2021

Deepwater Horizon Oceanic Fish Restoration Project

SUMMARY MONITORING REPORT 2017–2020

Deepwater Horizon Oceanic Fish Restoration Project

Summary Monitoring Report 2017-2020

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1 Introduction

The Oceanic Fish Restoration Project was approved in the Final Phase IV Early Restoration Plan and Environmental Assessments (DWH Trustees 2015) to offset injuries to pelagic finfish due to the *Deepwater Horizon* oil spill. This summary monitoring report documents the methods, data, and results of the project monitoring program from the beginning of the project in 2017 through 2020.

1.1 Project Overview

The project aims to restore biomass of offshore pelagic fishes by reducing mortality of fish caught unintentionally as bycatch during fishing activities. Reducing fishing mortality allows fish to remain in the environment and grow and reproduce, which helps restore pelagic fish populations in the Gulf. Beginning in 2017, pelagic longline (PLL) vessel owners have participated in a voluntary, temporary, six-month repose period each year. During this period, participating vessel owners refrain from PLL fishing and have the option to fish with alternative gear, which produces much less bycatch and dead discards than PLL gear. The project also aims to minimize economic effects from reduced catch of target species through the distribution and training in use of the alternative gear for the continued catch of target pelagic species during the repose, such as tuna and swordfish. Participants are compensated to offset revenue lost as a result of participating in the repose period. Those who also choose to fish with alternative gear during the repose receive additional compensation for every sea-day to help offset the costs of alternative gear fishing trips during the repose period.

The project engages participants in the PLL fishery in the waters of the U.S. Exclusive Economic Zone of the Gulf of Mexico (GOM PLL fishery, Figure 1), which has fishing ports throughout the Gulf (Figure 2). Participation in the project is open to PLL vessels that have made at least one PLL set in the Gulf of Mexico in the previous two years, possess all limited access permits necessary to engage in PLL fishing in the Gulf, and possess the minimum Individual Bluefin Quota (IBQ) allocation for a vessel fishing in the GOM PLL fishery, consistent with 50 C.F.R. § 635.15(b)(3) (2014). Eligible vessel owners are selected for participation by submitting an application with a price quotation in a uniform-price reverse auction (Holzer & Byler 2019).

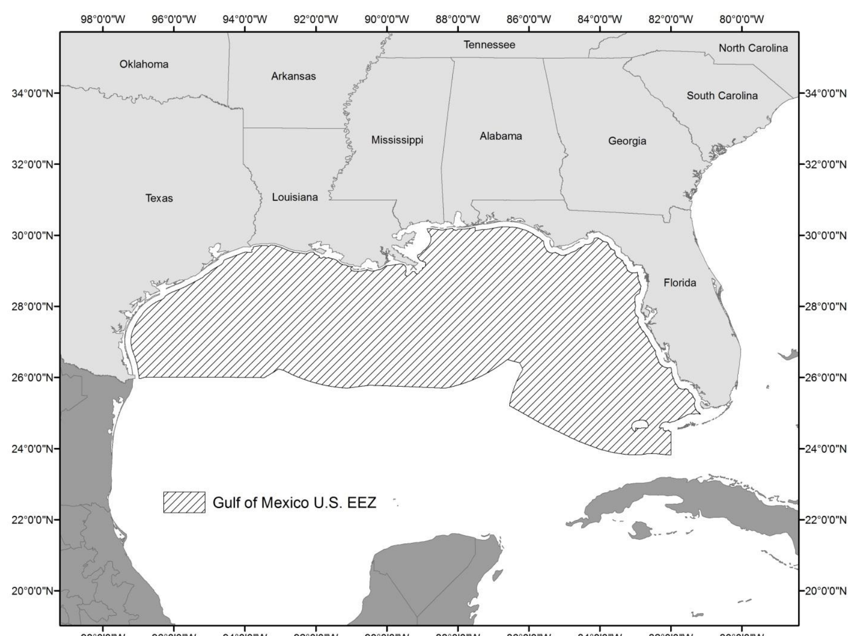

FIGURE 1. OCEANIC FISH RESTORATION PROJECT LOCATION IN THE U.S. EXCLUSIVE ECONOMIC ZONE IN THE GULF OF MEXICO INDICATED BY SHADED AREA

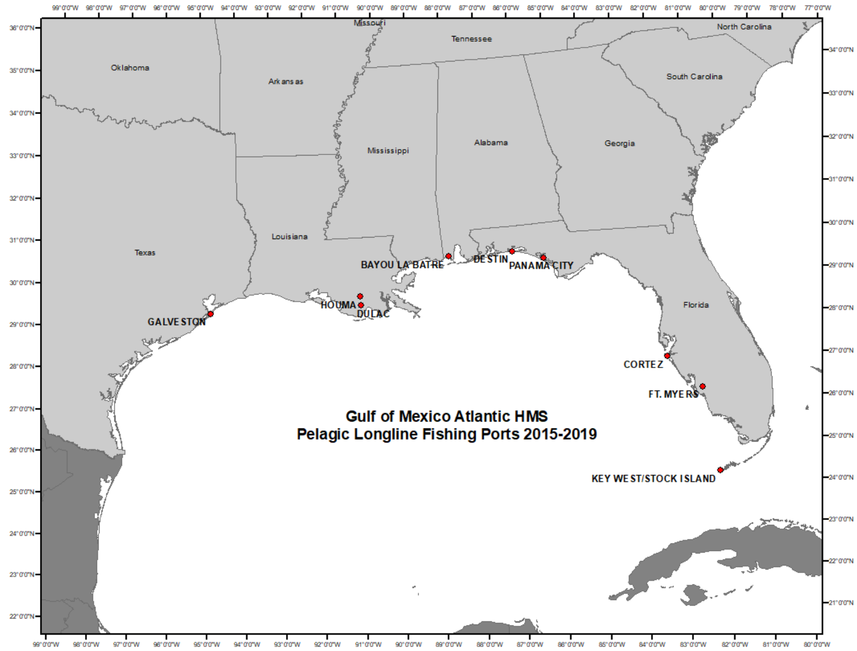

FIGURE 2. HIGHLY MIGRATORY SPECIES (HMS) PELAGIC LONGLINE FISHING PORTS IN THE GULF OF MEXICO FROM 2015 TO 2019. DATA SOURCE: HMS LOGBOOKS

1.2 Restoration Objectives and Performance Criteria

The goal of the Oceanic Fish Restoration Project is to restore biomass of offshore pelagic fishes through a reduction in bycatch mortality in the GOM PLL fishery and to minimize economic effects from potential reductions of catches of target species. Performance criteria—interim milestones that help determine if the project is performing at an acceptable level given the current stage of the project—are used to determine restoration success or the need for adaptive management.

The performance criteria for the project are identified by objective and phase in Table 1. The criteria may be adjusted throughout the project to reflect adaptive management of implementation or new understandings due to data analysis.

TABLE 1. PERFORMANCE CRITERIA BY RESTORATION OBJECTIVE

Performance Criteria Category	Project Execution	Post-Execution	Project End
OBJECTIVE 1 – Reduce Discards in the GOM PLL fishery			
Participation in annual repose periods	• Annual target number of executed agreements for participation in repose is reached	• Annual target participation in repose is achieved • Participants are in compliance with terms of active agreements	• Total of 60 vessel years participation in repose is achieved
Quantity and disposition of bycatch and discards by species		• Average biomass of dead discards avoided averages 11,600 dkg per vessel year	• Average biomass of dead discards avoided averages 11,600 dkg per vessel year

Performance Criteria Category	Project Execution	Post-Execution	Project End
OBJECTIVE 2 – Minimize Economic Effects through Use of Alternative Gears			
Participation in alternative gear installation and use	• Annual target number of executed agreements to use alternative gear	• Annual target level to use alternative gear is reached • Participating vessels have installed and are using their alternative gears as defined in their agreement	• Target level of participation is reached
Net profit of alternative gears		• Net profit of alternative gears will improve annually	• Net profit of alternative gears will improve annually

2 Methods

2.1 Reduce Discards in the GOM PLL Fishery

2.1.1 Participation in annual repose periods

In 2016, the National Oceanic and Atmospheric Administration (NOAA) and the National Fish and Wildlife Foundation (NFWF) developed a Cooperative Agreement to implement the Oceanic Fish Restoration Project. In 2017, for the pilot year, NFWF executed Participant Agreements with PLL vessel owners to participate in a four-month repose from fishing with PLL gear from March through June. In 2018 through 2020, NFWF executed Participant Agreements with PLL vessel owners to participate in the full six-month repose from January through June. The number of executed agreements, participation, and compliance with the Participant Agreement were tracked each year from 2017 through 2020.

2.1.2 Quantity and disposition of bycatch and discards by species

The National Marine Fisheries Service (NMFS) Pelagic Observer Program (POP)—an established program located at the Southeast Fisheries Science Center (SEFSC) that manages the training and placement of fisheries observers on Atlantic PLL vessels—recorded catch and other fisheries data for pelagic fishing vessels and managed observer data collection and processing through normal protocols (see Keene 2016). Observer protocols were updated or adapted for the project to include the alternative gears. POP observers collected data from participating vessels' fishing trips taken during the 2017 through 2019 repose periods.

A dataset from vessels fishing with PLL gear from the years 2012 to 2014 was created to establish a baseline for comparison with data collected from the vessels participating in the project (Appendix A, Kerstetter & Garvey 2020). These baseline years were prior to the implementation of the IBQ program in 2015, which allowed bycatch composition to be analyzed without this fisheries management change to influence the catch composition. The baseline data included gear type, date of capture, trip number, gear deployment number of the catch, and action taken after catch (e.g., kept, discarded). The biomass in kilograms of each individual fish was calculated using recorded length measurements when available and a length/weight coefficient unique to each species.

2.2 Minimize Economic Effects through Use of Alternative Gear

2.2.1 Participation in alternative gear installation and use

PLL vessel owners participating in the repose were eligible to fish with alternative gear for the continued catch of target pelagic species, such as tuna and swordfish. The alternative gear options included greenstick and buoy gear in all seasons of the project and deep drop rod and reel gear beginning in 2018; participants could select up to two alternative gear types to use during the repose. Participants had the option to use these gear types on an alternative vessel during the repose. The number of executed agreements to fish with alternative gear, participation, and compliance with the Participant Agreement were tracked each year from 2017 through 2020.

2.2.2 Net profit of alternative gear

The potential economic impacts of the alternative gear portion of the project for the 2017 and 2018 seasons were examined by analyzing fish quantity (count by weight, size, and product grade), price of landings of fishery target species, and annual expenses per vessel (e.g., equipment purchases and/or maintenance, staff and salaries, revenue sharing, fuel and trip costs) for project participant vessels fishing with alternative gears and vessels in the GOM PLL fishery (Appendix B, IEc 2020). In addition to testing how project participation affected these outcomes, the change of the effect of participation between the 2017 and 2018 seasons was also analyzed.

2.2.3 Evaluation of alternative gear

One of the alternative gear choices, greenstick gear, was evaluated independently by NOAA gear specialists from the NOAA SEFSC Harvesting Systems Unit (Appendix C, Foster 2020). In 2017 and 2018, gear studies were conducted to directly compare greenstick gear to PLL for yellowfin tuna catch rates, tuna quality, and bycatch. Research was also conducted in the vicinity of petroleum platforms to draw comparisons between fish caught around artificial structures and fish caught in the open ocean. Additional experiments were conducted to test methods for improving the quality of tuna caught on greenstick gear.

3 Results

Participation and compliance results are available for all years of the project to date, 2017–2020. Results from the fisheries data are available for 2017–2019 and results from the economic data are available for 2017–2018.

3.1 Reduce Discards in the GOM PLL Fishery

3.1.1 Participation in annual repose periods

The Oceanic Fish Restoration Project was expected to be complete within 10 years with the aim of vessels owners from across the Gulf of Mexico participating every year for five years (2017–2021), for a total participation of 60 vessel years over the life of the project. In 2017, based on initial feedback from vessel owners and other stakeholders, the project launched as a pilot with fewer vessel owners from a limited geographical region participating (i.e., seven vessel owners, all from Louisiana). In subsequent years, lessons learned from the pilot and the early seasons informed several adaptive management changes, which were incorporated into the project to attract new interest from vessel owners and allow a more diverse group of vessel owners to participate (see Section 4 for a discussion of the adaptive management changes). As a result of the adaptive management changes, by 2018 participation was broader geographically and the annual participation goal was met (Table 2).

TABLE 2. PARTICIPATION OF PELAGIC LONGLINE VESSEL OWNERS IN THE REPOSE BY YEAR AND LOCATION

Participation of PLL Vessel Owners in the Repose				
Year	**2017**	**2018**	**2019**	**2020**
Number of Participants	7	10	10	12
Participant's Home Port Location	All in Louisiana	7 in Louisiana, 3 in Florida	8 in Louisiana, 2 in Florida	7 in Louisiana, 5 in Florida

Overall, participants have complied with the project Participant Agreement. There have been issues that were brought into compliance quickly, such as expired U.S. Coast Guard Commercial Fishing Vessel Safety Examination decal and expired safety equipment. Non-compliance with proper vessel monitoring system (VMS) reporting has been a more persistent issue, which resulted in four participants not being granted a contract extension, although the vessel owners who maintained eligibility were allowed to submit a new application with a new price quotation for participation in the following season.

3.1.2 Quantity and disposition of bycatch and discards by species

The dataset for the alternative gear included species catch, gear configuration parameters, and environmental factors from 62 individual fishing trips taken by 13 unique vessels. The dataset included 872 greenstick gear sets, 938 buoy gear sets, and 33 deep drop rod and reel gear sets.

The repose performance metric to reduce dead discards by 11,600 discounted kilograms (dkg) of fish biomass per vessel year has been exceeded every year (2017–2019), including the shortened four-month pilot season in 2017, when biomass of avoided catch is considered (Table 3).

TABLE 3. BIOMASS AVOIDED BY YEAR PER VESSEL DUE TO THE REPOSE

Dead Discards Avoided by Year per Vessel			
	2017	**2018**	**2019**
Weight in discounted kilograms (dkg)	1,882	2,492	2,419
Counts	208	278	278
Catch Avoided by Year per Vessel			
Weight in discounted kilograms (dkg)	13,057	18,664	18,121
Counts	681	925	925
Total Biomass Avoided by Year per Vessel			
Weight in discounted kilograms (dkg)	14,939	21,156	20,540
Counts	889	1,203	1,203

The four fish species contributing the most to avoided dead discards were swordfish (*Xiphias gladius*), yellowfin tuna (*Thunnus albacares*), blackfin tuna (*Thunnus atlanticus*), and lancetfish (*Alepisaurus spp*.). Swordfish accounted for most of the biomass of avoided dead discards with 18,583 dkg of avoided discards across all repose periods, and lancetfish had the highest number of avoided dead discards at 2,141 individual fish across all repose periods (Table 4).

TABLE 4. TOTAL DEAD DISCARDS AVOIDED BY SPECIES DUE TO THE REPOSE

Total Dead Discards Avoided by Species				
	Swordfish	**Yellowfin tuna**	**Blackfin tuna**	**Lancetfish**
Weight in discounted kilograms (dkg)	18,583*	5,552	4,475	3,499
Counts	1,673	441	475	2,141*

*Highest in that category.

Additional statistical analyses were conducted to further characterize the bycatch and bycatch reduction. The full report can be found in Appendix A.

3.2 Minimize Economic Effects through Use of Alternative Gear

3.2.1 Participation in alternative gear installation and use

Every participant in the repose also adopted the use of the alternative gear provided through the project, except one participant in the 2018 season who elected to only participate in the repose. No participants elected to use an alternative vessel. Adaptive management changes that benefited participation in the repose also benefited participation in the use of alternative gear. In the first year of the project, despite having the options to select up to two gear types (see 2.2.1), participants only elected to use greenstick gear; as a result, several adaptive management changes were incorporated into the project to attract interest in the other gear types (see Section 4 for a discussion of the adaptive management changes). The changes were effective in diversifying the gear types selected by the participants (Table 5).

TABLE 5. PARTICIPATION OF PELAGIC LONGLINE VESSEL OWNERS IN THE USE OF ALTERNATIVE GEAR BY YEAR AND LOCATION

Participation of PLL Vessel Owners in the Use of Alternative Gear				
Year	**2017**	**2018**	**2019**	**2020**
Number of Participants	7	9	10	12
Participant's Home Port Location	All in Louisiana	6 in Louisiana, 3 in Florida	8 in Louisiana, 2 in Florida	7 in Louisiana, 5 in Florida
Gear Selected for Use	Greenstick (7)	Greenstick (6), deep drop (5), buoy gear(7)	Greenstick (8), deep drop (3), buoy gear(6)	Greenstick (8), deep drop (5), buoy gear(7)

3.2.2 Net profit of alternative gear

The economic data outside of the project were not available for all participants and project data from only the first two years of the project were available for analysis; thus, results are currently limited. For example, net revenue[1] was available for four out of seven participating vessels in 2017 and from seven out of nine participating vessels in 2018. From the data that were available, net profit did not increase annually from 2017 to 2018 and the performance metric of annual improvement of net profit was not met; no significant differences were found between the two years in expenses, sales, or net profit per trip.

In 2017, one of the four participating vessels with available net revenue information averaged positive net revenues during the repose period. In 2018, five out of seven participating vessels with available net revenue information, including all Florida participants, averaged negative net revenues during the repose period. Participants in 2017 averaged $1,349 in sales from fish caught with the alternative gear, whereas participants in 2018 averaged $3,293 in sales per vessel during the repose. Revenue does not include the repose or alternative gear compensation.

Additional statistical analyses were conducted to estimate alternative gear performance and to characterize the GOM PLL fishery. The full report can be found in Appendix B.

3.2.3 Evaluation of alternative gear

Over the two years of greenstick evaluation testing conducted independently by NOAA gear specialists from the NOAA SEFSC Harvesting Systems Unit, a total of 49 individual animals were caught on greenstick. The counts and mean lengths for fish species caught near petroleum platforms and in the open ocean while shadowing a PLL vessel are presented in Table 6. While shadowing the PLL vessel, the greenstick gear was trolled parallel to and within approximately two kilometers of the longline.

TABLE 6. FISH SPECIES CAUGHT DURING GREENSTICK GEAR EVALUATION

	Species Counts and Mean Lengths of Fish Caught on Greenstick Gear					
	Petroleum Platforms			**Open Ocean (PLL Shadowing)**		
	Count	Mean Length (cm)	Min/Max Length (cm)	Count	Mean Length (cm)	Min/Max Length (cm)
Blackfin Tuna	15	63.3	49-76	10	65.3	53-78
Dolphinfish	-	-	-	6	78.5	57-97
Skipjack Tuna	-	-	-	7	67.7	58-73
Yellowfin Tuna	5	99.8	57-130	3	145.3	144-147
Little Tunny	2	52.5	51-54	-	-	-

During nine fishing days of PLL shadowing to compare catch between a vessel using greenstick gear and a PLL vessel, the PLL vessel caught a total of 107 yellowfin tuna and the greenstick vessel caught three. The average PLL yellowfin catches per day for 2017 and 2018 were 14.8 and six per day, respectively; the greenstick vessel averaged one fish per three days of fishing in each of the two years. The yellowfin CPUE was 0.840/hr for the PLL and 0.048/hr for greenstick gear. The average dressed weight was higher for yellowfin tuna caught on greenstick gear at 41.5kg (91.3lb) than on PLL at 38.2kg (83.9lb). There was no bycatch on the greenstick vessel,

[1] Revenue does not include the compensation vessel owners received for voluntarily participating in the project.

while almost half of the catch from the PLL vessel was bycatch that was not retained. Despite attempts to improve the quality of tuna caught on greenstick, none of the greenstick-caught yellowfin tuna were graded as #1, whereas 38 percent of the tuna caught on PLL were graded as #1.

Additional statistical analyses were conducted to evaluate greenstick gear performance. The full report can be found in Appendix C.

4 Discussion

Because this is a novel restoration project, a commitment to adaptive management has been very important. The adaptive management changes adopted into the project were developed by close monitoring of performance metrics and results to determine where changes could be made that would improve outcomes. The changes also resulted from listening to the stakeholders, addressing their concerns, and incorporating their ideas.

Several adaptive management changes were incorporated to increase the number of participants and broaden the geographic scope of the project. Based on initial project outreach, the decision was made to launch the project as a pilot in 2017 to evaluate implementation, conduct adaptive management, and allow further engagement with vessel owners, dealers, and other stakeholders. NFWF and NOAA would then make adjustments and enhancements for the full rollout of the project in 2018. The 2017 pilot year was implemented as a shortened, four-month repose, geographically limited to Louisiana. Seven vessel owners were selected to participate. To accommodate the limited participation during the pilot year, the project was extended an additional season. This allowed the participation goal per season to be reduced.

Achieving Gulf-wide participation was challenged by operational differences across the Gulf, which created significant differences in annual revenue, effectively limiting the competitiveness of certain vessels in the Gulf-wide reverse-auction format. By creating separate regional auctions in 2018, vessel owners were able to submit competitive quotations within their respective regions, resulting in more vessel owners participating from a broader area.

Adaptive management changes were also adopted in an attempt to improve net profit of the alternative gears, which was not significantly different between the two years with available data. At the recommendation of the participants, deep drop rod and reel gear was added as gear choice to target swordfish, and Exempted Fishing Permits (EFPs) were issued to allow tuna to be landed with buoy gear and to allow buoy gear to be retrieved with a power hauler, making the gear more functional for fishing for tuna. In addition, the project offered participants at-sea training in the effective use of alternative gear, including learning from a captain with extensive experience in greenstick fishing in the Atlantic. The effects of these changes will be monitored in economic analyses in the following years.

The adaptive management changes and the year they were enacted included:

- The participation period was extended from five to six seasons and the annual participation goal per year was decreased from 12 to 10 vessels per season (2018).
- The Gulf-wide auction was split into regional auctions due to regional market differences (2018).
- Payments to participants were made more frequently (i.e., every month) (2018).
- The option to extend contracts from year-to-year was granted to eligible participants (2020).
- “Pay-as-you-bid” compensation was offered instead of fixed price compensation (2020; see Holzer & Byler 2019 for a description of these compensation mechanisms).

- Minimum insurance requirements were defined for participating in the alternative gear portion of the project (2020).

Adaptive management changes specifically targeting the use of alternative gear and the year they were enacted included:

- Deep drop rod and reel gear was added as an alternative gear choice (2018).
- EFPs were issued by the Atlantic Highly Migratory Species (HMS) Management Division to allow tuna to be targeted and landed with buoy gear (2018).
- EFPs were issued by the Atlantic HMS Management Division to allow buoy gear to be retrieved using a power hauler (2019).
- The project offered participants using buoy gear financial support to purchase a buoy tracking system that allowed them to use the gear more effectively (2020).

5 Conclusion

The Oceanic Fish Restoration Project reduced fishing pressure on pelagic fish species, resulting in reduced bycatch mortality in the GOM PLL fishery in the first years of the project. From 2017 through 2019, the biomass of dead discards avoided in the fishery due to the repose exceeded performance criteria every year, including the shortened four-month pilot season in 2017, when the biomass of avoided catch is considered. Thus, the restoration of pelagic fish populations—particularly the four fish species that benefited the most from the reduced bycatch mortality (swordfish, yellowfin tuna, blackfin tuna, and lancetfish)—was supported through the actions of the project by allowing commercial and non-commercial fish species to remain in the Gulf and to grow and breed.

Annual improvement—the alternative gear net profit performance criterion—was not met, with no significant difference found in the first two years of the project. However, data available for analysis to monitor this metric were limited. For example, economic data from outside the project were not available for all vessels and only two seasons of data from the project were available for analysis. Continued monitoring of this metric and analysis of data as it becomes available may show that the performance criterion was met in subsequent seasons because adaptive management changes, which boosted participation in the project, may have also affected this metric. Also, the inclusion of data that were previously not available may affect the results of the initial analysis. Despite not meeting the performance criteria, the project successfully demonstrated that the alternative gear is very effective at reducing dead discards in the pelagic fishery.

Although participation in the 2017 pilot year did not meet the performance criteria, adaptive management changes that resulted from the pilot increased the number of participants in following years. The project has met the annual participation targets every year beginning in 2018 and is on track to achieve the overall project participation target of 60 vessel years in six years of implementation, well within the expected timeline of five to 10 years.

Additional adaptive management changes in project implementation are not recommended at this time. It is recommended to expand the economic dataset by including data that were previously unavailable and analyze additional years of economic data, as well as explore the economic data in greater depth to better understand factors that affect profitability.

6 Project Highlights

The Oceanic Fish Restoration Project is a novel restoration project that depends on voluntary participation of the PLL fishery. Lessons learned from project implementation were valuable to informing adaptive management, leading to changes that improved outcomes. The adaptive management changes were wide-ranging, from timeliness of payments to consideration of regional market differences to gear choice. The most important tool used to realize the adaptive management changes from the lessons learned was communication with stakeholders, both through direct feedback and through liaisons who were employed specifically to perform targeted outreach to the PLL fishery and support communities. This approach will most likely be important to the success of future restoration projects that involve voluntary participation of stakeholders to achieve restoration goals.

7 Data

Data collected by existing NOAA programs, including Atlantic HMS Management Division logbooks, NMFS POP datasheets, and all other outside resources, were subject to the QA/QC requirements of the programs from which the data originated. Data collected specifically for the project were recorded on existing standardized datasheets when possible or on project-specific datasheets when standardized datasheets were not available. Project-specific data collection and QA/QC procedures matched existing POP procedures.

Observer data, logbooks, and cost and earnings forms were scanned to PDF files. All data, both the hard copies and digital datasheets, are archived at NMFS.

8 References

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Appendix A

Deepwater Horizon Oceanic Fish Restoration Project Monitoring Report 2017–2019

Deepwater Horizon Oceanic Fish Restoration Project

Monitoring Report 2017 - 2019

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November 2020

Introduction:

The 2010 *Deepwater Horizon* oil spill was the largest offshore oil spill in the history of the United States, resulting in the discharge of approximately 3.19 million barrels of oil into the Gulf of Mexico (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016). The release of oil had considerable detrimental impacts on the natural resources of the Gulf. Among the natural resources damaged by the spill were populations of oceanic, or pelagic, fish species. Pelagic fish include species that are recreationally and commercially important to local fisheries as well as species that are ecologically critical to the health of the Gulf of Mexico ecosystem. Yellowfin tuna (*Thunnus albacares*) and swordfish (*Xiphias gladius*) are of particular interest due to their commercial importance in the Gulf of Mexico (GOM) pelagic longline (PLL) fishery.

The *Deepwater Horizon* oil spill exposed pelagic fish to toxic levels of polycyclic aromatic hydrocarbons (PAHs). Exposure to PAHs is especially damaging to pelagic fish in their juvenile, planktonic life stages. In areas of the water column exposed to PAHs, the estimated mortality of early life stage fish ranged from 21% to 45% in more sensitive species such as mahi-mahi (*Coryphaena hippurus*) (Travers et al., 2015). It is estimated that 2 to 5 trillion larval fish were killed in the upper 20 meters of offshore surface waters in areas affected by the oil spill (French-McCay et al. 2015). Embryos and larvae that survive exposure to PAHs are likely to suffer from developmental issues, such as reduced cardiac function (Incardona et al., 2015) and reduced swimming performance (Mager et al. 2014). The abundance of pelagic fish larvae in parts of the Gulf of Mexico affected by the *Deepwater Horizon* oil spill was found to be lower in 2010 compared to the previous three years prior to the spill (Rooker et al. 2013). It is unknown to what extent this reduction can be attributed to the oil spill, and the long-term detrimental effects of the oil spill on fish populations have yet to be fully determined. In order to restore pelagic fish populations that were harmed by the oil spill, the National Oceanic and Atmospheric Administration (NOAA) partnered with the National Fish and Wildlife Foundation (NFWF) to work with the GOM PLL fishery and establish the Oceanic Fish Restoration Project (OFRP).

The objective of the OFRP is to restore pelagic fish populations through a reduction of fishing pressure and bycatch mortality in the GOM PLL fishery. PLL gear is composed of a mainline from which a series of baited hooks is suspended (called a gangion). Float lines are used to suspend the gear at depth, allowing it to target pelagic fish (Watson & Kerstetter 2006). In the Gulf of Mexico, the PLL fishery targets yellowfin tuna, bigeye tuna (*Thunnus obesus*), and swordfish. PLL gear may be configured in different ways to target either tuna or swordfish. Swordfish sets are suspended closer to the surface, use fewer hooks in between floats, and are typically set at sunrise and hauled at sunset. In contrast, tuna sets are suspended deeper in the water, utilize more hooks, and are set at sunrise and hauled at sunset. Vessels in the GOM PLL fishery primarily target yellowfin tuna throughout the year, although some vessels will also directly target swordfish either seasonally or year-round. The GOM PLL fishery also retains other pelagic fish species as incidental catch, such as escolar (*Lepidocybium flavobrunneum*). Other non-target species, including sharks, istiophorid billfishes, lancetfishes (*Alepisaursus* spp.), and Atlantic bluefin tuna (*Thunnus thynnus*) are caught as bycatch. Marine mammals, sea turtles, and sea birds also occasionally interact with PLL gear as bycatch. Circle hooks are currently required within the fishery to reduce the catch mortality associated with traditional J hooks. Weak circle hooks are currently required in the Gulf of Mexico from January through June to reduce the catch of bluefin tuna. The shank of weak circle hooks are comprised of a thinner diameter wire that straightens under pressure and releases the fish before the gear is retrieved (NMFS, 2006).

The OFRP aims to reduce bycatch mortality using a two-part approach: the implementation of a temporary, voluntary repose period in the fishery, and the optional use of alternative fishing gear. Time/area closures can be an effective tool in reducing bycatch in fisheries, and when combined with the use of alternative gear, are an economically viable strategy (O'Keefe et al. 2013). During the OFRP repose periods, participating vessels refrain from fishing with PLL gear for six months of the year, while still having the option to fish with alternative gear provided by the OFRP. Participating vessels are compensated to offset the loss of revenue during repose periods (Holzer & Byler, 2019). Repose periods take place in the first six months of the calendar year, coinciding with the spawning period of bluefin tuna in the northern GOM (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016). The combination of a reduction in fishing pressure and bycatch mortality aims to allow pelagic fish populations to recover during the repose periods.

Participating vessels can continue fishing activity during the repose with the use of alternative fishing gear, including greenstick gear, buoy gear, and deep-drop gear (50 CFR § 635.19). Vessels may choose to use up to two gear types during the repose. Greenstick gear is an actively trolled mainline which is suspended above the water. Up to 10 hooks or gangions may be attached to the mainline. Trolls of greenstick gear typically target yellowfin or bigeye tuna. Buoy gear consists of a mainline suspended by two to three buoys. From the mainline two hooks or gangions are attached. Buoy gear is typically deployed at night and targets swordfish. OFRP participating vessels may apply for an exempted fishing permit (EFP) which allows them to retain tuna while using buoy gear. Deep drop gear is a rod and reel type gear and is typically deployed at depths of 1,200–1,800 feet in order to catch swordfish. Due to the smaller number of hooks used, as well as the need for the gear to be more actively tended, greenstick gear and buoy gear have been found to have low rates of bycatch mortality (Kerstetter et al. 2014).

Restoration objectives of the OFRP include reducing discards in the GOM PLL fishery and minimizing the economic effects of reduction of catches through the use of alternative gear types. It is estimated that through the OFRP the biomass of dead discards avoided will average 11,600 dkg per vessel year (Deepwater Horizon Oil Spill Natural Resource Damage Assessment, 2015). The significant reduction of bycatch mortality through the OFRP should allow populations of pelagic fish in the Gulf of Mexico time to recover and offset injuries sustained as part of the *Deepwater Horizon* oil spill. Many of the pelagic fish species that stand to benefit from the implementation of the OFRP have been identified as keystone species (Dambacher et al. 2010). The restoration of these populations is a key step in improving the health of the Gulf of Mexico ecosystem.

The OFRP launched as a pilot in 2017, consisting of a shortened (four-month) repose period lasting from March 1 to June 30. During the pilot repose, seven vessels participated, and all opted to use alternative fishing gear. The following year, the first full repose took place from January 1 to June 30, 2018. In the 2018 repose, 10 vessels participated, of which nine opted to use alternative gear. In the 2019 season, 10 vessels participated, all of which chose to use alternative gear during the repose. The analyses in this final report are intended to quantify the reduction in bycatch that could be attributed to the OFRP-instituted repose periods.

Methods:

Data Preparation

Data on an observed subset of trips in the GOM PLL fishery were obtained from NOAA's Pelagic Observer Program (POP). As part of the POP, PLL vessels are selected at regular intervals (usually, once per calendar quarter) to carry a fisheries observer. The fisheries observer records data on catch and bycatch composition, gear configuration, geographic locations, and environmental conditions (e.g., sea state). Because vessels within the fishery do not host an observer on every trip, data gathered from the POP are a sample of what is occurring in the fishery as a whole. During repose periods, observers were placed aboard participating vessels in order to gather data on the effectiveness of the alternative fishing gears. In 2019, all 10 vessels using alternative gear were covered by observers. In 2018, 7 out of 9 vessels using alternative gear were observed. In 2017, 6 out of 7 vessels using alternative gear were observed. These data were then compared to POP data, which represents a sampling of the total GOM PLL fishery.

Observers collected data on alternative gear trips taken during the shortened 2017 and full 2018 and 2019 repose periods. The resulting data set includes catches, gear configuration parameters, and environmental factors from 62 individual trips taken by 13 unique vessels. The data set covers 872 greenstick gear sets, 938 buoy gear sets, and 33 deep-drop gear sets.

The dataset contains a record for each animal caught by alternative gear from 2017 to 2019, and PLL gear from the years 2000 to 2004 and 2009 to 2018. Each record contains the gear type the animal was caught with, as well as the date of the capture, the trip number the catch was made on, the gear deployment number of the catch, and the action taken (kept, discarded, etc.) after the catch was made. The biomass in kilograms of each individual fish was then calculated using the recorded length measurements (when available) and a length/weight coefficient unique to each species (Appendix 1).

The combined animal log data were then transformed into a new dataset organized by fish caught in a single gear deployment. A single deployment was defined as a set and haul of PLL gear, a troll of greenstick gear, a set of buoy gear from initial deployment to final retrieval, or a set of deep drop gear. Each gear deployment was separated by the action taken after catch (kept, released alive, released dead, or lost). Each record in the resulting data set shows the amount of fish caught per gear deployment and per action. The data were represented in terms of counts per species and in terms of biomass in kilograms per species.

Data Analysis

PLL and Alternative Gear Comparison

A comparative analysis of catch composition and bycatch rates between the GOM PLL and the alternative fishing gears required the establishment of a baseline period prior to the implementation of the project. The U.S. Atlantic PLL fishery has adapted to numerous regulations that have directly affected catch rates, such as the mandatory use of size 16/0 and greater circle hooks starting in 2004. The three years selected to act as a baseline period for the GOM PLL fishery were 2012, 2013, and 2014, as these years represent the PLL fishery before the implementation of the Individual Bluefin Quota (IBQ) program in 2015, and the first repose period in 2017. In this way, the bycatch composition can be analyzed without changes in fisheries management influencing the catch composition. The baseline period established for the comparative analyses used POP data from 207 PLL trips across 51 individual vessels and was used to describe the average set parameters of PLL vessels. This data set was compared to the 62 trips from 13 vessels using alternative gear.

In order to compare the catch rates of PLL gear to alternative gear, the data were fitted to a model that accounted for variations in the deployment duration of the gear and the calendar quarter in which the gear was deployed. Baseline PLL catches and alternative gear catches were separated into individual datasets for total catches, dead discards, and live releases. R Studio (Version 1.1.463 – © 2009-2018 RStudio, Inc.) and the glmmTMB package (Brooks et al. 2017) were used to fit the data to a zero inflated negative binomial generalized linear mixed model (GLMM). This GLMM determines the mean catch count of an individual gear deployment of the two gear types based on the quarter of the year, the total hours deployed, and random effects of different individual vessels. The following series of GLMMs were created to compare the gear types:

1) The mean total catch per gear type

   glmmTMB(Total_Catch~Gear + Quarter.Factor + Hours + (1|Vessel),zi=~1, family = nbinom2, data = Gear_Comp_Total_Catch_Count)

2) The mean dead discards per gear type

   glmmTMB(Total_Discards~Gear + Quarter.Factor + Hours + (1|Vessel), family = nbinom2, data = Gear_Comp_Count_Dead_Discard_R)

3) The mean live releases per gear type

   glmmTMB(Total_Releases~Gear + Quarter.Factor + Hours + (1|Vessel), family = nbinom2, data = Gear_Comp_Count_Live_Release)

Gear Configuration and Environmental Effects on Alternative Gear Catches

The catch frequency of alternative gear was examined across environmental factors as well as gear configuration patterns. Due to low catch numbers, alternative gear catches were converted into a binary number on a set by set basis, with 1 reflecting a successful catch of any amount, or 0 representing no catches in the individual gear deployment. Binary catch numbers were then joined with POP data on the gear configuration of the individual deployment and the environmental factors when the gear was deployed. In this way, it could be determined which factors have a significant effect on alternative gear making a catch. The environmental factors of wind speed, wind direction, wave height, weather, and bottom depth were tested for the significance of their effect on the likelihood of alternative gear making a catch. Weather was recorded as a categorical variable, with categories for rain, overcast, and clear skies. Gear configuration parameters examined in the greenstick gear included bird, mainline, and gangion measurements as well as hook type. For buoy gear, these parameters included mainline, gangion, and leader measurements, as well as hook type and the use of lights. The time of day the gear was fished was also tested. Greenstick gear was categorized as fishing during dawn if the gear was deployed between the start of astronomical twilight and the end of civil twilight. Gear that was deployed before astronomical twilight but fished throughout the dawn hours were categorized as fishing during dawn. Gear that was deployed after the end of civil twilight were categorized as fishing during the day. No greenstick gear was deployed during dusk hours. Buoy gear whose deployment time extended past the astronomical twilight of dusk were categorized as fishing during the night. If buoy gear deployment times did not extend beyond dusk, they were considered to be fishing during the day. Times of dusk and dawn were adjusted for each month and based on a New Orleans, LA position. Daylight savings time was considered for deployments occurring in March. The effectiveness of deep drop gear under environmental and configuration factors could not be determined due to the low number of catches recorded with the gear (n=33). Generalized additive models (GAM) with a binomial distribution were created (Wood, 2011). Variables that were found to be nonsignificant were systematically removed from the models through an exhaustive search until the model with the lowest Akaike information criterion was chosen. The following models were chosen to test the effects of environmental and gear configuration on the likelihood of making a catch with greenstick gear or buoy gear:

1) Determine the effect of environmental factors on greenstick gear catches:

   gam(Catch_Binary~s(Hours)+s(WIND_SPEED)+s(WAVE_HEIGHT)+s(BOTTOM_DEPTH_MAX)+factor(Weather)+factor(WIND_DIRECTION), family = binomial, data = Greenstick_config)

2) The effect of gear configuration on greenstick gear catches:

   gam(Catch_Binary~s(Hours)+MAINLINE_DIAMETER+GANGION_DIAMETER+BIRD_HEIGHT+BIRD_LENGTH+BIRD_WIDTH+factor(HOOK_SIZE_1)+factor(HOOK_TYPE_1)+factor(MAINLINE_TEST)+factor(GANGION_TEST)+factor(POLE_HEIGHT), family = binomial, data = Greenstick_config)

3) The effect of the time of day on greenstick catches:

   gam(Catch_Binary~s(Hours)+factor(Time_Of_Day), family = binomial, data = Greenstick_config)

4) The effect of environmental factors on buoy gear catches:

   gam(Catch_Binary~s(Hours)+WAVE_HEIGHT+BOTTOM_DEPTH_MIN+BOTTOM_DEPTH_MAX+factor(WIND_DIRECTION), family = binomial, data = Buoy_Config)

5) The effect of gear configuration on buoy gear catches:

   gam(Catch_Binary~s(Hours)+GANGION_LENGTH+LEADER_LENGTH+MLDiameter+HookSize, family = binomial, data = Buoy_Config)

6) The effect of lights (LED lights and glow sticks) on buoy gear catches:

   gam(Catch_Binary~s(Hours)+Lightstick+Elight, family = binomial, data = Buoy_Config)

7) The effect of the time of day on buoy gear catches:

   gam(Catch_Binary~s(Hours)+Time_Of_Day, family = binomial, data = Buoy_Config)

Catch Similarity of PLL and Alternative Gear

The similarity of the catch composition of alternative gear and PLL gear was compared using PRIMER (v. 7.0.13; Plymouth Routines in Multivariate Ecological Research). An analysis of catch composition was used to determine if bycatch species were less prevalent in alterative gear catches when compared to PLL catches. A Bray-Curtis similarity index was used to examine the presence and abundance of different species caught with PLL gear in comparison to the combined catch of the alternative gear types. An analysis of similarity (ANOSIM) test was used to determine if there was a significant difference between the catch compositions of the gear types. A one-way similarity percentage (SIMPER) test was used to determine which species were driving differences in catch composition between the groups.

Estimating Avoided Catch During Repose Periods

To determine the effectiveness of the repose periods in avoiding catch and discard mortality, models were constructed to determine how many fish the number of vessels participating in the repose would be expected to catch and how many would be discarded in quarter 1 and quarter 2 (the length of the full repose period) in a typical year. “Total catch” includes all fish kept for market, discarded dead, released alive or lost on the line. Estimates for “dead discard avoided” uses a subset of only the fish that were discarded dead. The constructed models use the cumulative number of hooks deployed by the vessels to make their estimates. In the case of 2018 and 2019, the models made estimates for 10 vessels. For the 2017 repose, the models made estimates for seven vessels. In order to determine the typical catch of PLL vessels by the number of hooks deployed, data were obtained from the POP for total catches as well as dead discards from two periods: 2000-2004 and 2009-2016. The previously used “baseline period” only covered three years of PLL data, so additional data were gathered from 2000-2004 and 2009-2016, as these years had accessible POP data. The following models were used to estimate total catch and dead discards generated by PLL vessels in a typical calendar quarter:

1) Total catch by count
glmmTMB(Total_Catch~Quarter.Factor + log(Hooks_Sum) + (1|Year.Factor),family = nbinom2, data = PLL_All_Counts_Quarter)

2) Total catch by biomass (kg)
glmmTMB(log(Biomass_Sum)~Quarter.Factor+Hooks_Sum, data = PLL_All_Catches_Biomass_R, family= gaussian)

3) Dead discards by count
glmmTMB(Total_Catch~Quarter.Factor + log(Hooks_Sum) + (1|Year.Factor), family = nbinom2, data = PLL_Discard_Quarter)

4) Dead discards by biomass (kg)
glmmTMB(log(Biomass_Sum)~Quarter.Factor+Hooks_Sum, data = PLL_Dead_Discard_Biomass_R, family= gaussian)

The models estimate avoided catch and discards in a quarter based on the cumulative hooks the participating vessels would have deployed during the repose period. For the models to make their estimates, it was first necessary to determine the expected fishing effort the number of vessels participating in the repose were expected to make in the first two calendar quarters. The POP dataset does not include trips made by vessels without observers present; therefore, it was necessary to use the PLL logbook dataset to determine the average number of hooks a PLL vessel deploys in a six-month period. Using the logbook dataset on PLL vessels in the Gulf of Mexico from 2012 to 2016, a GLM was used to estimate the average number of hooks fished by an individual vessel during the first semester (six months) of the year.

- Number of hooks fished during the first semester:
  glm log(hooks) ~ year + vessel ID

For the 2018 and 2019 repose periods, the models estimated the amount of catch and dead discards that 10 vessels would be expected to produce by deploying a cumulative total of 159,065 hooks in each quarter of the repose. For the shortened repose period of 2017, the model was adjusted to estimate the amount of catch and dead discards that seven vessels would be expected to produce by deploying 111,346 hooks in each quarter of the repose. Results of the estimates for quarter 1 were reduced by a third in order to account for the repose only being implemented for one month (the month of March) during the first quarter of 2017. Estimates of kilograms of biomass that avoided being caught due to the repose periods were converted to discounted kilograms (dkg). Discounted kilograms were calculated using a net present value equation, with an annual rate of 3% and a starting year of 2010 (the year of the *Deepwater Horizon* oil spill). The models were then adjusted to estimate the number of catches and dead discards avoided for particular species of recreational, commercial, or ecological importance. The species investigated further were the yellowfin tuna, swordfish, lancetfish, and blackfin tuna (*Thunnus atlanticus*). Data from the POP on each species' catch and dead discard numbers were fitted to a negative binomial GLMM. Estimates were made for counts and biomass of total catch and dead discards for each of the repose periods using the following GLMs:

1. Yellowfin Tuna:
   Total catch avoided (counts and biomass):

   - glmmTMB(YFT_Sum~Quarter.Factor + log(Hooks_Sum) + (1|Year.Factor),family = nbinom2, data = PLL_All_Counts_Quarter)

   - glmmTMB(YFT_Sum~Quarter.Factor+Hooks_Sum, data = PLL_All_Catches_Biomass_R, family= gaussian)

   Dead discard avoided (counts and biomass):

   - glmmTMB(YFT_Sum~Quarter.Factor + log(Hooks_Sum) + (1|Year.Factor),family = nbinom2, data = PLL_Discard_Quarter)

   - glmmTMB(YFT_Sum~Quarter.Factor+Hooks_Sum, data = PLL_Dead_Discard_Biomass_R, family= gaussian)

2. Swordfish:
   Total catch avoided (counts and biomass):

   - glmmTMB(SWO_Sum~Quarter.Factor + log(Hooks_Sum) + (1|Year.Factor), family = nbinom2, data = PLL_All_Counts_Quarter)
   - glmmTMB(SWO_Sum~Quarter.Factor+Hooks_Sum, data = PLL_All_Catches_Biomass_R, family= gaussian)

   Dead discard avoided (counts and biomass):

   - glmmTMB(SWO_Sum~Quarter.Factor + log(Hooks_Sum) + (1|Year.Factor), family = nbinom2, data = PLL_Discard_Quarter)
   - glmmTMB(SWO_Sum~Quarter.Factor+Hooks_Sum, data = PLL_Dead_Discard_Biomass_R, family= gaussian)

3. Lancetfish:
   Total catch avoided (counts and biomass):

   - glmmTMB(Lax_Sum~Quarter.Factor + log(Hooks_Sum), family = nbinom2, data = PLL_All_Counts_Quarter)
   - glmmTMB(LAX_Sum~Quarter.Factor+Hooks_Sum, data = PLL_All_Catches_Biomass_R, family= gaussian)

   Dead discard avoided (counts and biomass):

   - glmmTMB(LAX_Sum~Quarter.Factor + log(Hooks_Sum), family = nbinom2, data = PLL_Discard_Quarter)
   - glmmTMB(LAX_Sum~Quarter.Factor+Hooks_Sum, data = PLL_Dead_Discard_Biomass_R, family= gaussian)

4. Blackfin Tuna:
   Total catch avoided (counts and biomass):

   - glmmTMB(BLK_Sum~Quarter.Factor + log(Hooks_Sum) + (1|Year.Factor), family = nbinom2, data = PLL_All_Counts_Quarter)
   - glmmTMB(BLK_Sum~Quarter.Factor+Hooks_Sum, data = PLL_All_Catches_Biomass_R, family= gaussian)

   Dead discard avoided (counts and biomass):

   - glmmTMB(BLK_Sum~Quarter.Factor + log(Hooks_Sum) + (1|Year.Factor), family = nbinom2, data = PLL_Discard_Quarter)
   - glmmTMB(BLK_Sum~Quarter.Factor+Hooks_Sum, data = PLL_Dead_Discard_Biomass_R, family= gaussian)

Results:

Pelagic Longline Gear

PLL vessels showed the most fishing effort on the edge of the continental shelf off the Louisiana coast according to POP data from 2012 to 2014 (Figure 1). During the 2012-2014 sample period, the average PLL vessel spent 14 ± 4 days at sea per trip, made 9 ± 3 sets per trip, and had a mean set duration of 4 ± 1 Hours (Table 1). PLL vessels in the POP caught 42,136 individual fish across the three sample years, for a mean of 205 ± 109 catches per trip. During the sample period 11,805 catches were discarded dead, for a mean of 57 ± 40 discards per trip (Table 2).

Yellowfin tuna were the most commonly caught species with PLL gear from 2012-2014, with 10,272 catches being made in the sample period (Appendix 2, Table 13). Escolar and mahi-mahi were commonly kept as incidental catch. Just under half of observed catches were kept, while over a quarter of catches were discarded dead (Figure 2A). Lancetfish were the most common dead discard species. Swordfish were the second most common species to be discarded dead and contributed the most to the overall biomass of the dead discard observed. Species with commercial value, such as yellowfin tuna or swordfish, were released alive if they were undersized or discarded dead if the fish was damaged on the line (Figure 3). Live releases comprised under a quarter of observed catches, with pelagic stingrays (*Pteroplatytrygon violacea*) and unidentified requiem shark species being the most common (Figure 2B).

Table 1: Average set parameters for Gulf of Mexico PLL vessels participating in the Pelagic Observer Program from the years 2012-2014. Error is reported as standard deviation for calculated means.

Mean Sea Days per Trip	14 ± 4	**Mean Number of Hooks Set**	685 ± 203
Mean Sets per Trip	9 ± 3	**Mean Number of Light Sticks**	347 ± 249
Mean Hauls per Trip	9 ± 3	**Mean Number of Radio Beacons**	5 ± 3
Mean Set Duration	4 ± 1 Hours	**Mean Number of Floats**	170 ± 54
Mean Haul Duration	7 ± 2 Hours	**Mode Quarter**	Q2
Average Set Time	12:57:14 PM (± 5 Hours)	**Most Common Target Species**	Mixed Species

Table 2: Catches of PLL gear in the POP from 2012 – 2014. Kept catches include target species as well as incidental catch. Catches, dead discards and live releases are given as counts and as biomass in kilograms (kg). Means are calculated with a standard deviation.

Number of Observed Trips	207
Total Observed Sea Days	2,807
Total Catches	42,136 (1,600,945 kg)
Kept Catches	19,379 (930,698 kg)
Dead Discards	11,805 (190,875 kg)
Live Release	9,396 (442,664 kg)
Mean Total Catches per Trip	205 ± 109 (7,772 ± 4,943 kg)
Mean Discards per Trip	57 ± 40 (927 ± 813 kg)

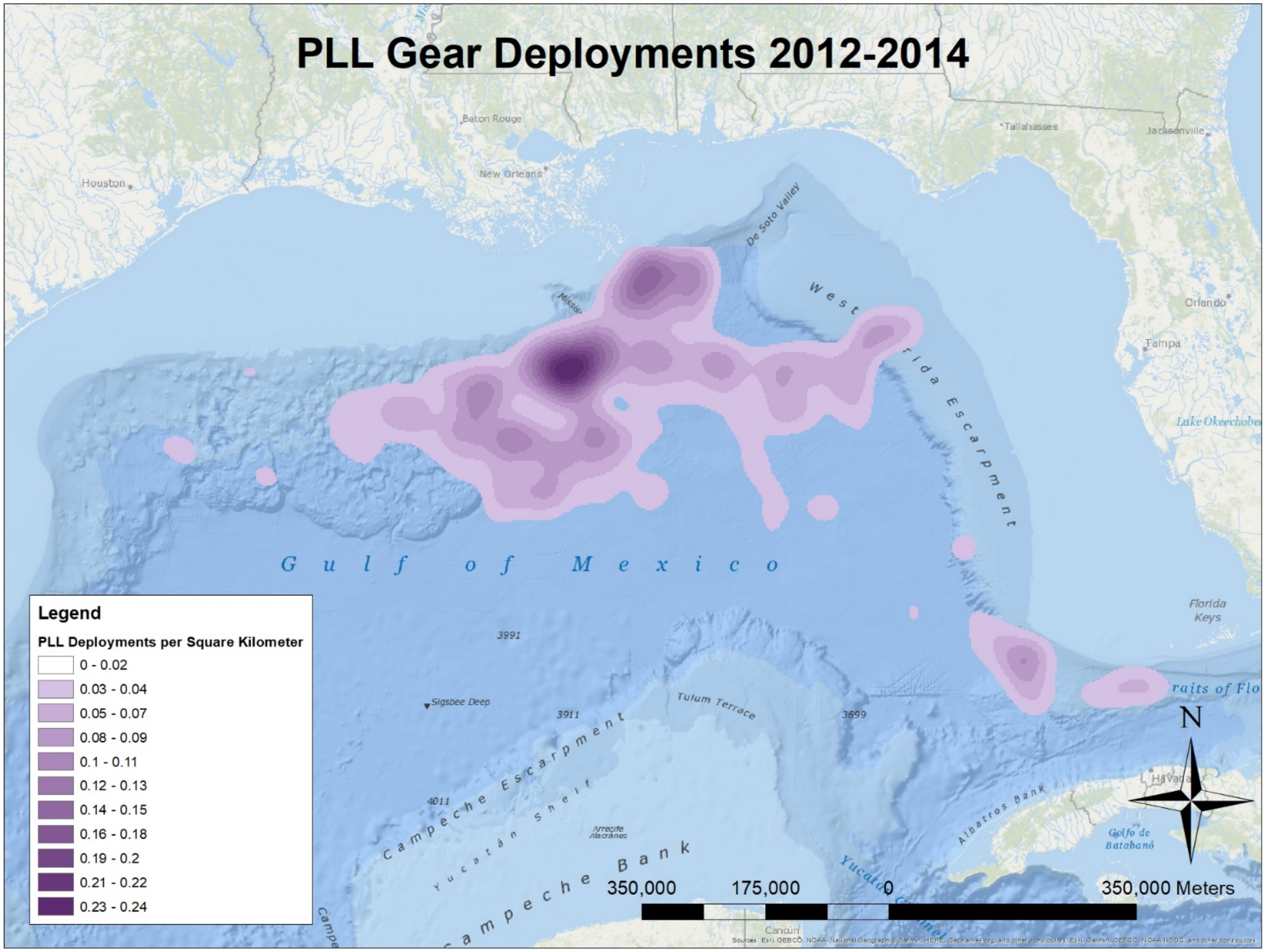

Figure 3: Deployment density of pelagic longline (PLL) gear in the Gulf of Mexico from 2012 – 2014. Data were gathered from vessels participating in the Pelagic Observer Program. Density is shown as number of deployments that occurred per square kilometer.

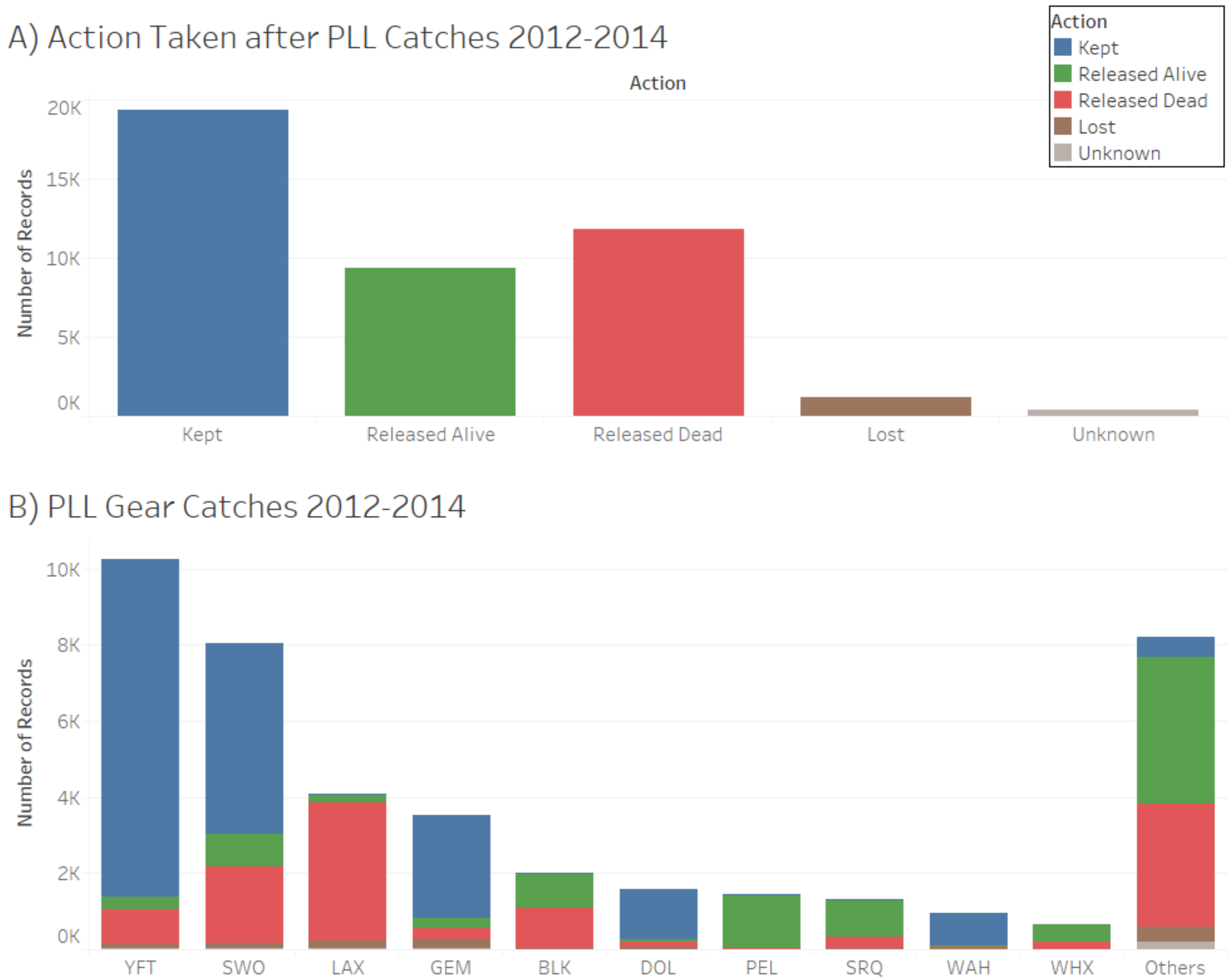

Figure 4: Catch composition of observed PLL deployments from 2012-2014. A) PLL action after catch: count of actions taken after a catch was made. B) PLL species composition: count of individuals caught categorized by species.

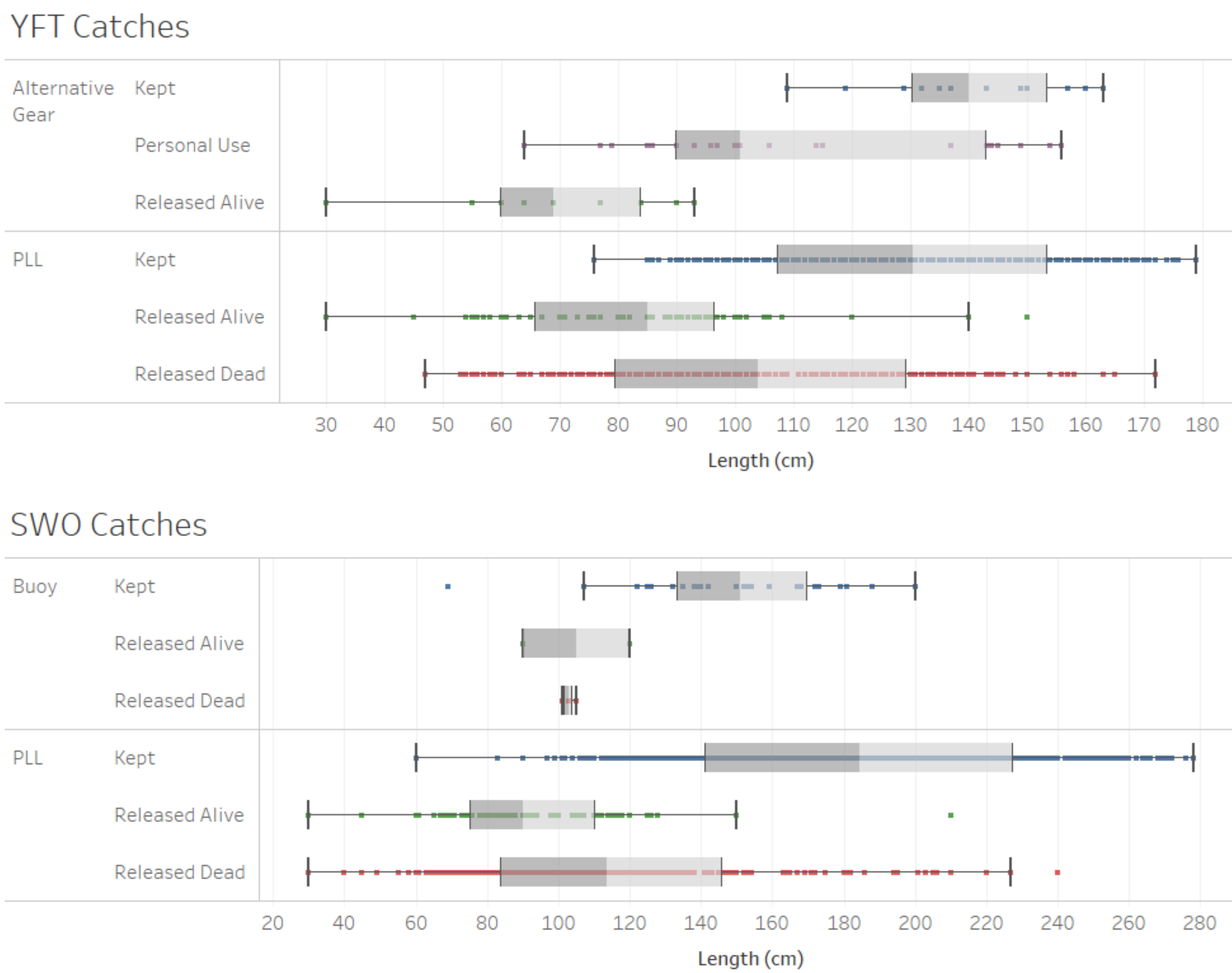

Figure 3: Length (cm) of swordfish and yellowfin tuna catches, categorized by gear type and action taken after catch. Data were gathered from observed PLL deployments from 2012-2014 and observed alternative gear deployments from 2017-2019.

Alternative Gear

Alternative gear was deployed off the Louisiana coast and the Florida Atlantic coast. Greenstick gear deployments were concentrated off the Louisiana coast while buoy gear was deployed in the De Soto Valley and off the Atlantic coast of Florida (Figure 4). During the repose periods (2017-2019), vessels using alternative gear caught 404 individual fish over the course of 64 trips (Table 3). Of these catches, greenstick gear made 288 catches, buoy gear made 94, and deep drop gear made 22. Trips using alternative gear caught a mean of 6.0 ± 7.6 fish per trip, of which a mean of 0.4 ± 0.7 were discarded per trip.

Yellowfin tuna were the most common species caught by greenstick gear (Figure 5B), while swordfish was the most common catch for buoy gear (Figure 5C). Mahi-mahi and blackfin tuna were the next most common species in greenstick catches, with mahi-mahi typically being kept as incidental catch and blackfin tuna typically being released alive (Figure 5B). For the buoy gear, sharks such as blacktip sharks (*Carcharhinus limbatus*) and hammerheads (*Sphyrna* spp.) were the most common catches after swordfish. The majority of shark catches on buoy gear were released alive (Figure 5C). Tilefish were the most commonly caught species by deep drop gear (Figure 5D). Catches kept for personal use or for sale together composed 41% of the observed catches over all alternative gear types. Over a third of all observed catches with alternative gears were live releases (Figure 5A). Only 23 dead discards were observed over the three repose periods, totaling 226 kg. Swordfish and lancetfish were the most common dead discard species. The most common live release species was yellowfin tuna.

Table 3: Catches of alternative gear in the first 6 months of the year from 2017 – 2019. Certain vessels used multiple alternative gear types in a single trip, resulting in the total number of alternative gear trips being lower than the sum of all trips by gear type. Kept catches include target species as well as incidental catch. Catches, dead discards, and live releases are given as counts and as biomass in kilograms (kg). Means are calculated with a standard deviation.

	Greenstick	**Buoy Gear**	**Deep Drop**	**All Alternative Gear**
Number of Observed Trips	52	19	16	64
Total Catches	288 (5,590 kg)	94 (4,318 kg)	22 (496 kg)	404 (10,404 kg)
Kept Catches	36 (1,506 kg)	31 (2,314 kg)	3 (7 kg)	70 (3,827 kg)
Dead Discards	11 (42 kg)	10 (182 kg)	2 (2 kg)	23 (226 kg)
Live Releases	121 (2,317 kg)	37 (1,627 kg)	1 (144 kg)	159 (4,089 kg)
Mean Total Catch per Trip	5.6 ± 7.6 (110 ± 174 kg)	5.2 ± 6.8 (240 ± 288 kg)	1.4 ± 3.2 (31 ± 55 kg)	6.0 ± 7.6 (162 ± 230 kg)
Mean Discards per Trip	0.2 ± 0.5 (0.8 ± 3.7 kg)	0.6 ± 1.0 (10.1 ± 38.5 kg)	0.1 ± 0.3 (0.1 ± 0.4 kg)	0.4 ± 0.7 (3.5 ± 20.7 kg)

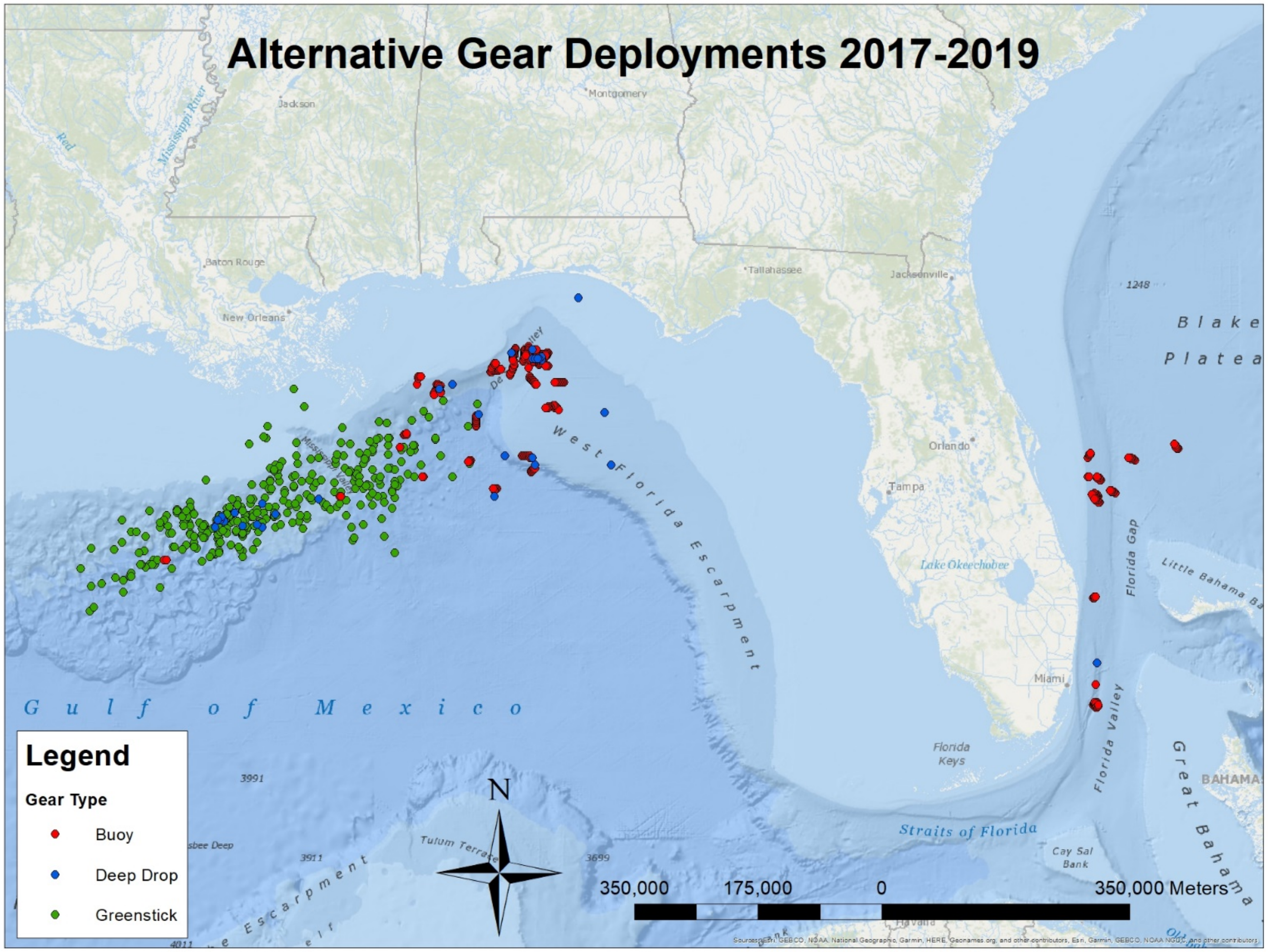

Figure 4: Deployments of alternative gear in the Gulf of Mexico from 2017 – 2019. Data were gathered from vessels participating in the OFRP repose with observers onboard.

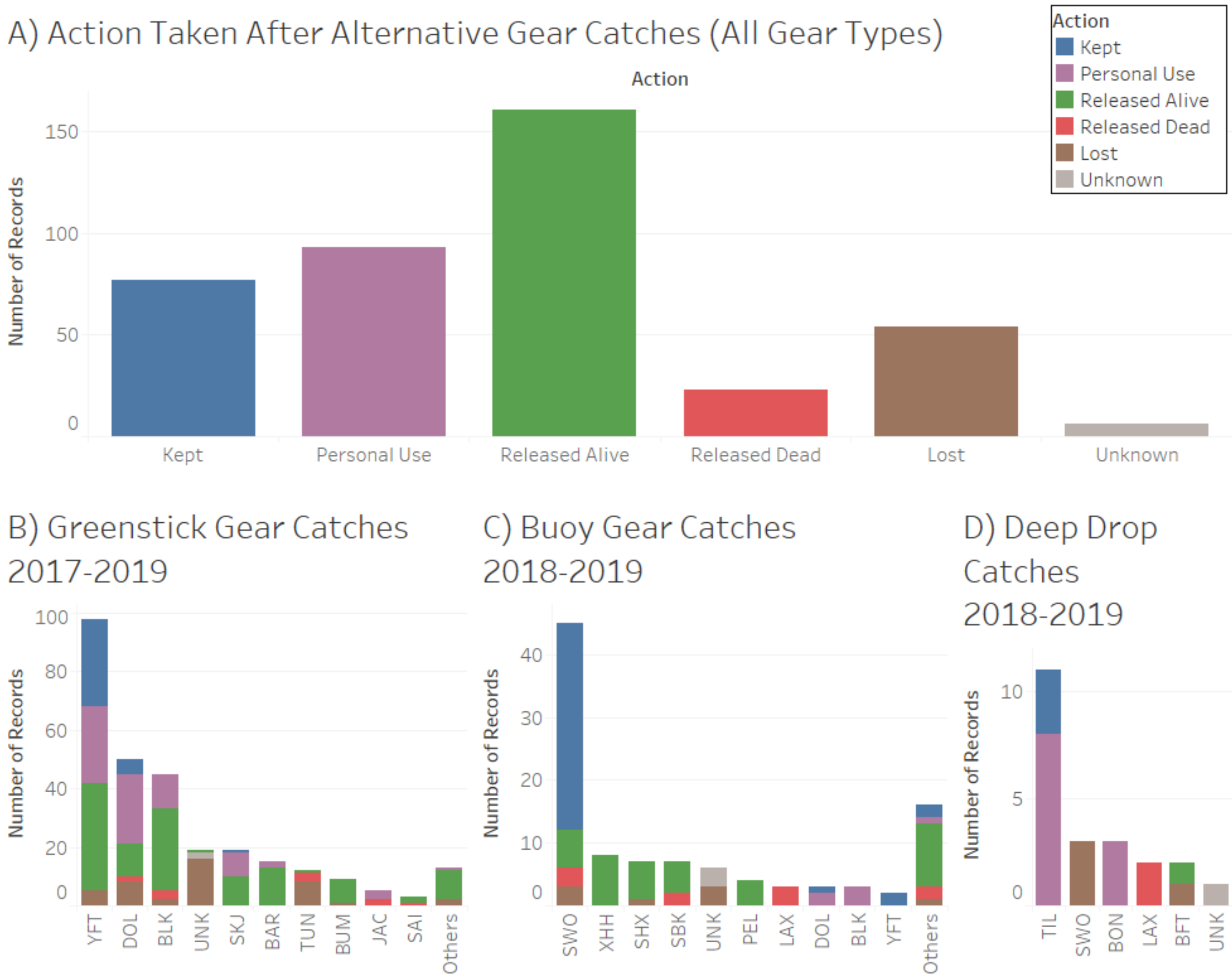

Figure 5: Catch composition of observed alternative gear deployments during the first 6 months of 2017-2019. A) Action after catch: count of actions taken after a catch was made. B) Count of species caught with greenstick gear. C) Count of species caught with buoy gear. D) Count of species caught with deep drop gear.

PLL and Alternative Gear Comparison

The GLMM model constructed to estimate the mean catch of PLL gear and alternative gear produced estimates made at a 95% confidence level (Table 4). The model estimated the mean total catch of a single PLL deployment as 23.87 individual fish (Lower CL: 22.38; Upper CL: 25.47). The mean catch of a single alternative gear deployment was estimated as 0.21 individual fish (Lower CL: 0.18; Upper CL: 0.24). The average PLL gear deployment in the baseline time period was found to have a 1.14 dead discard per live release ratio, while the average alternative gear deployment was found to have a 0.10 dead discard to live release ratio.

Table 4: Results of modeling the mean total catch count of a single PLL deployment versus a single deployment of alternative gear. Data were gathered from observed PLL deployments from 2012-2014 and observed alternative gear deployments from 2017-2019. Catch data were fitted to a zero inflated negative binomial GLMM. All estimates are made at a 95% confidence level [Lower Confidence interval; Upper Confidence interval].

Gear Type	Mean Total Catch	Mean Dead Discards	Mean Live Release	Dead Discard : Live Release Ratio
PLL	23.87 [22.38 ; 25.47]	6.30 [5.70 ; 7.00]	5.52 [4.94 ; 6.17]	1.14 [1.13 ; 1.15]
Alternative Gear	0.21 [0.18 ; 0.24]	0.01 [0.01 ; 0.02]	0.10 [0.08 ; 0.13]	0.13 [0.10 ; 0.15]

Catch Similarity of PLL and Alternative Gear

The similarity of catch composition between gear types was transformed into a Bray-Curtis similarity index. An analysis of similarity test determined that there is a significant difference in the similarity of catch composition in PLL gear and alternative gear (R= 0.669, p= 0.001). The similarity percentage test found that higher catch rates of yellowfin tuna, swordfish, lancetfish, and escolar with PLL gear drove the majority of the dissimilarity between the catches. Overall, the PLL catches showed a high level of dissimilarity to alternative gear catches, with the similarity percentage test showing a mean dissimilarity of 87.45 between the groups (Table 5).

Table 5: Catch composition comparison between PLL gear and alternative gear. Results are generated from a one-way similarity percentages test in PRIMER. The test was run on data gathered from the NOAA Pelagic Observer Program.

Species	PLL Average Abundance	Alternative Gear Average Abundance	Average Dissimilarity	Dissimilarity SD
Yellowfin Tuna	1.81	0.7	10.74	1.45
Swordfish	1.54	0.67	9.99	1.29
Lancetfish	1.15	0.04	7.25	1.07
Escolar	1.08	0.01	6.85	1.03
Mahi-mahi	0.59	0.51	5.65	0.76
Blackfin Tuna	0.64	0.31	4.94	0.75
Pelagic Stingray	0.55	0.03	3.46	0.63
Requiem Shark sp.	0.48	0.06	3.21	0.59
Wahoo	0.47	0.02	2.84	0.6
Skipjack Tuna	0.33	0.13	2.58	0.5
Unknown sp.	0.22	0.19	2.38	0.43
Blue Marlin	0.22	0.16	2.18	0.42

Gear Configuration and Environmental Effects on Alternative Gear Catches

Average observed greenstick gear configuration parameters are described in Table 6. Analysis of the effect of greenstick gear configuration on total catch frequency using a GAM (R^2= 0.178) determined that the most significant factors were bird width (p = 0.00854) and 9/0 hook size (p = 0.03688). A bird width of 35 cm and a 9/0 hook size were found to make a catch significantly more likely. An analysis of environmental factors on greenstick catches using a GAM (R^2=0.142) found that the tested environmental factors did not lead to a significant difference in catch likelihood. The GAM testing the effect of time of day on catch likelihood (R^2= 0.133) found that time of day had a significant (p=1.20e-05) effect. Greenstick gear that fished throughout the dawn hours were significantly more likely to make a catch versus gear that was only fishing during daylight hours.

Average buoy gear configuration parameters are described in Table 7. Running a GAM (R^2=0.0311) on the gear configuration in buoy gear found no significant effects on catch likelihood. The effect of light sticks and LEDs on catches was modeled in a GAM (R^2=0.0112, p= 0.024) which found that the use of LEDs had a significant effect on increasing catch likelihood in buoy gear. However, the low R^2 value of the model suggests that other factors are also influencing the variability of catch likelihood.

Environmental factors were modeled in a GAM (R^2=0.0238) which found that environmental factors did not significantly affect the likelihood of buoy gear making a catch. A GAM modeling the effect of time of day (R^2=0.00774) found no significant effect (p= 0.0663) on catch likelihood between nighttime fishing and daytime fishing.

Table 6: Average set parameters for observed vessels using greenstick gear during the repose periods from 2017-2019. Calculated means are given with standard deviation.

Mean Mainline Diameter (mm)	3.2 ± 0.28	**Mean Gangion 2 Length (Feet)**	35.67 ± 9.10
Mean Bird Length (cm)	121.07 ± 5.71	**Mean Bird Height (cm)**	17.43 ± 5.57
Mean Gangion Diameter (mm)	2.11 ± 0.27	**Mode Mainline Test (lbs)**	800
Mean Bird Width (cm)	31.70 ± 8.92	**Mode Hook Size**	9/0
Mean Gangion 1 Length (Feet)	6.52 ± 2.84	**Mode Gangion Test (lbs)**	400

Table 7: Average set parameters for observed vessels using buoy gear during the repose periods from 2017-2019. Calculated means are given with standard deviation.

Mean Mainline Diameter (mm)	2.88 ± 0.78	**Mean Gangion Length (Feet)**	217.47 ± 412.22	**Mode Leader Test (lbs)**	300
Mean Leader Length (Inches)	1430.82 ± 814.73	**Mode Hook Size**	9/0	**Percentage using Light Sticks**	65%
Mean Leader Diameter (mm)	1.88 ± 0.10	**Mode Mainline Test (lbs)**	300	**Percentage using LED's**	55%
Mean Gangion Diameter (mm)	2.36 ± 0.76	**Mode Gangion Test (lbs)**	300		

Estimating Avoided Catch During Repose Periods

A PLL vessel on average deploys an estimated 31,813 ± 18,234 hooks in the first 6 months of a typical year. This number was adjusted to 15,907 hooks in an average quarter (3 months). Across all repose periods, 23,259 individual catches (459,247 dkg) including 7,026 (62,286 dkg) of dead discard were avoided (Table 8). A greater number of total catch and dead discards were avoided in the 2018 and 2019 repose periods, due to their longer duration (Figure 6). The amount of total catch and dead discards avoided per vessel exceeded expectations every year, even during the shortened 2017 season (Table 9). Avoided catches and dead discards were estimated for yellowfin tuna, swordfish, lancetfish, and blackfin tuna in terms of counts (Table 10) and discounted kilograms of biomass (Table 11). Yellowfin tuna had the highest number of avoided catches, with 5,317 tuna avoiding being caught across all repose periods (Figure 7). Yellowfin tuna also contributed the most to the overall biomass of the avoided catch, with 234,244 dkg of tuna avoiding being caught across all repose periods (Figure 8). Lancetfish had the highest number of avoided dead discards at 2,141 individual fish across all repose periods (Figure 9). Swordfish, with 18,583 dkg of avoided discards across all repose periods, contributed the most to the biomass of avoided dead discards (Figure 10).

Table 8: Results of GLMM's estimating total catch avoided and avoided dead discards during the 2017, 2018, and 2019 repose periods. Estimates are given in counts of individual fish and in terms of discounted kilograms of biomass (dkg). All estimates are made with lower and upper confidence intervals at a 95% confidence level.

Year	Total Catch Avoided (counts)	Total Catch Avoided (dkg)	Avoided Dead Discards (count)	Avoided Dead Discards (dkg)
2017	4,765 [4,279 ; 5,308]	91,398 [58,844 ; 142,020]	1,459 [1,278 ; 1,665]	13,174 [8,145 ; 21,309]
2018	9,247 [8,242 ; 10,376]	186,643 [118,194 ; 296,028]	2,784 [2,409 ; 3,218]	24,919 [15,224 ; 40,891]
2019	9,247 [8,242 ; 10,376]	181,206 [114,751 ; 287,406]	2,784 [2,409 ; 3,218]	24,193 [14,781 ; 39,700]
Total	23,259 [20,762 ; 26,059]	459,247 [291,789 ; 725,455]	7,026 [6,096 ; 8,100]	62,286 [38,150 ; 101,900]

Table 9: Estimates of total catch avoided and avoided dead discards during the 2017, 2018, and 2019 repose periods per individual vessel. Estimates are given in counts of individual fish and in terms of discounted kilograms of biomass (dkg). All estimates are made with lower and upper confidence intervals at a 95% confidence level.

Year	Total Catch Avoided (count)	Total Catch Avoided (dkg)	Avoided Discards (count)	Avoided Discards (dkg)
2017	681 [611 ; 758]	13,057 [8,406 ; 20,289]	208 [183 ; 238]	1,882 [1,164 ; 3,044]
2018	925 [824 ; 1,038]	18,664 [11,819 ; 29,603]	278 [241 ; 322]	2,492 [1,522 ; 4,089]
2019	925 [824 ; 1,038]	18,121 [11,475 ; 28,741]	278 [241 ; 322]	2,419 [1,478 ; 3,970]

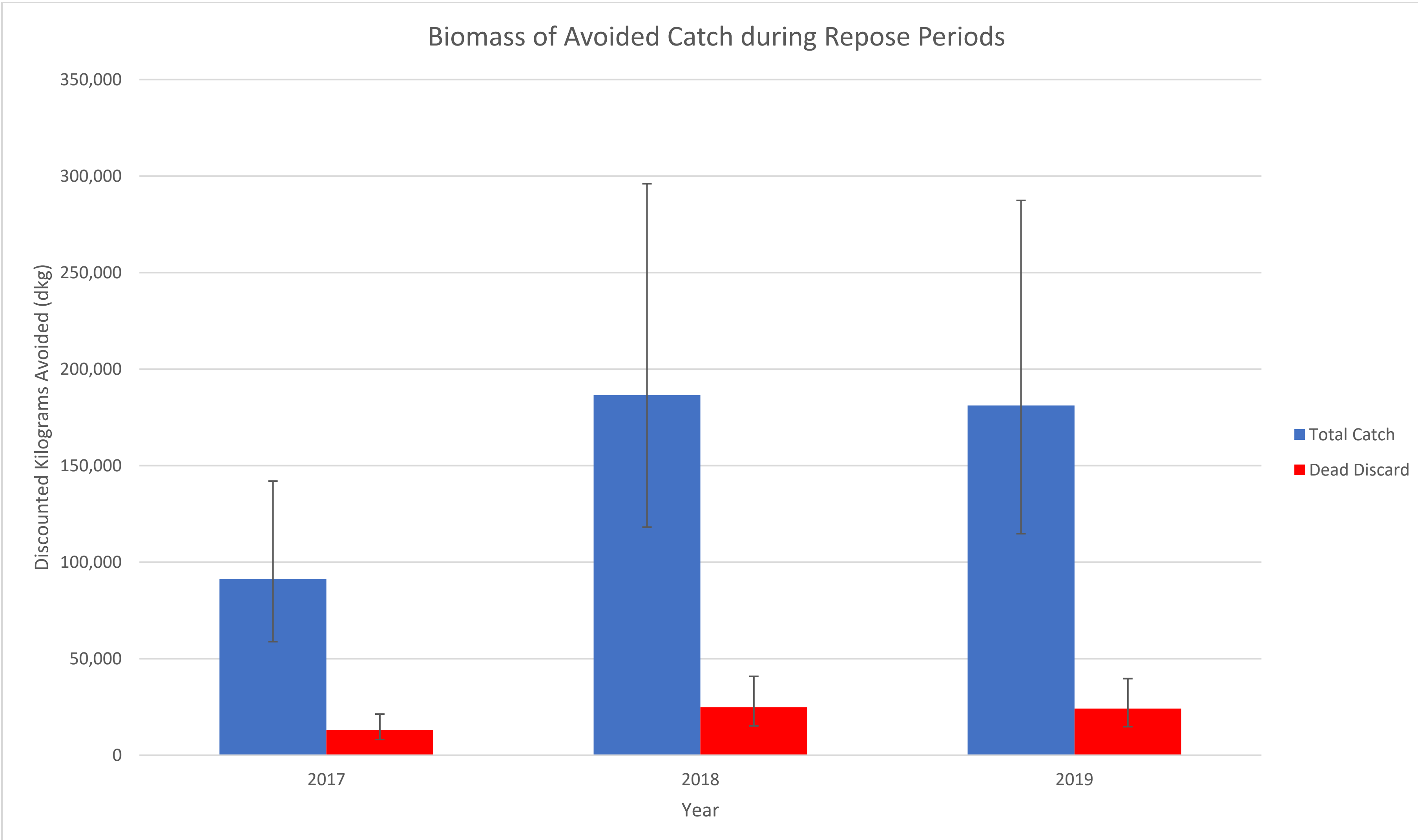

Figure 6: Estimation of total catch avoided and avoided dead discards in the GOM PLL fishery during each repose period in terms of discounted kilograms of biomass (dkg). Error bars represent the upper and lower confidence intervals at a 95% confidence level.

Table 10: Estimated number of total catches and dead discards avoided within selected species during the 2017, 2018 and 2019 GOM PLL repose periods. Estimates are given in counts of individual fish. Upper and lower confidence intervals are made at a 95% confidence level.

Action	Year	Yellowfin Tuna	Swordfish	Lancetfish	Blackfin Tuna
Total Catch	2017	1,144 [944 ; 1,388]	1,083 [854 ; 1,372]	427 [327 ; 558]	194 [133 ; 283]
	2018	2,086 [1,693 ; 2,571]	2,115 [1,634 ; 2,740]	1,019 [756 ; 1,376]	352 [233 ; 534]
	2019	2,086 [1,693 ; 2,571]	2,115 [1,634 ; 2,740]	1,019 [756 ; 1,376]	352 [233 ; 534]
	Total	5,317 [4,330 ; 6,530]	5,313 [4,122 ; 6,852]	2,465 [1,839 ; 3,310]	898 [599 ; 1,351]
Dead Discard	2017	105 [76 ; 146]	353 [257 ; 484]	377 [286 ; 498]	107 [74 ; 156]
	2018	168 [118 ; 241]	660 [468 ; 933]	882 [648 ; 1,203]	184 [123 ; 277]
	2019	168 [118 ; 241]	660 [468 ; 933]	882 [648 ; 1,203]	184 [123 ; 277]
	Total	441 [312 ; 628]	1,673 [1,193 ; 2,350]	2,141 [1,582 ; 2,904]	475 [320 ; 710]

Table 11: Estimated biomass of total catches and dead discards avoided within selected species during the 2017, 2018 and 2019 GOM PLL repose periods. Estimates are given in terms of discounted kilograms of biomass (dkg). Upper and lower confidence intervals are made at a 95% confidence level.

Action	Year	Yellowfin Tuna	Swordfish	Lancetfish	Blackfin Tuna
Total Catch	2017	49,769 [43,870 ; 55,670]	35,739 [27,488 ; 43,991]	743 [563 ; 924]	1,834 [1,311 ; 2,356]
	2018	93,600 [84,514 ; 102,686]	76,980 [64,203 ; 89757]	1,563 [1,286 ; 1,840]	3,232 [2,426 ; 4,037]
	2019	90,874 [82,053 ; 99,695]	74,738 [62,333 ; 87,143]	1,518 [1,248 ; 1,787]	3,138 [2,355 ; 3,919]
	Total	234,244 [210,436 ; 258,050]	187,457 [154,024 ; 220,891]	3,824 [3,098 ; 4,550]	8,203 [6,092 ; 10,313]
Dead Discard	2017	1,190 [906 ; 1,473]	3,759 [29,409 ; 4,507]	671 [496 ; 846]	991 [739 ; 1,244]
	2018	2,214 [1,777 ; 2,651]	7,521 [6,264 ; 8,779]	1,435 [1,165 ; 1,705]	1,767 [1,378 ; 2,156]
	2019	2,149 [1,725 ; 2,574]	7,302 [6,082 ; 8,523]	1,393 [1,131 ; 1,655]	1,716 [1,338 ; 2,093]
	Total	5,552 [4,408 ; 6,697]	18,583 [41,754 ; 21,809]	3,499 [2,792 ; 4,207]	4,475 [3,456 ; 5,493]

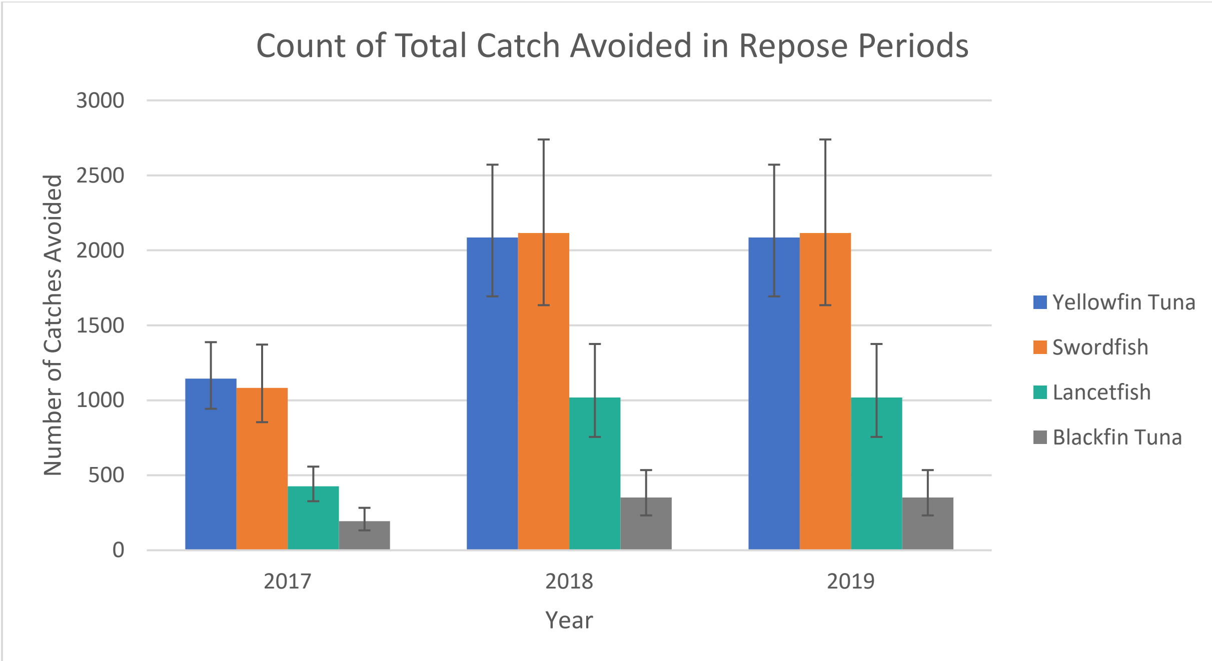

Figure 7: Count of total catch avoided within selected species during the 2017, 2018 and 2019 GOM PLL repose periods. Error bars represent the upper and lower confidence intervals at a 95% confidence level.

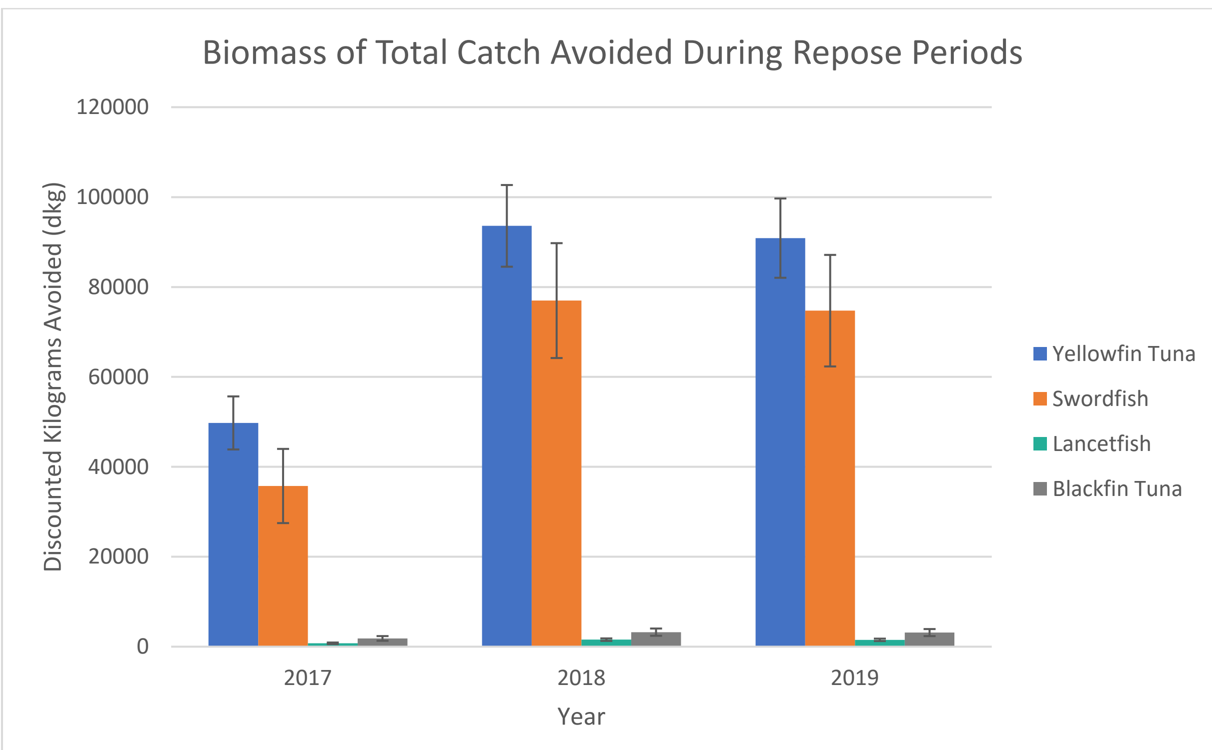

Figure 8: Discounted kilograms of biomass of total catches avoided within selected species during the 2017, 2018 and 2019 GOM PLL repose periods. Error bars represent the upper and lower confidence intervals at a 95% confidence level.

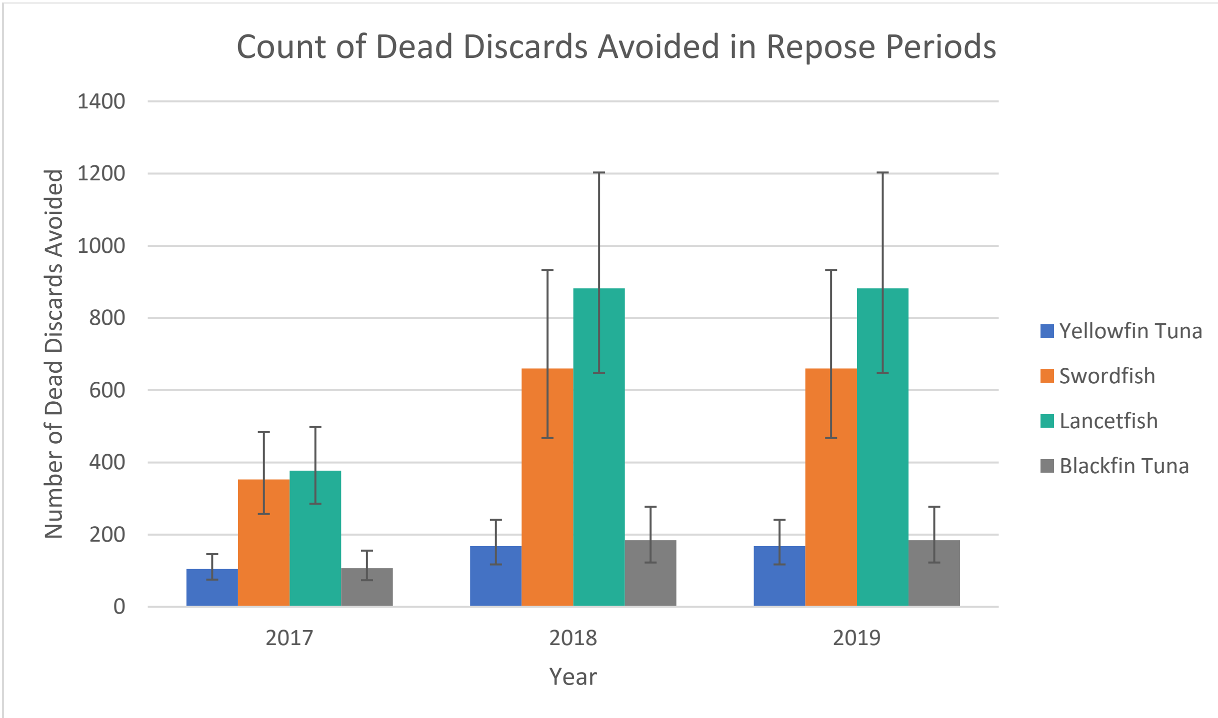

Figure 9: Count of dead discards avoided within selected species during the 2017, 2018 and 2019 GOM PLL repose periods. Error bars represent the upper and lower confidence intervals at a 95% confidence level.

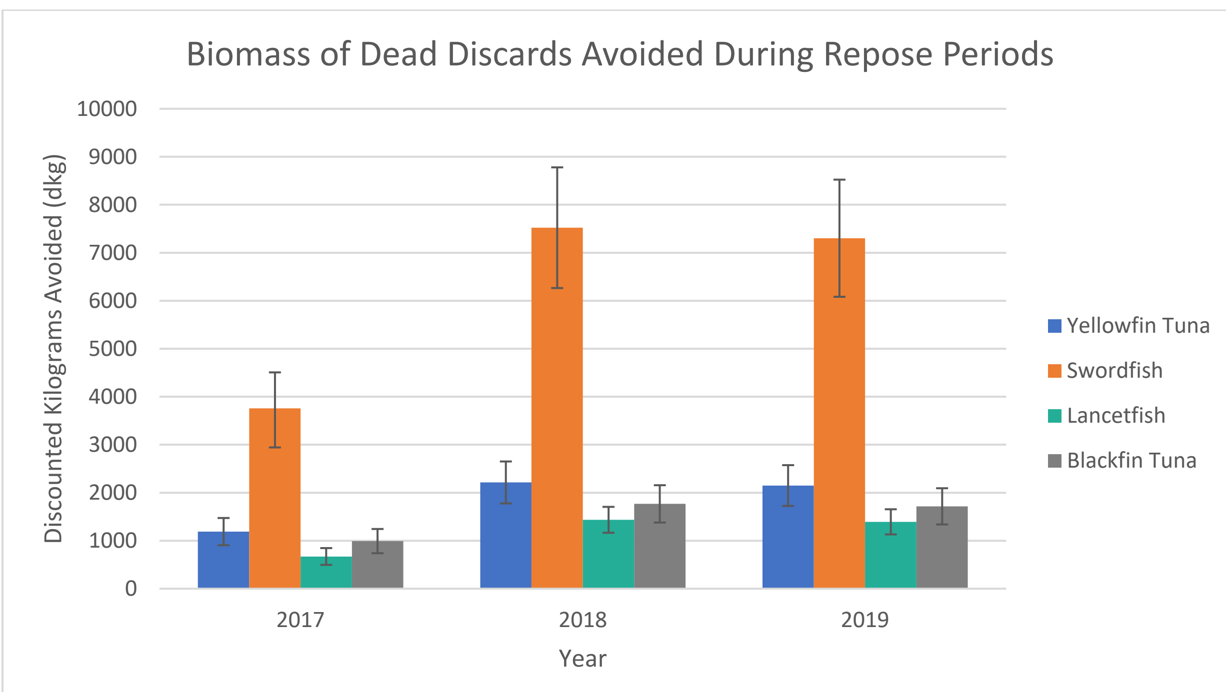

Figure 10: Discounted kilograms of biomass of dead discards avoided within selected species during the 2017, 2018 and 2019 GOM PLL repose periods. Error bars represent the upper and lower confidence intervals at a 95% confidence level.

Discussion:

The Gulf of Mexico PLL fishery interacts with many species, with over half of observed catches occurring on non-target species. Many pelagic fish outside of the fishery's target species stand to benefit from the restoration as implemented by the OFRP. The pelagic fish that interact with the GOM PLL fishery occupy a variety of ecological niches. Many epipelagic species, such as albacore (*Thunnus alalunga*) and yellowfin tuna, have extensive ranges and form connections between ecosystems across their range (Young et al. 2010). Other species, such as swordfish and bigeye tuna, feed at depth and act as a trophic link between the epipelagic and mesopelagic zones (Duffy et al. 2017). Species of little commercial importance, such as lancetfish and skipjack tuna (*Katsuwonus pelamis*) have been identified as keystone species in pelagic food webs (Dambacher et al. 2010). Lancetfish are of special ecological importance because of the large number of species they interact with due to their varied diet and vertical movement between the epipelagic and mesopelagic zones (Portner et al. 2017). A number of species of ecological importance, but little commercial value, were found to have high mortality within the observed PLL dataset. Skipjack tuna were found to have a dead discard to live release ratio of 9.30, while lancetfish had an even higher ratio of 15.98 (Appendix 2, Table 13). Considering the scale of the GOM PLL fishery, a reduction of the number of dead discards should be an effective tool in the restoration of species with high mortality. Commercial and non-commercial species alike occupy ecologically important niches within the pelagic food web, and their restoration is crucial to the health of the Gulf of Mexico ecosystem.

Vessels participating in the OFRP were successful in utilizing alternative fishing gear during repose periods. However, these alternative gear types are not competitive with PLL gear in the number of target catches. Alternative gear across all types was found to have a fraction of the catch rate observed with PLL gear. Despite the lower overall catch rates, alternative gear was found to be highly successful in converting dead discards into live releases. Modeling found that the average PLL gear deployment produced 1.14 dead discards for every live release, while alternative gear produced only 0.13 dead discards for every live release. The dead discard rate associated with alternative gear is minimal, allowing those vessels participating in repose periods to continue fishing activity without contributing to mortality in bycatch species.

Similarity tests of the catch composition showed that alternative gear was less likely to catch bycatch species such as lancetfish and blackfin tuna; however, they were also less likely to catch species with commercial value. Lower catches of yellowfin tuna and swordfish were the largest sources of dissimilarity between the catches of PLL gear and alternative gear. The dissimilarity in catch composition may be more of a reflection of alternative gear being less likely to make a catch across all species.

Further research is required to investigate how to best maximize the effectiveness of the alternative gear types. Results of the modeling suggest that the effect of environmental factors were not significant in greenstick gear or buoy gear. While the gear configuration in buoy gear was not found to be significant, the use of LED lights was found to increase catch likelihood. Gear configuration was more important in greenstick gear, where hook size and bird width were significant factors in increasing the likelihood of a catch. Time of day was found to have a significant effect on catch likelihood in greenstick gear when fished during the dawn compared to gear fishing during the daylight hours. Yellowfin tuna, which is the target catch of greenstick trolls, are more likely to be feeding during the crepuscular dawn and dusk hours (Buckley & Miller 1994). Active foraging may make the fish more likely to interact with the greenstick gear. Time of day was not found to have a significant effect on buoy gear catches.

Repose periods (2017-2019) were found to be successful in reducing fishing pressure and avoiding dead discards. Throughout the duration of the OFRP thousands of individual fish were prevented from being removed from the Gulf of Mexico ecosystem, and the production of a significant amount of dead discard biomass was avoided. Large numbers of commercially important swordfish and yellowfin tuna, as well as several bycatch species, avoided becoming dead discards due to the implementation of the repose periods. The higher number of vessels, as well as the extended time period, led to higher levels of avoided catch in the 2018 and 2019 repose years as compared to the 2017 pilot year.

Conclusions:

The OFRP has been successful in reducing fishing pressure on pelagic fish species and avoiding bycatch mortality in the GOM PLL fishery. The combination of repose periods and the implementation of alternative gear allows for large numbers of both commercial and non-commercial species to continue breeding in the Gulf of Mexico, encouraging the restoration of pelagic fish populations. Although alternative gear was found to have lower catch rates than PLL gear, they were found to be extremely effective at reducing dead discards. With a dead discard to live release ratio of 0.13, dead discards are minimized through the use of alternative gear. An estimated 23,259 individual fish (459,247 dkg) avoided being caught through the implementation of the three repose periods. Of these fish, 7,026 or

62,286 dkg of dead discards were avoided across all repose periods. In the 2017 repose, 13,057 dkg of total catch was avoided per vessel. In the 2018 repose 18,664 dkg of total catch was avoided and in 2019, 18,121 dkg of catch was avoided per vessel. Initial estimates in the OFRP monitoring plan (Deepwater Horizon Oil Spill Natural Resource Damage Assessment, 2015) set a goal for 11,600 dkg of dead discard avoided per vessel. Each of the repose periods exceeds this amount of avoided biomass removed from the ecosystem when looking at the biomass of total catch avoided per vessel. The addition of more vessels volunteering to take part in the OFRP will only serve to further the benefits produced by the project, and lead to a healthier Gulf of Mexico ecosystem.

Appendix 1:

Table 12: Species Length/Weight Formulas. W = mass in kilograms, L = standard length, TL = total length

Species Code	Length/Weight Formula	Source
ALB	W = 2.60E-05*(L^2.95)	Curran & Bigelow (2016)
AMJ	W= 3.67659E-05*(L^2.79692)	Uchiyama & Kazama (2003)
BAR	W = 9.80E-06*(L^2.88)	Curran & Bigelow (2016)
BET	W = 3.51E-05*(L^2.91)	Curran & Bigelow (2016)
BFT	W = 4.94E-05*(L^2.8094)	Rodriguez-Marin et al. (2015)
BIL	W = 1.30E-05*(L^3.07)	Curran & Bigelow (2016)
BLK	W = 0.053*L*2.765	Tagliafico et. al (2015)
BLU	W = 9.1E-06*(TL^3.012)	Morato et al. (2000)
BON	W = 1.76E-05*(TL^2.877)	Morato et al. (2000)
BSH	W= 1.82E-06*(L^3.13)	Curran & Bigelow (2016)
BTH	W = 9.10E-06*(L^3.08)	Curran & Bigelow (2016)
BUM	W = 2.72E-06*(L^3.31)	Curran & Bigelow (2016)
CUB	W = 9.0E-06*(L^3.09)	Froese, R. & D. Pauly, Fishbase.org
DEA	W = 6.01E-06*(L^2.76)	Curran & Bigelow (2016)
DOL	W = 3.69E-06*(L^3.17)	Curran & Bigelow (2016)
DUS	W = 3.24E-05*(L^2.786)	Froese, R. & D. Pauly, Fishbase.org
FAL	W = 1.90E-05*(L^2.93)	Curran & Bigelow (2016)
FRM	W = 8.9E-06*(L^3.17)	Froese, R. & D. Pauly, Fishbase.org
GEM	W = 1.18E-05*(L^3.00)	Curran & Bigelow (2016)
GHH	W = 1.91E-06*(L^3.16)	Froese, R. & D. Pauly, Fishbase.org
JAC	W= 1.48E -05*(L^2.94)	Froese, R. & D. Pauly, Fishbase.org
KGM	W = 1.5E-05*(L^2.893)	Froese, R. & D. Pauly, Fishbase.org
LAX	W = 2.239E-07*(TL^3.358)	Keller & Kerstetter (2014)
LMA	W = 1.12E-05*((L/0.91)^2.93)	Curran & Bigelow (2016)
LTA	W = 3.1E-05*(L^2.815)	Hajjej et al. (2011)
MAN	W = 1.64E-05*(L^3)	Froese, R. & D. Pauly, Fishbase.org
MOC	W = 4.54E-05*(L^3.05)	Curran & Bigelow (2016)
MOX	W = 4.54E-05*(L^3.05)	Curran & Bigelow (2016)
MST	W = 9.9E-04*(L^2.45)	Froese, R. & D. Pauly, Fishbase.org
OCS	W = 1.70E-05*(L^2.98)	Curran & Bigelow (2016)
OIL	W = 9.60E-06*((L/0.95)^3)	Curran & Bigelow (2016)
OPA	W = 1.16E-04*(L^2.73)	Curran & Bigelow (2016)
PEL	W = 2.73E-05*(L^2.95)	Curran & Bigelow (2016)
POA	W = 2.60E-05*(L^2.9)	Curran & Bigelow (2016)
PTH	W = 9.10E-06*(L^3.08)	Curran & Bigelow (2016)
REM	W = 4.18E-06*(L^3)	Froese, R. & D. Pauly, Fishbase.org
SAI	W = 1.2869E-06*(L^3.2439)	Prager et al. (1995)
SAS	W = 7.62E-05*(L^2.62)	Froese, R. & D. Pauly, Fishbase.org

SBK	W = 1.44E-05*(L^2.87)	Froese, R. & D. Pauly, Fishbase.org
SBU	W = 1.75E-05*(L^2.84)	Froese, R. & D. Pauly, Fishbase.org
SDG	W = 3.2E-06*(L^3.07)	Froese, R. & D. Pauly, Fishbase.org
SHH	W = 7.80E-06*(L^3.07)	Curran & Bigelow (2016)
SHX	W = 9.10E-06*(L^3.08)	Curran & Bigelow (2016)
SKJ	W = 4.82E-06*(L^3.37)	Curran & Bigelow (2016)
SMA	W = 1.12E-05*(L^2.93)	Curran & Bigelow (2016)
SNI	W = 2.92E-06*(L^3.247)	Froese, R. & D. Pauly, Fishbase.org
SPF	W = 4.42E-06*(L^3)	Froese, R. & D. Pauly, Fishbase.org
SPL	W = 7.80E-06*(L^3.07)	Froese, R. & D. Pauly, Fishbase.org
SPX	W = 4.42E-06*(L^3)	Froese, R. & D. Pauly, Fishbase.org
SRQ	W = 9.10E-06*(L^3.08)	Curran & Bigelow (2016)
SRX	W = 2.73E-05*(L^2.95)	Curran & Bigelow (2016)
SSB	W = 3.13E-06*(L^3.17)	Curran & Bigelow (2016)
SSP	W = 7.51E-06*(L^2.97)	Froese, R. & D. Pauly, Fishbase.org
SWO	W = 1.30E-05*(L^3.07)	Curran & Bigelow (2016)
TIG	W = 2.53E-06*(L^3.26)	Curran & Bigelow (2016)
TIL	W = 1.38E-05*(L^2.95)	Froese, R. & D. Pauly, Fishbase.org
TRX	W = 5E-07*(L^3.14)	Froese, R. & D. Pauly, Fishbase.org
TUN	W = 2.60E-05*(L^2.95)	Curran & Bigelow (2016)
WAH	W = 1.35E-06*(L^3.31)	Curran & Bigelow (2016)
WHM	W = 5.2068E-06*(L^3.0120)	Prager et al. (1995)
WHX	W = 5.2068E-06*(L^3.0120)	Prager et al. (1995)
XHH	W = 7.80E-06*(L^3.07)	Curran & Bigelow (2016)
XMA	W = 1.12E-05*((L/0.91)^2.93)	Curran & Bigelow (2016)
XTH	W = 9.10E-06*(L^3.08)	Curran & Bigelow (2016)
YFT	W = 1.48E-05*(L^3.06)	Curran & Bigelow (2016)

Appendix 2:

Table 13: Catches of POP PLL vessels in the Gulf of Mexico from 2012 – 2014. Biomass was calculated in kilograms (kg). Calculations do not include individual fish that were lost on the line, or individuals from which a length measurement was unable to be recorded. Biomass was not calculated for marine mammals, sea turtles, or seabirds.

Species	Total (count)	Total (kg)	Kept (count)	Kept (kg)	Dead Discard (count)	Dead Discard (kg)	Live Release (count)	Live Release (kg)	Dead:Live Release Ratio
ALB	262	6841	174	4906	51	1027	35	855	1.46
AMJ	7	110	0	0	5	60	2	50	2.50
BAR	172	988	7	53	21	114	140	802	0.15
BET	169	6984	107	5717	42	655	16	309	2.63
BFT	311	65003	51	12832	154	31011	79	15142	1.95
BIL	344	20944	1	13	112	5966	208	13747	0.54
BLK	2006	19010	41	421	1068	9927	872	8464	1.22
BLR	1	NA	0	0	1	NA	0	0	
BLU	2	3	0	0	2	3	0	0	
BON	11	30	0	0	3	8	8	21	0.38
BSH	28	702	0	0	1	34	26	635	0.04
BTH	97	14070	0	0	35	3916	62	10154	0.56
BUM	340	48830	1	79	86	13716	246	34302	0.35
CBA	1	NA	1	NA	0	0	0	0	
CUB	55	421	0	0	31	226	22	172	1.41
DEA	8	85	1	9	4	51	3	26	1.33
DOL	1598	14690	1338	13271	116	512	74	234	1.57
DUS	40	3072	0	0	9	306	31	2766	0.29
FAL	458	14657	0	0	205	5023	253	9634	0.81
GEM	3526	35481	2711	30288	280	1266	260	1473	1.08
GHH	31	1616	0	0	13	650	18	966	0.72
GLA	2	NA	0	0	2	NA	0	0	
JAC	11	62	0	0	2	9	9	53	0.22
KGM	15	135	0	0	15	135	0	0	
LAX	4078	8465	6	12	3612	7459	226	538	15.98
LMA	41	4332	0	0	20	2414	20	1883	1.00
LOU	1	NA	1	NA	0	0	0	0	
LTA	379	1668	1	12	330	1430	45	205	7.33
MAN	48	11222	0	0	2	261	45	9789	0.04
MBD	1	NA	0	0	0	0	1	NA	0.00
MDO	2	NA	0	0	0	0	2	NA	0.00
MFI	1	NA	0	0	0	0	0	0	
MOC	39	9189	0	0	1	310	38	8879	0.03
MOX	109	37189	1	343	2	394	104	36352	0.02

MPD	4	NA	0	0	0	0	4	NA	0.00
MPW	2	NA	0	0	0	0	1	NA	0.00
MRD	2	NA	0	0	0	0	2	NA	0.00
MST	144	38295	0	0	2	969	141	37114	0.01
OCS	20	869	0	0	3	69	16	749	0.19
OIL	250	1483	39	377	76	189	130	900	0.58
OPA	4	143	0	0	4	143	0	0	
PBR	1	NA	0	0	0	0	1	0	0.00
PEL	1465	7618	2	21	33	163	1420	7395	0.02
PJA	1	NA	0	0	1	NA	0	0	
POA	523	2409	6	27	249	1143	261	1202	0.95
POR	1	NA	0	0	1	0	0	0	
PSW	1	NA	0	0	0	0	1	0	0.00
PTH	10	1472	1	11	2	600	7	861	0.29
PUX	26	NA	0	0	9	0	17	0	0.53
REM	5	10	0	0	1	3	4	7	0.25
RTD	2	NA	0	0	0	0	2	NA	0.00
SAI	395	5834	0	0	186	2926	206	2880	0.90
SAS	9	16	0	0	6	8	3	8	2.00
SBG	1	NA	0	0	0	0	1	0	0.00
SBK	4	57	0	0	2	8	2	49	1.00
SBU	17	1401	0	0	3	503	14	898	0.21
SHX	522	51371	1	80	129	5244	357	42639	0.36
SKJ	633	5017	34	248	530	4173	57	513	9.30
SMA	286	11601	101	5154	41	1199	127	4403	0.32
SNI	69	2021	0	0	42	1292	27	728	1.56
SPF	3	65	0	0	3	65	0	0	
SPL	357	19733	0	0	195	10353	162	9381	1.20
SPX	12	149	0	0	6	56	6	94	1.00
SRQ	1317	85304	2	90	299	12941	992	70420	0.30
SRX	3	NA	0	0	0	0	2	0	0.00
SSB	76	2686	0	0	16	564	60	2122	0.27
SSP	11	174	0	0	8	156	3	17	2.67
SWO	8034	433746	5001	376657	2021	33887	859	14906	2.35
TAR	1	NA	0	0	0	0	1	0	0.00
TIG	377	58697	1	57	20	4186	354	53949	0.06
TIL	2	6	0	0	2	6	0	0	
TLB	107	NA	0	0	2	NA	90	NA	0.02
TPL	1	NA	0	0	0	0	0	0	
TRX	41	31	0	0	31	24	10	8	3.10
TTL	13	NA	0	0	0	0	12	0	0.00
TUN	459	1888	0	0	325	571	120	983	2.71
UNC	3	NA	0	0	1	NA	1	NA	1.00

UNK	424	NA	0	0	11	NA	15	NA	0.73
WAH	966	25831	872	25343	73	269	4	35	18.25
WHM	120	2331	0	0	90	1818	30	513	3.00
WHX	654	12475	0	0	171	3138	471	9037	0.36
XHH	181	11773	0	0	45	2683	135	9024	0.33
XMA	37	5195	0	0	11	2766	23	2116	0.48
XTH	74	9750	0	0	22	1923	52	7827	0.42
YFT	10272	475694	8877	454675	908	9953	348	4437	2.61

Table 14: Catches of observed vessels using greenstick gear, 2017-2019. Biomass was calculated in kilograms (kg). Calculations do not include individual fish that were lost on the line, or individuals from which a length measurement was unable to be recorded.

Species	Total (count)	Total (kg)	Kept (count)	Kept (kg)	Pers. Use (count)	Pers. Use (kg)	Dead Discard (count)	Dead Discard (kg)	Live Release (count)	Live Release (kg)	Dead:Live Release Ratio
ALB	2	10	0	0	0	0	0	0	2	10	0.00
BAR	15	93	0	0	2	11	0	0	13	82	0.00
BFT	1	165	0	0	0	0	0	0	1	165	0.00
BLK	45	360	0	0	12	105	3	0	28	242	0.11
BUM	9	1329	0	0	0	0	0	0	8	1250	0.00
DOL	50	157	5	7	24	103	2	3	11	19	0.18
FAL	1	23	0	0	0	0	0	0	1	23	0.00
JAC	5	19	0	0	3	3	2	16	0	0	
SAI	3	45	0	0	0	0	1	23	2	22	0.50
SHX	1	46	0	0	0	0	0	0	0	0	
SKJ	19	120	1	5	8	43	0	0	10	73	0.00
SPX	1	15	0	0	0	0	0	0	1	15	0.00
TUN	12	146	0	0	0	0	3	NA	1	5	3.00
UNK	19	NA	0	0	0	0	0	0	1	NA	0.00
WAH	2	14	0	0	1	10	0	0	1	4	0.00
WHM	2	28	0	0	0	0	0	0	2	28	0.00
WHX	2	51	0	0	0	0	0	0	2	51	0.00
XHH	1	105	0	0	0	0	0	0	0	0	
YFT	98	2865	30	1494	26	828	0	0	37	329	0.00

Table 15: Catches of observed vessels using buoy gear, 2018-2019. Biomass was calculated in kilograms (kg). Calculations do not include individual fish that were lost on the line, or individuals from which a length measurement was unable to be recorded.

Species	Total (count)	Total (kg)	Kept (count)	Kept (kg)	Pers. Use (count)	Pers. Use (kg)	Dead Discard (count)	Dead Discard (kg)	Live Release (count)	Live Release (kg)	Dead:Live Release Ratio
BAR	1	5	0	0	1	5	0	0	0	0	
BFT	1	298	1	298	0	0	0	0	0	0	
BLK	2	26	0	0	2	26	0	0	0	0	
BUM	2	41	0	0	0	0	0	0	2	41	0.00
DOL	3	18	1	4	2	14	0	0	0	0	
FAL	1	10	0	0	0	0	0	0	1	10	0.00
GEM	1	13	1	13	0	0	0	0	0	0	
LAX	3	4	0	0	0	0	3	4	0	0	
OIL	2	9	0	0	0	0	0	0	2	9	0.00
PEL	4	1	0	0	0	0	0	0	4	1	0.00
SBK	7	144	0	0	0	0	2	8	5	136	0.40
SHH	1	703	0	0	0	0	0	0	1	703	0.00
SHX	7	344	0	0	0	0	0	0	6	321	0.00
SNI	2	108	0	0	0	0	1	6	1	101	1.00
SPL	2	105	0	0	0	0	1	105	1	NA	1.00
SRQ	2	33	0	0	0	0	0	0	2	33	0.00
SWO	37	2033	26	1854	0	0	3	59	5	76	0.60
TUN	1	83	0	0	0	0	0	0	0	0	
UNK	6	0	0	0	0	0	0	0	0	0	
XHH	8	196	0	0	0	0	0	0	8	196	0.00
YFT	2	145	2	145	0	0	0	0	0	0	

Table 16: Catches of observed vessels using deep drop gear, 2018-2019. Biomass was calculated in kilograms (kg). Calculations do not include individual fish that were lost on the line, or individuals from which a length measurement was unable to be recorded.

Species	Total (count)	Total (kg)	Kept (count)	Kept (kg)	Pers. Use (count)	Pers. Use (kg)	Dead Discard (count)	Dead Discard (kg)	Live Release (count)	Live Release (kg)
BFT	2	251	0	0	0	0	0	0	1	143
BON	3	4	0	0	0	0	0	0	0	0
LAX	2	2	0	0	0	0	2	2	0	0
SWO	3	218	0	0	0	0	0	0	0	0
TIL	11	21	3	7	8	14	0	0	0	0
UNK	1	NA	0	0	0	0	0	0	0	0

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Appendix B

Analysis of Potential Economic Impacts of OFRP Alternative Gear Project for the 2017 and 2018 Seasons

IEc

Analysis of Potential Economic Impacts of OFRP Alternative Gear Project for the 2017and 2018 Seasons

Final Report | April 30, 2020

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SECTION 1 | INTRODUCTION

The Deepwater Horizon Oceanic Fish Restoration Project (OFRP) aims to restore pelagic fish biomass through reductions in incidental bycatch in the Gulf of Mexico pelagic longline fishery. The project was founded through the Deepwater Horizon Final Phase IV Early Restoration Plan and Environmental Assessment released in September 2015 to compensate for the losses to these species related to the 2010 oil spill.[1] The project protects pelagic fish biomass by establishing a voluntary annual six-month repose period to coincide with the spawning season for many important pelagic fishes. During the repose period, participating vessels are provided with alternative fishing gear (greenstick, buoy gear, and deep drop gear)to target yellowfin tuna and swordfish in place of pelagic longlines (PLL). Alternative gears, such as greenstick and buoy gear, have proven effective at reducing bycatch; however, additional testing and refinement is needed to increase the efficiency of these alternative gear types in catching target species.
All participants in the repose period receive compensation to help offset potential losses in revenue.

1.1 1 CHARGE

The purpose of this report is to examine the potential economic impacts of the alternative gear portion ofthe OFRP for the 2017 and 2018 seasons. Specifically, IEc was asked to analyze the following:

- Quantity (count by weight, size, and product grade), and price of landings of fishery target species landed by project participant vessels with alternative gears and vessels in the Gulf of Mexico Pelagic Longline (GOM PLL) fishery.
- Annual expenses per vessel (e.g., equipment purchases and/or maintenance, staff and salaries, revenue sharing, fuel and trip costs), for project participant vessels with alternative gears and vessels in the GOM PLL fishery.

In addition to testing how project participation affects these outcomes, we also test how the effect of participation has (or has not) changed over time (i.e., between the 2017 and 2018 seasons).

To address these questions, we relied on three datasets: **eDealer**, which provides information on trip landings; **HMS Logbooks,** which provide information on gear set characteristics; and **Cost and Earnings**, a trip-level dataset that includes data on expenses and revenues. We also received a list of eligible vessels and participating vessels for the 2017 and 2018 seasons. Prior to conducting the analyses,both datasets were filtered to include only observations classified as Florida or Louisiana.[2]

1.2 2 METHODS

This analysis relies on information from the three datasets to identify differences between participants and eligible non-participants. As described in more detail below, the comparisons are further divided by state

[1] Deepwater Horizon Oil Spill Final Phase IV Early Restoration Plan and Environmental Assessment. Available online: www.gulfspillrestoration.noaa.gov/wp-content/uploads/Final-Phase-IV-ERP-EA.pdf

[2] In the eDealer dataset, state was identified by the variable *registering_state*, in the logbook data we identify state using the variable *state_name* and in the costs and earnings dataset, *state*.

and time of year (i.e., in repose period, after repose period, and full year). This section first describes the datasets and variables used and then describes the analytical tests employed to identify differences between groups.

Note that the following analysis does not consider the compensation vessel owners received for voluntarily participating in the project. Participating vessel owners received compensation to offset any potential losses in revenue associated with refraining from using PLL gear during the repose period each year. In addition, participants received alternative gear payments in the amount of $1,000 per sea-day for up to 40 sea-days in 2017 (up to $40,000) and 60 sea-days in 2018 (up to $60,000) over the repose period.

1.2.1 .1 Data

All data used in this analysis were provided by NOAA via a secure portal. In each dataset, all observations are assigned the following identifying variables:

- *Year*: The season in which the fishing event (trip, landing, or gear set) occurred.
- *Period*: Splits the year into repose period (i.e., March 1 to June 30 in 2017 and January 1 to June 30 in 2018) and remainder of year. Analyses consider each period separately in addition to the full year.
- *State*: Identifies whether vessels are registered in Florida or Louisiana.
- *Eligible2017* and *Eligibile2018*: Identifies project eligibility in each year.
- *Participant2017* and *Participant2018*: Identifies project participation in each year.
- *Vessel_ID*/*Supplier_Vessel_ID*: Unique identifier of each vessel in the fleet.

The **eDealer** dataset provides landings-level information.

- *totalLandings*: IEc generated, count of observations by Vessel ID.
- *Year_built*: Year in which the vessel was built.
- *Species_Id*: Species of landings, where ID is classified as 18 (Pelagic), 42 (Swordfish), 44 (Albacore), 48 (Skipjack), 49 (Yellowfin), and 50 (Bigeye).
- *Purchase_price*: Price of landings, in dollars per pound.
- *Weight*: Weight of landing, in pounds.
- We calculate *Total_sales* as the product of *purchase_price* and *weight*. Note that this measure only covers the species tracked in eDealer reporting. Specifically, it excludes non-HMS species and bluefin tuna.

In the **HMS Logbook** data, each line represents one gear set.[3] This dataset is used to identify the gear used for each set. These data are not used for catch information because the eDealer data is generally seenas a more reliable source; however, the gear code information in the eDealer dataset is not sufficient to separate out the gear types of interest.

[3] Pelagic longline "sets" can include multiple PLL sets.

- *Gear* is an IEc generated variable derived from the variables *pelagic_longline, rod_and_reel, buoy*, and *green_stick_tuna*—all of which are yes/no variables indicating the gear type used. Each set is assigned one gear type.

The **Cost and Earnings** dataset provides trip-level information. It provides information about trip expenses and revenues. Variables below are defined using the 2017 Trip Summary Forms.[4]

- *Total_trips*: IEc generated variable, count of observations by Vessel ID. Where a vessel appeared in the dataset in one time period but not in the other, we assume zero trips in the other period.
- *Total_expense*: IEc generated variable, sum of below cost variables per trip. Except where noted, each of the following were reported directly in the original dataset and the descriptions provided here explain how the variables were originally computed. Note that other cost and expense variables in the dataset (*broker_expense, trip_grocery_expense, misc_expense, freight_cost, bait2_cost*) contained all missing observations.
    - *Fuel_cost*: Fuel used (gallons) during the trip multiplied by the price per gallon paid.
    - *Bait_cost*: Pounds of bait multiplied by price per pound of bait purchased for the trip.
    - *Ice_cost*: Quantity of ice purchased multiplied by price per unit (units vary by ice type).
    - *Grocery_expenses:* Cost of groceries (food, toiletries, etc.) incurred for the trip.
    - *Other_cost:* Other costs not covered in other recorded cost categories. It may include docking/offloading fees (if separate from broker fee), crew travel/lodging, and fishing supplies.
    - *Lightstick_cost:* IEc generated variable, number of lightsticks purchased multiplied by the reported cost per lightstick.
- *Total_trip_sales:* Gross revenue received from dealer(s) for the fish sold at offload for this trip. Note that we use the sales information from the eDealer dataset as our primary measure of sales but the Cost and Earnings sales data is used to calculate net revenue.
- *Net Revenue*: The net of *total_trip_sales* and *total_expenses*.

NOAA also provided a list of eligible and participating vessels for each year.

1.2.2 .2 Analysis

All analyses are run at the vessel level, meaning the variables described above that describe trips, landings, or gear sets are first averaged by vessel. We are interested in identifying the impacts on the average vessel and by averaging by vessel we avoid overweighting vessels that took more trips (or hadmore landings or gear sets).

The first set of analyses compares participants to non-participants during the 2016, 2017, and 2018 seasons. We first compare participants and non-participants, where participants are defined as vessels participating in the project in either 2017 or 2018, during the 2016 season to identify any preexisting

[4] NOAA. 2017. 2017 Trip Summary Forms: Fishing Vessel Logbook Record Atlantic Highly Migratory Species Fisheries. NOAA FORM 88-191.

differences between the two groups, before the project began. The 2017 and 2018 season comparisons testfor the effects of project participation.

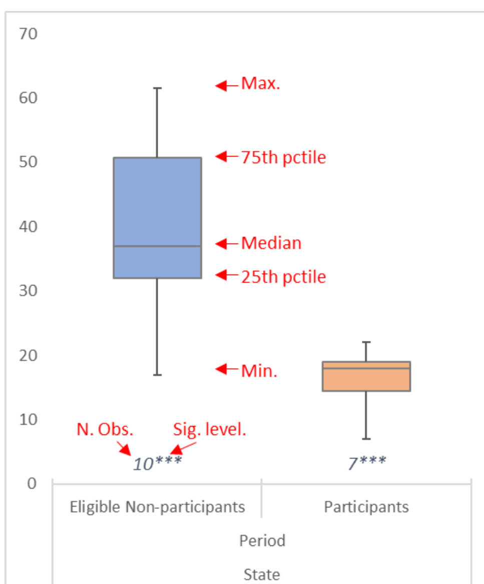
The comparisons identify each observation by eligibility and year, participation and year, state, and period within year. Comparisons are run between participants and non-participants by state and period within the year. "Non-participants" are eligible vessels that did not participate in the project in that year. Splitting comparisons by period allows us to separately identify differences during the repose period, afterthe repose period, and over the full year. We separate observations by state because of known differences between the fleets from Louisiana and Florida and the uneven representation of the two fleets in terms of project participation. If we do not separate by state, we may inadvertently attribute observed differences to the project when they may be more related to the state of origin.

For this first set of analyses we use three methods to identify differences between groups:

- **Visual tests**: using box and whisker plots or bar charts;
- **T-test**: tests whether the means of two groups (i.e., participants and non-participants) are significantly different. This test does not assume equal variance in the two groups.
- **Wilcoxon rank sum test** (or Mann-Whitney two-sample statistic): tests whether two independent samples are from populations with the same distribution. It includes a correction to accurately estimate p-values for sample sizes less than 25.

The "box" of the box plot represents the interquartile range (i.e., 25th to 75th percentile) and the "whiskers" identify the minimum and maximum values. The horizontal line within the box shows the median value. Along the bottom of each box and whisker plot, the values represent the number of observations used to calculate the distribution shown and the stars are used to identify statistical significance (where significance levels are shown as * = 10% level; ** = 5% level; and *** = 1% level). Figure 1 annotates the elements of the box and whisker plots. Variables shown as bar charts use the samesignificance symbology.

FIGURE 1. ANNOTATED BOX AND WHISKERS PLOT



The two statistical tests used are a t-test and Wilcoxon rank sum. Because the number of observations is limited, particularly for certain variables, there are instances where these statistical tests cannot be used. A t-test cannot be performed when there is only one observation (in this case one vessel) in either comparison group. A rank sum test does allow for single observations per group, but as is the case with at-test, requires one observation in each group. In the tables in the sections that follow we present the p- values for each of these tests where the tests can be computed.

Due to the small number of observations, we recommend a composite approach to evaluating differences between groups, where the visual tests are considered in conjunction with the two statistical tests. There may be situations where the statistical tests differ in terms of assigning significance to a particular comparison, therefore it is important to consider the overall balance of information.

In addition to examining the impact of project participation on these key outcomes, we also test whetherany effects of project participation changed over time. We use a difference-in-difference (DID) analysisto identify how the change in outcome between 2017 and 2018 varies between participants and non-participants.

DID analyses are typically used to identify the effect of treatment on an outcome over time when there is likely to be an overall trend affecting both the treated group and the control group. Here we look at the difference in a particular variable between 2017 and 2018 by participation group, and then test to see if the *difference* in those *differences* is significant, controlling for state and species, where appropriate. In other words, we may expect to see general trends between 2017 and 2018, but do participants and non- participants have different rates of change during this period?

This can also be pictured as a two by two box, with participants vs. non-participants as the rows and the 2017 and 2018 seasons as the columns as shown in Table 1. In Sections 3 and 4, we test for significant differences between the rows of the box (i.e., A vs. C and B vs. D). We are not necessarily interested in overall differences between the columns (i.e., A vs. B and C vs. D), but instead we want to know how the difference between A and B compares to the difference between C and D; DID analysis allows us to do soand therefore identify the difference in rate of change between participants and non-participants over the two seasons of the project.

TABLE 1. EXAMPLE OF COMPARISON GROUPS FOR DIFFERENCE IN DIFFERENCE (DID) ANALYSIS

	2017	2018
Participant	A	B
Non-Participant	C	D

1.3 3 RESULTS

We can summarize the overall results of all reported analyses as follows:

Prior to the project, in 2016, vessels that would go on to participate in the project did not differ significantly from vessels that do not participate. The most consistent and significant difference observed during the project is during the repose period in both 2017 and 2018- participants landed significantly less total weight per vessel and had significantly lower sales and net revenues than non-participants. The average total weight landed and number of trips per vessel decreased between 2017

and 2018 for all vessels regardless of participation; however, participants had a smaller decrease in number of trips over the two years than non-participants, all else equal.

The bullets below summarize how the following outcomes vary by project participation in 2017 and 2018with important caveats noted in the following section. These results are elaborated further in Section 3 (2017 season) and Section 4 (2018 season).

- **Trips per vessel:** In 2017 participants took similar numbers of trips per vessel to non-participants during the repose period but in 2018, participants took more trips during the repose than non-participants.
- **Weight landed per vessel:** Despite taking a similar number or more trips than their non-participant counterparts, participants landed significantly less weight than non-participants, during and after the repose period.
- **Proportion of species landed**: During the repose participants only landed yellowfin and swordfish. Outside of the repose, overall there were not significant differences between participants and non-participants.
- **Price per pound:** Participants and non-participants received similar prices per pound, controlling for the species landed, indicating minimal differences in the grade of fish landed. Note that here we only account for species landed, and therefore any low-quality products not sold (e.g. retained for personal consumption) would not be accounted for in this analysis.
- **Weight per landing:** Yellowfin landings, particularly for Louisiana boats, weighed significantly less on average during the repose period. A similar pattern is seen outside of the repose period in 2018.
- **Sales per vessel:** Total sales per vessel were lower for participants than non-participants for all states, years, and periods. This is one of the most pronounced differences between the two groups across all comparisons.
- **Expenses per trip:** Participants had higher expenses outside of the repose period than non-participants but had significantly lower expenses per vessel during the repose period.
- **Net Revenue per trip:** Participants had significantly lower net revenues per trip, particularly during the repose and particularly in 2018. This is driven by the significant differences in sales figures.

We can also provide a limited comparison of catch and sales data from eligible and participating vesselsto the Florida and Louisiana fishery in general. The fishery-wide data are available from the NOAA fisheries portal for 2016 and 2017. The table below shows the change in total pounds, total dollar value,and dollars per pound for the entire fishery, eligible vessels (a subset of the fishery), and participating vessels (a subset of eligible vessels). Trends in dollars per pound are fairly similar across all groups; however, while eligible vessels show a similar trend of a four to seven percent drop in both total poundsand total dollar value, participants have a much higher drop of 63 percent in total pounds and 64 percentin total value over the same period.

TABLE 2. CHANGE IN KEY INDICATORS BETWEEN 2016 AND 2017

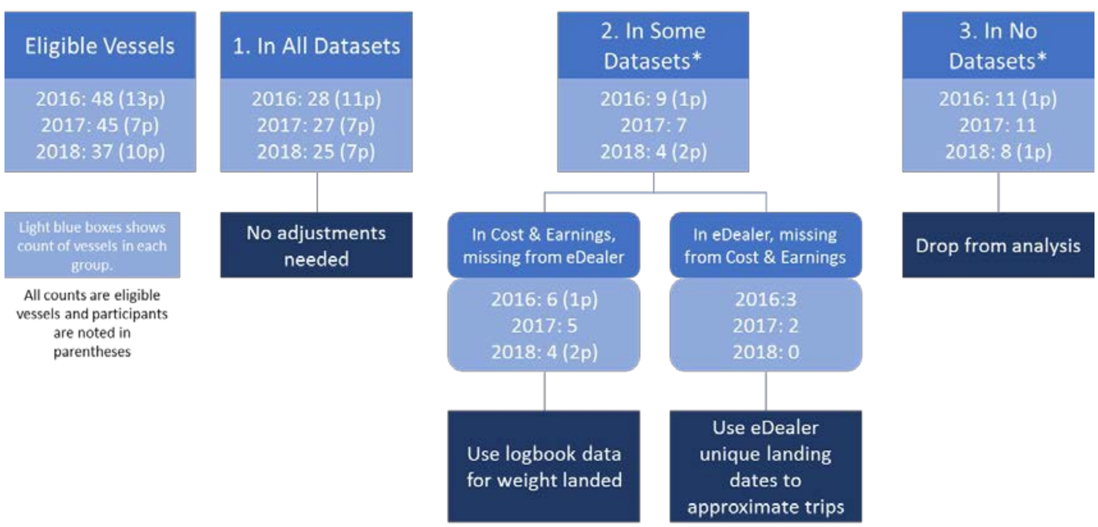
	TOTAL POUNDS	TOTAL DOLLAR VALUE	DOLLARS PER POUND
Fishery-wide (LA and FL)	-14%	-10%	-4%
Eligible Vessels	-7%	-4%	-4%
Participating Vessels	-63%	-64%	1%
Note: *Statistics above include landings of swordfish, albacore, bigeye, skipjack, and yellowfin. Fishery-wide includes Louisiana and both coasts of Florida.*[5]			

1.4 4 LIMITATIONS AND CAVEATS

It is important to note that the comparisons/differences described here are limited in some cases by missing data and relatively few observations in several categories. For each comparison in the sectionsbelow, we provide the number of observations to highlight areas where the data are thin. With few observations it can be difficult to identify significant differences and results are sensitive to outlier observations.

There are instances where eligible or participating vessels do not appear in the trip and landing datasets, and there are additional instances where the vessel does appear in the dataset but is missing information for certain variables of interest. When a vessel does not appear in the dataset it is possible that the vessel did not take any trips or have any landings, or that the activity was not recorded. Figure 2 presents the treatment of vessels with various levels of data availability. We exclude vessels that do not appear in any dataset from the analysis. This assumes that the decision to be active in the year was made independently of the project and therefore these vessels are not an appropriate comparison group. Vessels missing from either the Cost & Earnings or eDealer datasets, but not both, have missing information filled in from otherdata sources where possible. This analysis therefore considers the 37, 34, and 29 vessels appearing in datasets in 2016, 2017, and 2018, respectively.

FIGURE 2. TREATMENT OF VESSELS NOT APPEARING IN ACTIVITY DATASETS



[5] Fishery-wide data from NOAA Fisheries data portal (https://foss.nmfs.noaa.gov/apexfoss/f?p=215:200:7792461124737::NO:::)

SECTION 2 | PRE-PROJECT COMPARISONS: 2016 SEASON

Before comparing outcomes between participants and eligible non-participants during the project, we first compare the two groups in 2016, before the project began. The purpose of this analysis is to identify any differences between participants and eligible non-participants outside of project participation which might impact outcomes *during* but not *as a result of* project participation.

In this section we compare the following characteristics:

- Year the vessels were built
- Number of trips per vessel
- Total landings per vessel
- Number of landings by species
- Gear usage per trip
- Average purchase price by species
- Average weight by species
- Total sales per vessel
- Expenses per trip
- Net revenue per trip

Each comparison is run for participants versus eligible non-participants by state, for the repose period, thetime outside of the repose period, and the full year. Here participants are defined as participants in either the 2017 or the 2018 season. The repose period is defined using the 2017 period (March through June) and trips or landings occurring in January or February are dropped from the analysis. Statistical tests are used to identify differences between participants and non-participants by state and portion of the year.

The comparisons that follow demonstrate an absence of significant differences between participants and non-participants prior to project participation. There is some uncertainty in this conclusion given the number of vessels that do not have recorded trips in 2016, however this gives us reasonable support for attributing differences that may appear during the project to participation and not preexisting differences.

21 1 YEAR BUILT

The age of a vessel could impact economic outcomes and it also serves as a proxy for other vessel characteristics that could impact outcomes. Here we test if the age of participating vessels differs from that of non-participating vessels. We find that participating vessels in Louisiana are generally newer thannon-participating vessels; however, the difference in mean years built (1985 versus 1990) is unlikely to represent a functional difference between the fleets. Additionally, many vessels undergo extensive renovations which are not represented in the reported year built.

FIGURE 3. VESSEL YEAR BUILT

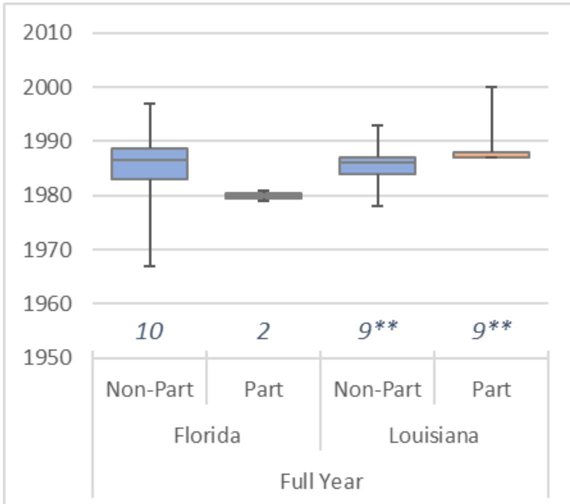


TABLE 3. YEAR BUILT: NUMBER OF VESSELS AND STATISTICAL TESTS OF DIFFERENCES

		FULL YEAR	
		FLORIDA	LOUISIANA
p-values	T-test	0.449	0.050
	Rank sum test	0.120	0.009

Statistics based on 9 LA participants, 2 FL participants, 9 LA eligible non-participants, and 10 FL eligible non-participants.No eDealer data for 1 FL participant and 5 FL eligible non-participants. Year built information missing for one FL eligible non-participant.

22 2 TRIPS PER VESSEL

Significant differences here would signal that participants and non-participants had different levels of effort prior to project participation. Note that this analysis only includes vessels that recorded at least onetrip in the year, signified by appearing in at least one dataset.

There are no significant differences between the two groups in any time periods in either state.

FIGURE 4. TRIPS PER VESSEL (2016)

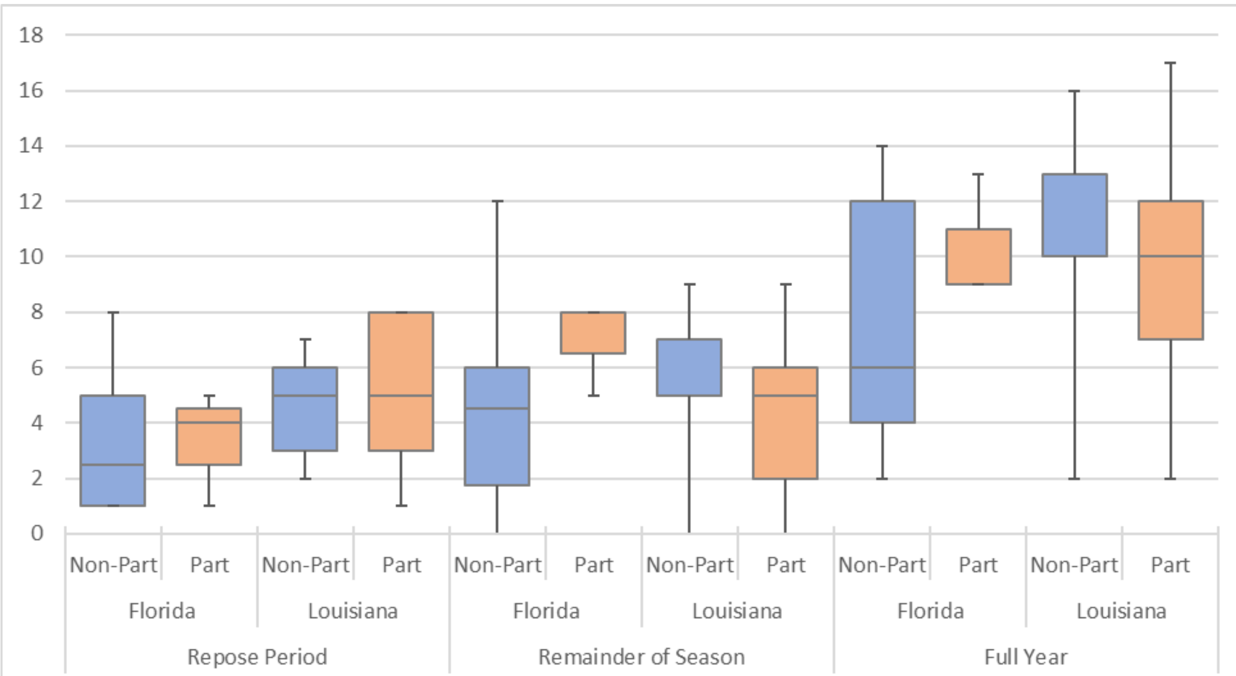


TABLE 4. TRIPS PER VESSEL (2016): STATISTICAL TESTS OF DIFFERENCE

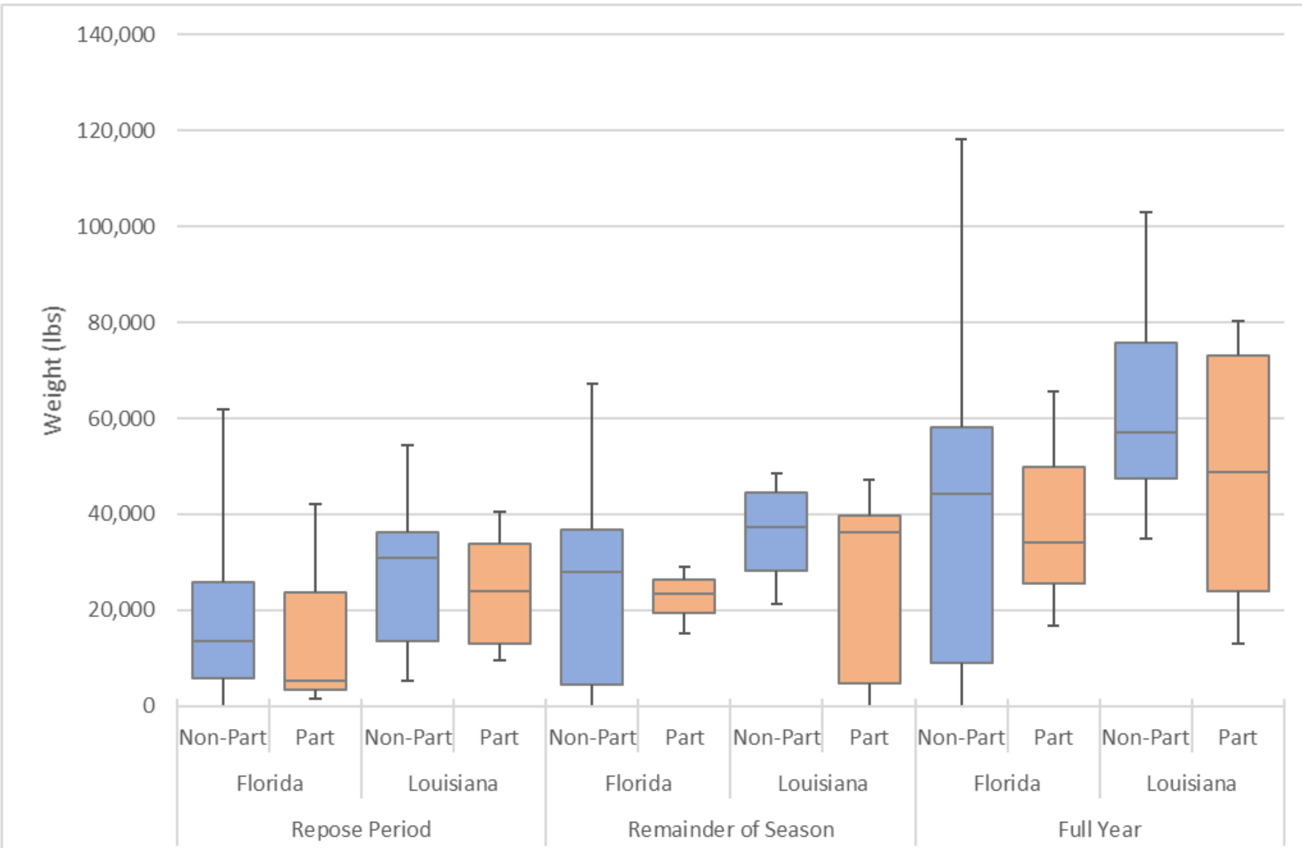
		REPOSE PERIOD		REMAINDER OF SEASON		FULL YEAR	
		FLORIDA	LOUISIANA	FLORIDA	LOUISIANA	FLORIDA	LOUISIANA
p-values	T-test	0.916	0.694	0.219	0.300	0.260	0.625
	Rank sum test	0.909	0.624	0.128	0.286	0.236	0.532

Statistics based on a total of 3 FL participants, 9 LA participants, 16 FL eligible non-participants, and 9 LA eligiblenon-participants.

23 3 WEIGHT OF LANDINGS PER VESSEL

Here we test whether eventual project participants brought in more or less total weight in landings than non-participants in 2016. Total weight is partially a function of effort and catch, but it also depends on thetarget species. On average, participants landed less total weight than non-participants in 2016 (45,321 lbs.vs. 58,754 lbs.) but this difference is not statistically significant.

FIGURE 5. WEIGHT LANDED PER VESSEL (2016)



Graph excludes one outlier vessel (FL eligible non-participant) which landed 273,221 lbs. over the full year.

TABLE 5. LANDING WEIGHT PER VESSEL (2016): STATISTICAL TESTS OF DIFFERENCE

		REPOSE PERIOD		REMAINDER OF SEASON		FULL YEAR	
		FLORIDA	LOUISIANA	FLORIDA	LOUISIANA	FLORIDA	LOUISIANA
p-values	T-test	0.189	0.529	0.464	0.167	0.345	0.198
	Rank sum test	0.099	0.508	0.236	0.354	0.076	0.200

Statistics based on a total of 2 FL participants, 9 LA participants, 11 FL eligible non-participants, and 9 LA eligiblenon-participants.

This test explores whether participants and non-participants land a similar proportion of each species. In the figure below, the difference between participants and non-participants can be seen by comparing barsof the same color across groups. Florida participants (those that participated in the 2018 repose) caught proportionally less bigeye than non-participants, however in general, there are no meaningful differences observed between the two groups.

FIGURE 6. LANDINGS BY SPECIES (2016)

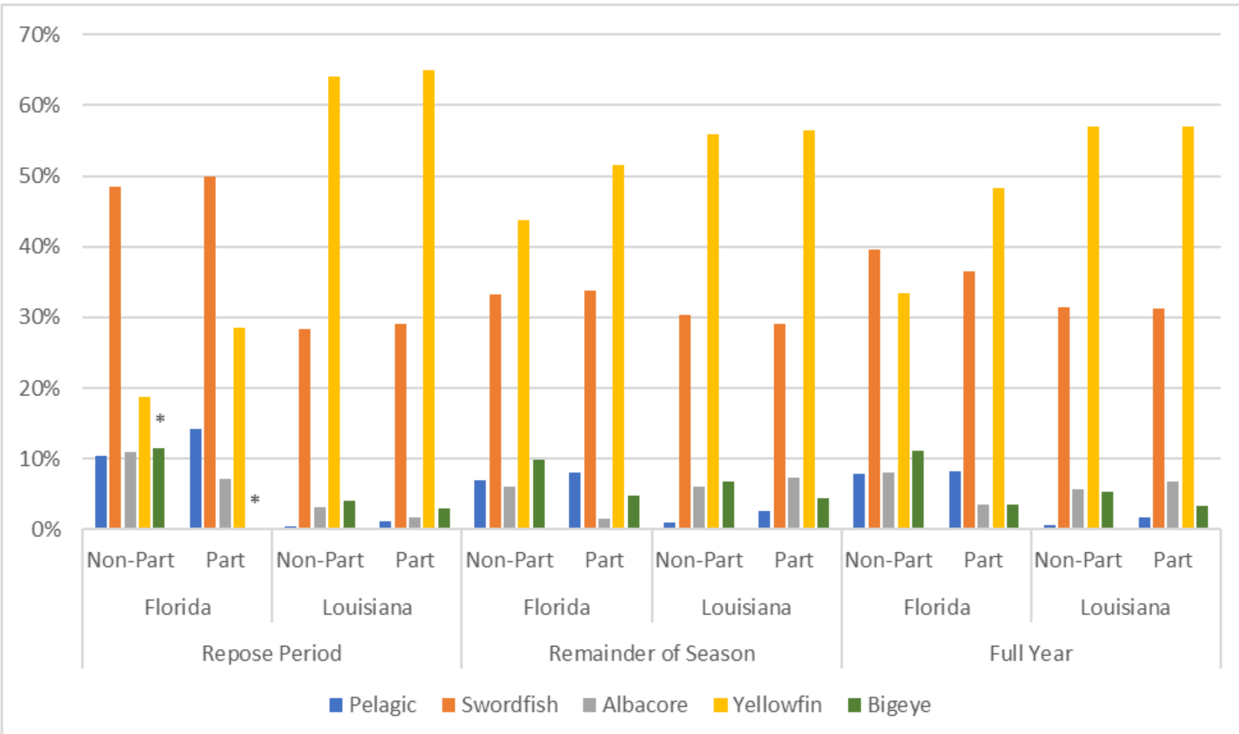


TABLE 6. LANDINGS BY SPECIES (2016): STATISTICAL TESTS OF DIFFERENCE

			REPOSE PERIOD		REMAINDER OF SEASON		FULL YEAR	
			FLORIDA	LOUISIANA	FLORIDA	LOUISIANA	FLORIDA	LOUISIANA
p-values	Pelagic	T-test	0.353	0.776	0.627	0.250	0.536	0.420
		Rank sum test	0.686	0.485	0.843	0.164	0.843	0.175
	Swordfish	T-test	0.887	0.818	0.785	0.245	0.638	0.884
		Rank sum test	0.794	0.874	0.693	0.318	0.324	0.724
	Albacore	T-test	0.987	0.369	0.372	0.706	0.661	0.437
		Rank sum test	0.893	0.348	0.310	0.916	0.542	0.691
	Yellowfin	T-test	0.973	0.756	0.976	0.241	0.901	0.827
		Rank sum test	0.694	0.832	-	0.600	-	0.627
	Bigeye	T-test	0.100	0.452	0.374	0.127	0.206	0.330
		Rank sum test	0.106	0.580	0.236	0.114	0.164	0.427

No landings recorded in 2016 (and therefore no species information) for 1 FL participant and 5 FL eligible non-participants.

25 5 GEAR USAGE

In 2016, all trips and all sets in the dataset used pelagic longlines. Gear usage information was missing for three FL eligible non-participants.

No graphics or statistics are presented given the uniformity of the data.

26 6 PURCHASE PRICE BY SPECIES

This comparison tests if, prior to project participation, there was a difference in the price per pound received for participants and non-participants, controlling for the species landed. This would signify a difference in the quality of the fish landed. Over the full year, Florida participants (those that participatedin the 2018 repose) received slightly more per pound for bigeye than non-participants, however given thecomparison of the two groups across all species, there is unlikely to be meaningful differences in the quality of fish landed.

FIGURE 7. PURCHASE PRICE PER POUND BY SPECIES (2016)

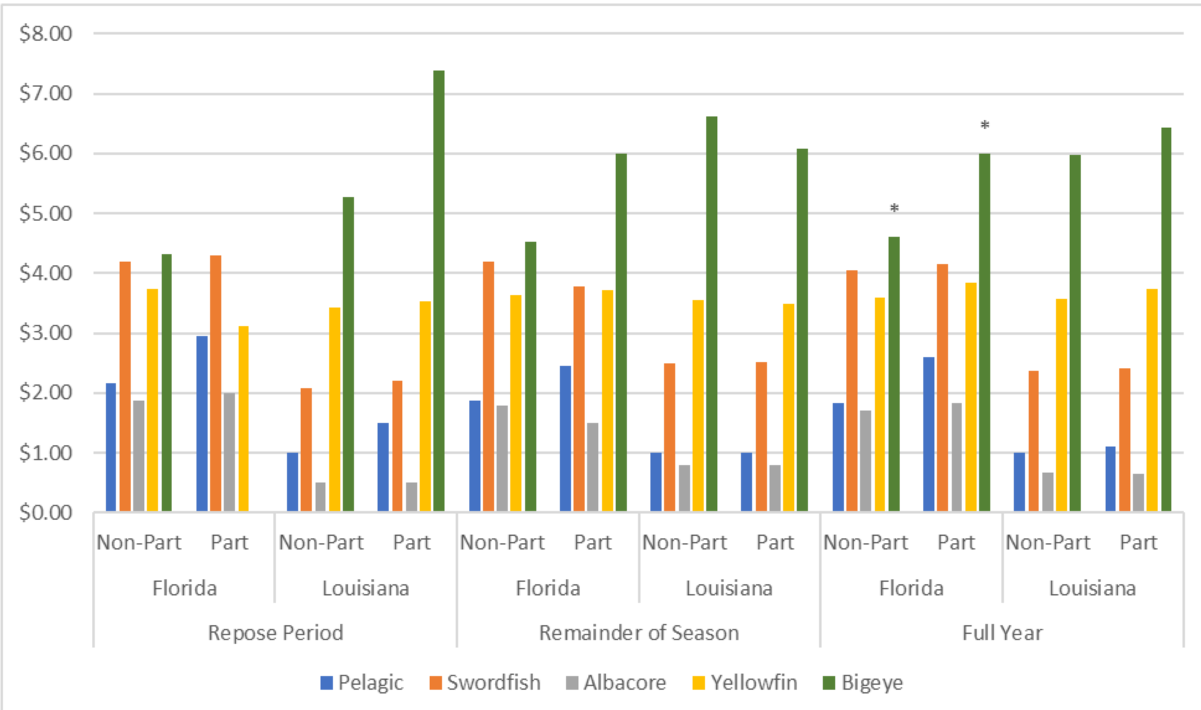


TABLE 7. PRICE PER POUND BY SPECIES (2016): STATISTICAL TESTS OF DIFFERENCE

			REPOSE PERIOD		REMAINDER OF SEASON		FULL YEAR	
			FLORIDA	LOUISIANA	FLORIDA	LOUISIANA	FLORIDA	LOUISIANA
p-values	Pelagic	T-test	-	-	-	-	-	0.576
		Rank sum test	0.143	0.480	0.222	-	0.222	0.527
	Swordfish	T-test	0.904	0.341	0.507	0.762	0.822	0.250
		Rank sum test	0.770	0.523	0.637	0.874	0.667	0.450
	Albacore	T-test	-	-	-	0.951	-	0.603
		Rank sum test	0.235	-	0.380	0.882	0.827	0.478
	Yellowfin	T-test	-	0.486	0.850	0.659	0.594	0.293
		Rank sum test	0.510	0.368	-	0.600	0.554	0.508
	Bigeye	T-test	-	0.167	0.195	0.629	0.086	0.668
		Rank sum test	-	0.118	0.125	0.745	0.099	0.225

No landings recorded in 2016 (and therefore no price information) for 1 FL participant and 5 FL eligible non-participants.

27 7 WEIGHT BY SPECIES

Because weight per landing is partially a function of the species landed, here we test for differences in pounds per landing, controlling for the species landed. Based on a visual examination of the data, participants tend to land smaller swordfish and pelagic fish, and the difference in swordfish weight is statistically significant for Louisiana vessels outside of the repose period and for the full year.

FIGURE 8. AVERAGE WEIGHT (IN POUNDS) BY SPECIES (2016)

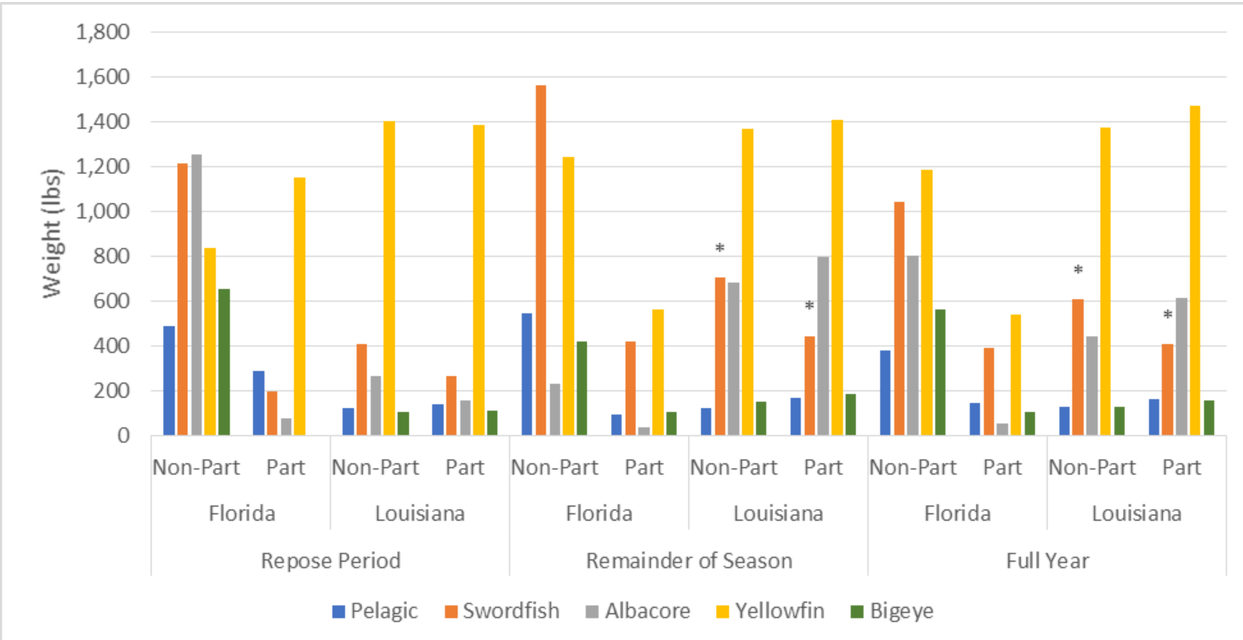


TABLE 8. WEIGHT BY SPECIES (2016): STATISTICAL TESTS OF DIFFERENCE

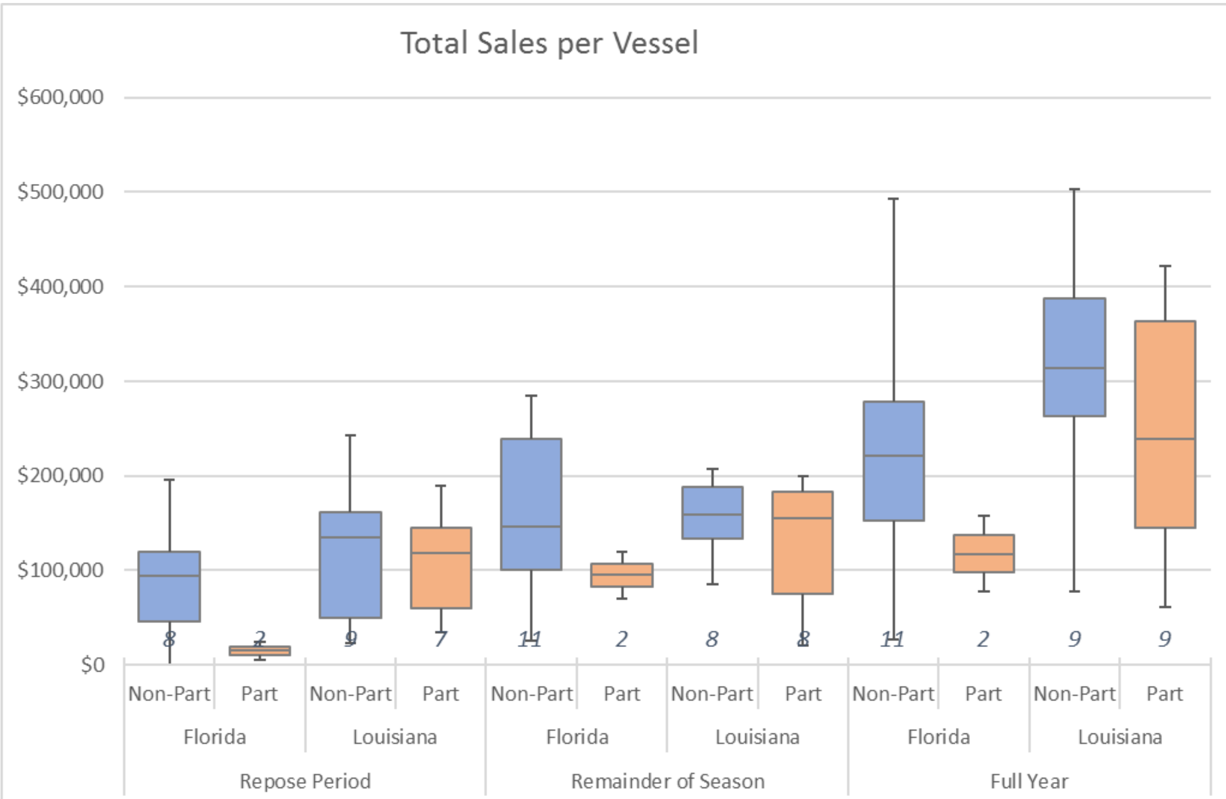
			REPOSE PERIOD		REMAINDER OF SEASON		FULL YEAR	
			FLORIDA	LOUISIANA	FLORIDA	LOUISIANA	FLORIDA	LOUISIANA
p-values	Pelagic	T-test	-	-	-	0.677	-	0.750
		Rank sum test	0.770	0.221	0.223	0.699	0.602	1.000
	Swordfish	T-test	0.213	0.249	0.614	0.069	0.555	0.061
		Rank sum test	0.242	0.165	0.814	0.046	0.830	0.038
	Albacore	T-test	-	0.444	-	0.641	-	0.299
		Rank sum test	0.143	0.121	0.275	1.000	0.127	0.453
	Yellowfin	T-test	-	0.944	0.233	0.786	0.246	0.511
		Rank sum test	0.513	0.958	0.167	0.462	0.167	0.453
	Bigeye	T-test	-	0.804	0.295	0.398	0.178	0.198
		Rank sum test	-	0.517	0.099	0.253	0.059	0.227

No landings recorded in 2016 (and therefore no weight information) for 1 FL participant and 5 FL eligible non-participants.

28 8 TOTAL SALES PER VESSEL

The eDealer dataset provides information on weight per landing and price per pound, which we use to calculate total sales per landing. The figure below shows the average landing sales by group, where several groups (i.e. Louisiana non-participants and Florida participants) only have one observation, making it difficult to identify differences.

FIGURE 9. SALES PER TRIP (2016)



**Graph excludes one outlier observation (FL, non-participant, full year sum of $937,366)*

TABLE 9. TOTAL SALES (2016): STATISTICAL TESTS OF DIFFERENCE

		REPOSE PERIOD		REMAINDER OF SEASON		FULL YEAR	
		FLORIDA	LOUISIANA	FLORIDA	LOUISIANA	FLORIDA	LOUISIANA
# Vessels with Expense Data	Participants (2017 or 2018)	8	9	11	8	11	9
	Non-Participants (2017 or 2018)	2	7	2	8	2	9
p-values	T-test	0.247	0.696	0.354	0.333	0.355	0.276
	Rank sum test	0.117	0.711	0.236	0.529	0.167	0.310

No landings recorded in 2016 (and therefore no weight, price or sales information) for 1 FL participant and 5 FL eligible non-participants.

29 9 EXPENSES PER TRIP

The expenses per trip in 2016 were not significantly different between vessels who participated in the project in 2017 or 2018 and those that did not. For Florida, expenses for the one participating vessel withexpense data for the 2016 season falls within the interquartile range of expenses for non-participants. As noted below, expense data are missing for a number of vessels and trips which makes it difficult to draw conclusions from this analysis.

FIGURE 10. EXPENSES PER TRIP (2016)

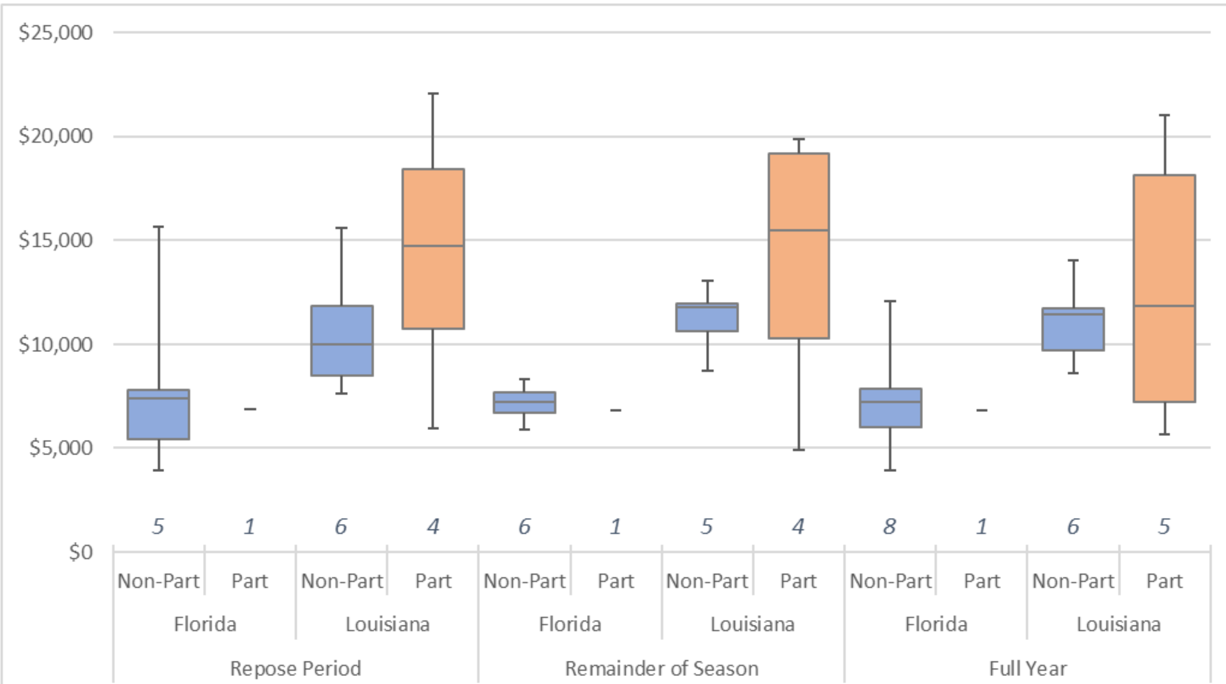


TABLE 10. EXPENSES PER TRIP (2016): STATISTICAL TESTS OF DIFFERENCE

		REPOSE PERIOD		REMAINDER OF SEASON		FULL YEAR	
		FLORIDA	LOUISIANA	FLORIDA	LOUISIANA	FLORIDA	LOUISIANA
# Vessels with ExpenseData	Participants (2017 or 2018)	5	6	6	5	8	6
	Non-Participants (2017 or 2018)	1	4	1	4	1	5
p-values	T-test	-	0.262	-	0.421	-	0.569
	Rank sum test	0.770	0.286	0.617	0.327	0.699	0.715

No trips recorded, for 3 eligible FL vessels and expense data missing for an additional 6 participants (4 LA, 2 FL)and 8 eligible non-participants (3 LA, 5 FL).

2.10 0 NET REVENUE PER TRIP

There are no significant differences between the two groups in terms of net revenues per trip in 2016. Because net revenue is calculated as total trip sales less expenses per trip, this analysis suffers from the same issue of missing information described above. Note that this net revenue calculation is based on Cost and Earnings data on trip sales, in place of the eDealer sales information presented above, for consistency with the expense data.

FIGURE 11. NET REVENUE PER TRIP (2016)

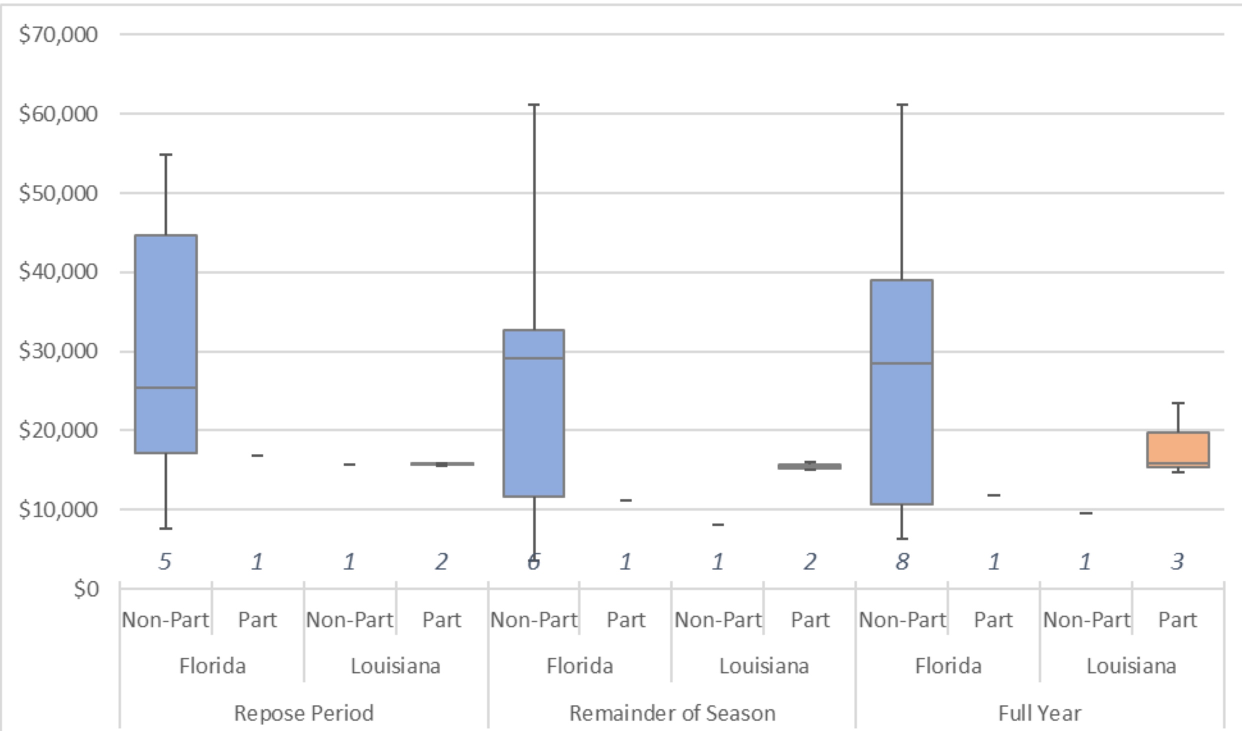


TABLE 11. NET REVENUE (2016): STATISTICAL TESTS OF DIFFERENCE

		REPOSE PERIOD		REMAINDER OF SEASON		FULL YEAR	
		FLORIDA	LOUISIANA	FLORIDA	LOUISIANA	FLORIDA	LOUISIANA
# Vessels with Expense Data	Participants (2017 or 2018)	5	1	6	1	8	1
	Non-Participants (2017 or 2018)	1	2	1	2	1	3
p-values	T-test	-	-	-	-	-	-
	Rank sum test	0.380	-	0.617	0.221	0.699	0.180

No trips recorded for 3 FL eligible vessels and expense and/or sales information missing for an additional 8 participants (6 LA, 2 FL) and 13 eligible non-participants (8 LA, 5 FL) for the full year.

SECTION 3 | PARTICIPATION EFFECTS: 2017 SEASON

This section compares participants and non-participants in 2017 to identify the effects of the project on various outcomes. In this section we compare the following characteristics:

- Number of trips per vessel
- Total weight of landings per vessel
- Number of landings by species
- Gear usage per trip
- Average purchase price by species
- Average weight by species
- Total sales per vessel
- Expenses per trip
- Net Revenue per trip

Each comparison is run for participants versus eligible non-participants for the repose period (March 1 toJune 30), outside of the repose period (January, February, and July through December), and the full year.Here the participants are limited to only those vessels that participated in 2017. There were no participants from Florida in 2017, therefore we only present Louisiana non-participating vessels as an appropriate comparison group. There were seven participants and nine eligible non-participants with at least one recorded trip in 2017. Statistical tests are used to identify differences between participants and non-participants by state and portion of the year.

During the repose period, we find that there was no significant difference in the number of trips taken by participants and non-participants, however participants landed significantly less total weight per vessel. Participants only landed yellowfin during the repose period and caught proportionally (and significantly)more albacore than non-participants outside of the repose. The average yellowfin landing for participantsweighed significantly less than the yellowfin landings for non-participants during the repose. Participantshad significantly lower total sales compared to non-participants, particularly during the repose periods. Even with lower expenses on average, net revenues were statistically lower for participants versus non-participants, with the majority of participants experiencing negative net revenues during the repose period. The following analysis does not consider the compensation vessel owners received for voluntarilyparticipating in the project. During the 2017 pilot year of the project, participating vessel owners receivedcompensation to offset any potential losses in revenue associated with refraining from using PLL gear during the repose period. In addition, participants received alternative gear payments in the amount of
$1,500 per sea-day for up to 40 sea-days over the four-month repose period (up to $60,000).

3.1 1 TRIPS PER VESSEL

Participants and non-participants did not record a significantly different number of trips during the repose period (note, during the repose period, five of the seven participating vessels took five trips, one took fourtrips, and one took six trips, creating a narrow distribution which appears without an interquartile range inthe graphic). Outside of the repose period and when summed over the full season, participants took statistically fewer trips on average. Over the full year, participants averaged 10 trips per vessel and eligible non-participants averaged 12 trips per vessel. When considering only vessels that took at least onetrip in the year, the difference is more pronounced: eligible non-participants averaged 17 trips compared to the 10 trips per vessel for participants (all of which took at least one trip). Interestingly, this difference is driven by trips taken (or not taken) outside of the repose period, not activity during the repose.

FIGURE 12. TRIPS PER VESSEL (2017), LOUISIANA VESSELS

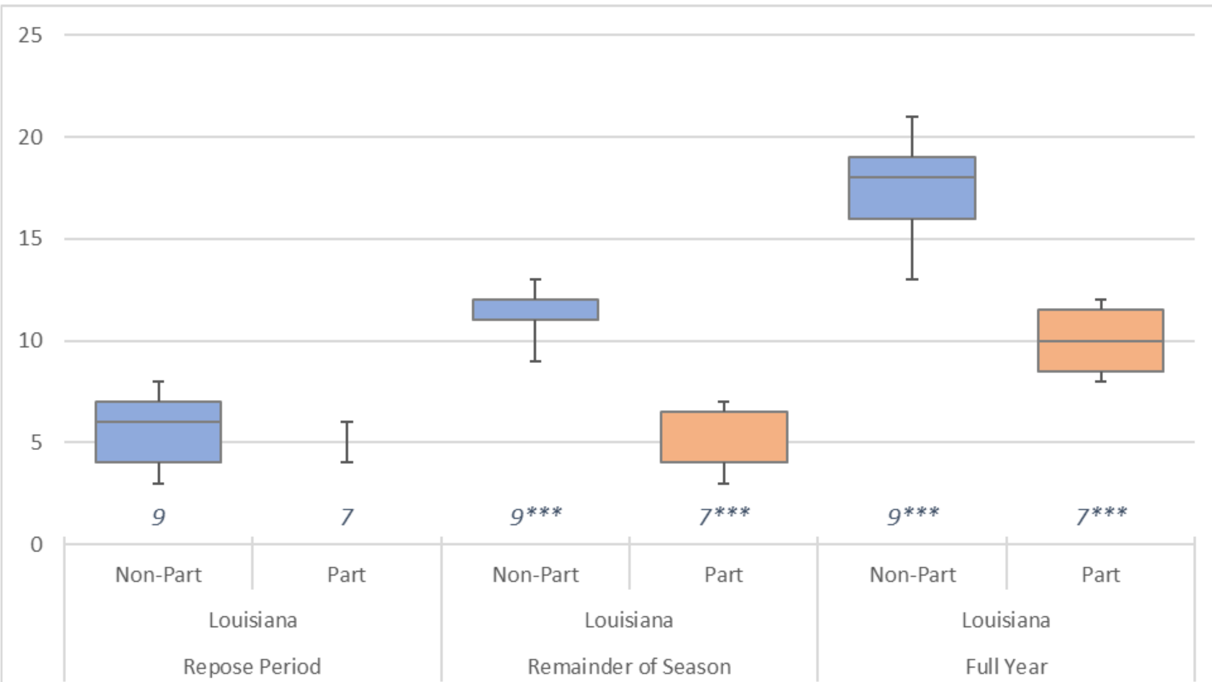


TABLE 12. TRIPS PER VESSEL (2017, LOUISIANA VESSELS): STATISTICAL TESTS OF DIFFERENCE

		REPOSE PERIOD	REMAINDER OF SEASON	FULL YEAR
p-values	T-test	0.348	0.000	0.000
	Rank sum test	0.412	0.001	0.001

Statistics based on a total of 7 participants and 9 eligible non-participants, all from LA.

3.2.2 WEIGHT OF LANDINGS PER VESSEL

Total landings (in pounds) varied significantly between participants and non-participants. Across all time periods, participants landed significantly fewer total pounds than non-participants. This is likely the resultof a combination of fewer trips outside of the repose period (see Table 12), a shifting of the proportion of each species landed (Table 14) and a lower average weight by species (Table 16).

FIGURE 13. WEIGHT LANDED PER VESSEL (2017), LOUISIANA

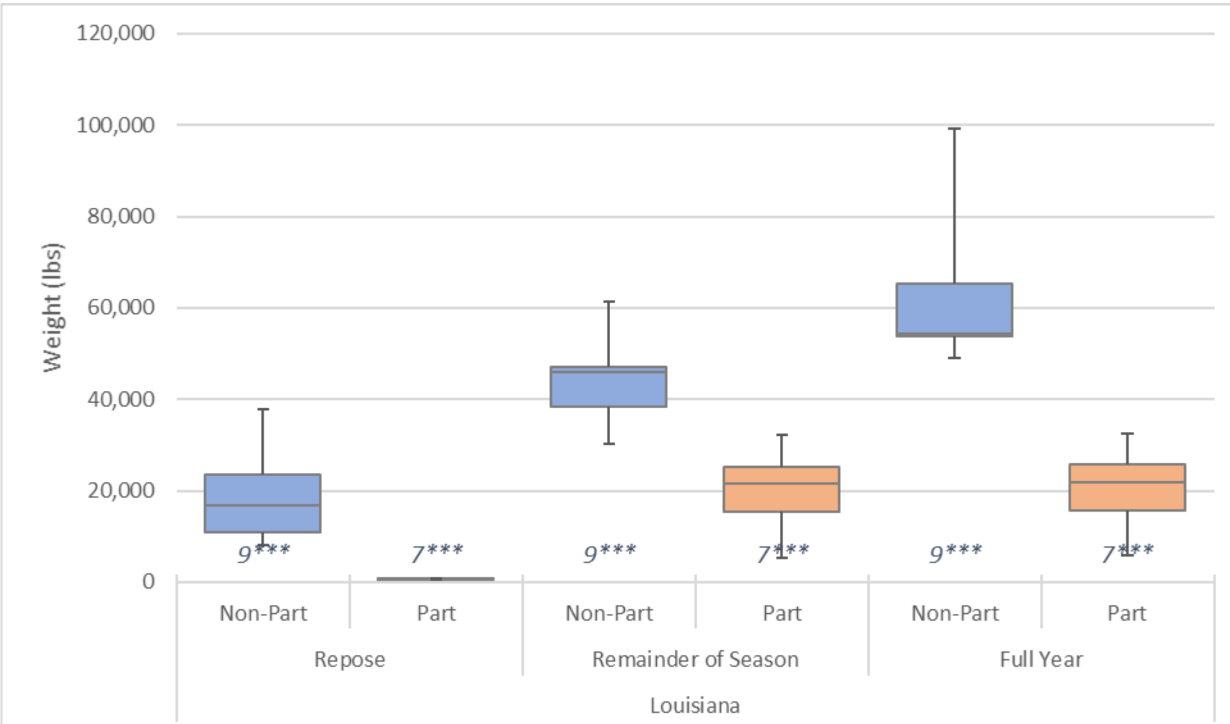


TABLE 13. LANDING WEIGHT (2017): STATISTICAL TESTS OF DIFFERENCE

		REPOSE PERIOD	REMAINDER OF SEASON	FULL YEAR
p-values	T-test	0.000	0.000	0.000
	Rank sum test	0.001	0.001	0.001

Statistics based on a total of 7 participants and 9 eligible non-participants, all from LA.

3.3 3 LANDINGS BY SPECIES

Participants landed only yellowfin during the repose period while non-participants landed a mix of species, primarily yellowfin and swordfish. Outside of the repose period participants landed proportionally more albacore and less yellowfin than non-participants. Over the course of the full year, the difference in proportion of yellowfin landings evens out and there is not a significant difference between groups. Pelagic species were landed the least frequently for non-participants and were not landedat all by participants.

FIGURE 14. LANDINGS BY SPECIES (2017), LOUISIANA

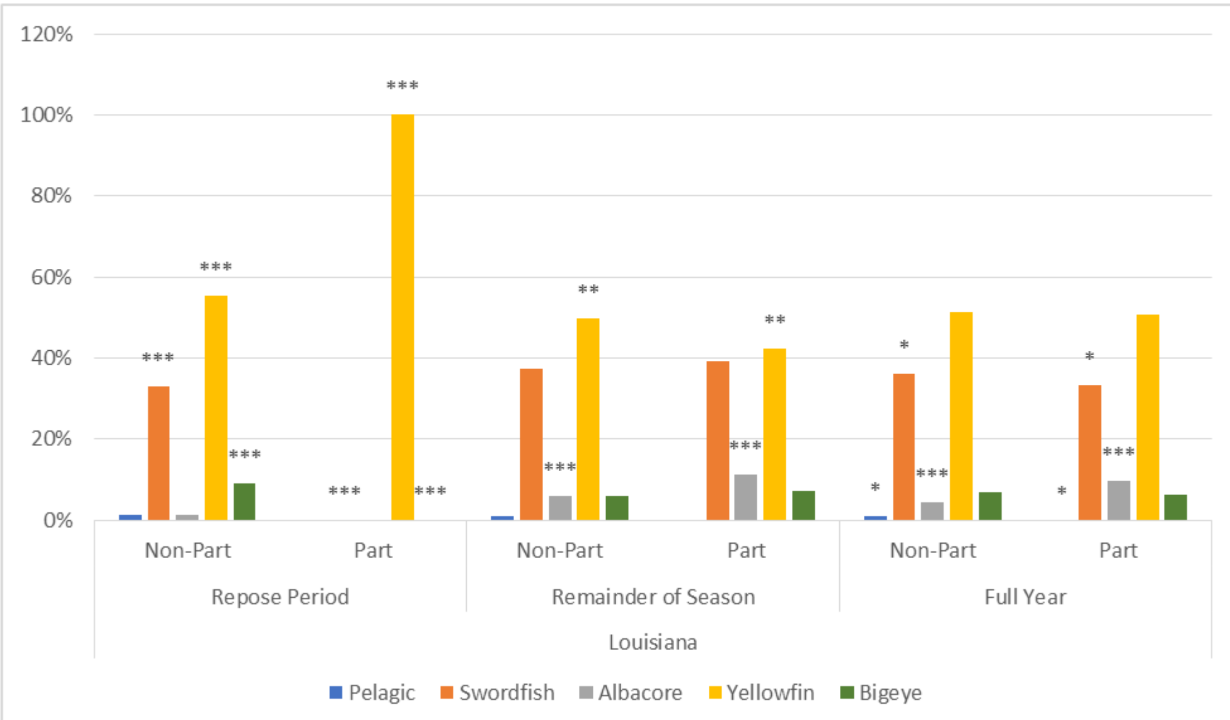


TABLE 14. LANDINGS BY SPECIES (2017): STATISTICAL TESTS OF DIFFERENCE

			REPOSE PERIOD	REMAINDER OF SEASON	FULL YEAR
p-values	Pelagic	T-test	0.243	0.145	0.073
		Rank sum test	0.198	1.630	1.947
	Swordfish	T-test	0.000	0.350	0.091
		Rank sum test	0.000	-0.691	1.802
	Albacore	T-test	0.103	0.004	0.004
		Rank sum test	0.102	-2.809	-2.593
	Yellowfin	T-test	0.000	-	-
		Rank sum test	0.001	-	-
	Bigeye	T-test	0.001	0.016	0.885
		Rank sum test	0.001	2.382	-0.159

Statistics include all 16 eligible and participating Louisiana vessels.

3.4 4 GEAR USAGE PER GEAR SET

As defined in the OFRP, participants did not use pelagic longline gear during the repose period but wereable to use alterative fishing gear. Outside of the repose period, all groups exclusively used longlines.

FIGURE 15. GEAR USAGE BY GEAR SET (2017), LOUISIANA

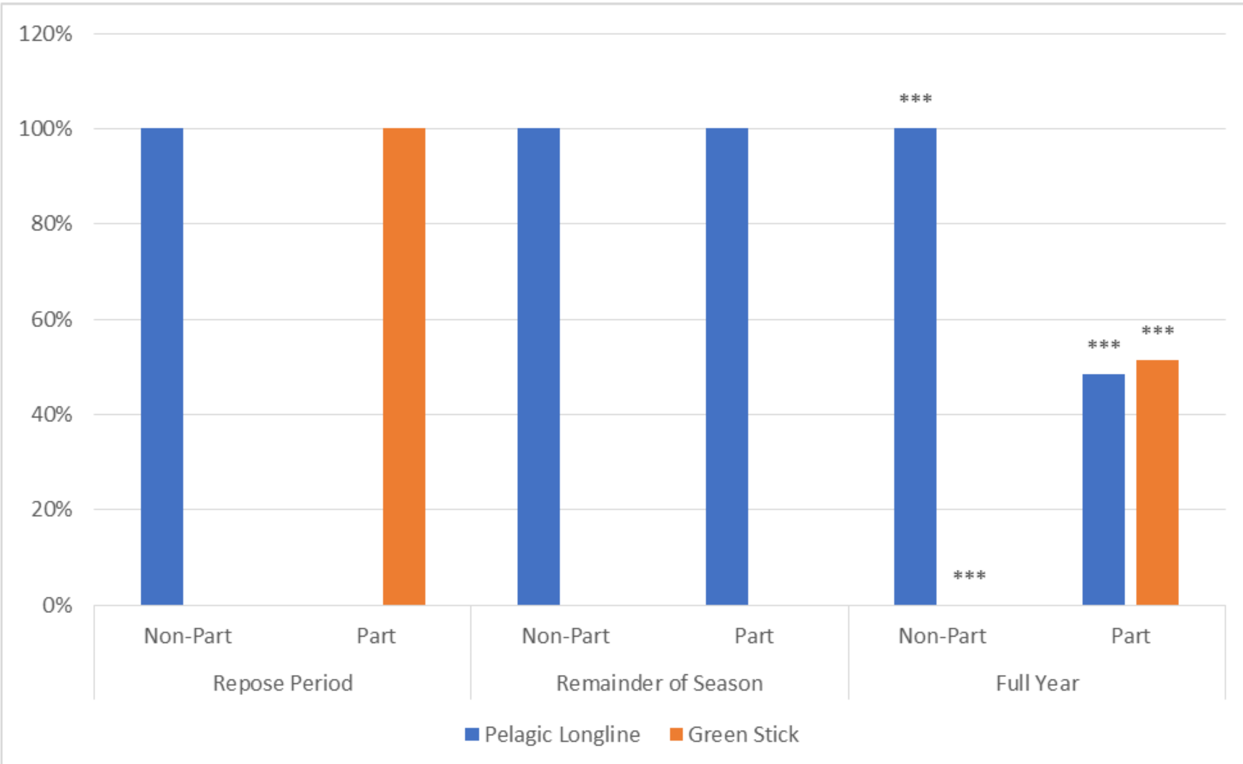


TABLE 15. GEAR USAGE (2017): STATISTICAL TESTS OF DIFFERENCE

			REPOSE PERIOD	FULL YEAR
p-values	Pelagic Long Lines	T-test	0.000	0.000
		Rank sum test	0.000	0.000
	Green Stick	T-test	0.000	0.000
		Rank sum test	0.000	0.000

Statistics include all 16 eligible and participating Louisiana vessels. No statistics shown forremainder of season because all vessels used pelagic longlines.

3.5 5 PURCHASE PRICE BY SPECIES

After the repose, participants received a significantly higher price per pound for yellowfin than non-participants, but generally there is little difference in prices between the two groups.

FIGURE 16. PURCHASE PRICE PER POUND BY SPECIES (2017), LOUISIANA

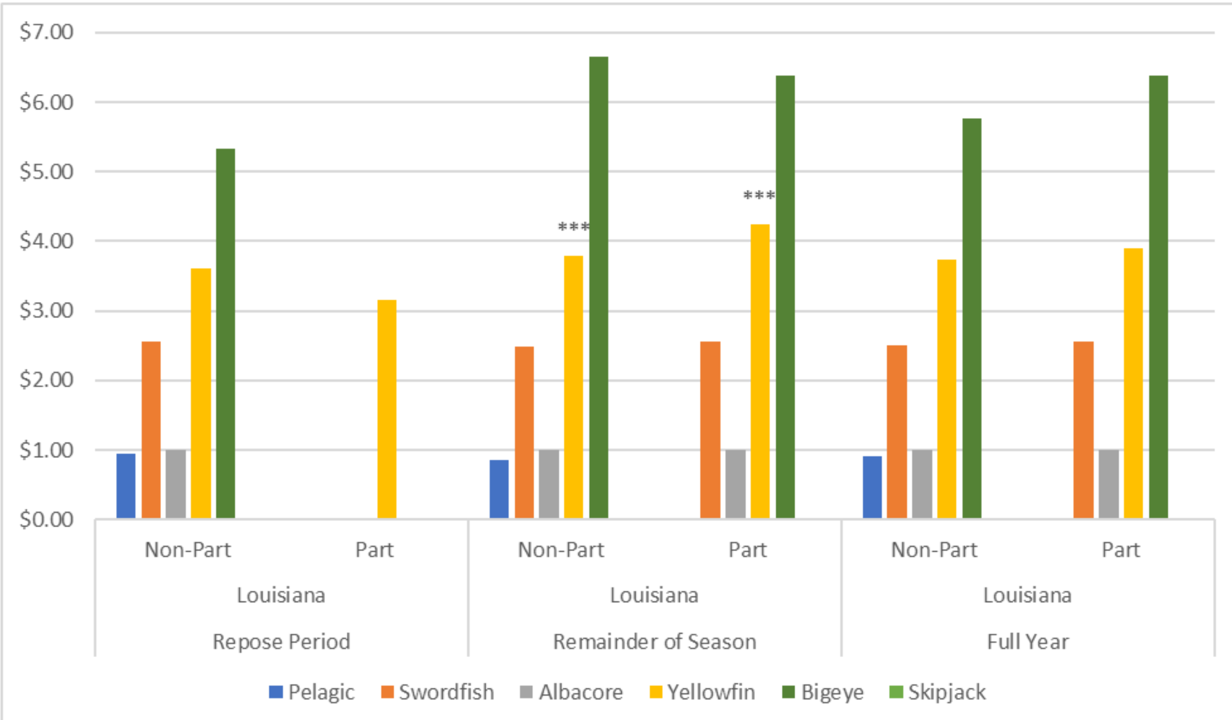


TABLE 16. PRICE PER POUND BY SPECIES (2017): STATISTICAL TESTS OF DIFFERENCE

			REPOSE PERIOD	REMAINDER OF SEASON	FULL YEAR
p-values	Pelagic	T-test	-	-	-
		Rank sum test	-	-	-
	Swordfish	T-test	-	0.063	0.135
		Rank sum test	-	0.055	0.313
	Albacore	T-test	-	0.369	0.369
		Rank sum test	-	0.350	0.350
	Yellowfin	T-test	0.117	0.009	0.314
		Rank sum test	0.153	0.023	0.560
	Bigeye	T-test	-	0.692	0.368
		Rank sum test	-	0.770	0.222

Statistics include all 16 eligible and participating Louisiana vessels. Participants only landed yellowfin during the repose period therefore comparisons for other species are unavailable during that period. Participants also did notland any pelagic species, therefore comparisons on price for pelagic species are not available for any period.

3.6 6 WEIGHT BY SPECIES

During the repose period participants landed yellowfin that weighed significantly less on average thannon-participants. This pattern is reversed, although not significantly, outside of the repose period.

FIGURE 17. WEIGHT (POUNDS) BY SPECIES (2017), LOUISIANA

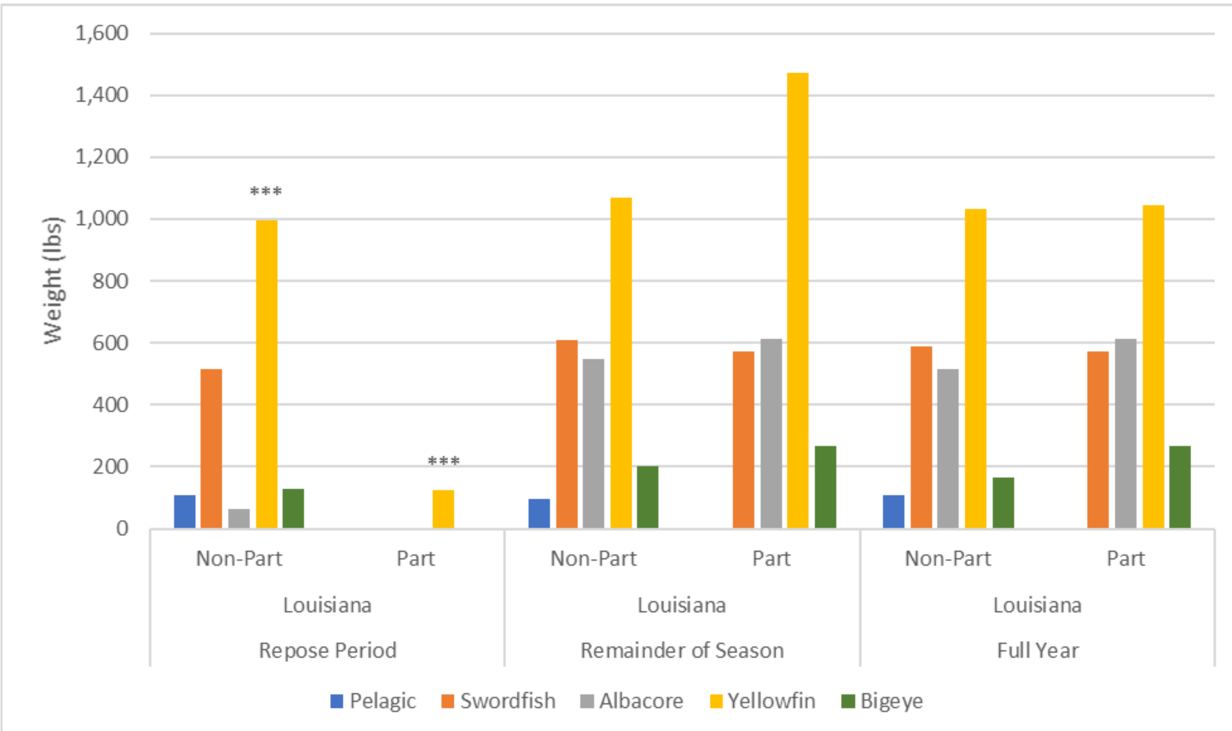


TABLE 17. WEIGHT BY SPECIES (2016): STATISTICAL TESTS OF DIFFERENCE

			REPOSE PERIOD	REMAINDER OF SEASON	FULL YEAR
p-values	Pelagic	T-test	-	-	-
		Rank sum test	-	-	-
	Swordfish	T-test	-	0.544	0.800
		Rank sum test	-	0.711	0.634
	Albacore	T-test	-	0.711	0.634
		Rank sum test	-	0.643	0.563
	Yellowfin	T-test	0.000	0.103	0.947
		Rank sum test	0.001	0.017	0.634
	Bigeye	T-test	-	0.382	0.105
		Rank sum test	-	0.563	0.223

Statistics include all 16 eligible and participating Louisiana vessels. Participants only landed yellowfin during the repose period therefore comparisons for other species are unavailable during that period. Participants also did notland any pelagic species, therefore comparisons on price for pelagic species are not available for any period.

3.7 7 TOTAL SALES PER VESSEL

Based on eDealer landings weight and price per pound, on average, participants had significantly and considerably lower sales per vessel for all time periods. During the repose period, participating vessels averaged $1,349 in sales compared to non-participants who averaged $77,879 in sales. This follows the patterns observed in total weight landed per vessel. Analysis of total sales does not account for the alternative gear payments (up to $60,000) or repose compensation provided to vessel owners that participated in the project.

FIGURE 18. AVERAGE SALES PER TRIP (2017), LOUISIANA

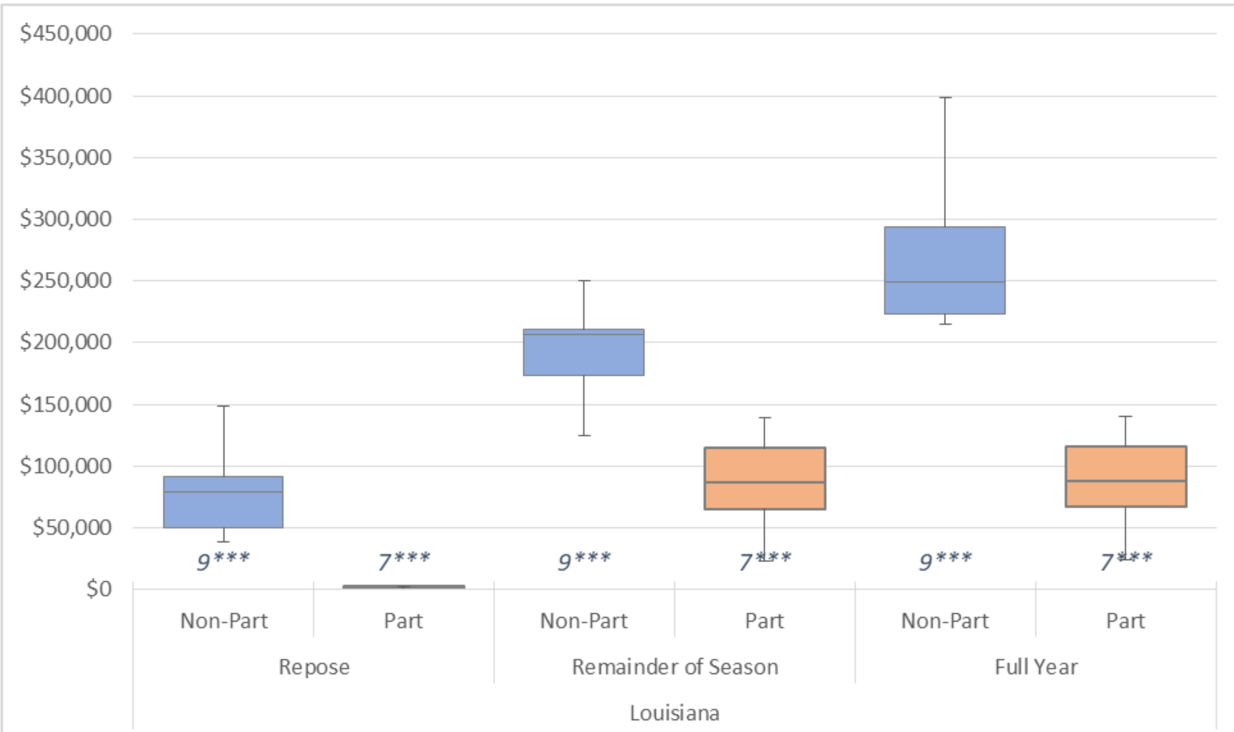


TABLE 18. TOTAL SALES (2017): STATISTICAL TESTS OF DIFFERENCE

		REPOSE PERIOD	REMAINDEROF SEASON	FULL YEAR
p-values	T-test	0.000	0.000	0.000
	Rank sum test	0.001	0.001	0.001

Statistics include all 16 eligible and participating Louisiana vessels.

3.8 8 EXPENSES PER TRIP

During the repose period, participants had significantly lower expenses per trip than non-participants. Outside of the repose period this trend reversed, but not significantly.

FIGURE 19. EXPENSES PER TRIP (2017), LOUISIANA

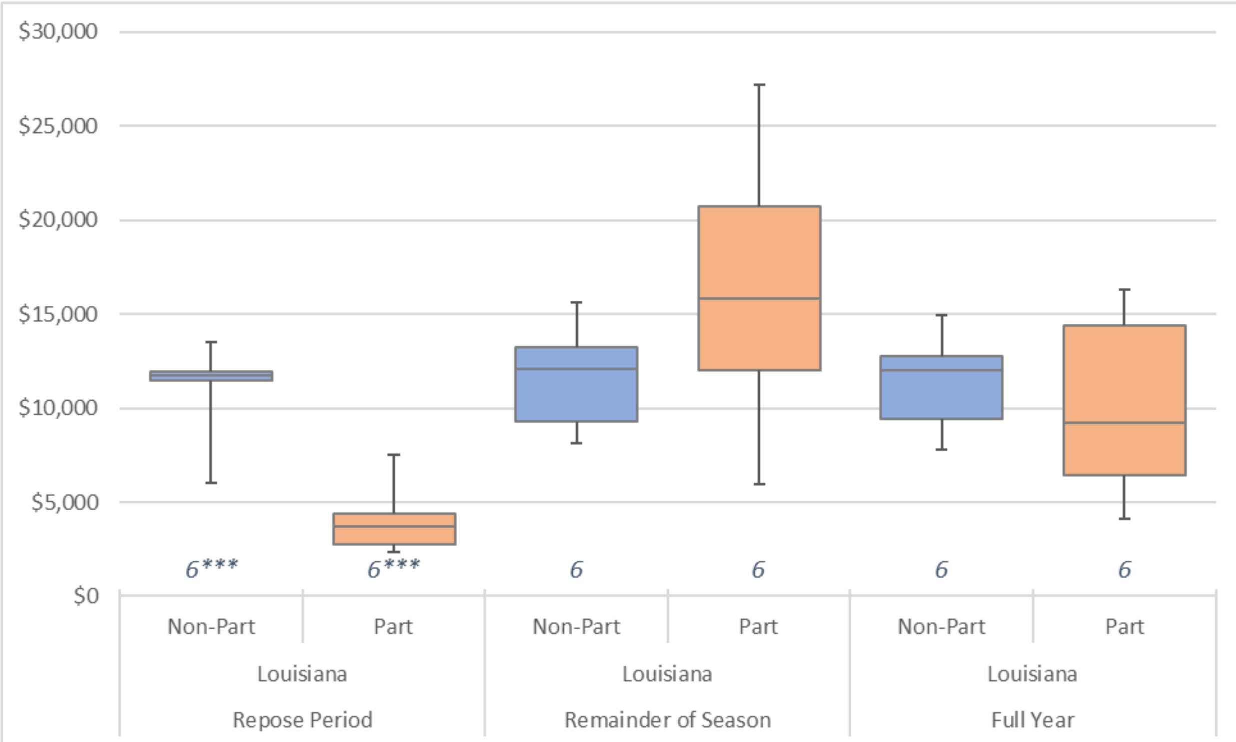


TABLE 19. EXPENSES PER TRIP (2017): STATISTICAL TESTS OF DIFFERENCE

		REPOSE PERIOD	REMAINDER OF SEASON	FULL YEAR
p-values	T-test	0.000	0.193	0.589
	Rank sum test	0.006	0.262	0.631

Statistics include 12 eligible and participating Louisiana vessels. Expense information missingfor three eligible non-participants and one participant.

3.9 9 NET REVENUE PER TRIP

Participants had significantly lower net revenues on average during the repose period than non- participants. Only one of the four participating vessels with net revenue information averaged positive netrevenues during the repose period. Outside of the repose period, participants generally were similar to non-participants, though there was greater variation in net revenues for participants. Analysis of net revenue per trip does not account for the alternative gear payments (up to $60,000) or repose compensation provided to vessel owners that participated in the project.

FIGURE 20. NET REVENUE PER TRIP (2017), LOUISIANA

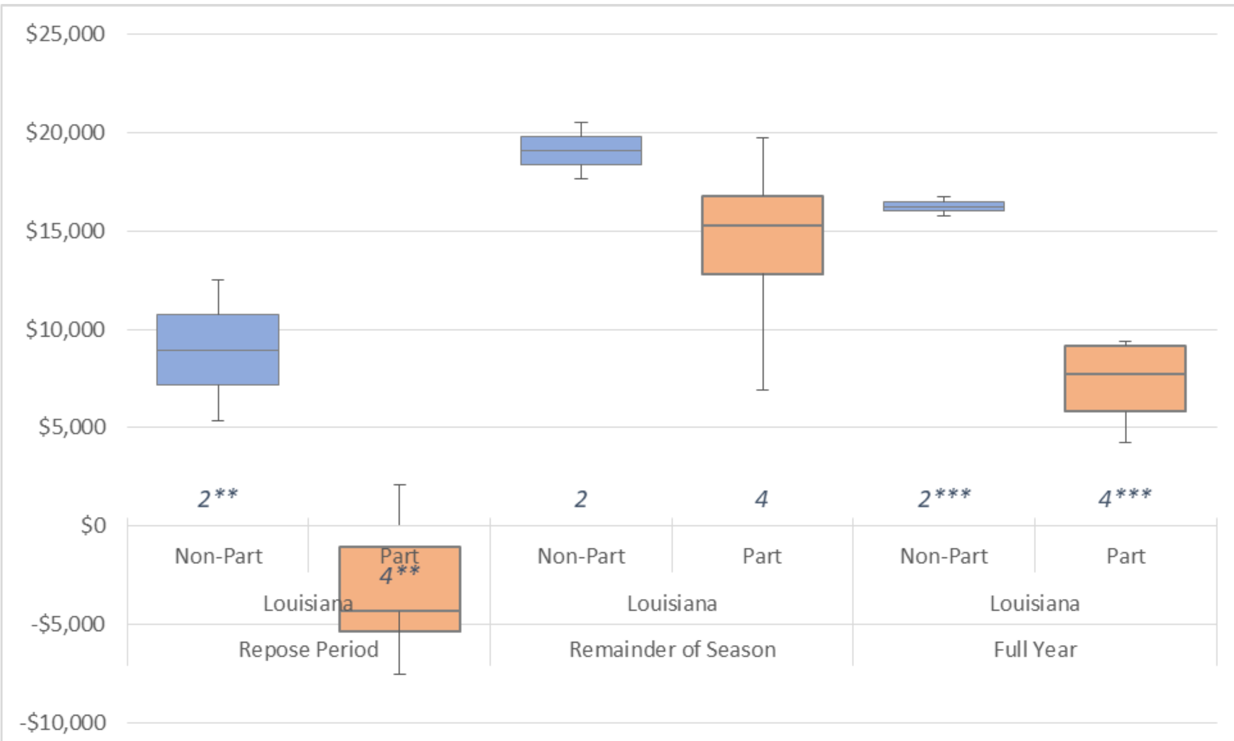


TABLE 20. NET REVENUE (2017): STATISTICAL TESTS OF DIFFERENCE

		REPOSE PERIOD	REMAINDEROF SEASON	FULL YEAR
		LOUISIANA	LOUISIANA	LOUISIANA
# Vessels with Expense Data	Participants (2017 or 2018)	2	2	2
	Non-Participants (2017 or 2018)	4	4	4
p-values	T-test	-0.029	-0.313	0.008
	Rank sum test	0.064	0.165	1.852

Statistics include 6 eligible and participating Louisiana vessels. Expense and/or sales informationmissing for an additional 7 eligible non-participants and 3 participants.

SECTION 4 | PARTICIPATION EFFECTS: 2018 SEASON

This section compares participants and non-participants in 2018 to identify the effects of the project on various outcomes.

In this section we compare the following characteristics:

- Number of trips per vessel
- Total weigh of landings per vessel
- Number of landings by species
- Gear usage per trip
- Average purchase price by species
- Average weight by species
- Total sales per vessel
- Expenses per trip
- Net revenues

Each comparison is run for participants versus eligible non-participants by state for the repose period (first six months of the year), the second half of the year, and the full year. Here the participants are limited to only those vessels that participated in 2018. There were six participants and 10 eligible non- participants from Louisiana and three participants and 10 eligible non-participants from Florida in 2018.Statistical tests are used to identify differences between participants and non-participants by state and portion of the year.

During the repose period, we find that participants landed significantly less total weight per vessel than non-participants but took significantly more trips. Participants only landed swordfish and yellowfin during the repose period while non-participants landed a wider variety of species. For most species, the average weight per landing was similar between the two groups, however participants in Louisiana landedsignificantly fewer pounds per landing of yellowfin than non-participants and received a lower price per pound for yellowfin during the repose. During the repose, participants had lower expenses on average but had substantially lower sales, leading to significantly lower net revenues per trip. The following analysis does not consider the compensation vessel owners received for voluntarily participating in the project. In 2018, participating vessel owners received compensation to offset any potential losses in revenue associated with refraining from using PLL gear during the repose period. In addition, participants received alternative gear payments in the amount of $1,000 per sea-day for up to 60 sea-days over the six-month repose period (up to $60,000).

4.1.1 TRIPS PER VESSEL

For Florida vessels, participants recorded significantly more trips during the repose period than non-participants (average of eight for participants versus an average of three for non-participants). Louisiana vessels did not differ significantly during the repose; however, outside of the repose, participants took fewer trips on average than non-participants (although not significant, in part due to assumed zero trips for missing non-participant vessels) - the same pattern that was observed in 2017.

FIGURE 21. TRIPS PER VESSEL (2018)

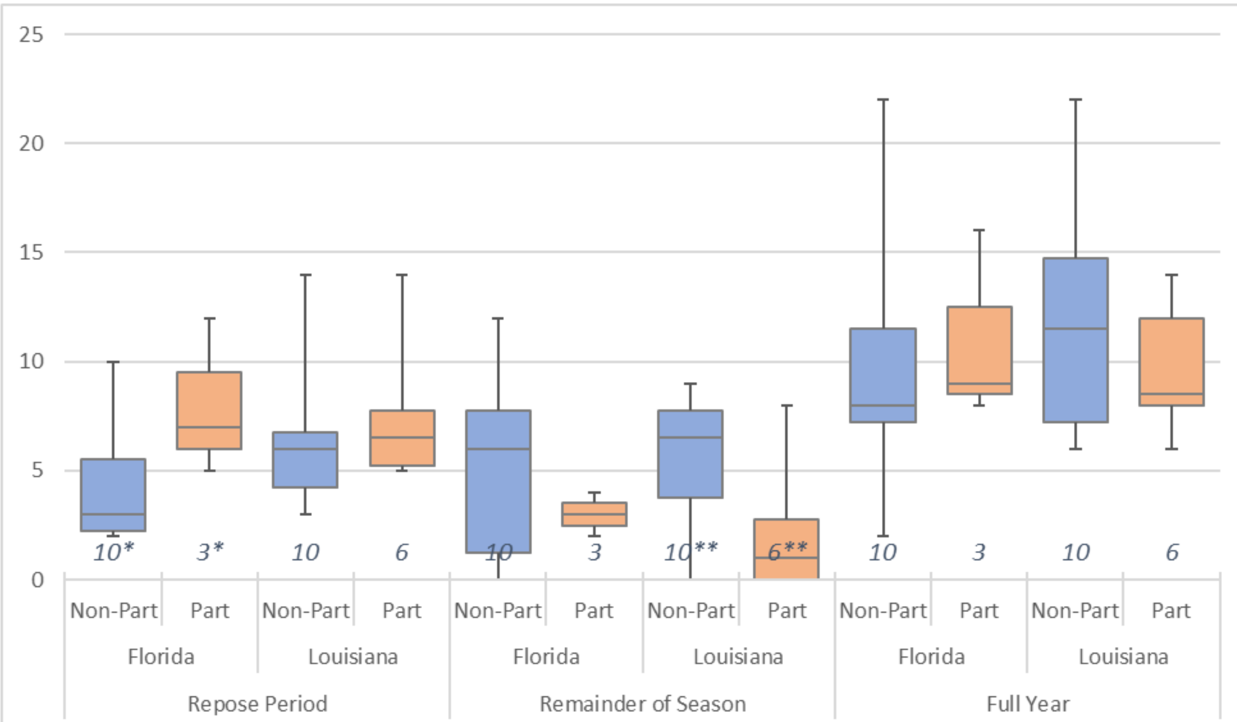


TABLE 21. TRIPS PER VESSEL (2018): STATISTICAL TESTS OF DIFFERENCE

		REPOSE PERIOD		REMAINDER OF SEASON		FULL YEAR	
		FLORIDA	LOUISIANA	FLORIDA	LOUISIANA	FLORIDA	LOUISIANA
p-values	T-test	0.068	0.416	0.374	0.035	0.681	0.372
	Rank sum test	0.072	0.322	0.307	0.054	0.441	0.443

Statistics based on a total of 3 FL participants, 6 LA participants, 10 FL eligible non-participants, and 10 LA eligible non-participants.

42 2 WEIGHT OF LANDINGS PER VESSEL

As in 2017, participants continued to have lower average total weight landed across the full year in Louisiana, and a similar, yet not significant, pattern is observed in Florida. Across the full year and both states, participants averaged a total weight per vessel of 7,269 pounds while non-participants averaged atotal of 28,494 pounds.

FIGURE 22. WEIGHT OF LANDINGS PER VESSEL (2018)

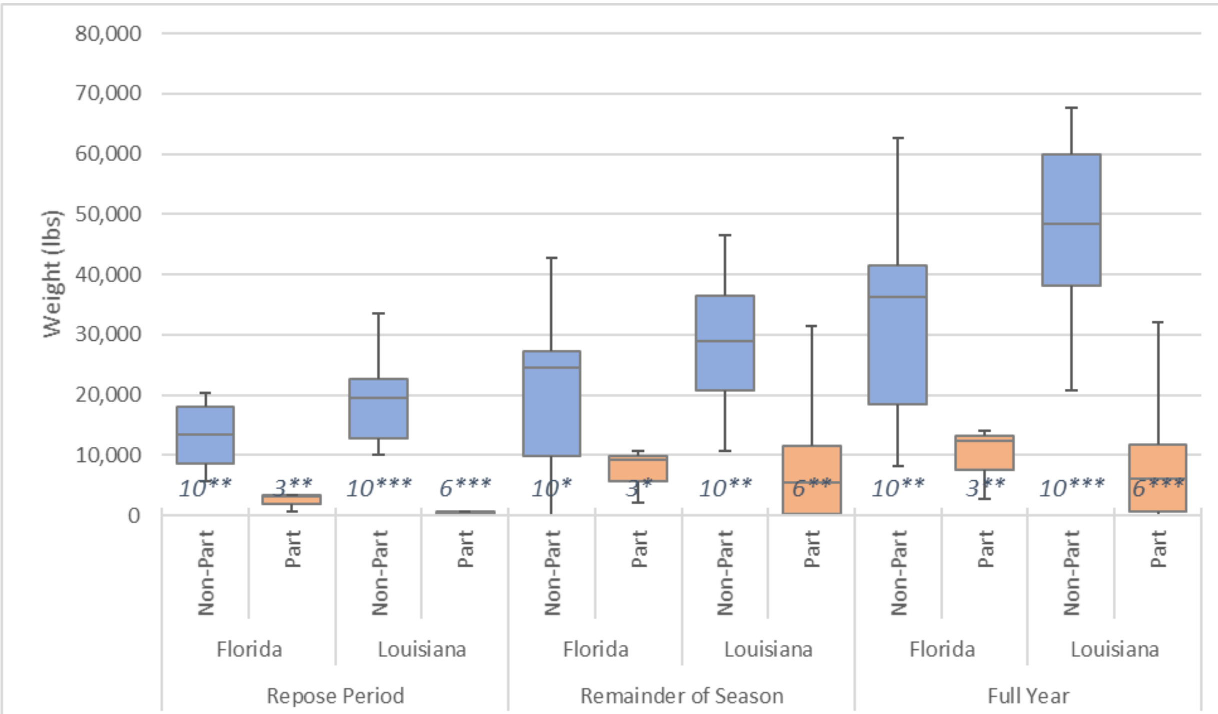


TABLE 22. LANDING WEIGHT PER VESSEL (2018): STATISTICAL TESTS OF DIFFERENCE

		REPOSE PERIOD		REMAINDER OF SEASON		FULL YEAR	
		FLORIDA	LOUISIANA	FLORIDA	LOUISIANA	FLORIDA	LOUISIANA
p-values	T-test	0.192	0.002	0.298	0.089	0.244	0.015
	Rank sum test	0.433	0.028	0.642	0.093	0.514	0.042

Statistics based on a total of 3 FL participants, 6 LA participants, 10 FL eligible non-participants, and 10 LA eligible non-participants.

43 3 LANDINGS BY SPECIES

There were significant differences in the proportion of species landed across many of the comparison groups, however the direction of these difference was often opposite in Florida and Louisiana, making it difficult to identify a meaningful pattern. During the repose period, Florida participants caught proportionally *more* swordfish and *less* yellowfin than their non-participant counterparts while Louisianaparticipants caught proportionally *less* swordfish and *more* yellowfin. As was the case in 2017, all of the landings for participants in Louisiana during the repose period were yellowfin.

FIGURE 23. DISTRIBUTION OF LANDINGS BY SPECIES (2018)

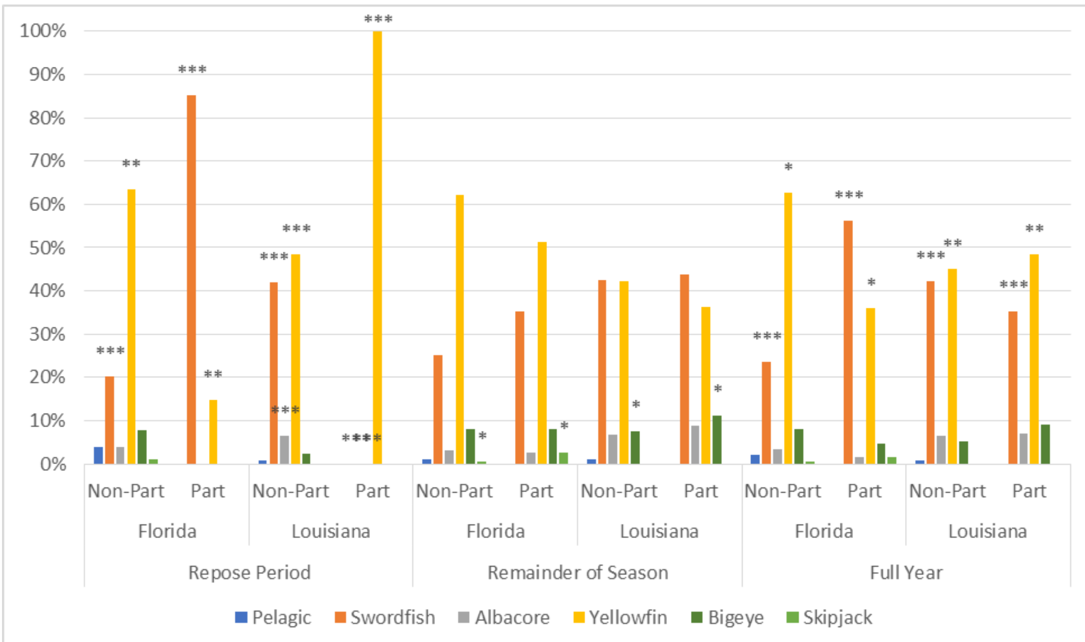


TABLE 23. LANDINGS BY SPECIES (2018): STATISTICAL TESTS OF DIFFERENCE

			REPOSE PERIOD		REMAINDER OF SEASON		FULL YEAR	
			FLORIDA	LOUISIANA	FLORIDA	LOUISIANA	FLORIDA	LOUISIANA
p-values	Pelagic	T-test	0.384	0.353	0.503	0.313	0.404	0.132
		Rank sum test	0.297	0.301	0.456	0.275	0.335	0.068
	Swordfish	T-test	0.000	0.000	0.169	0.614	0.002	0.009
		Rank sum test	0.040	0.002	0.117	0.515	0.037	0.020
	Albacore	T-test	0.626	0.004	0.988	0.307	0.758	0.557
		Rank sum test	0.593	0.004	0.883	0.354	0.883	0.461
	Skipjack	T-test	0.626	-	0.090	-	0.364	-
		Rank sum test	0.593	-	0.192	-	0.420	-
	Yellowfin	T-test	0.015	0.000	0.334	0.141	0.052	0.045
		Rank sum test	0.079	0.002	0.116	0.266	0.117	0.297
	Bigeye	T-test	0.626	0.200	0.859	0.051	0.808	0.706
		Rank sum test	0.593	0.238	0.232	0.478	0.372	0.776

No landings recorded in 2018 (and therefore no species information) for 2 participants (1 LA, 1 FL) and 2 FL eligible non-participants.

44 4 GEAR USAGE PER GEAR SET

In 2018, participants used a combination of rod and reel, buoy, and green stick gear during the repose period. In Florida, the majority (71%) of participants used buoy gear and the rest used deep drop rod andreel, while in Louisiana the majority (82%) of participants used greensticks. During the remainder of theseason almost all sets were pelagic longline.

FIGURE 24. GEAR USAGE PER GEAR SET (2018)

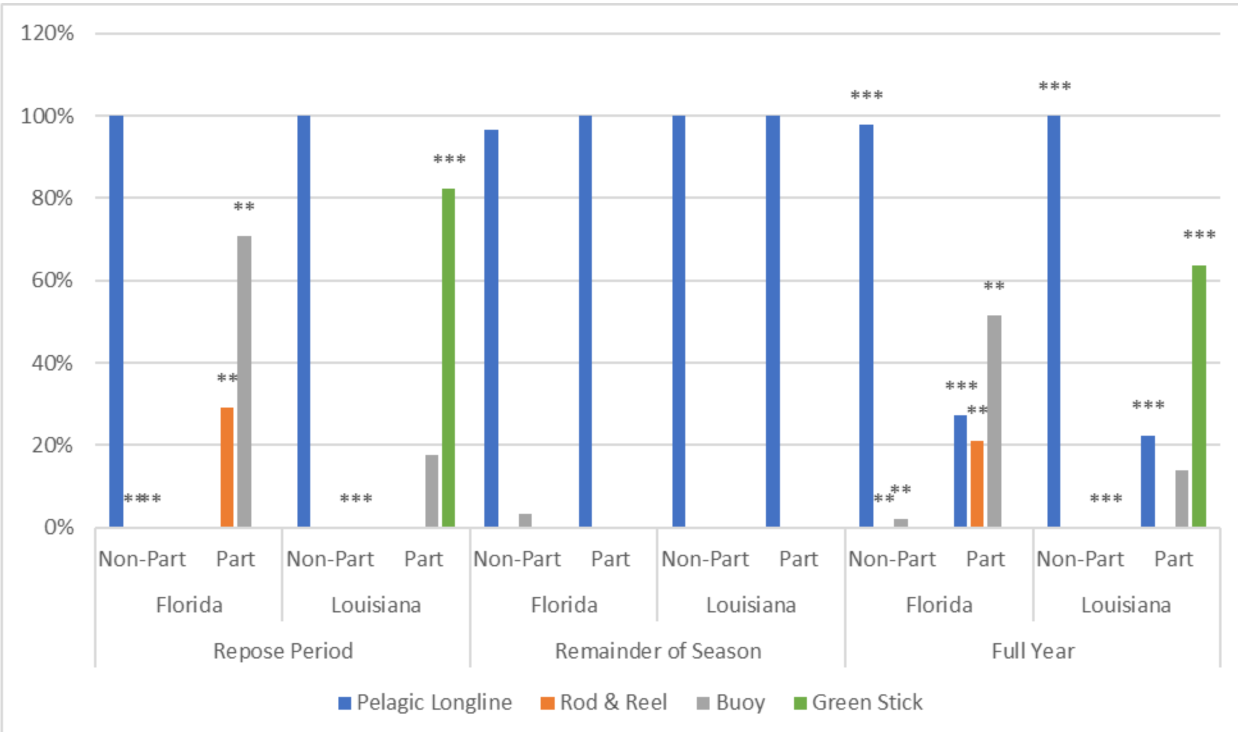


TABLE 24. GEAR USAGE (2018): STATISTICAL TESTS OF DIFFERENCE

			REPOSE PERIOD		REMAINDER OF SEASON		FULL YEAR	
			FLORIDA	LOUISIANA	FLORIDA	LOUISIANA	FLORIDA	LOUISIANA
p-values	Pelagic Longline	T-test	0.384	0.353	0.503	0.313	0.404	0.132
		Rank sum test	0.297	0.301	0.456	0.275	0.335	0.068
	Rod & Reel	T-test	0.000	0.000	0.169	0.614	0.002	0.009
		Rank sum test	0.040	0.002	0.117	0.515	0.037	0.020
	Buoy	T-test	0.626	0.004	0.988	0.307	0.758	0.557
		Rank sum test	0.593	0.004	0.883	0.354	0.883	0.461
	Green Stick	T-test	0.626	-	0.090	-	0.364	-
		Rank sum test	0.593	-	0.192	-	0.420	-

Statistics include all 29 eligible and participating vessels.

45 5 PURCHASE PRICE BY SPECIES

In 2018, participants in Louisiana received significantly less per pound for yellowfin landed during the repose period, a trend not observed in 2017. Outside of the repose period, Florida participants received significantly more per pound for yellowfin than non-participants. Participants in both states did not catchany bigeye, the species with the highest price per pound, during the repose period.

FIGURE 25. PURCHASE PRICE PER POUND BY SPECIES (2018)

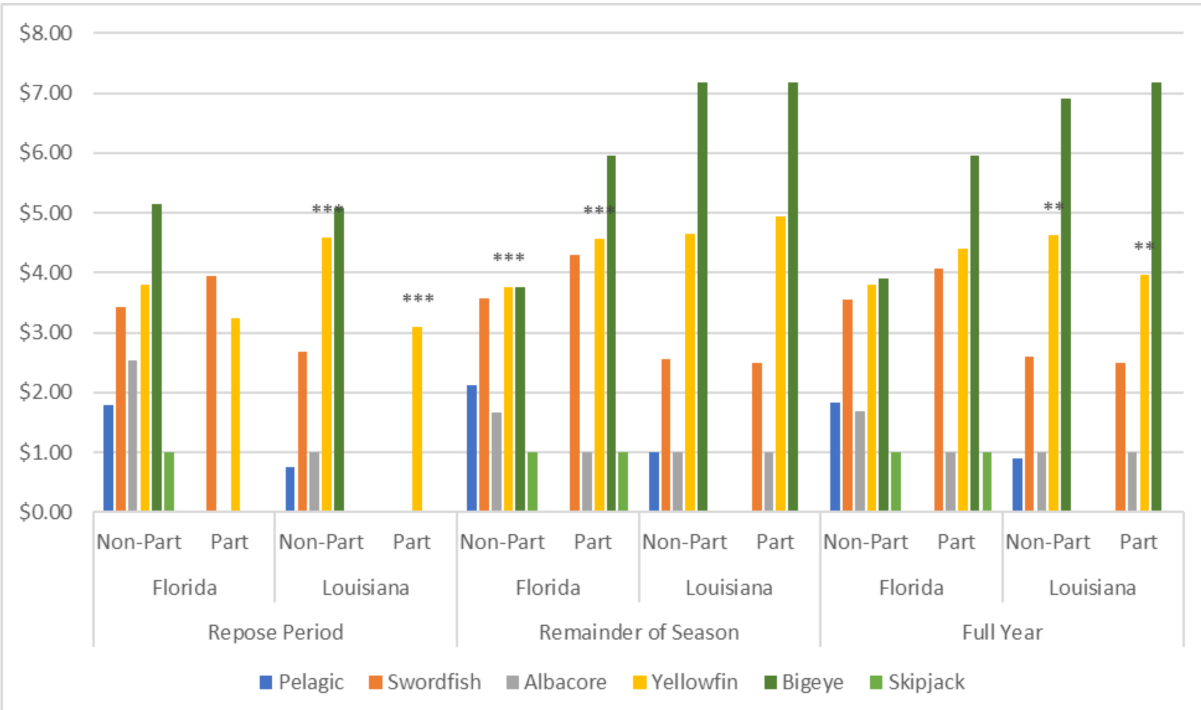


TABLE 25. PRICE PER POUND BY SPECIES (2018): STATISTICAL TESTS OF DIFFERENCE

			REPOSE PERIOD		REMAINDER OF SEASON		FULL YEAR	
			FLORIDA	LOUISIANA	FLORIDA	LOUISIANA	FLORIDA	LOUISIANA
p-values	Pelagic	T-test	-	-	-	-	-	-
		Rank sum test	-	-	-	-	-	-
	Swordfish	T-test	0.555	-	0.127	0.604	0.315	0.312
		Rank sum test	0.242	-	0.192	0.518	0.296	0.237
	Albacore	T-test	-	-	-	-	-	-
		Rank sum test	-	-	0.346	-	0.346	-
	Skipjack	T-test	-	-	-	-	-	-
		Rank sum test	-	-	-	-	-	-
	Yellowfin	T-test	-	0.001	0.006	0.323	0.139	0.012
		Rank sum test	0.380	0.003	0.037	0.195	0.117	0.020
	Bigeye	T-test	-	-	0.223	-	0.252	0.692
		Rank sum test	-	-	0.245	0.808	0.245	0.912

No landings recorded in 2018 (and therefore no species information) for 2 participants (1 LA, 1 FL) and 2 FL eligible non-participants.

Participants landed less yellowfin per landing, in terms of weight per landing. This difference is significant in Louisiana during the repose but pronounced in both states and across all time periods.

FIGURE 26. WEIGHT BY SPECIES (2018) IN POUNDS

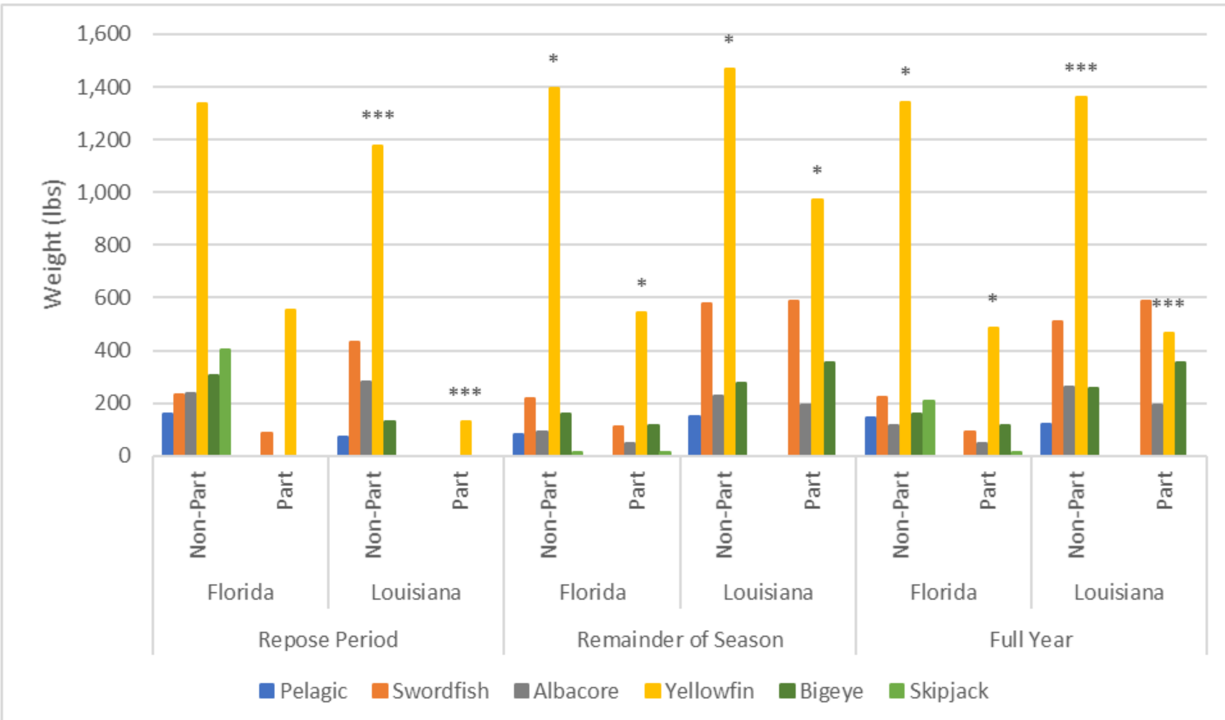


TABLE 26. WEIGHT BY SPECIES (2018): STATISTICAL TESTS OF DIFFERENCE

			REPOSE PERIOD		REMAINDER OF SEASON		FULL YEAR	
			FLORIDA	LOUISIANA	FLORIDA	LOUISIANA	FLORIDA	LOUISIANA
p-values	Pelagic	T-test	-	-	-	-	-	-
		Rank sum test	-	-	-	-	-	-
	Swordfish	T-test	0.665	-	0.639	0.971	0.615	0.563
		Rank sum test	0.769	-	0.694	0.782	0.433	0.735
	Albacore	T-test	-	-	-	0.748	-	0.504
		Rank sum test	-	-	0.180	0.644	0.180	0.405
	Skipjack	T-test	-	-	-	-	-	-
		Rank sum test	-	-	0.317	-	-	-
	Yellowfin	T-test	-	0.000	0.087	0.097	0.066	0.000
		Rank sum test	0.275	0.002	0.117	0.116	0.117	0.005
	Bigeye	T-test	-	-	0.559	0.432	0.557	0.333
		Rank sum test	-	-	0.439	0.166	0.439	0.079

No landings recorded in 2018 (and therefore no species information) for 2 participants (1 LA, 1 FL) and 2 FL eligible non-participants.

47 7 TOTAL SALES PER VESSEL

Participants had significantly lower total sales per vessel than non-participants across the majority of time periods in both states. During the repose period, participants averaged $3,293 in total sales while non-participants averaged $82,617 per vessel. This effect is similar to the pattern observed in 2017. Analysis of total sales does not account for the alternative gear payments (up to $60,000) or repose compensation provided to vessel owners that participated in the project.

FIGURE 27. TOTAL SALES PER VESSEL (2018)

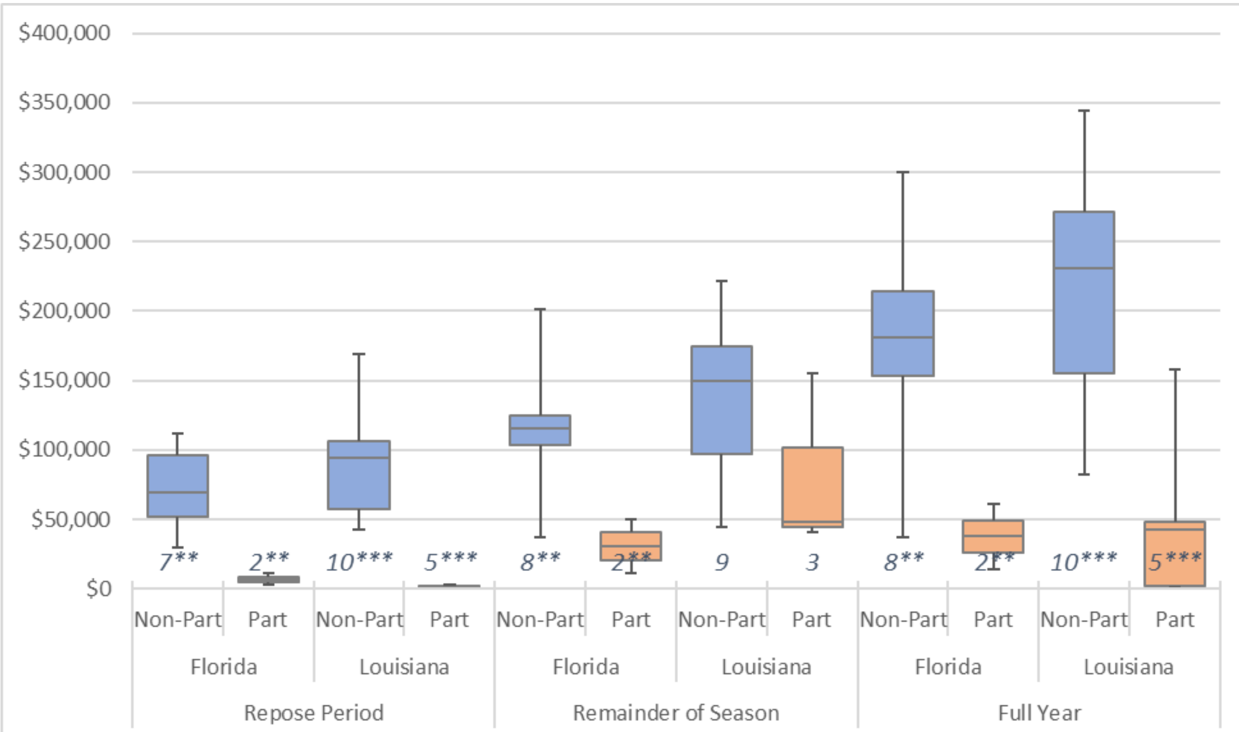


TABLE 27. TOTAL SALES (2018): STATISTICAL TESTS OF DIFFERENCES

		REPOSE PERIOD		REMAINDER OF SEASON		FULL YEAR	
		FLORIDA	LOUISIANA	FLORIDA	LOUISIANA	FLORIDA	LOUISIANA
p-values	T-test	0.024	0.000	0.037	0.160	0.036	0.003
	Rank sum test	0.040	0.002	0.068	0.166	0.068	0.007

No landings recorded in 2018 (and therefore no sales information) 2 participants (1 LA, 1 FL) and 2 FL eligiblenon-participants.

As in 2017 in Louisiana, participants had significantly lower expenses per trip on average than non-participants during the repose period. This difference is not seen in the Florida fleet.

FIGURE 28. EXPENSES PER TRIP (2018)

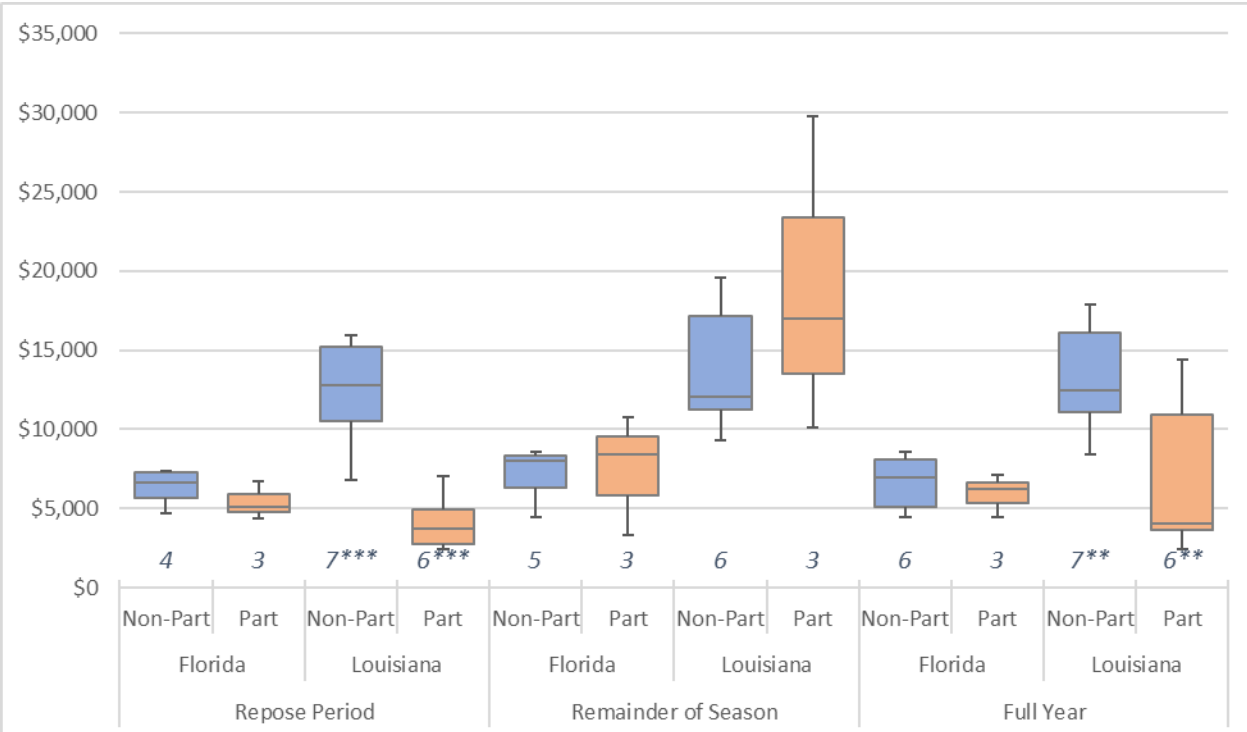


TABLE 28. EXPENSES PER TRIP (2018): STATISTICAL TESTS OF DIFFERENCE

		REPOSE PERIOD		REMAINDER OF SEASON		FULL YEAR	
		FLORIDA	LOUISIANA	FLORIDA	LOUISIANA	FLORIDA	LOUISIANA
p-values	T-test	0.361	0.000	0.865	0.295	0.560	0.027
	Rank sum test	0.289	0.004	0.655	0.606	0.302	0.063

Expense information missing for 4 FL eligible non-participants and 3 LA eligible non-participants.

49 9 NET REVENUE PER TRIP

Even though total expenses per trip were lower for participants than non-participants during the repose, the lower sales per trip for participants led to lower net revenues for participants versus non-participants, particularly in Florida, during the repose period. Five out of seven participating vessels, including all Florida participants, averaged negative net revenues during the repose period. Analysis of net revenue pertrip does not account for the alternative gear payments (up to $60,000) or repose compensation provided to vessel owners that participated in the project.

FIGURE 29. NET REVENUE PER TRIP (2018)

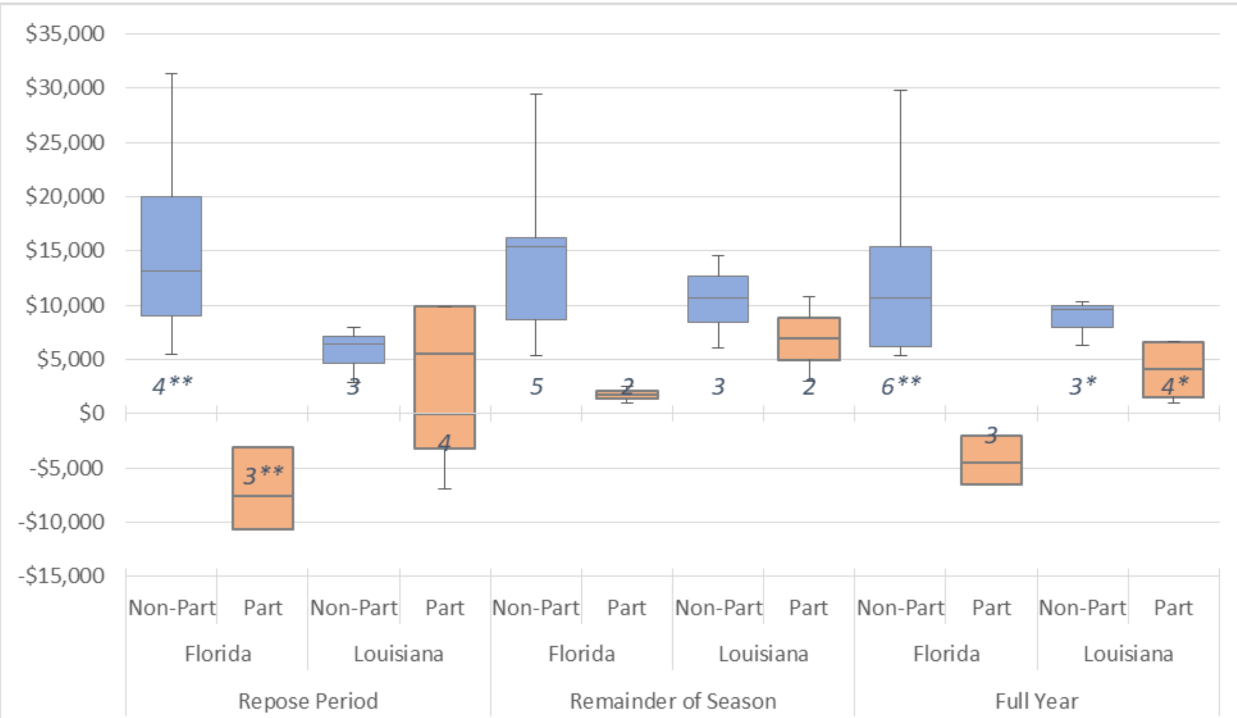


TABLE 29. NET REVENUE (2018): STATISTICAL TESTS OF DIFFERENCE

		REPOSE PERIOD		REMAINDER OF SEASON		FULL YEAR	
		FLORIDA	LOUISIANA	FLORIDA	LOUISIANA	FLORIDA	LOUISIANA
# Vessels with Expense Data	Participants (2017 or 2018)	4	3	5	3	6	3
	Non-Participants (2017 or 2018)	3	4	2	2	3	4
p-values	T-test	0.033	0.315	0.115	0.471	0.026	0.074
	Rank sum test	0.034	0.480	0.053	0.564	0.020	0.157

Expense and/or sales information missing for 2 LA participants, 4 FL eligible non-participants, and 7 LA eligiblenon-participants.

SECTION 5 | CHANGE IN PARTICIPATION EFFECTS: 2017 VS. 2018 SEASON

The tables below present the outputs of the difference-in-difference regressions. For each explanatory variable (listed along the left-hand side), we first report the coefficient, or effect of that variable. The p-value, or significance level of the estimated effect, is shown in parentheses below the estimate.

The first row (participation) compares the effect of participation on the outcome. The second row (Year = 2018) shows the effect of the trip or landing occurring in 2018, all else constant. The highlighted row represents the difference-in-difference variable, where the coefficients reflect differences in the rate of change between 2017 and 2018 by participation status.

5.1 1 TOTAL TRIPS AND TOTAL WEIGHT OF LANDINGS PER VESSEL

While on average, vessels took slightly fewer trips in 2018 compared to 2017 (average of 9.0 in 2017 versus 8.2 in 2018), trips taken by participants decreased by less on average between 2017 and 2018 whencontrolling for state, including during the repose period. This suggests participants may be getting more comfortable using alternative gears or are becoming more profitable over time. There are no significant differences in the total weight landed between participants and non-participants from 2017 to 2018. It is interesting to also note that the regression shows participants took significantly fewer trips than non- participants outside of the repose period and that participants had significantly lower total weight landed across all time periods, as described in Sections 3 and 4 (see Table 12, Table 13, Table 21, and Table 22).

TABLE 30. REGRESSION OUTPUT: 2017 VS. 2018 TOTAL TRIPS AND TOTAL WEIGHT OF LANDINGS

	TOTAL TRIPS			TOTAL WEIGHT OF LANDINGS		
	REPOSE	REMAINDER OF SEASON	FULL YEAR	REPOSE	REMAINDER OF SEASON	FULL YEAR
Participation	-0.281	-5.678***	-7.015*	-19561***	-30778***	-100677***
	(0.780)	(0.002)	(0.096)	(0.001)	(0.005)	(0.001)
Year = 2018	-1.043	-2.779**	0.534	-10484**	-19127***	-59221***
	(0.116)	(0.017)	(0.844)	(0.010)	(0.010)	(0.005)
Participant in Year 2018	3.391**	2.785	4.004	9576.992	16032.687	51219.357
	(0.012)	(0.218)	(0.459)	(0.224)	(0.259)	(0.201)
State = LA	1.377**	0.828	3.470	-4524.654	-11695*	-32440*
	(0.027)	(0.432)	(0.170)	(0.222)	(0.083)	(0.087)
Constant	3.904***	7.564***	18.831***	24515.676***	51692.610***	152416***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
R-squared	0.267	0.272	0.071	0.378	0.371	0.420
Adj. R-squared	0.215	0.219	0.005	0.327	0.319	0.372
N	61	60	61	54	54	54

p-values in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

5.2 2 EXPENSES, SALES, AND NET REVENUES

There are no significant differences in the change in expenses, sales and net revenues per trip between participants and non-participants over the two years. As shown in Sections 3 and 4, expenses were significantly lower on average for participants during the repose period compared to non-participants andsales were lower for participants across all periods. Participants had significantly lower net revenues during the repose period.

TABLE 31. REGRESSION OUTPUT: 2017 VS. 2018 EXPENSES AND SALES PER TRIP

	EXPENSES PER TRIP			TOTAL SALES PER VESSEL		
	REPOSE	REMAINDER OF SEASON	FULL YEAR	REPOSE	REMAINDER OF SEASON	FULL YEAR
Participation	-5448.117**	5659.528**	-3183.269	-87922.6***	-125165***	-214080***
	(0.027)	(0.050)	(0.115)	(0.001)	(0.008)	(0.001)
Year = 2018	1249.357	434.589	752.247	-25765	-62968**	-108323**
	(0.512)	(0.830)	(0.604)	(0.151)	(0.039)	(0.011)
Participant in Year 2018	2032.467	-2970.510	-643.168	23382.928	59260.367	92954.113
	(0.515)	(0.435)	(0.800)	(0.485)	(0.360)	(0.259)
State = LA	1961.072	5570.324***	3559.093***	-13442	-34708	-58811
	(0.232)	(0.004)	(0.008)	(0.408)	(0.217)	(0.131)
Constant	7529.040***	7302.099***	7788.545***	102713***	210916***	317991***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
R-squared	0.214	0.421	0.247	0.403	0.305	0.415
Adj. R-squared	0.118	0.346	0.168	0.349	0.244	0.367
N	38	36	43	50	50	54

p-values in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

TABLE 32. REGRESSION OUTPUT: 2017 VS. 2018 NET REVENUES PER TRIP

	NET REVENUE PER TRIP		
	REPOSE	REMAINDER OF SEASON	FULL YEAR
Participation	-20181.1***	522.022	-10397**
	(0.004)	(0.925)	(0.029)
Year = 2018	-4192.824	-1676.670	-3163.876
	(0.379)	(0.667)	(0.306)
Participant in Year 2018	2595.763	-9663.615	-1131.018
	(0.734)	(0.190)	(0.834)
State	-1350.146	1455.968	1698.115
	(0.746)	(0.699)	(0.555)
Constant	18787.836***	14432.619***	14707.522***
	(0.000)	(0.000)	(0.000)
R-squared	0.619	0.240	0.467
Adj. R-squared	0.547	0.088	0.382
N	26	25	30

p-values in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

5.3 3 PURCHASE PRICE AND WEIGHT PER LANDING

On average across all eligible vessels, weight per landing was down slightly in 2018 compared to 2017;however, weight per landing outside of the repose period and for the full year dropped more for participants between the two years compared to non-participants. Purchase price does not vary significantly by participation or year but is significantly different by species, as would be expected.

TABLE 33. REGRESSION OUTPUT: 2017 VS. 2018 PURCHASE PRICE AND WEIGHT PER LANDING

	PURCHASE PRICE PER LANDING			WEIGHT PER LANDING		
	REPOSE	REMAINDER OF SEASON	FULL YEAR	REPOSE	REMAINDER OF SEASON	FULL YEAR
Participation	-0.567	-0.008	-0.153	-1076.411***	377.471**	-12.277
	(0.159)	(0.974)	(0.520)	(0.000)	(0.032)	(0.923)
Year = 2018	-0.013	0.022	0.119	-89.980	-186.943*	-100.462
	(0.948)	(0.884)	(0.424)	(0.456)	(0.090)	(0.208)
Participant in Year 2018	0.105	0.355	0.307	225.427	-542.023**	-292.208*
	(0.841)	(0.292)	(0.347)	(0.490)	(0.027)	(0.097)
State = LA	-0.425**	0.015	-0.101	-254.184**	-101.913	-91.595
	(0.014)	(0.918)	(0.471)	(0.018)	(0.328)	(0.224)
Species = Swordfish	1.812***	1.438***	1.619***	468.115**	251.077	366.584***
	(0.000)	(0.000)	(0.000)	(0.011)	(0.173)	(0.004)
Species = Albacore	0.115	-0.449	-0.261	336.305	188.969	314.167**
	(0.760)	(0.091)*	(0.297)	(0.149)	(0.327)	(0.020)
Species = Skipjack	-0.756	-0.465	-0.421	249.694	-154.851	-21.417
	(0.437)	(0.366)	(0.368)	(0.678)	(0.678)	(0.932)
Species = Yellowfin	2.378***	2.487***	2.483***	1212.671***	1307.561***	1077.753***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Species = Bigeye	3.312***	4.245***	4.147***	124.353	170.885	175.729
	(0.000)	(0.000)	(0.000)	(0.545)	(0.366)	(0.177)
Constant	1.769***	1.617***	1.519***	242.286	346.211**	268.391**
	(0.000)	(0.000)	(0.000)	(0.131)	(0.030)	(0.015)
R-squared	0.574	0.773	0.752	0.425	0.398	0.392
Adj. R-squared	0.543	0.763	0.741	0.382	0.370	0.366
N	131	203	216	131	203	216

p-values in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

5.4 4 CONCLUSIONS

During both project years participants have fewer trips and landings, and lower sales and net revenues, particularly during the repose period. These differences did not exist prior to the project implementation in 2017. Participants have shown a slight improvement in number of trips over time (i.e. between the 2017 and 2018 seasons) compared to non-participants, which suggests some learning, adaptation, or otherefficiency gains by participants over these two years.

The findings in this report could be further verified by exploring similar results for future seasons of theOFRP project.

APPENDIX C

EVALUATION OF GREENSTICK GEAR IN THE GULF OF MEXICO

Deepwater Horizon Oceanic Fish Restoration Project (OFRP)

Evaluation of Greenstick Gear in the Gulf of Mexico

Final Report

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Executive Summary

Scientists from the NOAA Southeast Fisheries Science Center conducted greenstick gear (GSG) research, in support of the Deepwater Horizon Oceanic Fish Restoration Project. In 2017 and 2018, gear studies were conducted to directly compare GSG to pelagic longline (PLL) for yellowfin tuna catch rates, tuna quality, and bycatch. Research was also conducted in the vicinity of petroleum platforms to draw comparisons between fish caught around artificial structures and fish caught in the open ocean. Additional experiments were conducted to test methods for improving the quality of tuna caught on GSG.

During 14 fishing days onboard the R/V *Southern Journey,* a total of 116 GSG fishing hours were conducted; nine days (70 hours) were conducted in the open ocean to compare GSG to PLL gear and five days (46 hours) were conducted near petroleum platforms. A total of 49 individual animals were captured on GSG. The dominant species caught was blackfin tuna, comprising 51% of the total catch. Yellowfin tuna accounted for 16% of the total. Skipjack tuna and little tunny made up 14% and 4% of the catch respectively. A total of eight yellowfin tuna were caught on GSG, five captured from around petroleum platforms and three coming from open water during the GSG/PLL comparison.

During the nine days of gear comparison, the PLL vessel caught a total of 107 retained yellowfin while the GS vessel caught three. The average dressed weight for yellowfin caught on PLL and GSG was 38.2kg (83.9lb) and 41.5kg (91.3lb), respectively. During three days of gear comparisons that occurred in 2018, a total 60 animals were caught by the PLL vessel, with 55% being retained for sale, while the GSG caught two fish, both of which were retained. The three largest yellowfin caught by GSG were caught in open water during the gear comparison portion of the research.

Of the yellowfin retained by the PLL vessel, 38% graded as #1 (sashimi grade). Forty-four percent graded as #2, and the remaining 18% graded as either #3 or no grade. All of the GSG caught fish graded either #2 or #2+. Two GSG fish were tethered to a buoy for 6-8 hours to evaluate the potential benefit of buoying on tuna quality. The professional fish grader rated the two buoyed fish as the highest quality of the GSG fish caught, but came short of giving the fish a #1 rating.

The fish quality results observed during this study are consistent with previous research, which has documented that troll or handline caught yellowfin tuna often suffer from a product quality problem known as "burnt tuna syndrome". Burnt tuna have pale, soft flesh and a slightly sour taste. Although perfectly palatable when cooked or canned, burnt tuna are considered unsuitable for raw consumption and commands only a fraction of the price of prime quality

fish. The burnt tuna condition also results in a reduced shelf life. While buoying fish gave indication that this technique may offer some benefit to improving tuna quality, it is unlikely that this process would be logistically feasible in a commercial fishery.

Previous studies of GSG in the Gulf of Mexico concluded that GSG yellowfin tuna were generally smaller than those caught in the PLL fishery. In contrast, the current study has shown that the previous results may have been a result of fishing location rather than gear type. While fishing in the same area of open waters as active PLL longline vessels, the GSG produced yellowfin that were comparable in size to that of to the partner PLL vessel.

In the Gulf of Mexico pelagic longline fishery, the primary economic component of the catch is sashimi grade yellowfin tuna. Therefore, the fishery can be accurately described as a sashimi fishery. While the goal of this research was not to evaluate GSG as a possible replacement for PLL fishing, the results of the current research are in agreement with previous research, suggesting that the use of GSG in the Gulf of Mexico will not likely be a viable alternative to PLL gear. However, GSG may be a viable method for providing a reliable source of tuna served as cooked product in the restaurant market. However, the regional markets, including the supply chains would need to be developed.

1 Introduction

The U.S. Gulf of Mexico pelagic longline fishery (PLL) primarily targets large, high-quality yellowfin tuna (*Thunnus albacares*) intended for the sashimi market (Foster et al., 2015a). The fishery accounted for between 12% and 41% of the total U.S. Atlantic yellowfin tuna landings from 2007 to 2011 (NMFS, 2012). In addition to landed catch, pelagic longline fisheries worldwide discard a host of species as bycatch, which includes undersize target catch and unwanted or protected species, such as *Istiophorid* billfish, bluefin tuna, shark, sea turtles and marine mammals (Uozumi, Y., 2003; Block et al. 2005, Garrison, L. P., 2005; Cortes et al., 2010).

During the 2010 Deepwater Horizon oil spill, many pelagic fish species associated with the PLL fishery in the Gulf were injured. In 2017, the National Oceanic and Atmospheric Administration (NOAA) implemented a project to help restore some of the pelagic fish affected by the oil spill. The Deepwater Horizon Oceanic Fish Restoration Project (OFRP) is a multi-year project designed to restore fish species that were injured as a result of the oil spill by reducing fishing mortality during a temporary, voluntary, six-month repose period each year where participating vessel owners will refrain from PLL fishing. During the repose, vessels are provided with alternative fishing gear that specifically target yellowfin tuna and swordfish and result in lower bycatch of other fish species.

One of the alterative gear methods offered to the participants during the repose is known as greenstick gear (GSG) (see Methods). This method of trolling for tuna is reported to have been developed in Japan during the 1960s. The current method utilizes a large fiberglass or carbon-fiber pole to troll for tuna. The original GSG utilized green bamboo, thus the name “greenstick”.

Preliminary results of testing with GSG in the Gulf of Mexico indicates that the majority of the yellowfin landed are smaller than fish caught in the PLL fishery and are smaller than that which the industry considers suitable for the sashimi market (Kerstetter et al., 2014; Steen, 2016). Additionally, tuna caught with GSG on average grade lower than those caught on longlines due to poor flesh quality. Handline or troll fisheries such as GSG that target tuna, suffer from a product quality problem known as "burnt tuna syndrome" (Cramer et al., 1981). Burnt tuna have pale, soft flesh and a slightly sour taste. Although perfectly palatable when cooked or canned, burnt tuna are considered unsuitable for raw consumption and commands only a fraction of the price of prime quality fish. The burnt tuna condition also results in a reduced shelf life.

To better understand these issues associated with GSG, scientists at the NOAA Southeast Fisheries Science Center conducted fishing gear research in support of the OFRP. In 2017 and 2018, gear studies were conducted to directly compare GSG to PLL for yellowfin tuna catch rates, tuna quality, and bycatch. Research was also conducted in the vicinity of petroleum platforms to draw comparisons between fish caught around artificial structures and fish caught in the open ocean. Additional experiments were conducted to test methods for improving the quality of tuna caught on GSG. Results of the research were used to assess the potential of GSG in the Gulf of Mexico as well as improve the proficiency of project participants with the new gear type.

2 Methods

2.1 Gear Configuration

Greenstick research was conducted onboard the R/V *Southern Journey* – a 23.5-meter, twin engine (550 total horsepower), NMFS research vessel (Figure 1). Three research cruises, lasting from 5-8 days, were conducted in 2017-18 and departed from the NMFS laboratory in Pascagoula, Mississippi.

FIGURE 5: R/V SOUTHERN JOURNEY

The trolling gear consisted of a 12.2m (40ft) Hamaguchi Hybrid greenstick installed into a 1m long x 12.7cm diameter stainless steel pipe welded onto the secondary deck of the vessel, approximately 2.5m above the main deck and 3.5m above the water (Figure 2). The mainline was deployed and retrieved with a Waterman Industries hydraulic bandit reel with a

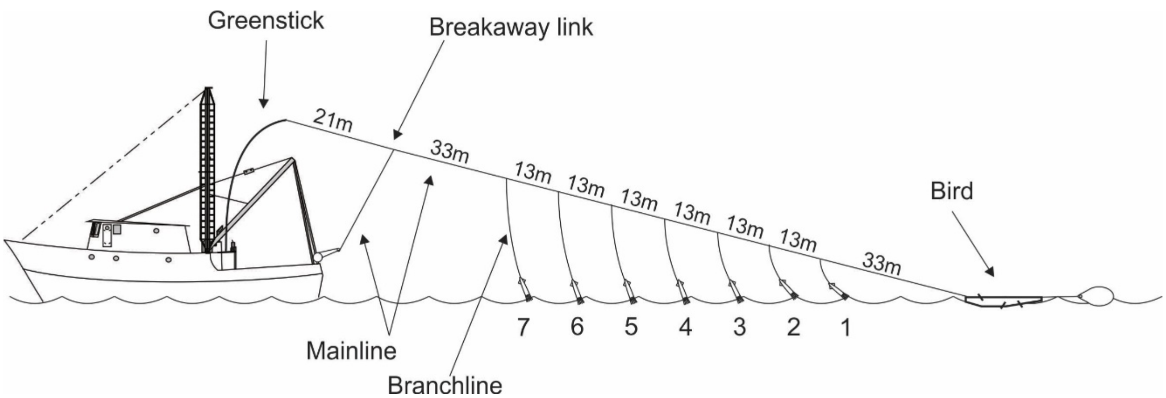

FIGURE 6: GREENSTICK GEAR CONFIGURATION

greenstick spool, placed on the main deck at the stern of the vessel. The mainline was constructed of 3.2mm monofilament. The greenstick was attached to the mainline via a 21m tagline, also constructed of 3.2mm monofilament. The tagline was connected to the mainline by a 1.2mm diameter x 0.5 meter-long monofilament breakaway link. There was 33m of mainline between the breakaway link and the branchlines. Branchlines were spaced 13m apart and there was 33m of 2.0mm monofilament mainline between the first branchline and the Bird. Ringed bullet swivels were placed in the mainline at the breakaway point and branchline attachment points (Figure 3). The Bird used was the Hamaguchi Jumbo Bird (HAM009). A polyform float (LD-2) was towed approximately three meters behind the Bird with a polyethylene rope.

FIGURE 7: RINGED BULLET SWIVELS, PLACED AT THE JUNCTION OF THE MAINLINE AND BRANCHLINES

Branchlines were constructed from 2.0mm monofilament. Branchline lengths were adjusted (tuned) in order to achieve the desired action, which was to have the lures mimic flying fish and “skip” on the surface of the water. The adjusted branchline lengths were approximately 2.7m, 2.7m, 4.5m, 6.4m, 8.2m, 10.0m, and 11.9m for branchlines numbered 1-7 sequentially. The lures used were 23cm Moldcraft squid lures in two colors, clear with colored flake (Syka), and green with metal flake, and had 11/0 non-offset J hooks. The lure colors were alternated along the mainline in two configurations, green lures on odd hooks (configuration A) and clear lures on odd hooks (configuration B) (Figure 4). The first cruise fished the lures in configuration A for the entire trip. During cruises two and three, the color configurations were alternated daily.

FIGURE 8: SOFT PLASTIC SQUID BAITS USED DURING THE GSG STUDY.

The research was conducted in two phases, with both phases occurring in each of the project years. In phase one, GSG fishing occurred around petroleum platforms, whereas in phase two, GSG was compared to PLL gear (PLL shadowing). When trolling near petroleum platforms, fishing operations started approximately 30 minutes before twilight and ended approximately 30 minutes after dark. During the PLL shadowing phase, trolling began each day concurrent with the start of longline deployment (just before daylight) and conclude approximately 30 minutes after dark. Based on the results of previous research (Steen, 2016), trolling operations lasted for approximately 12 hours each day and focused on the peak feeding periods of morning and evening. Therefore, trolling was halted during the slow feeding period in the middle of the day.

Trolling speeds ranged from 5.7-8.0 knots. When trolling in the vicinity of petroleum platforms, the vessel trolled in straight line passes within a few hundred meters of the platform. Once past the platform by one or two kilometers, the vessel made a slow U-turn and trolled past the platform again in a daisy pattern. When PLL shadowing, GSG was trolled parallel to and within approximately two kilometers of the longline. In both phases of research, when surface feeding activity was observed (i.e., fish or bird activity), the trolling pattern would deviate to focus on the area of feeding activity.

2.2 Data Collection

2.2.1 Greenstick Gear

The sampling unit was counted as "trolls", i.e., replicates of gear deployment and retrieval. At each gear deployment, time, vessel position, wind direction, and wave height were recorded. Gear was hauled when an animal was caught or when a fishing period ended. Project personnel continually "jigged" the mainline at the reel in order to cause the lures to skip or jump out of the water, an action that is thought to entice fish to strike. When the sea state was rough enough, there was no need to jig the line due to the rocking of the vessel causing the lures to leave the water.

When a hook-up occurred resulting in the detachment of the breakaway link, the vessel was immediately slowed to around 1-2 knots. The mainline was then hauled and the fish were boarded. When a hook-up occurred without resulting in a detachment of the breakaway link, the gear continued to be trolled for a brief period to allow the opportunity for additional fish to become hooked. Data collected for each fish that was boarded included species, length, and hook number. For legal size yellowfin tuna (at least 27 inches curved fork length), dressed weight was also recorded.

In an attempt to evaluate methods to reduce the effects of Burnt Tuna Syndrome, two yellowfin were buoyed for 6-8 hours during the PLL shadowing phase in order to potentially improve the quality (grade) of the tuna. This experiment was based on the recommendation of Gibson (1981), who recommended that troll caught fish be tethered to a buoy for one hour prior to being hauled and processed. However, results from Foster et al. (2015a) suggested that soak times need to be much longer than was suggested previously.

Fish that were buoyed, were transferred to the buoy line during hauling process, without removing fish from the water. When the branchline containing the fish was detached from the mainline, the branchline was immediately attached to 80 meters of 8mm nylon line with a longline high-flyer and two polyform floats on the other end. The fish were allowed to swim freely for a predetermined period of time (Figure 5). A Temperature/Depth Recorder (TDR) was placed on the buoy line just above the branchline to record fish activity while the fish were buoyed. The high-flyer was tracked by marine radar while trolling continued. At the end of the buoying process, fish were boarded and processed in the same manner as the other fish.

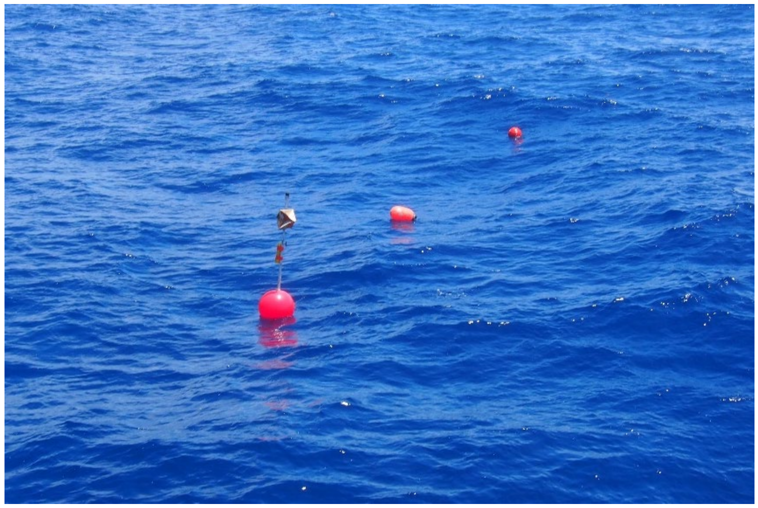

FIGURE 9: YELLOWFIN TUNA TETHERED TO A LONGLINE HIGH-FLYER BY 80 METERS OF NYLON LINE.

Legal sized yellowfin were processed as described in Foster et al. (2015a). When brought aboard, fish were placed on a foam mat to minimize damage while struggling on deck. A club was used to stun and subdue the fish and small incisions were made along the midline of the fish and caudal peduncle in order to bleed the fish. A stainless wire (Taniguchi) was inserted into the neural canal through a notch cut into the forehead in order to cease all neural activity. The fish was then gutted and the pectoral fin on the topside removed. Fish carcasses were then tagged and iced with the cut pectoral fin on top for the remainder of the trip. Fish were repacked with ice daily until transported to the professional fish grader.

2.2.2 Pelagic Longline

The F/V *Orion*, a 19.5m PLL vessel operating out of Panama City, FL was used for two gear comparison trips. The first trip was conducted in August of 2017, with the second occurring in May of 2018. For each trip, the fishing location was chosen by the PLL vessel captain and each vessel departed from their respective ports to rendezvous at the predetermined location. Each fishing day, the setting of the longline began at approximately 05:00. Hauling commenced at around 17:00 on the same day and concluded around midnight. Previous studies have shown that yellowfin bite PLL gear almost exclusively during the day (Foster et al. 2015b). Therefore, CPUEs for the PLL versus greenstick comparisons are expressed as catch per daylight hour fished (i.e., from 30 minutes before sunrise to 30 minutes after sunset).

For each fish that was kept, a carcass tag was applied to match the data collected on that animal at-sea with the grade and dressed weight of the fish recorded during the unloading process at the dock. For the 2017 trip, data were only recorded for fish retained. The 2018 trip had an observer from the NOAA Pelagic Observer Program on board; therefore, data were recorded for all species caught.

2.3 Tuna Grade

At the conclusion of each trip, yellowfin dressed weight ≥ 27.3 kg (60 lb) were transported to a professional fish grader to be evaluated. It is customary in the Gulf of Mexico for fish weighing less than 27.3 kg to be classified as “no grade”, due to a lower myoglobin content in the flesh of younger tunas (Nurilmala et al. 2013). During the gear comparison phase, GSG and PLL tuna were graded at the same time at the PLL vessel landing site to eliminate the potential for temporal bias in fish grade. Tail and core samples of muscle were used to evaluate the color, clarity, and fat content of the tuna. Fish were graded from #1 to #3, with #1 being the highest (sashimi) grade. All retained greenstick caught fish were donated to charities in accordance with NOAA Fisheries Service policy.

3 Results

3.1 Fishing Effort

Between 2017 and 2018, a total of 20 sea days were completed with 14 active fishing days onboard the R/V *Southern Journey*. The PLL shadowing trips took place in August of 2017 and May of 2018. The final trip of the project was cut short by three days due to Tropical Storm Alberto entering the Gulf in May of 2018. A total of 60 trolls were conducted, averaging 116 minutes each and ranging 1-467 minutes. Fishing effort totaled 116 fishing hours with 70 hours occurring during the PLL shadowing phase of the project.

3.2 Greenstick Catch Composition

A total of 49 individual animals were captured on GSG. The counts, mean lengths, and size ranges for species caught are presented in Table 1. Additional animal interactions were observed with the gear, but were not counted due to the fact that on several occasions interaction were occurring at such a fast rate that they could not be enumerated. Overall, *thunnid* tunas accounted for 88% of all captures, with the remaining captures being dolphinfish *Coryphaena spp.* The dominant species caught was blackfin tuna (*Thunnus atlanticus)*, comprising 51% of the total catch. Yellowfin tuna accounted for 16% of the total. Skipjack tuna (*Katsuwonus pelamis)* and little tunny (*Euthynnus alletteratus)* made up 14% and 4% of the catch, respectively. One animal was hooked and tripped the break-away link but escaped before it could be identified. A total of five yellowfin that weighed greater than 60lb (27.3kg) were retained for grading; two were caught around petroleum platforms and three from PLL shadowing. One yellowfin was below the minimum length requirement of 27in (68.58cm) and was released alive.

Greenstick gear interactions occurred with roughtooth dolphin (*Steno bredanensis*) on two instances. In the first occurrence, the pod was observed following the lures and on occasion nosing or biting the lures. However, no hooking events were observed. In the second occurrence, the vessel was stopped and the gear hauled as soon as the pod of dolphin was observed approaching the gear.

TABLE 1: SPECIES COUNTS, MEAN LENGTHS IN CENTIMETERS AND SIZE RANGES FOR ANIMALS CAUGHT ON GSG.

	PETROLEUM PLATFORMS				OPEN OCEAN (PLL SHADOWING)			
SPECIES	Count	Mean Length (cm)	Min.	Max.	Count	Mean Length (cm)	Min.	Max.
BLACKFIN	15	63.3	49	76	10	65.3	53	78
DOLPHINFISH	-	-	-	-	6	78.5	57	97
SKIPJACK	-	-	-	-	7	67.7	58	73
YELLOWFIN	5	99.8	57	130	3	145.3	144	147
LITTLE TUNNY	2	52.5	51	54	-	-	-	-

3.3 Catches per Troll

Of the 60 trolls conducted, 24 resulted in no catch (Figure 6). The majority of successful trolls resulted in one animal caught. The maximum number of animals caught on the seven hooks trolled was five, which occurred two times. Five of the six dolphinfish were caught during one troll as the vessel passed through a sargassum line on the surface. Multiple hookups with yellowfin occurred on one occasion while trolling in the vicinity of a petroleum platform and were associated with a mixed blackfin/yellowfin tuna school, which was visible from the surface. All of the gradable yellowfin were single capture trolls, two near petroleum platforms and three while PLL shadowing.

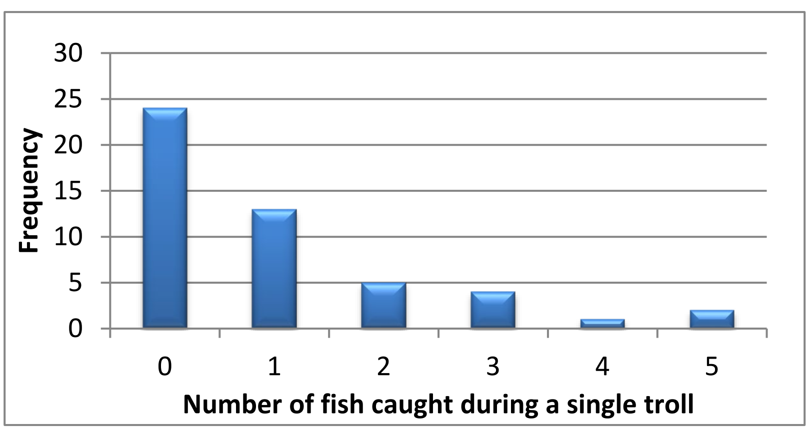

FIGURE 6: GSG, DISTRIBUTION OF THE NUMBER OF FISH CAUGHT PER TROLL.

All of the blackfin and skipjack tuna caught during the PLL vessel shadowing were associated with mixed blackfin/skipjack surface schools, identified by the presence of birds. All trolls associated with the blackfin/skipjack schools resulted in multiple catches (ranging from 2-5 animals) (Figure 7).

FIGURE 7: MIX OF BLACKFIN AND SKIPJACK TUNA CAUGHT ON A SINGLE GSG TROLL.

3.4 Time of day

Catches on the GSG were crepuscular, with the majority of the catches occurring around the twilight periods of morning and evening. All of the yellowfin were caught either before 08:30 or after 18:00. Of fish caught around petroleum platforms, 78% (100% of yellowfin) occurred during two high feeding activity periods lasting three hours each: during one evening period in 2017 and one morning period in 2018.

3.5 Hook Position

The hooks on the GSG were numbered corresponding to the order they were deployed. Therefore, hook number one was the hook that was closest to the bird and farthest from the vessel. Figure 8 shows the frequency of fish caught by hook position. Catches occurred on all hook positions. The distribution was unimodal with a peak occurring at hook number four (middle hook). The distribution of yellowfin across the hooks was similar to the pattern for the total catch, with the lowest yellowfin catches (zero) occurring on hooks one and seven. The highest catches of yellowfin occurred on hooks three and five.

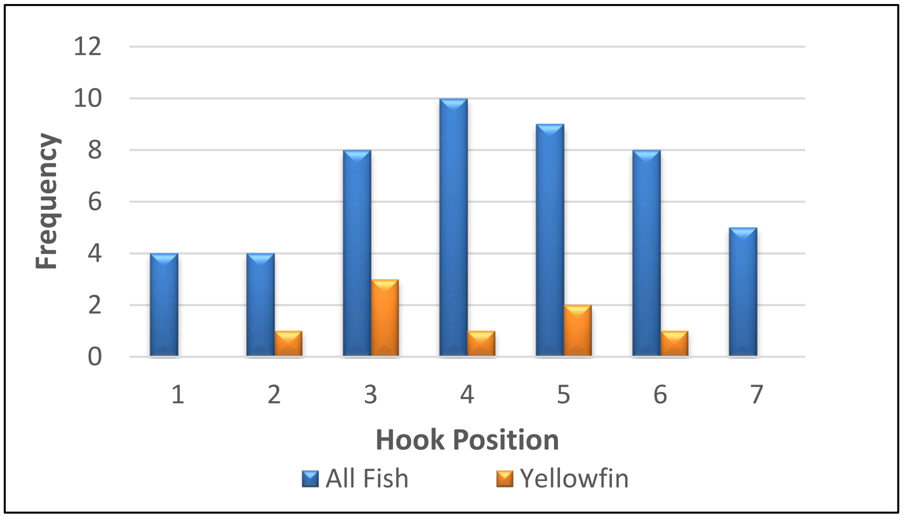

FIGURE 8: GSG, NUMBER OF FISH CAUGHT BY HOOK POSITION.

3.6 Lure Color

During each troll, the two lure colors were alternated on the mainline. The fact that there were an odd number of hooks deployed resulted in a daily effort and position bias. To addresses these biases, the hook colors for each hook position was alternated daily. The CPUEs for the lure color comparison are expressed as catch per 100 hook hours. The total effort for clear and green lures were 393.1 and 415.6 hours, respectively.

The sample sizes for all species caught were insufficient for a meaningful statistical analysis. However, with the exception of little tunny which had one fish on each lure color, all tuna species had a higher catch rate on the clear lures with colored flake as compared to the green lures (Table 2). The increase in catch rate ranged from a 59% increase for blackfin to an increase of 217% for yellowfin tuna. The lure color had no apparent effect on the catch rate of dolphinfish with three being caught on each lure color.

TABLE 2: GSG CATCH RATES BY LURE COLOR (CPUE= CATCH/HOOK HOUR X100).

SPECIES	CLEAR LURE	GREEN LURE
BLACKFIN	3.815499406	2.406159769
DOLPHINFISH	0.763099881	0.721847931
LITTLE TUNNY	0.254366627	0.240615977
SKIPJACK	1.271833135	0.481231954
YELLOWFIN	1.526199763	0.481231954

3.7 PLL vs Greenstick Catch Comparison

A gear comparison study was conducted during two trips taken in 2017 and 2018. During both trips, it was noted that several PLL vessels were observed actively fishing in the area of operation. A total of 4700 hooks were deployed by the F/V Orion during nine fishing days of the gear comparison. The daily number of hooks set ranged from 560-576 in 2017 and 380-456 in 2018. During the comparison, the PLL vessel caught a total of 107 yellowfin tuna while the GSG vessel caught three. The average PLL yellowfin catches per day for 2017 and 2018 were 14.8 and 6 per day respectively. The GSG averaged one fish per three days of fishing in each of the two years. The yellowfin CPUE was 0.840/hr for the PLL and 0.048/hr for GSG. The average dressed weight for PLL and GSG was 38.2kg (83.9lb) and 41.5kg (91.3lb), respectively. Four carcass tags were lost in transit; therefore, the average PLL yellowfin weight was calculated from 103 fish. The dressed weight distribution of yellowfin for the two fishing methods are shown in Figure 9. The additional marketable catches caught in 2017 and 2018 consisted of six dolphinfish caught by the GSG and 14 dolphinfish, three bigeye tuna (*Thunnus obesus*), two escolar (*Lepidocybium flavobrunneum),* and one swordfish (*Xiphias gladius)* caught with the PLL.

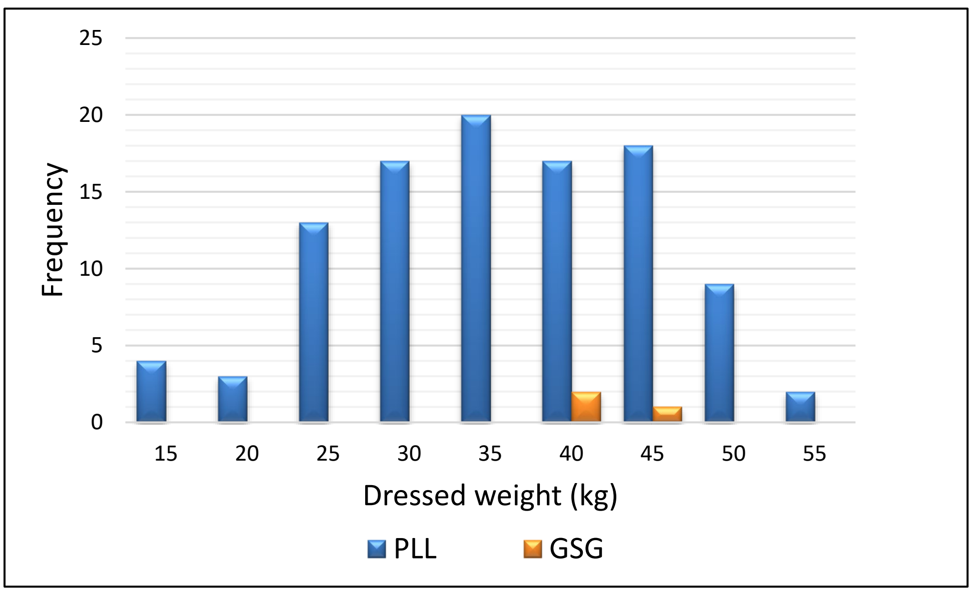

FIGURE 9: DRESSED WEIGHT DISTRIBUTION OF YELLOWFIN TUNA BY GEAR TYPE.

During the 2018 PLL shadowing trip, a NOAA observer was onboard the vessel. Therefore, all fish caught were recorded. The catch for all species by gear type is presented in Table 3. Of the 60 animals caught during the three days of PLL fishing in 2018, 55% were retained for sale, while 100% of the GSG were retained. Notable bycatch with PLL gear included two Istiphorid billfish and 18 swordfish. The Istiphorid billfish were discarded alive and all but one of the swordfish were discarded dead. There were no billfish caught on GSG during this study.

TABLE 3: CATCH COMPOSITION OF THE 2018 PLL/GSG GEAR COMPARISON TRIALS.

SPECIES		PLL		GSG	
COMMON NAME	Scientific Name	Total	Retained	Total	Retained
BLACKFIN TUNA	*Thunnus atlanticus*	1			
BLUE MARLIN	*Makaira nigricans*	1			
DOLPHINFISH	*Coryphaena*	14	14	1	1
PELAGIC RAY	*Pteroplatytrygon violacea*	1			
SKIPJACK TUNA	*Euthynnus pelamis*	2			
REQUIEM SHARK	*Carcharhinidae*	2			
SWORDFISH	*Xiphias gladius*	18			
WAHOO	*Acanthocybium solandri*	1	1		
WHITE MARLIN / ROUNDSCALE SPEARFISH	*Tetrapturus albidus/georgii*	1			
YELLOWFIN TUNA	*Thunnus albacares*	19	18	1	1

3.8 Buoyed Yellowfin Tuna

On each of the two PLL shadowing trips, one yellowfin tuna that was caught on the greenstick was immediately transferred to a buoy, tethered by 80 meters of nylon rope. The intent was to buoy each fish for eight hours. However, on the second trip, the fish was hauled after six hours due to a tropical disturbance in the area.

The TDR recording from the first yellowfin is presented in Figure 10. The yellowfin in the figure, was 39.5kg (85.9lb) dressed weight. It struck the greenstick at 06:15 and took approximately 10 minutes to be hauled to the vessel. The branchline was transferred to the tether and the tuna was released at approximately 06:25. Upon being released on the tether, the fish proceeded to swim erratically at depths from 10-80m for approximately 2.5 hours. At approximately 10:55, the tuna began to swim within a narrow depth range of approximately 10m. At approximately 10:30 and 13:05, researchers raised the line to determine whether or not the tuna was still alive. This is shown by the two spikes in the TDR depth profile.

Both tethered tuna appeared docile while the line was being hauled and did not begin to struggle against the line until brought along side of the vessels. Upon boarding, both tuna were tagged and processed in the same way as the other tuna.

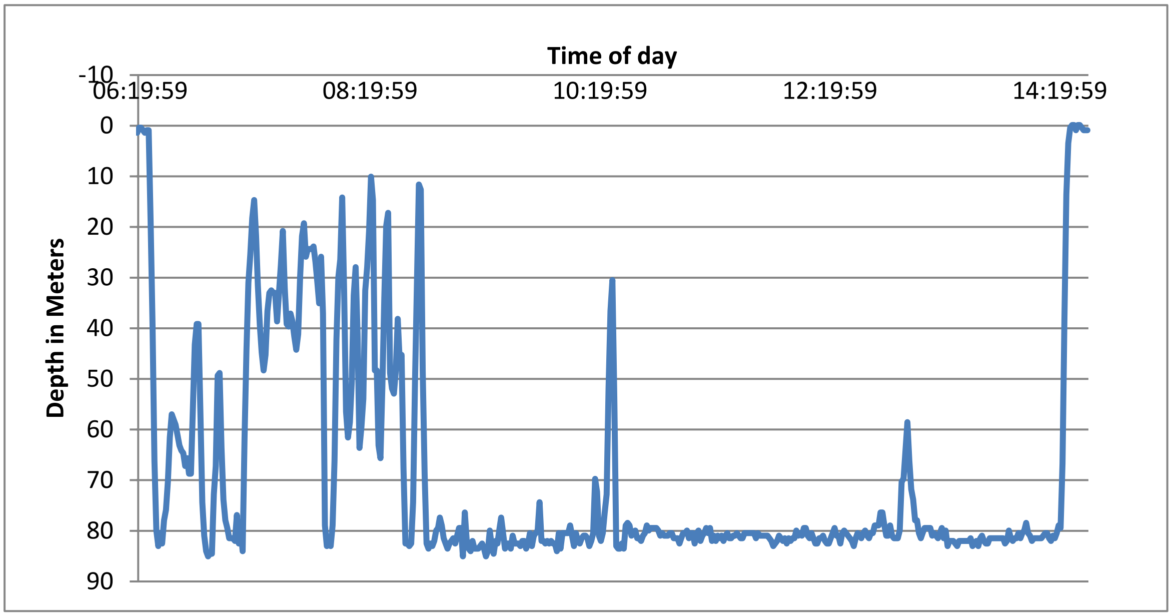

FIGURE 10: TDR DEPTH PROFILE OF A GSG CAUGHT YELLOWFIN TUNA TETHERED TO A BUOY FOR EIGHT HOURS.

3.9 Yellowfin Tuna Grade Comparison

At the conclusion of each PLL shadowing trip, fish were offloaded from the R/V *Southern Journey* and transported on ice to Panama City, FL and graded along with the fish caught by the F/V Orion. A total of five greenstick caught tuna were graded, two from the first trip and three from the second. Two of the three yellowfin graded from the second trip were caught near a petroleum platform while in transit to the rendezvous point with the PLL vessel.

After the flesh samples were taken from the GSG caught fish, the grader was asked to determine which of the GSG caught fish appeared to be the best quality. Each time the grader identified the fish that had been buoyed, without knowing that those fish had been treated any differently. Of the five GSG yellowfin graded, four received a grade of #2 and one fish received a #2+. While the "+" was not used in the grading processes of the PLL vessel, the grader indicated that the #2+ fish was extremely close to receiving a #1 (sashimi grade).

Of the yellowfin offloaded by the PLL vessel, 38% graded as #1 (sashimi grade) (Figure 11). Forty-four percent graded as #2, and the remaining 18% graded as either #3 or no grade.

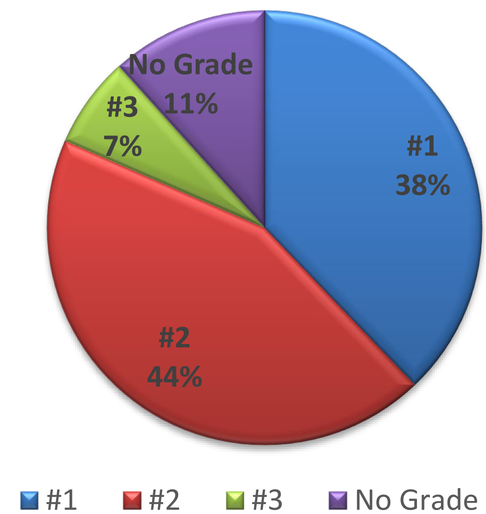

FIGURE 11: PROPORTION OF PLL YELLOWFIN CATCH BY TUNA GRADE.

4 Discussion

The catch rates observed in the current study were lower than those reported in previous GSG studies in the Gulf of Mexico (Kerstetter et al., 2014; Steen, 2016). However, previous GSG studies in the Gulf of Mexico focused most of the effort around petroleum platforms, which function as fish attracting devices (FADs). The current study found that when fishing in the same open waters as active PLL longline vessels, the yellowfin CPUE with GSG was 94% lower than the PLL. The GSG produced yellowfin that were comparable in size to those of to the partner PLL vessel. In fact, the mean size of the GSG caught fish (41.5kg) was slightly larger than those caught by PLL (38.2kg). In contrast, Kerstetter et al. (2014) concluded that GSG tuna were generally smaller than those caught in the PLL fishery. However, their results may have been a product of fishing location rather than gear type. The results of the current study are consistent with other research that found that yellowfin tuna caught around FADs tend to be smaller in size than those caught in open water (Lewis and Hampton, 1992).

Previous GSG studies in the Gulf of Mexico indicate that yellowfin tuna show a lure color preference with the fishers reporting the highest catch rates with a green soft plastic squid bait (Kerstetter et al., 2014; Steen, 2016). However, in both studies the fishers were allowed to use a variety of colors and in whatever combination of color the fishers preferred. Therefore, neither study was able to quantify the catch rate differences by lure color. The current study was limited to two contrasting colors. The color green was selected based on the previous research and clear with colored flake was selected based on the lure seller’s recommendations. With the exception of little tunny, the results of the current study showed an increased catch rate for all tuna species with the clear colored plastic squid bait. The observed catch rate for yellowfin with the clear lure was more than three times that of the green lure.

During this study, 38% of the yellowfin caught by PLL gear graded as #1 (sashimi grade). These results are similar to results from Foster et al. (2015a), which reported 44.8% of yellowfin grading #1 in the same fishery. All of the tuna caught in the current GSG study graded as #2 or #2+. Tuna that are caught by trolling or handline often suffer from a condition known as Burnt Tuna Syndrome (BTS) (Williams, 1986). Burnt tuna syndrome (BTS) is a term used to describe changes in raw tuna that are characterized by pale color, poor texture, and an “off” flavor. This reduction in tuna quality results in a much lower price for the tuna (Cramer et al. 1981). The occurrence of BTS appears to be much lower in the PLL fishery. Davie and Sparksman (1986) compared ultrastructural changes in postmortem tunas and found that fewer sub-cellular changes were evident and ultrastructural quality of the flesh was better in tuna captured on PLL as opposed to those captured on handline or rod and reel. The observed differences were attributed to the difference in capture times (time on the hook) between the fishing methods. Watson et al. (1988) suggested that fish that are on the line for several hours prior to being killed have an opportunity to clear catecholamines from tissues, resulting in a lower percentage of burnt fish. This assertion was supported by Foster et al. (2015a), who found a direct correlation between the time on the line and the proportion of tuna that graded #1 in the Gulf of Mexico PLL fishery.

Gibson (1981), recommended that troll or handline fish be attached to a buoy and left for an hour before being harvested to prevent BTS. However, results from Foster et al. (2015a) suggest that several hours of buoying are necessary to achieve a measurable reduction in BTS. To test this hypothesis, two of the tuna caught in open water were tethered to a buoy from six to eight hours in order to test the effect and feasibility of buoying GSG caught fish. While the sample size was small, this study showed that it is possible to successfully transfer fish from the GSG to a buoy and allow the fish to swim for an extended period of time. Both of the buoyed fish were landed alive and in good condition. The fish grader blindly selected the two buoyed fish as the highest quality fish caught by the GSG, but failed to give either fish a #1 grade. One of the two fish were given a grade of #2+. The result of the buoying experiment demonstrated that the hypothesis described by Gibson (1981) is plausible. However, the amount of time that a tuna would need to be buoyed to have a measurable effect on tuna quality makes this practice impractical for commercial purposes.

All yellowfin caught with GSG were captured either early in the morning or late in the evening. All yellowfin caught on GSG during PLL shadowing were caught in the morning. Studies in the Gulf of Mexico using satellite tags to track the movements of yellowfin tuna have shown that yellowfin spend the majority of the night in the upper mixed layer of the water column (<50m) (Weng et al. 2009). At the onset of daylight, yellowfin begin making dives to depths that on occasion exceed 200m, presumably to feed on organisms in the upper margins of the deep scattering layer (Marchal et al., 1993). The results from the previous studies may explain why the PLL, which fishes at approximately 80m depth, is more effective at harvesting yellowfin in open water than GSG. The results of the current study suggest that yellowfin are most susceptible to being caught on GSG during the twilight period, when they are likely transitioning between the night-time surface behavior and day-time feeding dives.

5 Conclusion

In the Gulf of Mexico pelagic longline fishery, the primary economic component of the catch is sashimi grade yellowfin tuna. Therefore, the fishery can be accurately described as a sashimi fishery. While the goal of this research was not to evaluate GSG as a possible replacement for PLL fishing, the results of the current research are in agreement with previous studies, suggesting that the use of GSG in the Gulf of Mexico will not likely produce the quantity or quality of tuna needed to be a viable alternative to PLL gear. However, GSG may be a viable method to fish around petroleum platforms and provide a reliable source of tuna served as cooked product in the restaurant market. However, the regional markets, including the supply chains would need to be developed.

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