Assessing the effect of soak times on bycatch discard weight from lobster traps in LFA 41 (offshore southwestern Nova Scotia)

Edited for Public Distribution

Analyses of DFO obtained *observer* and *log* fishing records between February 2002 and July 2016

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Introduction for Public Distribution

The original version of this report was finalized in August 2017 and contained information relating to catch rates, locations, and temporal details of catch that are considered corporately sensitive information by the operator. In this version some of these data have been omitted. In addition, some additional information has been provided for context and clarity. However, all efforts have been made to retain the report's integrity, completeness, and accuracy and where changes are made from the original, these are noted with italics in green.

Objectives

The primary objective of these analyses is to compare bycatch species discard weight from lobster traps to various soak times, with a particular focus to know whether or not shorter soak times (e.g. <72hrs) are associated with fewer bycatch. As a secondary objective, and an important first step in the analyses, we described potential spatial and temporal trends to bycatch data and included any significant spatiotemporal trends in the analyses for soak times.

Source of data

The data were provided by DFO, and given as two datasets: 1) observer, and 2) log book; see below for field names and descriptions.

OBSERVER DATA	
TRIP_ID	System generated unique identifier for the trip.
CFV	Vessel registration number
VESSEL_NAME	Name of vessel
LICENSE_NO	License number of the vessel.
NUM_HOOK_HAUL	Number of hooks/traps hauled during the set.
FISHSET_ID	System generated unique identifier for the fishing set.
BOARD_DATE	Boarding date for this trip.
SET_NO	The observer assigned numeric identifier of the fishing set.
SPECCD_ID	Code identifying the species.
COMMON	Common name for the species.
LATITUDE	Latitude (decimal degrees) when vessel position (etc.) was recorded.
LONGITUDE	Longitude (decimal degrees) when vessel position (etc.) was recorded.
EST_NUM_CAUGHT	Estimated number of this species caught during this set.
EST_KEPT_WT	Estimated kept weight(kg) of this species from this set.
EST_DISCARD_WT	Estimated discarded weight(kg) of this species from this set.
COMMENTS	Comments regarding the data.

LOG DATA	
MON_DOC_ID	System generated unique identifier for the log
LOG_EFRT_STD_INFO_ID	System generated unique identifier for the string / group of traps
VR_NUMBER	Vessel registration number
VESSEL_NAME	Name of vessel
CAPTAIN	Name of Captain
LICENCE_ID	License number
FV_FISHED_DATETIME	Date fished
SOAK_DAYS	Number of days since gear last hauled
DEPTH_FM	Depth (fm) of gear

ENT_LATITUDE	Latitude in DDMMMM of the start of string / group of traps
ENT_LONGITUDE	Longitude in DDMMMM of the start of string / group of traps
TRAPS_CORRECTED	Number of traps hauled per string / group of traps corrected for obvious errors (C. Denton)
EST_WEIGHT_LOG_LBS	Estimated weight (lbs) of catch per string / group of trap
ADJCATCH	Estimated weight (lbs) pro-rated by the total weighed catch for the trip

Materials and Methods

Merging datasets

Both DFO datasets (OBSERVER DATA and LOG DATA) were merged to the lowest possible level of aggregation. Given that the 'system-generated unique identifier for the group of traps' (LOG_EFRT_STD_INFO_ID) provided in the LOG DATA dataset were different to the 'system generated unique identifier for the fishing set' (FISHSET_ID) in the OBSERVER DATA dataset, a 1:1 merger for the group of traps was not possible. As such, the OBSERVER DATA trips were matched to their closest associated dates with the LOG DATA trips (referred to as 'trips'). All 70 observed trips were included in the final dataset and matched with one, respective, log trip - most observed board dates were within a day or two prior to the recorded fishing date, which facilitated the merging process.

With the merger occurring at the trip level, aggregation of variables of interest from the LOG DATA dataset included: 1) minimum, maximum, average, and median values for soak days (days), depth (converted to m), number of traps set, and estimated weight (lbs) of catch per group of traps; and 2) mean values for latitude and longitude. Approximately 10% of the soak days recorded in the LOG DATA dataset were zero, therefore the aggregated values were recorded for both soak days with zeros, and again separately for soak days after removing zeros (rendered missing).

Descriptive analyses

From the available OBSERVER DATA, the outcome of interest was derived from both the bycatch discard weight (total per string; kg) and the number of traps (traps per string), to generate a standardized discard weight per trap using the following equation: $Weight_{Standardized} = (Weight_{String}/\#Traps) \times 100$. If data were missing for the number of traps (and discard weights were available), the median value for the number of traps for each respective vessel was imputed. The standardized bycatch discard weights will simply be referred to as discard weights.

Preliminary analyses included descriptive statistics to determine important variables to analyze, and to generate new variables appropriate for the given data. These analyses focused predominantly on bycatch species and soak days variables. Bycatch species were ranked on their total discard weights, and their percent contribution to overall discard weights. Based on their ranks and potential importance for conservation, the final list of bycatch species included: Lobster, Jonah crab, Cusk, Cod, Rock crab, and other (all remaining species).

Soak days for each trip, aggregated into two variables (one with and without zeros), were categorized into 5 biologically meaningful groups: <7, 7-14, 15-30, 31-45, and 46+ days. The aggregated depths, originally recorded in Fathoms, were converted into metres (1 m = 0.5468 fm).

Soak days analyses

Linear mixed models were used to estimate the effect of soak days on the weight (kg) of bycatch recorded for each group of traps from the observed dataset. To account for the repeated measures of traps per trip, trips were included as a random effect. Power transformations, based on Box-Cox analyses, were carried out to correct for model violations for continuous outcomes. Interactions between bycatch species and soak days were assessed. Final models were constructed by a forward and backward stepwise procedure of significant terms, at a significance level of $p < 0.05$. Model diagnostics included the inspection of the trip-level best linear unbiased predictions and trap-level residuals for homoscedasticity and normality. All pairwise comparisons were made with Bonferroni adjustments.

Models were stratified by bycatch species and time periods (before/after April 2009), and were also ran for the whole study (overall) and all bycatch species (all species).

Space-time analyses

The space-time scan statistic was used to detect clusters of increased (or decreased) weight of bycatch in space and time, and was implemented in SaTScan (Kulldorff, M., SaTScan™: Software for the spatial and space-time scan statistic, version 9.0.1. 2010, Available: http://www.satscan.org: Information Management Services.). More specifically, the exponential model was used on the total weight (kg) of bycatch per observation trip – note, these models are computationally demanding, and therefore, the outcome was aggregated to the observation trip (requiring approximately 2 hours of computing time per run), as opposed to using the individual groups of traps per trip (requiring approximately 27 hours of computing time). The exponential model in SaTScan is appropriate for continuous variables, particularly for those with right-skewed distributions, as was noted in these data. Separate models were run for total weights (kg) for each of the 6 outcome species of interest: 1) Lobster, 2) Jonah crab, 3) Cusk, 4) Cod, 5) Rock crab, and 6) all other bycatch species. In addition, two separate temporal windows were used, aimed at (1) the overall temporal trend, with each month from the start of the dataset as the temporal period (months 2 to 175), and (2) seasonal trends within years, with months January to December (1 to 12, respectively) as temporal periods.

Results

From the 70 recorded trips between February 13, 2002 and July 21, 2016, there were a total of 6,974 observations from 7 vessels. Prior to March 2009, all observations came from 6 vessels; however, from July 2009 onward, observations were taken from a single vessel (#107314), and occurred more frequently (see Fig. 1).

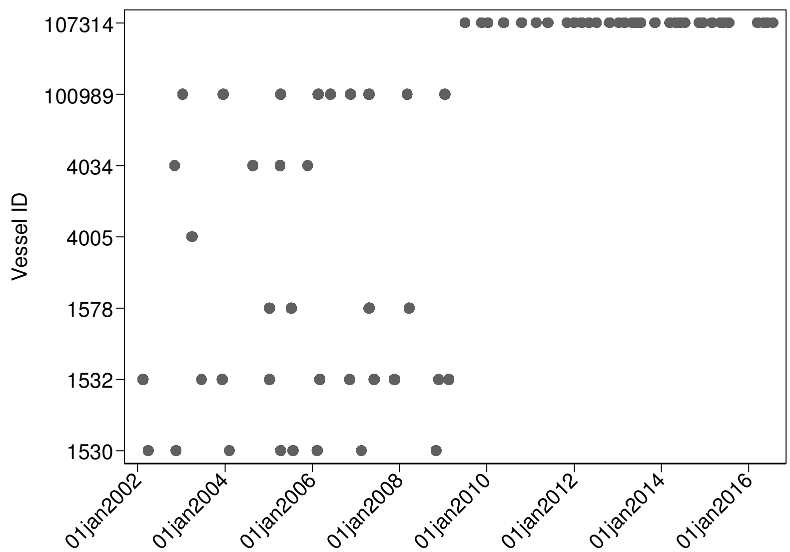

Figure 1. Boarding dates by vessel since 2002. Six vessels were included in the first seven years of this study (February 2002 to February 2009), and only one vessel (#107314) participated since July 2009, but much more frequently.

There were a total of 47 different bycatch species recorded, and their ranking is included in Table 1.

Table 1. Ranking of bycatch species, by total discard weight, including and excluding lobster bycatch. Percentages are calculated as weight of bycatch species over the total bycatch weight for the entire study period (2002-2016).

Top bycatch species (>98% discard weight) Including lobster bycatch	Top bycatch species (>98% discard weight) Excluding lobster bycatch
1. American Lobster (68.7%)	1. Jonah Crab (59.1%)
2. Jonah Crab (18.5%)	2. Cusk (20.5%)
3. Cusk (6.4%)	3. Cod (7.1%)
4. Cod (2.2%)	4. White Hake (5.8%)
5. White Hake (1.8%)	5. Rock Crab (2.7%)
6. Rock Crab (0.8%)	6. Red Hake (1.6%)
	7. Sea Raven (0.7%)
	8. Haddock (0.7%)

Depth was missing for most of the recordings from vessel #107314 (missing for 3,143/4,426 observations; 71%), meaning that few depths were available after April 2009, while it was missing for only ~8% (204/2,548) from recordings taken before April 2009. As such, depth was excluded from models which included observations from April 2009 onward. The range for those 3,627 recoded depths, was between 0 and 2,844 m (after excluding 9 very large values – ranging from 17,016 to 1,194,263 m) and when depth values were aggregated to trips, the range of the average trip depth was reduced to 103 and 304 m (mean=212.1 m, median=218 m; see Fig. 2a).

In the LOG DATA dataset, soak days ranged from 0 to 292 d (mean=9.3 d, median=8 d; without zeros, min=0.2 d, mean=10.6 d, median=8 d), and after aggregating to trips, the average soak days ranged from 5 to 97 days (see Fig. 2b). Ten trips did not record soak days, leaving a total of 60 trips for the analyses. The final categorical variable for soak days included 860 (<7d), 4,339 (7-14d), 806 (15-30d), 65 (31-45d), and 226 (46+d) observations (at the species and trap level), with 678 missing values. The values for the average number of soak days before April 2009 compared to after April 2009 were different – before April 2009, there were no traps left 46+ d in the water, and after April 2009, there were no traps left 31-45 d, but some were left 46+ days (see Table 2).

Table 2. Number of trips (n) with recorded average number of soak days (rows) before and after April 2009. ***Editor's note****: Extensively long soak times are the result of mistakes in the historic data (>100 days) or associated with the historic practice of gear storage.*

	Before April 2009		After April 2009	
Soak Days	n	%	n	%
<7d	4	13.8	4	12.9
7-14d	18	62.1	22	71.0
15-30d	6	20.7	3	9.7
31-45d	1	3.4	0	0
46+	0	0	2	6.4
Total	29	100	31	100

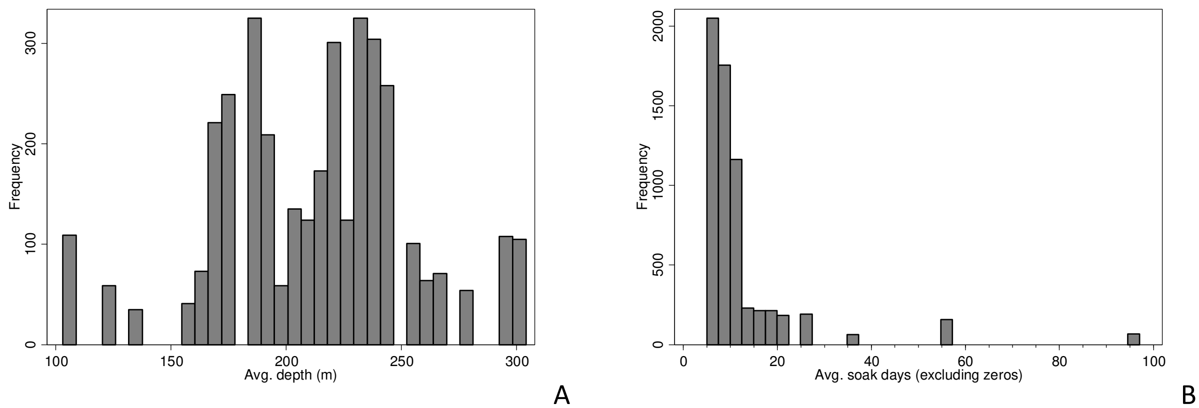

Figure 2. Histogram showing the frequencies of aggregated average depths (left; A) and soak days (right; B) per trip, after removing soak days with zeros. ***Editor's note****: Extensively long soak times are the result of mistakes in the historic data (>100 days) or associated with the historic practice of gear storage.*

It is worth noting that the 'Estimated number of species caught' variable was completely removed from all analyses since there were only 496 entries (6.1%), leaving discard weight (standardized by the number of traps) as the only outcome of interest. Of all of the observations with total bycatch discard weight (for the string of traps), there were 210 with missing values for the number of traps – for those missing values, the median number of traps for their respective vessel (n=3) were imputed to calculate the standardized bycatch discard weight for the outcome variable.

Soak days analyses

Box-Cox analyses indicated that bycatch discard weights *(**Editor's note**: with the dataset that excluded zeros)* required a log-transformation (ln). The random variable for trip was always significant for all models, indicating a clustering effect of bycatch discard weight within fishing trips.

Months were excluded from linear mixed models, on the basis that no seasonal trends were seen on the space-time scan statistic (see further below).

Depth was an overall significant predictor for observations before April 2009 (the only time period that could be evaluated for this predictor), where deeper traps had fewer bycatch weights (p=0.007); see Table 3.

Despite having standardized the bycatch discard weight per trap (as opposed to using the total weight per string, regardless of the number of traps on the string), the number of traps was still associated with standardized bycatch weights for the study period after April 2009, where laying more traps per string, on average per trip, increased bycatch weights (Table 3). This relationship was only seen for bycatch lobsters in the stratified models, indicating that this association is driven by lobster bycatch, and only since April 2009.

Data were consistently sparse for Rock Crab for the duration of the study, and were also relatively sparse for Cod bycatch before April 2009; as such, care should be taken when interpreting results for those two species. Depth was a significant predictor for Rock Crab before April 2009; however, readers should not over interpret the strangely elevated estimate, given only 61 observations were included in this model.

Table 3. Results from the linear mixed models, with trip as the random effect, for bycatch discard weight (standardized by the number of traps; ln-transformed). Models were stratified by bycatch species and time periods (before/after April 2009), and were also ran with all time periods (overall) and bycatch species (all species). Models with all species had an interaction term between species and soak days. Bonferroni methods were used for all pairwise comparisons, and non-significant (NS) results ($p \geq 0.05$) were not presented.

	Before April 2009	After April 2009	Overall (2002-2016)
Lobster	n=563 NS	n=1,002 Traps[b]: 3.243 (0.897, 5.588)	n=1,565 NS
Jonah Crab	n=455 Depth[a]: -1.100 (-2.102, -0.987) Soak days: *p*=0.049	n=698 NS	n=1,190 NS
Cusk	n=357 NS	n=471 NS	n=828 NS
Cod	n=137 NS	n=364 NS	n=501 NS
Rock Crab	n=61 Depth[a]: 18.173 (14.805, 21.540)	n=20 NS	n=92 NS
Other	n=380 NS	n=973 NS	n=1,353 NS
All species	n=1,797 Depth[a]: -0.631 (-1.086 -0.176) Interaction: *p*<0.001[c]	n=3,528 Traps[b]: 2.078 (0.333, 3.823) Interaction: *p*<0.001[c]	n=5,529 Interaction: *p*=0.001
<7 vs 7-14 d[d]	Jonah Crab: -1.216 (-2.430,-0.001)	NS	NS
<7 vs 15-30 d[d]	Jonah Crab: -1.527 (-2.880,-0.175)	NS	NS
<7 vs 31-45 d[d]	Jonah Crab: -2.141 (-4.252,-0.030)	-	NS
<7 vs 46+ d[d]	-	NS	NS

a Depths were rescaled to 100 m intervals (m/100)
b Traps were rescaled to include 10 units (traps/10)
c See Fig. 4 for estimated soak days
d Significant comparisons (Bonferroni adjusted) between soak day categories are reported by species

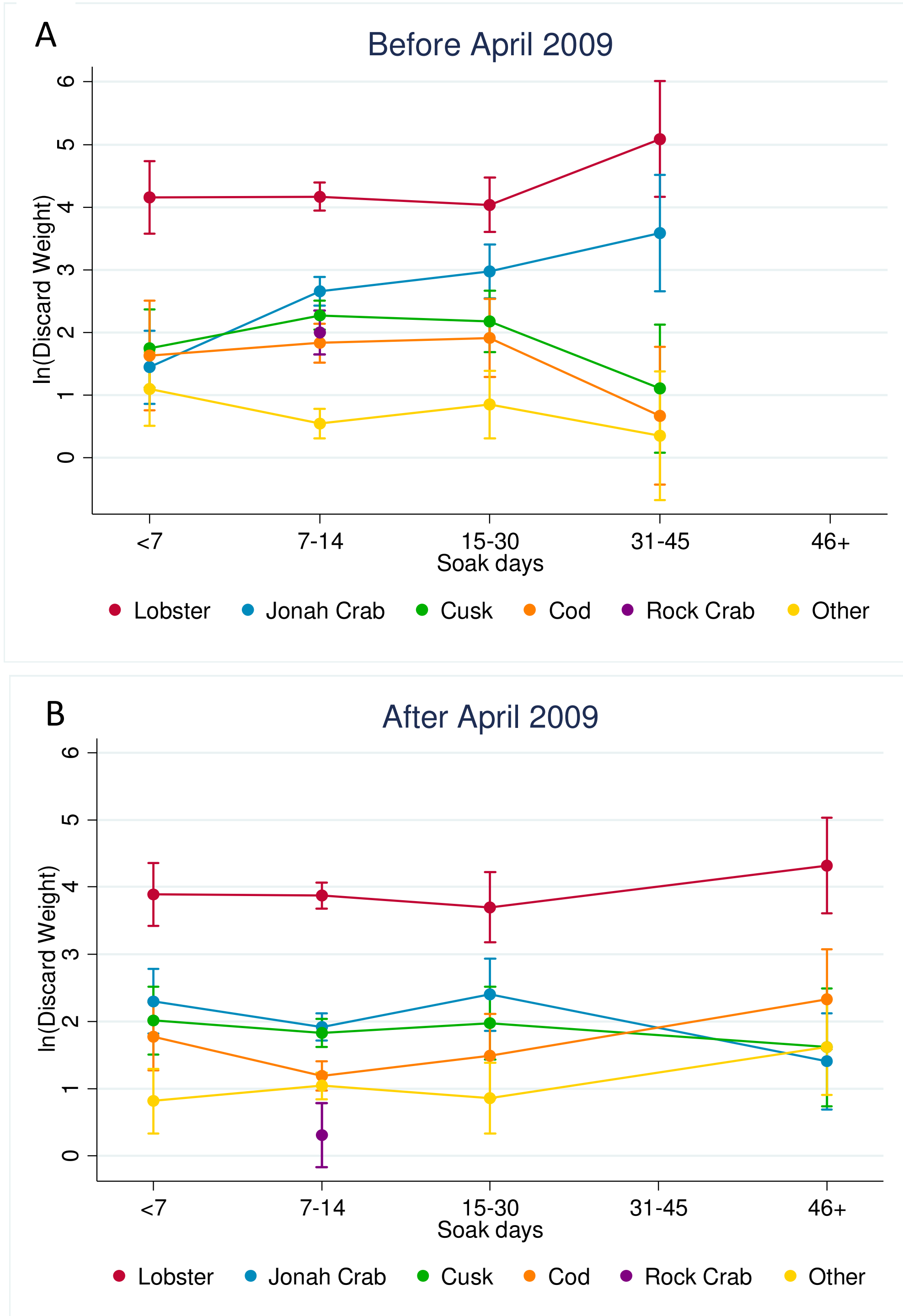

Figure 4. Estimated bycatch discard weight (standardized by the number of traps; ln-transformed) for the interaction between bycatch species and soak days, as presented in Table 3. These included estimates before April 2009 (top; A), and after April 2009 (bottom; B). Significant pairwise comparisons, with Bonferroni adjustments, between soak days within species were only present for Jonah Crab before April 2009, and included differences between <7 and 7-14 d , <7 and 15-30 d, and <7 and 31-45 days. The error bars represent the 95% confidence intervals.

Soak days was a significant predictor for Jonah Crab bycatch before April 2009 (Table 3 and Fig. 4a), where gear left in the water for more than 1 week was associated with higher bycatch weight than gear left for less than one week (<7 vs. 7-14 d, p=0.049; <7 vs. 15-30 d, p=0.006; and <7 vs. 31-45 d, p=0.040). Although there were significant interactions between species and soak days in the 'all species' models (p<0.001 for all three models), after accounting for multiple comparisons, these were no longer significant – see Fig. 4b for trends after April 2009. The most notable trend, but not statistically significant, was for Cod, where leaving gear out for 7-14 days seemed to reduce bycatch weight. Figure 4 data are also presented in supplemental material, where they are re-graphed to show Lobster and Jonah Crab species separately (before and after April 2009; Fig. S1a and S1c, respectively) from Cusk, Cod, Rock Crab, and Other species (before and after April 2009; Suppl. Fig. S1b and S1d, respectively).

Space-time analyses

The temporal component of the space-time scan statistic results are presented in Table 4, and both spatial and temporal results are presented as supplementary material (Table S2, Fig. S1). The temporal component of the analyses indicates that there was an increased amount of Jonah Crab bycatch between the months 150 and 175 (June 2014 to July 2016). In addition, there was one temporal cluster for all other bycatch (all excluding Lobster, Jonah Crab, Cusk, Cod, and Rock Crab) between December 2003 and February 2006 (months 24-50).

Table 4. Results of the temporal component of the space-time scan statistic, using the exponential model for total weight (kg) of bycatch per trips (standardized by the number of traps; n=70). The months spanned from February 2002 (2) to July 2016 (175); non-significant (NS) results ($p \geq 0.05$), were omitted.

		Lobster	**Jonah Crab**	**Cusk**	**Cod**	**Rock Crab**	**Other**
Overall 2-175 months	Time Period	NS	150-175	NS	NS	NS	24-50
	P value		0.002				0.005

Discussion

In this study, there were differences in the fishing practices between 2002-2009 and 2009 onward, where many vessels were replaced with a single vessel. This led to slightly different profiles of average soak days per trip, and the need to stratify parts of the analyses into these two time periods (before/after April 2009).

For the analyses surrounding soak times, the only significant differences between soak times and the baseline of <7 days, were observed before April 2009 for Jonah Crabs, where leaving gear for one or more weeks in the water led to higher Jonah Crab bycatch weights. No significant differences in bycatch as influenced by soak days were seen with these data since April 2009.

Data to assess the effect of soak days on Rock Crab bycatch weight separately were sparse, demonstrating the range to which individual species could be analyzed separately. Rock Crab represented less than 1% of the total bycatch weight, which was the smallest amount for the individual species (compared to Lobster, Jonah Crab, Cusk, and Cod; Table 1). Rock Crab bycatch could have been included in the 'Other' species category for these analyses, but by leaving it on its own, it informed the readers of the practical range for how many individual species could be presented separately for these analyses. The inclusion of Rock Crab in the 'Other' species category would have had little (if any) impact on the estimates for the 'Other' species (see Fig. 4).

The effect of soak times was assessed using an interaction term between species and soak times, and included in the model if it was statistically significant. However, pairwise comparisons were made within the interaction terms using the very conservative Bonferroni adjustments, which is known to gravitate estimates towards the null hypothesis (conclude no effect is present, when a true effect exists). Interestingly, the only other relationship that would have been significant without Bonferroni adjustments was for Cod after April 2009, where average soak days of 7-14 d was associated with smaller bycatch weights than soak days less than 7 days. Given the minimal impact Bonferroni adjustments had on the interpretation of results, this method was deemed appropriate for this report.

The other two significant predictors of bycatch weight were the number and depth of trap placements. Average depth of traps was associated with bycatch weight before April 2009, where deeper traps had fewer bycatch weights – this observation was (anecdotally) suspected by fishers, but the association was not seen in these data after April 2009. Despite having standardized bycatch weights, laying more traps per string was associated with increased bycatch weights for Lobster bycatch after April 2009. There is no obvious reason for this observed relationship, and could be due to potential confounding variables, such as increasing number of traps in seasons associated with more Lobster bycatch weight. Regardless of hypothesized reasons, the effects of these two predictors require further investigation with trap string-level information to properly assess their impact on bycatch weight (see below for details on study limitations).

The temporal results indicate that there was an increase of all other bycatch (all species excluding Lobster, Jonah Crab, Cusk, Cod, and Rock Crab) between December 2003 and February 2006 (before

April 2009), and of Jonah Crab bycatch for the last two years (between June 2014 and July 2016). It is not clear whether the increase in other species of bycatch observed before April 2009 is related to earlier fishing practices or to increases in abundance of other species in the marine environment – this question is clearly beyond the scope of this study. The increase in Jonah Crab bycatch in the last two years was present during the same time period where there were no observed effects of soak times on Jonah Crab bycatch weight (or any other bycatch species) – we were not able to relate these results to regional abundance of Jonah Crab over the last two years, which is also beyond the scope of this study.

Only the temporal results of the spatio-temporal analyses were presented in the results section of this report. The reason for including only the temporal component is because the spatial data had to be aggregated to one average location per trip due to computational demands, which considerably limited the spatial extent and the interpretation of the spatial clusters. Figure S2 demonstrates the issue, where the red and orange dots show the spatial extent of all the trap string locations belonging to significant spatial clusters (enclosed by their respective circles), and when compared to the green dots (all trap strings in the study), it is rather difficult to see meaningful spatial trends. Also the spatial scale of the clusters is so large, encompassing massive fishing areas, that it is impossible to provide practical recommendations for fishing areas to reduce bycatch weights.

Limitations

Most of the limitations of this study came from the initial source of the data, where there were no trap string-level unique identifiers to link the observed information (OBSERVER DATA) to the trip (LOG DATA). More specifically, the most important trip variables for trap strings (soak days, depth, and number of traps) were aggregated to the whole trip – this changed the study design from a fundamentally *cross-sectional* to an *ecological* study, downgrading the quality of the study and evidence for assessing spatial trends and the effect of soak days on bycatch weights.

***Editor's note**: The nature of the data collection was such that weights of bycatch species were only recorded in the observed information if that species was present in the traps, meaning it was impossible to distinguish between zero weights and missing information. The analyses presented in this report were only for those traps with recorded bycatch species. As such, the reported estimated weights are likely to overestimate the true values. Future studies should make a clear distinction between zeros and missing data.*

Soak days, being the most important variable to investigate, was categorized for these analyses. The categorization was done in an attempt to capture as much information as possible, while maintaining statistical power (with interaction terms), and dealing with extreme values. Keeping in mind there is always a certain amount of subjectivity in choosing categories, these categories demonstrated the additional issue of having different soak day profiles before and after April 2009 (31-45 vs 46+ days). The most important limitation to soak days, as previously mentioned, is that they were recorded as overall averages per trip. Had trap string-level data been available for this study, the sample size would have increased, leading to a richer amount of information for soak days – potentially lending themselves to being analyzed as non-linear predictors rather than categorical predictors. Future studies are needed to properly assess the impact of soak days on bycatch weight. These studies will be most relevant if they include data from more recent fishing trips (representing current fishing practices), provided they also include sufficient variability in soak-days to properly assess the impact of a wide range of soak days on bycatch weight. Given the specific focus of the question at hand, namely the effect of soak days on bycatch weight, future study designs could include an observational study (e.g. cohort or longitudinal using observational data, and recording bycatch weight from vessels with various soak days), or a controlled trial (e.g. randomly allocating soak days regimens to vessels and recording their bycatch weights). The selection of one design over another will depend mostly on the availability of resources and the logistical feasibility of assigning soak days regimens to vessels; additional factors to consider include the variability of soak days, and expected amounts of bycatch weight which may change by regions and seasons.

Concluding remarks

Despite the limitations in the data for this study, soak days prior to April 2009 seemed to have an influence on Jonah Crab bycatch, where gear left out for at least one week had higher bycatch weights compared to leaving gear for less than one week. This association was not seen after April 2009, despite there being more Jonah Crab bycatch observed for the last two years – no other bycatch species were associated with soak days. Future studies are needed with trap string-level information linked directly to bycatch weights, and these studies require sufficient variability in fishing practices to capture wide ranges of soak days, depth, and number of traps per string.

Supplemental material

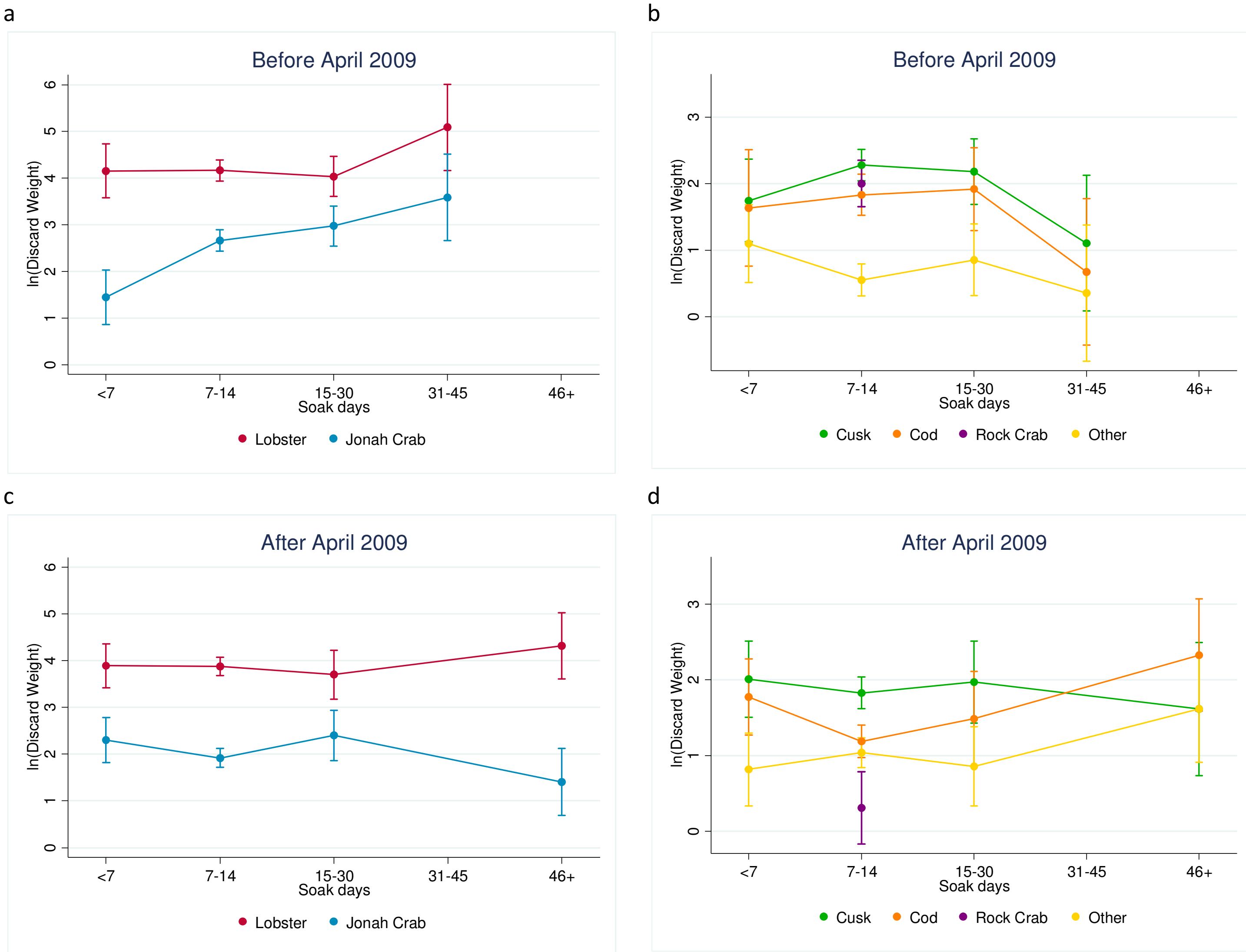

Figure S1. Data from Figure 4 are presented here separately for Lobster and Jonah Crab species (before (a) and after (c) April 2009), and for Cusk, Cod, Rock Crab, and Other species (before (b) and after (d) April 2009). These graphs show the estimated bycatch discard weight (standardized by the number of traps; ln-transformed) for the interaction between bycatch species and soak days. Significant pairwise comparisons, with Bonferroni adjustments, between soak days within species were only present for Jonah Crab before April 2009, and included differences between <7 and 7-14 d , <7 and 15-30 d, and <7 and 31-45 days. Y-scales are not similar for all graphs, and the error bars represent the 95% confidence intervals.

***Editor's note**: The original report included data and maps associated with space-time analyses that attempted to investigate the effect of season (month of the year) on bycatch weight. As noted above, the analysis was not able to determine seasonality to bycatch distribution. It is unknown whether this indicates a real lack of seasonal trend to bycatch, or simply a limitation of the data and statistical power to detect these more subtle trends. These have been removed due to details on fishing locations.*