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Short-term post-release mortality of skates (family Rajidae) discarded in a western North Atlantic commercial otter trawl fishery

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ABSTRACT

Due to market and regulatory factors, Rajidae skates are routinely discarded by commercial otter trawlers in the western North Atlantic. Accounting for post-release mortality is therefore essential to total fishing mortality estimates, stock status and management of this group of fishes. However, despite a presumed species-specific range in tolerance, few studies have investigated the short-term post-release mortality among skates indigenous to the western North Atlantic following capture by mobile fishing gears, and never in the Gulf of Maine. This study addresses this shortfall for the prohibited thorny skate, *Amblyraja radiate* and smooth skate, *Malacoraja senta*, and the targeted winter skate, *Leucoraja ocellata*, and little skate, *Leucoraja erinacea*. Of 1288 skates evaluated, negligible immediate mortality was observed at the time of capture, even in relation to the largest catches and/or most prolonged tows. However, injury frequency was moderate, with highest levels in the smooth (60%) and thorny (52%) skates. Aside from the smooth skate (59%), 72 h mortality rates were low overall (19% across all species when accounting tow durations indicative of the fishery), with the winter skate (8%) exhibiting the lowest levels. Logistic regression modeling revealed tow duration as the most universal predictor of condition and 72 h mortality, while catch biomass, sex, temperature changes, and animal size also held influence in certain species. Although in general the studied species appear more resilient to trawl capture and handling than previously estimated, interspecific differences must be accounted for when managing this group.

1. Introduction

Post-release (P-R) mortality estimates for discarded fish are highly important toward, among other management goals, calculating total fishing mortality and biologically acceptable catch limits (Alverson, 1999; Davis, 2002). While complex due to various influencing factors (Davis, 2002) and species differences, pinpointing the specific aspects of the capture and handling process most impactful on P-R mortality can also be exploited to help illuminate best practice scenarios to reduce that mortality (e.g., Parker et al., 2003; Cooke and Suski, 2005).

Skates, like other elasmobranchs, display a K-selected life history (i.e., long lived, late sexual maturation, low fecundity), which make them vulnerable to fishing pressures (e.g., Waring, 1984; Hoening and Gruber, 1990; Sulikowski et al., 2003). These life history characteristics, coupled with global increases in skate landings (e.g., Dulvy et al., 2000; Sulikowski et al., 2005) and high discard rates have led to increasing management and conservation concerns and the need for estimates of fishing mortality. However, only a handful of studies to date have investigated discard mortality rates in skates in general (e.g., Benoît, 2006; Enever et al., 2009; Benoît et al., 2010a), all of which focused on demersal mobile fishing gears. Based on the collective results of these studies, skates suffer moderate P-R mortality (i.e., majority = 40–50%), with factors that influence risk of crushing/compaction and resulting physical trauma (e.g., tow duration, species, animal size, and total catch biomass) appearing to exert the most influence.

The Northeast Skate Complex (NESC) comprises seven species, five of which occur in the Gulf of Maine (GOM) (NEFMC, 2003), where otter trawl is the primary gear responsible for the capture and discard of skates (Sosebee, 1998; NEFMC, 2003, 2011). P-R mortality estimates of trawled skates under a wide range of true commercial conditions are vital toward, among other endpoints, estimating exploitation rates and establishing total allowable landings (NEFMC, 2005, 2011). It is also an important management goal to elucidate interspecific differences regarding both the rate and factors that influence P-R mortality in this complex.

Although a few studies have evaluated discard mortality in trawled NESC species within Canadian waters, sample sizes were either small for certain species (Benoît, 2006), or mortality rates

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were not distinguished by species (Benoît et al., 2010b). Moreover, intraspecific morphological and biological disparities in NESC species between Canadian and USA stocks (Swain et al., 2006) emphasizes the need for P-R mortality investigations specific to the GOM. Thus, the objective of the present study was to investigate the interspecific acute condition and short-term P-R mortality in four NESC skate species under standard commercial otter trawl conditions in the GOM. The little (*Leucoraja erinacea*) and winter (*Leucoraja ocellata*) skates are the subject of directed fisheries, whereas the thorny (*Amblyraja radiata*) and smooth skates (*Malacoraja senta*) are prohibited from commercial retention due to overfished stock conditions. A secondary goal of this work was to identify the biological and/or physical factors with the most influence on condition and P-R mortality.

2. Materials and methods

2.1. Study overview

Discard mortality trials were conducted in the GOM aboard two commercial trawlers (Fishing Vessels; F/Vs "Mystique Lady" and "Lady Victoria"), of comparable size (~13 m) and gear specifications. The trawls had an 11 m long groundgear and an 18.5 m long headline, and were constructed with 152 mm mesh size in the trawl body and 165 mm diamond mesh in the codend. The groundgear was outfitted with a 30.5 cm rockhopper and 20.4 cm rubber disks. Research trips (2009–2011) took place annually from April–July, with the exception of 2011, where fishing was only conducted in June and during the fall (October–December), when temperature regimes were comparable to the spring (April–May) in previous field seasons. All work was conducted in coastal and offshore waters off northern Massachusetts and southern New Hampshire, USA (boundaries of quadrilateral study area = upper left–right (42°53′N 70°45′W–42°56′N 70°24′W); lower left–right (42°22′N 70°25′W–42°24′N 70°20′W), exclusively on sand and/or mud substrate and a depth range of 15.8–75 m. Ranges for bottom seawater temperatures, air temperatures, and the gradient between the two were (3.47–9.6 °C), (7.0–33.0 °C), and (−1.7–28.6 °C), respectively.

2.2. Fishing research protocols

A total of 71 tows were conducted between the two vessels, partially based on fishing protocols described in Mandelman and Farrington (2007). During each research trip tows of differing durations ("control" (15–20 min, refer to Section 2.3); moderate (90–120 min); and extended (180–240 min)) were randomly conducted between 0600 and 1300 h. Similar to past studies (e.g., Neilson et al., 1989), the precise time-point skates entered the trawl net during the course of a tow was indeterminable, and tow durations therefore represented maximum codend residence times (i.e., maximum period of gear exposure and capture stress). Hobo temperature loggers (Onset Computer Corporation, Bourne, MA, USA) were affixed to the trawl net and boat deck to evaluate real-time seawater and air temperature profiles experienced during the process of capture and catch handling, respectively. Catch (codend) biomass (i.e., tow weight) for each tow was estimated (lbs) by the collaborating commercial fisherman (presented here in kg; range = ~34–4990 kg), but binned into broader categories (small: <318 kg; moderate: ≥318 kg, ≤1270 kg; and large catch: >1270 kg) for analysis.

2.3. Condition index and mortality investigations

Once deposited on deck, the target and non-target catch was sorted by the fishermen as would occur under normal circumstances. Given, however, the previously noted indeterminate time of entry for skates into the net during the course of trawling, and the multiple additional interacting factors at play, the condition of skates from a given tow at the point of landing on deck was assumed to vary considerably animal-to-animal. To avoid misleading results from adding an additional layer, time on deck (i.e., air exposure) was therefore standardized (~10 min) for all skates in the study. Readers are referred to a recent study on air exposure and skates for a more controlled investigation of this factor in the little skate (Cicia et al., 2012).

Approximately 10 min after haul-back, any immediate fatalities were recorded, while randomly selected live skates were transferred to circular deck tanks (dimension: 61 cm in depth; 121.9 cm diameter; held at consistent densities: 10–15 animals/tank), which were continuously flushed with surface sea water (range = 9–15 °C). Because surface seawater temperature (SST) varied as a function of month, which was accounted for as a predictor variable in the logistic regression models, SST was not included as a factor in study analyses. As specimens were traversing the surface stratum temperatures during net haul-back and initial deployment of pens, it was decided to utilize ambient surface sea water and not to chill deck tanks. Additionally, to more closely reflect typical commercial handling producers, random subsamples of skates were "picked" with a deck gaff, a hand-held fish-sorting tool utilized to maneuver catch, which is known to inflict puncture wounds.

Following the transfer to deck tanks, each skate was removed (60–90 s) to record species of skate, sex, total length (TL, cm), condition (scale 1–3), and subsequently each individual was coded in the lateral tail region with a dart tag (Floy Tag & Mfg. Inc., Seattle, WA, USA). Viability/condition categories were partially based on indices previously described (e.g., Neilson et al., 1989; Enever et al., 2009; Benoît et al., 2010b), with employment of the following criteria: category 1 (intact), no obvious physical trauma, vigorous; category 2 (moderate), overt minor-to-moderate hemorrhaging/trauma, diminished vigor; or category 3 (extensive), hemorrhaging, deep tissue trauma/tearing, listless or moribund (Fig. 1). As such, no "picked" skates were assigned as category 1. These categories were kept purposefully broad to reduce any inherent biases associated with the subjectivity of vitality coding and multiple research staff assigning scores.

After a short steam (~30 min after the termination of a tow), skates were transferred from the deck tanks into partially submerged net pens, and slowly lowered to the seafloor (exclusively on mud substrate to reduce the likelihood of amphipod/isopod (i.e., "sand fleas") infestation) for in situ 72 h mortality trials. To maximize surface area on the seafloor and reduce the likelihood of dislodgement, circular net pens (diameter of bottom ring = ~1.8 m; diameter of upper ring = ~1.2 m; height = ~0.9 m) were utilized, based on a modified crab pot design (Burkes Custom Metal Works, PEI, CA). Each pen was also outfitted with a special mesh bottom designed to further reduce potential for sand flea infestation. Within each pen, the total number of specimens and species make-up varied; however, biomass range was held consistent (i.e., ~15–20 smaller individuals; ~5–15 larger individuals). For logistical purposes, all skates within a pen (trial) were derived from a single tow (i.e., skates from multiple tows were never combined in a pen). Following 72 h trials, pens were retrieved to evaluate alive/dead status of skates, after which all surviving animals were released.

To account for potential additive effects on 72 h mortality from pen containment and to evaluate condition and 72 h mortality in abrupt versus the more commercially indicative (moderate and extended category) tows, eleven "control" tows (15–20 min) were conducted to obtain a subset of skates with minimal gear exposure (winter: $n = 86$; little: $n = 96$; thorny: $n = 56$). Although skates were handled gently and exposed to minimal (3–5 min) deck times to reduce handling stress prior to pen trials, specimens

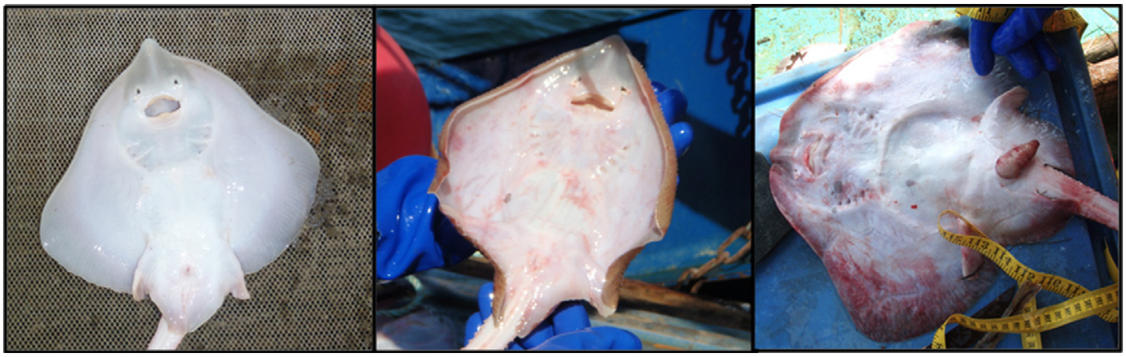

Fig. 1. Post-capture images of skates progressing (left-to-right) in condition from *minor* (category 1), to *moderate* (category 2), to *extensive* (category 3) injuries sustained from otter trawl capture.

from "control" tows sustaining injuries were still included in associated 72 h pen trials. All other factors in these trials adhered to protocols previously described. A small sample (n = 29) of these "control" specimens (little and winter skate only) were "picked" to evaluate whether this treatment coupled with short duration tows was enough to incite mortality.

In response to the general low rate of vigor and substandard condition in surviving individuals following 72 h pen trials (relative to other species), a subset of thorny skates (n = 35) caught by moderate duration tows during the larger research efforts was transported (~1 h steam to the dock and ~1 h to laboratory) to holding tanks at the University of New England for a more extended (7 d) mortality monitoring period. A group of little skates (n = 41) were concurrently subjected to the same capture and handling conditions and served as a control/reference group for this exercise. Captive conditions adhered to protocols described in Cicia et al. (2012).

2.4. Analyses

Preliminary contingency analyses confirmed that 72 h mortality by species was similar among (multiple) pen trials (stemming from a given tows), and between the vessels, allowing the data to be pooled across these factors prior to subsequent analyses. Similar to previous studies of this nature (in the Bristol Channel, UK; Enever et al., 2009), a logistic modeling scheme was utilized to determine which biological and physical variables (Table 1) were significant predictors of post-capture condition (classified here as a binomial variable: *uninjured*, category 1; and *injured*, combined categories 2 and 3) and 72 h mortality (defined as the binomial variable resulting from life or death of each specimen at termination of pen trials), respectively, in individual trawl-captured skate species, as well as an aggregate (i.e., multispecies model) of all species. Given the plethora of interacting factors that hold influence in such studies, a more conservative approach was utilized, whereby continuous independent factors (e.g., temperature change, fishing depth, catch biomass, TL of skates) were categorized/binned during the model building process (Table 1). Although low overall sample size precluded modeling and results on what factor(s) influenced condition and 72 h mortality of the smooth skate, the multispecies models for both condition and 72 h mortality included this species. In addition, a distinct multispecies model for 72 h mortality excluding the smooth skate was also run.

The logistic model used herein is represented by the following equation:

$$\mathbf{p} = \frac{e^{\mathbf{X}\boldsymbol{\beta}+\boldsymbol{\varepsilon}}}{1+e^{\mathbf{X}\boldsymbol{\beta}+\boldsymbol{\varepsilon}}}$$

where $\mathbf{p}$ is a vector of the mortality or condition data, $\mathbf{X}$ is the design matrix for main effects, $\boldsymbol{\beta}$ is the parameter vector for main effects, and $\boldsymbol{\varepsilon}$ is a vector of independent normally distributed errors with expectation zero and variance σ^2. Model results were considered significant according to α = 0.05 for entering a variable into the model, and α = 0.10 for variable removal. For both multispecies and individual species models, only the significant predictors of condition or 72 h mortality were reported. In addition, a chi-square test (χ^2) was utilized to evaluate whether 72 h mortality was influenced by the condition of skates independent of species and all additional factors (α = 0.05 for significance). All analyses were performed used SAS software (SAS Institute Inc., Cary, NC, USA).

Table 1
Covariates evaluated as predictors of condition and 72 h mortality in individual and multispecies logistic regression models.

Covariate	Levels	Condition models[a]	72 h mortality models
Month	April–December		X
Tow duration	Control/moderate/extended	X	X
Picked	Yes/no		X
Estimated catch biomass	Small/moderate/large	X	X
Fishing depth	Shallow/shallow-medium/medium-deep/deep		X
Temperature change	Small/medium/large		X
Species[b]	Little/smooth/thorny/winter	X	X
Condition	1 (intact)/2 (moderate)/3 (extensive)		X
TL[c] of skates	Small/medium/large	X	X
Sex	Male/female	X	X

[a] As the dependent factor in this model, condition was a treated as a binomial variable (*injured* (category 1) versus *uninjured* (categories 2 and 3)).
[b] Only a covariate in the multispecies (aggregate) models.
[c] TL, total length.

3. Results

A total of 1288 skate specimens were analyzed in this study (little skate: n = 251; smooth skate: n = 58; thorny skate: n = 407; and winter skate: n = 572; Table 2).

3.1. At-vessel mortality and condition

At-vessel mortality was negligible, with only eight dead specimens (<1%) observed at the immediate point of capture across species, with the exception of winter skates (no immediate mortality). All dead specimens came from moderate-extended tows, and were impinged in the net/head ropes. Thus, no immediate within net (codend) mortality was observed during this study, even from the longest tows and largest catches; however, of all

Table 2
Sample size, sex, morphometric and 72 h mortality data (by species and sex) of skates evaluated in the study.

Species	Little skate		Smooth skate		Thorny skate		Winter skate	
Sample size	251		58		407		572	
Average TL[a]	49.5 ± 5		53.5 ± 8		47.9 ± 21		66.3 ± 13	
TL[a] range	29.0–60.0		33.5–65.0		17.5–109.0		33.8–96.0	
Sex	Female	Male	Female	Male	Female	Male	Female	Male
Sample size	194	57	37	21	229	177	450	122
Average TL[a]	49.4 ± 5	49.5 ± 5	53.4 ± 6	53.7 ± 9	48 ± 20	46.4 ± 22	67.5 ± 12	61.7 ± 16
Range TL[a]	29.0–58.0	30.0–60.0	33.5–60.6	36.0–65.0	17.5–106.0	20.5–109.0	33.8–94.0	34.0–96.0
Mortality[b]	16%	9%	54%	67%	18%	21%	6%	14%

[a] TL, total length; values are presented as mean ± SD.
[b] Mortality presented to the nearest 1-percent (%).

skates alive immediately following capture, 44% were classified as injured (combined categories 2 and 3), with the majority of those displaying a condition category of 2 (Table 3). More specifically, thorny (52%) and smooth (60%) skates exhibited the highest rates of injury. In general, there were relatively few skates (6% across all species) classified as condition category 3, with smooth skates (15% of specimens of this species) having the highest observed incidence (Table 3). Interestingly, the 79 total specimens (independent of species) in this category arose from a roughly equal proportion of tows with small and moderate-large catches (Table 3).

3.2. 72 h mortality

Independent of species and all other variables, 72 h mortality was 15%, with winter (8%) and smooth (59%) skates exhibiting the lowest and highest mortality, respectively (little = 14%; thorny = 19%; Fig. 2a). When only accounting for moderate and extended tow durations (which more closely reflect typical commercial fishing practices), the overall mortality rate increased to 19% (winter = 9%; little = 22%; thorny = 23%; smooth = 60%; Fig. 2b). Although no standardized evaluation of condition was performed after the 72 h pen trials, surviving thorny and smooth skates were

Table 3
Percent mortality (rounded to the nearest 1%) broken down by tow duration (with respective catch biomasses), species and condition indices (categories: 1 (minor); 2 (moderate); 3 (extensive)).

Tow duration	Catch biomass[a]	Species	% Mortality	% Mortality-1[b]	% Mortality-2[b]	% Mortality-3[b]
15–20 min	423 ± 211	Little	2	2 (88)	0 (10)	N/A
		Thorny	2	0 (34)	4 (23)	0 (1)
		Winter	3	1 (86)	4 (25)	17 (6)
2 h	1520 ± 381	Little	25	31 (49)	18 (39)	33 (6)
		Smooth	67	79 (14)	59 (22)	67 (6)
		Thorny	23	19 (67)	25 (95)	37 (8)
		Winter	7	4 (145)	9 (67)	40 (10)
4 h	1735 ± 578	Little	17	13 (23)	8 (25)	45 (11)
		Smooth	40	62 (8)	25 (4)	0 (3)
		Thorny	21	20 (95)	25 (75)	0 (9)
		Winter	11	2 (116)	14 (98)	53 (19)

[a] Catch biomass (kg) presented as mean ± SD.
[b] Parentheses following % mortality represent sample sizes.

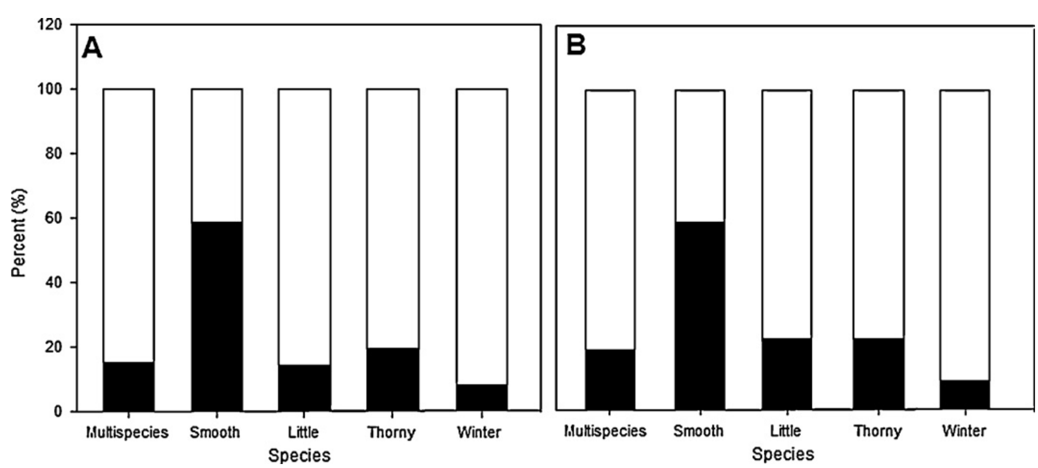

Fig. 2. The proportion of total alive (□) and dead (■) skates after the 72 h pen trials for individual and aggregated skate species for (A) all combined tows including controls; and (B) only moderate (2 h) and extended (4 h) tows. Given no captured specimens during control tows, percent-mortality for the smooth skate is identical in the two plots.

Table 4
Significant predictors of the viability/condition in multispecies and individual trawl-caught skate species according to logistic regression modeling. See Table 1 for covariates included in the models.

Model	Covariates[c]	*df*	χ^2	*p*
Viability/condition[a]; multispecies and individual species[b]				
Multispecies	Tow duration	2	9.83	<0.007
Little	Sex	1	4.01	0.045
	Tow duration	2	6.81	0.033
Winter	Tow duration	2	5.52	0.063
Thorny	Size	2	9.62	0.008
	Tow biomass	2	4.60	0.032

[a] Condition (dependent factor) was classified as a binomial variable: uninjured (category 1) and injured (combination of categories 2 and 3).
[b] Although included in the multispecies model, the low sample size for the smooth skates precluded statistical modeling of the species individually.
[c] Variables entered model according to $\alpha = 0.05$, and were removed according to $\alpha = 0.10$.

relatively listless upon release relative to surviving little and winter skates, which swam away vigorously under the same circumstances.

3.3. Variables influencing skate condition and 72 h mortality

3.3.1. Multispecies

When accounting for all species, the lone significant predictor of post-capture condition was tow duration (Table 4), with abbreviated "control" tows associated with the lowest injury levels relative to those moderate and extended (Fig. 3a).

In contrast, the lone significant predictor of 72 h mortality was species (Table 5), with smooth skates exhibiting a higher rate of mortality relative to the three remaining species, which displayed similar mortality rates (Fig. 4a). However, when the logistic regression was rerun excluding smooth skate data, tow duration emerged as the lone significant predictor of multispecies 72 h mortality (Table 5). Similar to the results with the condition model, moderate and extended tows led to similar rates of mortality, which both exceeded levels produced by short "control" tows (Fig. 4b). Lastly, a more extensive injury level at the time of capture was associated with higher 72 h mortality rates, both with

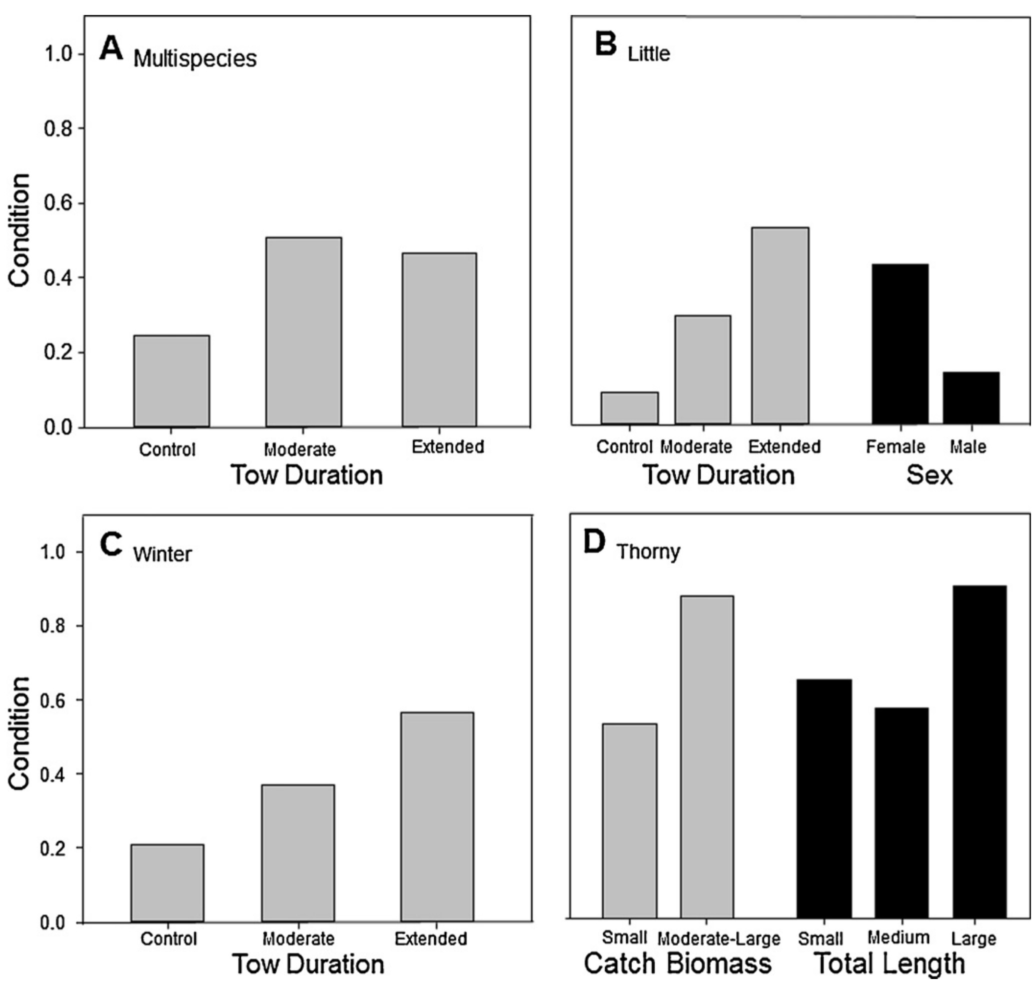

Fig. 3. Categorical least squares means for those covariates found to be significant predictors of condition (through logistic regression modeling) in (A) multispecies aggregate; (B) little skate; (C) winter skate; and (D) thorny skate. Model results were considered significant according to $\alpha = 0.05$ for entering a variable into the model, and $\alpha = 0.10$ for variable removal.

Table 5
Significant predictors of 72 h mortality in multispecies and individual trawl-caught skate species according to logistic regression modeling. See Table 1 for covariates included in the models.

Model[a]	Covariates[b]	*df*	χ^2	*p*
72 h mortality; multispecies and individual species				
Multispecies	Species	3	30.45	<0.0001
Little	Catch biomass	2	5.70	0.017
	Temperature change	2	8.96	0.011
Winter	Tow duration	2	8.45	0.015
	Temperature change	2	6.19	0.045
	Sex	1	4.53	0.033
Thorny[c]	N/A	N/A	N/A	N/A
72 h mortality; multispecies (excluding the smooth skate)				
Multispecies	Tow duration	2	11.28	0.004

[a] The low sample size for the smooth skates precluded statistical modeling of the species individually.
[b] Variables entered the model according to $\alpha = 0.05$, and were removed according to $\alpha = 0.10$.
[c] No significant predictors of 72 h mortality were detected in the thorny skate.

($\chi^2 = 6.39$, $df = 2$, $p = 0.04$) and without ($\chi^2 = 9.89$, $df = 2$, $p < 0.01$) inclusion of smooth skate in the analysis.

3.3.2. Little skate

Sex was a significant predictor of post-capture condition in little skates (Table 4), with females exhibiting a higher rate of injury (Fig. 3b). Tow duration also significantly influenced condition (Table 4), with a higher presence of injury corresponding with more prolonged tows (Fig. 3b).

Estimated catch biomass and temperature change were significant predictors of 72 h mortality in little skates (Table 5), with mortality increasing with catch biomass, and lower temperature changes (Fig. 5a). Little skates classified as injury category 3 suffered (∼30%) higher 72 h mortality than did category 2 specimens.

3.3.3. Winter skate

In the winter skate, tow duration was a predictor of both condition (Table 4) and P-R mortality (Table 5), with higher injury (Fig. 3c) and 72 h mortality rates (Fig. 5b) associated with increased tow durations.

Similar to the little skate, temperature change was also a significant predictor of 72 h mortality (Table 5), again with higher mortality linked to the smallest (lowest) temperature changes (Fig. 5b). The model also revealed a significant effect of sex on 72 h mortality (Table 5), with male winter skates experiencing a higher 72 h mortality rate than females (Fig. 5b). Akin to the little skate, winter skates classified as injury category 3 suffered (∼30%) higher 72 h mortality than did individuals classified as category 2.

3.3.4. Thorny skate

Estimated catch biomasses and TL were significant predictors of post-capture condition in thorny skates (Table 4). Specifically, the largest animals and catch biomasses were associated with higher injury rates (Fig. 3d). No relationship between any covariate and 72 h mortality was evident in this species.

3.3.5. Extended mortality investigations

In the laboratory, 66% of thorny skates died during the 7 d monitoring period, with 19 of the 23 total fatalities (or 54% of the original sample) occurring in the first 72 h following capture. Conversely,

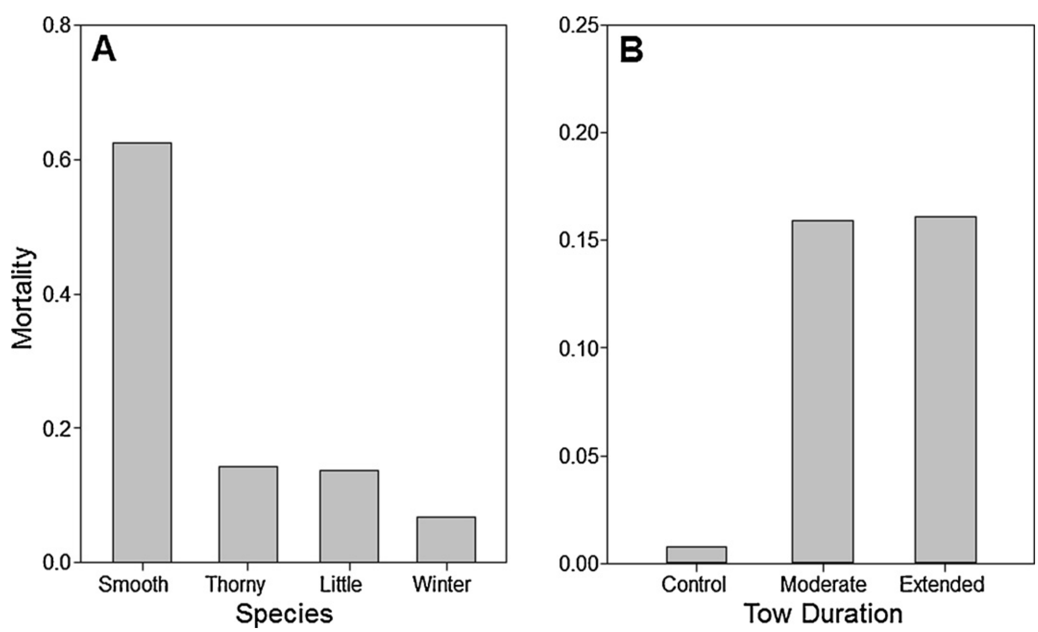

Fig. 4. Categorical least squares means for the lone respective covariates found to be significant predictors of 72 h mortality (through logistic regression modeling) in (A) multispecies aggregate including the smooth skate; and (B) multispecies aggregate excluding the smooth skate. When removing the smooth skate from the model, tow duration rather than species was the only factor found to predict 72 h mortality. Model results were considered significant according to $\alpha = 0.05$ for entering a variable into the model, and $\alpha = 0.10$ for variable removal.

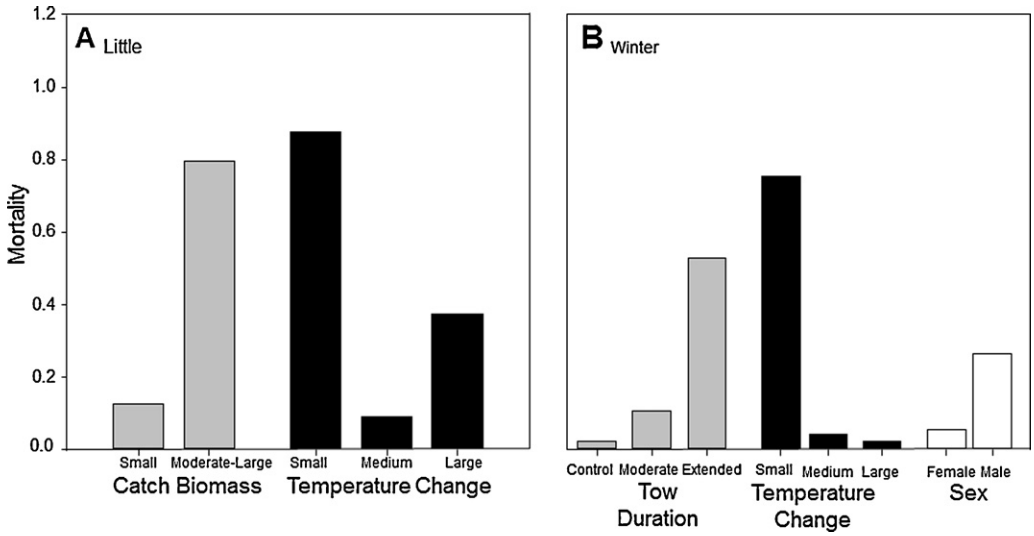

Fig. 5. Categorical least squares means for those covariates found to be significant predictors of 72 h mortality (through logistic regression modeling) in (A) little; and (B) winter skate. No covariates were found to be significant predictors of 72 h mortality in the thorny skate. Model results were considered significant according to $\alpha = 0.05$ for entering a variable into the model, and $\alpha = 0.10$ for variable removal.

only nine total little skate fatalities (22% of overall sample) were observed during the 7 d period, with six dying in the first 72 h (15% of total sample).

4. Discussion

4.1. 72 h mortality of skates

Based on the collectively low (15%) 72 h mortality, the NESC species evaluated were in general resilient to the rigors of otter trawl capture and handling. Furthermore, when only considering moderate and extended tows (2 and 4 h), which correspond with normal industry practices in the GOM, the overall 72 h mortality rate remained low (19% = all species combined). In previous studies evaluating P-R mortality in trawled NESC skate species, P-R (48 h) mortality ranged from ~10% (Benoît et al., 2010a) to ~50% (Benoît, 2006). The inflated mortality in the Benoît (2006) study, however, utilized 1–2 h deck times (according to the median duration observed in Canadian trawl fishery), far exceeding the typical handling/processing time on mid-size trawlers in the GOM.

When considering species independently, the winter skate demonstrated the lowest 72 h mortality (3–12%, contingent upon tow duration), which agrees with previous reports of 3% in Canadian winter skates (10% reported as a conservative estimate; Benoît et al., 2010a). Conversely, the smooth skate—despite a limited sample size and no predictive species model—exhibited the highest overall mortality trend in the present study (59%). Given the injury status of skates in general varied positively with 72 h mortality, and 60% of smooth skates captured were classified as injured, the high mortality trend was not surprising. Additionally, smooth skates attain a small maximum TL (Sulikowski et al., 2009) and lack the musculature and dorso-ventral body mass to withstand the physical compaction within the codend of the trawl net, increasing susceptibility to crushing injuries associated with this gear type. Although thorny skates exhibited a low (22%) 72 h mortality (identical to little skates (22%) when looking exclusively at moderate and extended tows), the high injury rate (52%) at the time of capture, compromised state of individuals following 72 h pen trials, and high mortality in the 7 d trials, preliminarily suggests this species to be less resilient than indicated by the low 72 h mortality alone.

4.2. Parameters impacting condition and survival

It is well established that the condition and mortality of discarded bycatch is dictated by multiple “interacting factors” (Davis, 2002), a conclusion corroborated in this as well as other studies on trawled elasmobranchs (Rodriguez-Cabello et al., 2005). In addition, evaluating the influence of tow duration on mortality is inherently limited by the inability to pinpoint the precise time-points animals are captured, and thus the extent of exposure to the gear, during the course of a trawl event (Neilson et al., 1989). Nevertheless, when accounting for all species, injury and mortality rates in the current study were higher (in the model excluding the smooth skate) for commercially relevant (moderate and extended) tows (versus short “control” tows). These results were likely driven by the large sample sizes for winter and little skates, wherein both species displayed a higher frequency of injury and mortality (winter skates only) in prolonged tows. A positive relationship between tow duration and mortality has previously been reported in skates (Cedrola et al., 2005; Enever et al., 2009). The negligible 72 h mortality for species captured by “control” tows in the present study suggests winter, little and thorny skates are resilient to the mere acts of trawl capture and haul-back. However, results support the logical notion that tow durations indicative of standard GOM commercial operations increase the likelihood of lethal outcomes.

Due to the risk of mechanical stress (e.g., interference with scales (in teleosts) and mucus layer) physical trauma (e.g., lacerations, hemorrhages) due to compaction in the codend, catch composition and biomass can hold considerable influence on the fate of fish captured in trawl gear (Neilson et al., 1989; Davis, 2002). Previous work on this gear type has demonstrated a strong positive correlation between estimated catch biomass and mortality in demersal fish species (Neilson et al., 1989; Richards et al., 1995), including skates (Enever et al., 2009) and other elasmobranchs (Mandelman and Farrington, 2007). This factor also held influence in the present study, where larger estimated catch biomass was associated with a higher injury occurrence in thorny skates, and higher 72 h mortality in little skates. Moreover, based on the aforementioned factors, catch weight would likely have also held influence in the smooth skate had low sample size not precluded predictive modeling. The winter skate was the lone species not exhibiting any effect from a larger catch biomass, likely due to a composition of almost exclusively large mature specimens, with a denser and more rigid morphology than the other study species. While thorny skates also attain a large maximum TL (Sulikowski et al., 2005), the present study included a mix of smaller more vulnerable juveniles, likely explaining the higher injury rate as a function of larger catch biomass.

The 72 h mortality of certain skate species was also influenced by additional factors. For example, male winter skates died at a higher rate than female conspecifics, despite no presence of a size-related sexual dimorphism that might have influenced resilience. This coincides with other studies showing a reduced rate of survival in trawled male skates (Enever et al., 2009) and other elasmobranchs (Stobutzki et al., 2002). This comparatively lower male resilience may have resulted from a greater potential for traumatic injury due to the presence of claspers and/or, additional protection associated with a thicker integument in female elasmobranchs associated with the protection against mating bites during copulation (Kajiura et al., 2000; Enever et al., 2009), and/or differential sex-specific physiological thresholds for tolerating trawl capture and handling stressors. Conversely, however, female little skates exhibited a higher post-capture injury rate than did male cohorts. Additional work in a controlled environment with mixed sexes is necessary for finer resolution on factor among skate species.

The 72 h mortality of skates was expected to be lowest when the seawater-to-air temperature gradient was at its highest. Mortality in demersal teleosts captured by simulated trawl has indeed been shown to increase with elevations in air temperature (Olla et al., 1998; Davis and Schreck, 2005), and during warmer months, when the gradients in temperature from (cold) bottom seawater to (warmer) surface seawater and air/deck are widest (e.g., Robinson et al., 1993). In the present study, however, it was the smallest temperature changes that led to the highest 72 h mortality in both little and winter skates. These results were also unexpected based on a recent investigation on little skates that showed a more pronounced physiological stress response and rate of mortality when sustained (15 and 50 min) air exposure was accompanied by acute (seawater-to-air) temperature increases (Cicia et al., 2012). It is possible that the elevated number of fatalities (caused by additional factors not pinpointed by the models) in these two species during the relatively colder months (e.g., November; lower seawater-to-air gradients) artificially skewed the results, leading to this finding.

4.3. Penning considerations and extended mortality trials

Negligible 72 h mortality in skates captured in "control" tows suggest that abbreviated exposure to trawl capture and "penning" alone is nonlethal in little, winter and thorny skates. In shielding skates from avian (Laptikhovsky, 2004) and other types of post-capture predation (Davis and Parker, 2004), it can in fact be argued that pen containment may have artificially deflated 72 h mortality in comparison to what might have occurred under non-experimental conditions. Conversely, however, penning could have potentially exacerbated stress levels already experienced from capture, and thus played a role in the 72 h mortality observed in the study. Despite these possible caveats with the penning environment, pens deployed to the seafloor appear to be an appropriate setting for assessing P-R mortality in skates, whose comparatively sedentary lifestyle and/or lack of swim bladder might reduce the negative impacts associated with this approach in other species in the GOM (e.g., Milliken et al., 1999; Mandelman and Farrington, 2007).

Although mortality in this study was low and pen effects unapparent, it is plausible that sublethal impacts (i.e., such as inconspicuous trauma and latent pathology) and unresolved physiological repercussion could have increased predation risks after 72 h, driving additional unaccounted mortality beyond this monitoring period. For example, some of the 44% of skates categorized as injured (conditions 2 and 3) at the time of capture but alive at the time of pen retrieval could have succumbed to various sublethal impacts during the days/weeks that followed. Thorny skates in particular suffered a high rate of physical trauma as a function of higher catch biomass, and conceivably could have experienced high mortality subsequent to the 72 h monitoring window. Indeed, post-capture fatalities have been reported in teleosts beyond this time window (e.g., 30 d: Davis and Olla, 2001). In the present study, however, the majority of skate fatalities during the extended 7 d extended trials occurred in the initial 72 h post-capture phase (19/23 in thorny skate; 6/9 in little skate), suggesting the largest extent of acute skate mortality occurred during the initial days subsequent to capture. Additional work under more extended post-capture windows is needed for better resolution on this.

When looking exclusively at the 72 h post-capture window, mortality in the subset of thorny skates exposed to 7 d extended trials (54%) disagrees with the larger body of 72 h mortality data (19%) in the study. Although this likely reflects a more stressful set of conditions during the extended trials, thorny skates, as referenced, generally appeared listless and lacked discernible vigor at the culmination of pen trials. As such, the ultimate mortality of penned specimens beyond the 72 h point might have proven far higher, possibly in line with that found in the extended trials.

4.4. Management implications and conclusions

While tow duration significantly influenced short-term P-R mortality of skates in the present study, the practical utility of this finding is not yet clear. For example, while mortality was negligible in short ("control") tows, rates were similar between moderate and extended tows, which are representative of typical fishing practices within the GOM. Additional work evaluating intermediate tow durations between 20 min and 2 h are necessary to establish practical (time) mortality thresholds that could reduce mortality in the actual fishery. Optimally, this would occur under standardized net residence times, only truly possible in the laboratory environment (Davis, 2002). Nevertheless, the present study supports the hypothesis that terminating a tow in its earlier stages reduces the potential for physiological stress and physical trauma.

The estimates of short-term P-R mortality in NESC species provided by this study, particularly in relation to the commercially important winter and little skates, are lower than previously assumed, and can be utilized for management purposes (NEFMC, 2011). However, application of study findings assumes similar handling protocols and moderate deck times, which in reality vary by fishing vessel, and hold influence on skate mortality. Nevertheless, the current findings preliminarily suggest that the two currently prohibited species (smooth and thorny skate) are more vulnerable to mortality in trawl gear than the other species assessed. For reasons discussed, caution is recommended before utilizing the low (22% for commercially relevant tow durations) 72 h thorny skate mortality figures at face value for management purposes; additional work on this species, as well as that to bolster sample sizes in the smooth skate, is warranted. In addition to expanded explorations regarding trawl gear, management would benefit from similar studies on other gear types, particularly those associated with the highest catch rates (e.g., scallop dredge).

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