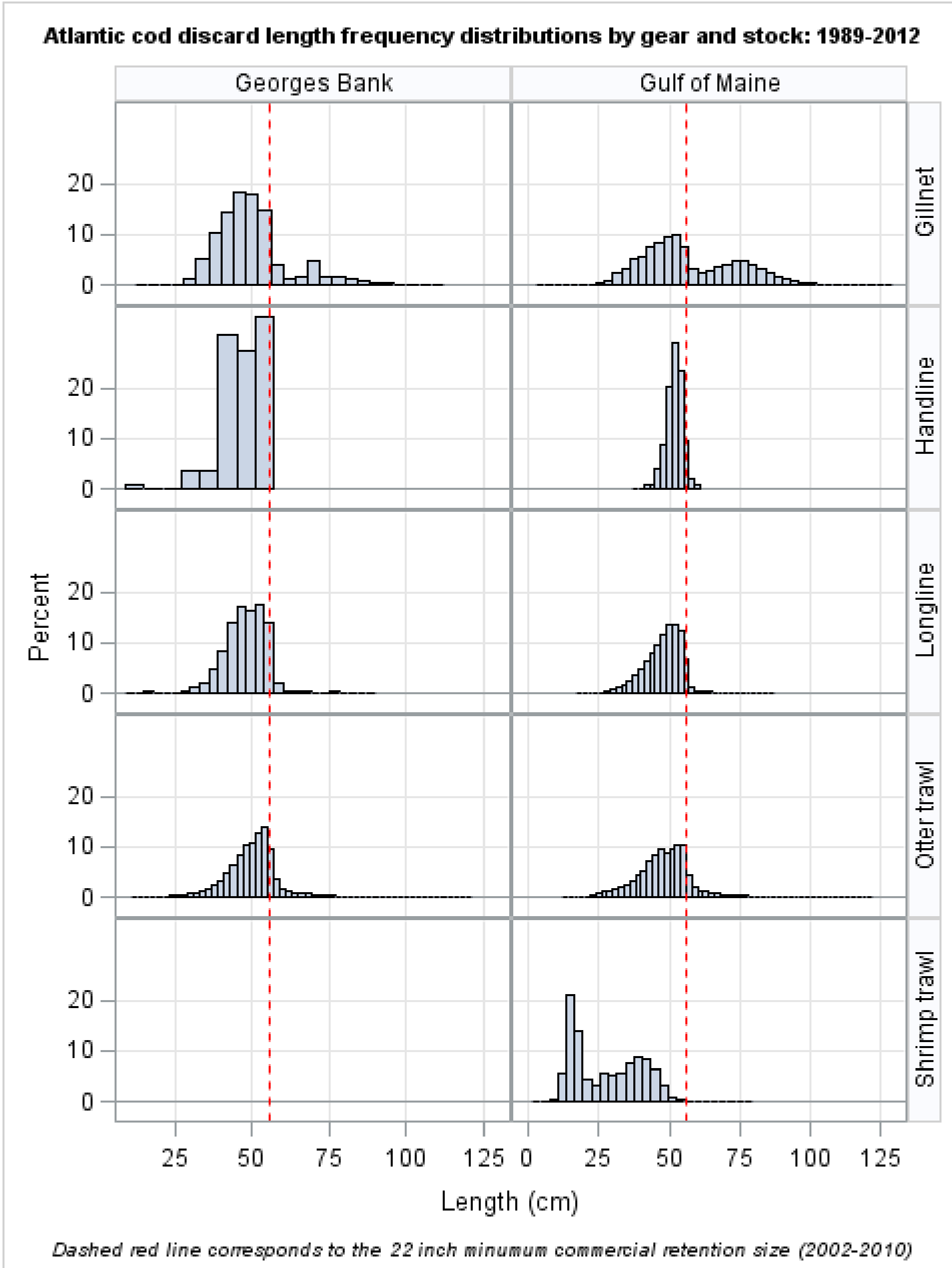


Figure 6. Distributions of observed discards of Georges Bank and Gulf of Maine Atlantic cod (*Gadus morhua*) by fork length and gear type between 1989 and 2010. Gear types are as follows: longline (010), small mesh trawl (050_SM), large mesh trawl (050_LM), shrimp trawl (058), large mesh gillnet (100_LM) and extra large mesh gillnet (100_ELM). There was insufficient sampling of handline gear (020) to adequately characterize the length frequency distribution.

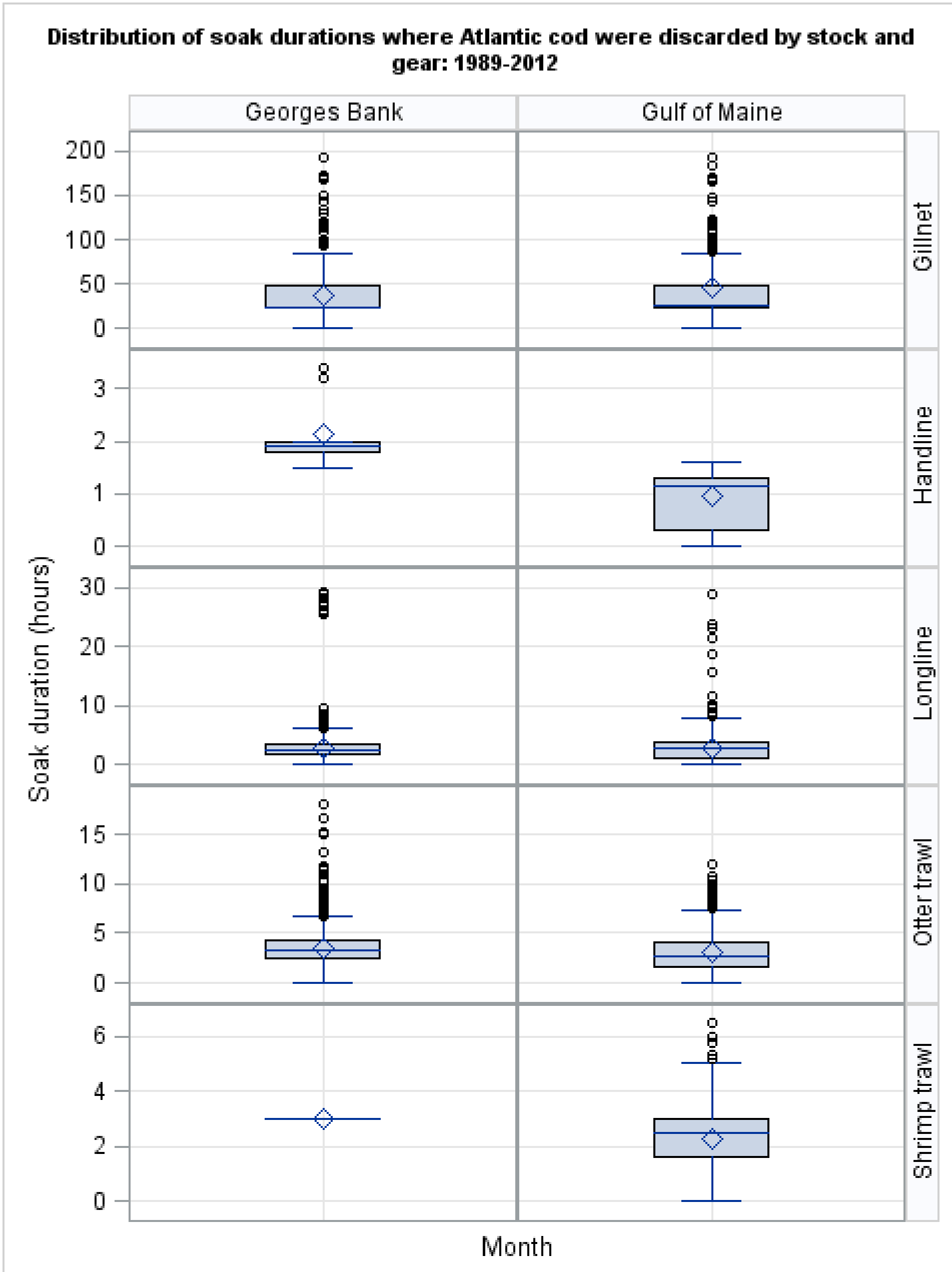


Figure 7. Soak/haul duration distributions of gears responsible for discards of the Georges Bank (top) and Gulf of Maine (bottom) Atlantic cod (*Gadus morhua*) stocks between 1989 and 2012.

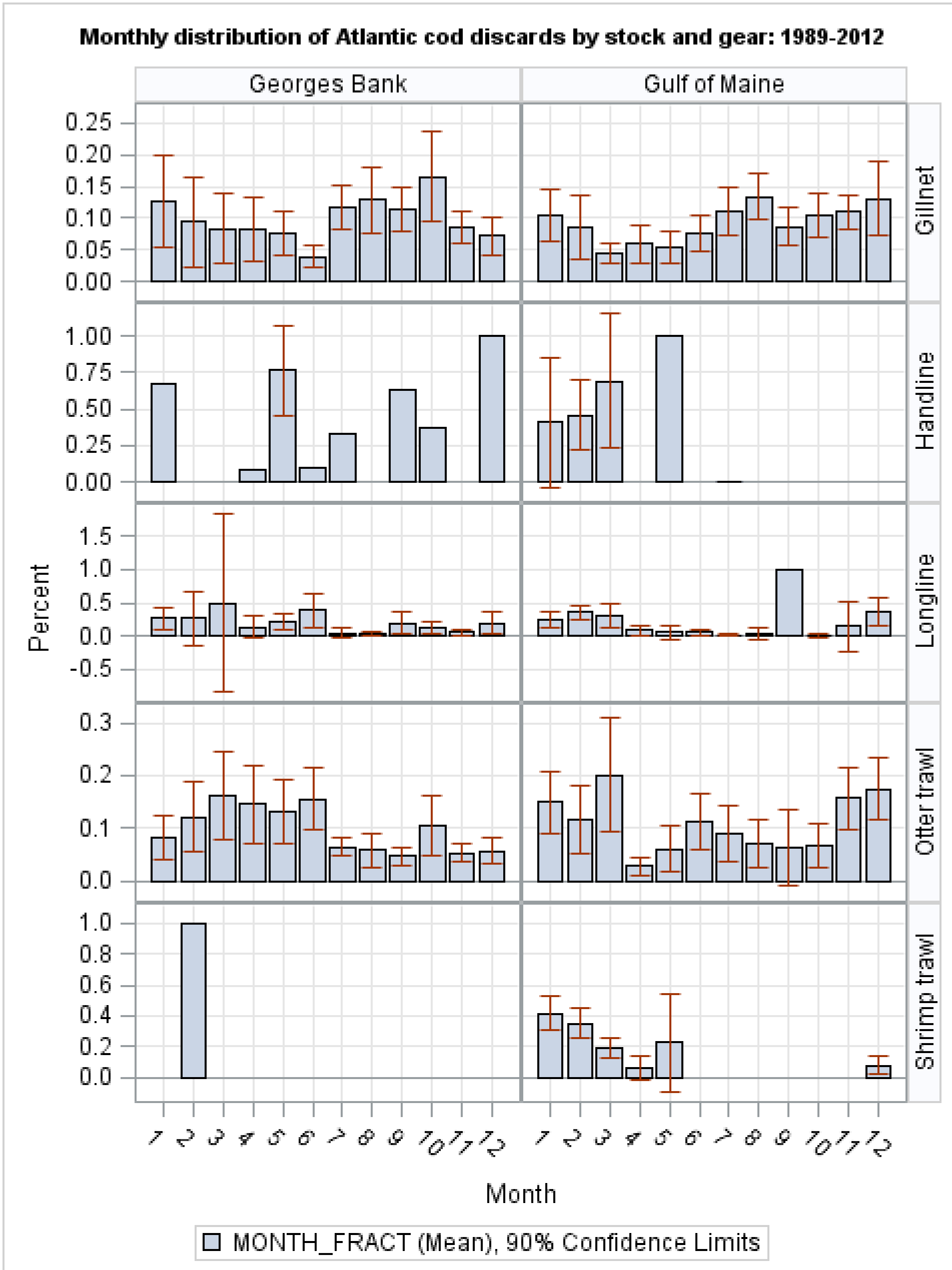


Figure 8. Monthly distribution of observed discards of Georges Bank and Gulf of Maine Atlantic cod (*Gadus morhua*) by stock and gear type between 1989 and 2012.

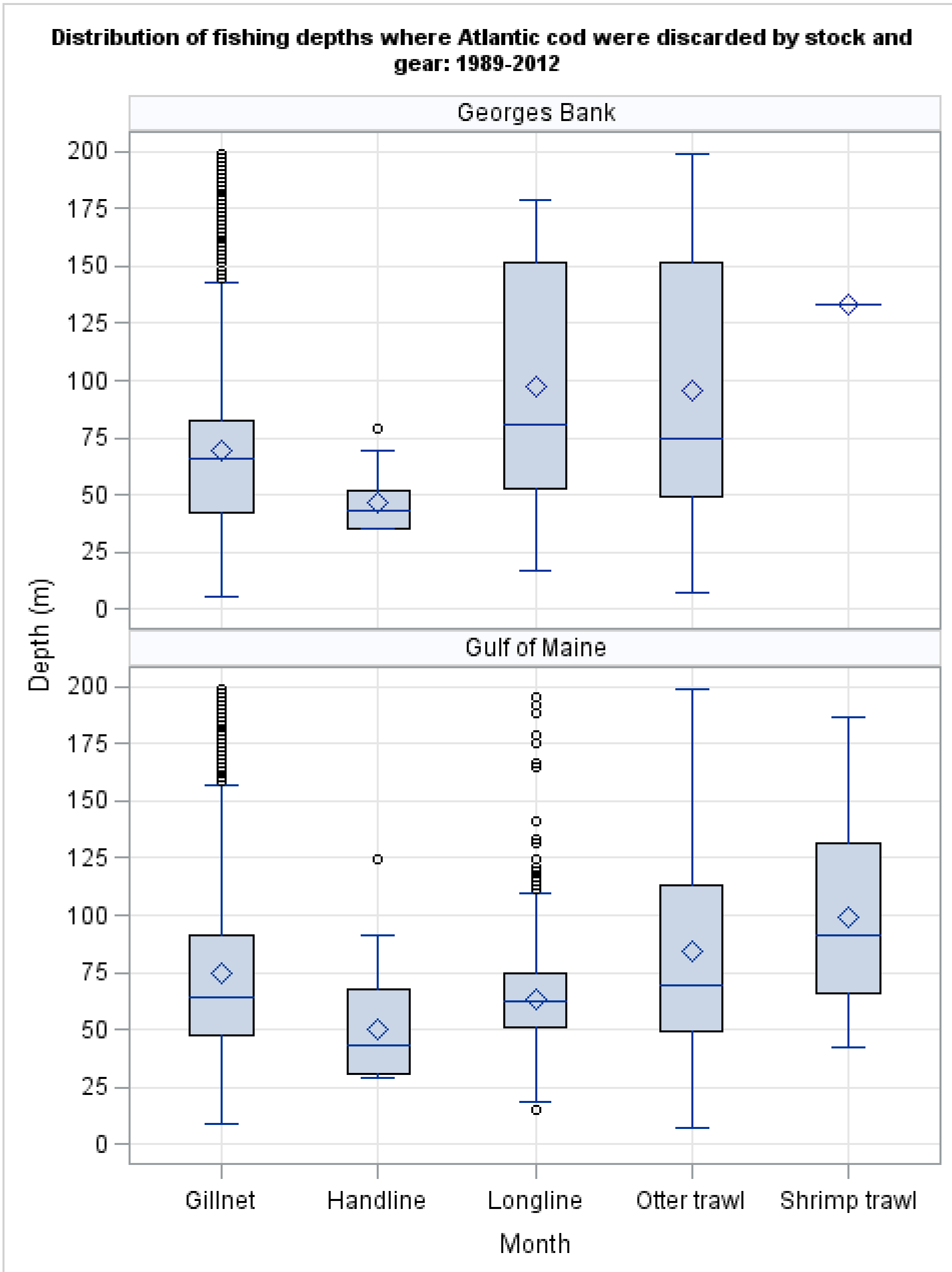


Figure 9. Fishing depth distributions of gears responsible for discards of the Georges Bank (top) and Gulf of Maine (bottom) Atlantic cod (*Gadus morhua*) stocks between 1989 and 2012.

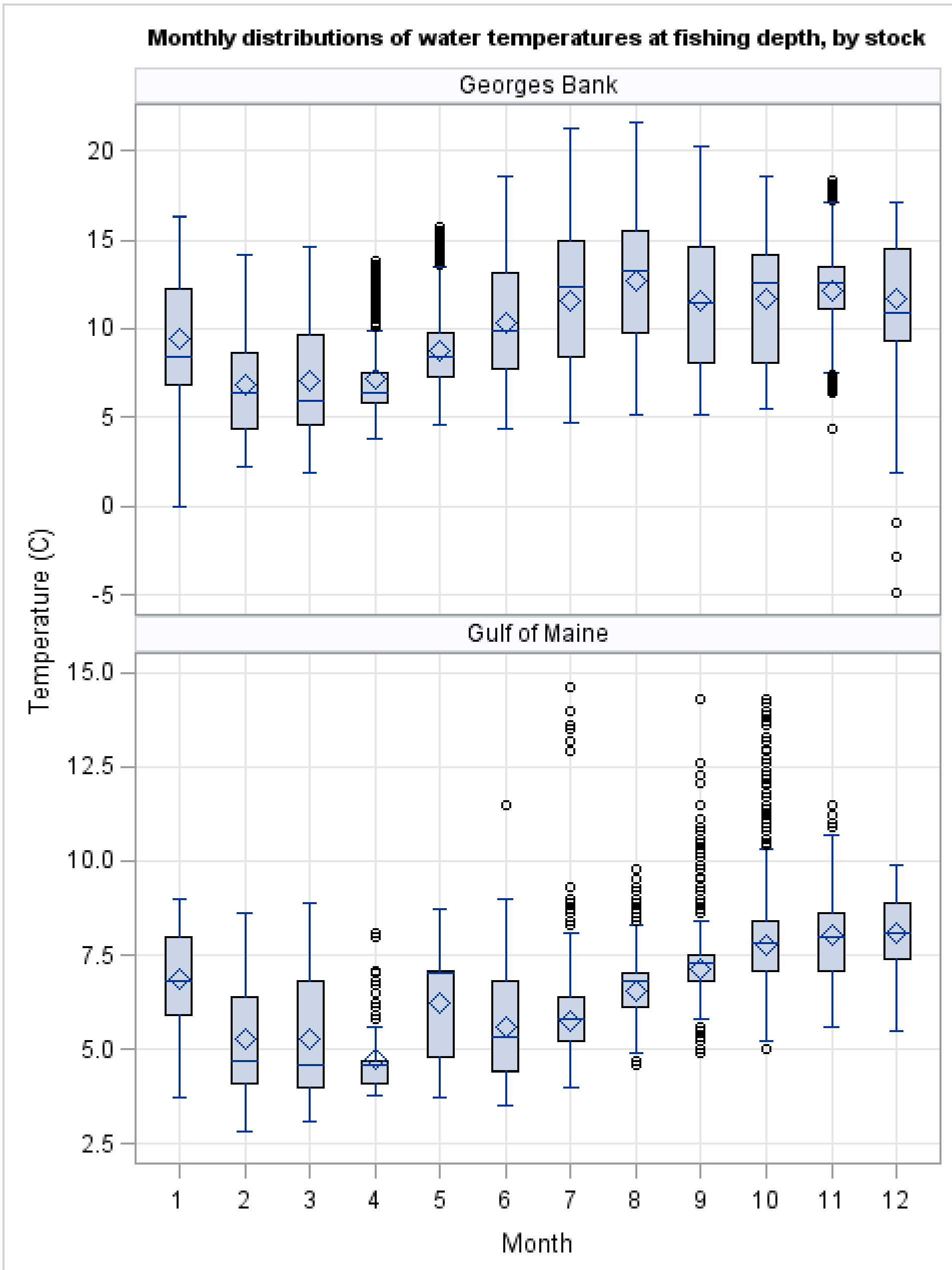


Figure 10. Monthly water temperatures at fishing depths observed in the Georges Bank and Gulf of Maine Atlantic cod (Gadus morhua) stock areas between 1989 and 2012.

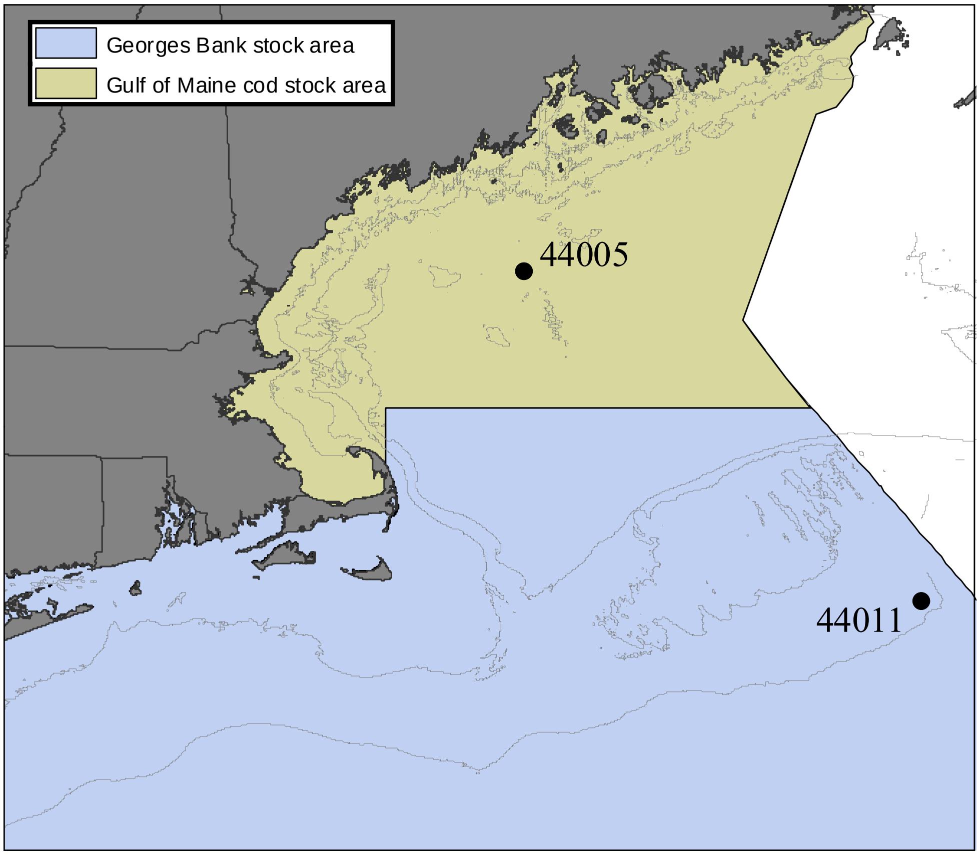
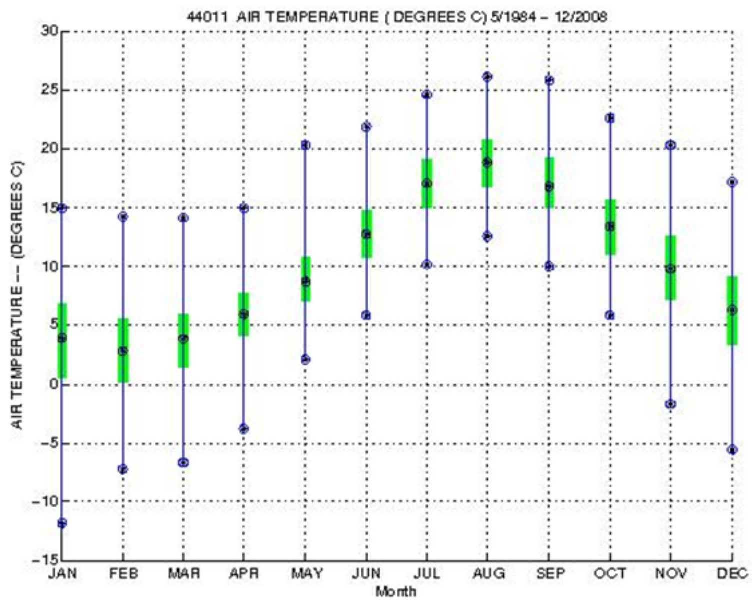


Figure 11. Location of National Buoy Center oceanographic stations 44011 and 44005 and their relationship relative to the Gulf of Maine and Georges Bank Atlantic cod stock area boundaries. The 50 m and 100 m depth contours are shown in light grey.



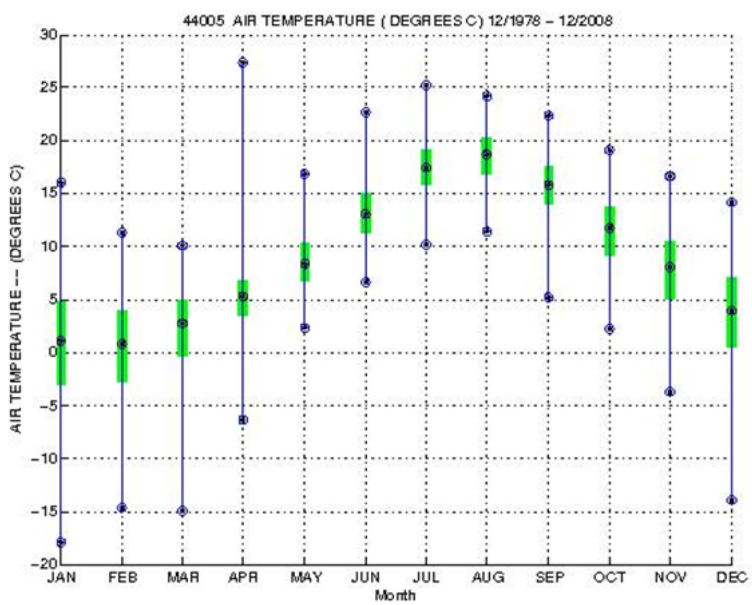


Figure 12. Quartile plot of monthly air temperatures (ºC) from oceanographic stations 44011 (top) and 44005 (bottom). Data included in the 44011 series extends from 1984 to 2008 and for the 44005 plot, from 1978 to 2008. The location of each buoy is shown in Figure 10. Figures are from the National Data Buoy Center (http://www.ndbc.noaa.gov).

Appendix 1. Research summaries from selected cited work.

Benoit HP, Hurlbut T (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 HP, Hurlbut, T, Chasse J (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, Cook R (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 (se = 0.75). This was particularly true for the calculation of equilibrium yield and comparing the effects of different gear selectivities.

Carr HA, Farrington M, Harris J, Lutcavage M (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 FS, Arimoto T (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 behavior.

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, Szymanksi M (2003): were captured off the eastern coast of Cape Cod, MA and into the Great South Channel 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. These results are contradictory to other studies.

Farrington M, Milliken H, Lent E, Carr HA (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 LC, Nies T (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 AV, Huse I (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 OA, Soldal AV, Huse I, Breen M (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 SM (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).

Kaimmer SM, Trumble RJ (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.

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 counter-intuitive is the finding that this also results in smaller estimates of the population number and biomass for the ages concerned.

Milliken HO, Farrington M, Carr HA, Lent E (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 HO, Farrington M, Rudolph T, Sanderson M (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 OH, Einarsson A, Bjornsson H (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 LJ, Fargo J, Schnute JT (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 WE, Carr HA (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.

Ryer CH (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 GI, Lehmann K, Breen M (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 AV, Isaksen B, Marteinsson JE, Engas A (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.

Suuronen P, Lehtonen E, Jounela P (2005): Study examined the mortality of cod from the Baltic Sea that escape through trawl codend meshes under commercial fishing conditions. Three codend configurations were evaluated: a 120mm diamond mesh codend, a Danish type 105mm escape window codend, and a 105mm square mesh top-panel codend (Bacoma-window). A total of 30 tows were carried out over three different experiments. Mean tow duration was 3 h and average codend catch 536 kg (range 47–2592 kg). Escapees were collected during the last 20 min of each haul by a caging method. Fish were then held in cages anchored on the seabed and checked daily by divers.

The mortality of escapees was low in normal water temperatures (<10 ◦C) in all codend types. Higher mortalities were observed when cages were held in temperatures above 15 ◦C. The majority of these deaths occurred during the first day after the tow. The study found no clear influence of fish size and codend fullness on cod mortality. They did note that there results in these areas were not conclusive and that more work was needed.