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Analysis of "Observer Effect" in Logbook Reporting Accuracy for U.S. Pelagic Longline Fishing Vessels in the Atlantic and Gulf of Mexico

Thomas J. Morrell
Nova Southeastern University, tm1518@mynsu.nova.edu

Thesis of
Thomas J. Morrell

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Approved:
Thesis Committee

Major Professor: David Kerstetter, Ph.D.

Committee Member: Wayne Law, Ph.D.

Committee Member: Bernhard Riegl, Ph.D.

HALMOS COLLEGE OF NATURAL SCIENCES AND OCEANOGRAPHY

ANALYSIS OF "OBSERVER EFFECT" IN LOGBOOK REPORTING ACCURACY FOR U.S. PELAGIC LONGLINE FISHING VESSELS IN THE ATLANTIC AND GULF OF MEXICO

By

Thomas J. Morrell

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ABSTRACT

Thomas J. Morrell: Analysis of “Observer Effect” in Logbook Reporting Accuracy for U.S. Pelagic Longline Fishing Vessels in the Atlantic and Gulf of Mexico

Commercial pelagic longline fishers within the U.S. Atlantic, Gulf of Mexico, and Caribbean are required to report all fishing interactions per each gear deployment to NOAA’s Vessel Logbook Program of the Southeast Fisheries Science Center to quantify bycatch, increase conservation efforts, and avoid jeopardizing the existence of vulnerable species listed under the Endangered Species Act (ESA). To provide additional accuracy, the Pelagic Observer Program (POP) of the SEFSC deploys professionally trained observers on longline vessels to produce a statistically reliable subset of longline fisheries data. A comparison of self-reported (“unobserved”) datasets versus observer-collected (“observed”) datasets showed a general consistency for most target species but non-reporting or under-reporting for a number of bycatch species and “lesser-valued” target species. These discrepancies between catch compositions and abundancies regarding targeted species, species of bycatch concern, and species of minimum economic value can provide insight into increased fisheries regulations, stricter requirements, or additional observer coverage.

Keywords: catch per unit effort (CPUE), bycatch, Highly Migratory Species (HMS), tuna, NOAA, General Additive Model (GAM)

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<u>**Analysis of "observer effect" in logbook reporting accuracy for U.S. pelagic longline fishing vessels in the Atlantic and Gulf of Mexico**</u>

1. Introduction

Under the Magnuson-Stevens Fishery Conservation and Management Act (16 U.S.C. § 1812, 2007), the U.S. National Marine Fisheries Service (NMFS), part of the National Oceanographic and Atmospheric Administration (NOAA), is charged with managing fisheries under its purview to an optimum yield through eliminating overfishing and rebuilding overfished stocks. To better achieve this optimum yield goal and simultaneously evaluate the effects of existing management efforts, NOAA monitors commercial fisheries data from both self-reported logbook records and professional fisheries observers. Both data sources are used for management decisions, and it is critical that interactions with targeted and by-catch species are reported in an accurate, timely manner.

To assist in achieving an accurate account of interactions with both target and by-catch species, the vessel logbook program (see <u>*Agencies, Acts, and Programs Associated with the U.S. Pelagic Longline Fishery*</u> as Appendix I), implemented in 1986 by NOAA's Southeast Fisheries Science Center (SEFSC), created the UDP (Unified Data Processing) system (formerly Fisheries Logbook System [FLS]) to allow fishers the opportunity to submit confidential fishing data to a secure database within the Fishing Monitoring Branch division of the SEFSC (InPort, NMFS Enterprise Data Management Program, 2019). Though a mandatory system requiring all longline vessels to record set-specific data such as hook types, soak time, and total interaction numbers, the aim of the logbook program is to provide a better overview of the U.S. domestic commercial fishing activities and non-fishing activities being conducted in the western Atlantic waters of the eastern U.S. coast, Gulf of Mexico, and Greater Caribbean ("Fishery Logbook System," n.d.). In addition to assessing population and sustainability of fish stocks and accounting for interactions with the pelagic longline fleet (hereafter, simply "longline"), this self-reported data is used to determine the effects of existing management policies on those who participate within the fishery, but even with a regulatory incentive to provide accurate catch records for future sustainable practices, there is still potential for imprecision, particularly for bycatch and discarded species. Defined by NOAA as "discarded catch of marine species and unobserved mortality due to a direct encounter with fishing vessels and gear," bycatch is a major concern for not only the longline industry, but also all fishing industries in general because of the high rate of mortality and unavoidable injuries. Alverson et al. (2009) estimated the weight of bycatch records at 25% of the total worldwide catch.

To provide additional accuracy and improve upon misidentification (under the authority of the MSA and Section 7 of Endangered Species Act [ESA]), the Pelagic Observer Program (POP) of the SEFSC – initiated in 1992 – deploys NMFS-trained fisheries observers (see *Pelagic Longline Gear and Fishery Terms* as Appendix 2) on a minimum of 8% of commercial pelagic longline vessels to produce a statistically reliable sample of Highly Migratory Species (HMS) including (but not limited to) Swordfish *Xiphias Gladius* and Yellowfin Tuna *Thunnus albacares* (ESA, §8.1.2.1, 2004). The POP is responsible for obtaining target and bycatch numbers for pelagic species caught on longline gear, recording length measurements and sex for all pelagic species brought onboard, and recording detailed gear characteristics of commercial longline vessels. All responsibilities fall within the fishery management plan (FMP), which has jurisdiction over all U.S. flagged pelagic longline (PLL) vessels that possess an Atlantic Tuna Longline permit. This permit pertains to vessels in the Atlantic, Gulf of Mexico, Exclusive Economic Zone (EEZ) of the Caribbean and even including vessels that fish outside EEZ. Similar to self-reported data from fishers, POP fisheries observers are responsible for environmental information associated with the gear set (deployment) and haul (retrieval), and various information associated with weight and proper identification of pelagic fishes, mammals, seabirds, and sea turtles, all for the ultimate use of both evaluating pelagic fish stocks and gauging the effectiveness of management efforts.

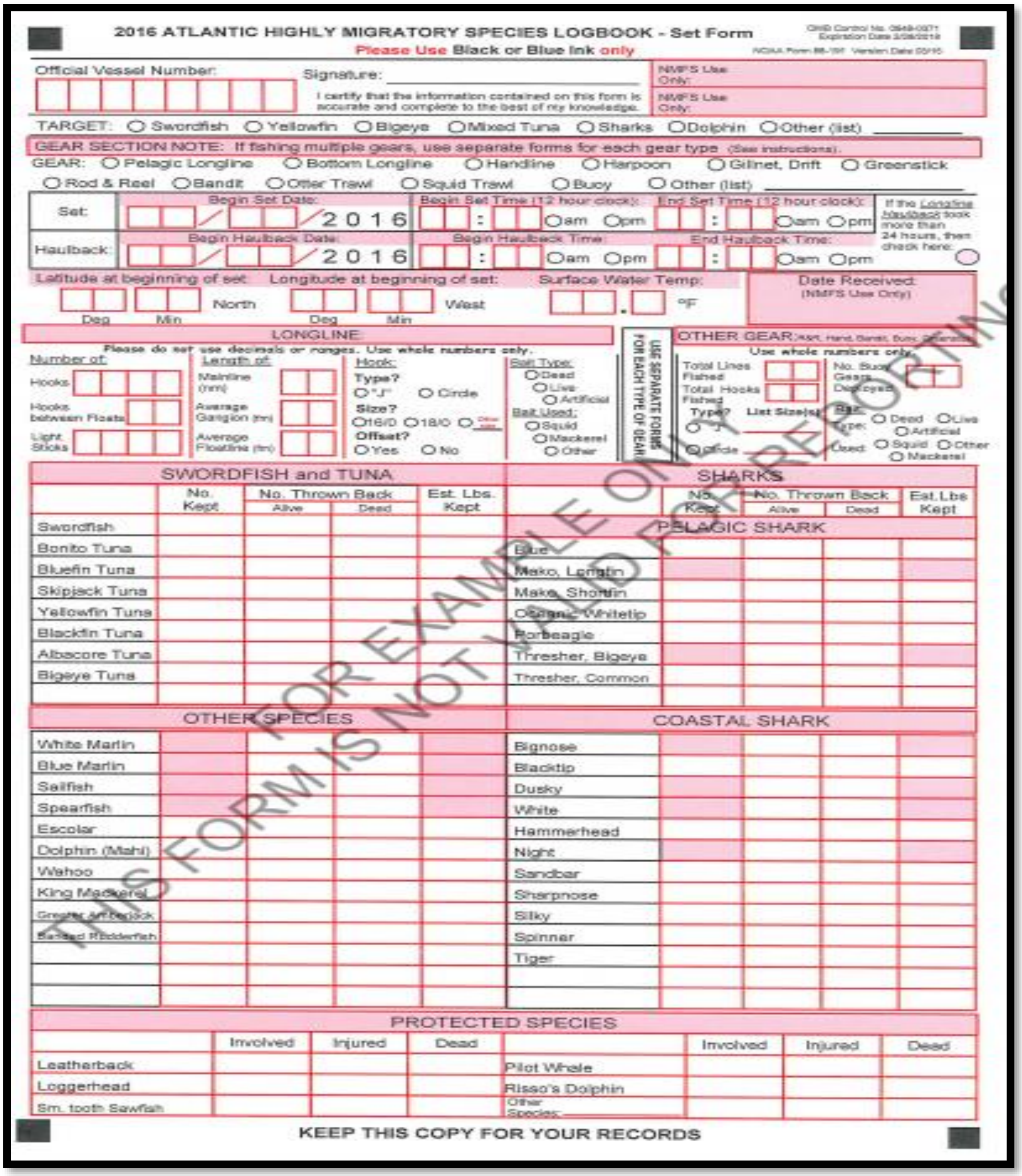
Within the Consolidated Atlantic HMS FMP (Consolidated HMS FMP, §4.1.2, 2006), there is "no doubt" among the two data sources (POP and HMS Logbook) of non-reporting or under-reporting for most species, showing a lesser accuracy from logbook data compared to observer data. Due to logistical and budgetary constraints, however, it is unrealistic to obtain 100% observer coverage for the Atlantic pelagic longline fleet, but through an accessory data source to the self-reported fisheries logbooks – regardless of the low percentage of coverage – the POP can provide additional accuracy to the data. With self-reported fishing data, the issue is veracity, and with only *ca.* 8% of longline fishing sets being monitored annually via observers through the POP (ESA, §8.1.2.1, 2004), there is minimal validation of the data being submitted via logbook trip summary forms by commercial longline fishers. While it is believed that underreporting of catch is an issue with self-reported data, it is possible there is considerable variation in the accuracy across species. A species-specific evaluation of self-reported and observer-collected pelagic longline fisheries data could help inform managers on the efficacy of current regulations regarding quotas, bycatch reduction efforts, and overall fisheries management strategies.

In addition to documenting the total number of animals caught and their eventual disposition, the HMS Agreements component of the International Fishery Agreements provisions (Section 202) in the MSA also requires longline fishers to report fishing location, gear configuration, and duration of fishing activity (16 U.S.C. §1822, 2007). Within this Section 202 of the MSA, HMS Agreement (B) specifically promotes the establishment of measures to ensure proper conservation and biological sustainability of the industry. The effectiveness of measures applicable to the fishery, however, relies solely on the veracity of the fisheries data being reported and without accuracy from the fishing industry's offshore interactions, it can be difficult to utilize self-reported, fisheries-dependent UDP datasets to determine the effects of existing and proposed management efforts. Stock assessments, establishment of annual catch limits, and other fisheries management efforts – and even observer program initiatives – can all benefit from a comparative analysis of self-reported data against observer-collected data.

Background

Within the Atlantic Ocean, the U.S. Atlantic pelagic longline fleet deploys gear, year round, targeting commercially sellable catch, including swordfish and yellowfin tuna. Although the U.S. fleet has some historical effort reported from the eastern North Atlantic and both eastern and western South Atlantic, the vast majority has been in the western North Atlantic, including the Gulf of Mexico and the Caribbean Sea; this western North Atlantic region will be the focus of this thesis project.

As a result of a Biological Opinion, Section 7(a)(2) of the ESA (2004), U.S. Atlantic longline fishers are required to report catches for each trip on a per set basis to quantify species interactions, increase conservation efforts, and avoid jeopardizing the existence of species listed under the Act (16 U.S.C. §1531, 2004). Each vessel's self-reported data is submitted through two forms: the Trip Summary Form and Set Form, as seen in Figures 1 and 2. At the completion of each pelagic longline trip, defined by the Atlantic Tunas Convention Act (ATCA) as any port-



2016 ATLANTIC HIGHLY MIGRATORY SPECIES LOGBOOK - Set Form

Please Use Black or Blue Ink only

OMB Control No. 0648-0371 Expiration Date 2/28/2019

NOAA Form 88-191 Version Date 05/15

Official Vessel Number:

Signature:

I certify that the information contained on this form is accurate and complete to the best of my knowledge.

NMFS Use Only:

NMFS Use Only:

TARGET: ○ Swordfish ○ Yellowfin ○ Bigeye ○ Mixed Tuna ○ Sharks ○ Dolphin ○ Other (list)

GEAR SECTION NOTE: If fishing multiple gears, use separate forms for each gear type (See instructions).

GEAR: ○ Pelagic Longline ○ Bottom Longline ○ Handline ○ Harpoon ○ Gillnet, Drift ○ Greenstick

○ Rod & Reel ○ Bandit ○ Otter Trawl ○ Squid Trawl ○ Buoy ○ Other (list)

Set: Begin Set Date: / / 2016 | Begin Set Time (12 hour clock): : ○am ○pm | End Set Time (12 hour clock): : ○am ○pm

Haulback: Begin Haulback Date: / / 2016 | Begin Haulback Time: : ○am ○pm | End Haulback Time: : ○am ○pm

If the Longline Haulback took more than 24 hours, then check here: ○

Latitude at beginning of set: Deg Min North | Longitude at beginning of set: Deg Min West | Surface Water Temp: . °F | Date Received: (NMFS Use Only)

LONGLINE

Please do not use decimals or ranges. Use whole numbers only.

Number of: Hooks; Hooks between Floats; Light Sticks

Length of: Mainline (nm); Average Gangion (fm); Average Floatline (fm)

Hook: Type? ○ "J" ○ Circle; Size? ○ 16/0 ○ 18/0 ○ Other size; Offset? ○ Yes ○ No

Bait Type: ○ Dead ○ Live ○ Artificial; Bait Used: ○ Squid ○ Mackerel ○ Other

USE SEPARATE FORMS FOR EACH TYPE OF GEAR

OTHER GEAR: (Rod, Hand, Bandit, Buoy, Greenstick) Use whole numbers only.

Total Lines Fished; Total Hooks Fished; No. Buoy Gears Deployed

Hook: Type? ○ "J" ○ Circle; List Size(s)

Bait: Type: ○ Dead ○ Live ○ Artificial; Used: ○ Squid ○ Other ○ Mackerel

SWORDFISH and TUNA	No. Kept	No. Thrown Back: Alive	No. Thrown Back: Dead	Est. Lbs. Kept
Swordfish				
Bonito Tuna				
Bluefin Tuna				
Skipjack Tuna				
Yellowfin Tuna				
Blackfin Tuna				
Albacore Tuna				
Bigeye Tuna				

SHARKS	No. Kept	No. Thrown Back: Alive	No. Thrown Back: Dead	Est. Lbs Kept
PELAGIC SHARK				
Blue				
Mako, Longfin				
Mako, Shortfin				
Oceanic Whitetip				
Porbeagle				
Thresher, Bigeye				
Thresher, Common				
COASTAL SHARK				
Bignose				
Blacktip				
Dusky				
White				
Hammerhead				
Night				
Sandbar				
Sharpnose				
Silky				
Spinner				
Tiger				

OTHER SPECIES				
White Marlin				
Blue Marlin				
Sailfish				
Spearfish				
Escolar				
Dolphin (Mahi)				
Wahoo				
King Mackerel				
Greater Amberjack				
Banded Rudderfish				

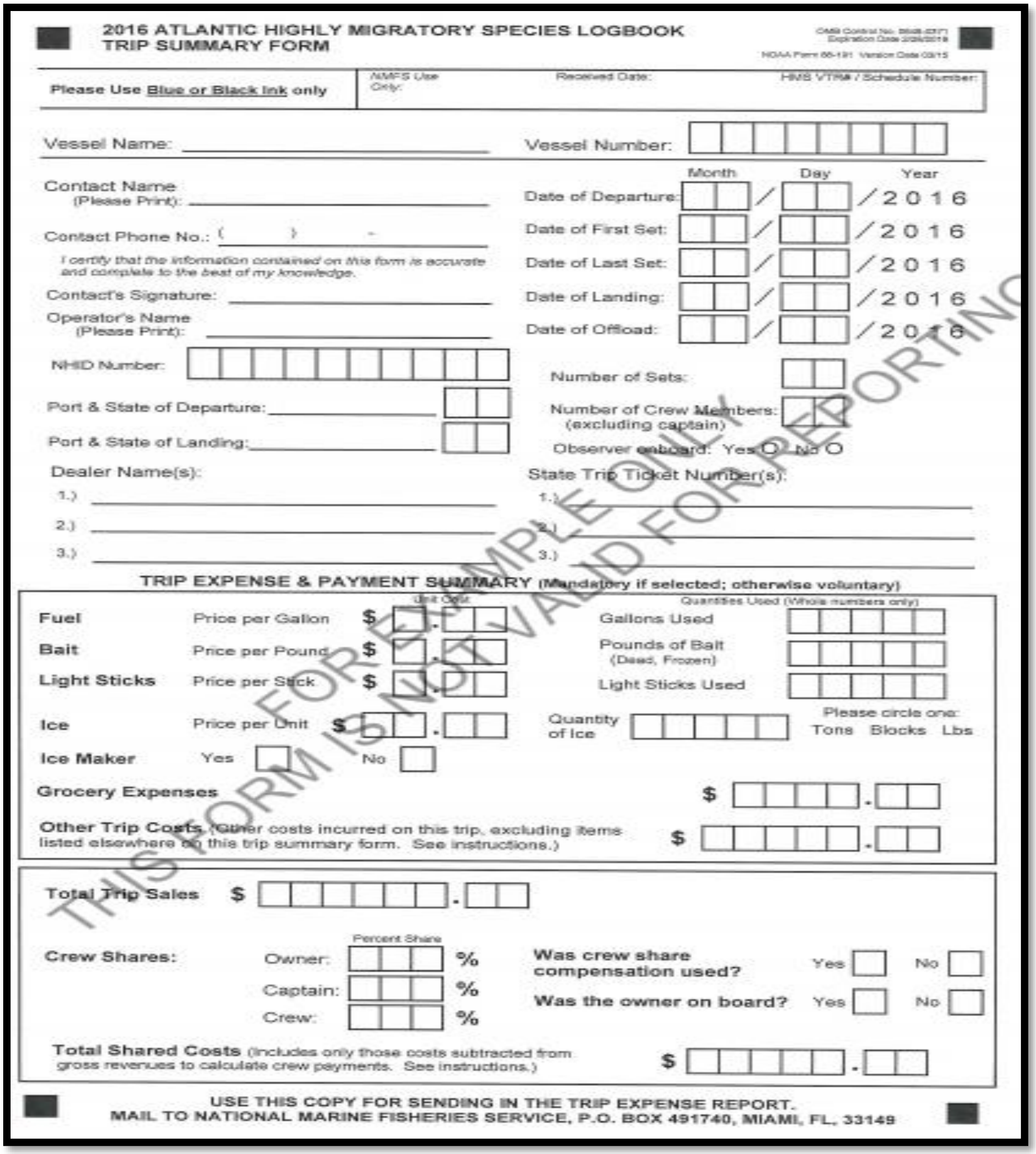
PROTECTED SPECIES	Involved	Injured	Dead
Leatherback			
Loggerhead			
Sm. tooth Sawfish			
Pilot Whale			
Risso's Dolphin			
Other Species:			

KEEP THIS COPY FOR YOUR RECORDS

THIS FORM IS NOT VALID FOR REPORTING

FOR EXAMPLE ONLY

Figure 1. Logbook Set Form for year 2016 used by the U.S. National Marine Fisheries Service for self-reported fishing data from fisheries targeting Atlantic Highly Migratory Species. The form is required to be completed for each "set" (deployment and retrieval) of the fishing gear.



2016 ATLANTIC HIGHLY MIGRATORY SPECIES LOGBOOK
TRIP SUMMARY FORM

Please Use Blue or Black Ink only | NMFS Use Only: | Received Date: | HMS VTR# / Schedule Number:

Vessel Name: ____ Vessel Number:

Contact Name (Please Print): ____

Contact Phone No.: ( ) -

I certify that the information contained on this form is accurate and complete to the best of my knowledge.

Contact's Signature: ____

Operator's Name (Please Print): ____

NHID Number:

Port & State of Departure: ____

Port & State of Landing: ____

Dealer Name(s):
1.)
2.)
3.)

	Month	Day	Year
Date of Departure:	/	/	2016
Date of First Set:	/	/	2016
Date of Last Set:	/	/	2016
Date of Landing:	/	/	2016
Date of Offload:	/	/	2016

Number of Sets:

Number of Crew Members: (excluding captain)

Observer onboard: Yes O No O

State Trip Ticket Number(s):
1.)
2.)
3.)

FOR EXAMPLE ONLY
THIS FORM IS NOT VALID FOR REPORTING

TRIP EXPENSE & PAYMENT SUMMARY (Mandatory if selected; otherwise voluntary)

		Unit Cost		Quantities Used (Whole numbers only)
Fuel	Price per Gallon	$.	Gallons Used	
Bait	Price per Pound	$.	Pounds of Bait (Dead, Frozen)	
Light Sticks	Price per Stick	$.	Light Sticks Used	
Ice	Price per Unit	$.	Quantity of Ice	Please circle one: Tons Blocks Lbs
Ice Maker	Yes	No		

Grocery Expenses $.

Other Trip Costs (Other costs incurred on this trip, excluding items listed elsewhere on this trip summary form. See instructions.) $.

Total Trip Sales $.

Crew Shares: Percent Share
Owner: %
Captain: %
Crew: %

Was crew share compensation used? Yes No

Was the owner on board? Yes No

Total Shared Costs (Includes only those costs subtracted from gross revenues to calculate crew payments. See instructions.) $.

USE THIS COPY FOR SENDING IN THE TRIP EXPENSE REPORT.
MAIL TO NATIONAL MARINE FISHERIES SERVICE, P.O. BOX 491740, MIAMI, FL, 33149

Figure 2. Trip Summary Form for year 2016 used by the U.S. National Marine Fisheries Service for self-reported fishing data from fisheries targeting Atlantic Highly Migratory Species. The form is required to be completed for each "trip" (all sets of gear during the period between leaving and returning to port).

to-port deployment during which fish are caught or operations occur that support fishing activity (16 U.S.C. § 971, 1975), vessels are required to submit these two forms in accordance with the ATCA and MSA. The "Trip Summary Form," in Figure 2, which is submitted for each trip, involves the overall logistics of the trip (port of departure, expenses, sales, number of crew), while the "Set Form", Figure 1, focuses on each individual set made during said longline trip, including any associated fishing activity (i.e., number of hooks, gear type, total catches, interactions with protected species) (16 U.S.C. §1801, 2007).

Once collected, the self-reported data are stored and managed within the UDP logbook system, falling within the NOAA Administrative Order (NOA) 216-100. This order regarding the Protection of Confidential Fisheries Statistics allows NOAA to collect this information, to protect parties involved, and prevent public disclosure of trade-related practices (50 C.F.R. §300.220, 2016). The POP then utilizes these pelagic longline deployments and reported sets to determine the required at-sea fisheries observer coverage. The goal of 8% observer coverage aims to represent the entire fishery by quantifying fishing interactions on commercial longline vessels. However, despite *ca.* 1,000 pelagic longline sets being observed annually by the POP for the U.S. Atlantic fleet (Keene 2016), more than 80% of the total catch and effort data from this fishery is being self-reported by the fishing vessel captains.

While the observer-reported POP data could be highly accurate, there is a possibility the presence of a government fisheries observer could result in longline fishers altering their fishing activities from their normal practice. In recent years, the observer presence on pelagic longline fishing vessels has been referred to as an "observer bias" or "observer effect," in which the act of observing will influence the event being observed. In reference to commercial fishing, the "observer effect" refers to the influence fisheries observers have on catch reporting, as Faunce and Barbeaux (2008) described for data from a commercial groundfish fishery. Using linear mixed-effects models on landed pounds of fish in 2008, and including whether the trip was observed or not as part of the models' fixed effects, Faunce and Barbeaux (2008) showed 1-in-5 examined fisheries had significant differences in total weight landed as a result of an observer onboard during trip (four other fisheries showed no effect). By applying similar methods, an examination of self-reported data against fisheries observer-collected data could assess whether this "observer effect" is present in the U.S. Atlantic pelagic longline fleet.

Garrison and Stokes (2016) noted possible observer effects within the longline industry related to bycatch estimates. Though they mention consistency between the reporting for each program for targeted species such as swordfish, yellowfin tuna, and bigeye tuna, there are notable gaps for species of bycatch concern. Even with other fisheries, such as tuna purse seining in the eastern tropical Atlantic Ocean, Torres-Irineo et al. (2014) showed that lower levels of observer coverage compared to the true scope of the fishery may not be an accurate representation for abundance in terms of catch per unit effort (CPUE) for non-target species.

Within this analysis, fisheries interactions were emphasized through three disposition categories: 1) retained, 2) bycatch concern, 3) minimum economic value historically, but now retained. For species of particular bycatch concern, such as Atlantic Bluefin Tuna *Thunnus thynnus* or Sandbar Shark *Carcharhinus plumbeus*, as well as marine mammals and sea turtles, there is more incentive to minimize self-reported interactions and avoid subsequent penalties or even increased regulations. Similarly, species with no economic value, such as the Pelagic Stingray *Pteroplatytrygon violacea* or Lancetfish *Alepisaurus* spp., have the potential for under-reporting due to minimal benefit to the fishery, despite being commonly caught on a large percentage of longline trips. Escolar *Lepidocybium flavobrunneum*, which historically had been considered of lesser or no value and thus discarded, has become part of the "normal" retained incidental catch in recent years, thereby raising the potential for a higher level of accuracy in self-reporting.

In this thesis, both self-reported and fisheries observer data for the U.S. Atlantic pelagic longline fishery was analyzed to assess the putative observer effect for catches and disposition.

2. Materials and Methods

Through the SEFSC UDP logbook system and the POP fisheries observer (POP OBS) database, a comparison of "observed" sets against "unobserved" sets was analyzed for bias in the self-reported data. Twenty-five years of data, from 1992 until 2016, provided the datasets for analyses. When the analysis process began, 2016 was the last full year to have completed the internal NOAA quality assurance, quality control (QA/QC) procedure. By focusing on 40 key species reported in both datasets, an observer effect could be examined between the two datasets. To test the hypothesis of an observer influence on catch reporting, an examination of probability for a given species was analyzed with a model containing multiple covariates. This model was then applied to each species over the course of 25 years.

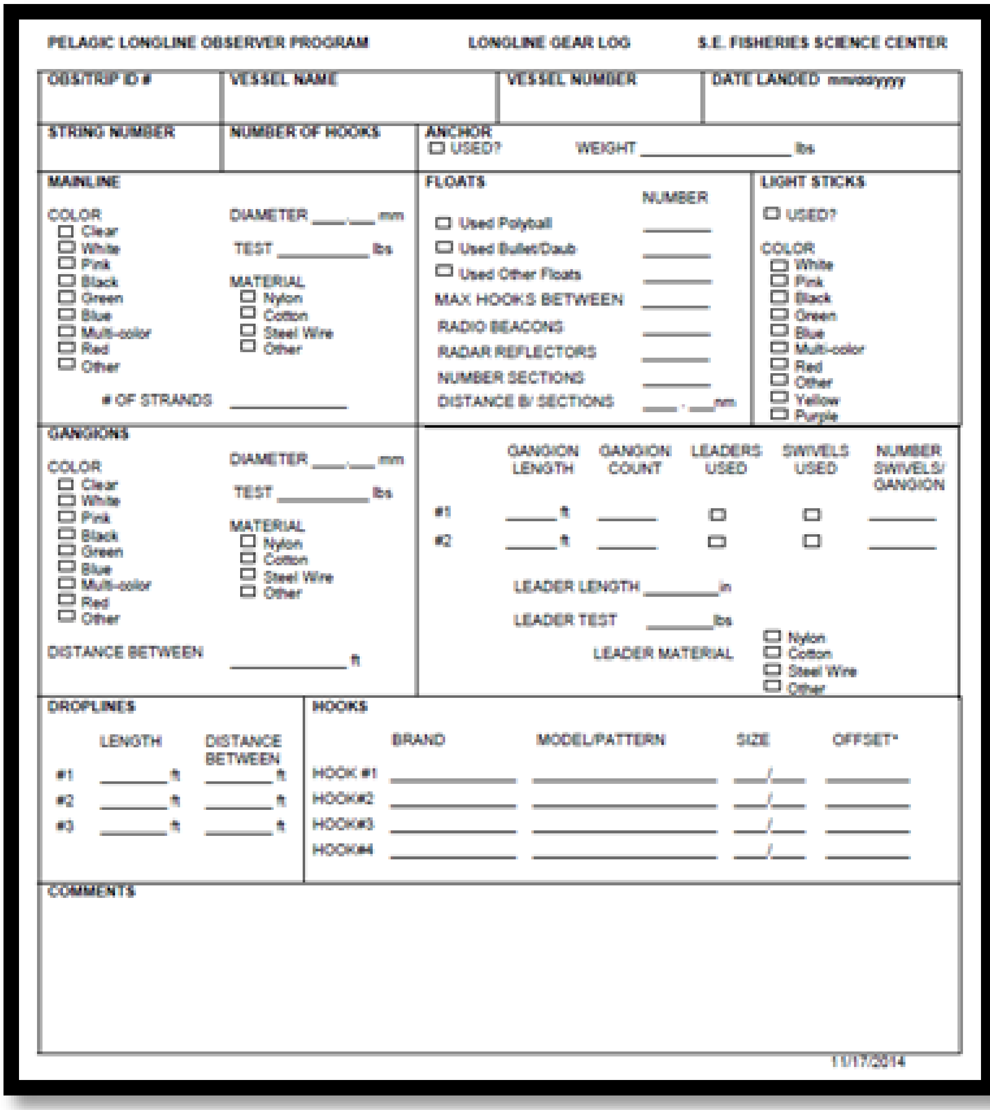
An overall observer effect was examined on a per-species base for each of the 40 species. Furthermore, tests were included for a “Year*observer effect” across the 25-year period which allows for an examination of inter-annual variation of reporting rates and trends over time which might change for several key bycatch species. Whether changes occurred in demand or regulations were introduced, an annual evaluation can help provide a better understanding of industry fluctuations over the last 25 years.

2.1 Data Preparation

Before the model could be implemented, a number of processes occurred with the datasets. Despite both programs collecting similar types of offshore data, there were innate differences in the data being collected, such as multiple operational and environmental variables. Figures 1 and 2 from the logbook program and Figures 3 through 5 from the POP, emphasize such differences, noting the variations between the forms being utilized.

From specifics of how pelagic longline vessels each configure and deploy gear at the set level, to the individual species being reported, there were subtle contrasts between the two datasets. Given the two datasets are stored in different databases and utilize different practices, the data had to be restructured into a compatible format to allow for comparison. The POP dataset includes much more detail on both the set metadata as well as the number of species recorded, and subsequently, all data fields which were not represented in both datasets were removed prior to any analysis. After a thorough reorganization and data cleansing of the SEFSC UDP logbook data and POP fisheries data, both datasets were combined into one, compatible dataset.

Each row of the dataset represented one set/haul combination, with each set/haul falling within one vessel’s trip. Defined as any dock to dock deployment where fishing occurs, each longline trip varies in the amount of set/haul combinations (e.g., trip 123456 had seven sets, representing seven rows of the dataset all under one trip identifier). For this analysis, a total of 33,974 sets were included from the logbook program and 21,331 from the observer program. Only complete sets were included within the model, i.e., any values of “NA” for any model variable would exclude that particular set from being included. Once all incomplete sets were


PELAGIC LONGLINE OBSERVER PROGRAM LONGLINE GEAR LOG S.E. FISHERIES SCIENCE CENTER

OBS/TRIP ID # | VESSEL NAME | VESSEL NUMBER | DATE LANDED mm/dd/yyyy

STRING NUMBER | NUMBER OF HOOKS | ANCHOR ☐ USED? WEIGHT ____ lbs

MAINLINE
COLOR ☐ Clear ☐ White ☐ Pink ☐ Black ☐ Green ☐ Blue ☐ Multi-color ☐ Red ☐ Other
DIAMETER ___.___ mm
TEST ____ lbs
MATERIAL ☐ Nylon ☐ Cotton ☐ Steel Wire ☐ Other
OF STRANDS ____

FLOATS NUMBER
☐ Used Polyball ____
☐ Used Bullet/Daub ____
☐ Used Other Floats ____
MAX HOOKS BETWEEN ____
RADIO BEACONS ____
RADAR REFLECTORS ____
NUMBER SECTIONS ____
DISTANCE B/ SECTIONS ___.___ nm

LIGHT STICKS
☐ USED?
COLOR ☐ White ☐ Pink ☐ Black ☐ Green ☐ Blue ☐ Multi-color ☐ Red ☐ Other ☐ Yellow ☐ Purple

GANGIONS
COLOR ☐ Clear ☐ White ☐ Pink ☐ Black ☐ Green ☐ Blue ☐ Multi-color ☐ Red ☐ Other
DIAMETER ___.___ mm
TEST ____ lbs
MATERIAL ☐ Nylon ☐ Cotton ☐ Steel Wire ☐ Other
DISTANCE BETWEEN ____ ft

	GANGION LENGTH	GANGION COUNT	LEADERS USED	SWIVELS USED	NUMBER SWIVELS/ GANGION
#1	____ ft	____	☐	☐	____
#2	____ ft	____	☐	☐	____

LEADER LENGTH ____ in
LEADER TEST ____ lbs
LEADER MATERIAL ☐ Nylon ☐ Cotton ☐ Steel Wire ☐ Other

DROPLINES

	LENGTH	DISTANCE BETWEEN
#1	____ ft	____ ft
#2	____ ft	____ ft
#3	____ ft	____ ft

HOOKS

	BRAND	MODEL/PATTERN	SIZE	OFFSET*
HOOK #1	____	____	___/___	____
HOOK#2	____	____	___/___	____
HOOK#3	____	____	___/___	____
HOOK#4	____	____	___/___	____

COMMENTS

11/17/2014

Figure 3. Longline Gear Log for 2016 (created in 2014) contains detailed questions about the gear fished by longline vessels. Used by pelagic longline fisheries observers working for the POP, this form is required to be completed for each "trip" (all sets of gear during the period between leaving and returning to port) and defines all gear characteristics utilized by a vessel during trip.

PELAGIC LONGLINE OBSERVER PROGRAM — LONGLINE HAUL LOG — SOUTHEAST FISHERIES SCIENCE CENTER

OBS/TRIP ID	VESSEL NAME	VESSEL NUMBER	DATE LANDED mm/dd/yyyy	HAUL #	GEAR CODE	PAGE # 1 OF ______

HAUL OBS?	CATCH?	INC TAKE?	WEATHER	WIND SPEED KN	WIND DIRECTION °	WAVE HEIGHT FT	REVERSE HAUL? NO ____ YES ____	GEAR COND	STRING NUMBER

MAINLINE LENGTH . NM	SET SPEED . KN	BOTTOM DEPTH RANGE ___ FM	HOOK DEPTH RANGE ___ FM	TOTAL ADD. WEIGHT ________ LBS	TARGET SPECIES ABBR.

ITEMS USED?

TYPE	NUMBER	TYPE	NUMBER
Floats	________	Radio Beacons/ Satellite Buoys	________
Light Sticks	________	Radar Reflectors	________
Rattlers	________	Add. Line Wts.	________
Surface Lights	________		

NUMBER OF HOOKS

SET	__________
LOST	__________
TENDED	__________
REBAITED	__________

BAIT INFORMATION

	NUMBER	LBS	KIND	TYPE	COND
# 1	______	______	______	______	______
# 2	______	______	______	______	______
# 3	______	______	______	______	______

SET/HAUL INFO		DATE mm/dd/yyyy	TIME 24 hours	POSITION INFORMATION BEARING/LATITUDE N OR S	BEARING/LONGITUDE E OR W	TEMP fahrenheit	
SET	BEGIN					.	
	END					.	
HAUL	BEGIN					.	Time lost
	END					.	.

COMMENTS: BH = __ __

11/2015

Figure 4. Longline Haul Log for 2016 (created in 2015) is used by pelagic longline fisheries observers working for the POP. This form is required to be completed for each deployment of pelagic longline gear set and hauled and reflects all the physical information relating to a single set/haul fished.

SOUTHEAST FISHERIES SCIENCE CENTER
INDIVIDUAL ANIMAL LOG

11/17/2014

Obs/Trip Identifier	Vessel Name	Vessel Number	Date of Haul mm/dd/yyyy	Haul Number	Page
			/ /		____ of ____

CARCASS TAG NUMBER OR SPECIMEN NUMBER	SPECIES		Damg.	STATUS	ACTION	LENGTH MEASUREMENTS (cm)				Actual Dressed Weight (Lbs)	SEX	TAG NUMBER OR SAMPLE INFORMATION OR COMMENT(r)	TAG CODE	Est. Round Weight (Lbs)
	Name (Abbr)	Code	Code	Unknown (0) Alive (1) Dead (2) Damage (3)	Unknown (0) Kept (1) Released dead (2) Released alive (3) Finned (4) Lost (5) Tended (6)	#1	#2	#3	Code		U (0) M (1) F (2)		TR (1) TT (2) RC (3)	

COMMENTS: NO_______ YES _______

Figure 5. Individual Animal Log for 2016 (created in 2014) is used by pelagic longline fisheries observers working for the POP. This log records catch information on each species such as size, sex, and including whether species was alive, dead, kept, released, and/or damaged.

removed, the remaining sets consisted of 25,601 from the logbook program and 19,812 from the observer program. The combined dataset consisted of 402 unique vessel identification numbers from the logbook program and 261 from the observer program, dating from 1992 until the end of 2016 and ranging in location from the Caribbean to the western North Atlantic, including the Gulf of Mexico. To prevent bias, each logbook record in which an observer was also present during the set had been removed from the analysis. This removal precluded those circumstances in which a vessel captain requested to see the observer-collected catch data to mimic the number and character of animal interactions on the logbook set form.

Once compiled into a similar format, specific variables were predetermined as potentially significant. Reviewing the set-specific information collected by observers (location, date, time, sea surface temperature) along with species-related information such as number of individuals, and then cross referencing these variables with information present in the UDP logbook data, the following variables were initially deemed potentially important: area, time, year, season, number of hooks, number of light sticks, bait kind, soak time, sea surface temperature and presence of an observer. Various combinations of these variables were also considered.

Once predetermined as a model predictor, each variable was then assessed to verify all information fell within appropriate ranges and totals. Histograms and box plots were used to detect data anomalies. During this verification process, some errors with the original data from both programs were discovered. For example, using Figure 7 as a reference, the number of light sticks used during a pelagic longline set is typically used as a variable for target species and ranges between 0 and 1650, with different vessels utilizing different patterns and configurations to target swordfish versus targeting various species of tuna. Regardless of how many light sticks are utilized, they are an added value to a gear configuration and typically associated with the amount of hooks set. Being an added value to the gear eliminates the possibility for negative values and presents the rarest of occasions to have a ratio greater than 1:1 for light sticks to hooks. The lowest value for light sticks therefore could only be zero, an indication light sticks were not deployed on said gear (a value of zero light sticks generally indicates the set targeted tuna). During a value assessment for light stick totals – as seen in Figure 6 – discrepancies in the 1:1 ratio occurred, indicating issues within the original raw data.

SET_DAY	SET_MONTH_NUM	SET_YEAR	LIGHT_STICKS_SET	HOOKS_SET
26	6	1992	700	300
29	1	1993	300	7
4	5	1993	300	100
7	7	1993	800	0
15	7	1993	100	35
22	8	1993	3000	1000
24	2	1994	250	102
6	3	1994	350	40
16	6	1994	200	20
27	9	1994	200	90
6	2	1995	350	7
9	2	1995	350	7
6	7	1995	900	400

Figure 6. An excerpt of the raw data used within the model, the two columns "LIGHT_STICKS_SET" and "HOOKS_SET" show discrepancies between the ratios of light sticks to hooks. Typically a 1:1 ratio, these anomalies were either verified to be true, adjusted/corrected within the databases, or removed from the analysis.

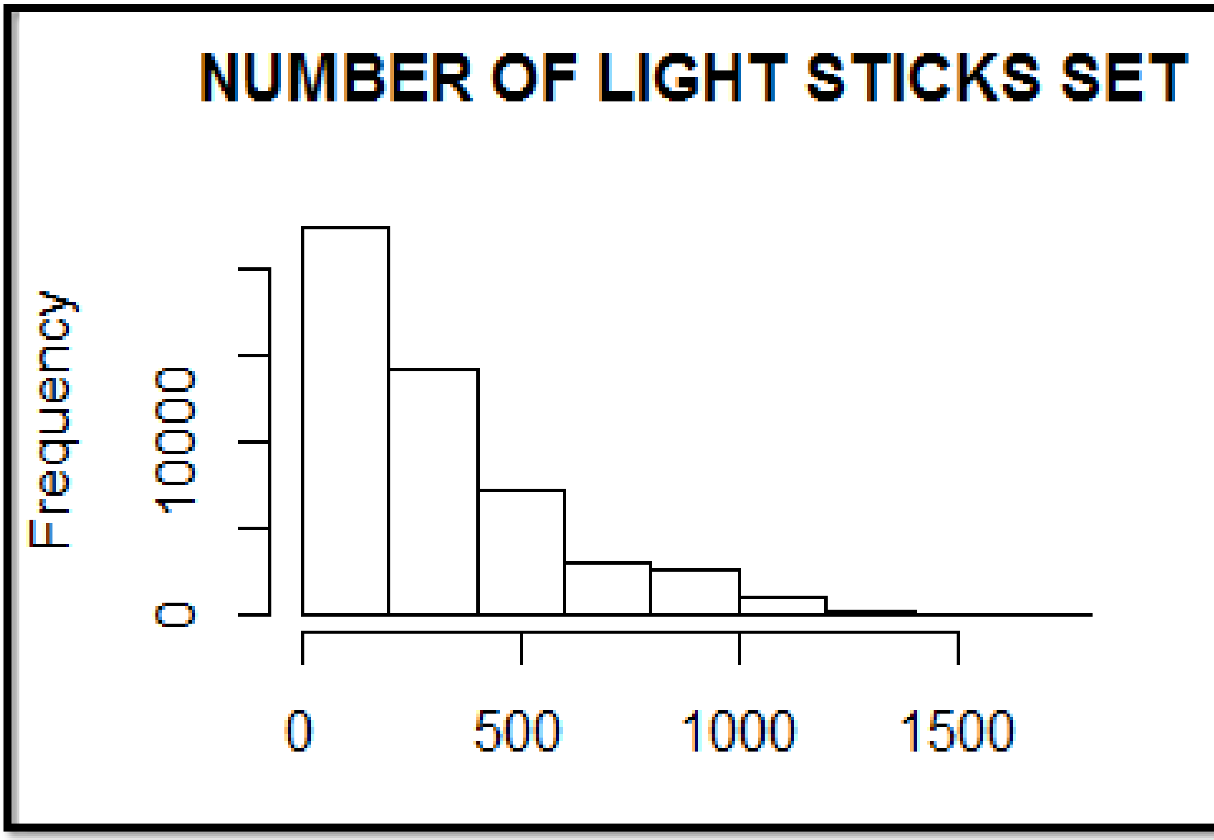


Figure 7. Using a histogram of all available data from both logbook and POP, a range and frequency of light sticks set [0-1650] was measured for all longline vessels. As mentioned in Figure 6, any anomalies were verified to be true, adjusted within the databases, or removed from the analysis until the histogram represented an accurate range.

Though these errors represented less than three percent of the data in comparison to the thousands of applicable rows (sets), incorrect values such as these distort the results and disrupt the accuracy of the analyses. Each suspected error discovered was eventually verified or adjusted within the dataset. If a suspected error occurred, but could not be disproven with absolute certainty (such with the case of self-reported data), that information was subsequently removed. For each variable deemed significant (soak time, area), a thorough review was conducted for each program. Certain unverifiable errors found within the self-reported logbook data were unable to be corrected and were removed from the analysis.

2.2 Variable Selection

Each potential predictor variable was defined prior to inclusion within the model. Based on the definitions provided by the POP and logbook program, the following sections define each variable and how it was applied to the model being analyzed.

2.2.1 Variables

- Area Names – The variable "area names" represents the 11 geographic regions of the western North Atlantic, Gulf of Mexico and Greater Caribbean, which are defined within the POP as either CAR (Caribbean), GOM (Gulf of Mexico), FEC (Florida East Coast), SAB (South Atlantic Bight), MAB (Mid Atlantic Bight), NEC (Northeast Coast), NED (Northeast Distant), SAR (Sargasso), NCA (North Central Atlantic), TUN (Tuna North), or TUS (Tuna South). Each area is defined via latitude and longitude and delineated by NOAA for the U.S. domestic HMS fisheries. A majority of longline sets occur in coastal areas such as the GOM, FEC, SAB, MAB, and NEC compared to deeper offshore areas such as TUS, TUN, and NCA.
- Sea Surface Temperature - The variable "sea surface temperature" (in Celsius), which was collected at the beginning of each haul, was collected in Fahrenheit and converted to Celsius.
- Season – Begin set month was used to assign sets to one of four seasons, March, April, and May were defined as "spring"; June, July, and August as "summer"; September, October, and November as "fall"; and December, January, and February as "winter."

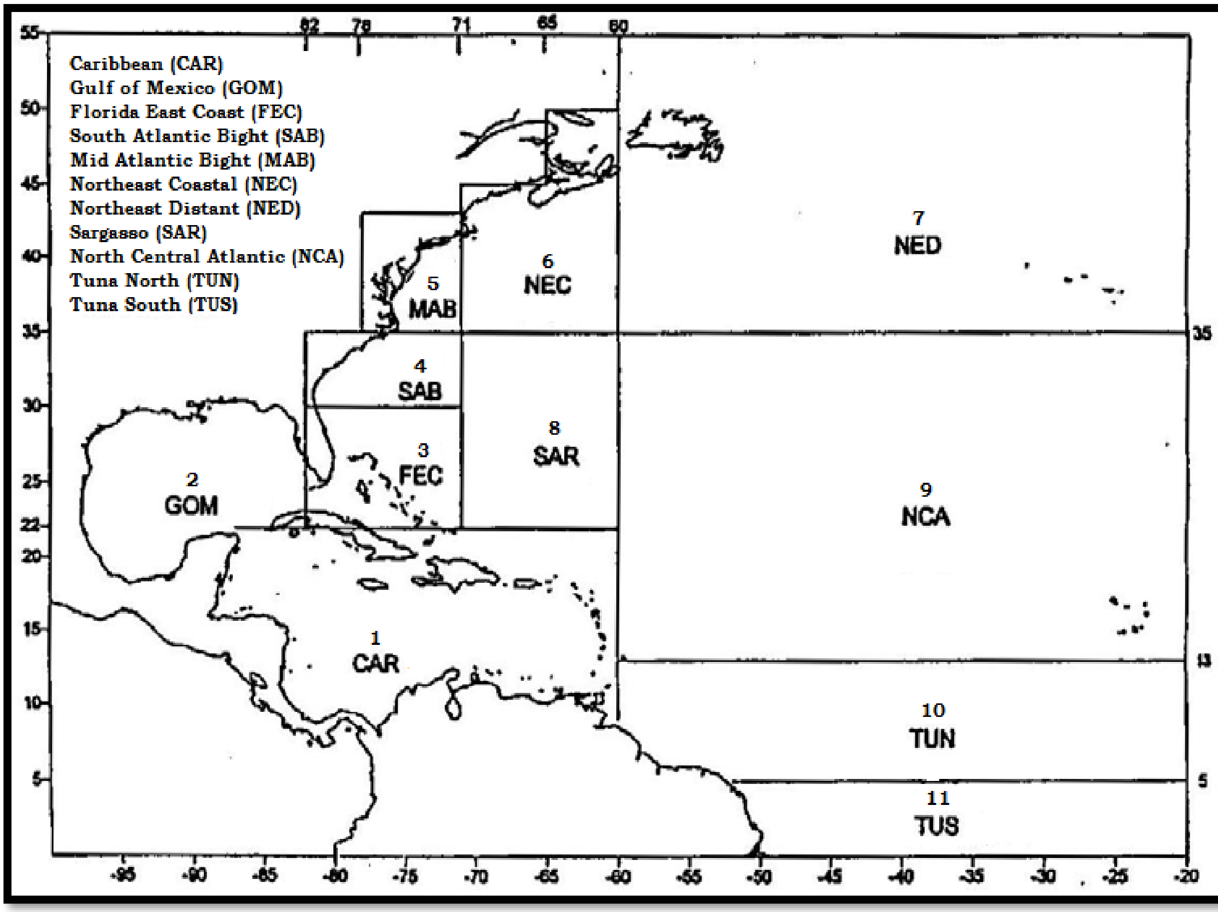


Figure 8. Eleven management areas of the western North Atlantic, Gulf of Mexico and Greater Caribbean. Delineated by NOAA and used by POP to designate fishing areas for the pelagic longline fishery (Keene et al., 2010), each area is defined as: CAR (Caribbean), GOM (Gulf of Mexico), FEC (Florida East Coast), SAB (South Atlantic Bight), MAB (Mid Atlantic Bight), NEC (Northeast Coast), NED (Northeast Distant), SAR (Sargasso), NCA (North Central Atlantic), TUN (Tuna North), or TUS (Tuna South).

- Year - Utilizing “year” as a variable allowed for an annual analysis compared to one, 25-year period.
- Hooks Set - The “number of hooks set” is associated with gear configuration and is determined based on the number of hooks deployed during a given daily set. For self-reported data, there was a mean of 653 hooks per set against 720 hooks per set with an observer. Within the model, a total of 16,339,585 hooks were included from the logbook program and 14,223,079 for the observer program, with the observer program observing *ca.* 46% of the total hooks set for this analysis. The total number of hooks set can be useful in determining Catch Per Unit Effort (CPUE), traditionally characterized for the pelagic longline fishery as catch per 1000 hooks.
- Light Sticks - As mentioned above, the number of light sticks deployed in a set can be used to retroactively determine intended target species. General deployment characteristics for light sticks were designated in the following categories. If each hook is associated with one light stick (100% light sticks), then soak will occur at night and target species is swordfish. If each hook is not associated with a light stick (0% light sticks), then soak will occur during daytime and target species is tuna. Any percentage less than 100% (meaning light sticks were not placed on every hook), the target species is declared as a mixture of multiple species and the time of day varies. For this analysis, the proportion of light sticks was defined as either <0.25 | ≥ 0.25 and ≤ 0.50 | >0.50 and ≤ 0.75 | >0.75.
- Soak Time - “Soak time” is defined as the time (expressed in hours) elapsed from the deployment of the last hook during the set and the first hook removed during the haulback. A common practice of longline vessels, “reverse haul,” is defined as, “the last hook set is the first hook hauled.” Benefits to utilizing a reverse haul include reduction in gasoline usage and traveling time, but is disadvantageous based on amount of time the most recent hooks remained in the water. As with light sticks, there were anomalies within the data for soak times, forcing a range of soak time for this analysis to be included as zero to 50 hours. Any values beyond this range were removed from analysis.
- Presence of an Observer - The final variable, presence of an observer on any given trip, is defined as a binary of 1 (presence) or 0 (absence). Utilizing this information, in combination with the multiple other covariates above, can provide a percentage value

(along with 95% confidence intervals) to determine how the presence of an observer increases or decreases the amount a particular species is kept or discarded on average.

2.3 R Modeling

General Additive Models (GAMs) were used for the CPUE analyses. Rather than using a linear coefficient for each variable as in a GLM, a smooth function is estimated for each predictor, resulting in a superior fit when predictors are non-linear (Hastie and Tibshirani 1986). Initially, a GLM with a Poisson response was fit using the R package `nlme`, but due to the high number of zeros in the dataset (an indication of no individuals caught during a particular set), a different response structure was required. This was confirmed by the residual deviance, which determines the suitability of the response distribution given the model predictors. With the residual deviance being substantially higher relative to the degrees of freedom, it became clear over dispersion was present within the dataset. After observing strongly non-linear relationships between many of the predictors and responses, a GAM with a negative-binomial response structure proved to be the most appropriate analysis method.

The GAM model (see *R code* as Appendix 4) was used to determine the significance of the predictor variables for observer presence during a longline trip. Distinctive to generalized additive models, non-parametric, unspecific functions of the predictor variables (e.g., temperature, soak time, or hooks set), can be used to increase the accuracy of these predictors on smooth functions of dependent variables (Hastie and Tibshirani 1986). These GAMs can discern hidden patterns of significance and assist in the interpretation of relationships between years, geographic locations, fleet demographics, catch species abundancies and discrepancies between what is kept, discarded alive, and discarded dead. An individual GAM was applied to each species or species group (e.g., "XHH_ALL" referred to all hammerhead shark species combined into one variable). To account for variance in catchability between vessels, a "random effect" for each vessel – defined as each vessel's individual vessel identification number – was included in the model. Written as "s(VESSEL_ID_NUMBER, bs = "re") in the R package `mgcv` (Wood 2011), this random effect helped ensure non-independence of vessels was accounted for by reducing bias and allowing for a correlation between trips on the same vessel (e.g., same vessels tend to yield more similar catches relative to other vessels). All vessels, even those which have never been deployed with an observer, were averaged together and analyzed collectively.

Due to model insignificance and less than 500 records of live bait (or the combination of live and dead bait) present within the data, "bait_kind" was removed as a potential predictor variable for the analysis and extracted from the model. With "time" and "light stick proportion" both being used as a variable for targeting species, only "light stick proportion" was included within the model to maximize accuracy and minimize the number of variables. By utilizing independent predictors and only including interactions if there was evidence of significance, this helped ensure multicollinearity was not an issue. All remaining predictor variables, including combination of temperature by season and hooks set by season were included in final model.

2.3.1 `gam.check` Function

Once all models successfully completed, the results were analyzed for significance. The function `gam.check` (see *R Code* as Appendix 4), which produces diagnostic information about the results via general information and residual plots, showed the dimension parameters (*k*) to be adequate in Figure 9. If the p-value was < 0.05, or the effective degrees of freedom (edf) value was too close to the *k* value, the model was rerun with a higher *k* parameter for that particular covariate, adjusting each variable until it was evident there would be no substantial gain in edf. This ensured an adequate degree of smoothing to sufficiently capture the relationship between predictor and response.

2.3.2 Summary Function

Next, the summary function determined significance for each predictor. Referring to the categorical variables within the "Parametric coefficients" section of the summary results in Figure 10, any row value <0.05 is deemed significant. The most important value within this summary, "OBSERVER.1", determines if the presence of an observer (based on other predictors within model), is significant. Focusing on the Pr(>|z|) column in Figure 10, a number of predictor variables proved to be significant (<0.05). "Deviance explained = XX%", shown in Figure 11 within the results of the summary function, demonstrates variability in the response variable based on the terms in the model. If the deviance explained value is low, it is an indication other potentially influential factors are not being accounted for in the model.

2.3.3 ANOVA Function

	k'	edf	k-index	p-value
s(SOAK_TIME)	29.000	14.318	0.890	0.28
s(HOOKS_SET)	29.000	16.620	0.892	0.36
s(HOOKS_SET):SEASONAUTUMN	29.000	8.213	0.892	0.37
s(HOOKS_SET):SEASONSPRING	29.000	0.142	0.892	0.39
s(HOOKS_SET):SEASONSUMMER	29.000	16.193	0.892	0.36
s(HOOKS_SET):SEASONWINTER	29.000	1.103	0.892	0.36
s(FAHtoCEL)	29.000	1.006	0.878	0.08
s(FAHtoCEL):SEASONAUTUMN	29.000	8.236	0.878	0.08
s(FAHtoCEL):SEASONSPRING	29.000	10.862	0.878	0.06
s(FAHtoCEL):SEASONSUMMER	29.000	13.289	0.878	0.06
s(FAHtoCEL):SEASONWINTER	29.000	7.159	0.878	0.08
s(VESSEL_ID_NUMBER)	407.000	328.759	NA	NA

Figure 9. Using the number of swordfish kept as an example, here are the results of the `gam.check` function. A p-value > 0.05 is an indicator "k" was an adequate fit for model. A low p-value is an indication 'k" was too low, especially if the columns "k" and "edf" are too close in numerical value.

```
Parametric coefficients:
                    Estimate Std. Error z value Pr(>|z|)
(Intercept)          0.63845    0.05546  11.512  < 2e-16 ***
AREA_NAMESFEC       -0.66584    0.03480 -19.135  < 2e-16 ***
AREA_NAMESGOM       -0.34799    0.03840  -9.062  < 2e-16 ***
AREA_NAMESMAB       -0.49328    0.04304 -11.461  < 2e-16 ***
AREA_NAMESNCA       -0.08649    0.04632  -1.867  0.06187 .
AREA_NAMESNEC       -0.30651    0.04365  -7.022 2.18e-12 ***
AREA_NAMESNED       -0.89217    0.66393  -1.344  0.17902
AREA_NAMESSAB       -0.01992    0.03496  -0.570  0.56890
AREA_NAMESSAR       -0.34943    0.05026  -6.952 3.61e-12 ***
AREA_NAMESTUN       -0.89148    0.07089 -12.576  < 2e-16 ***
AREA_NAMESTUS        0.25667    0.08629   2.974  0.00294 **
SEASONSPRING        -0.15354    0.02438  -6.297 3.03e-10 ***
SEASONSUMMER        -0.26548    0.01823 -14.564  < 2e-16 ***
SEASONWINTER         0.02490    0.02599   0.958  0.33796
OBSERVER.1          -0.27748    0.01258 -22.058  < 2e-16 ***
LIGHT_STICK_PROP0.5  1.00582    0.01821  55.220  < 2e-16 ***
LIGHT_STICK_PROP0.75 1.21606    0.02753  44.177  < 2e-16 ***
LIGHT_STICK_PROP1    1.33019    0.02160  61.575  < 2e-16 ***
```

Figure 10. Using the number of bigeye tuna discarded alive as an example, the results of the "Parametric Coefficients" portion of the Summary Function determines significance based on whether variables have a result < 0.05 in the "Pr(>|z|)" column. Each area, season, and light stick proportion is determined to be significant or not. For this analysis, the most important variable, "OBSERVER.1" has a value of 2e-16 (<0.05), determining the presence of an observer (based on all predictors within the model) to be significant.

```
s(FAHtoCEL):SEASONWINTER  1.000e+00 1.000e+00   2.877 0.089855 .
s(VESSEL_ID_NUMBER)       1.670e+02 4.060e+02 787.306  < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Rank: 795/797
R-sq.(adj) =  0.088   Deviance explained = 45.5%
-REML = 6000.7  Scale est. = 1         n = 38585
```

Figure 11. Using the number of bigeye tuna discarded alive as an example, another result of the summary function, "Deviance explained", shows the variability in the response variable based on the terms in the model. If the "Deviance explained" value is too low, there is an indication other influential factors are not being accounted for in the model.

Parametric Terms:

	df	Chi.sq	p-value
AREA_NAMES	1	0.00	1
SEASON	3	188.12	<2e-16
OBSERVER.	1	124.03	<2e-16
LIGHT_STICK_PROP	3	98.96	<2e-16

Approximate significance of smooth terms:

	edf	Ref.df	Chi.sq	p-value
s(SOAK_TIME)	7.611	9.545	30.003	0.000677
s(HOOKS_SET)	3.323	4.264	8.363	0.094200
s(HOOKS_SET):SEASONAUTUMN	1.313	1.948	2.249	0.299483
s(HOOKS_SET):SEASONSPRING	6.117	7.776	36.459	1.23e-05
s(HOOKS_SET):SEASONSUMMER	3.139	4.013	7.776	0.103350
s(HOOKS_SET):SEASONWINTER	1.001	1.002	0.539	0.463275
s(FAHtoCEL)	8.474	10.662	21.918	0.023117
s(FAHtoCEL):SEASONAUTUMN	14.452	16.223	43.064	0.000565
s(FAHtoCEL):SEASONSPRING	1.531	1.698	0.119	0.925452
s(FAHtoCEL):SEASONSUMMER	8.717	10.830	44.497	5.80e-06
s(FAHtoCEL):SEASONWINTER	7.465	9.577	21.753	0.021430
s(VESSEL_ID_NUMBER)	189.575	424.000	769.190	< 2e-16

Figure 12. Using all disposition categories of Bluefin tuna combined into one variable as the example, an analysis of variance (ANOVA) was used to determine differences among groups within a sample. Used more as an average for each group (rather that individually), an ANOVA focuses on the significance levels as a whole for each response variable. For "BFT_ALL_COMBINED", soak time, hooks sets (spring), temperature, and temperature by autumn, summer, and winter were all significant

An analysis of variance (ANOVA) was used to analyze the differences or variations among groups within a sample and determine which variables have an effect on the response. ANOVA, as opposed to the summary function, focuses on significance levels as a whole as opposed to levels of individual variables. Listed under the label "Parametric Terms" the significance of each predictor variable (e.g., season, area, temperature) is assessed.

2.3.4 Quantifying Results

The "Observer Coefficient" is the percentage value quantifying the model-based observer effect. (see *R code* as Appendix 4) The second group of code, the "95% Confidence Interval for Observer Coefficient" produces the range to which the observer coefficient value falls within (to a 95% certainty). (see *R code* as Appendix 4) If the percentage value for the observer coefficient is positive, there is an indication an observer on board a vessel causes a greater quantity of a species to be reported. If the coefficient were negative, that would be an indication of more interactions in the absence of an observer. If the confidence interval contains zero, that is an indication of no observer effect. After analyzing each species over the course of 25 years, the same response variables were analyzed annually. Table 4 represents a quantified observer effect for all species applied within the model.

2.4 Species

Using the Atlantic Highly Migratory Species Logbook form (NOAA Form 88-191, 2016) and cross-referencing it with the 2016 Pelagic Observer Program Species Code list seen in Table 2, 40 species were analyzed to determine if the presence of an observer affected the amount of individuals kept, discarded alive, or discarded dead. Shown in Table 1, due to changes in the species forms over 25 years, each species was analyzed only during the time frame in which the species were present for both programs.

2.4.1 Swordfish and Tuna

Table 1. An "X" indicates species presence for both observer and logbook program for given year. If box is blacked out, species was not present for one or both programs during given year(s). Bonito, Sandbar Shark, Escolar and the three mammal species (Short-finned Pilot Whale, Long-finned Pilot Whale, and Risso's Dolphins) were not present during the entire 25-year period, only being modeled during years both were present for both programs.

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
SWORDFISH (SWO)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
BONITO (BON)		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
BLUEFIN TUNA (BFT)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
SKIPJACK TUNA (SKJ)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
YELLOWFIN TUNA (YFT)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
BLACKFIN TUNA (BLK)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
ALBACORE (ALB)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
BIGEYE TUNA (BET)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
BLUE SHARK (BSH)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
SHORTFIN MAKO SHARK (SMA)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
LONGFIN MAKO SHARK (LMA)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
OCEANIC WHITETIP SHARK (OCS)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
PORBEAGLE SHARK (POR)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
BIGEYE THRESHER SHARK (BET)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
COMMON THRESHER SHARK (PTH)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
BIGNOSE SHARK (SBG)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
BLACKTIP SHARK (SBK)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
DUSKY SHARK (DUS)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
HAMMERHEAD SHARK (x3) (XHH)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NIGHT SHARK (SNI)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
SANDBAR SHARK (SSB)			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
SILKY SHARK (FAL)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
SPINNER SHARK (SSP)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
TIGER SHARK (TIG)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
ESCOLAR (GEM)			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
COMMON DOLPHINFISH (DOL)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
WAHOO (WAH)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
KING MACKEREL (KGM)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
GREATER AMBERJACK (AMJ)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
WHITE MARLIN (WHM)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
BLUE MARLIN (BUM)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
SAILFISH (SAI)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
ROUNDSCALE SPEARFISH (SPG)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
LOGGERHEAD TURTLE (TTL)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
LEATHERBACK TURTLE (TLB)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
PILOT WHALE (x2) (MPW)																X	X	X	X	X	X	X	X	X	X
RISSOS DOLPHIN (MRD)																X	X	X	X	X	X	X	X	X	X

Table 2. An excerpt from the Pelagic Observer Program Species Code List, each species is grouped together as either a billfish, shark, tuna, finfish, marine mammal, sea turtle, or sea bird. Including the species name, scientific name, and a three-letter code used to expedite the data collection process, this list is used as a reference by all observers working for the POP.

PELAGIC OBSERVER PROGRAM			SOUTHEAST FISHERIES SCIENCE CENTER		
Istiophoridae	BILLFISH	BIL		TUNA	TUN
Makaira nigricans	MARLIN BLUE	BUM	Thunnus thynnus	TUNA BLUEFIN	BFT
Kajikia albida	MARLIN WHITE	WHM	Thunnus albacares	TUNA YELLOWFIN	YFT
Istiophorus platypterus	SAILFISH ATLANTIC	SAI	Thunnus atlanticus	TUNA BLACKFIN	BLK
Tetrapturus spp.	SPEARFISH	SPX	Thunnus obesus	TUNA BIGEYE	BET
Tetrapturus pfluegeri	SPEARFISH LONGBILL	SPF	Katsuwonus pelamis	TUNA SKIPJACK	SKJ
Tetrapturus georgii	SPEARFISH ROUNDSCALE	SPG	Thunnus alalunga	TUNA ALBACORE	ALB
T. albidus georgii	WHITE MARLIN / R.S. SPEARFISH	WHX	Euthynnus allettaratus	LITTLE TUNNY	LTA
Xiphias gladius	SWORDFISH	SWO	Sarda sarda	BONITO	BON
Isurus spp	SHARK MAKO	XMA			
Isurus oxyrinchus	SHARK MAKO SHORTFIN	SMA	Acanthocybium solandri	WAHOO	WAH
Isurus paucus	SHARK MAKO LONGFIN	LMA	Scomberomorus cavalla	MACKEREL KING	KGM
Lamna nasus	SHARK PORBEAGLE	POR	Scomber japonicus	MACKEREL CHUB	CHM
Carcharhinus longimanus	SHARK OCEANIC WHITETIP	OCS	Auxis thazard	MACKEREL FRIGATE	FRM
Carcharhinidae spp	SHARK REQUIEM	SRQ	Rachycentron canadum	COBIA	CBA
Galeocerdo cuvier	SHARK TIGER	TIG	Coryphaena spp	DOLPHIN FISH	DOL
Rhizoprionodon terraenova	SHARK ATLANTIC SHARPNOSE	SAS			
Carcharhinus acronotus	SHARK BLACKNOSE	SBN	Lepidocybium flavobrunneum	ESCOLAR (SMOOTH SKIN)	GEM
Carcharhinus altimus	SHARK BIGNOSE	SBG	Ruvettus prestiosus	OILFISH (ROUGH SKIN)	OIL
Carcharhinus limbatus	SHARK BLACKTIP	SBK	Seriola spp.	AMBERJACK	AMJ
Prionace glauca	SHARK BLUE	BSH	Caranx spp.	JACK	JAC
Carcharhinus obscurus	SHARK DUSKY	DUS	Sphyraena spp.	BARRACUDA	BAR
Carcharhinus isodon	SHARK FINETOOTH	SFT	Elagatis bipinnulata	RAINBOW RUNNER	RUN
Carcharhinus plumbeus	SHARK SANDBAR	SSB	Pomatomus saltatrix	BLUEFISH	BLU
Carcharhinus falciformis	SHARK SILKY	FAL	Cubiceps pauciradiatus	CIGARFISH	CUB
Carcharhinus brevipinna	SHARK SPINNER	SSP	Trachipterus arcticus	DEALFISH	DEA
Carcharhinus signatus	SHARK NIGHT	SNI	Alepisaursus spp.	LANCETFISH	LAX
Carcharhinus perezi	SHARK REEF	SRF	Gempylus serpens	MACKEREL SNAKE	TRX
Alopias spp.	SHARK THRESHER	XTH	Lampris guttatus	OPAH	OPA
Alopias superciliosus	SHARK THRESHER BIGEYE	BTH	Bramadae spp.	POMFRET	POA
Alopias vulpinus	SHARK THRESHER COMMON	PTH		PUFFER	PUX
Sphyrna spp.	SHARK HAMMERHEAD	XHH	Echeneidae spp.	REMORA	REM
Sphyrna mokarran	SHARK HAMMERHEAD GREAT	GHH	Mola spp.	SUNFISH	MOX
Sphyrna lewini	SHARK HAMMERHEAD SCALLOPED	SPL	Masturus lanceolatus	SUNFISH SHARPTAIL	MST
Sphyrna zygaena	SHARK HAMMERHEAD SMOOTH	SHH	Mola mola	SUNFISH OCEAN	MOC
Pteroplatytrygon violacea	PELAGIC STINGRAY	PEL	Megalops atlanticus	TARPON	TAR
Mobulidae	MANTA RAY	MAN	Lobotes surinamensis	TRIPLETAIL	TPL
	SKATES/RAYS	SRX		WHALE	WHA
	TURTLE	TTX	Orcinus orca	WHALE KILLER	MKW
Chelonia mydas	TURTLE GREEN	TTG	Ziphiidae spp.	WHALE BEAKED	WBK
Eretmochelys imbricata	TURTLE HAWKSBILL	THB	Kogia breviceps	WHALE SPERM PYGMY	PSW
Caretta caretta	TURTLE LOGGERHEAD	TTL	Globicephala spp.	WHALE PILOT	MPW
Lepidochelys kempii	TURTLE KEMP'S RIDLEY	TKR	Globicephala melas	WHALE PILOT LONGFIN	PWL
Dermochelys coriacea	TURTLE LEATHERBACK	TLB	Globicephala macrorhynchus	WHALE PILOT SHORTFIN	PWS
			Hyperoodon ampullatus	WHALE NORTHERN BOTTLE	WNB

Swordfish and tuna were broken down into three separate categories before analysis, based on either being kept, discarded alive, or discarded dead. Each of the three analyses focused on the entire 25-year period, producing one result for each disposition category. Additionally, all three disposition categories were combined into one variable (e.g., "SWO_ALL") and measured again to provide an overall result for each species.

The combined variables were then graphed together – ranked in order of most to least affected – to show which species had the most significant observer effect. Using zero percent difference as the baseline, any result statistically above zero (more fish were caught in the presence of an observer) had a graphing point displayed in red. If the 95% confidence interval contained zero, an observer effect was not present and the graphing point is green. If more species were caught in the absence of an observer), the result would be presented beneath zero on the graph and the graph point color would be blue.

Each combined variable (e.g., "SWO_ALL") was then analyzed by year. The following species of tuna and swordfish were analyzed via GAM: Swordfish, Bluefin Tuna, Yellowfin Tuna, Bigeye Tuna, Bonito, Skipjack Tuna *Katsuwonis pelamis*, Blackfin *Thunnus atlanticus* and Albacore *Thunnus alalunga*.

2.4.2 Finfish

The same procedure for tuna and swordfish was utilized for the economically valued finfish, Escolar, Common Dolphinfish, Wahoo *Acanthocybium solandri*, King Mackerel *Scomberomorus cavalla*, and Greater Amberjack *Seriola dumerili*. Based on the same disposition categories (kept, discarded alive, discarded dead), these five species were also combined into one variable (e.g., "DOL_ALL") using the same color-coded criteria. An annual analysis using the combined variable was performed for each species as well.

2.4.3 Billfishes

For istiophorid billfishes, the following four species were analyzed: Blue Marlin, White Marlin *Kajikia albidus,* Sailfish *Istiophorus albicans*, and Roundscale Spearfish *Tetrapturus georgii*. Each species was analyzed according to the same disposition categories mentioned above (kept, discarded alive, discarded dead) and grouped together into one variable (e.g., "BUM_ALL"). During the analysis for billfish kept, the analysis could not be completed, thus eliminating the need for a graph. As with swordfish, tuna, and finfish, an annual analysis was conducted.

Misidentification with smaller billfishes can be a persistent problem, especially between the roundscale spearfish and white marlin. With white marlin, roundscale spearfish and sailfish having similar body types, and the major differences occurring in either the dorsal fins or relative position of the anus to the anal fins, it is understandable that incorrect identification could occur during longline procedures, especially if captains and crew have not been properly trained in identifying. For white marlin and roundscale spearfish, proper identification is nearly impossible, as these two species of billfish are nearly indistinguishable, even considered to be one species (white marlin) until 2007. A common method of identification (proximity of anus to anal fin) requires removal of billfish from the water, but due to environmental restrictions, cannot be legally performed. Because of these factors, the roundscale spearfish, white marlin, and an unidentified marlin/spearfish variable (WHX), were combined into one variable during all analyses and written as "WHX." Included as a tool for observers, the spearfish/marlin variable was added to identify billfish as one of the two, rather than just a generic "billfish." The "WHX" variable was included in all disposition categories (kept, discarded alive, discarded dead) so the results for billfishes represent four species, but only three variables. As a result of domestic regulations, all billfish species within the U.S. Atlantic pelagic longline industry cannot be retained and are considered bycatch.

2.4.4 Sharks

For sharks, 18 species – as seen in Table 3 – were analyzed in one of two groups: coastal or pelagic sharks, as determined by the only species pre-written on the logbook set form and also available within POP data. Important to note, as with the billfishes, some species of sharks are federally prohibited from retention by the U.S. Atlantic pelagic longline fishery. Within Table 3, all species with one asterisk may not be retained or possessed in any form. All species with two asterisks may not be retained by vessels with pelagic longline gear onboard. Porbeagle sharks, three asterisks, must be released when swordfish, tuna or billfish are onboard. Labeled with four asterisks, Sandbar Sharks can only be retained by vessels participating in shark research (HMS

Table 3: Coastal and Pelagic Sharks Used in Analysis. The following species were the only pre-written species included in both the POP and logbook data, defined as one of two groups for this analysis based on general habitat locations.

Coastal Sharks	Bignose* *Carcharhinus altimus*, Blacktip *Carcharhinus limbatus*, Dusky* *Carcharhinus obscurus*, Great Hammerhead** *Sphyrna mokarran*, Scalloped Hammerhead** *Sphyrna lewini*, Smooth Hammerhead** *Sphyrna zygaena*, Night* *Carcharhinus signatus*, Sandbar**** *Carcharhinus plumbeus*, Silky** *Carcharhinus falciformis*, Spinner *Carcharhinus brevipinna*, Tiger *Galeocerdo cuvier*
Pelagic Sharks	Blue *Prionace glauca*, Shortfin Mako *Isurus oxyrinchus*, Longfin Mako* *Isurus paucus*, Oceanic Whitetip** *Carcharhinus longimanus*, Porbeagle*** *Lamna nasus*, Bigeye Thresher* *Alopias superciliosus*, Common Thresher *Alopias vulpinus*

Compliance Guide: Commercial Fishing, 2018). Other species, such as the blacknose shark, can only be retained in the Atlantic region south of 34° 00’ N. latitude (50 C.F.R. §635.27, 2016).

2.4.4.1 Coastal Sharks

As a result of these ambiguities, all coastal shark species were grouped together into one variable (“COASTAL_SHARKS_ALL”) and analyzed under the same three disposition categories (kept, discarded alive, discarded dead). Similarly, this combined variable was analyzed annually.

In following with commonly misidentified species, all three hammerhead shark species (great, scalloped, smooth) – including a generic hammerhead shark variable – were grouped together into one variable (“XHH_ALL”).

2.4.4.2 Pelagic Sharks

The same procedure for coastal sharks was applied to pelagic species. Grouped together within the disposition categories and combined into one variable (“PELAGIC_SHARKS_ALL”), the group was graphed together as one, 25-year period as well as annually. The results for both the coastal sharks and pelagic sharks were then compared.

2.4.5 Sea Turtles and Marine Mammals

Under the Marine Mammal Protection Act (MMPA), the U.S. Atlantic pelagic longline fleet is classified as a Category I (50 C.F.R. 229.36, 2016) due to interactions with marine mammals. This fishery is also the subject of management actions under the ESA as a result of frequent interactions with marine turtles.

The Loggerhead Sea Turtle *Caretta caretta*, Leatherback Sea Turtle, Pilot Whale (including both Short-finned *Globicephala macrorhynchus* and Long-finned *Globicephala melas*), and Risso’s Dolphin are species of bycatch concern. The analysis of these five species offer input into the effectiveness of current management efforts, gear regulations, and observer programs regarding marine mammal and sea turtle interactions, and multiple restrictions on gear and area closures are aimed at reducing mortality rates for these species. Protected under either the ESA or the MMPA, these five species are prohibited from being harassed, harmed, hunted, or killed under any circumstances.

For sea turtles and marine mammals – as a result of numerous safe-handling and safe release requirements – three new disposition categories were used: uninjured, injured, and dead. According to Title 50 of the Code of Federal Regulations (Chapter VI), "When a marine mammal or sea turtle is hooked or entangled by pelagic longline gear, the operator of the vessel must immediately release the animal, retrieve the pelagic longline gear, and move at least 1 nm (2 km) from the location of the incident before resuming fishing." Encounters however, are an inevitable occurrence, so the goal focuses on minimizing interactions and maximizing safe releases.

2.4.5.1 Sea Turtles

On the 2016 Atlantic HMS Logbook Set Form, loggerhead and leatherback turtles are the only pre-written options for captains to self-report. Though the Green Sea Turtle *Chelonia mydas*, Hawksbill Sea Turtle *Eretmochelys imbricata*, and Kemp's Ridley Sea Turtle *Lepidochelys kempii* have occasionally been caught by pelagic longline vessels (142 total interactions), encounters are a rarity, representing roughly 0.002% of the longline catch from 1992-2016 (even including unidentified turtle species interactions). Of all 55,306 logbook and observer sets from 1992-2016 (not just the sets included within the thesis model), sea turtle encounters (3,267) represent 0.059% of the total catch. Those three species mentioned above (once again including unidentified turtle species interactions) represent 0.043% of the total sea turtle interactions.

Unfortunately, most of the variables surrounding these two species of sea turtles were inconsistently reported, resulting in these species being unable to be included in the models. The largest discrepancy occurred between individuals deemed "injured"; if caught, an interaction with the gear must have occurred, but final condition at release is unknown. For loggerhead sea turtles, 60 individuals were reported as caught uninjured according to the logbook records, while observers reported a total of zero uninjured individuals. For injured and dead turtles, the observer program reported 1,009 injured turtles against 488 via self-reporting and seven dead turtles against three from logbook. Total interactions resulted in 551 Loggerhead Sea Turtles being reported via logbooks and 1,016 via observer programs. For uninjured Leatherback Sea Turtles, the self-reported data showed 48 interactions against zero for the observer program, similar to loggerheads. For injured and dead individuals, the ratios were similar to loggerheads

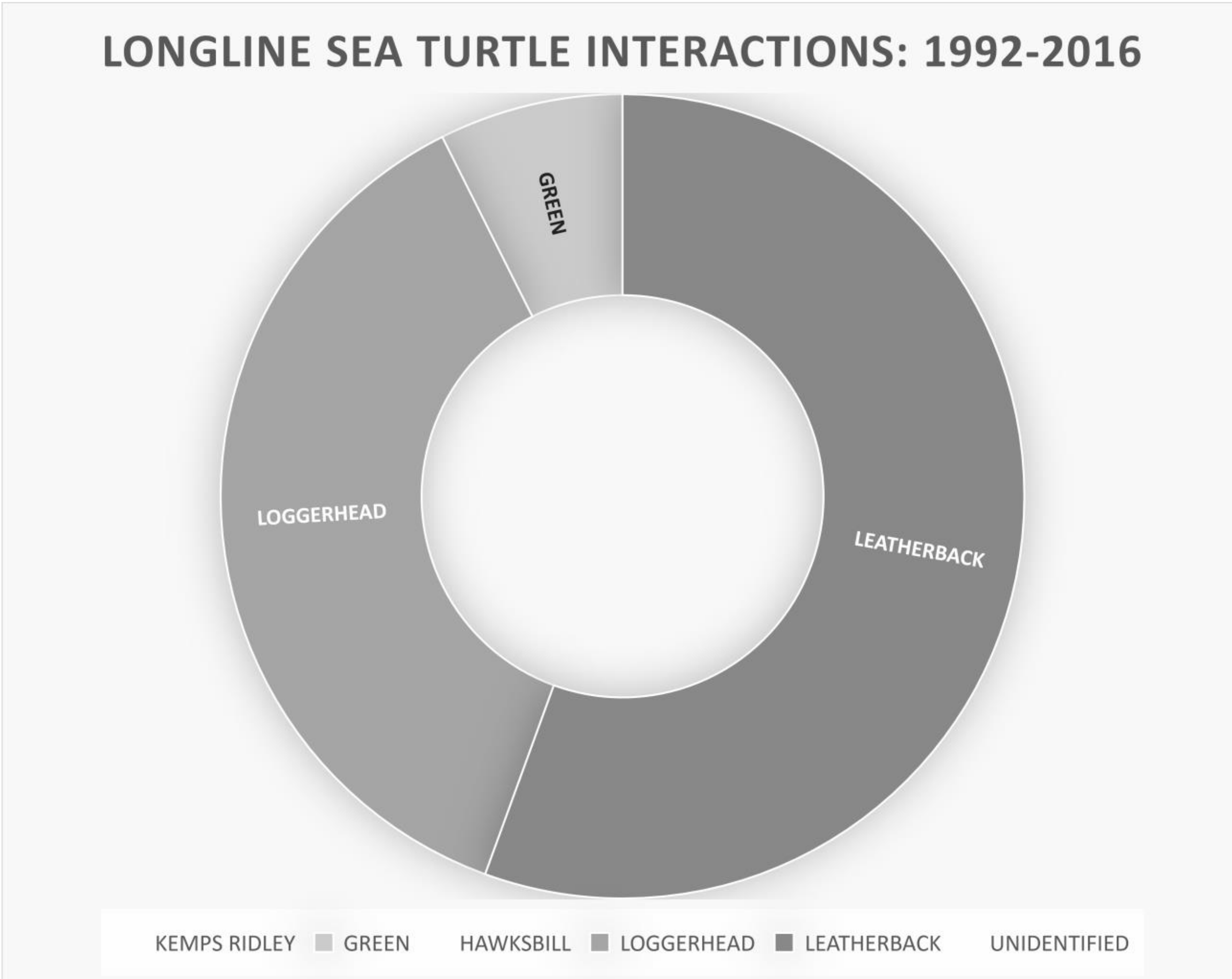


Figure 13. All longline sea turtle interactions based on individual species encounter percentages.

as well, showing 1,048 for the observers and 398 for the logbook regarding injured and 14 for observers and seven for logbook for total dead individuals. Total leatherback interactions resulted in 453 for logbook and 1,062 for the observer program.

2.4.5.2 Marine Mammals

Similar to the species constituting the "WHX" and "XHH" groupings, the Short-finned Pilot Whale and Long-finned Pilot Whale are nearly indistinguishable to species in the water. To account for this, both species, including a generic "pilot whale" variable, were combined into one variable called "MPW_ALL_COMBINED."

Based on the self-reported data, zero interactions from pilot whales or Risso's Dolphins occurred throughout the analysis. Focusing first on pilot whales (including the generic pilot whale variable), there were zero uninjured individuals according to both sets of data, following the same pattern seen with sea turtles. For injured pilot whales, the observer program documented 266 circumstances versus zero for logbook. For deaths, eight dead pilot whales were reported by the observer program against zero for the logbook program. For comparison, the observer data documented a total of 274 interactions with pilot whales versus zero interactions from logbooks.

As for the Risso's Dolphin, the analysis was conducted solely on the one dolphin species. Neither program had any interaction for uninjured Risso's Dolphins, but the observer data showed 76 injured interactions against zero from the logbook data. There were no deaths documented by the logbooks for Risso's Dolphins, but seven were accounted for by the observer program data. Total interactions included 83 for the observer data and zero for the self-reported logbooks.

For Risso's Dolphins and both the short-finned and long-finned pilot whales, the Pelagic Longline Take Reduction Plan (PLTRP) was implemented in 2009 under the MMPA to reduce serious injury and mortality. Fortunately, sea turtles, marine mammals, (and seabirds) represent roughly 1% of the observed catch composition for sets and hauls made by the commercial pelagic longliners (Keene et al. 2010). For marine mammals, the only pre-written options on the logbook forms are pilot whales (both short-finned and long-finned) and Risso's Dolphin. Despite the dozens of potential marine mammals interactions, these three species represent the majority, with incidents of other marine mammals being caught on mainlines representing only a small percentage of the encounters since 1992.

3. Results

For the following results, the model included 25,601 sets reported from the logbook program and 19,812 sets from the observer program. All species of swordfish and tuna (swordfish, Bluefin, bigeye, yellowfin, Blackfin, skipjack, albacore, bonito), finfish (escolar, dolphinfish, king mackerel, greater amberjack, wahoo), billfish (blue marlin, sailfish, composite of white marlin and roundscale spearfish), and sharks (both coastal and pelagic shark groupings) were included in the model. Figure 14, Panel A, collectively graphs all target species together for reference, while Figure 14, Panel B, collectively graphs all species of bycatch concern that were able to be applied to the model.

With all disposition categories combined for swordfish and tuna, the comparison showed underreporting (percent difference > 0) for skipjack, Blackfin, and Bluefin tunas (Figure 15A), with the greatest difference occurring with skipjack. Reporting intensity showed Blackfin, Bluefin, and skipjack to be underreported the entire 25-year period, while annual fluctuations of interactions per set occurred for the remaining five species. For all finfish disposition categories combined (Figure 17A), underreporting occurred with king mackerel and escolar, although both king mackerel and greater amberjack had significantly fewer interactions in comparison to the other three species of finfish. Reporting intensity showed interannual fluctuations for the average interactions reported per set for all five species. For billfish, the comparison showed logbook underreporting in all three species categories for both “all billfish interactions” (Fig 19A) and “discarded billfish” (Fig 19B) dispositions, although the differences were greatest with sailfish. Reporting intensity across all years of the dataset similarly show underreporting, with the model indicating an observer effect for all three species variable categories (Figs 20A-C). For sharks, the groupings of coastal sharks discarded alive and both coastal and pelagic sharks discarded dead showed underreporting, with the greatest discrepancy occuring in coastal sharks discarded dead. Reporting intensity showed interannual fluctuations for the average interactions reported per set. Table 4 showed skipjack, sailfish and the composite white marlin and Roundscale spearfish to be the most underreported species.

Marine mammals and sea turtles were unable to be applied to the model due to insufficient data. Instead, the species were compared using Table 5, Panels A-D, and included all interacted sets (33,974 from logbook and 21,331 from observer program) rather than only sets with complete information. For total sea turtle interactions (leatherback and loggerhead), 1004 were reported from the logbook sets against 2078 from the POP sets. For marine mammal interactions (short-finned pilot whales, long-finned pilot whales, and Risso's dolphin), zero interactions were reported from longline sets against 357 from the POP.

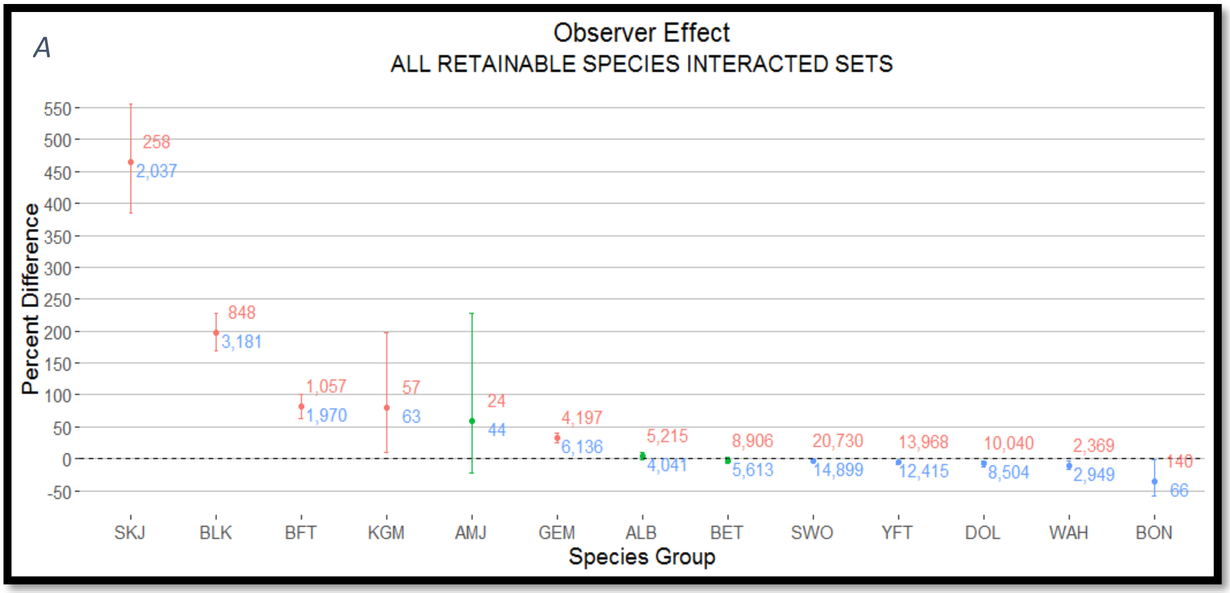


Figure 14A. Percent difference of observer effect for all retainable species from 1992-2016, ranked in order of most to least affected. Percent difference (y-axis) quantifies observer effect (i.e. influence of observer on catch) for each species. Any result above zero (more fish caught in presence of observer), graph point is displayed in red. If 95% confidence interval contains zero, an observer effect was not present and graph point is green. If more species were caught in observer's absence, result is below zero and graph point color is blue.

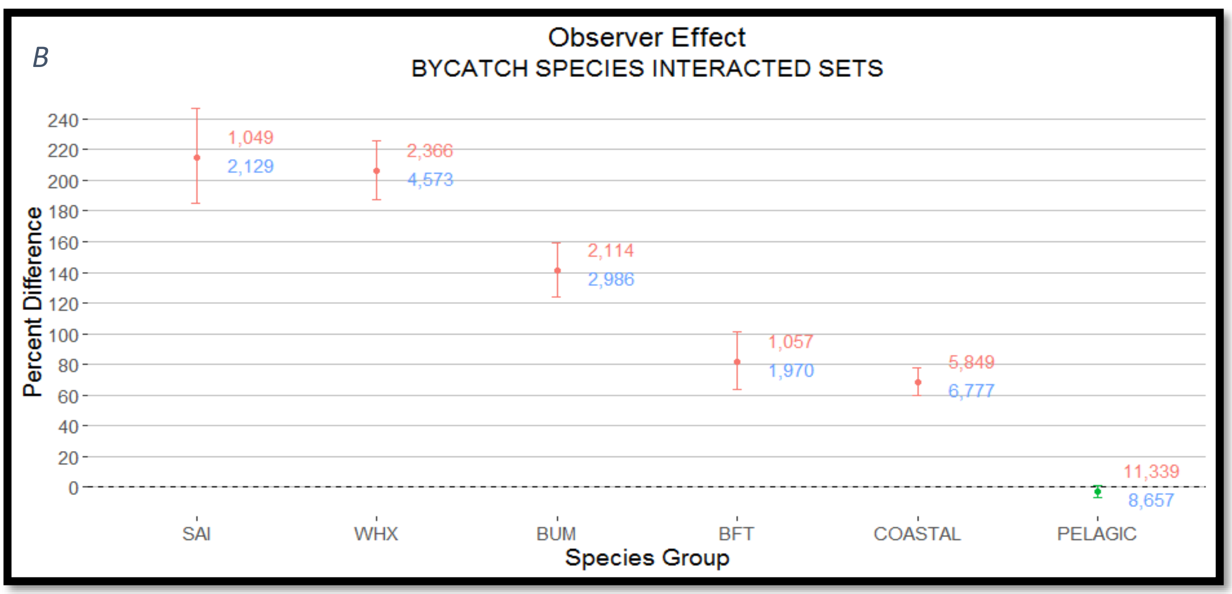
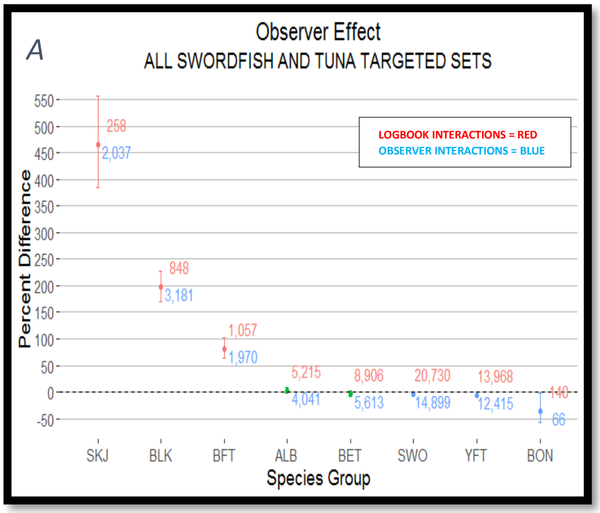
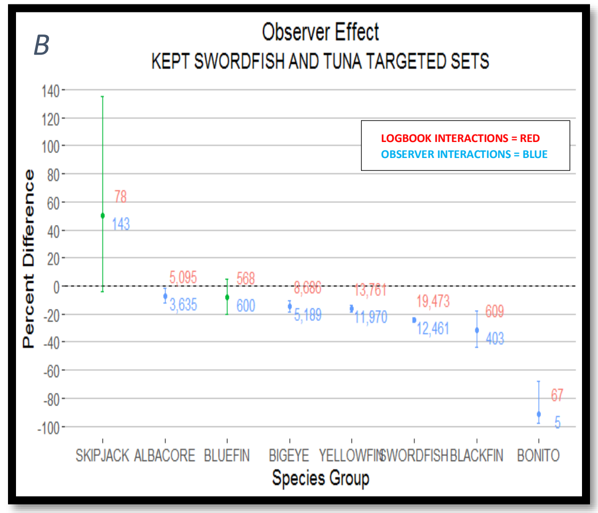


Figure 14B. Percent difference of observer effect for all species of bycatch concern (species able to be modeled) from 1992-2016, ranked in order of most to least affected. Percent difference (y-axis) quantifies observer effect (i.e. influence of observer on catch) for each species. Any result above zero (more fish caught in presence of observer), graph point is displayed in red. If 95% confidence interval contains zero, an observer effect was not present and graph point is green. If more species were caught in observer's absence, result is below zero and graph point color is blue.

Figure 15, Panels A-D: Using percent difference, all swordfish and tuna species from 1992-2016 were ranked in order of most to least significant observer effect (confidence interval included) and analyzed according to each disposition category (kept, discarded alive, discarded, and all categories combined). Percent difference (y-axis) quantifies observer effect (i.e. influence of observer on catch) for each species. Any result above zero (more fish caught in presence of observer), graph point is displayed in red. If 95% confidence interval contains zero, an observer effect was not present and graph point is green. If more species were caught in observer's absence, result is below zero and graph point color is blue.

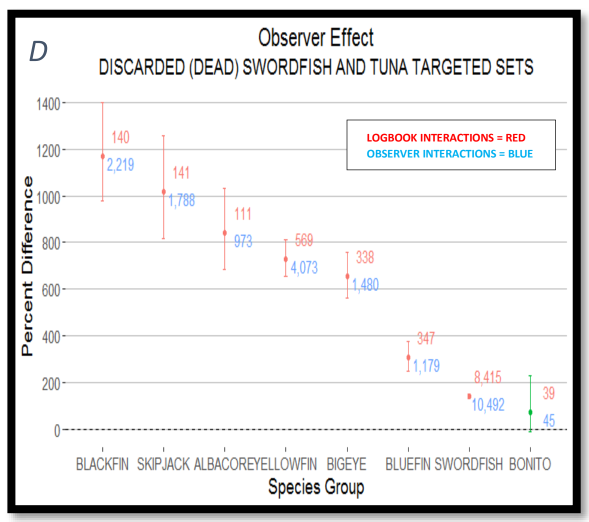


15A. Percent difference of observer effect for <u>ALL</u> swordfish and tuna species from 1992-2016. All disposition categories combined.



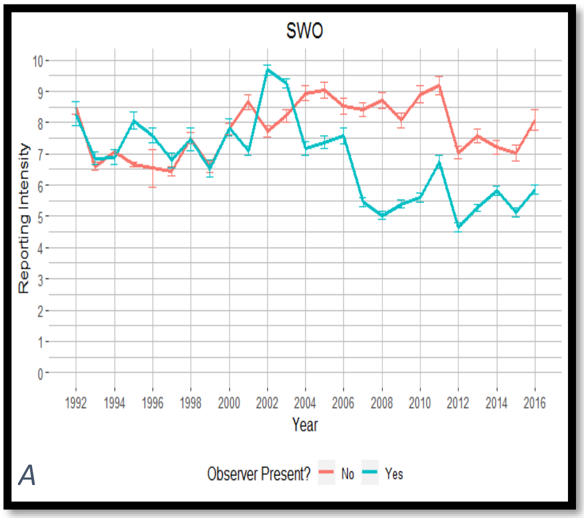
15B. Percent difference of observer effect for <u>KEPT</u> swordfish and tuna species from 1992-2016.

15C. Percent difference of observer effect for <u>DISCARDED ALIVE</u> swordfish and tuna species from 1992-2016.

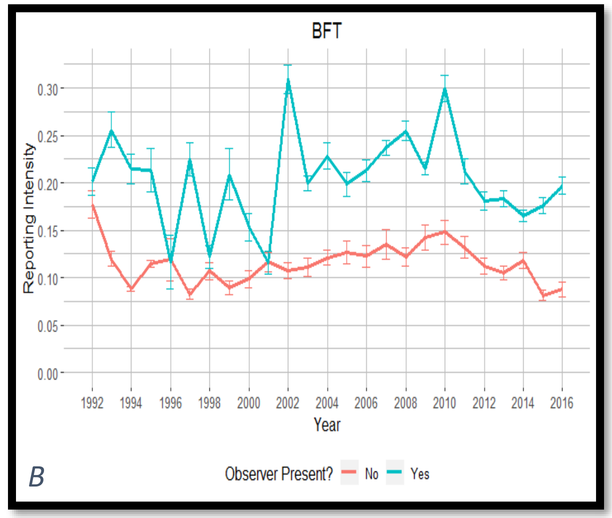


15D. Percent difference of observer effect for <u>DISCARDED</u> (DEAD) swordfish and tuna species from 1992-2016.

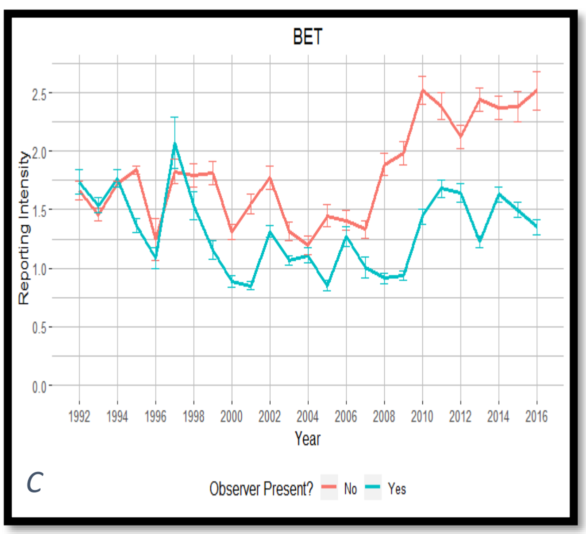
Figure 16, Panels A-H (Seen Here: A-D): Using reporting intensity, a comparison between observer and logbook data for all swordfish and tuna interactions from 1992-2016. Reporting intensity (y-axis) is the model predicted estimate of average number of interactions per set.



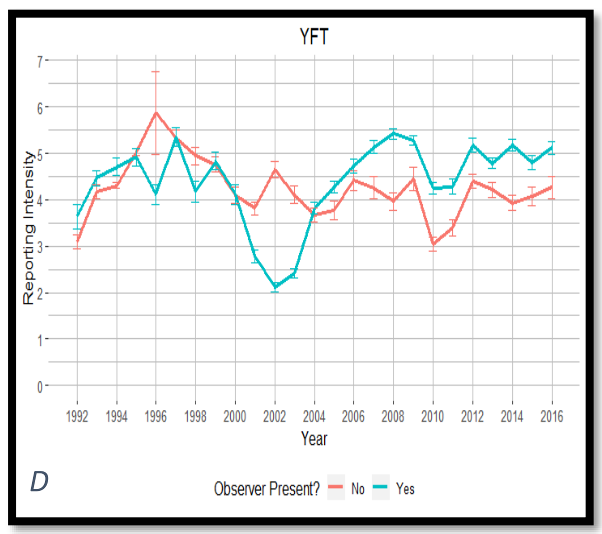
16A. Comparison of reporting intensity between observer and logbook data for all SWORDFISH interactions from 1992-2016.



16B. Comparison of reporting intensity between observer and logbook data for all BLUEFIN TUNA interactions from 1992-2016.

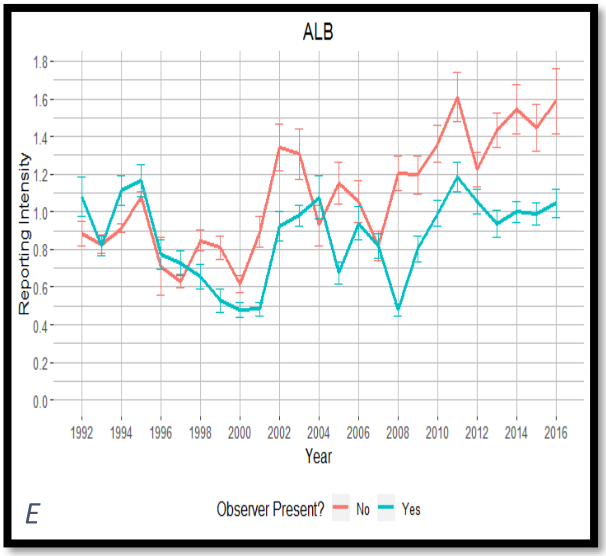


16C. Comparison of reporting intensity between observer and logbook data for all BIGEYE TUNA interactions from 1992-2016.

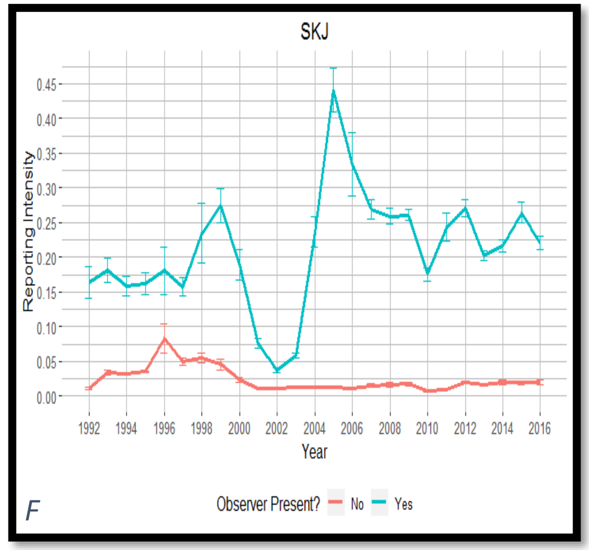


16D. Comparison of reporting intensity between observer and logbook data for all YELLOWFIN TUNA interactions from 1992-2016.

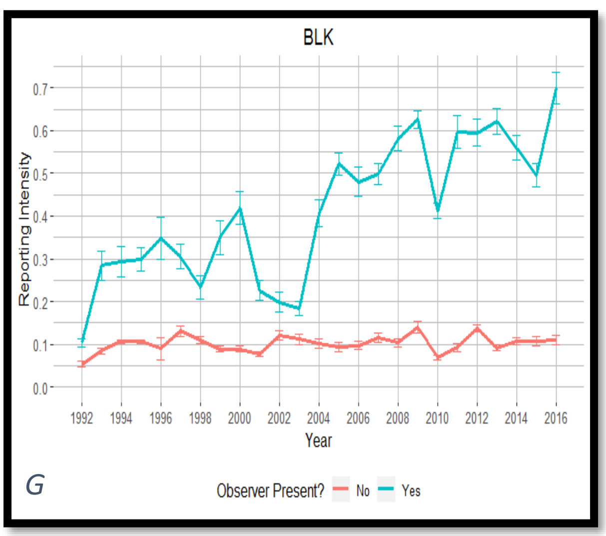
Figure 16, Panels A-H (Seen Here: E-H): Using reporting intensity, a comparison between observer and logbook data for all swordfish and tuna interactions from 1992-2016 Reporting intensity (y-axis) is the model predicted estimate of average number of interactions per set.



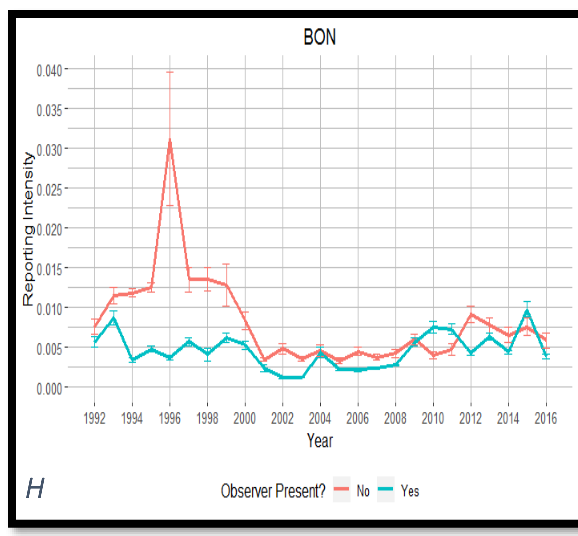
16E. Comparison of reporting intensity between observer and logbook data for all ALBACORE interactions from 1992-2016.



16F. Comparison of reporting intensity between observer and logbook data for all SKIPJACK TUNA interactions from 1992-2016.

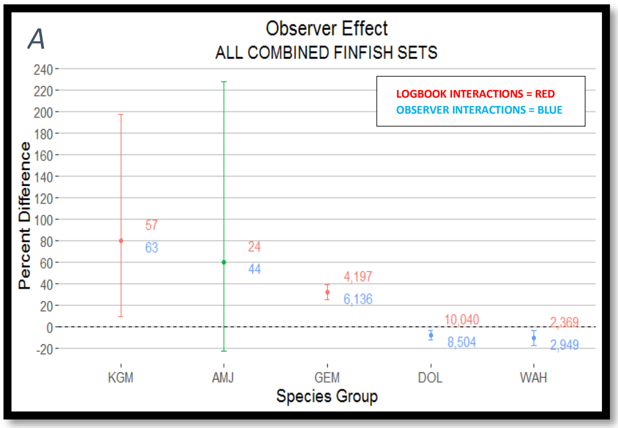


16G. Comparison of reporting intensity between observer and logbook data for all BLACKFIN TUNA interactions from 1992-2016.

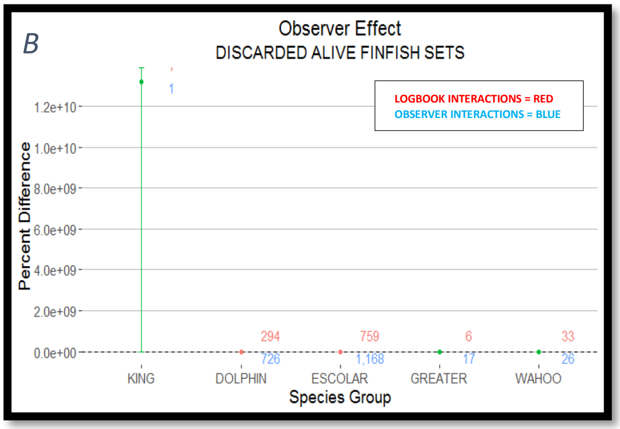


16H. Comparison of reporting intensity between observer and logbook data for all BONITO interactions from 1992-2016.

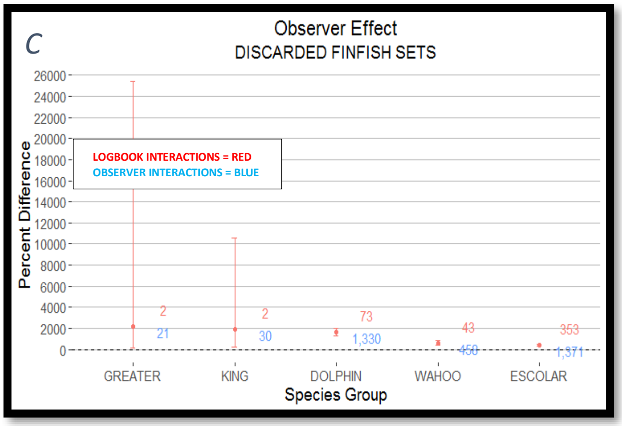
Figure 17, Panels A-C: Using percent difference, all finfish species from 1992-2016 were ranked in order of most to least significant observer effect (confidence interval included) and analyzed according to the disposition categories: all combined, discarded alive, discarded (dead). The finfish analysis for "kept" could not be completed within model, therefore no graph was included. Percent difference (y-axis) quantifies observer effect (i.e. influence of observer on catch) for each species. Any result above zero (more fish caught in presence of observer), graph point is displayed in red. If 95% confidence interval contains zero, an observer effect was not present and graph point is green. If more species were caught in observer's absence, result is below zero and graph point color is blue.



17A. Percent difference of observer effect for ALL finfish species from 1992-2016.

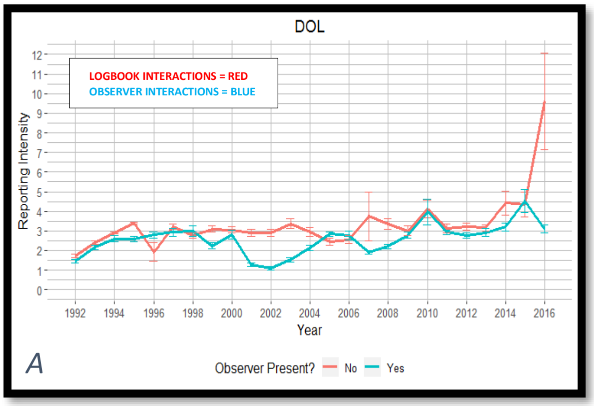


17B. Percent difference of observer effect for DISCARDED ALIVE finfish species from 1992-2016.

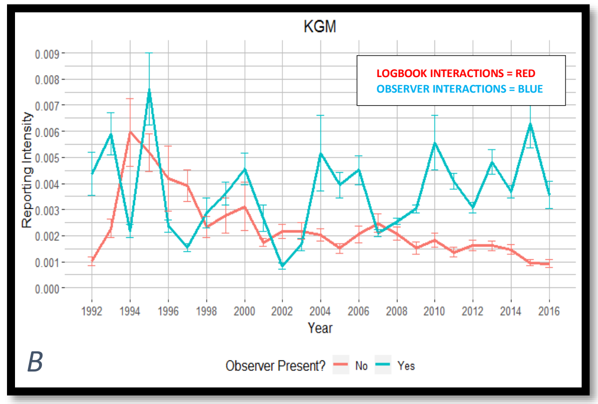


17C. Percent difference of observer effect for DISCARDED finfish species from 1992-2016.

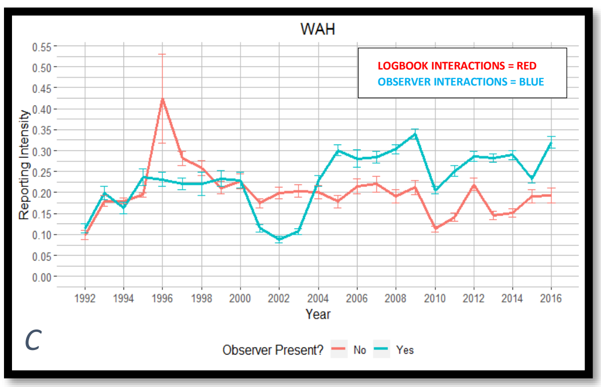
Figure 18, Panels A-E: Using reporting intensity, a comparison between observer and logbook data for all finfish interactions from 1992-2016. Reporting intensity (y-axis) is the model predicted estimate of average number of interactions per set.



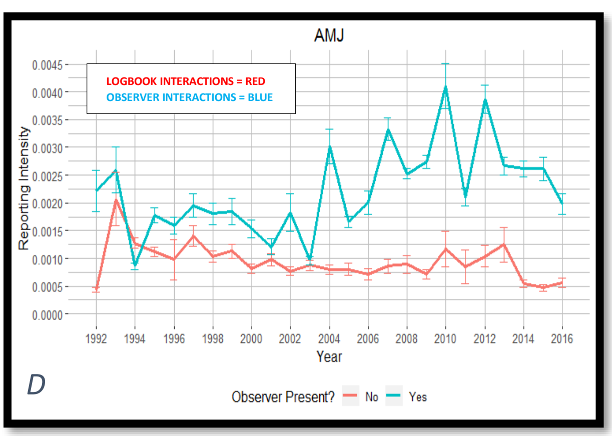
18A. Comparison of reporting intensity between observer and logbook data for all COMMON DOLPHINFISH interactions from 1992-2016.



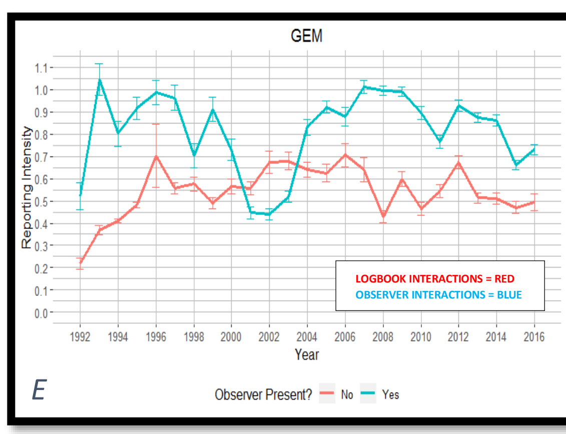
18B. Comparison of reporting intensity between observer and logbook data for all KING MACKEREL interactions from 1992-2016.



18C. Comparison of reporting intensity between observer and logbook data for all WAHOO interactions from 1992-2016.

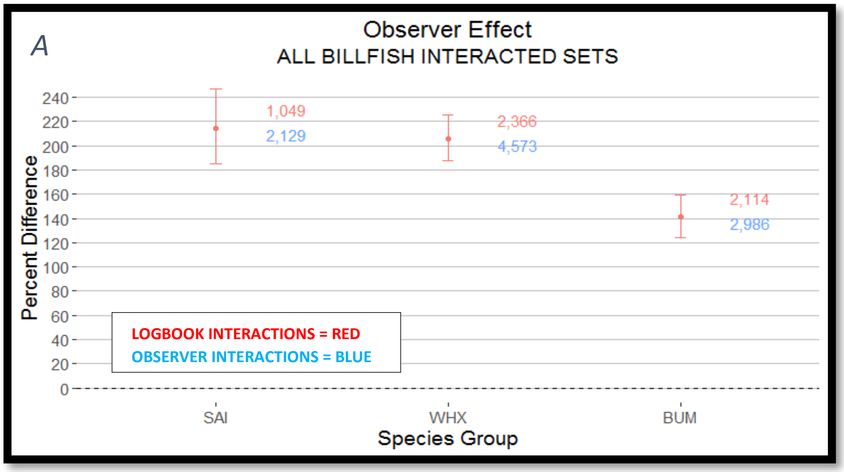


18D. Comparison of reporting intensity between observer and logbook data for all GREATER AMBERJACK interactions from 1992-2016.

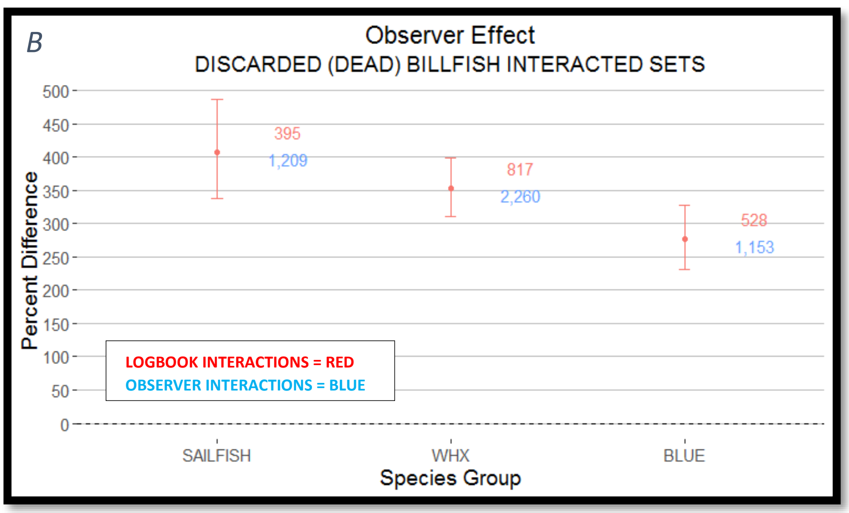


18E. Comparison of reporting intensity between observer and logbook data for all ESCOLAR interactions from 1992-2016.

Figure 19, Panels A-B: Using percent difference, all billfish species from 1992-2016 were ranked in order of most to least significant observer effect (confidence interval included) and analyzed according to the disposition categories: all combined and discarded (dead). The billfish analysis for "kept" and "discarded alive" could not be completed within the model, therefore no graphs were included. Percent difference (y-axis) quantifies observer effect (i.e. influence of observer on catch) for each species. Any result above zero (more fish caught in presence of observer), graph point is displayed in red. If 95% confidence interval contains zero, an observer effect was not present and graph point is green. If more species were caught in observer's absence, result is below zero and graph point color is blue.

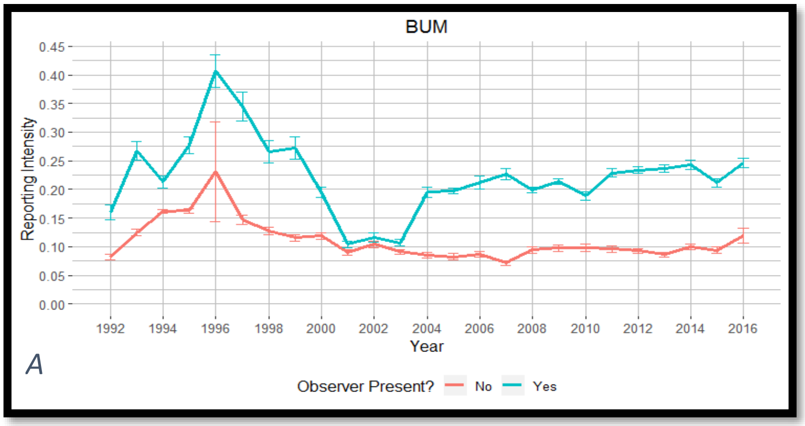


19A. Percent difference of observer effect for ALL billfish species from 1992-2016. Roundscale spearfish, white marlin, and generic "spearfish/white marlin variable" were all combined into one variable "WHX".

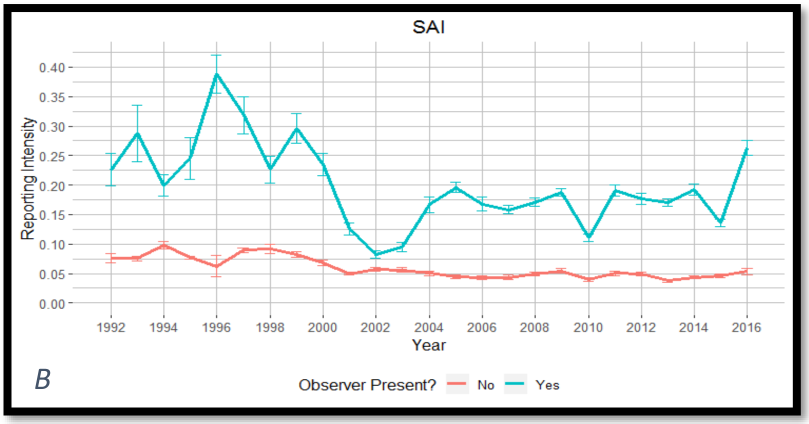


19B. Percent difference of observer effect for DISCARDED (DEAD) billfish species from 1992-2016. Roundscale spearfish, white marlin, and generic "spearfish/white marlin variable" were all combined into one variable "WHX".

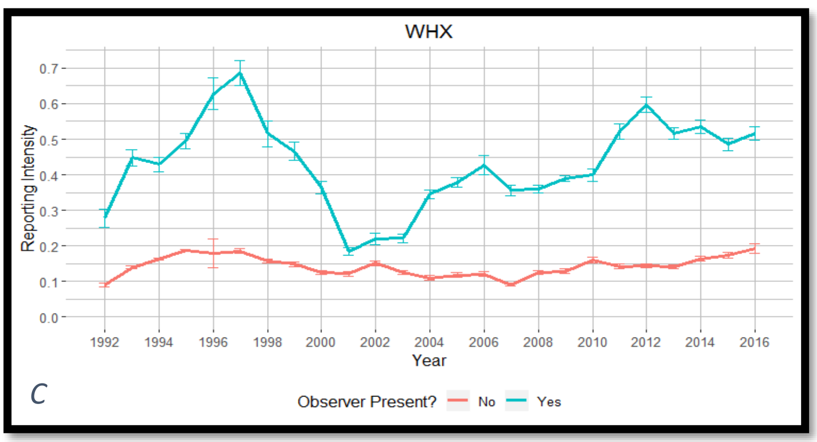
Figure 20, Panels A-C: Using reporting intensity, a comparison between observer and logbook data for all billfish interactions from 1992-2016. Reporting intensity (y-axis) is the model predicted estimate of average number of interactions per set.



20A. Comparison of reporting intensity between observer and logbook data for all BLUE MARLIN interactions from 1992-2016.

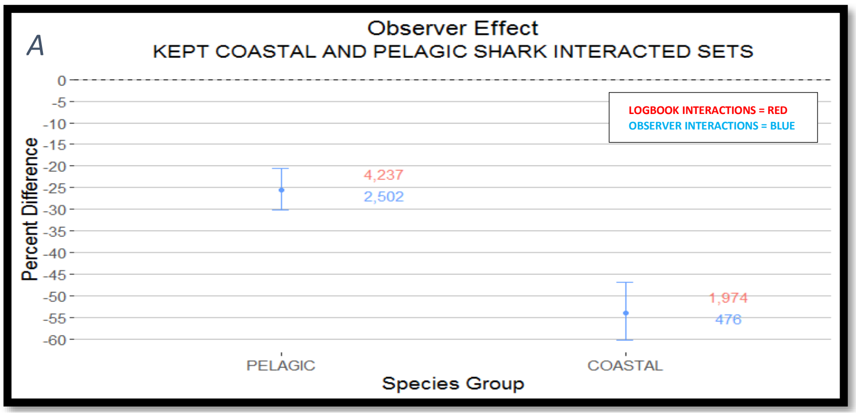


20B. Comparison of reporting intensity between observer and logbook data for all SAILFISH interactions from 1992-2016.

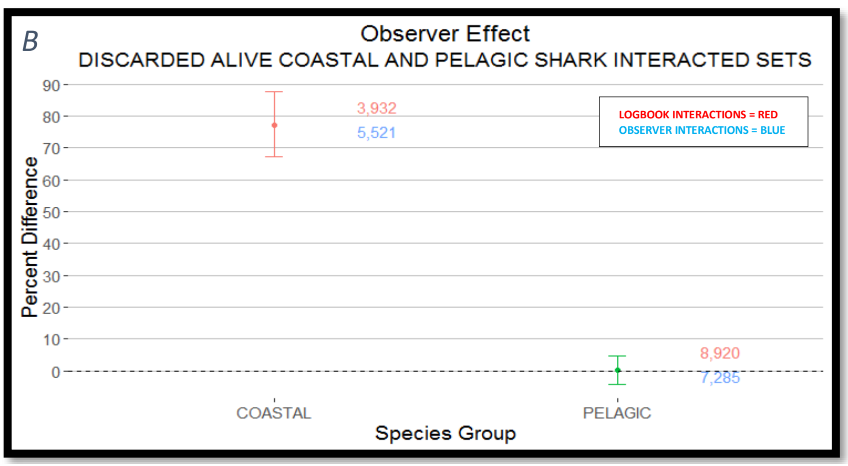


20C. Comparison of reporting intensity between observer and logbook data for all ROUNDSCALE SPEARFISH, WHITE MARLIN, (and including the generic spearfish/white marlin variable) interactions from 1992-2016 .

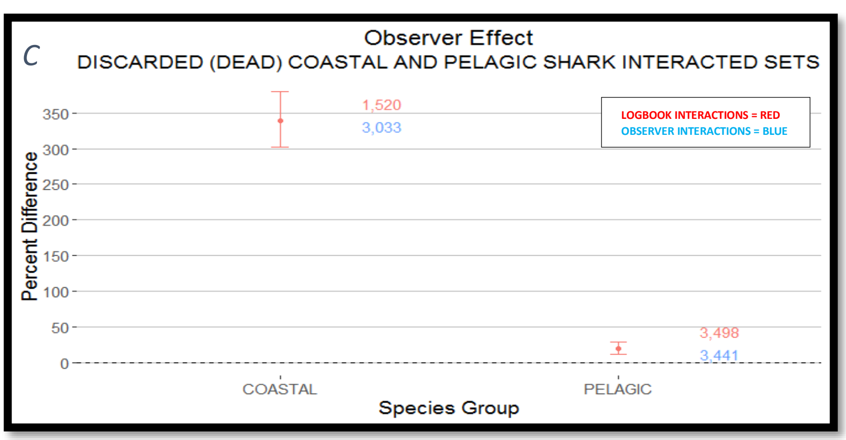
Figure 21, Panels A-C: Using percent difference, all coastal and pelagic shark species from 1992-2016 were ranked in order of most to least significant observer effect (confidence interval included) and analyzed according to each disposition category (kept, discarded alive, discarded (dead). Percent difference (y-axis) quantifies observer effect (i.e. influence of observer on catch) for each species. Any result above zero (more fish caught in presence of observer), graph point is displayed in red. If 95% confidence interval contains zero, an observer effect was not present and graph point is green. If more species were caught in observer's absence, result is below zero and graph point color is blue.



21A. Percent difference of observer effect for <u>KEPT</u> coastal and pelagic shark species *from 1992-2016.*

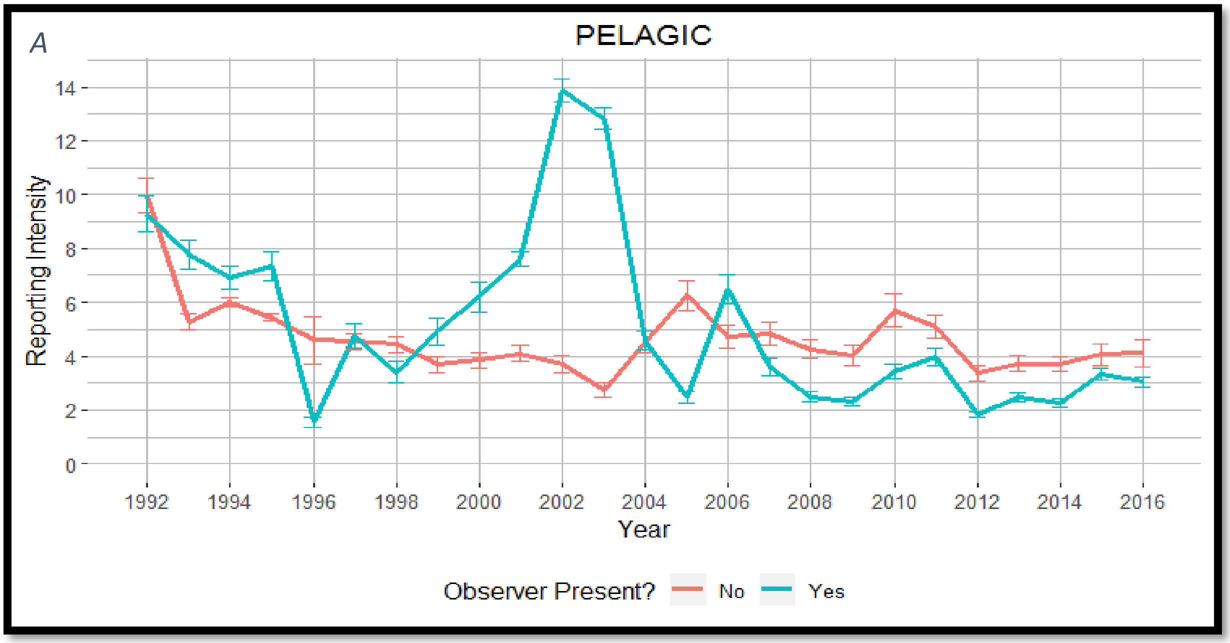


21B. Percent difference of observer effect for <u>DISCARDED ALIVE</u> coastal and pelagic shark species *from 1992-2016.*

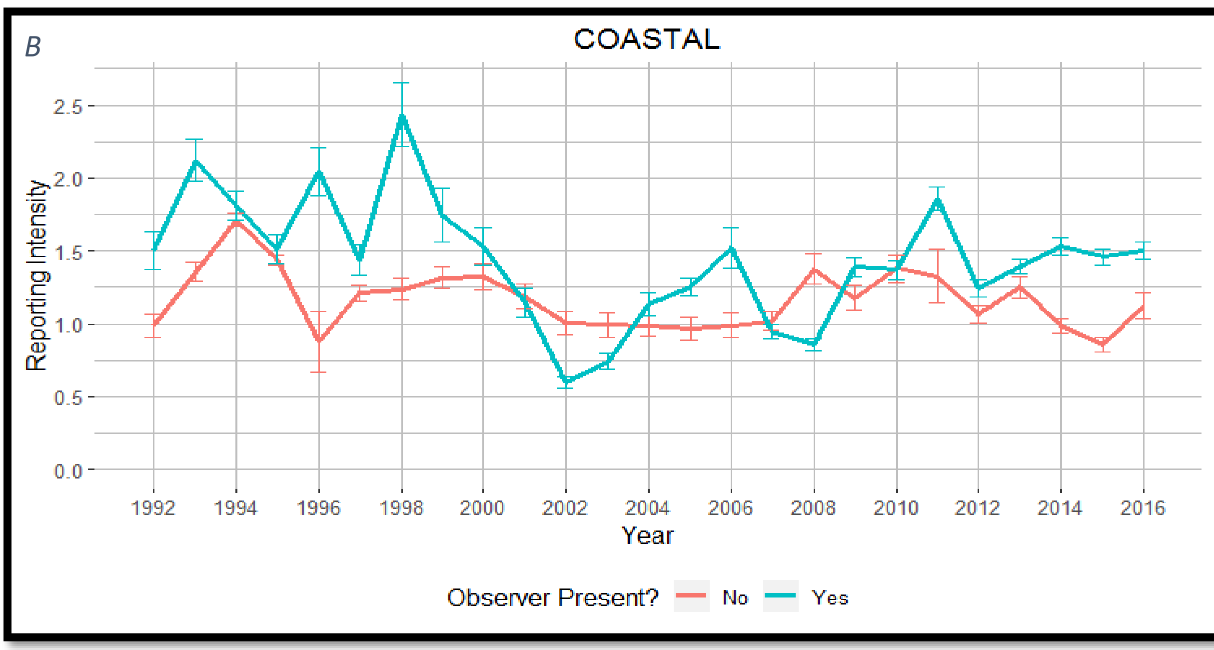


21C. Percent difference of observer effect for <u>DISCARDED</u> (DEAD) coastal and pelagic shark species *from 1992-2016.*

Figure 22, Panels A-B: Using reporting intensity, a comparison between observer and logbook data for all coastal and pelagic shark species interactions from 1992-2016. Reporting intensity (y-axis) is the model predicted estimate of average number of interactions per set.



22A. Comparison of reporting intensity between observer and logbook data for all PELAGIC SHARK interactions from 1992-2016.



22B. Comparison of reporting intensity between observer and logbook data for all COASTAL SHARK interactions from 1992-2016.

Table 4. Observer coefficient quantified and ranked in order of most to least affected according to observer effect, for all applicable species. Observer coefficient translated into "likelihood" of interaction with species based on observer data compared to logbook data, with confidence interval included. For example, Skipjack Tuna is 5.64 times more likely to be encountered in presence of an observer on a longline vessel.

SPECIES (RANKED)	OBSERVER COEFFICIENT	OBSERVER INFLUENCE LIKELIHOOD ("TIMES")	CONFIDENCE INTERVAL
SKIPJACK TUNA (SKJ)	464.02	5.64	4.85 - 6.56
SAILFISH (SAI)	214.62	3.15	2.85 - 3.47
WHX	206.11	3.06	2.88 - 3.26
BLACKFIN TUNA (BLK)	197.02	2.97	2.69 - 3.28
BLUE MARLIN (BUM)	140.89	2.41	2.24 - 2.59
BLUEFIN TUNA (BFT)	81.43	1.81	1.63 - 2.01
KING MACKEREL (KGM)	80.37	1.80	1.09 - 2.97
COASTAL SHARKS	68.82	1.69	1.60 - 1.78
GREATER AMBERJACK (AMJ)	59.83	1.60	0.78 - 3.28
ESCOLAR (GEM)	32.32	1.32	1.25 - 1.40
ALBACORE (ALB)	3.36	1.03	0.92 - 1.09
BASELINE (ZERO)	--	0.00	--
PELAGIC SHARKS	-2.72	0.97	0.94 - 1.01
BIGEYE TUNA (BET)	-2.95	0.97	0.93 - 1.02
SWORDFISH (SWO)	-3.27	0.97	0.94 - 0.99
YELLOWFIN TUNA (YFT)	-6.23	0.94	0.91 - 0.97
COMMON DOLPHINFISH (DOL)	-8.01	0.92	0.88 - 0.96
WAHOO (WAH)	-10.44	0.90	0.83 - 0.96
BONITO (BON)	-36.01	0.64	0.42 - 0.98

3.5 Sea Turtles and Marine Mammals

With insufficient data to complete all sea turtle and marine mammal interactions within the model, Table 5, Panels A-D was included for reference. Observer sets included in model: 21,331. Logbook sets included in model: 33,974. Number of Logbook Interactions/Total Logbook Sets (Column 1/33,974) provided logbook interactions per 100 sets. Number of Interactions/Total Observer Sets (Column 3/21,331) provided observer interactions per 100 sets. Ratio (likelihood of interaction between logbook and observer program) is observer interactions (per 100 sets)/logbook interactions (per 100 sets) (Column 4/Column 2 = Column 5)

Table 5A: Uninjured Sea Turtle and Marine Mammal Interactions (Logbook and POP)

Species	1 Uninjured (Logbook)	2 Interactions (Per 100 Sets)	3 Uninjured (POP)	4 Interactions (Per 100 Sets)	5 Ratio: (Observer/Logbook)
Loggerhead Sea Turtle	60	0.18	0	0	*NA*
Leatherback Sea Turtle	48	0.14	0	0	*NA*
Pilot Whales	0	0	0	0	*NA*
Risso's Dolphin	0	0	0	0	*NA*

Table 5B: Injured Sea Turtle and Marine Mammal Interactions (Logbook and POP)

Species	1 Injured (Logbook)	2 Interactions (Per 100 Sets)	3 Injured (POP)	4 Interactions (Per 100 Sets)	5 Ratio: (Observer/Logbook)
Loggerhead Sea Turtle	488	1.44	1009	4.73	*3.28*
Leatherback Sea Turtle	398	1.17	1048	4.91	*4.20*
Pilot Whales	0	0	266	1.25	*NA*
Risso's Dolphin	0	0	76	0.36	*NA*

Table 5C: Dead Sea Turtle and Marine Mammal Interactions (Logbook and POP)

Species	1 Dead (Logbook)	2 Interactions (Per 100 Sets)	3 Dead (POP)	4 Interactions (Per 100 Sets)	5 Ratio: (Observer/Logbook)
Loggerhead Sea Turtle	3	0.009	7	0.033	*3.67*
Leatherback Sea Turtle	7	0.021	14	0.066	*3.14*
Pilot Whales	0	0	8	0.038	*NA*
Risso's Dolphin	0	0	7	0.033	*NA*

Table 5D: Total Sea Turtle and Marine Mammal Interactions (Logbook and POP)

1 2 3 4 5

Species	TOTAL (Logbook)	Interactions (Per 100 Sets)	TOTAL (POP)	Interactions (Per 100 Sets)	Ratio: Observer/Logbook
Loggerhead Sea Turtle	551	1.62	1016	4.76	*2.94*
Leatherback Sea Turtle	453	1.33	1062	4.98	*3.74*
Pilot Whales	0	0	274	1.28	*NA*
Risso's Dolphin	0	0	83	0.39	*NA*

4. Discussion

The analyses of each species – and various grouping of species – led to one result for a majority of bycatch species: the presence of an observer results in an increase in reported catch. Based on the data results, the presence of an observer on longline vessels increases the accuracy of reporting for non-targeted species, but this is assuming observer data in itself is accurate. Though professionally trained, observer-based-identification errors are not uncommon. Observer experience levels vary, with an observer's first trip weighing equally against their 50th in the data, for example. Observer programs and the fishing industry operate under the assumption species identification is without error, but Faunce (2011) showed nearly all deliveries [catch] examined in the Rockfish Pilot Project (RPP) in the Gulf of Alaska contained misidentification between both the fishing industry and observers, with roughly one third of the comparisons having a species reported by one source and absent from the other. Identification of billfishes, sharks, marine mammals, and sea turtles for U.S. pelagic longlining requires observations of characteristics such as fin placement, tooth shape, and body shape and NMFS-trained pelagic fisheries observers are required to pass a species identification course during an extensive two-week training, but mistakes do occur.

Despite the POP data not being 100% accurate, the level of accuracy for self-reported data – in general – is lower than data collected by pelagic fisheries observers. Some vessels may have higher reporting accuracy for reporting and identification than others, but the fleet's reporting (as a whole) varies depending on the species. Focusing on vessel-specific analyses could offer a benefit into exploiting this topic, increasing overall reporting accuracy, and emphasizing techniques and vessel-specific variables that lead to increased accuracy. For self-reported data, attempts to increase data accuracy on non-observed trips have led to the implementation of electronic monitoring systems (video surveillance) on U.S. Atlantic pelagic longline vessels. Originally intended to monitor Bluefin Tuna, surveillance efforts offer additional options to obtain accurate reporting offshore without accruing the high cost of deploying an observer. Electronic monitoring could also assist with species not listed on the logbook pre-printed forms, considering those species are almost certainly under-reported. Additionally, with discrepancies in injury reporting for marine mammals and sea turtles between the two programs, a clear definition should be established to determine what qualifies as an injury. With more than one hundred logbook reporting of uninjured sea turtles (leatherback and loggerhead) versus zero uninjured reporting from the POP, the condition to what classifies an injury must be articulated to both entities. There might be concerns from the vessels regarding the reporting of minor injuries based on the multipliers for each injury category used to estimate take values from the whole fishery, but formal guidance might help deconstruct the differences in reporting on injuries upon release.

Several prior studies have similarly compared fisheries observer and self-reported data from the pelagic longline fishery. Walsh and Garrison (2006) calculated bycatch estimates of marine mammals and sea turtles from the U.S. Atlantic pelagic longline fleet based solely on fishing during 2005 from the observer program and self-reported data. After obtaining an estimated bycatch rate, it was then multiplied by the total fishing effort (number of hooks) reported to the FLS program to obtain interaction estimates for each marine mammal and turtle species (*Ibid.*). The mean and variance of these catch rates for marine mammals and sea turtles was then calculated through a delta estimator. Forrestal et al. (2018) performed a comparison of logbook data to observer data using a longline simulator (LLSIM) program and focusing on Blue Marlin. This simulator, using data from the U.S. Atlantic pelagic longline fishery, simulated catch datasets from known populations of Blue Marlin, but with the low level of coverage in comparison to the actual amount of data, the two datasets were simulated to provide an accurate index of abundance based on catch per unit effort.

By including a thorough year-by-year analysis focused on fishery management efforts, a demonstration of effectiveness for years prior, or currently, can lead to the implementation of more accurate regulations. From 1992 until 2016, there were arguably three major occurrences which dramatically altered the Atlantic longline industry: closure of the Florida Straits in 2000, implementation of circle hooks in 2004, and start of Individual Bluefin Tuna Quota (IBQ) in 2017. With the introduction of each, lower-producing captains were forced to leave the fishery, leaving an increasingly small number of captains who would have all once been considered high-liners in the fleet. These high-liner captains tend to be more knowledgeable in regards to reporting requirements and record-keepings, thereby incurring a slight bias over time, especially over the last few years.

By focusing on certain species or areas and determining which were affected more, assistance in future protected areas and time-area closures could result. Effort redistributions in the fleet from time-area closures (e.g., the DeSoto Canyon closure in the Gulf of Mexico) or the broad implementation of circle hook requirements in 2004 could be reviewed. Greater ratios between logbook and observer-collected data could result in increased knowledge for area-regulated closures. For example, the Cape Hatteras Gear Restricted Area, with Conditional Access, limits access for pelagic longline vessels from December through April to reduce Bluefin Tuna interactions. Theoretically, if observer data shows consistent Bluefin Tuna interactions during this time, while self-reported data declines, it is an indication of under-reporting and need for enhanced enforcement. Discrepancy between data collection could prove valid for edge effects (fishing along boundaries) with specific time-area closures. The Cape Hatteras Special Research Area was implemented to protect pilot whales and Risso's dolphins from pelagic longline vessels (50 C.F.R. §229.36, 2016). The springtime seasonal Gulf of Mexico (GOM) Gear Restricted Areas were introduced to reduce interactions with Bluefin tuna during spawning season (50 C.F.R §635.21, 2016). In the NED, there are restrictions that require vessels to use a circle hook size 18/0 or larger with an offset less than 10 degrees, as well as limiting the bait to whole Atlantic mackerel *Scomber scombrus* or squid (50 C.F.R. §635.21, 2016). Large and potentially unknown ecosystem effects could occur if management regulations change the gear configurations such that under-reported species are caught at a higher rate.

With a consecutive, multi-decade dataset such as this, there are several avenues for future research. Though beneficial to have multiple years of data, there are drawbacks to analyzing such an extensive dataset. In addition to the amount of time needed for each analysis to complete, drawbacks include number of model variables, data preparations, data cleansing, and time frame to complete analyses. During the initial stages of the model creation, the idea was to include as many potentially significant variables as possible. Unfortunately, while some proved to be insignificant, other variables and variable interactions resulted in either (a) the model failing to converge, or (b) the elapsed time for the system to complete the analysis required multiple days. The model was adjusted to account for these variances through the elimination of variables and the experimentation of run times and model capabilities. As computing power continues to improve, so too can the potential for more in-depth analyses.

With so many additional variables involved in this analysis, the addition of time-area closures (or hook implementation) into the current model may have had an effect, but would not have been a conclusive determinant of observer effect. By focusing solely on time-area closures in a controlled experiment, a better understanding effectiveness could result. Unfortunately, since the observational data being used in the current analysis encompasses 11 regions over a multi-decade period, specific regulations and closures would have to be examined in a separate analysis.

Future analyses on topics such as those mentioned above can prove to be all the more important as NOAA and other management efforts shift toward an Ecosystem-Based Fishery Management (EBFM). With unaccounted-for bycatch and under-reported mortalities of marine species, efforts to sustainably manage fisheries becomes more difficult, and these decisions – among others – rely on accessible, reliable, and accurate information to advance understandings of ecosystem processes, implement plans, prioritize vulnerabilities, and explore resiliency ("Ecosystem-Based Fishery Management", n.d.).

6. Conclusion

Fisheries management often require trade-offs between sufficiently accurate data for robust stock assessments and budgetary priorities. For years, NOAA monitoring of the U.S. Atlantic pelagic longline fishery has used a combination of logbook and fisheries observer data that reflects this trade-off. While this combination appears to be consistent for target species, these analyses suggest significant under-reporting for catches of non-target and bycatch species. As fisheries management transitions into ecosystem-based frameworks, better understanding of the ecosystem effects of present and proposed regulations is essential for ensuring sustainability.

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Appendix 1: Agencies, Acts, and Programs Associated with the U.S. Pelagic Longline Fishery

ATCA – (Atlantic Tunas Convention Act) federal law addressing the conservation of Atlantic Tunas

Consolidated Atlantic HMS FMP – (Consolidated Atlantic Highly Migratory Species Management Plan) Atlantic tunas, swordfish, sharks, and billfish are found throughout the Atlantic Ocean and must be managed both domestically and internationally; as a result, NOAA Fisheries has primary authority for developing and implementing this type of management effort

ESA – (Endangered Species Act of 1973) a key legislation for both domestic and international conservation and aims to provide a framework to conserve and protect endangered and threatened species and their habitats.

ICCAT – (International Commission for the Conservation of Atlantic Tunas) is an inter-governmental fishery organization responsible for the conservation of tunas and tuna-like species in the Atlantic Ocean and its adjacent seas

MMPA – (Marine Mammal Protection Act) passed by Congress in 1972 in response to increasing concerns among scientists and the public regarding declines in some species of marine mammals by human activities; established national policy to prevent marine mammal species and population stocks from declining beyond the point where they ceased to be significant functioning elements of the ecosystems they interact with; first legislation to mandate an ecosystem-based approach to marine resource management

MSA – (Magnuson-Stevens Fishery Conservation and Management Act) is the primary law governing marine fisheries management in U.S. federal waters

NMFS – (United States National Marine Fisheries Service) is an office of the National Oceanic and Atmospheric Administration within the Department of Commerce responsible for the stewardship of the nation's ocean resources and habitat; provides services for the nation through productive and sustainable fisheries, recovery and conservation of protected resources, and healthy ecosystems

NOAA – (National Oceanic Atmospheric Administration) is a U.S. environmental intelligence agency focusing on weather forecasts, storm warnings, climate monitoring, fisheries management, coastal restoration and support of marine commerce

NOAA Administrative Orders - durable intra-agency directives that remain effective until superseded or cancelled by an appropriate action; cover program matters and management policies, procedures, requirements, and responsibilities applicable to two or more organizations; provide NOAA-specific guidance supplementing the administrative policies and procedures issued in the Department Administrative Order (DAO) series

POP – (Pelagic Observer Program) – based out of SEFSC in Miami, FL and starting in May 1992, the POP deploys fisheries observers on longline fishing vessels to collect data along the eastern coast of the U.S., including GOM and Caribbean, to be used in a range of conservation and management issues

SEFSC – (Southeast Fisheries Science Center) conducts multi-disciplinary research programs to provide management information to support national and regional programs of NOAA's National Marine Fisheries Service; headquartered in Miami, FL, there are multiple divisions and labs across the southeast region of the U.S. including Beaufort, NC, Galveston, TX, Lafayette, LA, Panama City, FL, Pascagoula, MS and Stennis, MS.

UDP – (Unified Data Processing) formerly known as the Fisheries Logbook System (FLS), records the fishing and non-fishing activity of fishers who are required to report their fishing activity via logbooks submitted for each trip.

Vessel Logbook Program – within the Fisheries Statistics Division of NOAA, the logbook program manages commercial fisheries data for a number of fisheries for the Southeast region of the U.S.

Appendix 2: Pelagic Longline Gear and Fishery Terms

Bycatch – species caught by fishers other than those intended to be sold; whether there is no market value or the species are prohibited from being caught, bycatch can refer to marine mammals, sea turtles, seabirds, sharks, or fish

Circle Hook – type of hook aimed to reduce swallowing or ingestion beyond mouth, reducing mortality of both catch and bycatch alike

CPUE – (Catch Per Unit Effort) an indirect measure of the abundance of a target species; changes in the catch per unit effort are inferred to signify changes to the target species' true abundance.

Exclusive Economic Zone - the zone where the U.S. and other coastal nations have jurisdiction over natural resources

Fisheries Observer – professionally trained biological scientists and at-sea monitors who collect data from U.S. commercial fishing and processing vessels

Float – type of floatation device made of various material used to maintain fishing gear within the water column and prevent it from sinking; have also been referred to as daubs, bullets, polyballs, or buoys)

Haul – the act of retrieving or "hauling" longline gear from the water to determine catch

HMS – (Highly Migratory Species) travel long distances, often cross domestic and international boundaries and include tunas, sharks, swordfish, and billfish in U.S. Atlantic Ocean, Gulf of Mexico, and Caribbean waters

Light Stick – small piece of plastic tube which contains chemicals that illuminate when activated through a physical action such as bending or snapping; this chemical reactive substance is attached near a hook and used as an attraction for swordfish, which – according to the fishery – are attracted to light

Longline Vessel – type of vessel used in the longline fishing which uses a mainline ("longline") with baited hooks attached at intervals by branch lines called gangions

Mainline – line to which all hooks, floats, gangions, light sticks and bait are attached and connected to the vessel on a spool; made of various material and varies in diameter and color

PLL – pelagic longline; referring to the commercial longline fishing industry

Set – the act of placing or "setting" longline gear in the water with associated bait and gear configuration based on the target species

Tuna Purse Seining – style of fishing for tuna involving a net, floats and weights and is used to encircle schools of fish; net is enclosed using a purse line threaded through rings attached to the bottom of the net.

Time Area Closures - tool to reduce the incidental capture of bycatch species through fisheries regulations in certain areas of the ocean during specific times of the year

Vessel Identification Number - as defined by the USCG, Vessel Identification Numbers are 6 to 8 characters long and may contain all digits, or begin with 1 or 2 letters (A-Z) followed by 6 or 7 digits.

VMS – Vessel Monitoring System, used by a number of agencies via satellite to determine location and course of vessel during a particular trip; can determine date and location of departure and return and calculate vessel speed

Appendix 3: Species of Interest

Table 6: All species used during analysis

Swordfish and Tunas	Swordfish *Xiphias gladius*, Bonito *Sarda sarda*, Bluefin *Thunnus thynnus*, Skipjack *Katsuwonus pelamis*, Yellowfin *Thunnus albacares*, Blackfin *Thunnus atlanticus*, Albacore *Thunnus alalunga*, Bigeye *Thunnus obesus*
Finfish	Escolar *Lepidocybium flavobrunneum*, Dolphin *Coryphaena hippurus*, Wahoo *Acanthocybium solandri*, King Mackerel *Scomberomorus cavalla*, Greater Amberjack *Seriola dumerili*
Coastal Sharks	Bignose* *Carcharhinus altimus*, Blacktip *Carcharhinus limbatus*, Dusky* *Carcharhinus obscurus*, Great Hammerhead** *Sphyrna mokarran*, Scalloped Hammerhead** *Sphyrna lewini*, Smooth Hammerhead** *Sphyrna zygaena*, Night* *Carcharhinus signatus*, Sandbar**** *Carcharhinus plumbeus*, Silky** *Carcharhinus falciformis*, Spinner *Carcharhinus brevipinna*, Tiger *Galeocerdo cuvier*
Pelagic Sharks	Blue *Prionace glauca*, Shortfin Mako *Isurus oxyrinchus*, Longfin Mako* *Isurus paucus*, Oceanic Whitetip** *Carcharhinus longimanus*, Porbeagle***

	Lamna nasus, Bigeye Thresher* *Alopias superciliosus*, Common Thresher *Alopias vulpinus*
Billfishes	White Marlin *Kajikia albidus*, Blue Marlin *Makaira nigricans*, Sailfish *Istiophorus albicans*, Roundscale Spearfish, *Tetrapturus georgii*
Sea Turtles	Loggerhead *Caretta caretta*, Leatherback *Dermochelys coriacea*
Marine Mammals	Short-finned Pilot Whale *Globicephala macrorhynchus*, Long-finned Pilot Whale *Globicephala melas*, Risso's Dolphins *Grampus griseus*

Appendix 4: R Code

....***GAM Model***..

```
library(mgcv)
system.time(mod_gam_11 <- gam(BLUEFIN_TUNA_DISCARDED ~ AREA_NAMES
            + SEASON + OBSERVER. + LIGHT_STICK_PROP + s(SOAK_TIME, k =
                  30) + s(HOOKS_SET, k = 30) + s(HOOKS_SET, by = SEASON,
                        k = 30) + s(FAHtoCEL, k = 40) +  s(FAHtoCEL, by =
                              SEASON, k = 30) +
                        s(VESSEL_ID_NUMBER, bs = "re"),
                         data = combined_data_gam,
              family = "nb",
               method = "REML",
                       control = list(trace = TRUE)))
```

....***Quantified Observer Effect***...

```
 # 1.) Extract Observer Coefficient
round(100 * (exp(summary(BLUEFIN_KEPT)$p.table["OBSERVER.1",
      "Estimate"]) - 1), 3)
# 2.) 95% Confidence Interval for Observer Coefficient
round(100 * (exp(summary(BLUEFIN_KEPT)$p.table["OBSERVER.1",
      "Estimate"] + c(-1, 1)
        * summary(YFT_DISC_ALIVE)$p.table["OBSERVER.1", "Std. Error"] *
            qnorm(.975)) - 1), 3)
```

.............................***Quantified Observer Effect Example (Bluefin Tuna Kept)***.............................

```
1.) # Extract Observer Coefficient
round(100 * (exp(summary(BLUEFIN_KEPT)$p.table["OBSERVER.1",
      "Estimate"]) - 1), 3)
[1] 14.195
2.) # 95% Confidence Interval for Observer Coefficient
round(100 * (exp(summary(BLUEFIN_KEPT)$p.table["OBSERVER.1",
      "Estimate"] + c(-1, 1)
```

```
* summary(YFT_DISC_ALIVE)$p.table["OBSERVER.1", "Std. Error"] *
        qnorm(.975)) - 1), 3)
[2] -2.183  33.316
```

....................................***Species Grouping Example: Hammerhead Sharks***...................................

```
# HAMMERHEAD SHARK COMBINATION
HAMMERHEAD_ALL_KEPT <- combined_data$HAMMERHEAD_GREAT_KEPT +
        combined_data$HAMMERHEAD_SCALLOPED_KEPT +
                combined_data$HAMMERHEAD_SMOOTH_KEPT +
                        combined_data$HAMMERHEAD_KEPT
HAMMERHEAD_ALL_DISC_ALIVE <-
combined_data$HAMMERHEAD_GREAT_DISC_ALIVE
        + combined_data$HAMMERHEAD_SCALLOPED_ALIVE +
                combined_data$HAMMERHEAD_SMOOTH_DISC_ALIVE +
                        combined_data$HAMMERHEAD_DISC_ALIVE
HAMMERHEAD_ALL_DISCARDED <-
combined_data$HAMMERHEAD_GREAT_DISC_DEAD +
        combined_data$HAMMERHEAD_SCALLOPED_DEAD +
                combined_data$HAMMERHEAD_SMOOTH_DISC_DEAD +
                        combined_data$HAMMERHEAD_DISCARDED
HAMMERHEAD_ALL <- HAMMERHEAD_ALL_KEPT +
HAMMERHEAD_ALL_DISC_ALIVE +
        HAMMERHEAD_ALL_DISCARDED
```

.....................***Disposition Categories Combined into One Variable: "SWO_ALL"***........................

```
SWO_ALL <- combined_data$SWORDFISH_CAUGHT +
        combined_data$SWORDFISH_DISC_ALIVE +
                        combined_data$SWORDFISH_DISCARDED
```

Appendix 5: Logbook and Pop Forms: 1992 vs 2016

Figure 23, Panels A-H, compare the forms used in 1992 and 2016 for both the POP and Logbook Program. Forms Included: POP Animal Logs, POP Haul Logs, POP Gear Logs, and Logbook Set Forms.

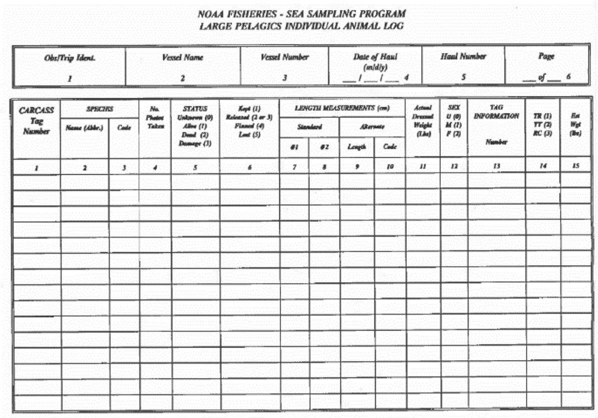


Figure 23A. 1992 POP Animal

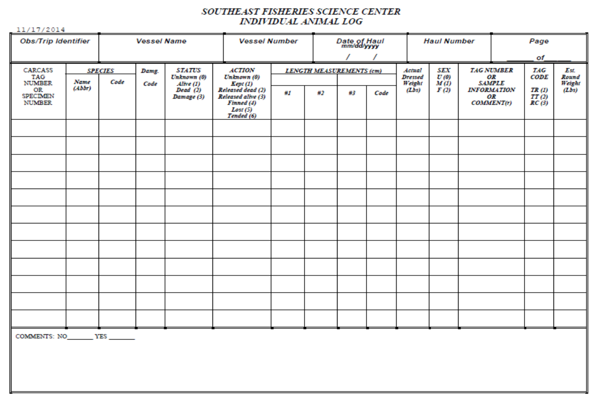


Figure 23B. 2016 POP Animal Log (Created in

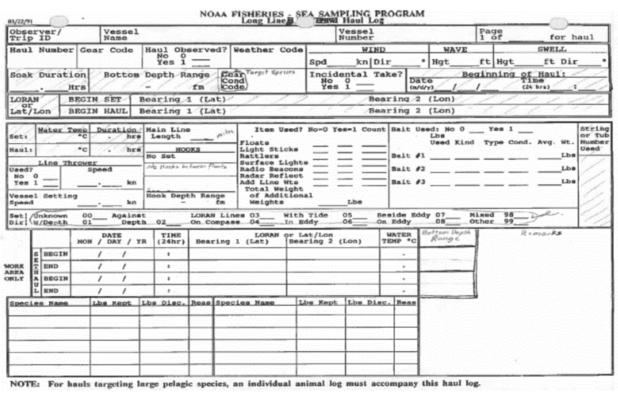


Figure 23C. 1992 POP Haul Log

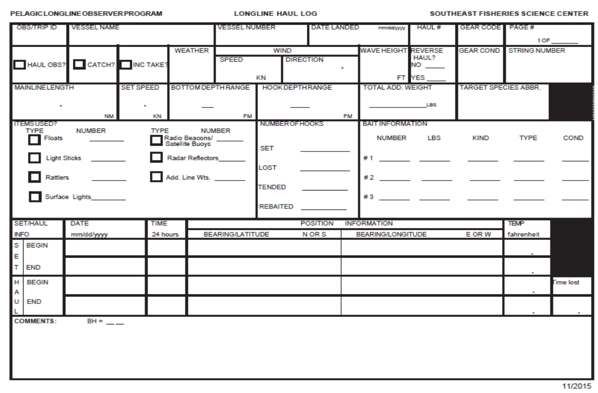


Figure 23D. 2016 POP Haul Log (Created in 2015)

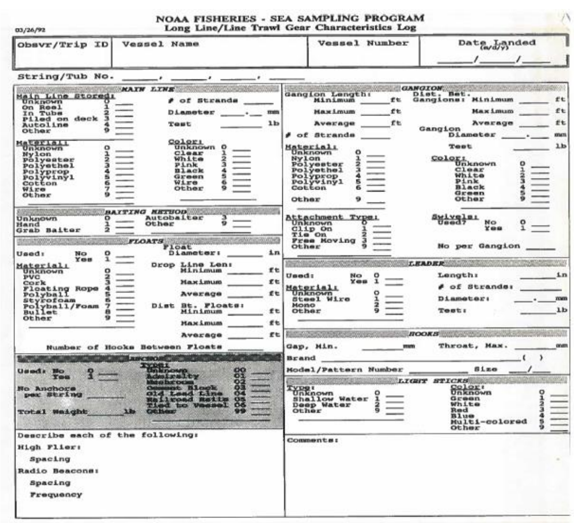


Figure 23E. 1992 POP Gear

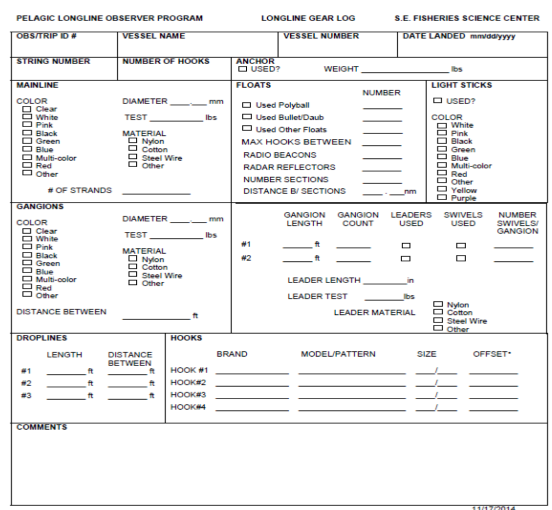
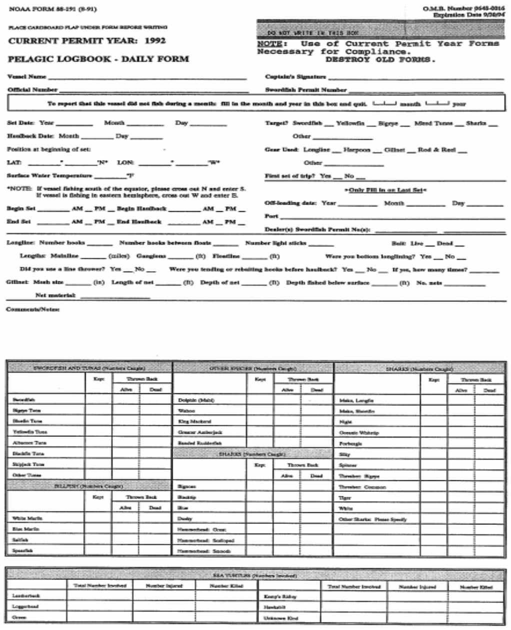


Figure 23F. 2016 POP Gear Log (Created in 2014)

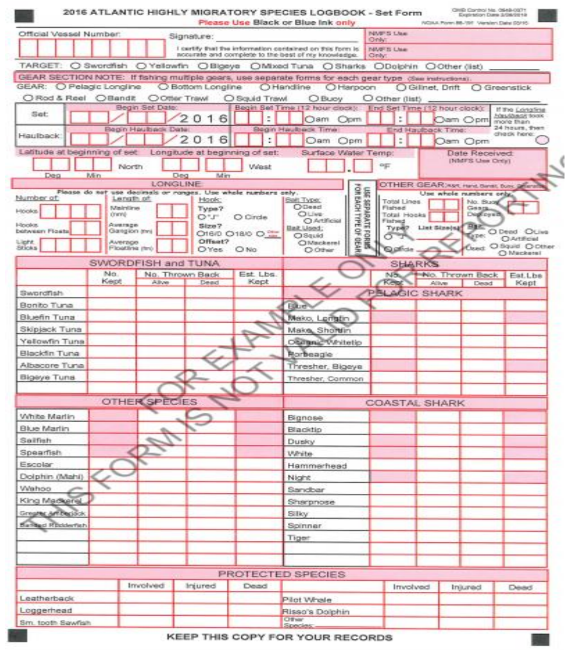


NOAA FORM 88-191 (9-91)

CURRENT PERMIT YEAR: 1992

PELAGIC LOGBOOK - DAILY FORM

Figure 23G. 1992 Logbook Set Form



2016 ATLANTIC HIGHLY MIGRATORY SPECIES LOGBOOK - Set Form

Please Use Black or Blue Ink only

KEEP THIS COPY FOR YOUR RECORDS

Figure 23H. 2016 Logbook Set Form