Injury Frequency for Discarded Summer Flounder (*Paralichthys dentatus*) in the Recreational Fishery of the Mid-Atlantic Bight: Influence of Landing Size Regulations

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Abstract

Summer flounder, *Paralichthys dentatus*, supports an important recreational fishery along the northeast coast of the United States. Successful rebuilding of the stock and the need to constrain landings within total-allowable-landing targets has resulted in declining bag limits and increasing size limits. Concurrent unwanted outcomes of these regulations include the increased rate of summer flounder discarding and the reduction in satisfaction derived from recreational fishing trips. A series of fishing trips were observed in which alternative management scenarios were tested to identify approaches to better optimize regulatory constraints through the use of bag limits and size limits. The alternatives included a slot limit in which some smaller fish were allowed to be landed, a reduced minimum size, and a cumulative size, in which the bag limit and size limit were conflated such that fish take was controlled by the cumulative size of the landed fish.

The control or 2006 legal scenario produced higher injury frequencies than other fishing scenarios due to discarding of larger fish that tended to be gut-hooked. Two alternatives performed significantly better in terms of reducing the potential for discard mortality among discarded fish, the slot-limit and the cumulative-size scenarios. An intermediate performance of the reduced-minimum-size scenario was due to an increased proportion of dead fish, but this association was unexplained. Fish uninjured saved for minor hook damage were common on all vessels and in all fishing approaches. Injury frequency was, in fact, remarkably low, less than half of the assumed discard mortality rate in present-day stock assessments. The study supports the use of size-specific mortality rates for fish discarded recreationally. The study offers no support for the efficacy of the 2006 management system in controlling discard mortality rate. Simply put, the present-day regulatory plan maximizes discards while simultaneously maximizing the discard of injured fish less likely to survive. Any of the alternative plans is an improvement, but the slot-limit and cumulative-size scenarios are deserving of the most scrutiny.

Introduction

Summer flounder, *Paralichthys dentatus*, is an important commercial and recreational fishery along the northeast coast of the United States from North Carolina to Massachusetts. Summer flounder is one of the most sought fish by consumers of seafood (Burger et al., 2004) and accounts for a substantial fraction of angling trips by Mid-Atlantic Bight anglers (Terceiro, 2002). Summer flounder was seriously overfished in the late 1980s to early 1990s (Terceiro, 2006). A stock rebuilding program began in the early 1990s that ultimately resulted, by 2004, in the return of spawning stock biomass to near historically-high levels (Terceiro, 2006), although the most recent assessment found the stock to remain in an overfished state. Nevertheless, the degree and rapidity of rebuilding of the stock is noteworthy. This remarkable accomplishment did not come without vexations, however. Achieving target fishing removals was readily accomplished for the commercial sector by monitoring landings referenced to a total-allowable-landing limit. Achieving the same for the recreational fishery proved a more formidable task. For the recreational fishery, as in the commercial fishery, allocations are based on biomass, but for the recreational fishery, regulation of take is based on the landing of individual fish. Reliance was placed on modulating the time-honored limitations on take (bag limits) and size (size limits). Size limits help restrain total landings, but also are instrumental in expanding size-frequency distributions truncated by overfishing. The potential for size-frequency truncation by recreational overharvesting is documented (e.g., Schroeder and Love, 2002; see also Richardson et al, 2006) and the impact of commercial harvesting on the size-frequency distribution is well-described (e.g., Greenstreet and Hall, 1996; Rago et al., 1998; Richardson et al., 2006). Coincident with the rebuilding of the summer flounder stock has been the establishment of a more normal, distributed size-frequency distribution from the seriously truncated state of the early 1990s (Terceiro, 2006).

For summer flounder, overages, wherein yearly landings exceed targets, became commonplace in the recreational fishery despite increases in size limits and reductions of bag limits. In no small measure, the increasing stock size militated against successful constraint of the recreational fishery through the increased abundance and availability of legal-sized fish to the angling public. Concomitantly and accordingly, as bag limits were reduced and size limits increased to constrain landings, the number of fish caught and discarded necessarily increased. By 2005, discards had reached a significant fraction of total catch and discard mortality, although a small fraction of total discards, had become an important source of total mortality for the stock, exceeding that of the commercial fishery by nearly a factor of four (Terceiro, 2006). Simultaneously, as most of the summer flounder recreational fishery is consumptively motivated, the quality of the fishing experience achieved by the recreational angler decreased as the number of fish kept became a small fraction of total catch and as fish of the size allowed to be landed became rarer inshore, where the majority of the angling public fished.

The problem of discards in fisheries management is well documented and widely discussed (e.g., DeAlteris et al., 1996; Murawski, 1996; Jennings and Kaiser, 1998; Halliday and Pinhorn, 2002). Discards issue from regulatory control (e.g., Coleman et al., 2004; Powell et al., 2004; Bochenek et al., 2005), but also through the approach to and economics of fishing (e.g., Gillis et al., 1995; Stratoudakis et al., 1999; Salthaug and Aanes, 2003). Much attention has been focused on discard mortality in the commercial sector (e.g., Suuronen et al., 1996; DeAlteris and La Valley, 1999; Maguire et al., 2002): much less attention has been focused on the mortality associated with recreational discarding (e.g., Render and Wilson, 1994; Monaghan and Ross, 1995; Coleman et al., 2004). As a consequence of the plethora of unintended repercussions from the institution of regulations decreasing bag limits and increasing size limits, we carried out a series of experiments designed to test the efficacy of three alternative management plans. Each varied either size limits or the relationship of size limits to bag limits with the target of converting discards into landings while retaining constraints on harvest required under total-allowable-landing goals. Options included the landing of a certain number of fish below the normal legal size under a defined bag limit and the conflation of bag limits and size limits by restricting the cumulative size of landed fish. Bochenek et al. (submitted) describe the impact of each scenario on the discard-to-catch ratio. Here, we evaluate the frequency of injury among fish discarded under each of the experimental plans to determine if varying the approaches to bag limits and size limits can both reduce discards and also discard mortality, while improving the angling experience by retaining or increasing landings.

Methods

Experimental Design

Four fishing scenarios were compared: (1) a reduced minimum legal size limit set at $\geq 14''$, under the legal bag limit; (2) a slot limit in which anglers were allowed to keep two fish between $14''$ and the state-specified minimum size limit; (3) a cumulative-size limit in which the state-specified bag limit and size limit were conflated to produce a cumulative size limit for fish $\geq 14''$ – for New Jersey, for example, this was obtained as $8\,\text{fish} \times 16.5'' = 132''$; and the 2006 legal bag limit and size limit, hereafter termed the control condition. The control conditions varied between states. For New Jersey in 2006, the bag limit was eight fish and the legal size was ≥16.5″. For New York, the bag limit was four fish and the legal size was ≥18″. Subsequent statistical analyses did not resolve any influence of the difference in regulatory control between states and thus control trips were not further distinguished. Fourteen inches was selected as the minimum size for the experimental trips because this was the minimum-size limit for the commercial fishery in 2006.

Vessels and Location

The study took place during the fishing season of 2006 using party boats from New Jersey and New York. Details are provided by Bochenek et al. (submitted). Five vessels were selected to encompass the variation in vessel sizes and areas fished along the coasts of New Jersey and Long Island, New York with three vessels from homeports in New Jersey and two vessels from homeports in New York. These vessels covered the range of party-boat activity along this stretch of coastline, fishing inshore in state waters, offshore in federal waters, and in lagoons and estuaries. The vessels covered a range of sizes and angler capacities from a lower limit of 50 anglers to a maximum of 131. Bochenek et al. (submitted) provide detailed descriptions of these vessels. The locations of the fishing trips observed for this study are shown in Figure 1. The four fishing scenarios were observed on each vessel three times with observations occurring in the early, middle, and late phases of the fishing season beginning in June and finishing in September of 2006. Each observation encompassed a full-day trip or two half-day trips, morning and afternoon. Catch statistics for these trips are provided by Bochenek et al. (submitted).

Health Assessment

On each drift of each trip, onboard observers recorded the condition of as many fish as could be observed and noted whether these fish were kept or discarded. Total length of each observed fish was measured to the nearest 0.125″. The observed fish included the vast majority of all fish caught, although occasional periods of rapid capture of fish may have resulted in some fish haphazardly being excused from observation. No fish known to have been caught escaped observation, however. Additionally, captains recorded the beginning and ending times and positions of each drift.

Observers were unable to follow released fish. As a consequence, health codes were developed that ranked fish according to obvious damage and that reflected an anticipated likely increase in the risk of mortality. We recognize that fish recover from even mild capture and release slowly, often over a period of weeks (Bouck and Ball, 1966; Pickering et al., 1982; Haux-Sjöbeck and Larsson, 1985). Fish were described as healthy, bleeding, gut-hooked, and/or dead. A healthy fish was a fish with no obvious injury save for mild damage in the mouth region due to hooking. Gradations were achieved by combining certain of these observations. For example, a fish with minor bleeding but otherwise healthy was described as both healthy and bleeding. Observers provided these ratings for each kept and discarded fish.

The observations of injuries and assessments of health were later combined into a 0-to-4-point morbidity scale and an injury scale. The morbidity scale was defined as follows. All fish observed to be healthy, without additional comment, were judged to be in GOOD condition (0). (Upper case denotations identify categories in subsequent figures; parenthetical numbers assign semiquantitative rankings for statistical analysis.) Fish with injuries noted, but still described as healthy, fish with minor bleeding for example, were given an overall morbidity rating of NWEL (not well) (1) . Fish described as bleeding or gut hooked were given the next lower morbidity rating of ILL (2). Fish both bleeding and gut-hooked were judged to be moribund (MORB) (3). Fish identified as DEAD (4) were so judged. The 0-to-4-point morbidity scale provided a ranking for each observed fish from fish apparently uninjured beyond minor damage due to hooking to fish that were dead that could be analyzed statistically. The injury scale focused on the type of injury observed and was inherently categorical rather than semiquantitative. This scale assigned fish to five categories. Those without observed injury beyond minor damage due to hooking were assigned to the uninjured category (NONE). Gut-hooked fish were so described (GUT). Fish bleeding were assigned to that category (BLED). Fish both bleeding and gut-hooked were so described (BGUT). The latter three conditions were assigned regardless of whether the fish was living or dead at the time of observation. If a fish was dead, but no injury was noted, it received a deceased code (DECD). Finally, we assigned fish to a binomial health index of WELL (0) or unwell (SICK) (1) by assigning any fish with any noted injury to the latter. The health index was also analyzed statistically.

Descriptors of Trip and Catch

Drifts were assigned to either forenoon (AM) or afternoon (PM) categories. Time-of-day for statistical analysis referenced these two categorical variables. Effort was calculated as the product of the number of anglers per vessel and the cumulative elapsed time of the drifts for each trip and time-of-day. Bochenek et al. (submitted) describe the use of this effort measure rather than one that focused on the cumulative distance of each drift. Catch rate did not influence effort as has been observed elsewhere (Miranda, 2005). Fish were assigned to a series of 1-inch length classes for statistical analysis with the upper class boundary falling in the higher class: $\geq 18''$ (L18), 17-18$''$ (L17), 16-17$''$ (L16), 15-16$''$ (L15), 14-15$''$ (L14), 13-14$''$ (L13), and $<13''$ (L12).

Statistical Analysis

In every case, analyses were conducted separately for kept and discarded fish. Statistical analysis followed a bipartite path. The relationships of the morbidity index and the binomial health index with the main effects of vessel, time-of-day, fishing scenario, and length class were evaluated using ANCOVA. Effort and depth were included as covariates. Initial investigation permitted the elimination of most pairwise interaction terms, the exceptions being the interaction of vessel and fishing scenario and vessel and time-of-day. Thus, overall, pairwise interactions were rarely significant. Tukey's Studentized Range Tests were used to evaluate the location of significance within significant ANCOVAs. As interaction terms were rarely significant, these tests were relatively reliable indicators of the rankings of category states; however, the reader is cautioned nevertheless concerning the use of *a posteriori* tests when interaction terms are significant.

In several cases where significant interaction terms occurred between two main effects, we followed up the primary ANCOVA with a more limited analysis targeting one of the two main effects analyzed sequentially for each of the second main-effect states. Where appropriate, additional main effects and interaction terms were retained in the subsidiary analyses.

The design of the fishing alternatives permitted the retention of fish smaller than the legal size in force in 2006. We anticipated that discard mortality would be affected by any differential in injury propensity between length classes. To identify variations in the size-frequency of discards, we described the discards of each trip in terms of descriptors of the size-frequency distribution, namely the mean size discarded, the 25^{th}, 50^{th}, and 75^{th} percentiles of size for fish discarded, and their interquartile range. Each was used as a dependent variable in ANCOVA with vessel, time-of-day, and fishing scenario as main effects. Depth and effort were included as covariates, as well as interaction terms that preliminary analysis indicated on occasion were significant.

In addition, correspondence analysis (Claussen, 1998) was used to visualize the relationship of certain main effects with morbidity and injury class. Correspondence analysis is a data-reduction technique that permits evaluation of correlational relationships within categorical datasets (e.g., Green, 1993; Ghertsos et al., 2001) analogous to principal components analysis for continuous or meristic (*sensu* Sokal and Oden, 1998) data. For this purpose, depth and effort were also converted into polytomous variables as follows. Drifts were assigned to four depth categories: 0-20 ft (Z20), 20-40 ft (Z40), 40-60 ft (Z60), and >60 ft (Z80). Effort was assigned to a series of effort categories: HIGH (>25 angler-hours), moderately high (MHGH, 15-25 angler-hours), moderately low (MLOW, 7-15 angler-hours), and LOW (<7 angler-hours). Again, in each case, the upper class boundary of intermediate states was assigned to the higher category.

Correspondence analysis used as primary data sources vessel, time-of-day, fishing scenario, length class, and the categorical variables for effort and depth. That is, axes were defined based on descriptors of the trip, not descriptors of fish health. Supplementary variables positioned on the axes thusly defined included the morbidity index, the injury index, and the health index.

Results

The number of trips, tows, anglers per trip, an other descriptive metrics of the fishing experience are provided by Bochenek et al. (submitted). Here, we examine the relationship of the health and morbidity indices on descriptors of the trip, fishing scenario, and catch. The health index was a binomial index discriminating injured or dead fish from those without apparent injury. The morbidity index was a 0-to-4-point ranking of fish health from apparently uninjured to dead. Several variables rarely influenced fish health (Table 1). These included time-of-day, effort, the interaction of vessel and time-of-day, and fish length. With the exception of fish length, these were not investigated further. Three variables were routinely significant, regardless of whether the fish was kept or discarded: vessel, fishing scenario, and the interaction of vessel with fishing scenario (Table 1). Depth was unique in significantly influencing the health of discarded fish, but not kept fish (Table 1).

Fish were injured more frequently on Vessel B and Vessel E than on the other three vessels (Table 2). For kept fish, this distinction cleanly discriminated these two vessels from the other three. Generally the health and morbidity indices doubled between these two vessel groups. For discarded fish, the distinctions were less clear, although the rankings were relatively consistent (Table 2). In particular Vessel C consistently returned to the water fish with lower injury frequencies than Vessel B and this difference was greater than a factor of two for both indices. In general, the condition of kept and discarded fish on a given vessel was similar.

Fishing scenario exerted a significant effect on the health and morbidity indices for that fishing scenario, but in no case did an *a posteriori* test identify the source of these significant differences (Table 3). Failure to identify the source of significance in the ANCOVA comes from the significant interaction between vessel and fishing scenario, as subsequently discussed (Table 1). For discarded fish, control fish consistently ranked higher in health or morbidity index; that is, these fish were injured more often and more seriously (Table 3). The fishing scenario using the slot limit consistently ranked lowest; that is, these fish were injured least often. Intermediate and never significantly different were the reduced-minimum-size and cumulative-size fishing scenarios (Table 3).

The interaction term between vessel and fishing scenario was significant in all cases (Table 1). We examined this interaction for discarded fish. The origin of this interaction is twofold. For the slot-limit trips, discards on Vessel B were in significantly poorer health than the discards on the remaining vessels. For the cumulative-size scenario, discards on Vessel D and Vessel C were in significantly better health than the discards on the remaining vessels. The latter trend was distinct from the overall trend in health for discarded fish among vessels (Table 2), whereas the former was consistent with it.

Overall, the morbidity index diverged significantly between kept and discarded fish; interaction terms with vessel and fishing scenario were also significant (Tables 1 and 4). To investigate the latter, we restricted the ANOVA and assigned each fish to a main-effect category of kept or discarded. We included the two important main effects identified in Table 1, vessel and fishing scenario, plus all pairwise interaction terms. The health of kept and discarded fish was significantly different (Table 4). Interestingly, the morbidity index averaged higher for kept fish, 13.1 versus 9.2 for discarded fish. Thus, the larger kept fish on average were characterized by more frequent and severe injuries.

As a consequence of the consistent significance of the interaction terms relating vessel to fishing scenario, we evaluated the morbidity index separately for each vessel and fishing scenario. We retained the other main effect and appropriate interaction term in each ANCOVA. For fishing scenario, the morbidity index diverged significantly for the control, 2006-legal, scenario ($P = 0.0027$) and the slot-limit scenario ($P = 0.0004$), and very nearly so for the cumulative-size scenario ($P = 0.057$). For the control scenario, the morbidity index was 0.133 for the discarded fish and 0.106 for the kept fish. The respective values for the cumulative-size scenario were 0.067 and 0.102 and, for the slot-limit scenario, 0.045 and 0.089. Thus, for the two alternative scenarios, the discarded fish were injured much less frequently than the kept fish. This was not true for the controls. In contrast to fishing scenario, only one vessel recorded a significant difference in the morbidity index between kept and discarded fish, Vessel E ($P < 0.0001$). Discarded fish were in significantly better condition on this vessel than kept fish (morbidity indices of 0.106 and 0.201, respectively)

Depth significantly influenced the health of discarded fish. Fish caught in deeper water were recorded with an increased frequency and severity of injury. The correlation between depth and the health of discarded fish, though significant, was not strong (Spearman's ρ = -0.078).

Fish length generated only a single significant result, for the morbidity index, for discarded fish (Table 1). An *a posteriori* test failed to resolve specific sizes that diverged significantly in morbidity from others; however, the trends between size classes were interesting. Fish averaging highest on the morbidity index were the smallest fish, $<13''$ (Table 5). Largest fish, 17-18$''$ and $\geq 18''$ ranked second and third highest in this injury index. Least injured fish were in size classes covering the 13-16$''$ range. The morbidity index averaged fully one-third lower for the least injured size class (14-15$''$) relative to the two most injured size classes, $<13''$ and 17-18$''$ (Table 5).

The size of fish discarded depended primarily on the vessel and the fishing scenario (Table 6). Time-of-day, depth, and effort were never significant and only a few interactions terms returned a weakly significant signal. Vessel influenced the largest size of fish discarded. The 25^{th} percentile of size did not vary significantly with vessel, whereas the 75^{th} percentile and the interquartile range were highly significantly different. The vessel effect issued from two sources. Vessel B had a higher proportion of smaller fish. The mean and 25^{th} percentile of size were significantly smaller for Vessel B than for the other vessels (Table 7). Vessel D and Vessel E caught larger fish than the other vessels. The 75^{th} percentile of size was significantly larger for these two vessels than for the others (Table 7).

Fishing scenario exerted a significant effect on all descriptors of the size-frequency distribution (Table 6). The mean and percentiles of size were significantly larger for the control scenario than for the others, as expected (Table 8). Each of the other scenarios allowed the landing of smaller fish. The slot-limit scenario fell intermediate between the controls and the cumulative-size and reduced-minimum-size scenario (Table 8). This too was expected as the landing of fish below legal size was more constrained by this fishing scenario than by the other two experimental alternatives. As anticipated, the trend towards significant variation in the size of fish landed was emphasized at the upper end of the size frequency distribution as exemplified by the 75^{th} percentile. The 25^{th} percentiles did not differ significantly among the three alternatives (Table 8). These fish were too small ($<14''$) to be landed using any fishing scenario.

Discussion

Perspective

The present-day management plan for constraining landings in the summer flounder recreational fishery to a total-allowable-landing target is based on the combined implementation of a bag limit and a size limit. A fish caught, if the bag limit has not yet been reached and if of sufficient size, can be landed if the angler so chooses. This implementation of bag and size limits has worked with decreasing efficacy as the spawning stock biomass of summer flounder has reached historical highs. First, the fraction of caught fish meeting bag-limit and size-limit criteria is low. This is particularly true nearshore where summer flounder tend to average of smaller size. This degrades the recreational experience. Second, the fraction of caught fish meeting bag-limit and size-limit criteria is low enough that discard mortality becomes an important component of total fishing mortality for the recreational fishery. This happenstance exists despite an assumed fraction of discards dying that is relatively low, 10%.

The recreational fishery comprises a number of angling approaches, including fishermen who fish from shore, anglers on small, often self-owned, boats, and anglers participating more communally on party boats. The party-boat fishery for summer flounder is an important recreational fishery in the Mid-Atlantic Bight. We examined vessels from two states, New York and New Jersey, with the intent of testing the efficacy of modifications in bag-limit and size-limit restrictions presumably reducing discards without increasing landings. As ultimately the management of this fish is based on biomass (Terceiro, 2006), the focus was on the conversion of discards of biomass to landings of biomass. The landing of smaller fish under a defined bag limit militates in favor of a decrease in landings biomass. The caveat is, of course, that a shift to the landing of smaller-sized fish would reduce biomass but increase numbers of fish removed from the stock without careful modulation of the bag limit. We did not explicitly evaluate that trade-off; rather, by observing fishing trips on party boats, we gathered data on the likely value of this trade-off (Bochenek et al., submitted) and estimated further in this study the influence on discard mortality by this shift of effort.

We compared three potential fishing scenarios to the 2006-legal, control scenario. The first was a slot limit in which a few of the fish were allowed to fall within a slot bounded on the lower end by a size restriction below legal size (14″ in our case). The second was a simple reduction in minimum size without a modification of the bag limit. The final alternative was the restriction of landings to a cumulative total size. This approach conflates bag limits with size limits, since landings are a function of the cumulative length of fish retained relative to a legally-imposed cumulative size calculated as the multiple of the legal size and bag limit. Bochenek et al. (submitted) evaluated the catch and discards of observed trips under each of the four fishing scenarios. Here, we examine the influence of these options on the likely survival of discards.

We stress one important additional caveat. The summer flounder recreational fishery has evolved such that the bag limit is nearly non-functional today. That is, the restriction on landings is achieved almost entirely by a size limit sufficiently draconian as to restrict the number of fish that can be landed by their abundance and availability to a very small number per angler per day. As a consequence, the influence of the three alternative plans is primarily in relaxing this size limitation, allowing the angler to retain a number of fish more near the bag limit. From the perspective of the stock, the result is likely a reduction in the biomass removed, but an increase in the number of individuals, due to the rapid increase in weight for a given increment in length. However, given the limited influence of the bag limit, the result may well be an increment in biomass and number. Consequently, cases where discard reduction minimized discard mortality should not blithely be assumed to indicate that a reduction in total fishing mortality would be achieved thereby, if implemented through regulation, as a portion of the present regulatory scheme is effectively dysfunctional[†].

The Fraction of Injured Fish

We identified a series of injuries and, building on previous studies (e.g., Muoneke and Childress, 1994; Zimmerman and Bochenek, 2002; Malchoff et al., 2002) partitioned them into two primary categories, fish that were gut hooked and

[†] We assume that the primary purpose of the dysfunctional bag limit is to generate hope in the optimistic angler.

fish that were bleeding after hook removal or from other injuries occurring during capture. The latter in particular covered a range of limited to more serious injuries. This range was encompassed by an observer's judgment as to whether the fish was generally healthy grading to moribund and the observation that more seriously injured fish often were both bleeding and gut hooked. Of course, fish were also recorded as dead. A binomial health index was generated based on the separation of fish into two categories, those without any observable injury beyond minor hook damage versus those injured in either way or dead.

What is surprising is the overall rarity of injured fish. The highest rates observed approximated the assumed frequency of discard mortality used in recent assessments of summer flounder, 10% (Terceiro, 2006). The overall mean for the study, however, including the fishing scenarios and vessels with the higher rates, was 4.88%, a value about half that high. Likely, many of these injured fish will not recover, but anticipating that even a few of them do, the results of this study suggest that the presently-assumed probability of mortality upon discard is high by at least a factor of two in the party boat sector of the recreational fishery.

Discard mortality is usually assumed equivalent across size classes in stock assessments. That is the case for summer flounder, as an example (Terceiro, 2006). In this study, the injury rate varied considerably across length classes, by a factor of three. Malchoff et al. (2002) did not find length to be a significant predictor of mortality in recreationally-caught summer flounder; however, that study did resolve an interaction between injuries resulting in bleeding and length. In our study, the trend in injury frequency was nonlinear. Medium-sized fish were injured less frequently than small and large fish. The differential was a primary modulator of the outcome of the effect of fishing scenario on the potential for discard mortality. The results of this study suggest that increased accuracy in the estimate of discard mortality can be acquired by the use of size-dependent mortality rates.

Vessel Effects

Vessels B and E were associated with higher overall injury rates for discarded fish. Vessel B fished inshore in locations where small ($<13''$) fish were particularly common. Small fish averaged highest in injury rate (Table 5). This association explains the unfortunate position of Vessel B in this hierarchy and suggests that discard mortality rates should not be considered equivalent over the inshore-offshore gradient of the fishery. Vessel E supplied a beak hook to anglers not supplying their own gear. This hook style differed from the wide gap or octopus hooks supplied by the remaining vessels. Although uncertain, the possibility exists that this hook style was responsible for the higher injury rates. Differing hook styles have been associated with differential mortality rates (Bartholomew and Bohnsack, 2005; Millard et al., 2005)

Vessel effects also modulated the size-frequency distribution. On average, Vessel D and Vessel E fished in relatively deep water offshore, whereas Vessel B fished in shallow estuarine and inshore waters. Smaller summer flounder tend to be found inshore and in estuaries (e.g., Szedlmayer and Able, 1996), thus explaining the vessel effects observed. Vessel B discarded disproportionately larger numbers of fish $<13''$ in size. Vessel D and Vessel E discarded many more fish $15''$ and larger.

Fishing Scenario

The three alternative fishing scenarios permitted retention of fish smaller than legal size. Not surprisingly, the fish discarded on the control trips which took place under 2006 legal conditions, averaged larger than the alternative scenarios. Discards averaged somewhat smaller for the slot-limit scenario and considerably smaller for the other two alternatives (Table 8). The differential between the three alternative scenarios is explained primarily by the differential in the number of medium-sized fish kept and hence the number of medium-sized fish discarded. Discarding of these medium-sized fish was proportionately more frequent with the slot-limit scenario because this scenario limited the retention of sublegal-sized fish more than did the other two alternatives. As a consequence, the three alternative fishing scenarios did not differ significantly in the 25^{th} percentile of size, but significant differences did exist in the 75^{th} percentile of the size distribution discarded.

Several facts are immediately apparent from the comparison of injury rate across fishing scenario. The control or 2006-legal scenario yielded the highest potential discard mortality rates. More injured fish were released in this fishing approach than any other. The slot-limit scenario and cumulative-size scenario consistently generated the lowest potential discard mortalities and both were consistently significantly lower than the control, 2006-legal, scenario (Table 3). The difference was a factor of two for the cumulative-size scenario and an impressive factor of three for the slot-limit scenario. Furthermore, the comparison of health between kept and discarded fish is increasingly favorable with these alternative plans. Discarded fish are consistently in better condition relative to kept fish in the alternate plans in comparison to the control plan. This trend is furthermore explained by the lower injury frequency for medium-sized fish 14″ to 16″ in size. The control scenario resulted in discarding of larger fish and these fish were characterized by a higher frequency of injury. The alternative scenarios allowed increased retention of fish 16″ to 18″ in size and thus fewer more-gravely-injured fish were discarded. Accordingly, the relative health of kept and discarded fish diverged to a greater degree for the three alternative fishing scenarios than observed on the control trips.

Factors Underlying the Outcomes

Correspondence analysis provides an holistic view of the dataset that permits ferreting out the interactions most responsible for the overall trends previously discussed. Three dimensions explained the distribution of injury states with respect to the descriptive variables defining the fishing trips: vessel, time-of-day, fishing scenario, depth, and effort. Dimensions 1 and 2 discriminate the five fishing vessels based on the depths fished and size classes of fish discarded (Figure 2). Note the association of Vessel A with the deepest depths (Z80), Vessel C with depths of 20-40 ft (Z40), and Vessel B with the shallowest depths (Z20) and the smallest fish (L12).

Several inferences concerning the relationship of the frequency of injured fish with descriptors of the fishing trips can be derived from a perusal of Figure 2. First, uninjured fish are positioned at the center of the diagram. These fish were observed commonly on all vessels and in all fishing scenarios. Second, Vessel E, the control scenario, and fish of sizes above 16″ are positioned near the fish injured by being gut hooked or observed gut hooked and bleeding. These characteristics distinguish the control scenario from the three alternatives. Fish simply bleeding are nearer the diagrams center and so were more distributed amongst all vessels, fish sizes, and fishing scenarios. The control trips were responsible for a disproportionate number of gut-hooked fish, as was Vessel E. Third, dead fish fall near the center of the diagram. Dead fish are relatively evenly distributed among all vessels. The relationship of fish injury frequency with vessel and fishing scenario is dominantly a function of the health of fish released alive. Finally, Dimension 1 identifies the slot-limit scenario as distinctive in the distance of this scenario from morbidity classes identifying injured fish.

Comparison of the positions of trip and health descriptors on axes defined by Dimensions 1 and 3 re-emphasize most of these previous observations (Figure 3). Dimension 3 clarifies the influence of length class on the remaining primary and supplementary variables. Of particular note is the consistent association of relatively large fish, those fish that were shown to be injured more frequently than medium-sized fish, with injuries from gut-hooking, and with the control, 2006-regulated, fishing scenario. Dimension 3 shows that fish simply bleeding are less associated with this former group of categorical identifiers. Once again, the slot-limit scenario occupies a unique position on this diagram well separated from any morbidity or injury categories identifying injured fish.

Dimension 6 separates two of the alternative fishing scenarios, reduced minimum size and cumulative size, a feat not accomplished by Dimensions 1-3 (Figure 4). (Dimensions 4 and 5 did not influence the distribution of health indices and so are not discussed herein.) The reduced-minimum-size scenario is associated more closely with dead fish than other fishing scenarios in this diagram, and this association explains the somewhat higher morbidity index for this fishing scenario than observed for the other two alternatives relative to the control scenario. The cumulative-size scenario occupies a unique position most closely associated with medium-to-small fish (12-13″). Note also in Figure 4 that the two alternative fishing scenarios, cumulative size and reduced minimum size, are not associated with any vessel. As in the previous two figures, the slot-limit scenario is associated with Vessel C. This suggests that the somewhat better performance of the slot-limit scenario may in part be explained by a uniquely better performance of this scenario on Vessel C. Vessel C had unusually good morbidity indices for discarded fish (Table 2). Of course, both Vessel C and slot-limit trips may have been uniquely associated with low injury frequencies and, so, coincidentally located in correspondence space.

Correspondence analysis, therefore, offers explanations for a number of the statistical results obtained. The control scenario produced higher injury frequencies than other fishing scenarios. This increased injury frequency was due to the discard of larger fish that tended to be gut-hooked. The reduced-minimum-size scenario had the poorest morbidity index of any alternative fishing scenario, due to the observation of an increased proportion of dead fish. Whether this is happenstance or inherent to this fishing approach is not known. The fishing approach that performed best, the slot-limit, may not be a true improvement over the cumulative-size approach, as the slot-limit may have benefited from the unusually good performance of Vessel C. Uninjured fish were common on all vessels and in all fishing approaches. Injury frequency was, in fact, remarkably low in comparison to the assumed frequency of mortality among discarded summer flounder in the recreational fishery (Terceiro, 2006).

The study offers no support for the efficacy of the present-day management system in controlling discard mortality. Simply put, the present-day regulatory plan maximizes discards (Bochenek et al., submitted) and at the same time maximizes the discard of injured fish less likely to survive. Any of the alternative plans is an improvement, but the slot-limit and cumulative-size plans are deserving of the most scrutiny. Both of these scenarios minimize the discard of relatively large fish, 16″ to -18″, that are more likely to be gut-hooked and therefore presumably more likely to die after discard. Furthermore, permitting enhanced retention of smaller fish properly managed would permit survival of more large fish. As the commercial fishery inherently acts to truncate the size-frequency distribution, with the degree of impact modulated solely by the landings limits, permitting increased survival of the largest size classes recreationally may be beneficial in retaining a distributed size-frequency distribution in the stock.

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Literature Cited

Bartholomew, A., and Bohnsack, J.A. 2005. A review of catch-and-release angling mortality with implications for no-take reserves. Rev. Fish Biol. Fish. **15:** 129-154.

Bochenek, E.A., Powell, E.N., DePersenaire, J., and King, S.E. submitted. Evaluating catch, effort, and bag limits on summer flounder directed trips in the recreational summer flounder party boat fishery.

Bochenek, E.A., Powell, E.N., Bonner, A.J., and Banta, S.E. 2005. An assessment of scup (*Stenotomus chrysops*) and black sea bass (*Centropristis striata*) discards in the directed otter trawl fisheries in the Mid-Atlantic Bight. Fish. Bull. **103:** 1-14.

Bouck, G.R., and Ball, R.C. 1966. Influence of capture methods on blood characteristics and mortality in the rainbow trout (*Salmo gairdneri*). Am. Fish. Soc. Trans. **95:** 170-176.

Burger, J., Stern, A.H., Dixon, C., Jeitner, C., Shukla, S., Burke, S., and Gochfeld, M. 2004. Fish availability in supermarkets and fish markets in New Jersey. Sci. Total Environ. **333:** 89-97.

Claussen, S-E. 1998. Applied correspondence analysis an introduction. Sage Univ. Pap. 07-121, pp. 1-69.

Coleman, F.C., Figueira, W.F., Ueland, J.S., and Crowder, L.B. 2004. The impact of United States recreational fisheries on marine fish populations. Science (Wash. D.C.) **305:** 1958-1960.

DeAlteris, J., Milliken, H., and Morse, D. 1996. Bycatch reduction in the northwest

Atlantic small-mesh bottom-trawl fishery for silver hake (*Merluccius bilinearis*). *In* Developing and sustaining world fisheries resources. The state of science and management. *Edited by* D.A. Hancock, D.C. Smith, A. Grant, and J.P. Beumer. 2^{nd} World Fisheries Congress Proceedings. CSIRO, Brisbane, Australia. pp. 568-573.

DeAlteris, J.T., and La Valley, K.J. 1999. Physiological response of scup, *Stenotomus chrysops*, to a simulated trawl capture and escape event. Mar. Technol. Soc. J. **33:** 25-34.

Ghertsos, K., Luczak, C., and Dauvin, J-C. 2001. Identification of global and local components of spatial structure of marine benthic communities: Example from the Bay of Seine (eastern English Channel). J. Sea Res. **45:** 63-77.

Gillis, D.M., Pikitch, E.K., and Peterman, R.M. 1995. Dynamic discarding decisions: Foraging theory for high-grading in a trawl fishery. Behav. Ecol. **6:** 146-154.

Green, R.H. 1993. Relating two sets of variables in environmental studies. *In* Multivariate environmental statistics. *Edited by* G.P. Patil and C.R. Rao. Elsevier Science Publishers, New York. pp. 149-163.

Greenstreet, S.P.R., and Hall, S.J. 1996. Fishing and the ground-fish assemblage structure in the north-western North Sea: An analysis of long-term and spatial trends. J. Anim. Ecol. **65:** 577-598.

Halliday, R.G., and Pinhorn, A.T. 2002. A review of the scientific and technical bases for polices on the capture of small fish in North Atlantic groundfish fisheries. Fish. Res. **57:** 211-222.

Haux, C., Sjöbeck, M-L., and Larsson, Å. 1985. Physiological stress responses in a wild fish population of perch (*Perca fluviatilis*) after capture and during subsequent recovery. Mar. Environ. Res. **15:** 77-95.

Jennings, S., and Kaiser, M.J. 1998. The effects of fishing on marine ecosystems. Adv. Mar. Biol. **34:** 201-352.

Maguire, J., O'Donoghue, M., Jenkins, S., Brand, A., and Burnell, G.M. 2002.

Temporal and spatial variability in dredging induced stress in the great scallop, *Pecten maximus* (L.). J. Shellfish Res. **21:** 81-86.

Malchoff, M.H., Gearhart, J., Lucy, J., and Sullivan, P.J. 2002. The influence of hook type, hook wound location, and other variables associated with post catch-and-release mortality in the U.S. summer flounder recreational fishery. Am. Fish. Soc. Symp. **30:** 101-105.

Millard, M.J., Mohler, J.W., Kahnle, A., and Cosman, A. 2005. Mortality associated with catch-and-release angling of striped bass in the Hudson River. N. Am. J. Fish. Manage. **25:** 1533-1541.

Miranda, L.E. 2005. Catch rates relative to angler party size with implications for monitoring angler success. Trans. Am. Fish. Soc. **134:** 1005-1010.

Monaghan Jr., J.P., and Ross, J.L. 1995. Reduction of bycatch of recreationally important fishes in North Carolina. Final Report Grant F-55, N.C. Dept. Environ. Health and Natur. Resour., Div. Mar. Fish. 51 pp.

Muoneke M.I., and Childress, 994. Hooking mortality: a review for recreational fisheries. Rev. Fish. Sci. **2:** 123:156.

Murawski, S.A. 1996. Factors influencing by-catch and discard rates: Analyses from multispecies/multifishery sea sampling. J. Northw. Atl. Fish. Sci. **19:** 31-39.

Pickering, A.D., Pottinger, T.G., and Christie, P. 1982. Recovery of the brown trout, *Salmo trutta* L., from acute handling stress: A time-course study. J. Fish. Res. Bd. Can. **20:** 229-244.

Powell, E.N., Bonner, A.J., Muller, B., and Bochenek, E.A. 2004. Assessment of the effectiveness of scup bycatch-reduction regulations in the *Loligo* squid fishery. J. Environ. Manag. **71:** 155-167.

Rago, P.J., Sosebee, K.A., Brodziak, J.K.T., Murawski, S.A., and Anderson, E.D. 1998. Implications of recent increases in catches on the dynamics of northwest Atlantic spiny dogfish (*Squalus acanthias*). Fish. Res. **39:** 165-181.

Render, J.H., and Wilson, C.A. 1994. Hook-and-line mortality of caught and released red snapper around oil and gas platform structural habitat. Bull. Mar.

Sci. **55:** 1106-1111.

Richardson, E.A., Kaiser, M.J., Edwards-Jones, G., and Ramsay, K. 2006. Trends in sea anglers' catches of trophy fish in relation to stock size. Fish. Res. **82:** 253-262.

Salthaug, A., and Aanes, S. 2003. Catchability and the spatial distribution of fishing vessels. Can. J. Fish. Aquat. Sci. **60:** 259-268.

Schroeder, D.M., and Love, M.S. 2002. Recreational fishing and marine fish populations in California. CCOFI Rep. **43:** 182-190.

Sokal, R.R., and Rohlf, F.J. 1998. Biometry. The principles and practice of statistics in biological sciences. 3^{rd} edition, W.H. Freeman and Company, New York.

Stratoudakis, Y., Fryer, R.J., Cook, R.M., and Pierce, G.J. 1999. Fish discarded from Scottish demersal vessels: Estimating of total discards and annual estimates for targeted gadoids. ICES J. Mar. Sci. **56:** 592-605.

Suuronen, P., Perez-Comas, J.A., Lehtonen, E., and Tschernij, V. 1996. Size-related mortality of herring (*Clupea harengus* L.) escaping through a rigid sorting grid and trawl codend meshes. ICES J. Mar. Sci. **53:** 691-700.

Szedlmayer, S.T., and Able, K.W. 1996. Patterns of seasonal availability and habitat use by fishes and decapod crustaceans in a southern New Jersey estuary. Estuaries **19:** 697-709.

Terceiro, M., 2002. The summer flounder chronicles: science, politics, and litigation, 1975-2000. Rev. Fish Biol. Fish. **11:** 125-168.

Terceiro, M. 2006, Stock assessment of summer flounder for 2006. NEFSC Ref. Doc. 06-17. 119 pp.

Zimmerman, S.R., and Bochenek, E.A. 2002. Evaluation of the effectiveness of circle hooks in New Jersey's recreational summer flounder fishery. Am. Fish. Soc. Symp. **30:** 106-109.

Table 1. Results of ANCOVA analyses examining the influence of trip and catch characteristics on the health (injured or uninjured) and morbidity indexes. Dependent and independent variables are described in the Methods section. –, not significant at $\alpha = 0.05$. $*$, an interaction term.

	Health index		Morbidity Index	
	Fish Discarded	Fish Kept	Fish Discarded	Fish Kept
	Significance Level	Significance Level	Significance Level	Significance Level
Vessel	<0.0001	<0.0001	0.03	<0.0001
Time-of-day	–	–	–	–
Vessel*Time-of-day	0.05	–	–	–
Effort	–	0.01	–	–
Fishing Scenario	0.0012	0.0009	0.024	<0.0001
Depth	<0.0001	–	<0.0001	–
Length Class	–	–	0.035	–
Vessel*Fishing Scenario	<0.0001	<0.0001	<0.0001	<0.0001

Table 2. Results of Tukey's Studentized Range tests for the influence of vessel on health (injured or uninjured) and morbidity indices. Similar letters within column categories indicate vessels not significantly different at $\alpha = 0.05$. Listed under the health index category, in order, are the Tukey ranking, ratio of injured to uninjured fish, and the number of fish analyzed. Listed under the morbidity index category, in order, are the Tukey ranking and the morbidity index (0-to-4-point scale).

	Health index		Morbidity Index	
Vessel	Fish Discarded Significance Level	Fish Kept Significance Level	Fish Discarded Significance Level	Fish Kept Significance Level
Vessel A	AB 0.051 412	B 0.032 728	AB 0.080	B 0.055
Vessel B	A 0.075 577	A 0.096 497	A 0.132	A 0.163
Vessel C	B 0.028 1744	B 0.027 999	B 0.062	B 0.056
Vessel D	AB 0.055 1060	B 0.049 571	AB 0.099	B 0.086
Vessel E	A 0.071 490	A 0.093 239	AB 0.106	A 0.201

Table 3. Results of Tukey's Studentized Range tests for the influence of fishing scenario on health (injured or uninjured) and morbidity indices. Similar letters within column categories indicate fishing scenarios not significantly different at $\alpha = 0.05$. Listed under the health index category, in order, are the Tukey ranking, ratio of injured to uninjured fish, and the number of fish analyzed. Listed under the morbidity index category, in order, are the Tukey ranking and the morbidity index (0-to-4-point scale).

	Health index		Morbidity Index	
	Fish Discarded	Fish Kept	Fish Discarded	Fish Kept
Fishing Scenario	Significance Level	Significance Level	Significance Level	Significance Level
Control	A 0.072 1352	A 0.053 188	A 0.133	A 0.106
Reduced Minimum Size	AB 0.056 790	A 0.041 966	AB 0.099	A 0.075
Cumulative Size	BC 0.042 908	A 0.056 1116	BC 0.067	A 0.102
Slot Limit	C 0.022 1233	A 0.045 764	C 0.045	A 0.089

Table 4. Results of ANOVA analyses examining differences in the morbidity index between kept and discarded fish. *, an interaction term.

	Significance level
Kept-versus-discarded	0.0046
Vessel	<0.0001
Fishing Scenario	0.0075
Vessel*Fishing Scenario	<0.0001
Vessel*Kept-versus-discarded	0.0004
Kept-versus-discarded*Fishing Scenario	0.034

Table 5. Average values of the morbidity index for each of the seven summer flounder length classes for summer flounder discards only. Morbidity is assigned to a 0-to-4-point scale with uninjured fish given a 0 rank and dead fish a rank of 4. Lowest averages indicate lowest injury rates. Fish with lengths equivalent to the length-class boundary were assigned to the higher length class.

Length Class	Morbidity Index	N
<13″	0.194	103
17-18″	0.184	201
>18″	0.125	48
16-17″	0.122	573
13-14″	0.080	427
15-16″	0.079	973
14-15″	0.066	1958

Table 6. Results of ANCOVA analyses examining descriptors of the size-frequency distribution of discards. –, not significant at $\alpha = 0.05$. $*$, an interaction term.

	Mean Size	25^{th} Percentile	Median	75^{th} Percentile	Interquartile Range
Vessel	0.0066	–	0.012	<0.0001	0.0009
Time-of-day	–	–	–	–	–
Fishing Scenario	<0.0001	<0.0001	<0.0001	<0.0001	0.0017
Depth	–	–	–	–	–
Effort	–	–	–	–	–
Effort*Vessel	–	–	–	–	0.028
Depth*Vessel	0.052	–	–	0.025	–

Table 7. Results of Tukey's Studentized Range tests for the influence of vessel on descriptors of the size-frequency distribution of summer flounder discards. Similar letters within column categories indicate vessels not significantly different at $\alpha = 0.05$. Listed under the mean size descriptor category, in order, are the Tukey ranking, the value, and the number of trips analyzed. Listed under the remaining categories, in order, are the Tukey ranking and the value.

	Mean Size			25^{th} Percentile		Median		75^{th} Percentile		Interquartile Range	
Vessel A	AB	13.92	20	A	13.40	AB	13.91	B	14.46	B	1.06
Vessel B	C	13.23	24	B	12.52	C	13.47	B	14.09	A	1.57
Vessel C	B	13.67	24	A	13.19	BC	13.67	B	14.22	B	1.03
Vessel D	A	14.26	22	A	13.58	A	14.16	A	14.94	AB	1.36
Vessel E	A	14.12	22	A	13.27	A	14.07	A	14.87	A	1.60

Table 8. Results of Tukey's Studentized Range tests for the influence of fishing scenario on descriptors of the size-frequency distribution of summer flounder discards. Similar letters within column categories indicate fishing scenarios not significantly different at $\alpha = 0.05$. Listed under each category, in order, are the Tukey ranking and the value. The number of trips measured is listed in Table 7.

	Mean Size		25^{th} Percentile		Median		75^{th} Percentile		Interquartile Range	
Control	A	14.55	A	13.74	A	14.52	A	15.39	A	1.65
Reduced Minimum Size	C	13.42	B	12.93	B	13.52	C	13.95	B	1.02
Cumulative Size	BC	13.56	B	12.96	B	13.60	C	14.18	B	1.22
Slot Limit	B	13.83	B	13.12	B	13.79	B	14.54	AB	1.42

Figure 1. Location of fishing trips on each of the five vessels participating in the study. Plotted are the central positions of each drift.

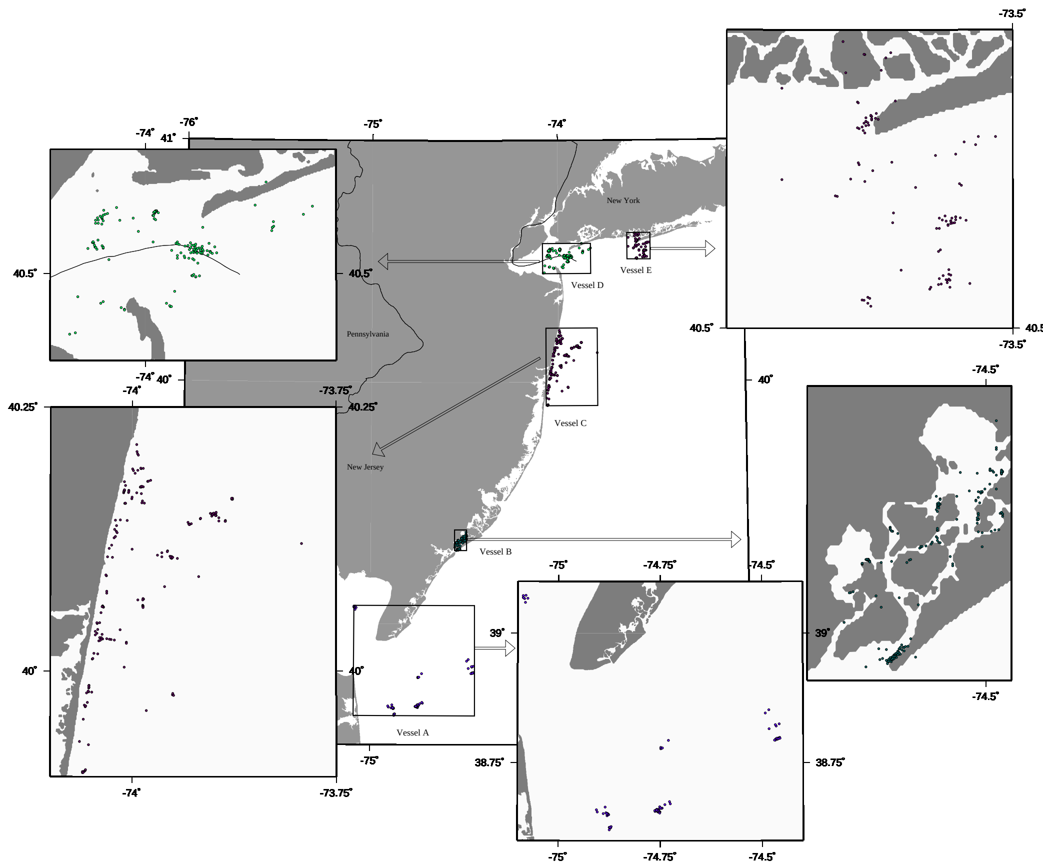

Figure 2. Results of correspondence analysis for the first two axes, Dimensions 1 and 2. The primary variables used were categorical variables describing the characteristics of the fishing trip: vessel, time-of-day, fishing scenario, length class, and the categorical variables for effort and depth. Supplementary variables positioned on the axes defined by the primary variables included the morbidity index, the injury index, and the health index. Category abbreviations are defined in the Methods section.

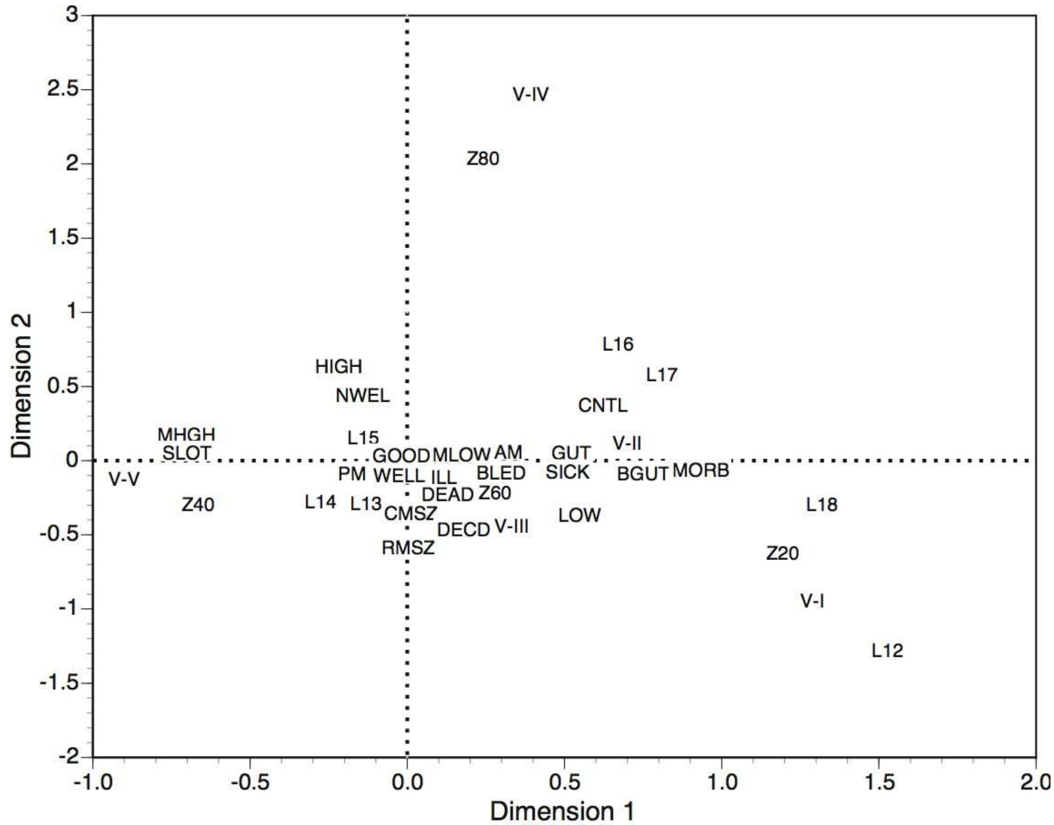

Figure 3. Results of correspondence analysis for the first and third axes, Dimensions 1 and 3. The primary variables used were categorical variables describing the characteristics of the fishing trip: vessel, time-of-day, fishing scenario, length class, and the categorical variables for effort and depth. Supplementary variables positioned on the axes defined by the primary variables included the morbidity index, the injury index, and the health index. Category abbreviations are defined in the Methods section.

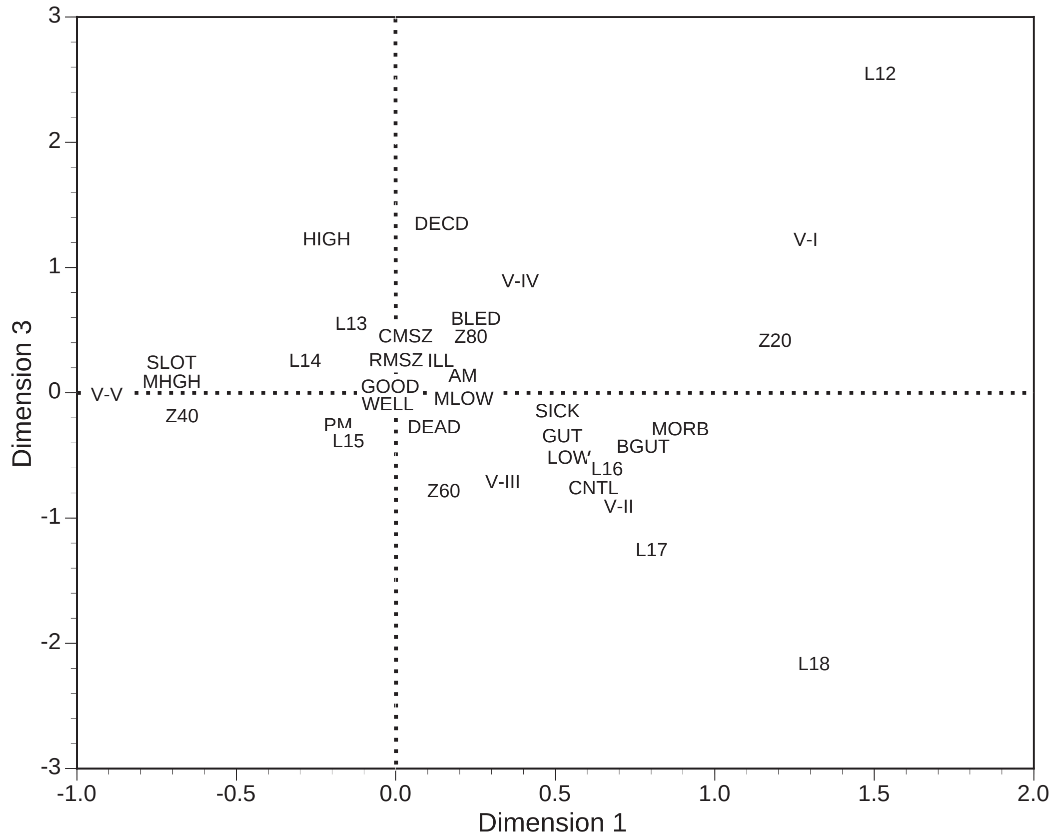

Figure 4. Results of correspondence analysis for the first and sixth axes, Dimensions 1 and 6. Dimensions 4 and 5 did not explain variation pertinent to the supplementary variables and are not figured. The primary variables used were categorical variables describing the characteristics of the fishing trip: vessel, time-of-day, fishing scenario, length class, and the categorical variables for effort and depth. Supplementary variables positioned on the axes defined by the primary variables included the morbidity index, the injury index, and the health index. Category abbreviations are defined in the Methods section.