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Host Organization: National Oceanic and Atmospheric Administration Fisheries
Project Title: HOW ALTERING TRAWL DURATIONS CAN SAVE NONTARGET SPECIES AND ADDRESS FOOD INSECURITY

Abstract:
The growing population and subsequent rise in food demand has resulted in a heavier reliance on fisheries, causing trawling to become more prevalent. Trawl use in fisheries has grown due to its efficiency in catching copious amounts of fish. However, since trawl nets are nonselective, nontarget species can also be caught. This increases these species' risks of unsustainable harvesting and death, while also reducing the chances for more target species to be caught due to bycatch quotas. The aim of this study was to determine ideal trawl durations to decrease the catch of nontarget species. To address this aim, I interned with the National Oceanic and Atmospheric Administration (NOAA) Fisheries and analyzed video footage from trawl net camera to identify how species behave and interact with the net. My observations were recorded in a Google Sheets data file where I noted information about the species, number of species encountered, and behaviors exhibited. The findings suggest that as trawl durations increase, nontarget species catch increases at exponential rates, whereas target species catch sees a slight increase in comparison. Ideally, short 30-minute-long durations would reduce nontarget species bycatch, but in return, less target species might be caught. This can pose problems by preventing target species catch from meeting food demand. Therefore, trawl durations and other mitigation strategies must be further assessed to weigh the benefits for the environment and people involved.

Context and Background:

With exponential increases in global population, food demand has also risen to accommodate unprecedented population growth. The World Health Organization found that in 2021, the number of people experiencing hunger grew to 828 million, which is around forty-six million more than in 2020 (UN Report… 2022). This causes developing countries to heavily depend on fisheries as they serve as the primary provider of important nutrients for starving lower income communities (Vianna et al. 2020). The Food and Agriculture Organization for the United Nations stated that one billion people rely on fish as their main source of animal protein, accounting for 16% of animal protein consumed globally (Tidwell and Allan 2001). This high dependence on fish has placed importance on using fisheries to address international food insecurity. To meet increasing food demands, many fisheries utilize bottom trawling as a harvesting method due to its efficiency. Bottom trawling is defined as a method of fishing that harvests and collects species by dragging a net across the sea floor (Fishing Gear… 2022). Trawl nets harvest substantial amounts of product through just one sweep. It is estimated that bottom trawling catches around nineteen million tons of annual catch, which is 25% of total aquatic catch (What is bottom trawling… 2020; Amoroso et al. 2018).

Although bottom trawls are efficient, there are negative impacts associated with its use, with the most prevalent issue being nontarget species bycatch. Bycatch is characterized as the catch of unintended species that are discarded or unused by fisheries (Davies et al. 2009). Worldwide, it is estimated that 40.4% of total catch (thirty-eight million tons) is bycatch (Davies et al. 2009). In the California Halibut Bottom Trawl Fishery during 2008, the California Halibut Trawl Grounds' bycatch study found that out of 1229 pounds of catch, the target species, California Halibut, only consisted of 328 pounds, while the other 901 pounds were nontarget species (Frimogid et al. 2008). Of the 901 pounds of nontarget species, 751 pounds were discarded, and 150 pounds were sold (Frimodig et al. 2008). For the California Halibut Bottom Trawl Fishery, green sturgeon is a significant nontarget species because of their susceptibility to being caught by trawls and their threatened status in the Endangered Species Act (Lindley et al. 2008). The excessive catch of green sturgeon and other nontarget species in this fishery can result in the implementation of bycatch quotas, in which once the cap for nontarget species is met, the fishery can no longer fish for the rest of the season (O'Keefe et al. 2014). This is serious as it can result in shorter fishing seasons, and less opportunities to catch target fish that would otherwise be used to feed communities experiencing hunger around the world.

But previous studies have shown that nontarget species catch can be reduced by changing bottom trawl durations (Ballara and Anderson 2009). In the North-Western Australian Fishery, longer trawl durations are correlated with larger bottlenose dolphin bycatch amounts (Allen et al. 2014). Alternatively, it has been shown that shorter trawl durations usually have less catch per unit of swept area and a decline in overall catch abundance in nontarget species (Sala 2018). For Australia's northern prawn trawl fishery, small nontarget species that are less than 300 millimeters long have seen an 8% decline in bycatch weight in shorter haul durations (Brewer et al. 2006). To add further, NOAA Fisheries has suggested that using shorter trawl haul durations may decrease the amount of bycatch within fisheries (Fishing Gear… 2022).

This paper asserts that shorter durations, such as 30-minute hauls, are the most ideal in reducing nontarget species catch as demonstrated by nontarget species having lower encounter quantities, smaller compositions, and reduced average encounters within shorter durations.

Research Question:

I examined this subject by performing video analysis on underwater trawl net footage, in which I posed the research question: How does altering trawl duration affect the quantity of nontarget species caught by the California Halibut Bottom Trawl Fishery?

Internship and Methods:

To answer this question, I worked as a video analyst intern with the National Oceanic and Atmospheric Administration (NOAA) Fisheries. NOAA Fisheries is a governmental agency with the aim of ocean resource stewardship and their mission is to use both ecosystem-based management and science to meet their goals (About Us). My primary tasks were to analyze footage from a camera attached to a trawl net and to record observations of species behavior in reaction to the trawl net. I specifically took note of data such as vessel information, haul durations, species, number of species encountered. I also recorded species behaviors prior to the species encountering the net, after the species encounters the net, and behavior in response to the net. During my internship, I successfully completed my two deliverables for NOAA Fisheries, with the purpose of identifying fish-gear interactions and creating bycatch reduction procedures for nontarget species (See Appendix A. Table 1 for list of deliverables).

The data examined in this study was obtained through my internship video observations that I recorded in the observation data sheet and the literature reviews I conducted when completing my annotated bibliography (See Appendix A. Table 1). In this study, species encounters were used as a proxy for species catch since the catch metrics from the California Halibut Bottom Trawl Fishery during 2021 and 2022 cannot be legally disclosed. I compiled data from all hauls observed by previous and current interns into a google sheets document. I specifically examined footage from 3/31/21 Tern Haul #1-4, 7/31/21 Johnny L Haul #1-3, 8/01/21 Linda Noelle Haul #1-3, 8/05/22 Tern Haul #1, 8/07/21 Moriah Lee Haul #1-2, 8/24/22

Moriah Lee Haul #1-3, and 8/26/22 Tern Haul #1-2. Then, I created a Google Sheets formula that automatically categorized every species encounter into distinct species categories, which included nontarget species, target species, and other. Target and nontarget species were predetermined by NOAA Fisheries, where target species were California Halibut, flatfish, and starry flounder. Conversely, nontarget species consisted of green sturgeon, bass, crab, forage fish, jellyfish, sharks, skates/rays, round fish, surfperch, and sea lion. The "other" category represents species encounters that were observed as not applicable, other, or unidentifiable. After species categorization, I split every haul into 30-minute intervals, up to 90 minutes. Thirty minutes was chosen as the smallest duration because it is one of the shortest durations that has relatively precise catch abundance (Godo et al. 1990). Sixty minutes was chosen as the medium duration because studies have shown that middle durations are double the smallest duration (Wieland and Storr-Paulsen 2006). 90 minutes was determined as the largest duration because the average duration of all the hauls combined was 82 minutes and I rounded up 90 minutes since it was the next closest 30-minute interval. Lastly, I used pivot tables on Google Sheets to generate total counts, composition proportions (%), and the standard deviation and average. To perform the Kruskal-Wallis test, I used the R programming language.

Results and Arguments:

Species Encounter Abundance

As haul durations increase, species encounter abundance for both nontarget and target species increases, meaning that shorter durations are better for minimizing nontarget encounters. Data collection from the internship indicated that over the entire duration of all hauls, there was a total of 57753 individuals encountered, where 55733 of these individuals were nontarget species and 885 of these individuals were target species (Table 1). When only examining the predetermined durations (30 minutes, 60 minutes, and 90 minutes into the haul), the total number of individuals, number of nontarget species, and number of target species increases as durations lengthen. From the 30-, 60- and 90-minute durations, nontarget species encounters were observed as 10668, 20966, and 29194, respectively (Table 2). Target species encounters are observed as being 326 at 30 minutes, 598 at 60 minutes, and 739 at 90 minutes (Table 2).

The growth in the number of nontarget species and target species can be explained by the fact that longer hauls yield more overall catch and more catch per species category (Ramakrishnan and Panda 2009). The results also show that the number of nontarget species is always greater than the number of target species at every haul duration, but, as haul durations become longer, nontarget species encounters see larger increases compared to target species. These findings are consistent with the Carothers and Chittenden (1985) study that found that there is a significant relationship between catch abundance and duration ($P < 0.024$) (Carothers and Chittenden 1985). This means that there is a strong correlation between the increase in catch abundance and the increase in haul duration. As a result, shorter durations that are around 30 minutes are ideal in reducing the bycatch of nontarget species when examining nontarget and target species encounters. This is because 30 minutes has the lowest count of nontarget species encountered compared to 60 and 90 minutes.

Species Encounter Composition for Nontarget and Target Encounters

Additionally, there are minimal differences between the proportion of nontarget and target species when haul durations increase, but shorter durations have the smallest proportion of nontarget species. When looking at the encounter composition over the entire duration of all hauls, nontarget species make up approximately 96.50% of encounters, while target species only make up 1.53% of encounters (Figure 1). Comparable results were obtained when examining the composition of encounters at 30, 60, and 90-minute durations. Regarding nontarget species, they composed 97.03%, 97.23%, and 97.53% of species encounters at 30, 60, and 90-minute hauls, whereas target species composed 2.97%, 2.77%, and 2.47% at those same durations (Figure 2). The results show that encounter proportions are largely composed of nontarget species, and that the composition is relatively the same regardless of the duration of the haul.

These results are consistent with the Carothers and Chittenden (1985) study, where it was discovered that the relationship between catch composition and haul duration was not statistically significant ($P < 0.332$). The video observations corroborate this finding by showing that the species encounter proportions remain almost equivalent, regardless of duration. The substantial percentage of nontarget species across the three different durations can be attributed to fact that much of the nontarget species encounters were forage fish, which typically swim in schools (Dell et al. 2009). To add further, my video observations illustrated that all target species were observed as swimming alone and not as part of a school, which would explain the small percentage of target species encounters.

Even though the composition is almost identical across the varying haul durations, nontarget species experience an increase over longer durations while target species experience a decrease. For nontarget species, there is a slight increase in the proportion as the duration increases. At the shortest duration (30 minutes), 97.03% of encounters are nontarget and this grows to 97.53% for the longest duration (90 minutes) (Figure 2). Although, for target species, there is a slight decrease in the proportion as the duration increases. At the shortest duration (30 minutes), 2.97% of encounters are target species and this declines to 2.47% for the longest duration (90 minutes) (Figure 2). Consequently, it can be determined that although shorter trawls have negligible impact on the proportion of encounters, shorter durations that are 30 minutes ensure that nontarget species encounters are as minimal as possible, while also maximizing the proportion of target species encounters.

Species Encounters Summary Statistics and Statistical Testing

Moreover, the mean and standard deviation of species encountered revealed that shorter durations had smaller nontarget species averages and were more precise. On average, 628 nontarget species were encountered within 30-minute trawls with a standard deviation of 984.27 (Figure 3.A). Target species had a mean of 30 encounters with a standard deviation of 42.85 within 30-minute trawls (Figure 3.B). For 60-minute trawls, the mean number of encounters for nontarget species was 1048 with a standard deviation of 1691.03, while the mean of target species encounters was 43 with a standard deviation of 71.64 (Figure 3.A; Figure 3.B). Finally, for 90-minute trawls, there was a mean of 1327 nontarget species encounters (2237.40 standard deviation) and 53 target species encounters (89.14 standard deviation) (Figure 3.A; Figure 3.B). The lower means for both nontarget and target species in 30 minutes trawls indicate that less species are encountered during shorter durations. In the case of standard deviations, larger values represent more spread and variability within data, making the measure of mean less precise. It is important to note that the standard deviations are extremely high because there are extreme variations in the observations obtained from each haul and the respective trawl duration. This shows that 30-minute durations are most ideal in terms of precision because it has the lowest standard deviation for both nontarget and target species.

When examining the changes in means, most of the nontarget and target species are encountered within the first 30 minutes and the average increase in encounters reduces as time passes. Within the 30-minute duration, there was an average growth of 628 nontarget and 30 target species (Figure 4). Between 30 and 60 minutes, nontarget species see an average increase of 420 and target species see a mean increase of 13 (Figure 4). However, between 60 and 90 minutes, nontarget species increased by an average of 279, while target species encounters increased by 10 on average (Figure 4). These results demonstrate that shorter hauls are more efficient in encountering both nontarget and target species. This result is further corroborated by other trawl surveys, where it has been determined that hauls that are 30 minutes catch more individuals on average, in comparison to 60-minute hauls (Sala 2018). It must be noted and considered that the 30-minute haul may be the most efficient because trawl nets commonly catch large numbers of schooling fish in durations that are 30 minutes or under (Dell et al. 2009).

Although shorter trawl durations seem to be the most efficient, the Kruskal-Wallis test found that there are no significant differences among the varying durations. For nontarget species, the Kruskal-Wallis test had a p-value of approximately 0.780 (Table 3). Since the p-value is greater than the 0.05 significance level, it can be determined that there are no significant differences between the mean number of nontarget species encounters during 30, 60, and 90 minute hauls. In regard to target species, the Kruskal-Wallis test calculated a p-value that is approximately 0.750 (Table 3). As the target species p-value is larger than the 0.05 significance level, it can be concluded that there are no significant differences between the mean target species encounters during 30, 60, and 90 minute durations. The high p-values for both nontarget and target species suggests that despite the encounter increases as trawl durations become longer, there is minimal differences in the mean encounters. This finding of minimal differences implies that the encounter increases are relatively small between the varying durations.

Therefore, shorter durations have lower mean encounters and more precise measures of average encounters for both nontarget and target species. The lower standard deviation and lower average encounters for nontarget species show that 30-minute durations are the most ideal for preventing the excessive bycatch of nontarget species.

Broader Significance and Implications:

In sum, short, 30-minute haul durations are recommended to minimize the nontarget species catch within the California Halibut Bottom Trawl Fishery. This finding was supported by lower nontarget species count, lower nontarget species proportions, and lower standard deviation and mean.

It is important to adopt bycatch mitigation strategies like altering trawl durations in order to maintain vulnerable marine populations. In the case of the California Halibut Bottom Trawl Fishery, green sturgeon is a species of concern due to being labelled threatened in the Endangered Species Act (Lindley et al. 2008). It is especially concerning that green sturgeon are susceptible to being caught by trawl nets due to their fast, frequent, and long-range migration patterns (Lindley et al. 2008). It is also crucial to consider that green sturgeon have an 18% mortality rate after being released from trawl nets (Doukakis et al. 2020). Thus, it is necessary to decrease haul durations to minimize nontarget species catch, prevent unnecessary death for discarded species, and to allow for nontarget populations to recover and regenerate (Doukakis et al. 2020).

While shorter haul durations are the most desirable when attempting to reduce nontarget species within the California Halibut Bottom Trawl Fishery, it is done at the expense of target species catch. As seen in the video observation data, shorter durations also have lower yields for target species. This was represented by lower target species encounters, smaller target species encounter percentages, and lower mean encounters for target species during 30-minute hauls. Since hunger continues to grow alongside global population, the maximization of target species catch must also be considered to meet food demand. It is difficult to use short durations to both minimize nontarget species catch and maximize target species catch. Other bycatch mitigations strategies must be employed in addition to altering trawl durations to meet both requirements. The mass amounts of nontarget schooling fish like forage fish can be greatly reduced by implementing nets with mesh that is larger than the average size and length of forage fish but smaller than the average size and length of California Halibut and other target species (Eigaard et al. 2021).

The results of this study can be applicable and relevant to trawl fisheries globally because altering trawl durations can easily be implemented into most fisheries to prevent excessive bycatch. But solely altering trawl durations is not sufficient in achieving both an efficient and sustainable trawl fisheries worldwide. Although shortening trawl durations can be effective in minimizing bycatch, it is also vital to consider that target catch needs to be maximized to meet international food needs. Through combining shorter trawl durations and the implementation of trawl net modifications, a sizable proportion of nontarget species would be able to escape, allowing for hauls to go on for longer before bycatch quotas are met. Multidisciplinary bycatch mitigation strategies and further research on this issue must be conducted to better address the conservation of vulnerable nontarget species and the pressing issue of global food insecurity.

Acknowledgements:

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Visuals:

Table 1. The number of individuals encountered for each species category across all hauls between 2021 and 2022 in the California Halibut Bottom Trawl Fishery. This table includes species encounters that occurred after the 90-minute haul duration.

Species Categories	Total Number of Individuals Encountered
Nontarget	55733
Target	885
Other	1135
Total	**57753**

Table 2. The number of individuals encountered for each species category during each duration (30 minutes, 60 minutes, 90 minutes) between 2021 and 2022 in the California Halibut Bottom Trawl Fishery. This table excludes any species encounters that occurred after the 90-minute duration.

	Nontarget	Target	Other	Total
30 Minutes into Haul	10668	326	169	11163
60 Minutes into Haul	20966	598	516	22080
90 Minutes into Haul	29194	739	974	30907

Table 3. The results from the Kruskal-Wallis test for nontarget and target species. The chi-squared values and p-values are rounded to the third decimal place.

	Chi-Squared Value	Degrees of Freedom	P-value
Nontarget Species	0.496	2	0.78
Target Species	0.576	2	0.75

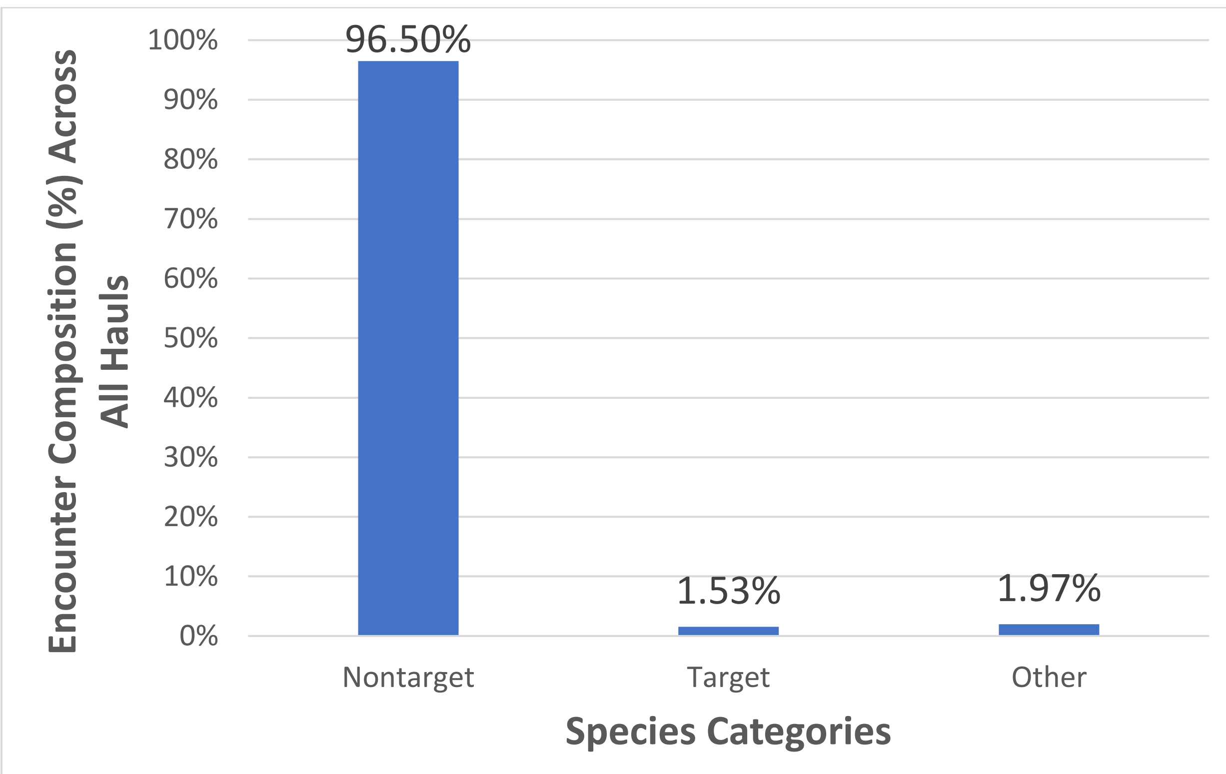

Figure 1. Overall encounter composition (%) of nontarget, target, and other species across the entire duration of all hauls from the California Halibut Bottom Trawl Fishery between 2021 and 2022. This graph includes species encounters that occurred after the 90-minute haul duration.

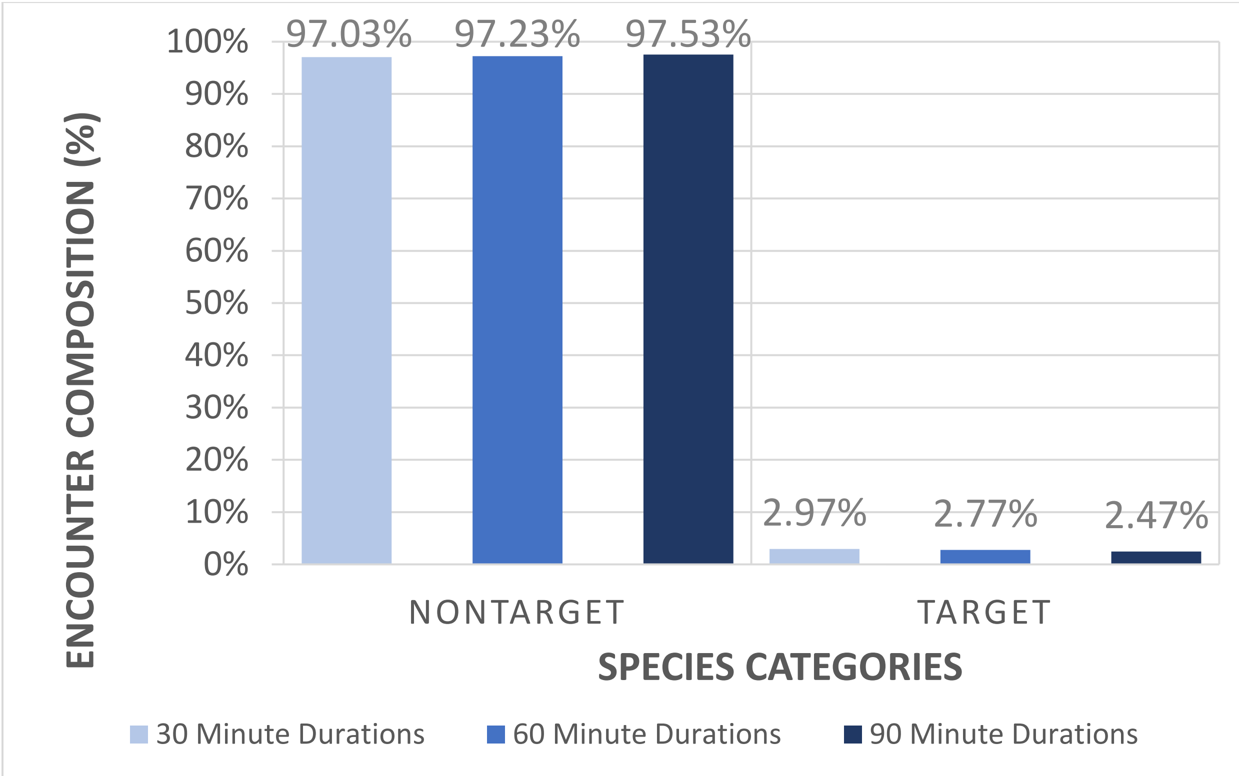

Figure 2. Encounter composition (%) of nontarget and target species at 30 minutes, 60 minutes, and 90 minutes into all hauls from the California Halibut Bottom Trawl Fishery between 2021 and 2022. This graph excludes species encounters that occurred after the 90-minute duration.

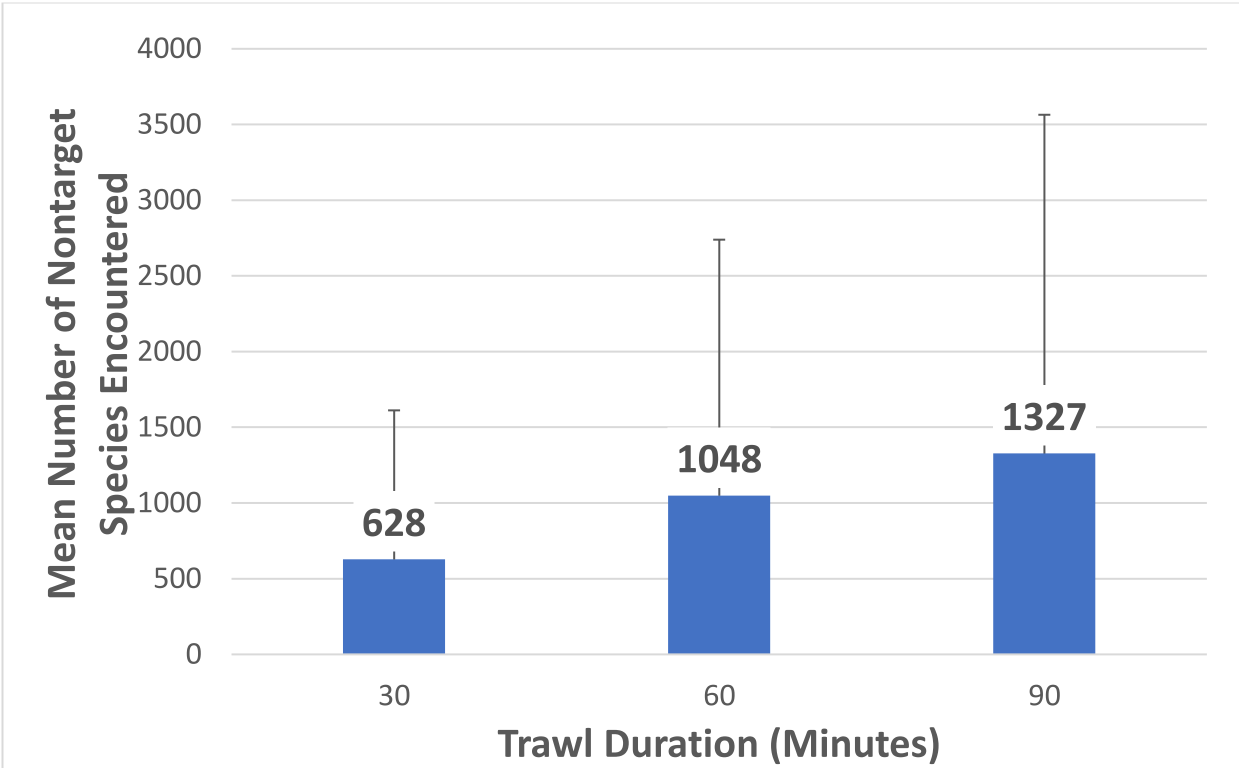

Figure 3.A. Mean number of nontarget species encountered (±SD) at 30, 60, and 90 minutes into all hauls from the California Halibut Bottom Trawl Fishery between 2021 and 2022. The bolded values above the bar indicate the average number of individuals encountered rounded up to the nearest integer.

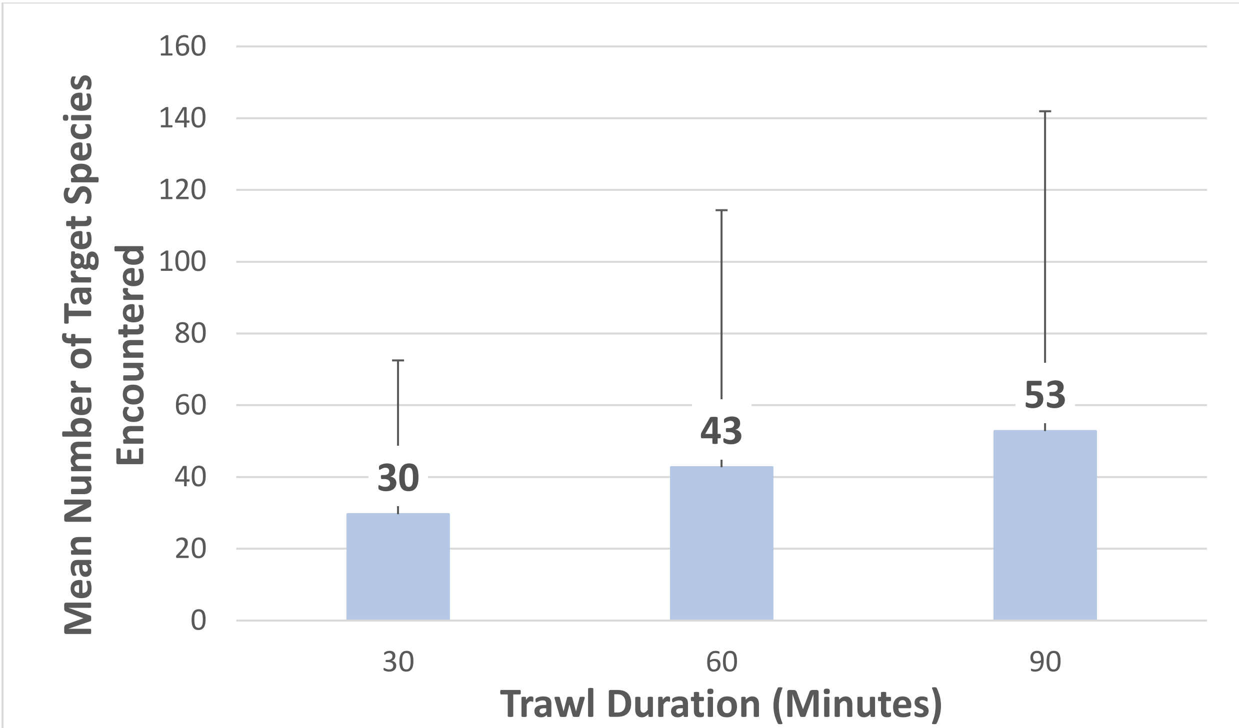

Figure 3.B. Mean number of target species encountered (±SD) at 30, 60, and 90 minutes into all hauls from the California Halibut Bottom Trawl Fishery between 2021 and 2022. The bolded values above the bar indicate the average number of individuals encountered rounded up to the nearest integer.

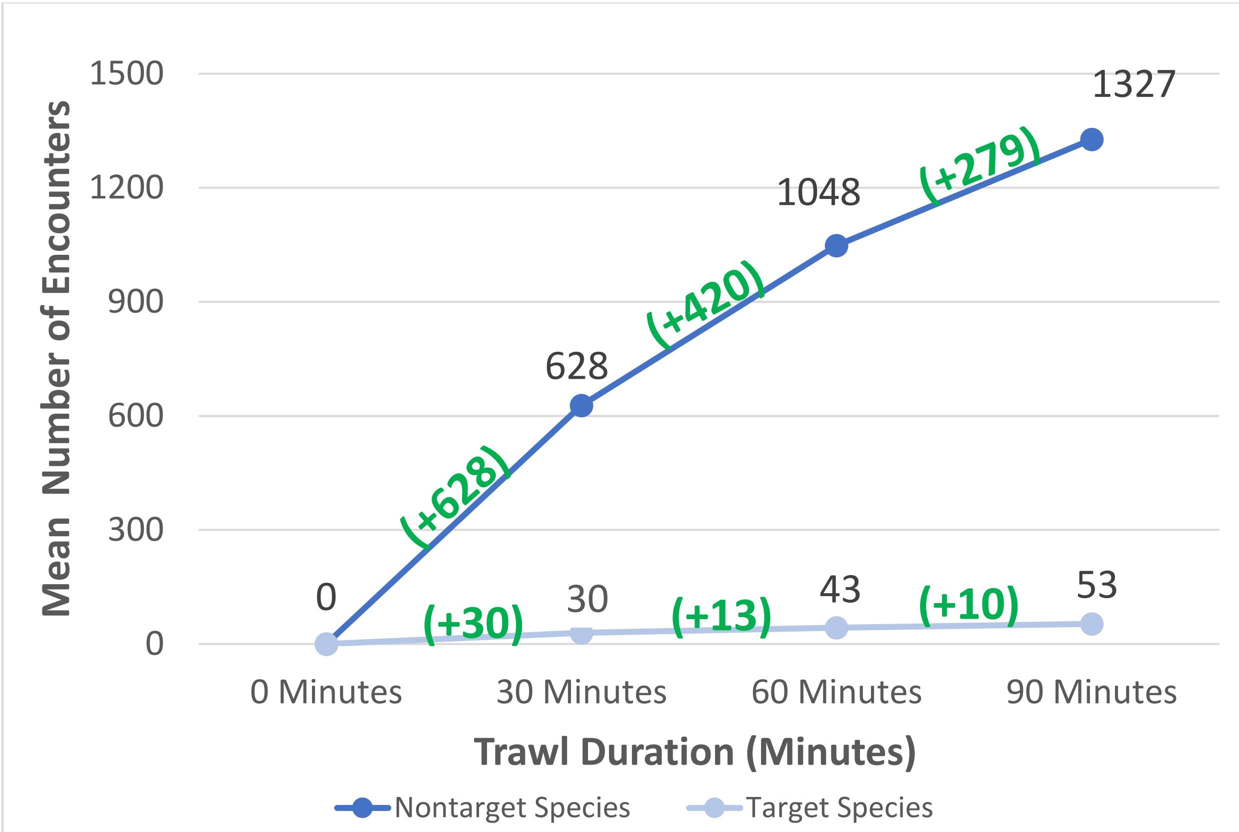

Figure 4. Mean and increase in nontarget and target species encounters at 30 minutes, 60 minutes, and 90 minutes into all hauls from the California Halibut Bottom Trawl Fishery between 2021 and 2022. The values above the dot represent the mean for that given duration. The green values in parentheses represent the growth in average encounters within that given duration.

APPENDIX A.

Table 1. Tangible deliverables created for the Capstone Experience during Winter 2023. Deliverables produced during ENVIR 492 are not included.

Deliverable Title	Recipient	Description
Summary Report on findings	Susan Wang, NOAA Fisheries Staff	A Google Docs document that contains a summary of species behavioral data obtained from the Observation Data Sheet. The document includes references to peer-reviewed studies to support the observations. The document also includes data visualizations of the results in the form of pivot tables, graphs, and pie charts. The purpose of this deliverable was to identify fish-gear interactions and to suggest bycatch mitigation methods.
Observation Data Sheet	Susan Wang, NOAA Fisheries Staff	A Google Sheets document where I recorded my observations of videos and took note of vessel information, species, species number, and species behavior in reaction to trawl nets. The Google Sheet contained data collected from prior and current interns that worked on this project.
Annotated Bibliography	Yen-Chu Weng, P. Sean McDonald	An annotated bibliography of ten peer-reviewed sources, created with the intention of being used in the Capstone paper.
Internship Progress Memorandum	P. Sean McDonald	A memorandum that discusses the progress made during the internship. This was further described through the topics of significant lessons, positive aspects, challenging aspects, personal performance assessments, and

		a host organization evaluation.
Capstone Journal	P. Sean McDonald	A Microsoft Word document that includes a log of hours worked. Also contains research notes and completed tasks.
Blog Post	P. Sean McDonald, ENVIR 491 Students	A Tumblr blog post detailing a brief overview of the internship experience and organization. Blog post incorporated interesting facts, challenges, and images taken during the internship.