Digital Aerial Baseline Survey of Marine Wildlife in Support of Offshore Wind Energy

Summer 2016-Spring 2019 Seasonal Surveys

Large Bony Fish and Fish Shoals Final Report

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NORMANDEAU ASSOCIATES ENVIRONMENTAL CONSULTANTS

APEM

Digital Aerial Baseline Survey of Marine Wildlife in Support of Offshore Wind Energy

Summer 2016–Spring 2019 Seasonal Surveys Large Bony Fish and Fish Shoals

FINAL REPORT

Prepared for
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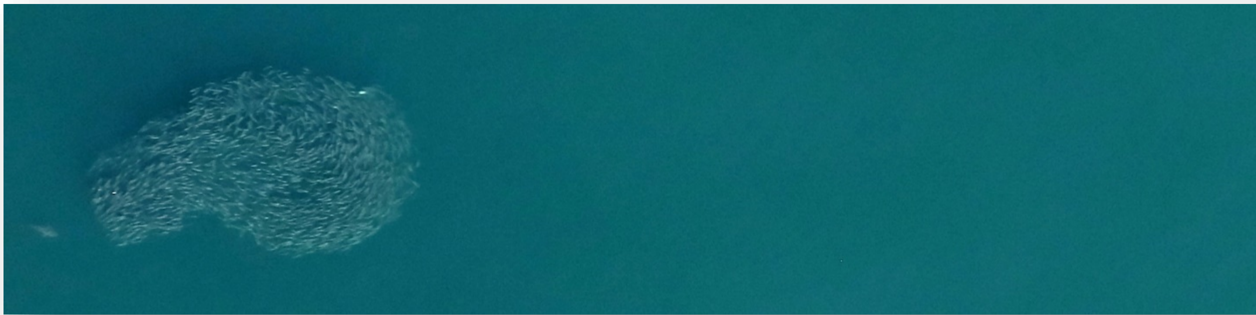

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Acronyms and Abbreviations

ANOVA	Analysis of variance
Normandeau	Normandeau Associates, Inc.
NYSERDA	New York State Energy Research and Development Authority
OPA	Offshore Planning Area
WEA	Wind Energy Area

Summary

In support of New York State's commitment to incorporating offshore wind into its energy portfolio, the New York State Energy Research and Development Authority (NYSERDA) embarked on a multi-year ultra-high–resolution aerial digital survey of marine resources in a 43,745.20 km^2 (12,754.06 mi^2) offshore planning area (OPA) in 2016. The OPA encompasses the waters of the New York Bight from Long Island southeast to the continental shelf break. Surveys are conducted on a quarterly basis, timed to coincide with periods of abundance of avian and marine species that could be vulnerable to impacts from offshore wind activities. This report summarizes the results of twelve surveys conducted during Summer 2016 through Spring 2019. Each survey collected images covering at least 7% of the OPA.

For each survey, approximately 300,000 images were collected within the OPA using a transect design. During the first survey year, special attention was also paid to the Wind Energy Area (WEA) using a more detailed grid survey design, collecting around 100,000 images. Each survey collected images covering at least 10% of the WEA. Information on the WEA surveys may be found in the second interim report available at https://remote.normandeau.com/aer_docs.php?pj=6.

There was some variation in sampling effort among surveys as a different camera system that captured a larger footprint was used after the Summer 2016 survey. Across all surveys, 98% of images contained no target species groups, vessels, or structures. Less than 2% of images contained target taxonomic groups.

The findings of this survey suggest that spatial distribution of bony fishes and fish shoals are strongly influenced by season. This project originally did not consider bony fishes and shoals from the survey efforts but later included them once their prevalence within the images became apparent. This project was designed for collecting information on avian species and other marine organisms such as marine mammals, turtles, sharks, and rays. Future surveys could consider shifting the survey times to coincide with bony fishes and/or fish shoal life history patterns more directly if the primary target of such a survey is bony fishes and fish shoals. It is perhaps most important to note the immense disparity in imaged fish shoals between survey one and all subsequent surveys. Although some shoals were observed in each season, they were most prevalent in the Summer. The Summer 2016 survey fish shoal abundance exceeds all subsequent surveys combined. Our results make it difficult to conclude or speculate about what might have driven such high numbers during this survey, but future investigators should be aware of such differences while planning surveys, particularly if fish shoals are the target. Despite potentially missing peak shoaling periods during the Fall 2016 through Spring 2019 surveys, the survey periods used for this baseline data survey were adequate indicators of overall bony fishes and fish shoal prevalence.

Across the 12 surveys, seven species of large bony fishes were observed with Ocean Sunfish, Mahi-Mahi, and Atlantic Bluefin Tuna the most common. Ocean Sunfish were present in every season except Winter. Atlantic Bluefin Tuna occurred in Summer and Spring surveys. Mahi-Mahi was present only during Summer surveys.

Results from high-resolution aerial surveys can provide insight into spatial and temporal animal distributions within a surveyed area. Data from these surveys can inform wind turbine siting decisions at a high-level and site level through better understanding of species composition, relative abundance, and animal movements. This information can also be used in developing project-specific environmental documents such as Environmental Assessments and Environmental Impact Statements should the need arise.

1 Introduction

There is growing interest in developing offshore wind (OSW) energy in New York and elsewhere in the country. However, it is still unclear what impacts OSW development will have on wildlife, including corals, birds, bats, sea turtles, fish, and marine mammals. Data gaps interfere with federal and state regulator efforts to avoid or minimize potential negative impacts on wildlife from OSW development. There have been several efforts in New York and elsewhere along the Atlantic coast to identify and fill these gaps in recent years, but many research needs are still unmet. One of the most pressing research needs is baseline data on potential wildlife exposure. Knowledge about species presence and absence in development areas helps regulators form appropriate site-specific questions to be addressed by developers. Regional-scale baseline information on wildlife distributions, abundance, and movements by season can reveal the relative biodiversity of development sites. These types of surveys can also provide a better understanding of the potential effects of individual projects, and any potential cumulative effects of multiple projects.

The New York State Energy Research and Development Authority (NYSERDA) contracted with Normandeau Associates Inc. (Normandeau) and teaming partner APEM Inc. (APEM) to use high-resolution aerial digital imagery to collect data on birds, marine mammals, sea turtles, cartilaginous fish, and other taxa encountered offshore. Surveys are conducted four times a year over three years. The surveys have been designed considering available historical data and use the latest digital and sensor technology to provide high identification success.

High-resolution aerial digital surveys of the OPA during the 12 surveys were flown in transects (Figure 1). During the first four surveys more detailed grid surveys were also conducted in the Wind Energy Area (WEA) to provide data suitable for impact analysis rather than site characterization. The objective of these surveys was to quantify the abundance and spatial distribution of marine fauna throughout the OPA to aid in the planning of offshore wind energy development. Though not a part of the original target fauna, large bony fish and fish shoals were detected in large numbers prompting NYSERDA to task the Normandeau–APEM Team with quantifying their presence in OPA. The abundance of bony fishes and fish shoals imaged during the WEA surveys was low (n = 160); therefore, we have excluded imaged fishes from the WEA survey from all remaining results presented here.

Findings on target classification and identification as well as an analysis of camera performance over the duration of the 3-year study are presented herein. Final findings on the abundance and spatial distribution of bony fish species and fish shoals are also presented. Beyond species identification of bony fishes, additional metrics have been quantified such as the distance between individuals and the shore, estimated ocean depth of the observation location, the proximity of individuals to shipping lanes, and the areal extent of fish shoals. This report summarizes the findings of these additional analyses. A combination of graphical and statistical methods are used and analyzed throughout this report.

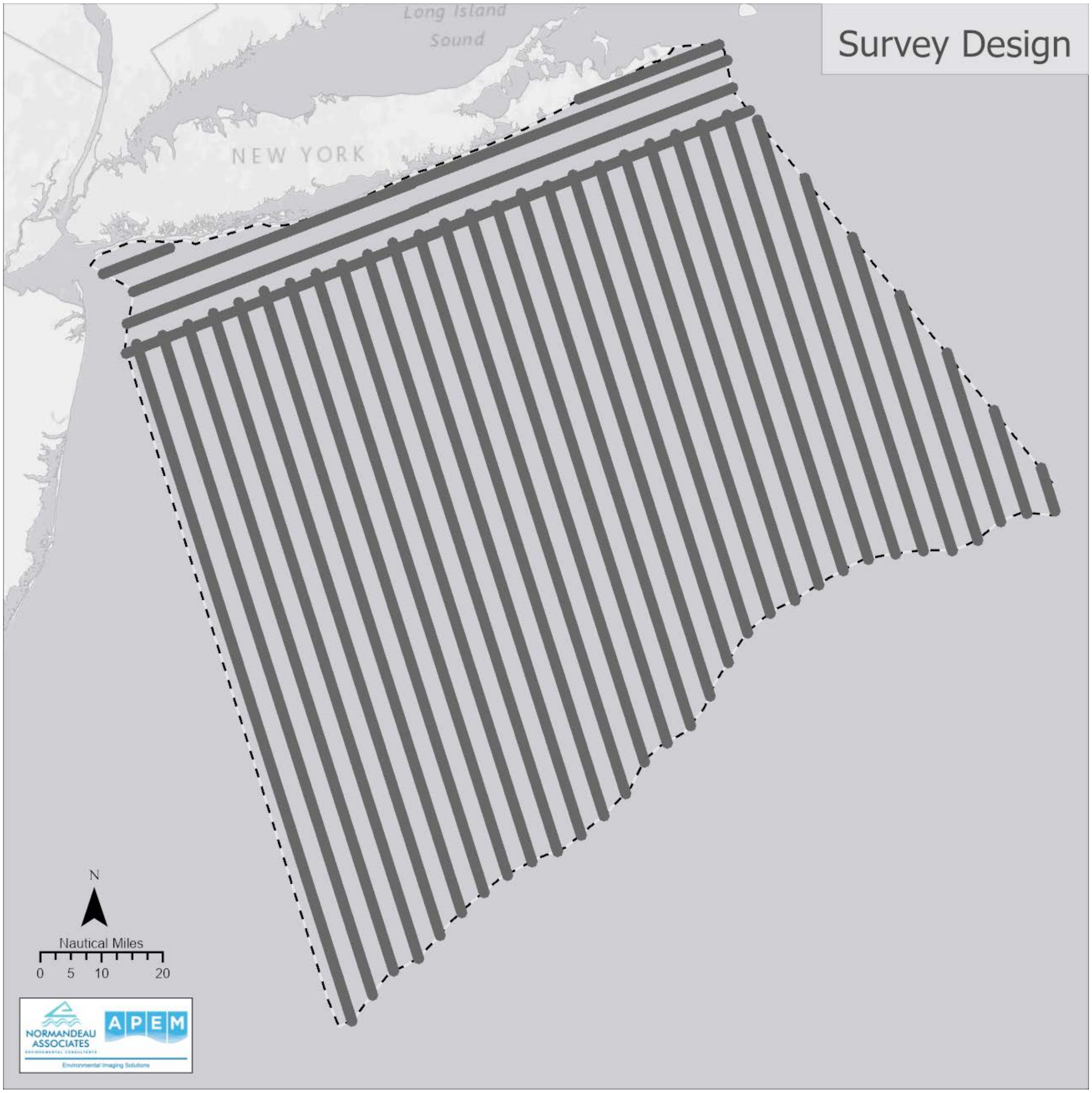

Figure 1. Transect lines used to collect imagery data in the Offshore Planning Area (showing exact transects flown in survey 2; transect coverage area enlarged for visual purposes).

2 Methods

The New York OPA, including a 300-m buffer, covers 43,745.20 km^2 (12,754.06 mi^2). During the first year, the New York WEA, including a 4-km buffer, was also surveyed in a grid pattern, which covers 850.92 km^2 (248.09 mi^2). After the lease was awarded, survey effort over the WEA was reduced to the same pattern as the rest of the OPA. Twelve surveys were completed within this reporting period (Table 1). There were differences in duration among surveys. Initially, the primary reason was the use of a different camera with a narrower field of view used for the Summer 2016 survey. This required more flying to achieve the target 7% coverage of the OPA. Minor differences over the following two surveys were attributable to adjustments for achieving correct coverage using a new camera system. Other factors that have continued to affect duration of surveys include weather conditions and day length. For all surveys, transects of the OPA covered approximately 3,062 km^2.

Two different camera systems were used for the surveys. The Shearwater II camera system was used during the Summer 2016 survey, and the new Shearwater III camera system was used for all subsequent surveys. Both systems collected data at 1.5-cm ground sampling distance (GSD), and both surveys used a Piper Aztec twin engine aircraft. In addition, during the Summer 2016 survey of the OPA, data were collected at 0.75-cm GSD on nearshore sample lines, which were flown at the lower altitude of approximately 152 m (500 ft) to accommodate restrictions imposed in controlled airspace around the John F. Kennedy Airport. Flight altitude for the remaining survey lines of the Summer survey was at 310.9 m (1,020 ft), and data were captured at 414.5 m (1,360 ft) for the subsequent surveys described in this report.

The survey team was based out of MacArthur Airport in Long Island, New York. Because there are several local airfields on Long Island, the Federal Aviation Administration (FAA) imposes varying altitude restrictions that survey aircraft must obey. These are designated according to distance from the airfield. Flights parallel to the shoreline within the restricted zone ensure that the survey aircraft can maintain constant altitude over a complete transect, thus ensuring consistency in image resolution and areal coverage along the transect. For all surveys, nearshore transects were flown parallel to the shoreline, and for the Fall 2016, Winter 2016–2017, Spring 2017, Summer 2017, Fall 2017, Winter 2017–2018, Spring 2018, Summer 2018, Fall 2018, Winter 2018–2019, and Spring 2019 surveys, these were split into east and west segments (Figure 2, Figure 3). FAA-controlled altitude restrictions cease to be an issue several miles offshore. At this point, transects were oriented perpendicular to the shoreline and consequently to the bathymetry, providing optimal orientation for expected clines in the distribution of target species (Figure 4).

Daily survey time maximized crew hours and avoided mid-day when glare/glint was most prevalent, and surveys were not conducted when sea state was ≥4 or above, cloud base was <426.7 m (<1,400 ft), visibility was <5 km (3.1 mi), or wind speed was >30 knots (34.5 mph). The onboard camera technician continuously monitored the images collected and if they ceased to be of sufficient quality, image acquisition stopped until suitable conditions returned. At each capture point, surplus images are collected to allow for replacement of any image found unsuitable for analysis. Data collected for the OPA included a 300-m buffer. All data capture points within the 300-m buffer of the OPA are included for analysis. The shape of the survey area sometimes means that a small part of the very large image might be outside of the 300 m buffer. Following each daily survey, sample imagery was evaluated to make sure it was of good quality for analysis. Data were backed up daily and shipped for analysis.

Table 1. Starting and Ending Dates, Number of Days to Complete for each Survey Period

Season	Reference Month	Date Started	Date Completed	# Flying Days
Year 1				
Summer 2016	Aug 2016	26 Jul 2016	9 Aug 2016	13
Fall 2016	Nov 2016	5 Nov 2016	27 Nov 2016	10
Winter 2016–2017	Mar 2017	6 Mar 2017	3 Apr 2017	10
Spring 2017	May 2017	4 May 2017	21 May 2017	9
Year 2				
Summer 2017	Aug 2017	6 Aug 2017	21 Aug 2017	8
Fall 2017	Nov 2017	9 Nov 2017	27 Nov 2017	8
Winter 2017–2018	Feb 2018	18 Feb 2018	1 Mar 2018	6
Spring 2018	Apr 2018	21 Apr 2018	26 Apr 2018	5
Year 3				
Summer 2018	Aug 2018	29 Jul 2018	16 Aug 2018	8
Fall 2018	Nov 2018	11 Nov 2018	7 Dec 2018	12
Winter 2018-19	Mar 2019	3 Feb 2019	17 Feb 2019	8
Spring 2019	May 2019	27 Apr 2019	7 May 2019	5

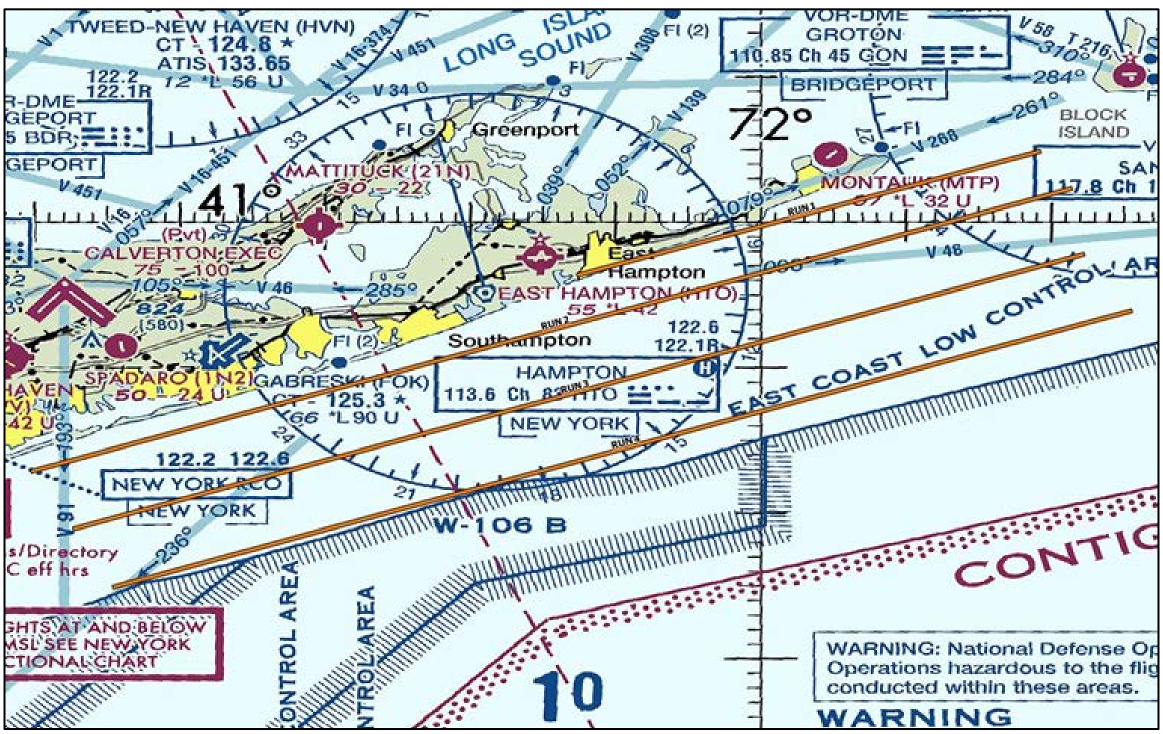

Figure 2. Flight plan used for Near Shore East.

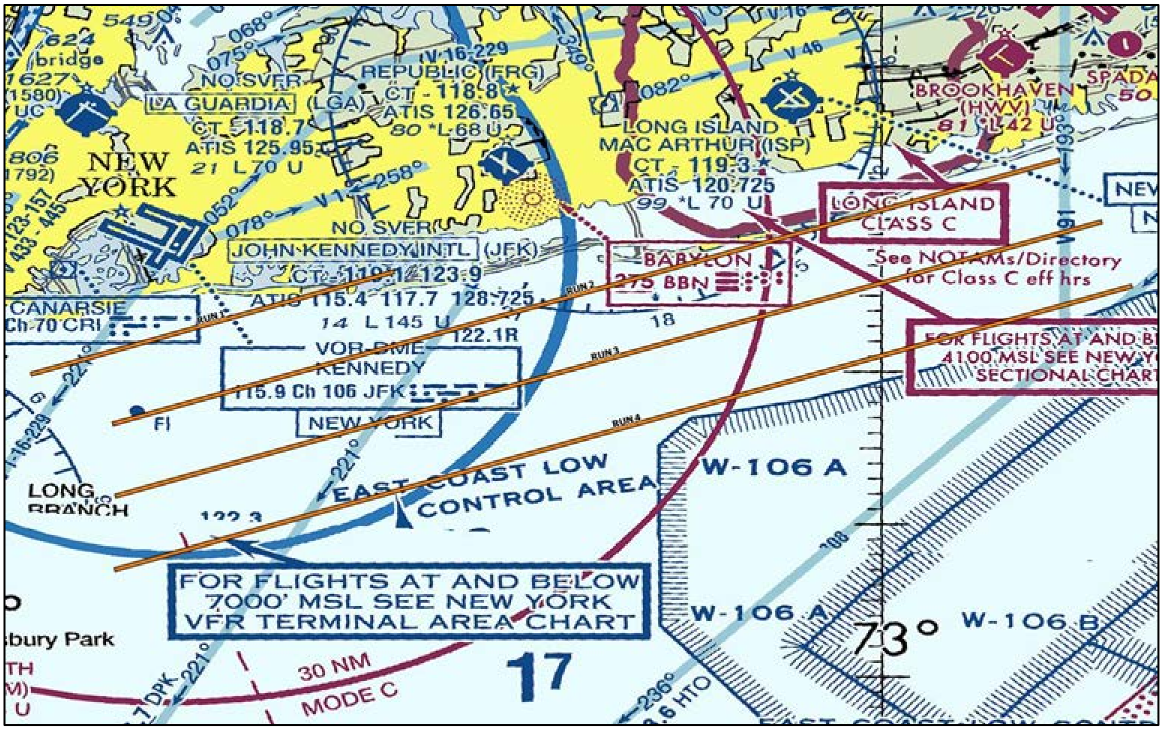

Figure 3. Flight plan used for Near Shore West.

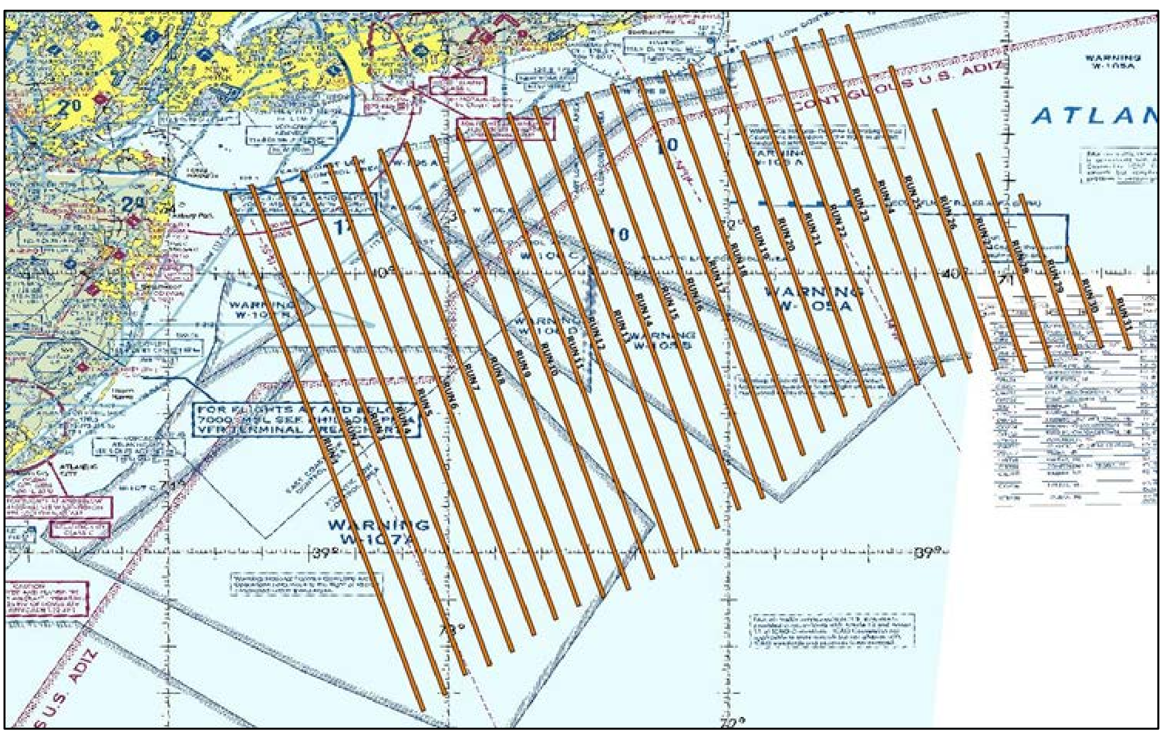

Figure 4. Flight plan used for the Offshore Planning Area.

2.1 Target Extraction and Quality Control

Target extraction is accomplished using automated and manual target identification and extraction methods, and all survey data underwent quality control. To continue monitoring the success of the automated and manual target extraction and ensure that data are not lost during the extraction process, at least 10% of the blank images were screened for quality control. By contract, quality control of target extraction had to meet a minimum agreement of 90%, but self-imposed higher levels of agreement during the extraction process meant that any unusual slippage in agreement below 98% to 99% triggered a review of the analysts involved and early action was taken to maintain high confidence in the target extraction process. Once the target extraction was complete, all images found to contain organisms are transmitted to taxonomists for identification using the ReMOTe portal (https://remote.normandeau.com) for data management, identification, and reporting. Initial extraction categorized targets into taxonomic groups and a cropped image of the animal was posted for identification.

2.2 Target Classification and Identification

Targets were categorized into ten groups representing birds, bats, turtles, marine mammals, rays, sharks, large bony fish, fish shoals, vessels, and fixed structures. These were then accessed for identification by biologists highly experienced in their taxonomic group, and identifications of species listed as "Endangered" or "Threatened" by the state or under the Endangered Species Act (ESA) were flagged.

2.3 Identification Quality Control

At least 20% of all images identified were reviewed by a second taxonomic expert, and taxonomic agreement had to meet at least 90% concurrence. Failure to reach this would trigger a review of 100% of identifications made by the initial taxonomist. The 20% review included quality control review of 100% of ESA and State-listed species, and for endangered species a 100% agreement had to be reached on identifications. Additional experts in the species concerned were called in to arbitrate identifications when concurrence could not be reached.

3 Results

3.1 Data Collection

High-resolution digital aerial images were collected for the OPA using an even distribution transect design that covered on average 7.54% of the total 43,745.20 km^2 area, resulting in surveys ranging from 289,393 to 400,657 images per survey (Table 2).

Large solitary fish were typically identified to family, genus, or species and were enumerated. Shoals were classified as cohesive groups of similarly sized individuals behaving alike (i.e., swimming together as a congregate of individuals either of the same or different species). Fish within shoals were not able to be classified to species because individuals were too small and too submerged to discern defining characteristics. In addition, the species most likely to occur in these schools (Atlantic Mackerel, Atlantic Menhaden, Atlantic Herring, or Hickory Shad; NYSDEC 2007) are similar enough in size that length cannot be used reliably to distinguish them. Based on historic fisheries data, it is likely that the shoals were monospecific. Number of individuals in each shoal was not determined because of the sheer numbers of visible fish and the inability to detect deeper swimming members. As an estimate of the magnitude of the shoals, the surface area was measured to supplement the data on number of shoals.

Table 2. Detection Success for Bony Fishes for All Surveys in the OPA

Survey	Group	No. Images	No. Images with Bony Fish or Fish Shoal	% Images Containing Bony Fish or Shoal
Summer 2016		**289,393**		
	Bony Fishes		577	0.2
	Fish Shoals		12,025	4.16
Fall 2016		**396,079**		
	Bony Fishes		171	0.04
	Fish Shoals		171	0.04
Winter 2016-17		**400,657**		
	Bony Fishes		1	0.0003
	Fish Shoals		15	0.004
Spring 2017		**338,141**		
	Bony Fishes		642	0.19
	Fish Shoals		51	0.02
Summer 2017		**318,741**		
	Bony Fishes		1,787	0.56
	Fish Shoals		617	0.19
Fall 2017		**323,554**		
	Bony Fishes		2	0.0006
	Fish Shoals		118	0.04
Winter 2017-18		**320,107**		
	Bony Fishes		9	0.003
	Fish Shoals		0	0
Spring 2018		**318,455**		
	Bony Fishes		653	0.21
	Fish Shoals		0	0
Summer 2018		**320,453**		
	Bony Fishes		488	0.15
	Fish Shoals		1,422	0.44
Fall 2018		**323,702**		
	Bony Fishes		41	0.01
	Fish Shoals		0	0
Winter 2018-19		**319,941**		
	Bony Fishes		6	0.002
	Fish Shoals		0	0
Spring 2019		**320,793**		
	Bony Fishes		362	0.11
	Fish Shoals		0	0

3.2 Classification and Identification Success

3.2.1 Bony Fish

Targets designated as bony fish were further classified to taxonomic group in 81.63% of cases (Table 3). Successful species level classifications were variable. Taxonomic groups containing only one species resulted in a 100% species classification success; however, we were unable to assign Billfish, Sunfish, and Tuna to species for an average of 34.68% of cases. Billfish were the most difficult to classify to species with 45.24% of cases classified as “billfish species unknown” (Table 3).

Table 3. Species Identification Success Rates for Bony Fishes for All Surveys in the OPA

Subtype	Species Taxonomic Group Frequency	% Classified to Subtype	Species	Species Frequency	% Classified to Species
Billfish	**42**	**0.9**			
			Billfish sp. Unknown	19	45.2
			Atlantic Swordfish	23	54.8
Cobia	**11**	**0.2**			
			Cobia	11	100
Mahi-Mahi	**994**	**20.4**			
			Mahi-Mahi	994	100
Sunfish	**1,633**	**33.6**			
			Ocean Sunfish	1,153	70.6
			Sharptail Sunfish	16	1.0
			Sunfish sp. Unknown	464	28.4
Tuna	**1,287**	**26.5**			
			Atlantic Bluefin Tuna	874	67.9
			Yellow Fin Tuna	22	1.7
			Tuna sp. Unknown	391	30.4
Unidentified Fish Species	**894**	**18.4**			

3.2.2 Remora

Across all surveys, five remora were identified: all were imaged on two Chilean devil rays, three on one ray (Figure 5 and Figure 6). Because of the very low detection rate of this species, conclusions about their hosts or patterns cannot be drawn, but it does highlight that any conclusions about remora made in future studies will most certainly be related to their host species. Beyond ecology, the imaged remora shows the incredible clarity and power of this survey method for detecting some of the most understudied fish species that can be observed at the surface.

Figure 5. Chilean devil ray with three remoras attached.

Figure 6. Chilean devil ray with two remoras attached.

3.3 Observation Rates

3.3.1 Bony Fish

Both raw and survey-effort corrected abundance are reported at the taxonomic group and species level for the total project as well as for each survey (Figure 8–Figure 17; Table 4–Table 6). We have corrected these numbers to assume equal coverage (effort) of the entire area by dividing the observed number of individuals in a given survey by the total area imaged during the survey of interest.

Despite annual variation, overall total observations were greatest during the Summer surveys and lowest during the Winter surveys for bony fishes (Table 4, Figure 8) and fish shoals (Table 4). Sunfishes were the most frequently observed bony fish in the OPA (area corrected abundance = 22,044; Table 6, Figure 9, Figure 10). This is partly due to their presence in the OPA during the Fall when the next two most abundant bony fishes (Tuna and Mahi-Mahi) had relatively low detection probabilities (Figure 11–Figure 14). Atlantic Bluefin Tuna had the greatest Spring abundance having a survey area corrected estimate of 7,507 observations with 93% of observations occurring in 2018 (Figure 13, Table 6). Mahi-Mahi had the greatest Summer season observation frequency, having a survey area corrected abundance estimate of 13,504 observations with 71.2% percent of observations occurring in 2017 (Table 6; Figure 14). Billfish were observed most often during the Summer surveys with a total corrected abundance of 569, which is 98% of the Billfish for all seasons (Figure 15, Figure 16, Table 6). Atlantic Swordfish comprised 55% of the total Billfish with the remaining 45% being classified as Billfish sp. unknown (Figure 16; Table 6). Cobia were seen most often in the Summer with a corrected abundance of 138, or 91% (Table 6, Figure 17). The remaining cobia were detected in Spring 2018 (Table 6).

Table 4. Relative Abundance of Each Species Group by Season in the OPA

Group	Season			
	Summer	Fall	Winter	Spring
Bony Fishes	2,854	330	30	1,657
Fish Shoals	14,064	173	1	51

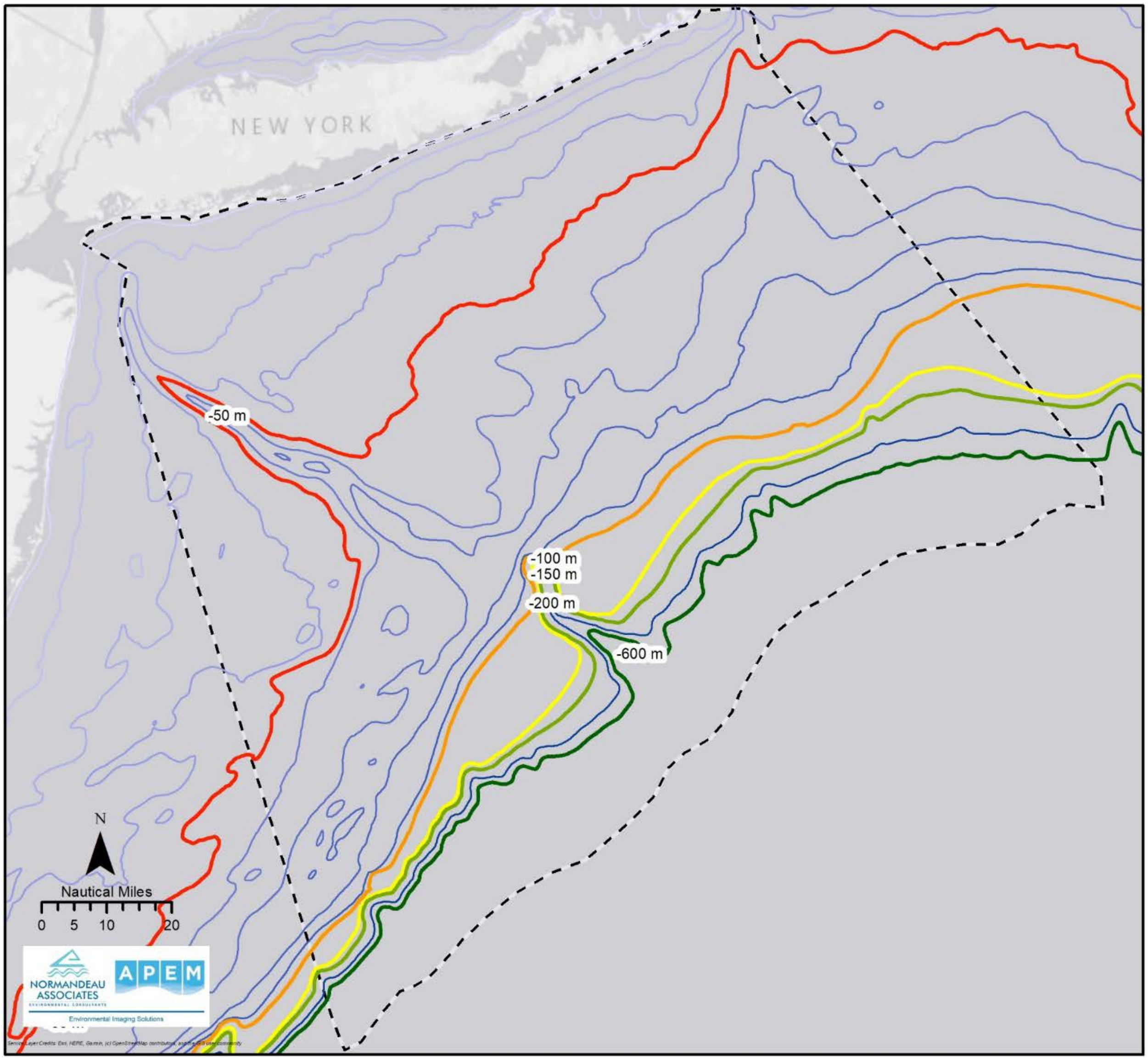

Figure 7. OPA displaying bathymetry contours (5 nautical miles = 9.26 km).

Contours from 10 m to 100 m increase in 10-m increments, then increase in 50-m increments to 200 m, and in 200-m increments to 600.

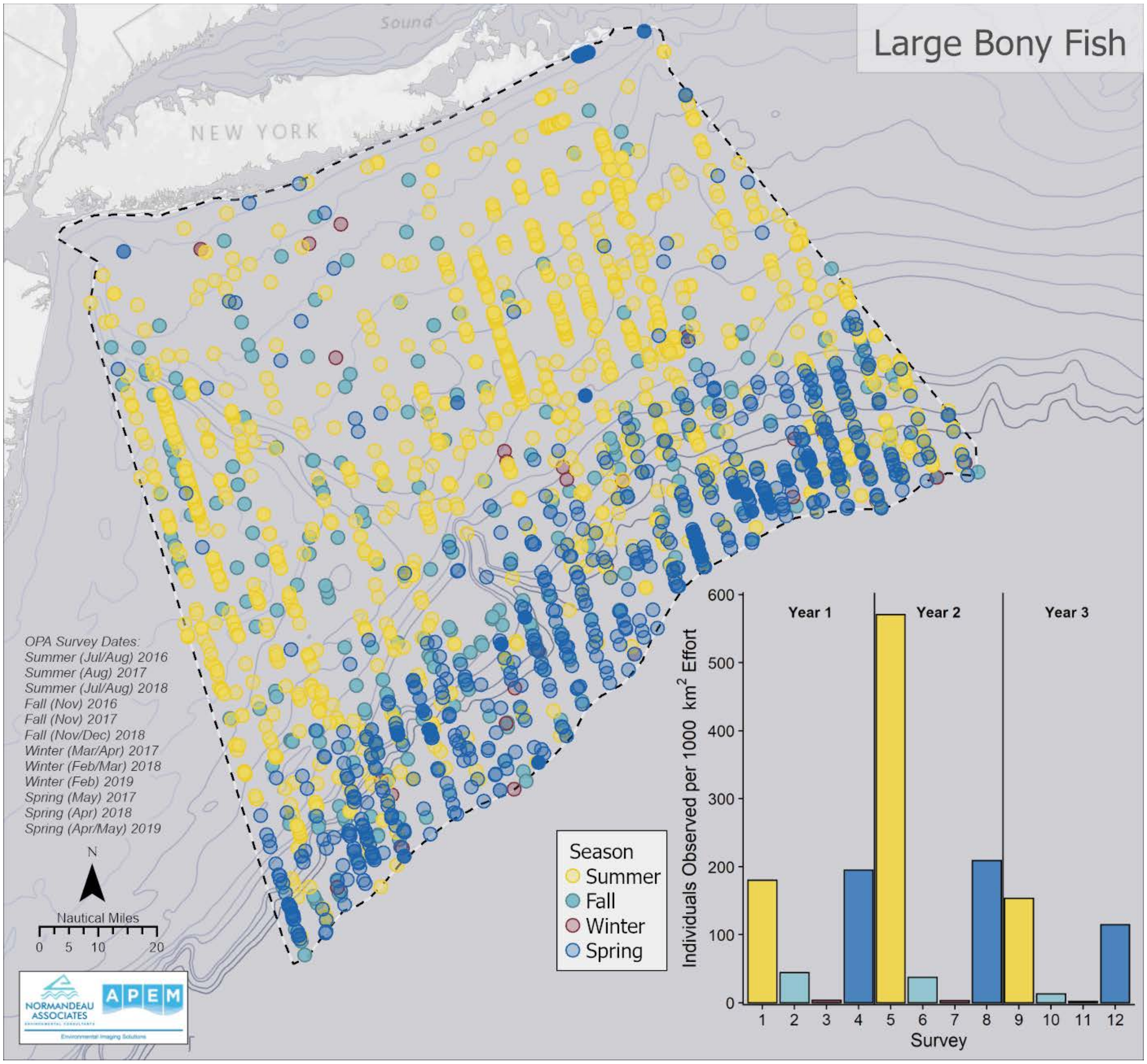

Figure 8. Locations of all bony fishes observed in the OPA during the Summer 2016 through Spring 2019 surveys (5 nautical miles = 9.26 km).

Inset represents the number of individual bony fishes observed per 1,000 km^2 of survey effort for each survey, color coded by season.

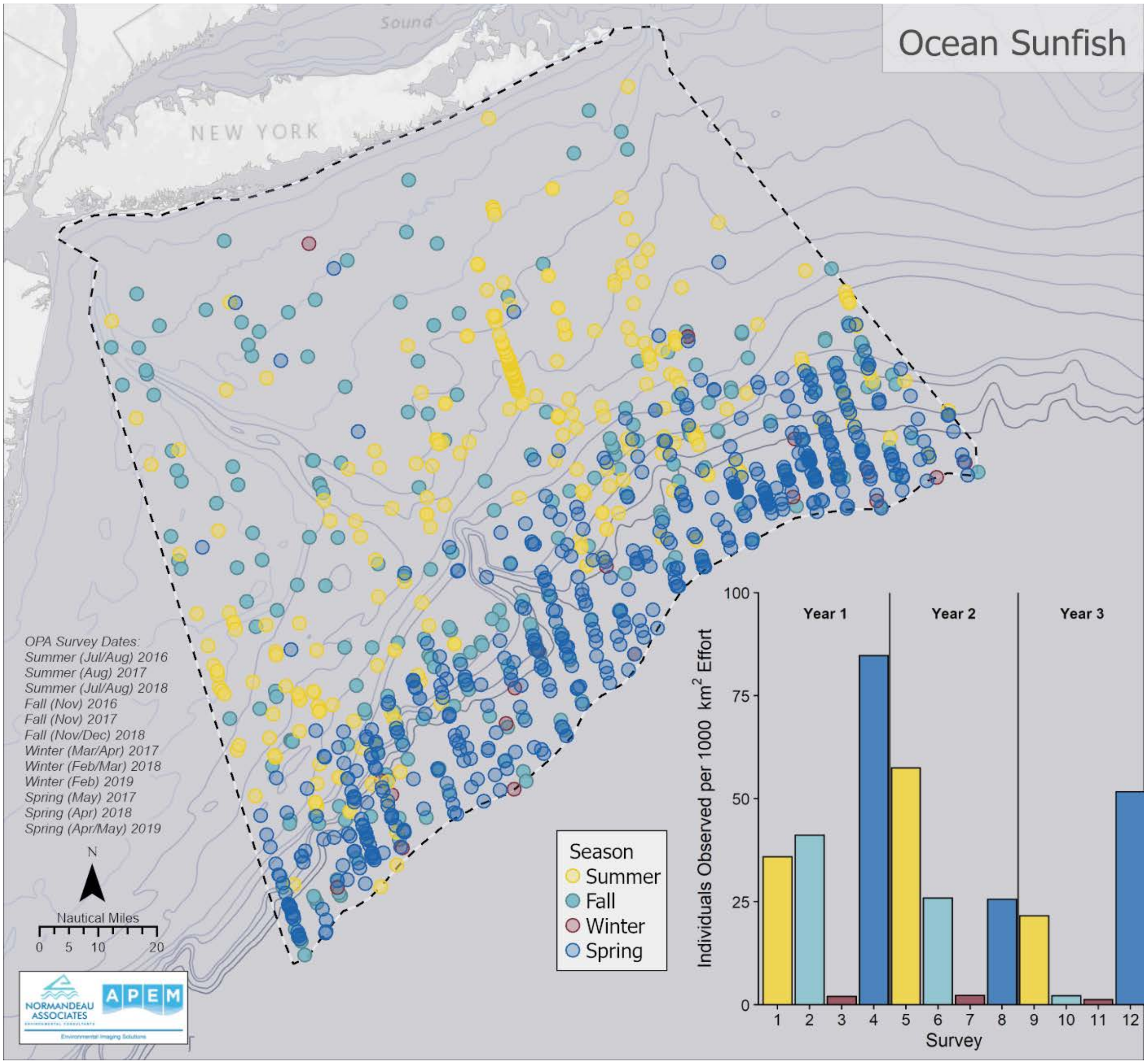

Figure 9. Locations of all Ocean Sunfish observed in the OPA during the Summer 2016 through Spring 2019 surveys (5 nautical miles = 9.26 km).

Inset represents the number of individual Sunfishes observed per 1,000 km² of survey effort for each survey, color coded by season.

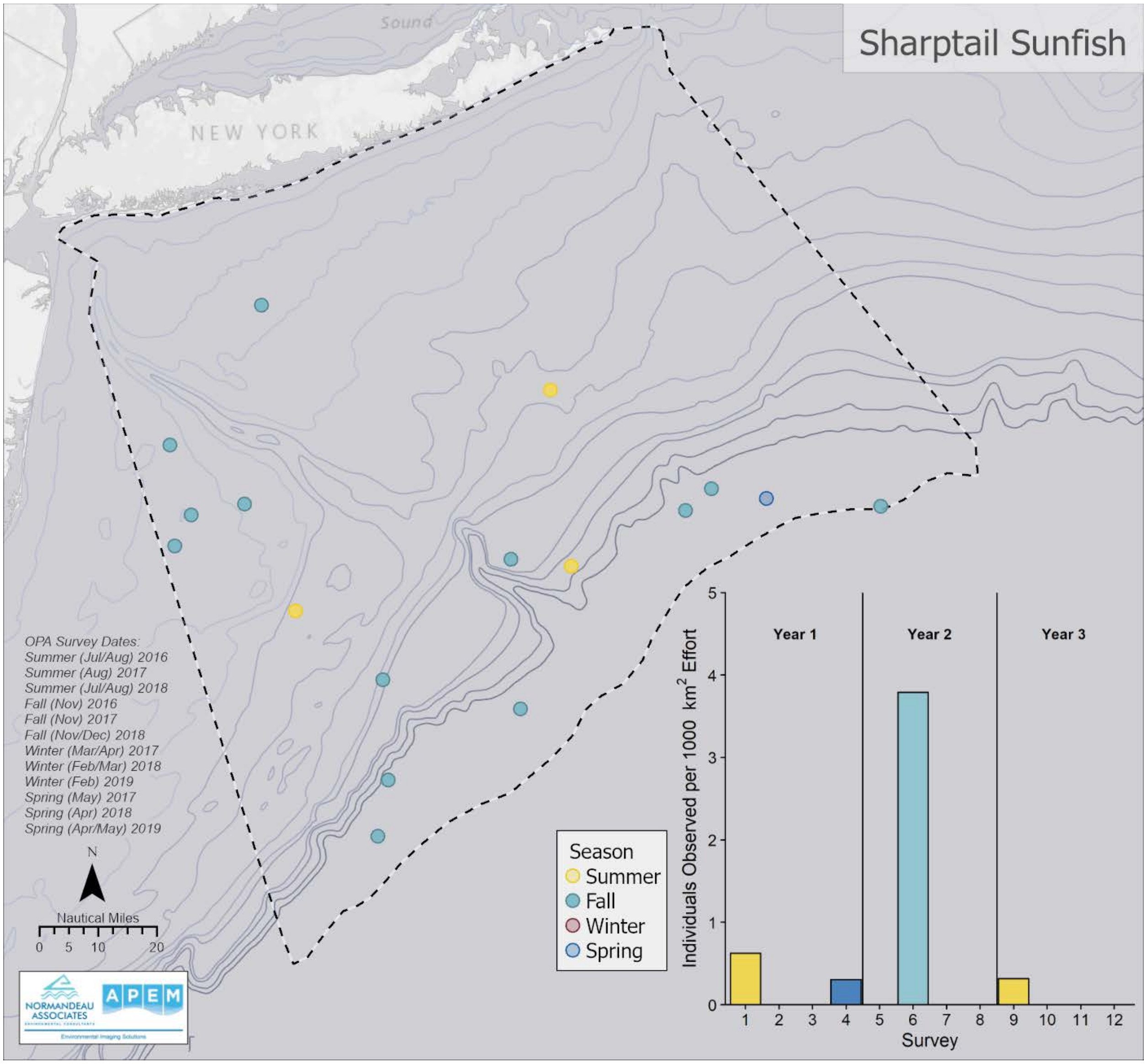

Figure 10. Locations of all Sharptail Sunfish observed in the OPA during the Summer 2016 through Spring 2019 surveys (5 nautical miles = 9.26 km).

Inset represents the number of individual Sunfishes observed per 1,000 km^2 of survey effort for each survey, color coded by season.

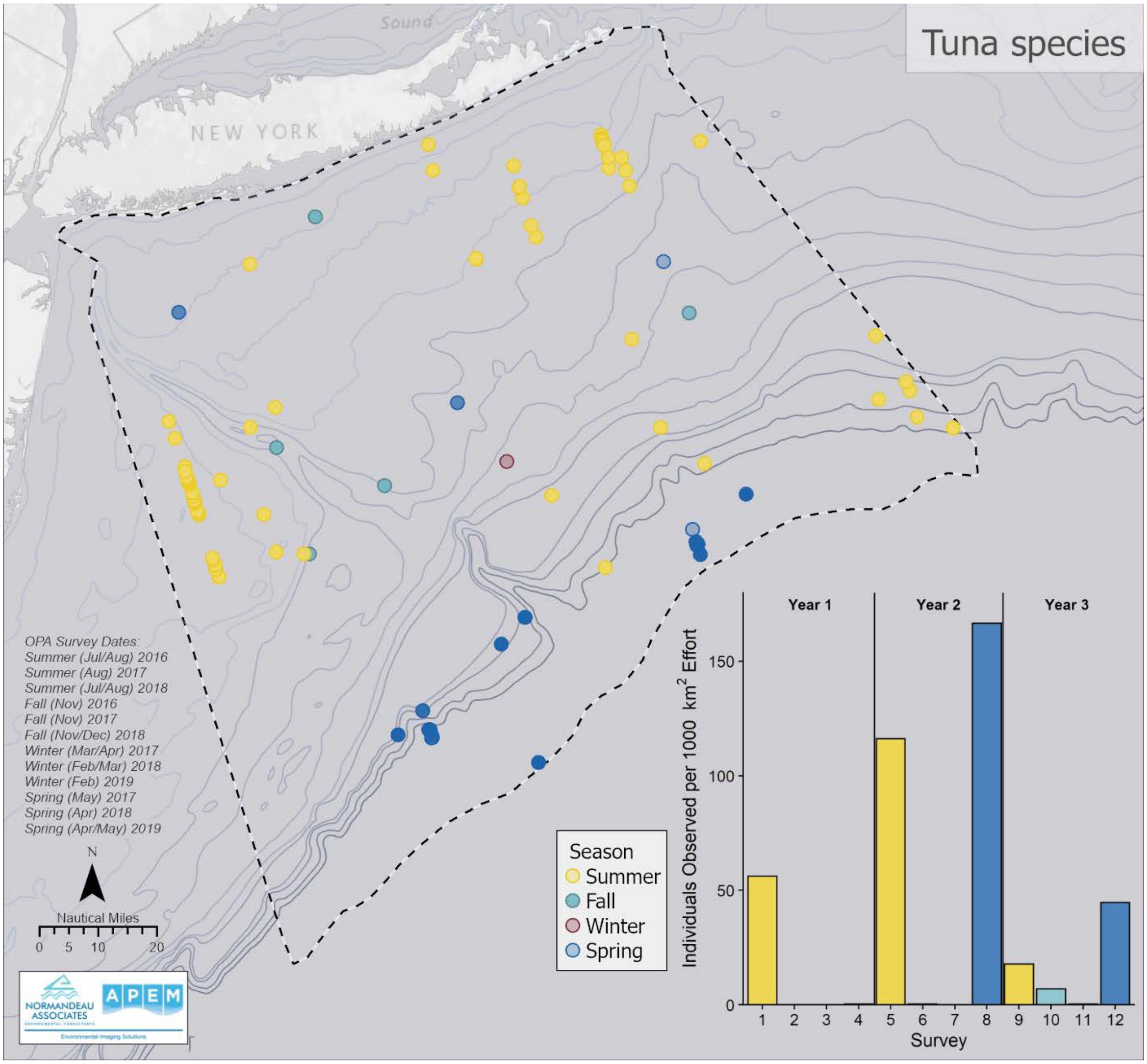

Figure 11. Locations of all Tuna species observed in the OPA during the Summer 2016 through Spring 2019 surveys (5 nautical miles = 9.26 km).

Inset represents the number of individual Tuna observed per 1,000 km^2 of survey effort for each survey, color coded by season.

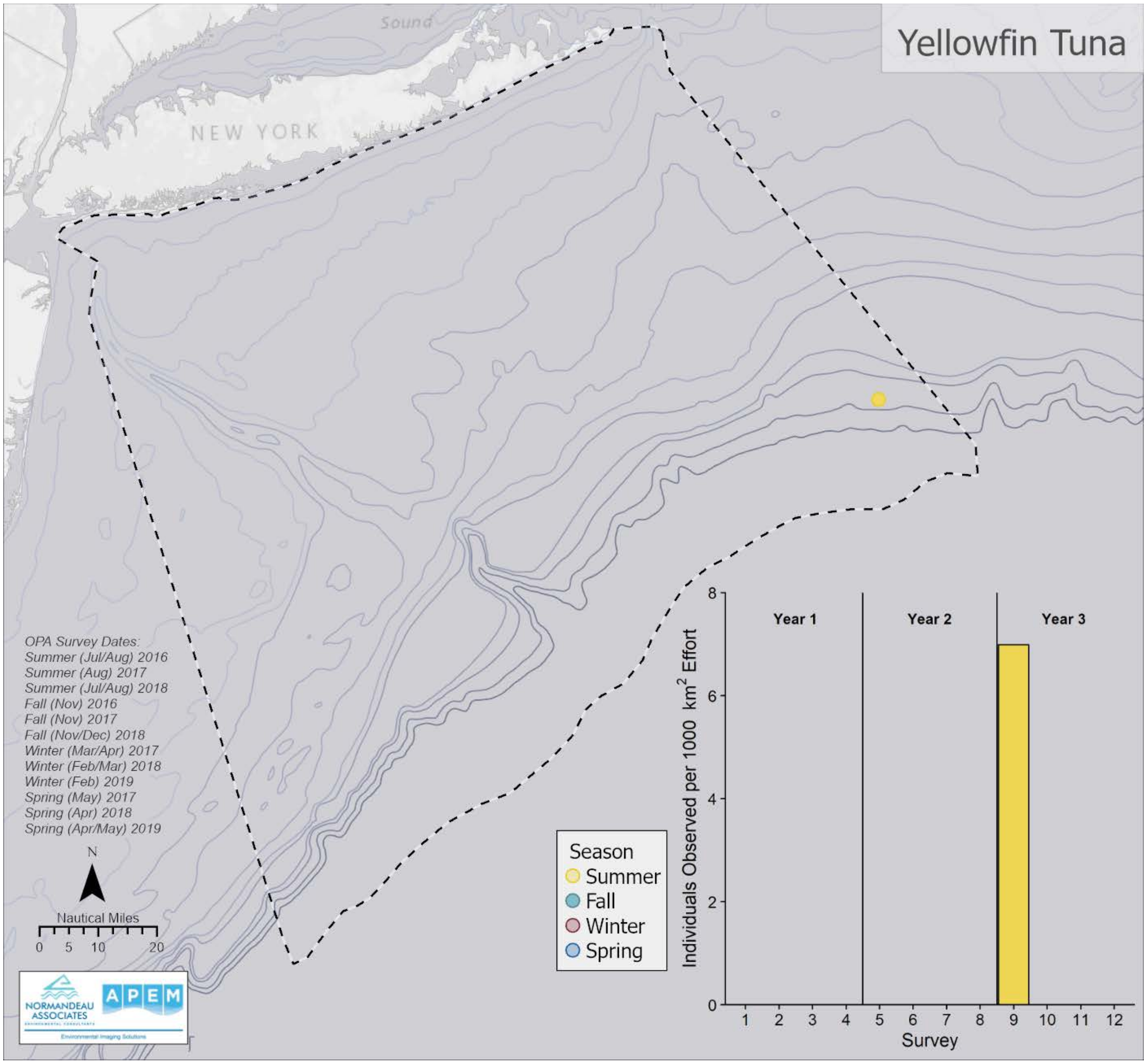

Figure 12. Locations of all Yellowfin Tuna observed in the OPA during the Summer 2016 through Spring 2019 surveys (5 nautical miles = 9.26 km).

Inset represents the number of individual Tuna observed per 1,000 km^2 of survey effort for each survey, color coded by season.

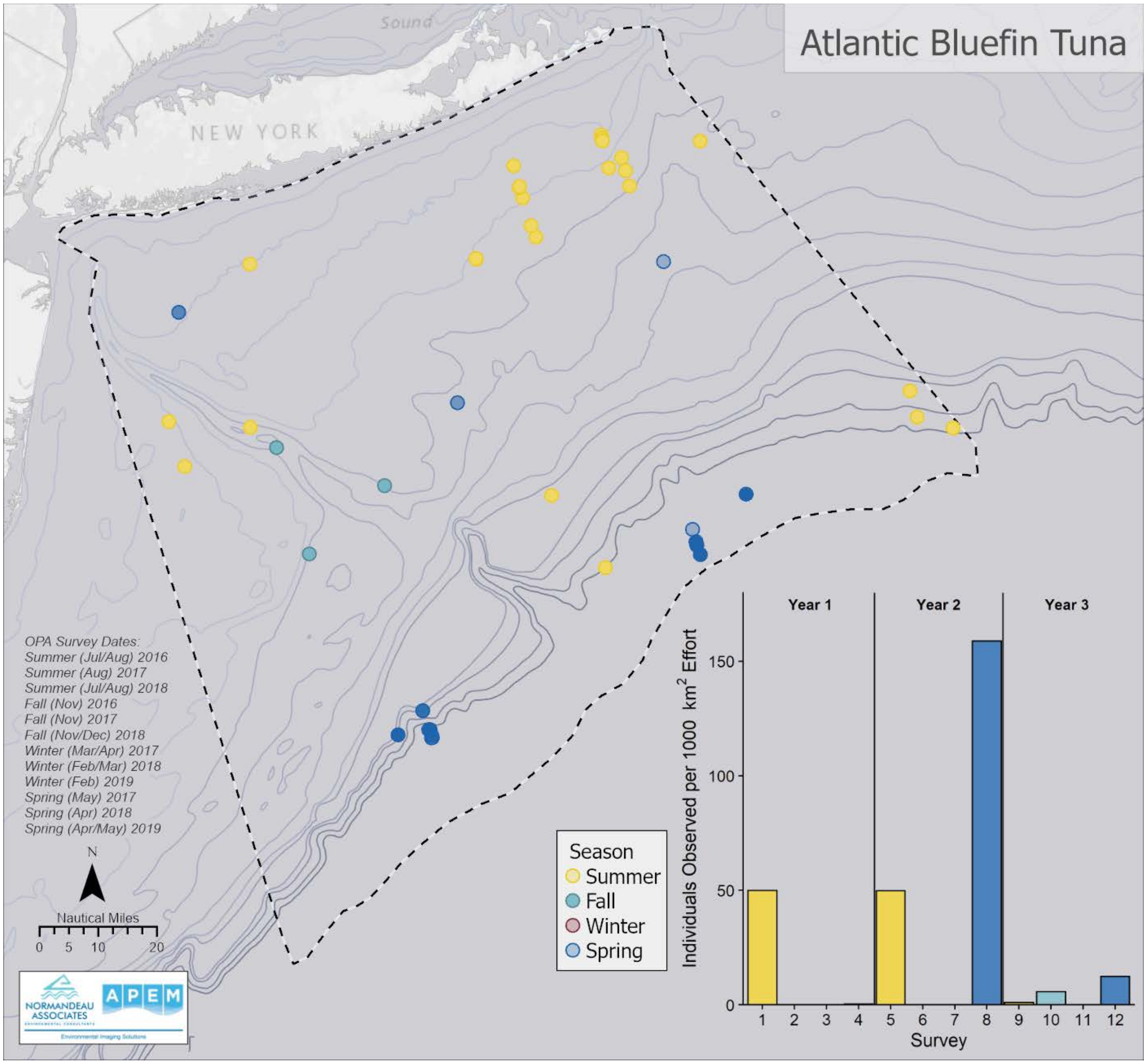

Figure 13. Locations of all Atlantic Bluefin Tuna observed in the OPA during the Summer 2016 through Spring 2019 surveys (5 nautical miles = 9.26 km)

Inset represents the number of individual Tuna observed per 1,000 km^2 of survey effort for each survey, color coded by season.

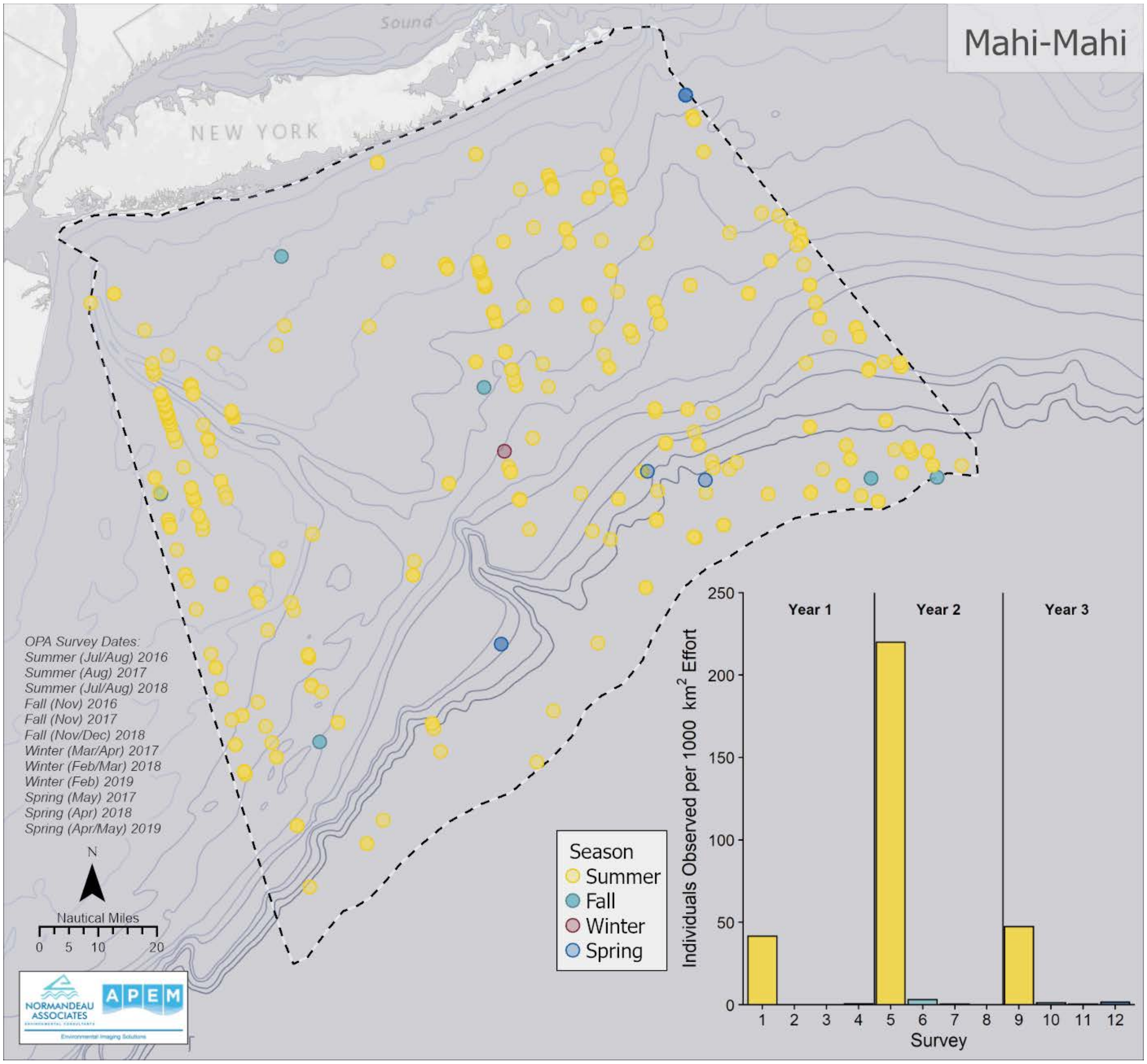

Figure 14. Locations of all Mahi-Mahi observed in the OPA during the Summer 2016 through Spring 2019 surveys (5 nautical miles = 9.26 km).

Inset represents the number of individual Mahi-Mahi observed per 1,000 km² of survey effort for each survey, color coded by season.

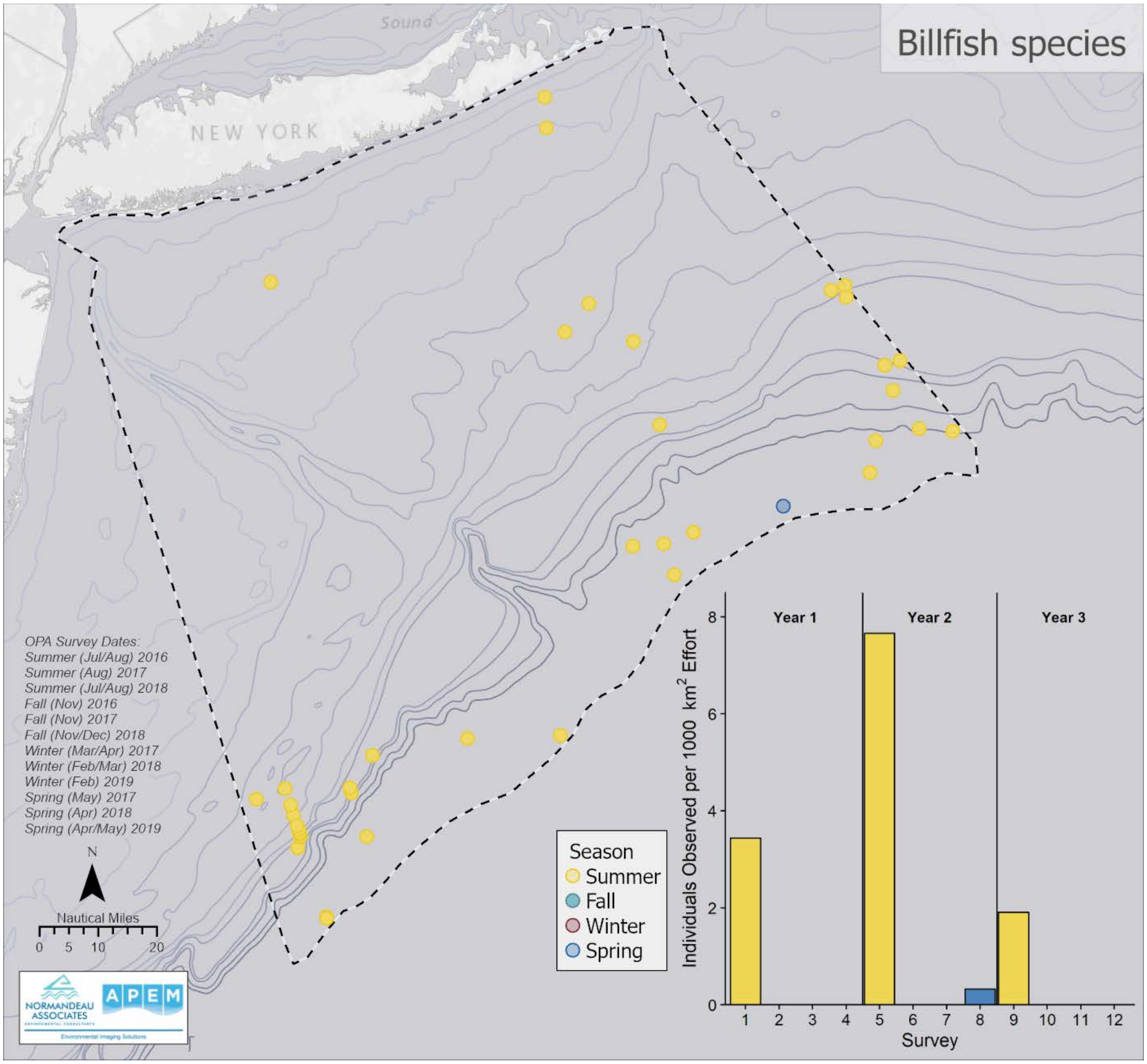

Figure 15. Locations of all Billfish observed in the OPA during the Summer 2016 through Spring 2019 surveys (5 nautical miles = 9.26 km).

Inset represents the number of individual billfish observed per 1,000 km^2 of survey effort for each survey, color coded by season.

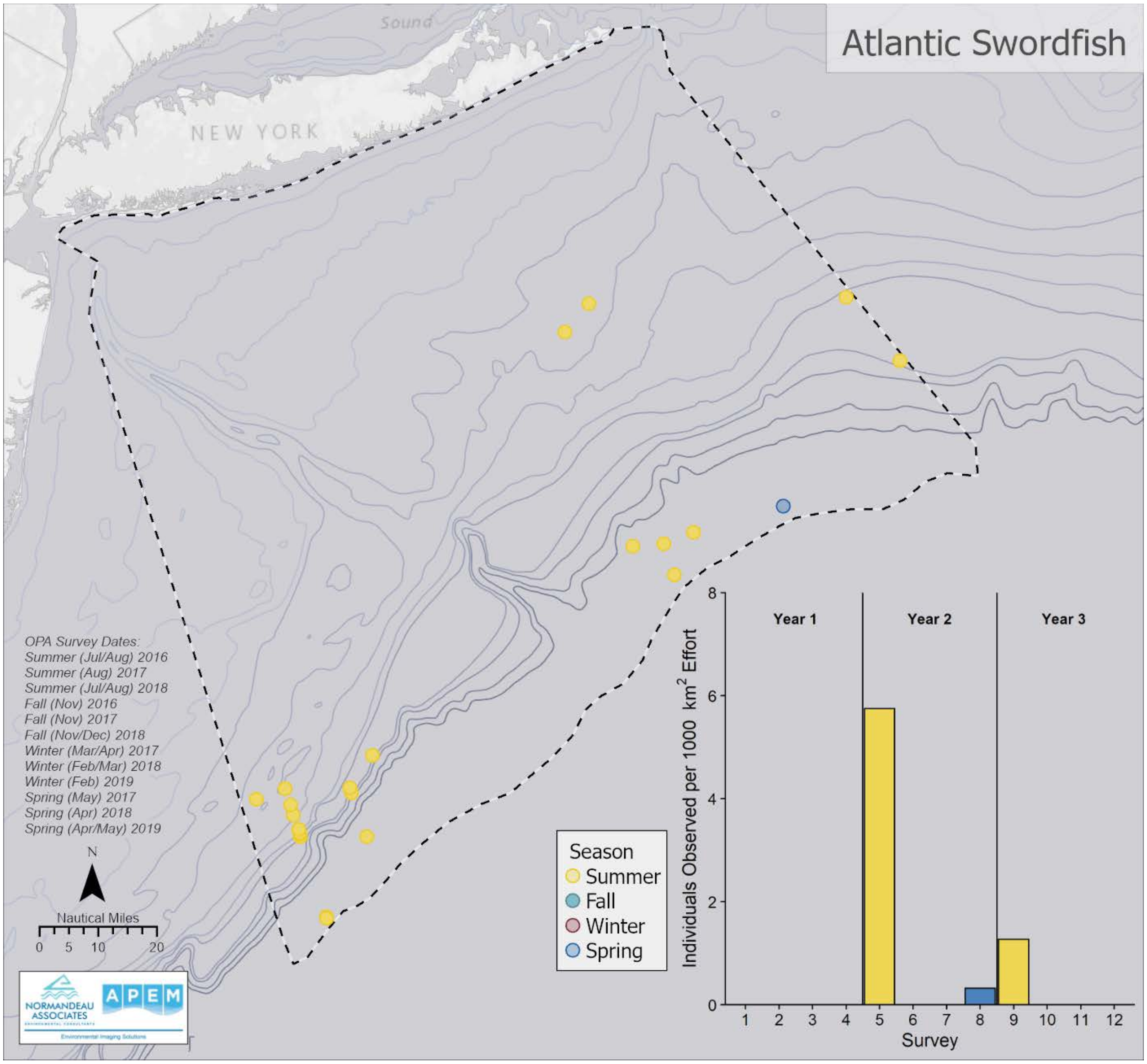

Figure 16. Locations of all Atlantic Swordfish observed in the OPA during the Summer 2016 through Spring 2019 surveys (5 nautical miles = 9.26 km).

Inset represents the number of individual billfish observed per 1,000 km^2 of survey effort for each survey, color coded by season.

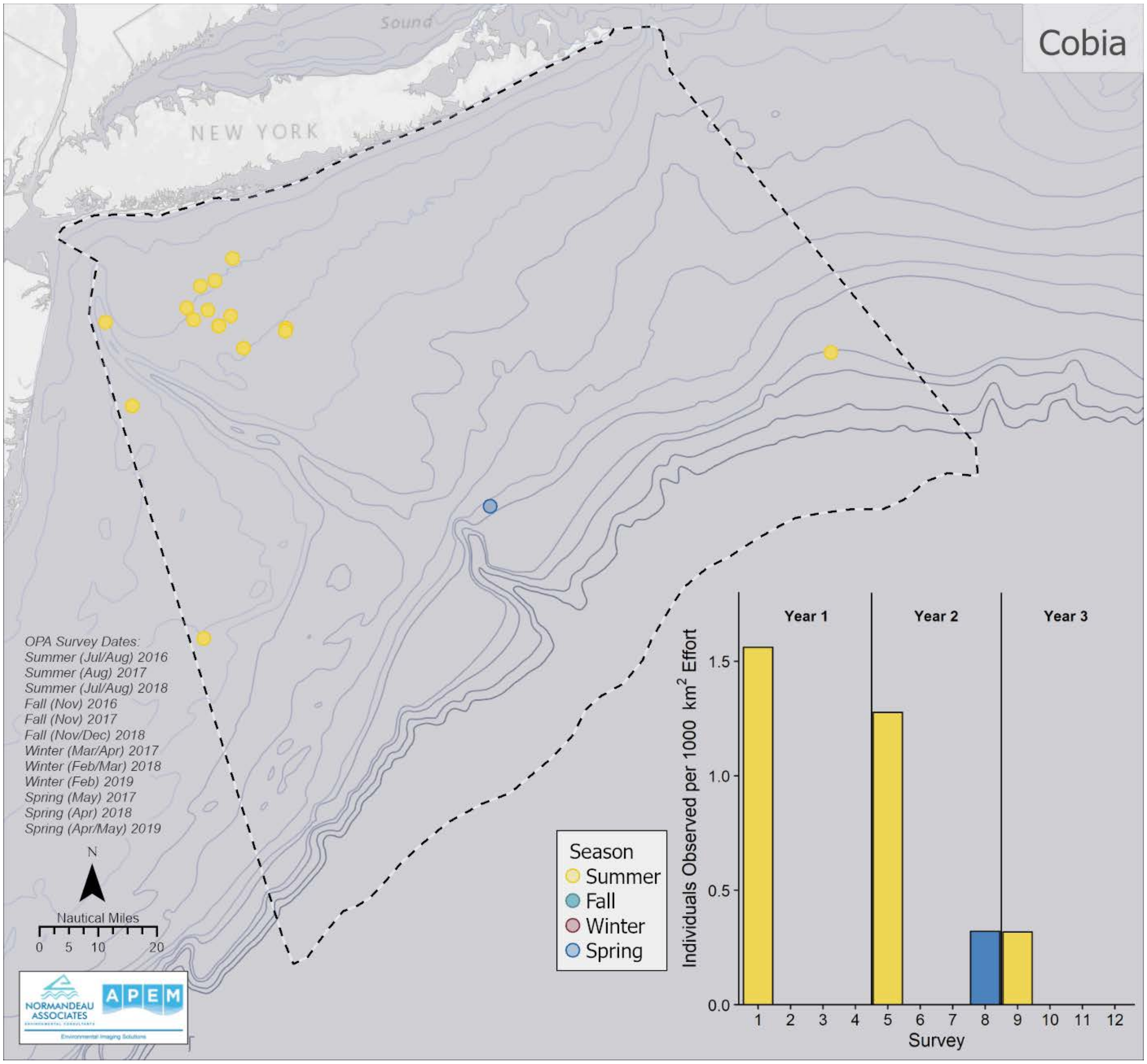

Figure 17. Locations of all Cobia observed in the OPA during the Summer 2016 through Spring 2019 surveys (5 nautical miles = 9.26 km).

Inset represents the number of individual Cobia observed per 1,000 km^2 of survey effort for each survey, color coded by season.

Table 5. Relative Abundance of each Species Group Observed in the OPA by Season and Year

Taxonomic Group & Species	Relative Raw Abundance												Species Total
	Summer			Fall			Winter			Spring			
	2016	2017	2018	2016	2017	2018	2016-2017	2017-2018	2018-2019	2017	2018	2019	
Billfish	**11**	**24**	**6**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**42**
Atlantic Swordfish	0	18	4	0	0	0	0	0	0	0	1	0	23
Billfish Sp. Unknown	11	6	2	0	0	0	0	0	0	0	0	0	19
Cobia	**5**	**4**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**11**
Cobia	5	4	1	0	0	0	0	0	0	0	1	0	11
Mahi-Mahi	**133**	**689**	**149**	**0**	**10**	**4**	**0**	**1**	**1**	**2**	**0**	**5**	**994**
Mahi-Mahi	133	689	149	0	10	4	0	1	1	2	0	5	994
Sunfish	**147**	**572**	**72**	**162**	**107**	**7**	**10**	**8**	**4**	**299**	**81**	**164**	**1,633**
Ocean Sunfish	115	180	68	160	82	7	8	7	4	279	80	163	1,153
Sharptail Sunfish	2	0	1	0	12	0	0	0	0	1	0	0	16
Sunfish sp. Unknown	30	392	3	2	13	0	2	1	0	19	1	1	464
Tuna	**180**	**364**	**56**	**0**	**1**	**22**	**0**	**0**	**1**	**1**	**521**	**141**	**1,287**
Atlantic Bluefin Tuna	160	156	3	0	0	18	0	0	0	1	497	39	874
Yellowfin Tuna	0	0	22	0	0	0	0	0	0	0	0	0	22
Tuna sp. Unknown	20	208	31	0	1	4	0	0	1	0	24	102	391
Remora	**0**	**0**	**5**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**5**
Remora unid.	0	0	5	0	0	0	0	0	0	0	0	0	5
Unid. Bony Fish Species	**101**	**134**	**199**	**9**	**0**	**8**	**5**	**0**	**0**	**340**	**49**	**52**	**897**
TOTAL Large Bony Fishes	**577**	**1,787**	**488**	**171**	**118**	**41**	**15**	**9**	**6**	**642**	**653**	**362**	**4,869**
Shoals [a]	**12,025**	**617**	**1,422**	**171**	**2**	**0**	**1**	**0**	**0**	**51**	**0**	**0**	**14,289**

[a] number of shoals, not individuals

Table 6. Total Corrected Abundance* of Individuals in Taxonomic Group by Season in the OPA

Species	Relative Corrected Abundance												Species Total
	Summer			Fall			Winter			Spring			
	2016	2017	2018	2016	2017	2018	2016-2017	2017-2018	2018-2019	2017	2018	2019	
Billfish	**150**	**335**	**84**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**14**	**0**	**583**
Atlantic Swordfish	0	251	56	0	0	0	0	0	0	0	14	0	321
Billfish sp. Unknown	150	84	28	0	0	0	0	0	0	0	0	0	262
Cobia	**68**	**56**	**14**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**14**	**0**	**152**
Cobia	68	56	14	0	0	0	0	0	0	0	14	0	152
Mahi-Mahi	**1,816**	**9,619**	**2,069**	**0**	**138**	**55**	**0**	**14**	**14**	**27**	**0**	**69**	**13,821**
Mahi-Mahi	1,816	9,619	2,069	0	138	55	0	14	14	27	0	70	13,821
Sunfish	**2,007**	**7,986**	**1,000**	**1,821**	**1,477**	**96**	**111**	**111**	**56**	**3,971**	**1,133**	**2,275**	**22,044**
Ocean Sunfish	1,570	2,513	944	1,799	1,132	96	89	97	56	3,706	1,119	2,261	15,382
Sharptail Sunfish	27	0	14	0	166	0	0	0	0	13	0	0	220
Sunfish sp. Unknown	410	5,473	42	22	179	0	22	14	0	252	14	14	6,442
Tuna	**2,458**	**5,082**	**777**	**0**	**14**	**302**	**0**	**0**	**14**	**13**	**7,289**	**1,956**	**17,905**
Atlantic Bluefin Tuna	2,185	2,178	42	0	0	247	0	0	0	13	6,953	541	12,159
Yellowfin Tuna	0	0	305	0	0	0	0	0	0	0	0	0	305
Tuna sp. Unknown	273	2,904	430	0	14	55	0	0	14	0	336	1,415	5,441
Remora	**0**	**0**	**69**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**69**
Remora unid.	0	0	69	0	0	0	0	0	0	0	0	0	69
Unid. Bony Fish Species	**1,379**	**1,871**	**2,763**	**101**	**0**	**110**	**55**	**0**	**0**	**4,516**	**686**	**721**	**12,202**
TOTAL Large Bony Fishes	**7,878**	**24,947**	**6,776**	**1,923**	**1,629**	**562**	**166**	**125**	**83**	**8,528**	**9,136**	**5,021**	**66,776**
Shoals [a]	**164,279**	**8,618**	**19,750**	**1,924**	**28**	**0**	**11**	**0**	**0**	**678**	**0**	**0**	**195,288**

*Corrected abundance was calculated by dividing the observed abundance by the proportion of the area surveyed for each season. This accounts for differing amounts of area surveyed and makes abundances comparable across seasons - Corrected abundances are frequently non-integers that have been rounded to whole numbers for display purposes. Thus, columns and rows may not sum to the totals in the table because the underlying values are non-integers.

[a] number of shoals, not individuals

3.3.2 Fish Shoals

Fish shoals were observed in the highest numbers in the Summer surveys with a corrected abundance of 192,647, or 99% of the total (Figure 18; Table 6). In the first year of surveys, fish shoals comprised 85.5% of the total number of fish shoals observed during the remaining 11 surveys.

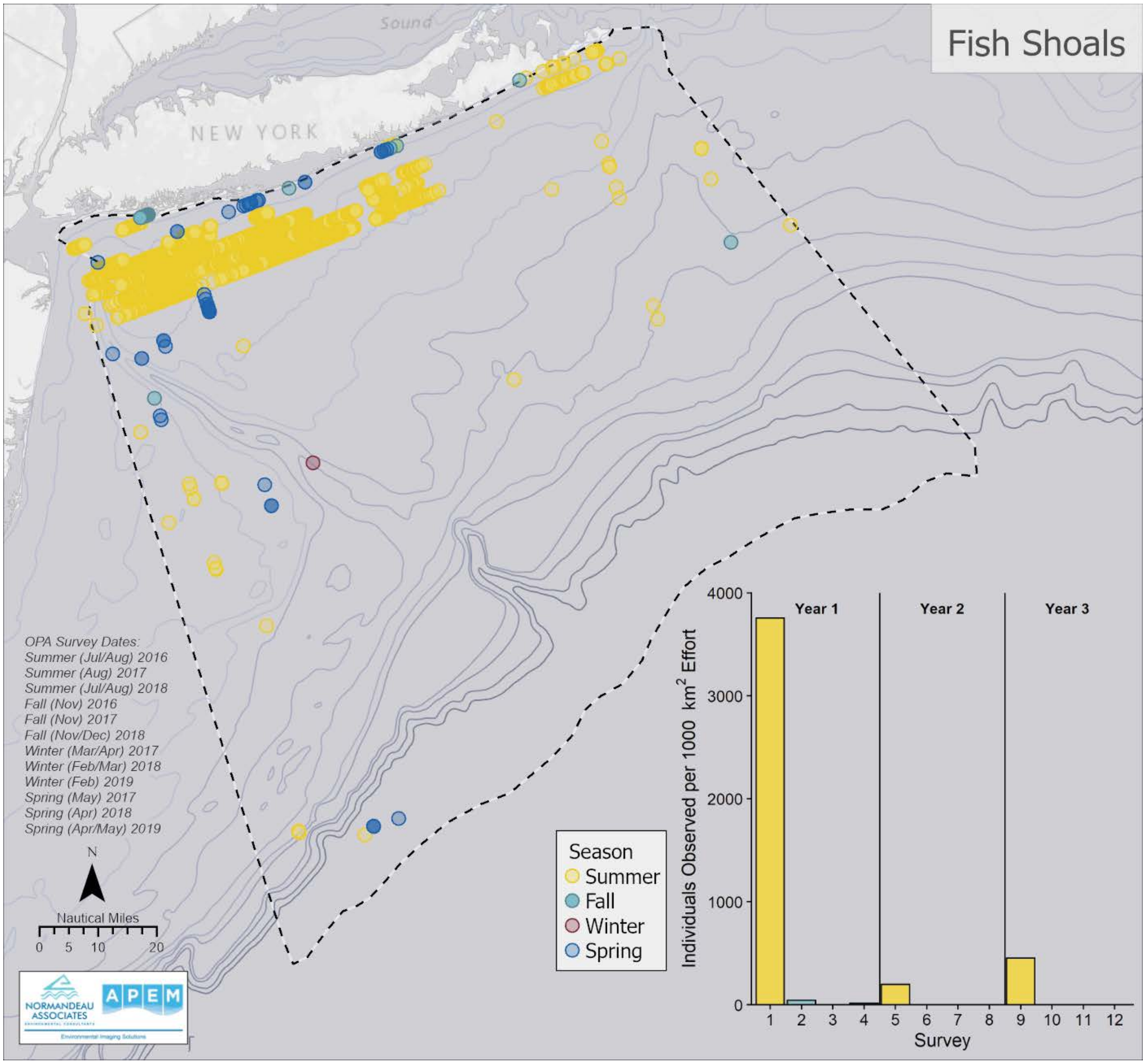

Figure 18. Locations of all Shoals observed in the OPA during the Summer 2016 through Spring 2019 surveys (5 nautical miles = 9.26 km).

Inset represents the number of fish shoals observed per 1,000 km² of survey effort for each survey, color coded by season

3.4 Spatial Distribution

To better understand what drives variation in spatial distribution, the distance of each individual was calculated from shore (m) based on their geographic proximity to the nearest landmass. In addition, the approximate ocean depth at which an individual was imaged and its proximity to shipping lanes within and adjacent to the OPA was quantified. Ocean depth was calculated by first determining to which bathymetric contour each individual was nearest. For bathymetric contours representing a range of depths (e.g., 30–50 m) the average depth was used and each individual was assigned to a categorical designation of approximate depth. Results show that distance from shore, depth, and proximity to shipping lanes are all influenced by taxonomic group-specific seasonal and annual temporal effects.

3.4.1 Distance from Shore

Differences in the average distance from shore that might be driven by subtype taxonomic group membership (i.e., large bony fishes or pelagic shoaling fishes) were investigated. Across all seasons large bony fishes were imaged approximately ten times farther from shore than fish shoals ($t_{1,4917.9} = 113.22$, $p = < 0.001$; Welch's Test), with fish shoals having an average offshore distance of 9.4 km and large bony fishes occurring, on average, 100.1 km from shore (Figure 19). Another feature of the dataset is the difference in variance. Large bony fishes exhibit 95% more variance in their distance from shore than fish shoals ($p < 0.01$; F-test). Differences relate to different behaviors exhibited by the species in the shoals versus the large bony fishes.

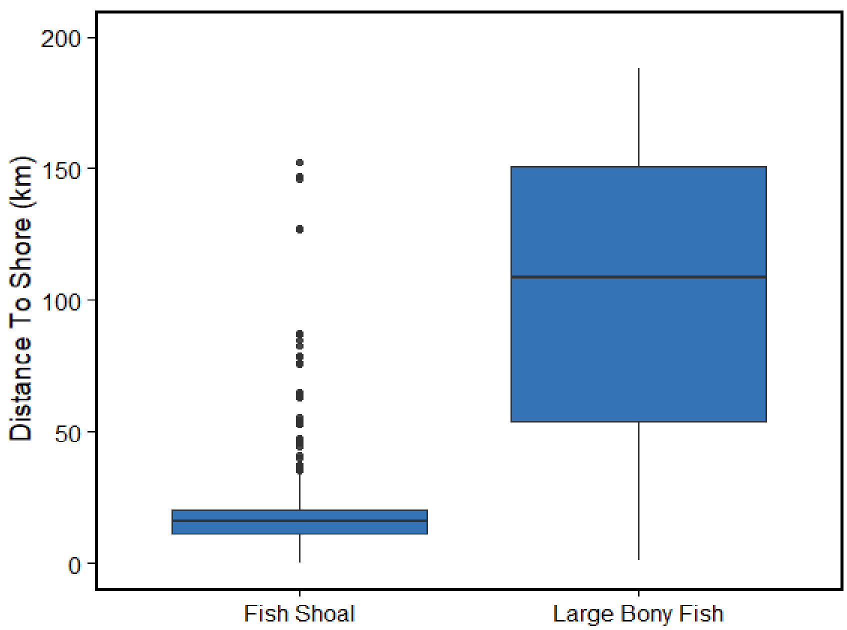

Figure 19. Difference in distance from shore (km) between pelagic fish shoals (n = 2,264) and large bony fishes (n = 4,292) across the Summer 2016 through Spring 2019 surveys.

Boxplots represent minimum, maximum, 25th percentile, 75th percentile and median (50th percentile) with points representing outliers.

Bony Fishes

We investigated if variation in distance from shore across bony fishes was driven by temporal and taxon-specific factors. A three-way analysis of variance (ANOVA) was performed that contained taxonomic group, survey year, season, and the interactions among the three as covariates. Two-way ANOVAs were used when investigating season-specific spatial distributions that included year and taxonomic group as well as the interaction between the two.

All covariates were found to affect spatial distribution over the course of the project. Individual distance from shore was significantly influenced by the interaction between survey year and season ($F_{5,4817} = 74.32$, $P < 0.001$). After accounting for annual variation, bony fishes on a whole did not differ in their distance from shore throughout the Fall, Winter, and Spring seasons but preferred to be closer to shore in the Summer ($F_{3,4852} = 297.74$, $P < 0.001$) with a mean Summer distance from shore of 84.29 km (Table 7, Figure 20).

Accounting for annual and seasonal variation, individual bony fish species differed in their spatial preferences ($F_{5,4855} = 256.4$, $P < 0.001$; Table 8, Figure 21). Billfishes were consistently observed offshore, and cobia preferred nearshore locales (Table 9).

Table 7. Summary of Observed Distance from Shore (km) for Bony Fishes during each Season across all Surveys in the OPA

Season	n	Mean	Median	Minimum	Maximum	Standard Error of the Mean
Fall	330	115.84	124.78	12.82	187.32	2.25
Spring	1,657	121.64	153.36	1.21	188.17	1.49
Summer	2,847	84.29	80.29	1.57	185.44	0.75
Winter	30	121.23	142.09	14.33	179.66	9.71

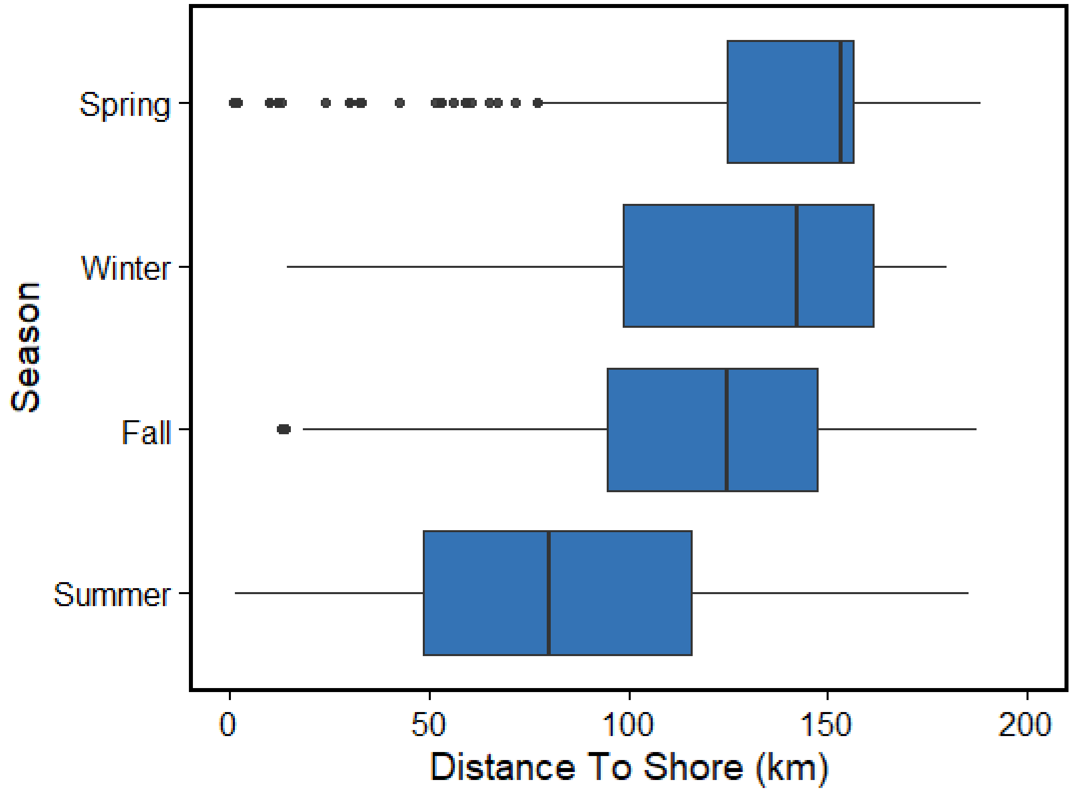

Figure 20. Seasonal differences in distance from shore (km) across seasons for all observed bony fishes during the Fall 2016 through Spring 2019 surveys.

Boxplots represent minimum, maximum, 25th percentile, 75th percentile and median (50th percentile) with points representing outliers.

Table 8. Summary of Distance from Shore (km) by each Taxonomic Group Across all Surveys in the OPA

Taxonomic Group	n	Mean	Median	Minimum	Maximum	Standard Error of the Mean
Cobia	11	47.3835	30.9546	17.5102	120.215	11.5859
Mahi-Mahi	994	95.4597	97.9463	5.2248	182.225	1.42112
Tuna	1,287	108.683	148.813	5.89672	182.771	1.53929
Billfish	42	123.504	128.911	8.48077	185.45	5.76026
Sunfish	1,633	115.446	124.207	6.04058	188.175	0.95487
Unid. Fish	897	60.65	65.9237	1.21805	172.671	1.79388

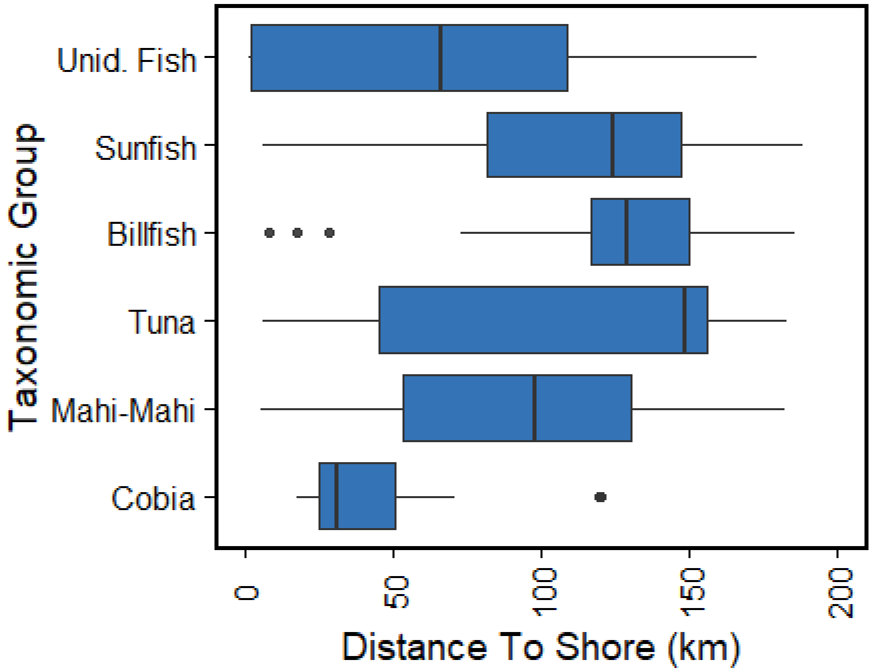

Figure 21. Distance from shore (km) for all taxonomic groups across all seasons and years.

Boxplots represent minimum, maximum, 25th percentile, 75th percentile and median (50th percentile) with points representing outliers.

Summer surveys revealed taxon-specific preference in spatial distribution ($F_{6,2267} = 48.65$, $P < 0.001$; Figure 22). Sunfishes and Mahi-Mahi preferred to be at similar distances from shore and Tuna and Cobia both preferred to be relatively near shore while billfishes were the farthest from shore (Figure 22).

Table 9. Summary of Distance from Shore (km) for each Taxonomic Group during the Summer 2016, 2017, and 2018 Surveys in the OPA

Taxonomic Group	n	Mean	Median	Minimum	Maximum	Standard Error of the Mean
Billfish	41	122.67	128.43	8.48	185.45	37.39525
Cobia	10	40.20	30.95	17.51	120.22	31.78229
Mahi-Mahi	971	95.05	97.90	5.22	182.22	44.43263
Sunfish	791	92.25	85.19	6.04	177.03	31.31426
Tuna	600	56.92	45.55	5.90	150.77	34.18993
Unid. Fish	434	80.92	84.09	1.58	166.27	31.88421

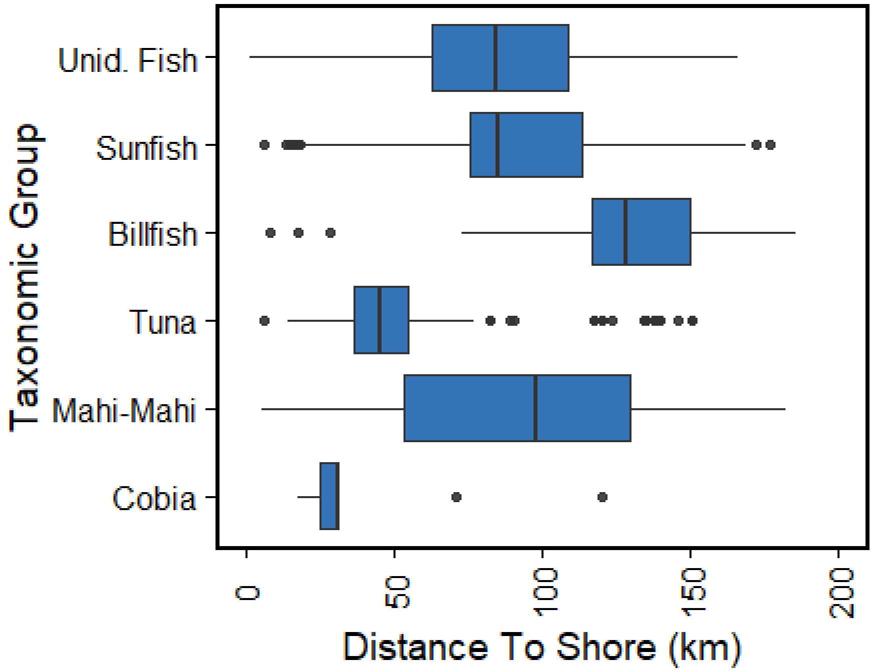

Figure 22. Distance from shore (km) for all taxonomic groups during the Summer 2016, 2017, and 2018 surveys.

Boxplots represent minimum, maximum, 25th percentile, 75th percentile and median (50th percentile) with points representing outliers.

In the Fall, Tuna fishes were observed significantly closer to shore than Sunfishes, Mahi-Mahi, and individuals unclassified to taxonomic group ($F_{3,321} = 6.71$, $P < 0.001$; Table 10, Figure 23). Individuals categorized as unidentified did not differ in distance from shore from Sunfishes and Mahi-Mahi in both the Summer and Fall surveys (Table 9, Table 10).

Table 10. Summary of Distance from Shore (km) for each Taxonomic Group during the Fall 2016, 2017, and 2018 Surveys in the OPA

Taxonomic Group	n	Mean	Median	Minimum	Maximum	Standard Error of the Mean
Mahi-Mahi	14	126.56	161.85	21.24	165.54	54.18278
Sunfish	276	118.03	129.34	13.43	187.32	40.33127
Tuna	23	81.62	100.17	12.82	100.18	32.92339
Unid. Fish	17	117.76	106.13	63.26	168.46	27.8739

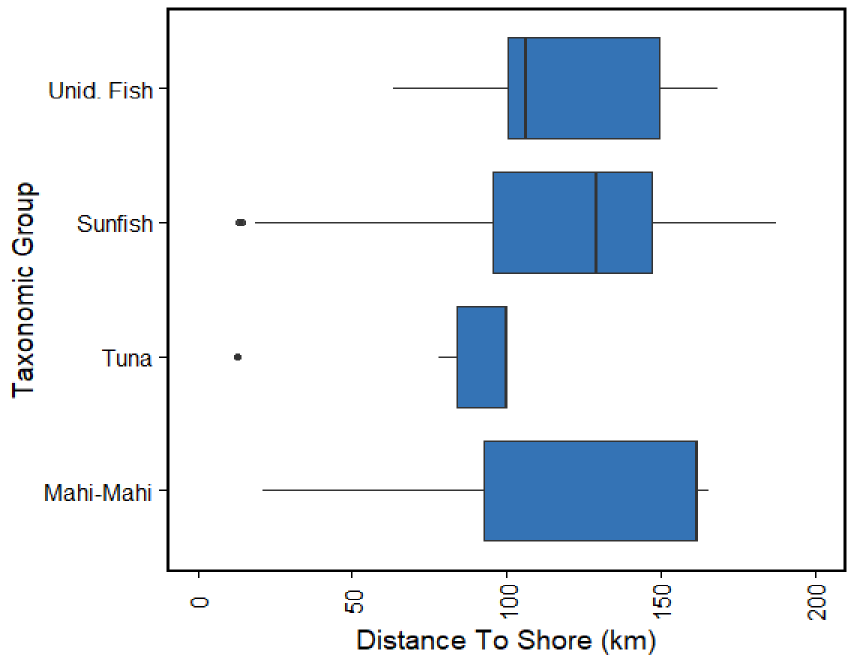

Figure 23. Distance from shore (km) for all taxonomic groups during the Fall 2016, 2017, and 2018 surveys.

Boxplots represent minimum, maximum, 25th percentile, 75th percentile and median (50th percentile) with points representing outliers.

Winter detections were low relative to the other season with Sunfishes being the only taxonomic group with greater than 5 observations across all three winter surveys (Table 11). Twelve of the 22 observations of Sunfishes in the Winter were made far offshore with a median distance from shore of 153.49 km (Table 11).

Table 11. Summary of Distance from Shore (km) for each Taxonomic Group during the Winter 2016–2017, 2017–2018, and 2018–2019 Surveys in the OPA

Taxonomic Group	n	Mean	Median	Minimum	Maximum	Standard Error of the Mean
Mahi-Mahi	2	73.99	73.99	43.08	104.90	43.71
Sunfish	22	143.16	153.49	20.03	179.66	36.14
Tuna	1	108.17	108.17	108.17	108.17	NA
Unid. Fish	5	46.28	18.34	14.32	127.46	48.80

During the Spring 2017, 2018, and 2019 surveys, Tuna fish were observed the farthest from shore with one individual having a maximum distance of 182.77 km from the nearest land mass (Table 12). Considering only taxonomic groups with greater than 10 occurrence records during the Spring surveys, Tuna fishes and Sunfishes observations did not differ in distance from shore; however, both taxonomic groups did differ from individuals that were classified as unknown ($F_{2,1639}$ = 5331.9, $P < 0.001$; Table 12; Figure 24).

Table 12. Summary of Distance from Shore (km) for each Taxonomic Group during the Spring 2017, 2018, and 2019 surveys in the OPA

Taxonomic Group	n	Mean	Median	Minimum	Maximum	Standard Error of the Mean
Billfish	1	157.74	157.74	157.74	157.74	*NA*
Cobia	1	119.21	119.21	119.21	119.21	*NA*
Mahi-Mahi	7	96.16	128.21	29.85	158.03	62.824995
Sunfish	544	146.74	148.13	30.10	188.18	19.348019
Tuna	663	156.47	156.05	71.73	182.77	9.465365
Unid. Fish	441	38.66	1.93	1.22	172.67	61.718729

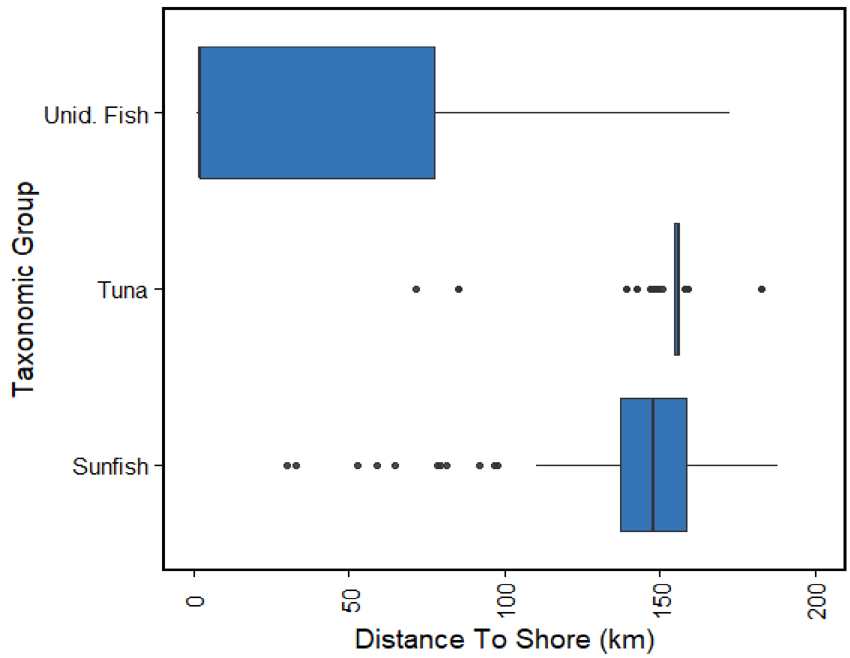

Figure 24. Distance from shore (km) for all taxonomic groups during the Spring 2017, 2018, and 2019 surveys, excluding taxonomic groups with fewer than 10 observations combined.

Boxplots represent minimum, maximum, 25th percentile, 75th percentile and median (50th percentile) with points representing outliers.

Fish Shoals

Fish shoals were observed nearest shore in the Fall and farthest from shore in the Winter; however, there was only one observation of a Winter fish shoal (Table 13). Excluding Winter, mean spatial preferences were significantly different for each season ($F_{7.83,2000.9} = 2009.3$, $P < 0.001$, two-way ANOVA unequal variance; Figure 25). Spatial relation with shore was much more variable in the Spring compared to the Fall and Summer seasons, which is partially driven by much lower sample sizes in the Spring (n=51; Table 13). However, despite randomly sampling 51 of the Fall and Summer observations, notable deviations were not found from estimates of standard error of the mean. This suggests that increased variance is not an artifact of sample size and that season influences the variability of spatial preferences in shoals. Further, 98.9% of observations in the Summer surveys occurred within 10 km of the shore, 79.3 % of observations in the Fall surveys occurred within 10 km of the shore, and in the Spring surveys only 37.2% of observations were within 10 km of the shore.

Table 13. Summary of Seasonal Differences in Distance from Shore (km) for Fish Shoals Observed during all Surveys in the OPA

Season	n	Mean	Median	Minimum	Maximum	Standard Error of the Mean
Fall	173	1.74	1.12	0.08	75.80	0.47958565
Spring	51	36.37	31.44	1.27	152.33	6.00142011
Summer	14,064	15.45	16.00	0.11	145.77	0.04880524
Winter	1	86.65	86.65	86.65	86.65	NA

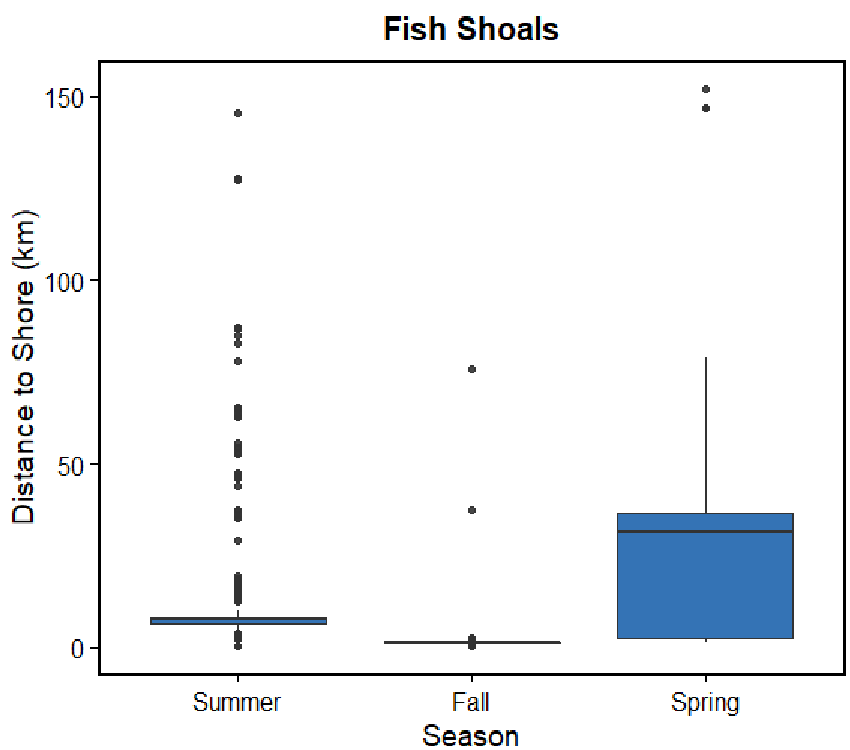

Figure 25. Distance from shore (km) among all the Spring, Summer, and Fall surveys for fish shoals observed in the OPA.

Boxplots represent minimum, maximum, 25th percentile, 75th percentile and median (50th percentile) with points representing outliers.

3.4.2 Ocean Depth

We estimated ocean depth for each individual by assigning them to the closest bathymetric zone. For areas where depth ranged between 10–50 m, 60–90 m, and 100–150 m; we report them as 30 m, 75 m, and 125 m. We used depth range instead of nearest contour because the results were the same and this coarser resolution assignment acknowledges the fact that these organisms are able to move with ease across bathymetric contours. Ocean depth is generally correlated with distance from shore following a "long tail" exponential distribution (Figure 26). Estimated depth increases gradually across the continental shelf (the first 100 km from shore); at the shelf break, depths increase rapidly across the continental slope (Figure 7, Figure 26).

A substantial amount of overlap was observed in the estimated depths and their relative distance from shore (Figure 26). For example, individuals observed greater than 100 km from shore were often occupying locales that had an estimated depth of 75 m. Thus the relationship between taxonomic groups and the estimated depth of the location where they were observed was graphically visualized to gain a deeper understanding of potential trends in OPA use (Figure 27 through Figure 29).

Bony Fishes

Across all surveys, bony fishes were observed in the greatest numbers in shallow water nearshore (Figure 27). In the Bony fishes were observed in the lowest abundance within the 125 m to 400 m estimated depth zones (Figure 29). The highest density of observations occurred offshore where ocean depths were estimated to be 600 m. Data by species by season are in Appendix B.

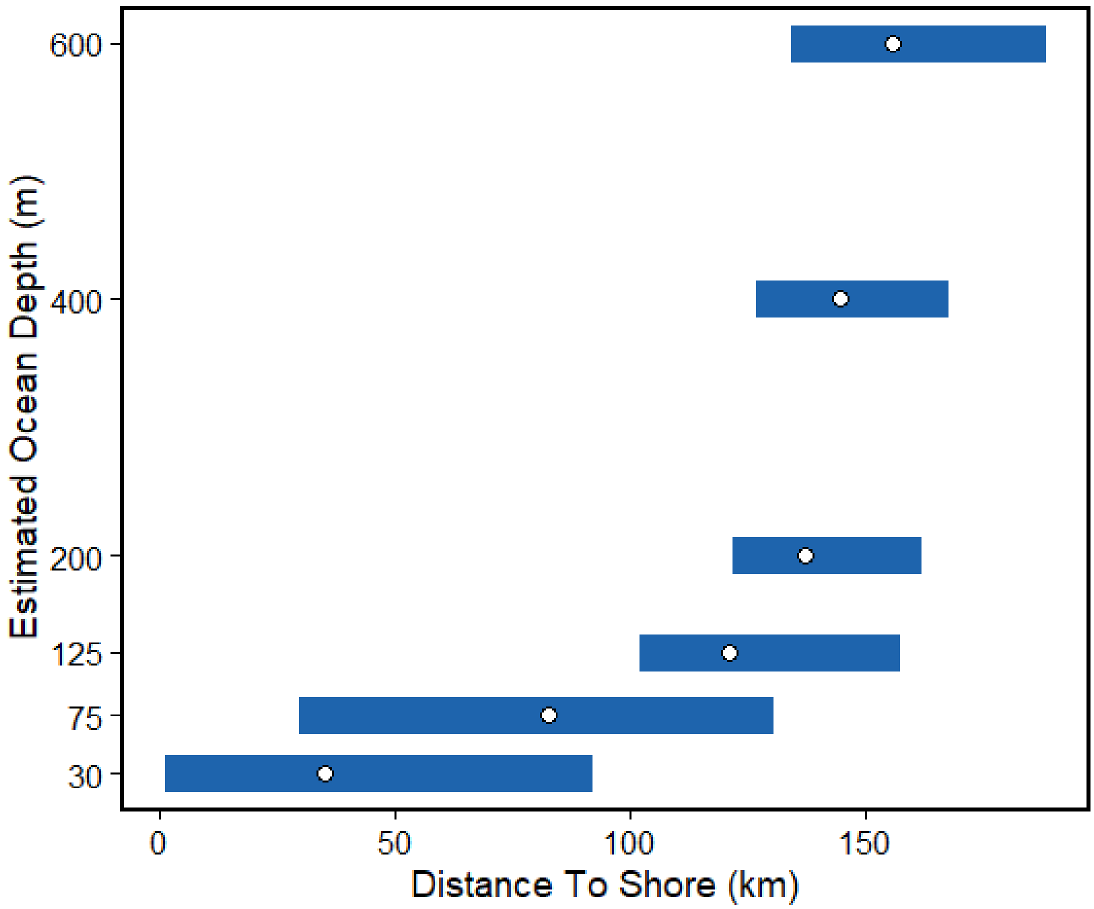

Figure 26. Range of distances from shore (km) observed at each estimated ocean depth (m) for all bony fishes observed in the OPA during the Summer 2016 through Spring 2019 surveys.

White circles represent mean distance from shore (km) for each estimated ocean depth zone.

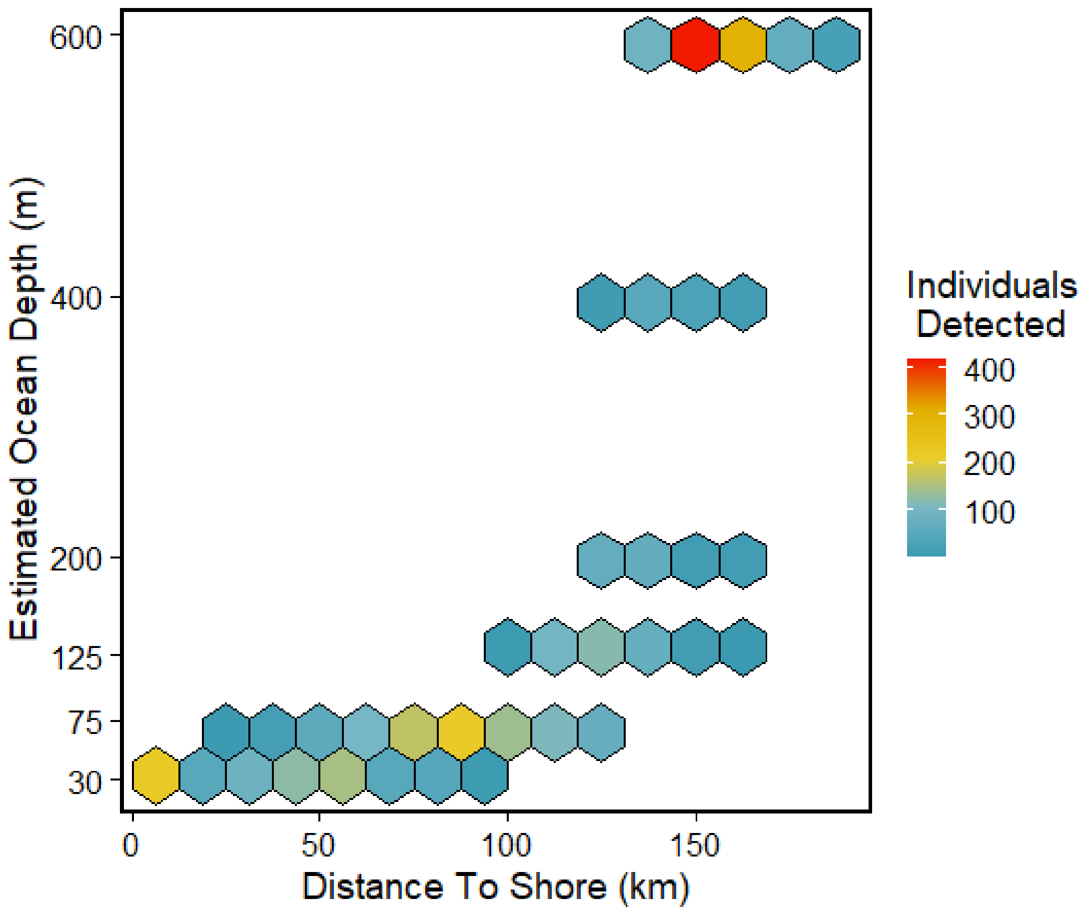

Figure 27. Distance from shore (km) and estimated ocean depth (m) for all bony fishes observed during the Summer 2016 through Spring 2019 surveys.

Color represents relative counts of individuals detected for each distance from shore and ocean depth estimate combination.

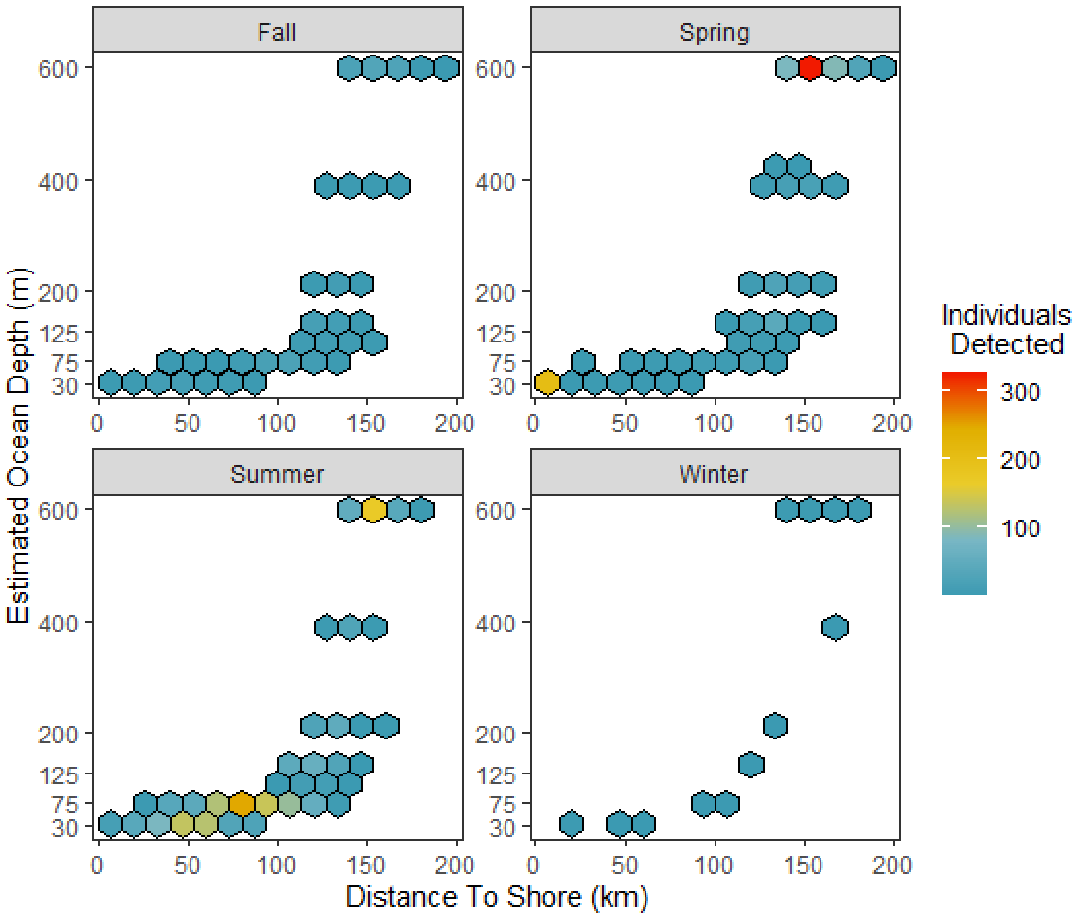

Figure 28. Distance from shore (km) and estimated ocean depth (m) for all bony fishes observed during the Summer 2016 through Summer 2019 surveys.

Each panel represents a different season and color represents relative counts of individuals detected for each distance from shore and ocean depth estimate combination.

Spring surveys, when the greatest number of observations are attributed to Sunfishes and Tuna fishes, preferences are found to be bimodal in that the majority of individuals are observed in either nearshore shallows or offshore deep waters (Figure 28). In the Spring, Tuna fishes and sunfishes concentrated offshore in the deepest waters of the OPA while a relatively large number of fish occurring nearshore were not identifiable (Figure 29). In the Summer, the most abundant species were observed most frequently in shallow waters (Figure 29).

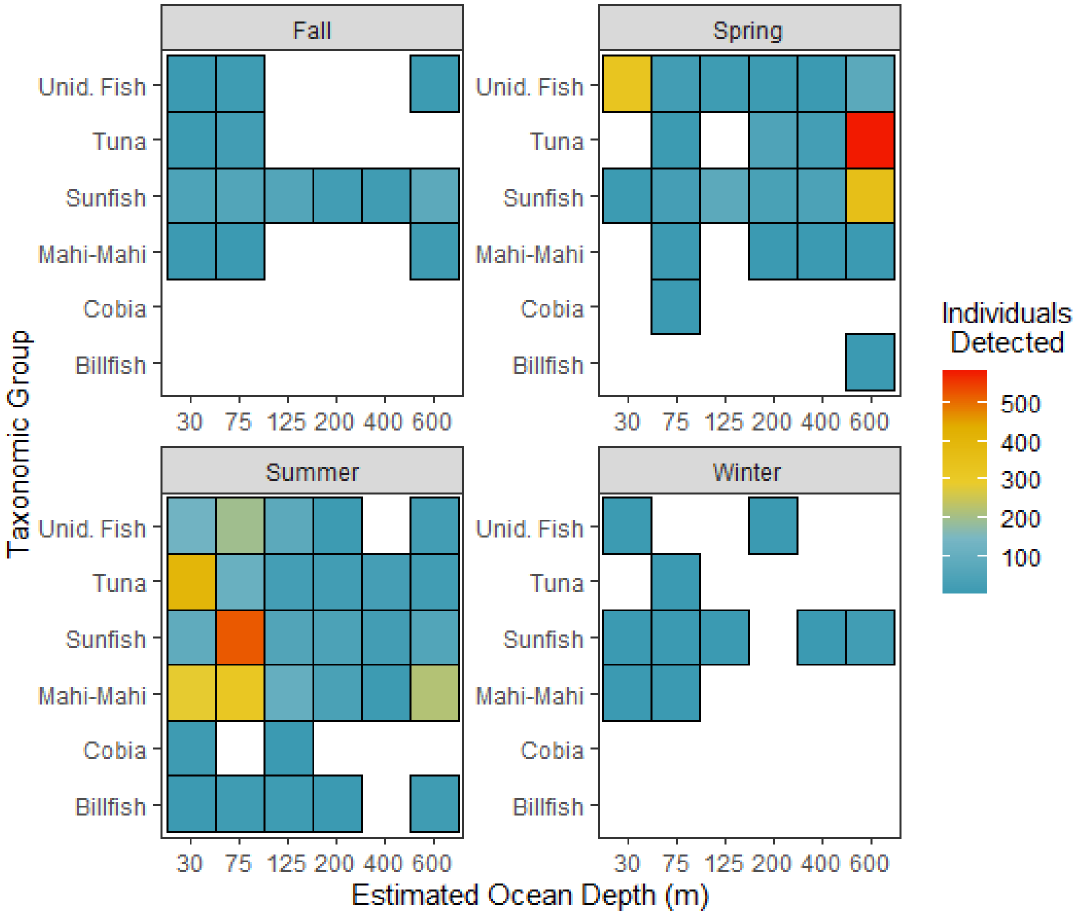

Figure 29. Heat map of abundance for each bony fish taxonomic group observed in each estimated ocean depth (m) group in the OPA during the Summer 2016 through Spring 2019 surveys.

Fish Shoals

The results of this study intuitively suggests that fish shoal distribution was driven more strongly by ocean depth than their position from shore as the variation of observed distances from shore (km) values are much wider than the variation in estimated ocean depth. (Figure 30). Despite variation in distance from shore, the greatest number of observations were seen nearshore in the 30-m estimated depth zone (Figure 32).

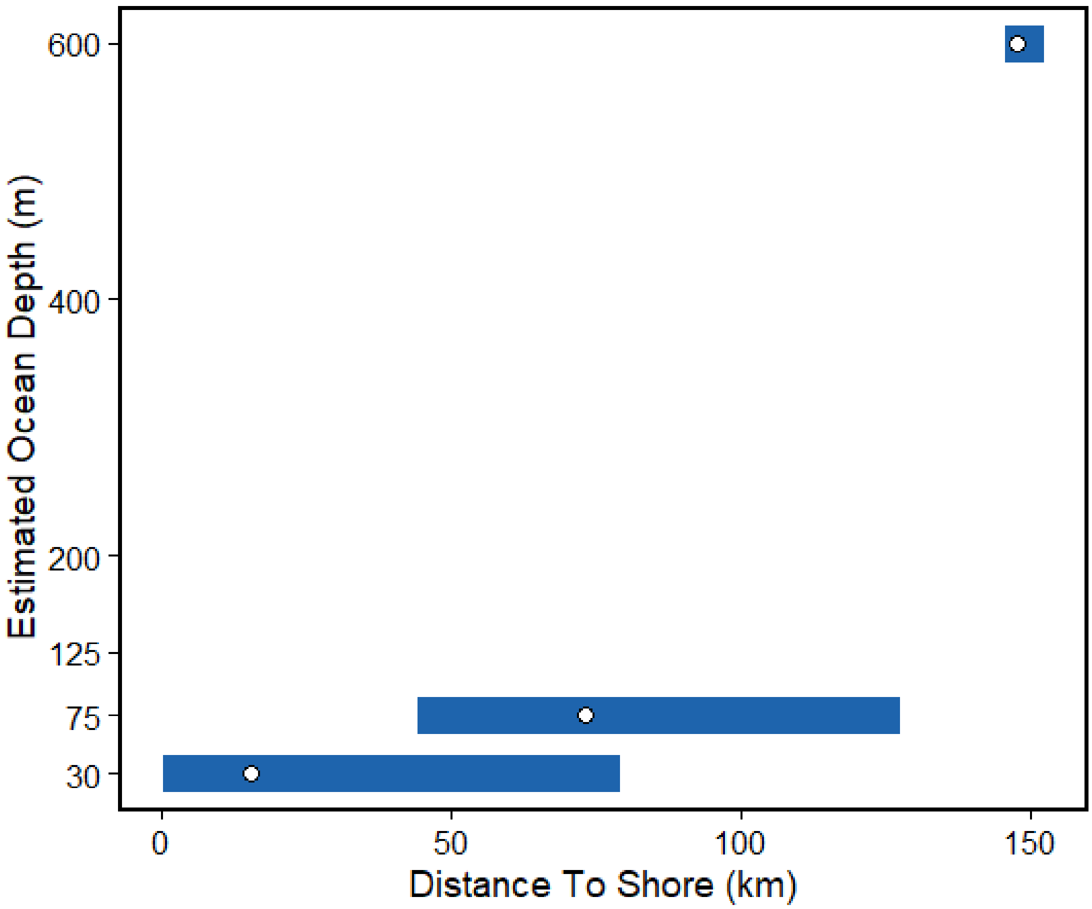

Figure 30. Range of distances from shore (km) observed at each estimated ocean depth (m) for all shoals observed in the OPA during the Summer 2016 through Spring 2019 surveys.

White circles represent mean distance from shore (km) for each estimated categorical ocean depth (m).

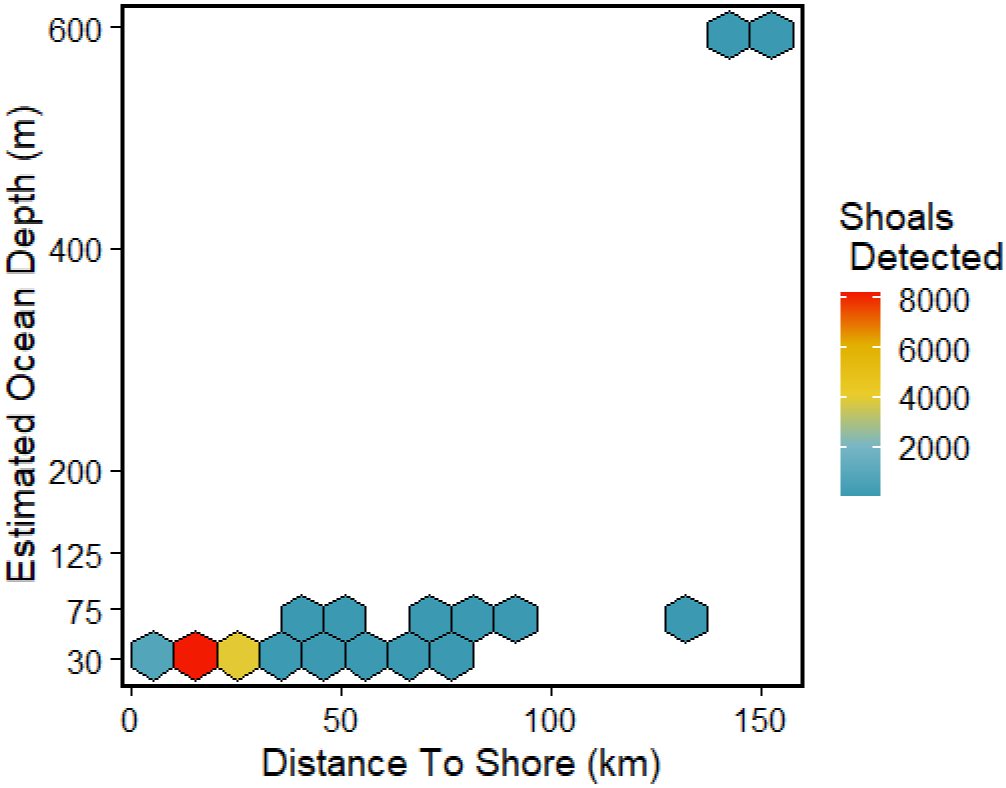

Figure 31. Distance from shore (km) and estimated ocean depth (m) for all fish shoals observed during the Summer 2016 through Spring 2019 surveys.

Color represents relative counts of individuals detected for each distance from shore and ocean depth estimate combination.

In the Spring, five shoals were observed at depths of approximately 600 m with the remaining 46 shoals (90.2%) occurring at 30-m depths. In the Summer and Fall, 99.3% and 99.4%, respectively, of fish shoal observations were estimated to be at 30-m depths. Despite most occurrences taking place within a 30-m depth zone, it is important to note that subtle differences in an individuals position within the water column could result in substantial temperature differences and thus play an important role in the physiological ecology of pelagic shoal fishes. Higher resolution mapping of the OPA with depths georeferenced to latitudinal and logitudinal data will be critical to future analyses.

3.5 Offshore Planning Area Post Stratification and Relative Abundance

The analyses of depth and distance from shore revealed patterns of spatial distribution. Specifically, no large bony fish species was detected evenly across space, nor were fish shoals. To account for spatial heterogeneity, we stratified the OPA into six discrete zones (Figure 32) to generate more informative estimates of density and abundance. Zones were defined by conditional combination of depth and distance from shore (i.e., If x depth and y distance from shore, then Zone Z (Figure 33, Table 14)). Zone 1A coverage averaged 549.42 km^2 and 7.59% total area (Table 14).

To calculate density and abundance for each zone, strip transects within each zone were considered with the assumption that detection probability was 100% (Figure 33). Estimated density for each transect was determined by dividing the total count of individual bony fishes or shoals by the transect area. Each transect surface density was then multiplied by the total area of the zone to generate multiple estimates of abundance, and the mean surface abundance estimates (Figure 34 through Figure 41) and the variance and standard error of the mean were reported (Table 15).

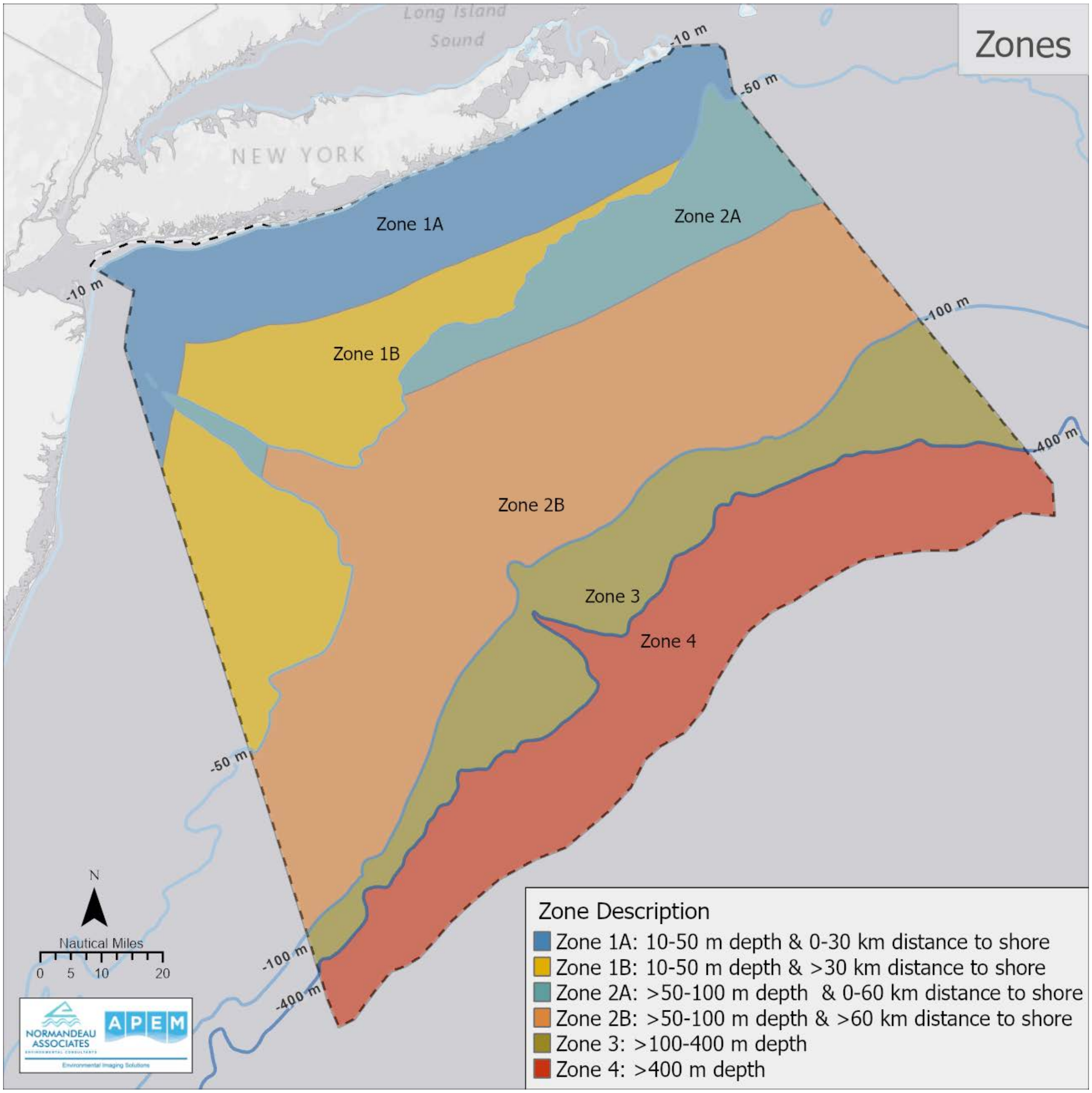

Figure 32. Map of six post stratification zones delineated by conditional combinations of depth and/or distance from shore (i.e., if x depth and y distance from shore then Zone Z; 5 nautical miles = 9.26 km) and can be read as 'if, and, then' statements.

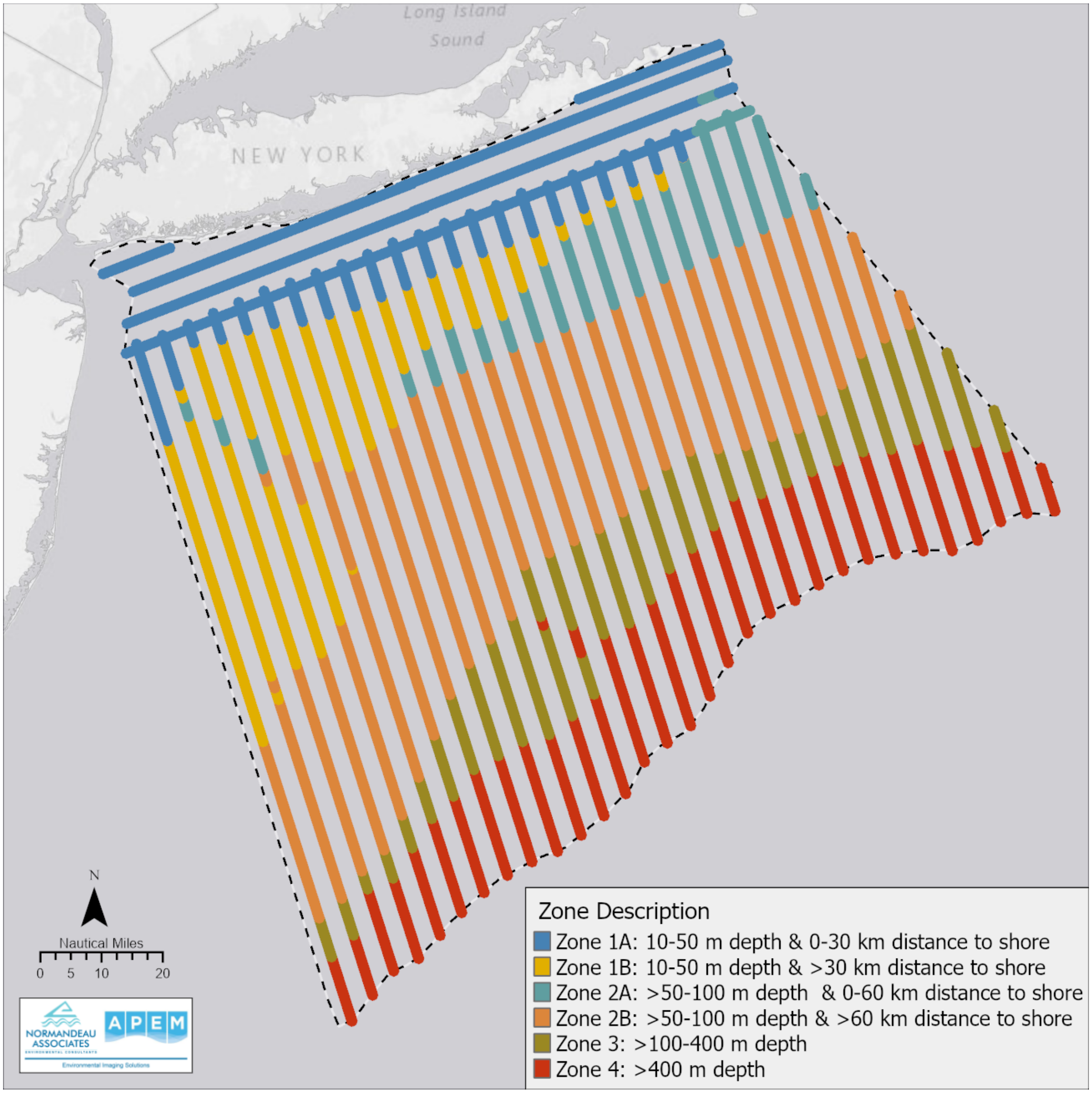

Figure 33. Transects flown by zone. Transect widths enlarged for visual purposes (5 nautical miles = 9.26 km).

Table 14. Mean Area Surveyed and Mean Percent Coverage in Each Zone Across the Summer 2016 through Spring 2019 Surveys

Zone	Zone Area (km²)	Mean Area Imaged (km²)	Mean Percent Coverage
Zone 1A	5,991	472	7.88
Zone 1B	6,308	469	7.43
Zone 2A	3,290	252	7.65
Zone 2B	14,197	1,063	7.48
Zone 3	5,734	434	7.57
Zone 4	8,063	606	7.52
Mean	**7,264**	**549**	**7.59**

3.5.1 Bony Fish

Analysis of bony fish abundance by zone (Figure 32) revealed the greatest estimated surface abundance was seen in Zone 2B during the Summer (Figure 34, Table 15) and Zone 4 for the Fall (Figure 35, Table 15), Winter (Figure 36, Table 15), and Spring surveys (Figure 37, Table 15). The lowest estimated surface abundance was seen in Zone 1B during the Summer (Figure 34, Table 15), Zones 1A, 1B, and 2A during the Fall (Figure 35, Table 15), and Zone 2A in both the Winter (Figure 36, Table 15) and Spring (Figure 37, Table 15) surveys.

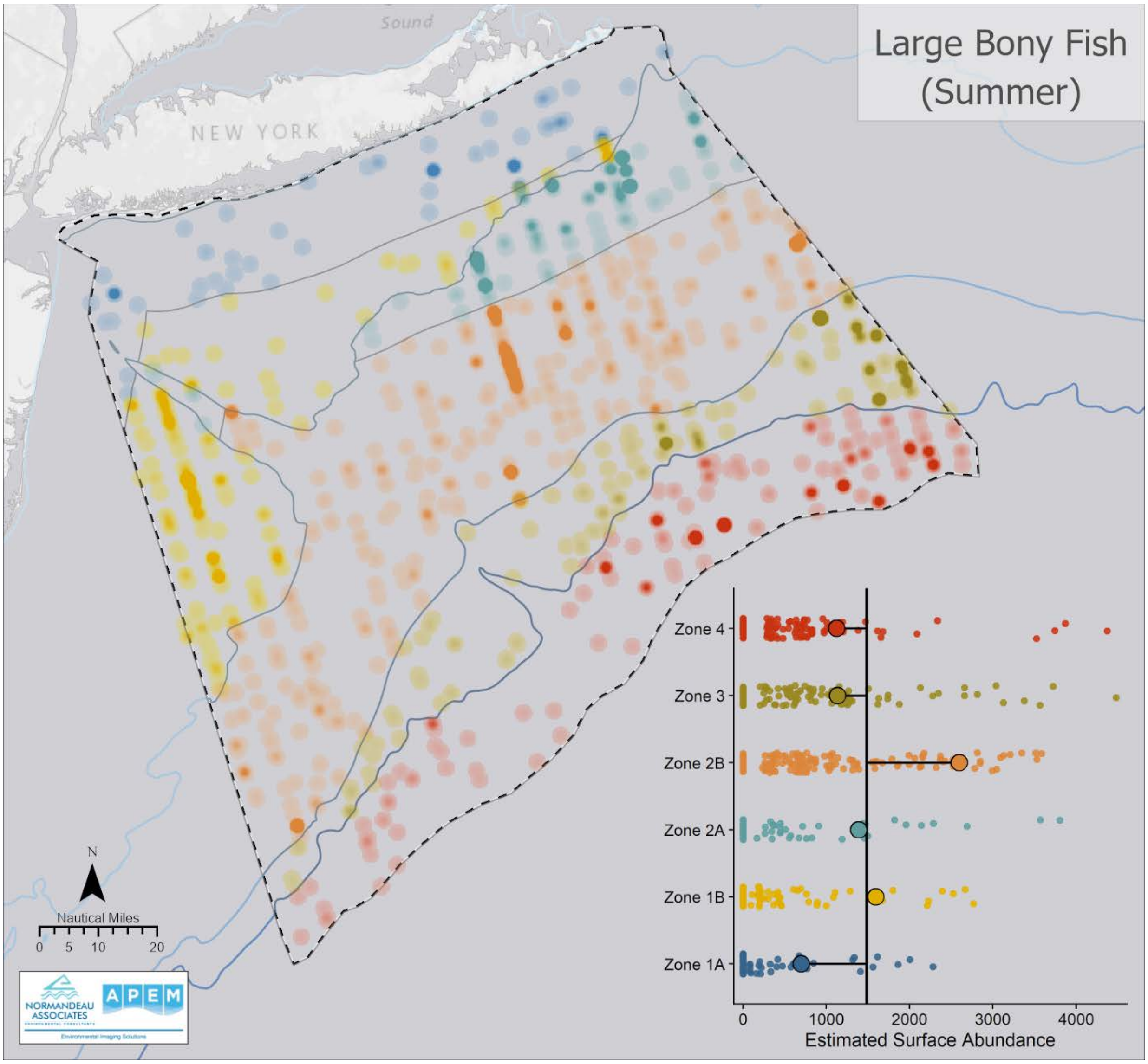

Figure 34. Heat map of all bony fishes observed in the OPA during the Summer 2016, 2017, and 2018 surveys (surveys 1, 5, & 9; 5 nautical miles = 9.26 km).

Inset "lollipop" chart represents estimated abundance for each zone, with points representing single surface abundance estimates based on each transect and larger outlined circles representing the mean estimated surface abundance for each zone. Vertical black line represents the mean estimated surface abundance for the entire OPA and thus the figure allows us to visualize whether a zone was relatively higher or lower than the area average.

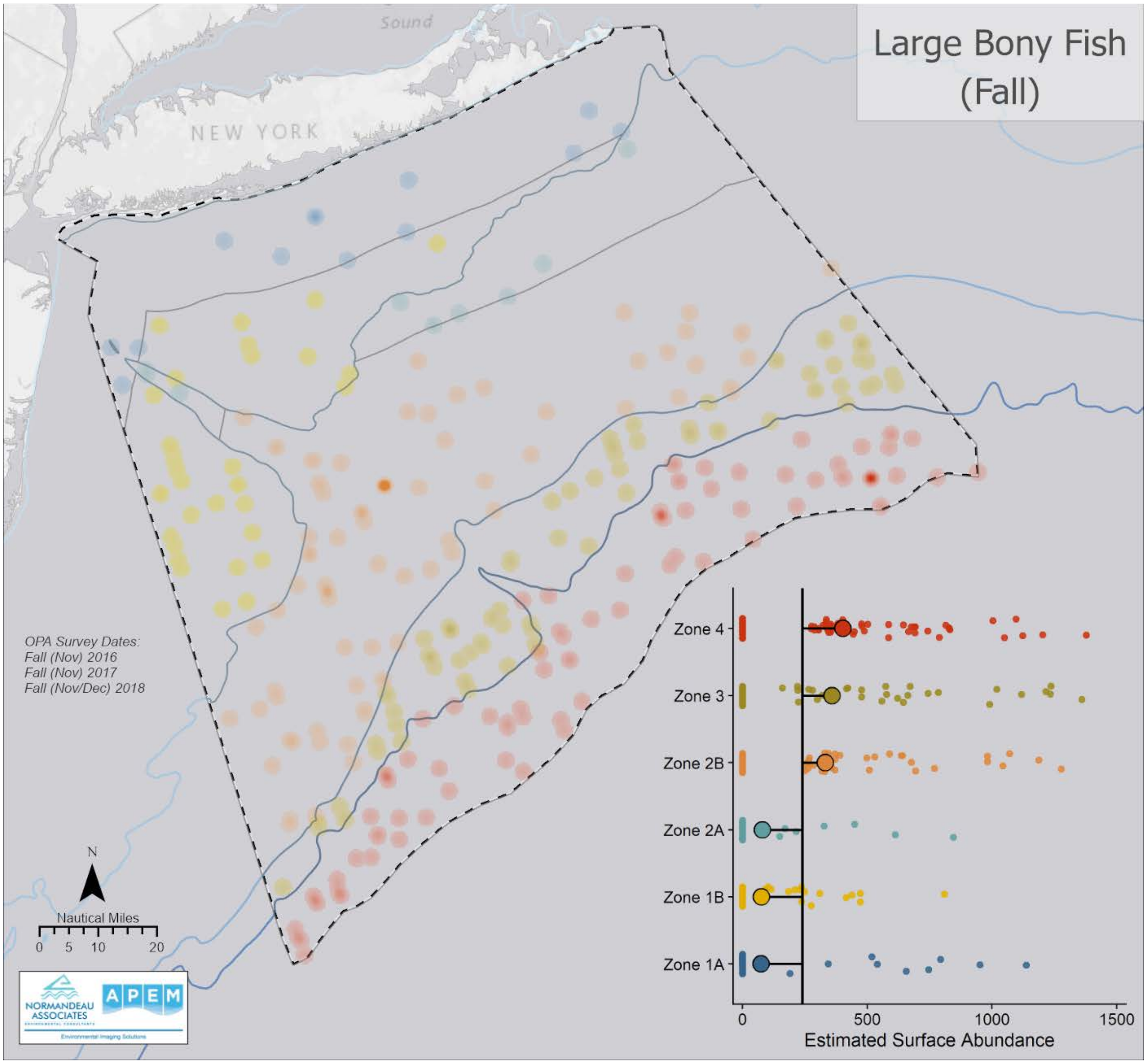

Figure 35. Heat map of all bony fishes observed in the OPA during the Fall 2016, 2017, and 2018 surveys (surveys 2, 6, & 10) color coded by zone (5 nautical miles = 9.26 km).

Inset “lollipop” chart represents estimated abundance for each zone, with points representing single estimates based on each transect and larger outlined circles representing the mean estimated surface abundance for each zone. Vertical black line represents the mean estimated surface abundance for the entire OPA and thus the figure allows us to visualize whether a zone was relatively higher or lower than the area average.

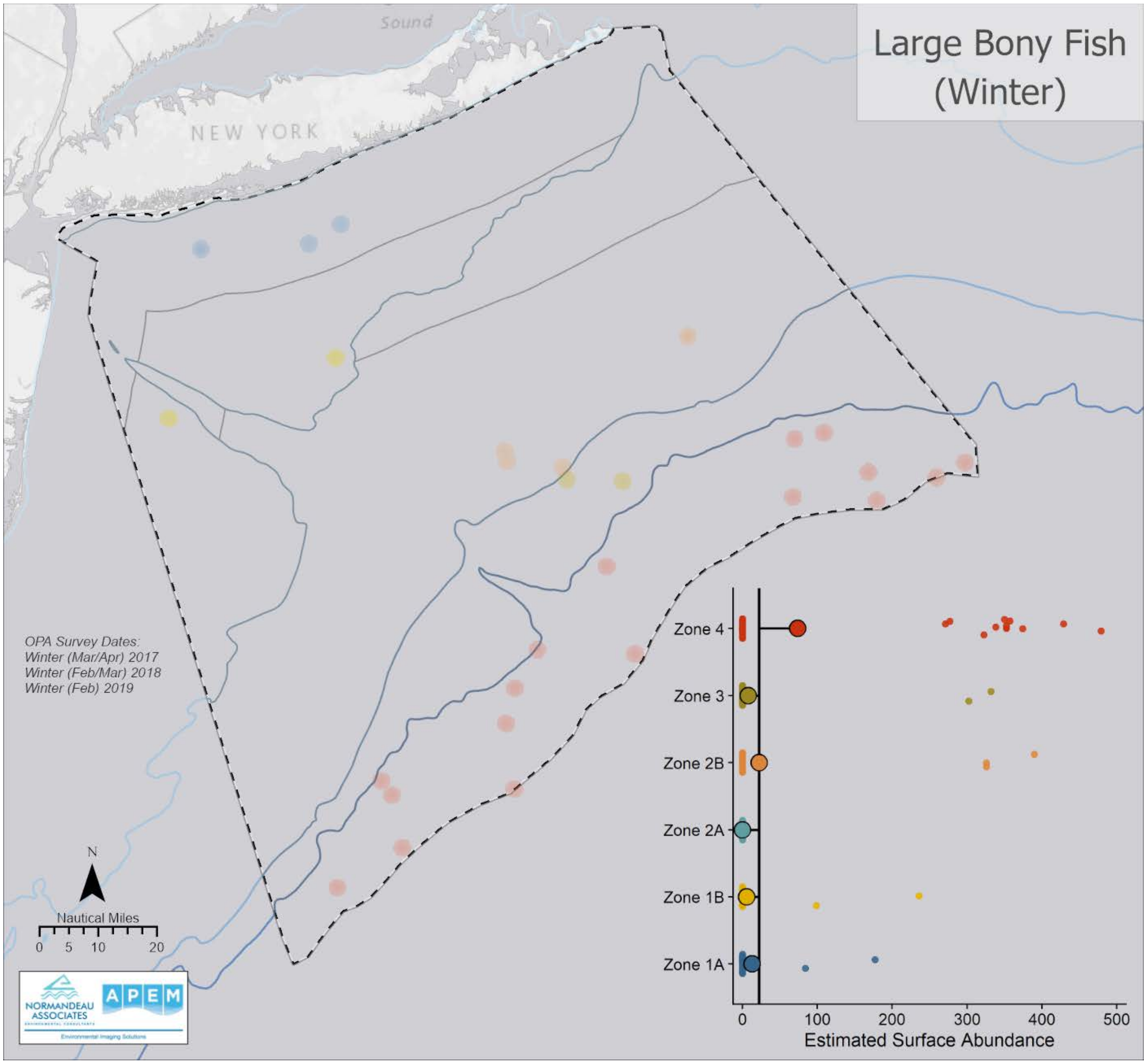

Figure 36. Heat map of all bony fishes observed in the OPA during the Winter 2016–2017, 2017–2018, and 2018–2019 surveys (surveys 3, 7, & 11; 5 nautical miles = 9.26 km).

Inset "lollipop" chart represents estimated abundance for each zone, with points representing single estimates based on each transect and larger outlined circles representing the mean estimated surface abundance for each zone. Vertical black line represents the mean estimated surface abundance for the entire OPA and thus the figure allows us to visualize whether a zone was relatively higher or lower than the area average.

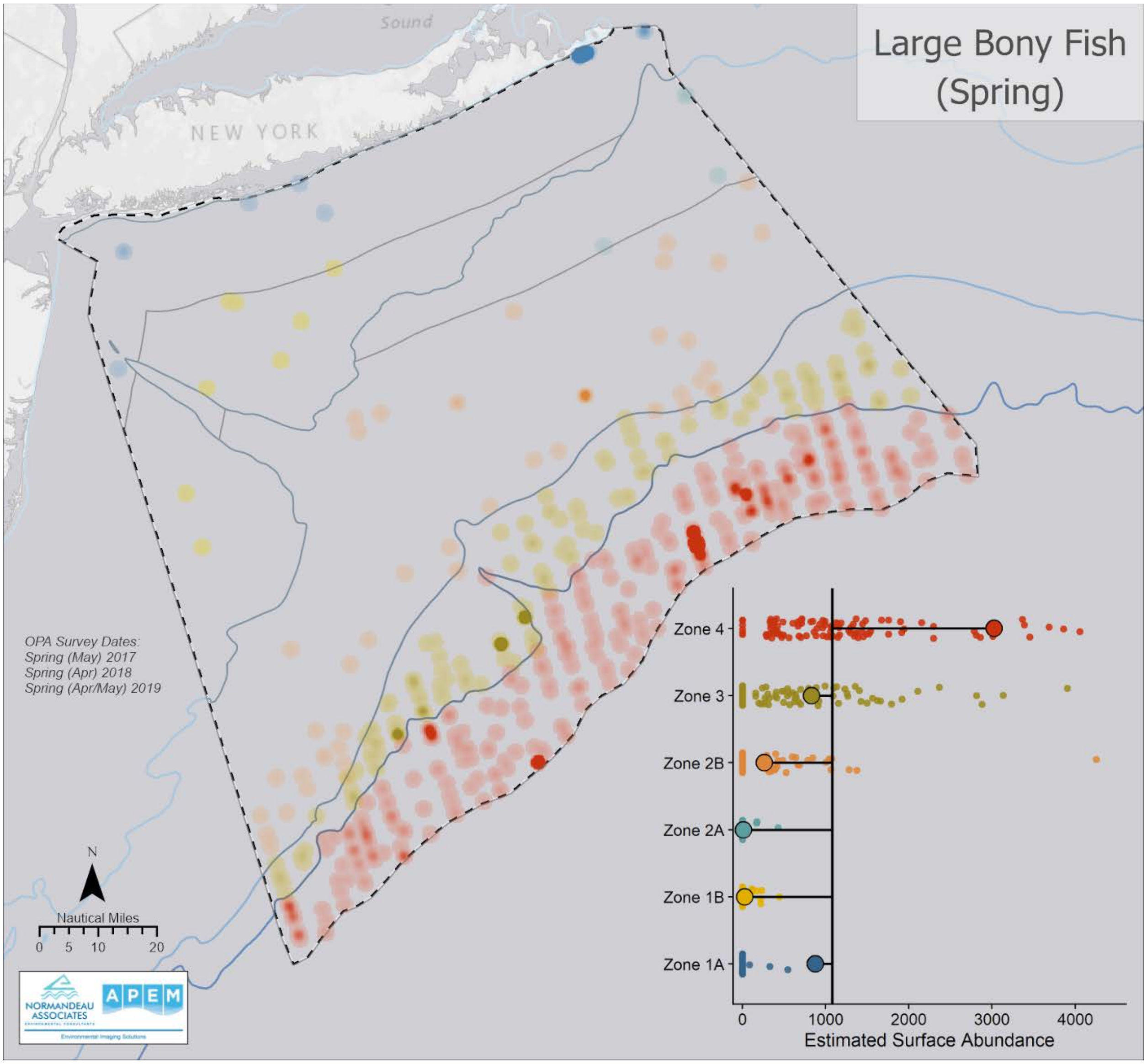

Figure 37. Heat map of all bony fishes observed in the OPA during the Spring 2017, 2018, and 2019 surveys (surveys 4, 8, & 12; 5 nautical miles = 9.26 km)

Inset "lollipop" chart represents estimated abundance for each zone, with points representing single estimates based on each transect and larger outlined circles representing the mean estimated surface abundance for each zone. Vertical black line represents the mean estimated surface abundance for the entire OPA and thus the figure allows us to visualize whether a zone was relatively higher or lower than the area average.

Table 15. Estimated Surface Abundance for Large Bony Fish for Each Survey and Zone

Survey	Season	Zone	No. Strip Transects	Mean Strip Transect Area (km²)	No. Bony Fish	Mean Surface Density per km²	Mean Surface Abundance per Zone	Maximum	Standard Deviation	Standard Error of the Mean
1	Summer	Zone 1A	56	8.8	19	0.0	204.1	2,280.8	504.32	67.39
	Summer	Zone 1B	44	14.3	34	0.1	603.5	17,410.9	2,635.82	397.36
	Summer	Zone 2A	39	6.6	176	0.5	1,515.1	50,943.8	8,149.91	1,305.03
	Summer	Zone 2B	77	21.4	154	0.1	1,493.9	21,408.5	2,671.85	304.48
	Summer	Zone 3	64	8.1	80	0.2	915.2	9,043.3	1,426.79	178.34
	Summer	Zone 4	65	10.9	102	0.1	1,205.4	14,315.0	2,684.38	332.95
2	Fall	Zone 1A	30	21.7	6	0.0	107.8	1,136.9	288.79	52.72
	Fall	Zone 1B	22	24.5	6	0.0	45.1	471.8	123.19	26.26
	Fall	Zone 2A	22	13.3	6	0.0	90.3	845.0	208.47	44.44
	Fall	Zone 2B	30	45.0	40	0.0	432.1	2,099.0	466.49	85.16
	Fall	Zone 3	30	16.2	62	0.1	779.4	2,804.0	726.87	132.7
	Fall	Zone 4	33	22.5	51	0.1	599.7	2,343.4	654.88	114
3	Winter	Zone 1A	30	21.8	3	0.0	8.7	177.2	35.34	6.45
	Winter	Zone 1B	22	24.6	1	0.0	10.7	235.9	50.29	10.72
	Winter	Zone 2A	22	13.6	0	0.0	0.0	0.0	0	0
	Winter	Zone 2B	28	44.3	3	0.0	38.1	676.1	145.1	27.42
	Winter	Zone 3	30	16.9	2	0.0	21.2	332.1	80.59	14.71
	Winter	Zone 4	31	23.0	6	0.0	66.4	429.0	139.95	25.13
4	Spring	Zone 1A	29	18.7	320	0.4	2,321.9	66,464.4	12,336.89	2,290.90
	Spring	Zone 1B	22	23.1	6	0.0	56.4	444.0	113.17	24.12
	Spring	Zone 2A	21	11.7	1	0.0	8.2	172.2	37.56	8.19
	Spring	Zone 2B	32	37.2	33	0.0	382.8	1,374.5	398.64	70.47
	Spring	Zone 3	34	13.8	61	0.2	844.0	3,132.7	810.82	139.05
	Spring	Zone 4	49	19.3	221	0.2	1,857.0	8,796.8	2,052.30	293.18
5	Summer	Zone 1A	33	27.2	85	0.3	1,883.1	34,277.8	6,231.68	1,084.79
	Summer	Zone 1B	35	37.1	422	0.6	3,654.7	42,776.1	7,896.68	1,334.78
	Summer	Zone 2A	33	15.1	310	0.6	1,991.1	14,675.7	3,243.40	564.6
	Summer	Zone 2B	63	43.8	705	0.3	3,730.5	36,697.4	6,646.19	837.34
	Summer	Zone 3	39	16.3	100	0.2	1,012.5	9,894.0	1,758.12	281.52
	Summer	Zone 4	48	23.1	165	0.1	1,152.1	13,445.5	2,366.23	341.53
6	Fall	Zone 1A	25	17.6	2	0.0	56.1	746.8	194.73	38.94
	Fall	Zone 1B	24	31.2	24	0.0	142.7	809.0	211.34	43.14
	Fall	Zone 2A	18	13.5	4	0.0	146.1	1,846.3	449.13	105.86
	Fall	Zone 2B	30	41.7	27	0.0	284.6	2,007.0	394.99	72.11
	Fall	Zone 3	30	16.4	19	0.0	250.3	1,561.4	416.21	75.99
	Fall	Zone 4	34	21.7	42	0.1	451.1	2,580.3	504.59	86.53

Survey	Season	Zone	No. Strip Transects	Mean Strip Transect Area (km²)	No. Bony Fish	Mean Surface Density per km²	Mean Surface Abundance per Zone	Maximum	Standard Deviation	Standard Error of the Mean
7	Winter	Zone 1A	24	17.5	0	0.0	0.0	0.0	0	0
	Winter	Zone 1B	18	25.2	1	0.0	5.5	98.8	23.28	5.48
	Winter	Zone 2A	18	13.4	0	0.0	0.0	0.0	0	0
	Winter	Zone 2B	24	42.8	0	0.0	0.0	0.0	0	0
	Winter	Zone 3	26	16.3	0	0.0	0.0	0.0	0	0
	Winter	Zone 4	26	22.5	8	0.0	114.6	576.0	199.35	39.09
8	Spring	Zone 1A	24	17.4	0	0.0	0.0	0.0	0	0
	Spring	Zone 1B	18	25.2	1	0.0	12.0	215.6	50.81	11.97
	Spring	Zone 2A	18	13.4	1	0.0	9.7	175.0	41.24	9.72
	Spring	Zone 2B	24	42.8	1	0.0	13.4	321.3	65.57	13.38
	Spring	Zone 3	26	16.1	7	0.0	81.2	645.2	187.65	36.8
	Spring	Zone 4	32	22.4	643	0.8	6,370.8	148,087.6	25,973.08	4,591.43
9	Summer	Zone 1A	25	19.6	40	0.0	251.8	1,860.4	528.87	105.77
	Summer	Zone 1B	19	27.4	15	0.0	87.8	691.4	178.1	40.86
	Summer	Zone 2A	18	13.4	2	0.0	18.4	330.6	77.93	18.36
	Summer	Zone 2B	30	42.7	155	0.2	3,040.5	79,265.1	14,403.91	2,629.78
	Summer	Zone 3	36	17.8	202	0.3	1,656.2	18,349.7	3412.44	568.74
	Summer	Zone 4	31	22.3	69	0.1	908.7	11,976.9	2,247.33	403.63
10	Fall	Zone 1A	24	17.7	7	0.0	55.3	793.5	175.811	35.88
	Fall	Zone 1B	18	25.4	3	0.0	24.0	248.3	70.79	16.68
	Fall	Zone 2A	18	13.8	0	0.0	0.0	0.0	0	0
	Fall	Zone 2B	24	43.4	25	0.0	264.6	3,420.8	749.68	153.02
	Fall	Zone 3	26	16.5	0	0.0	0.0	0.0	0	0
	Fall	Zone 4	26	22.8	6	0.0	87.5	788.6	197.9	38.81
11	Winter	Zone 1A	24	17.4	1	0.0	31.1	746.8	152.43	31.11
	Winter	Zone 1B	18	25.2	0	0.0	0.0	0.0	0	0
	Winter	Zone 2A	18	13.4	0	0.0	0.0	0.0	0	0
	Winter	Zone 2B	25	42.8	2	0.0	26.1	325.9	90.24	18.04
	Winter	Zone 3	26	16.3	0	0.0	0.0	0.0	0	0
	Winter	Zone 4	26	22.5	3	0.0	42.6	768.0	162.13	31.79
12	Spring	Zone 1A	24	17.5	1	0.0	3.6	87.5	17.85	3.64
	Spring	Zone 1B	18	25.1	1	0.0	9.7	174.0	41.01	9.66
	Spring	Zone 2A	18	13.4	3	0.0	23.8	428.8	101.06	23.82
	Spring	Zone 2B	27	43.3	26	0.0	338.5	4,251.9	845.05	162.63
	Spring	Zone 3	37	18.5	160	0.2	1,349.4	6,075.2	1,639.99	269.61
	Spring	Zone 4	37	23.1	171	0.2	1,676.7	15,097.4	2,717.69	446.78

3.5.2 Fish Shoals

Analysis of fish shoal abundance by zone (Figure 32) revealed the greatest estimated surface abundance was seen in Zone 1A during the Summer (Figure 38, Table 16), Fall (Figure 39, Table 16), and Spring (Figure 41, Table 16) surveys and in Zone 2B during the Winter (Figure 40, Table 16). The lowest estimated surface abundance occurred in all other zones during the Summer (Figure 38, Table 16), Fall (Figure 39, Table 16), and Winter (Figure 40, Table 16) and in Zones 2A, 2B, and 3 in the Spring (Figure 41, Table 16).

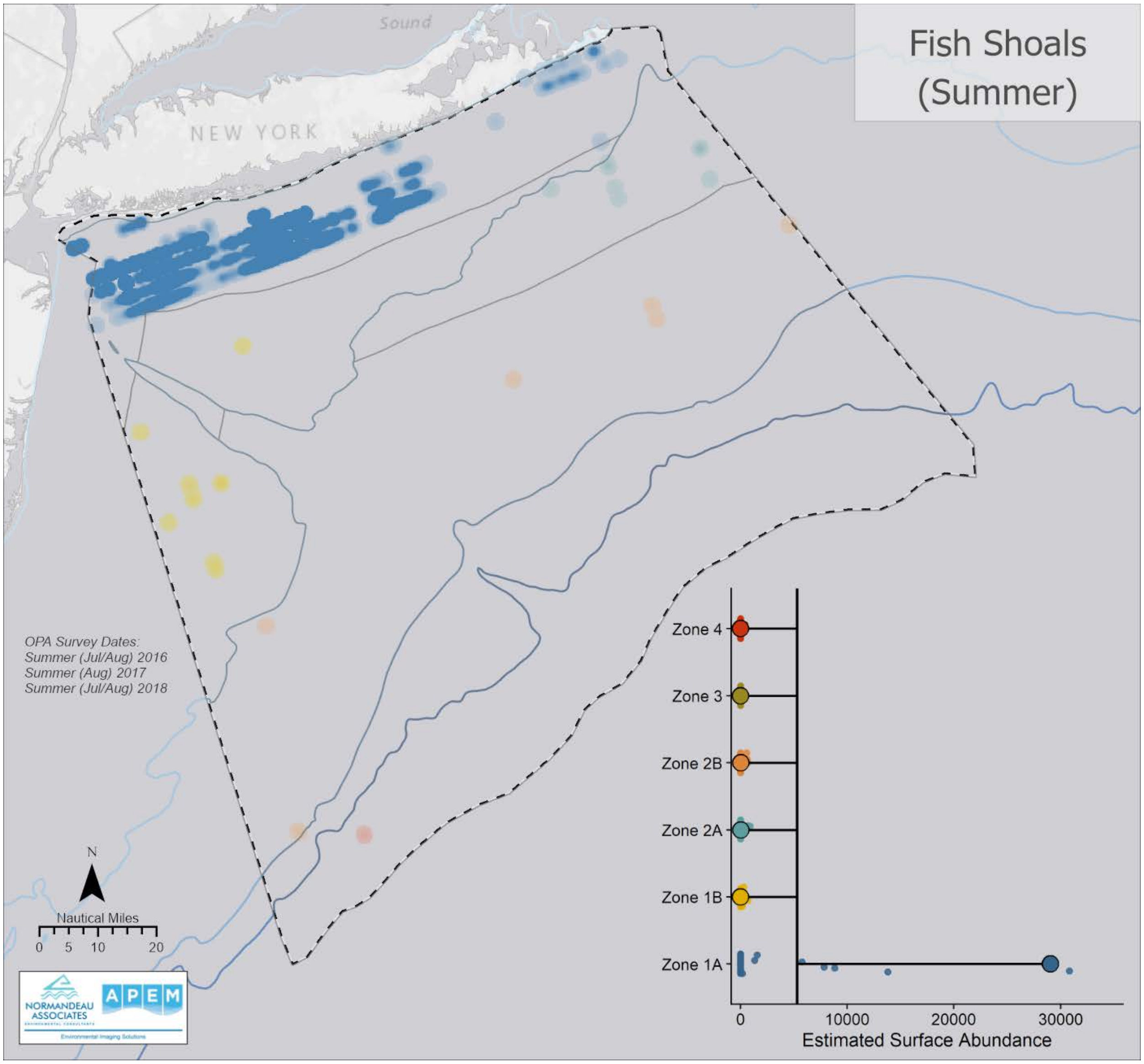

Figure 38. Heat map of all fish shoals observed in the OPA during the Summer 2016, 2017, and 2018 surveys (surveys 1, 5, & 9; 5 nautical miles = 9.26 km).

Inset “lollipop” chart represents estimated abundance for each zone, with points representing single estimates based on each transect and larger outlined circles representing the mean estimated surface abundance for each zone. Vertical black line represents the mean estimated surface abundance for the entire OPA and thus the figure allows us to visualize whether a zone was relatively higher or lower than the area average.

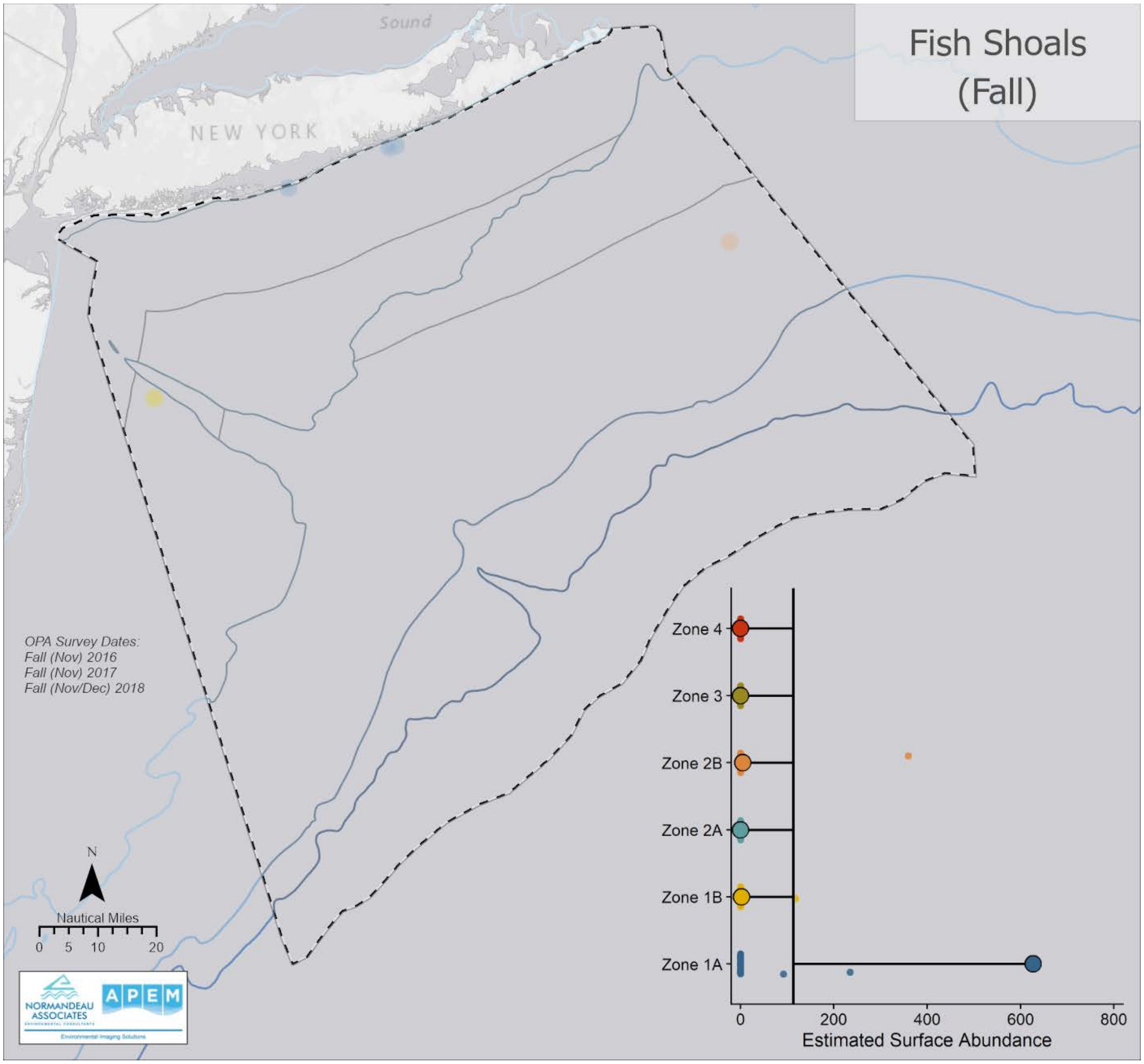

Figure 39. Heat map of all fish shoals observed in the OPA during the Fall 2016, 2017, and 2018 surveys (surveys 2, 6, & 10; 5 nautical miles = 9.26 km).

Inset "lollipop" chart represents estimated abundance for each zone, with points representing single estimates based on each transect and larger outlined circles representing the mean estimated surface abundance for each zone. Vertical black line represents the mean estimated surface abundance for the entire OPA and thus the figure allows us to visualize whether a zone was relatively higher or lower than the area average.

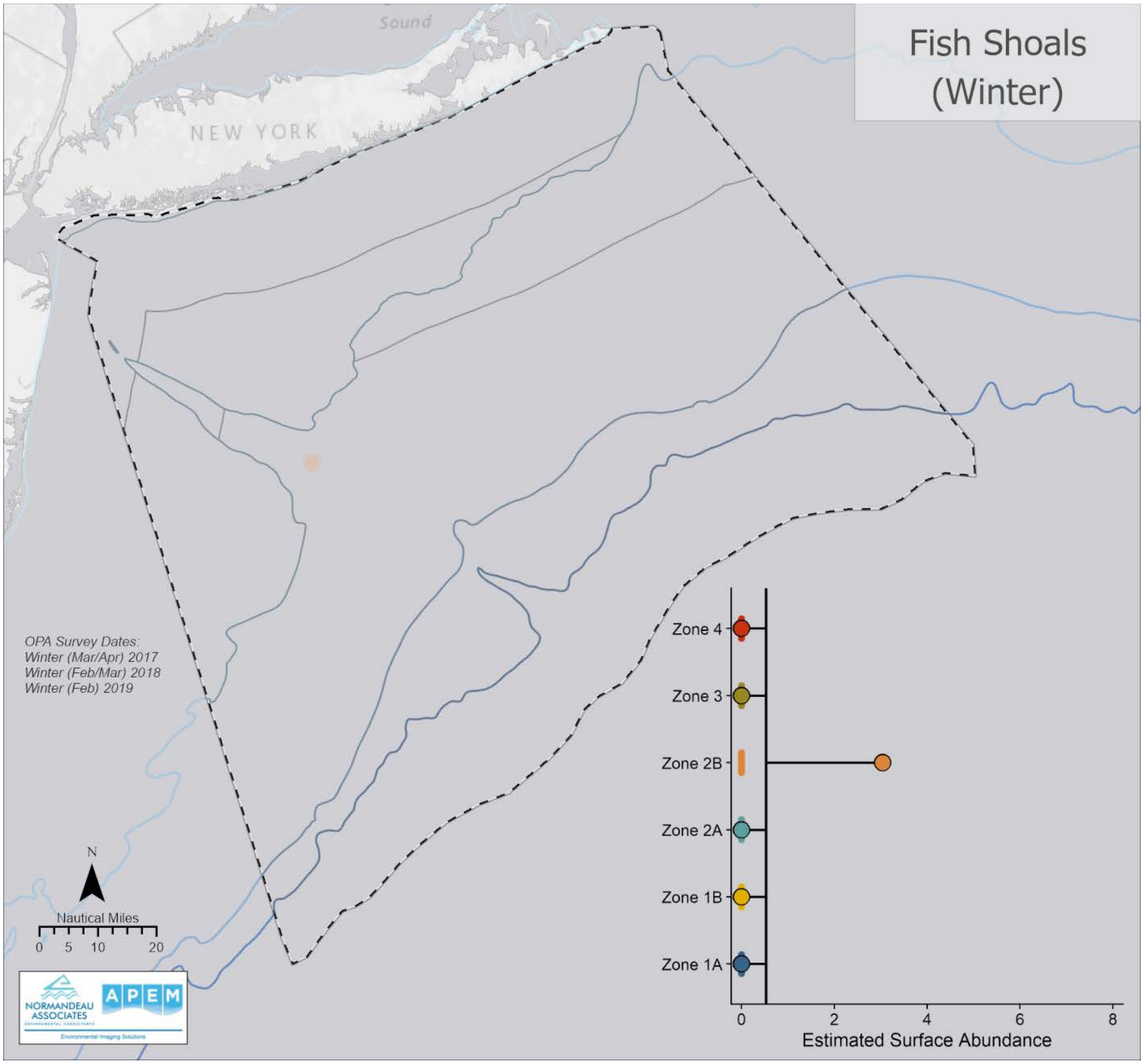

Figure 40. Heat map of all fish shoal observed in the OPA during the Winter 2016–2017, 2017–2018, and 2018–2019 surveys (surveys 3, 7, & 11; 5 nautical miles = 9.26 km).

Inset "lollipop" chart represents estimated abundance for each zone, with points representing single estimates based on each transect and larger outlined circles representing the mean estimated surface abundance for each zone. Vertical black line represents the mean estimated surface abundance for the entire OPA and thus the figure allows us to visualize whether a zone was relatively higher or lower than the area average.

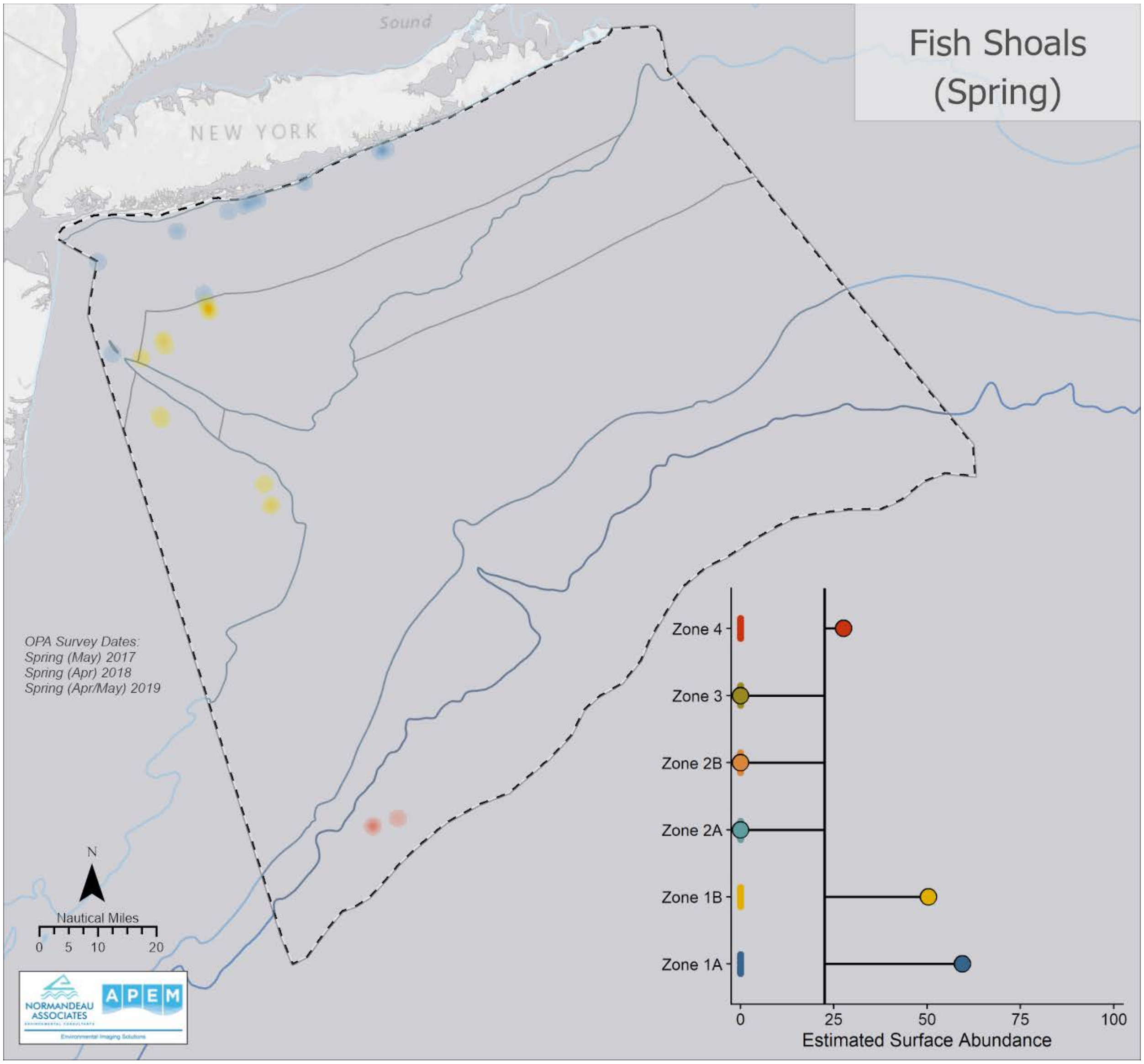

Figure 41. Heat map of all fish shoal observed in the OPA during the Spring 2017, 2018, and 2019 surveys (surveys 4, 8, & 12; 5 nautical miles = 9.26 km)

Inset "lollipop" chart represents estimated abundance for each zone, with points representing single estimates based on each transect and larger outlined circles representing the mean estimated surface abundance for each zone. Vertical black line represents the mean estimated surface abundance for the entire OPA and thus the figure allows us to visualize whether a zone was relatively higher or lower than the area average.

Table 16. Estimated Surface Abundance for Fish Shoals for Each Survey and Zone

Survey	Season	Zone	No. Strip Transects	Mean Strip Transect Area (km²)	No. Shoals	Mean Surface Density per km²	Mean Surface Abundance per Zone	Maximum	Standard Deviation	Standard Error of the Mean
1	Summer	Zone 1A	54	8.4	11,793	7.6	45,486.2	899,193.9	164,678.92	22,409.96
	Summer	Zone 1B	38	12.3	0	0.0	0.0	0.0	0	0
	Summer	Zone 2A	38	6.5	0	0.0	0.0	0.0	0	0
	Summer	Zone 2B	49	21.0	0	0.0	0.0	0.0	0	0
	Summer	Zone 3	53	7.9	0	0.0	0.0	0.0	0	0
	Summer	Zone 4	54	11.0	0	0.0	0.0	0.0	0	0
2	Fall	Zone 1A	30	21.7	170	0.3	1,650.9	49,201.1	8,980.91	1,639.68
	Fall	Zone 1B	22	24.5	0	0.0	0.0	0.0	0	0
	Fall	Zone 2A	22	13.3	0	0.0	0.0	0.0	0	0
	Fall	Zone 2B	28	43.7	0	0.0	0.0	0.0	0	0
	Fall	Zone 3	30	16.2	0	0.0	0.0	0.0	0	0
	Fall	Zone 4	31	22.4	0	0.0	0.0	0.0	0	0
3	Winter	Zone 1A	30	21.8	0	0.0	0.0	0.0	0	0
	Winter	Zone 1B	22	24.6	0	0.0	0.0	0.0	0	0
	Winter	Zone 2A	22	13.6	0	0.0	0.0	0.0	0	0
	Winter	Zone 2B	28	44.3	1	0.0	8.3	231.1	43.68	8.25
	Winter	Zone 3	30	16.9	0	0.0	0.0	0.0	0	0
	Winter	Zone 4	31	23.0	0	0.0	0.0	0.0	0	0
4	Spring	Zone 1A	29	18.7	23	0.0	157.8	2,176.0	490.59	91.1
	Spring	Zone 1B	21	21.5	23	0.0	136.7	1,988.4	444.43	96.98
	Spring	Zone 2A	21	11.7	0	0.0	0.0	0.0	0	0
	Spring	Zone 2B	28	36.8	0	0.0	0.0	0.0	0	0
	Spring	Zone 3	30	14.1	0	0.0	0.0	0.0	0	0
	Spring	Zone 4	31	19.4	5	0.0	74.0	1,860.6	340.57	61.17
5	Summer	Zone 1A	24	16.9	585	1.1	6,560.6	118,980.6	25,098.74	5,123.26
	Summer	Zone 1B	18	25.2	13	0.0	75.2	691.5	176.99	41.72
	Summer	Zone 2A	18	13.4	11	0.0	99.4	909.3	264.11	62.25
	Summer	Zone 2B	24	42.9	7	0.0	106.7	695.6	225.13	45.95
	Summer	Zone 3	26	16.2	0	0.0	0.0	0.0	0	0
	Summer	Zone 4	26	22.5	1	0.0	16.0	415.1	81.4	15.96
6	Fall	Zone 1A	25	17.6	0	0.0	0.0	0.0	0	0
	Fall	Zone 1B	19	24.1	1	0.0	6.2	118.2	27.12	6.22
	Fall	Zone 2A	18	13.5	0	0.0	0.0	0.0	0	0
	Fall	Zone 2B	25	40.9	1	0.0	14.4	359.6	71.92	14.38
	Fall	Zone 3	27	15.5	0	0.0	0.0	0.0	0	0
	Fall	Zone 4	27	21.7	0	0.0	0.0	0.0	0	0

Survey	Season	Zone	No. Strip Transects	Mean Strip Transect Area (km²)	No. Shoals	Mean Surface Density per km²	Mean Surface Abundance per Zone	Maximum	Standard Deviation	Standard Error of the Mean
7	Winter	Zone 1A	24	17.5	0	0.0	0.0	0.0	0	0
	Winter	Zone 1B	18	25.1	0	0.0	0.0	0.0	0	0
	Winter	Zone 2A	18	13.4	0	0.0	0.0	0.0	0	0
	Winter	Zone 2B	24	42.8	0	0.0	0.0	0.0	0	0
	Winter	Zone 3	26	16.3	0	0.0	0.0	0.0	0	0
	Winter	Zone 4	26	22.5	0	0.0	0.0	0.0	0	0
8	Spring	Zone 1A	24	17.4	0	0.0	0.0	0.0	0	0
	Spring	Zone 1B	18	25.1	0	0.0	0.0	0.0	0	0
	Spring	Zone 2A	18	13.4	0	0.0	0.0	0.0	0	0
	Spring	Zone 2B	24	42.8	0	0.0	0.0	0.0	0	0
	Spring	Zone 3	26	16.0	0	0.0	0.0	0.0	0	0
	Spring	Zone 4	26	22.0	0	0.0	0.0	0.0	0	0
9	Summer	Zone 1A	24	17.6	1,422	2.4	14,534.8	341,761.9	69,709.29	14,229.35
	Summer	Zone 1B	18	25.2	0	0.0	0.0	0.0	0	0
	Summer	Zone 2A	18	13.4	0	0.0	0.0	0.0	0	0
	Summer	Zone 2B	24	42.8	0	0.0	0.0	0.0	0	0
	Summer	Zone 3	26	16.3	0	0.0	0.0	0.0	0	0
	Summer	Zone 4	26	22.5	0	0.0	0.0	0.0	0	0
10	Fall	Zone 1A	24	17.7	0	0.0	0.0	0.0	0	0
	Fall	Zone 1B	18	25.4	0	0.0	0.0	0.0	0	0
	Fall	Zone 2A	18	13.8	0	0.0	0.0	0.0	0	0
	Fall	Zone 2B	24	43.4	0	0.0	0.0	0.0	0	0
	Fall	Zone 3	26	16.5	0	0.0	0.0	0.0	0	0
	Fall	Zone 4	26	22.8	0	0.0	0.0	0.0	0	0
11	Winter	Zone 1A	24	17.4	0	0.0	0.0	0.0	0	0
	Winter	Zone 1B	18	25.1	0	0.0	0.0	0.0	0	0
	Winter	Zone 2A	18	13.3	0	0.0	0.0	0.0	0	0
	Winter	Zone 2B	24	42.8	0	0.0	0.0	0.0	0	0
	Winter	Zone 3	26	16.3	0	0.0	0.0	0.0	0	0
	Winter	Zone 4	26	22.5	0	0.0	0.0	0.0	0	0
12	Spring	Zone 1A	24	17.5	0	0.0	0.0	0.0	0	0
	Spring	Zone 1B	18	25.1	0	0.0	0.0	0.0	0	0
	Spring	Zone 2A	18	13.4	0	0.0	0.0	0.0	0	0
	Spring	Zone 2B	24	42.8	0	0.0	0.0	0.0	0	0
	Spring	Zone 3	26	16.3	0	0.0	0.0	0.0	0	0
	Spring	Zone 4	26	22.6	0	0.0	0.0	0.0	0	0

3.6 Direction of Travel

Direction of travel for fish shoals was not quantified; therefore, only data for bony fishes are reported when a direction was recorded (849 out of a total of 4,864 bony fish observations did not have a heading direction recorded). Mean headings differed, however, looking at the density of observations (Figure 42) mean heading does not accurately represent the bimodal distribution of points particularly evident in the Summer and Fall surveys (Figure 42 and Figure 43). The bimodality of heading becomes even more apparent when only the most abundant bony fishes are considered (Figure 44 through Figure 46). All three species show a tendency to be heading one of two ways during the Summer at a heading ranging between 240 and 300 degrees or 60 and 120 degrees. Tuna appear to prefer a different heading in the Spring relative to their Summer headings (Figure 47). In the Summer they follow the same bimodal distribution seen in the other taxonomic groups but in the Spring there were more observations of Tuna fishes moving with a heading ranging between 190 and 220 degrees. This Spring season heading also appears to be associated with moving through areas that have an estimated ocean depth of 400 m (Figure 48). In contrast to Tuna fishes, sunfishes were consistent in their headings across all three seasons where 25 or more observations of heading were documented (Figure 49).

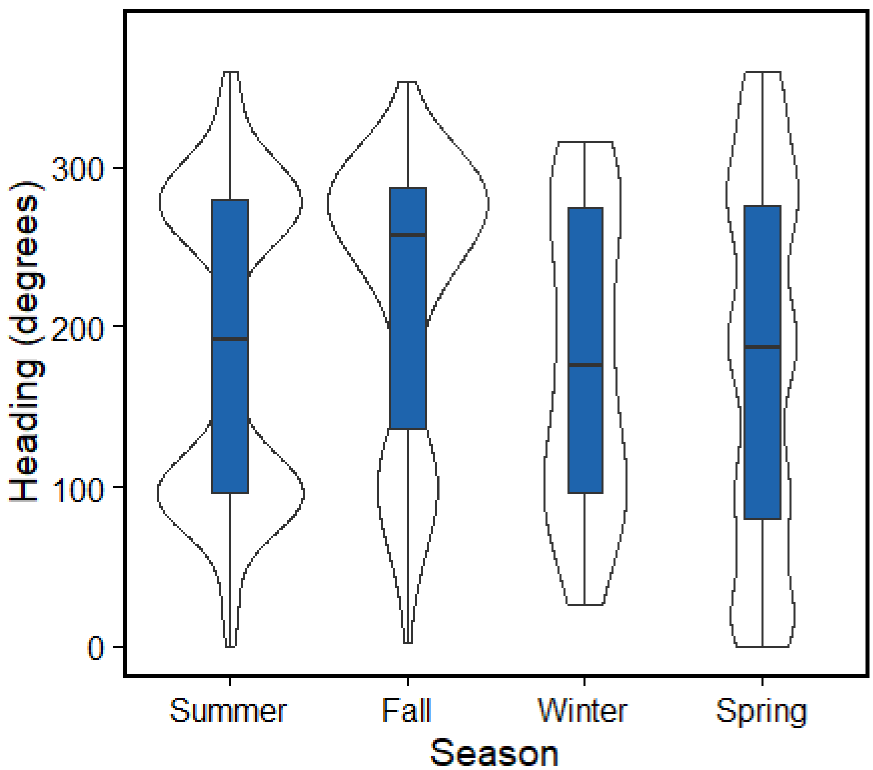

Figure 42. Heading and density for all bony fishes observed in the OPA for each season across the Summer 2016 through Spring 2019 surveys.

Boxplots represent minimum, maximum, 25th percentile, 75th percentile and median (50th percentile) with points representing outliers. Outlines around boxplots are violin plots representing the density of data points within each season. Larger bulge equates to more observations of individuals at that particular heading.

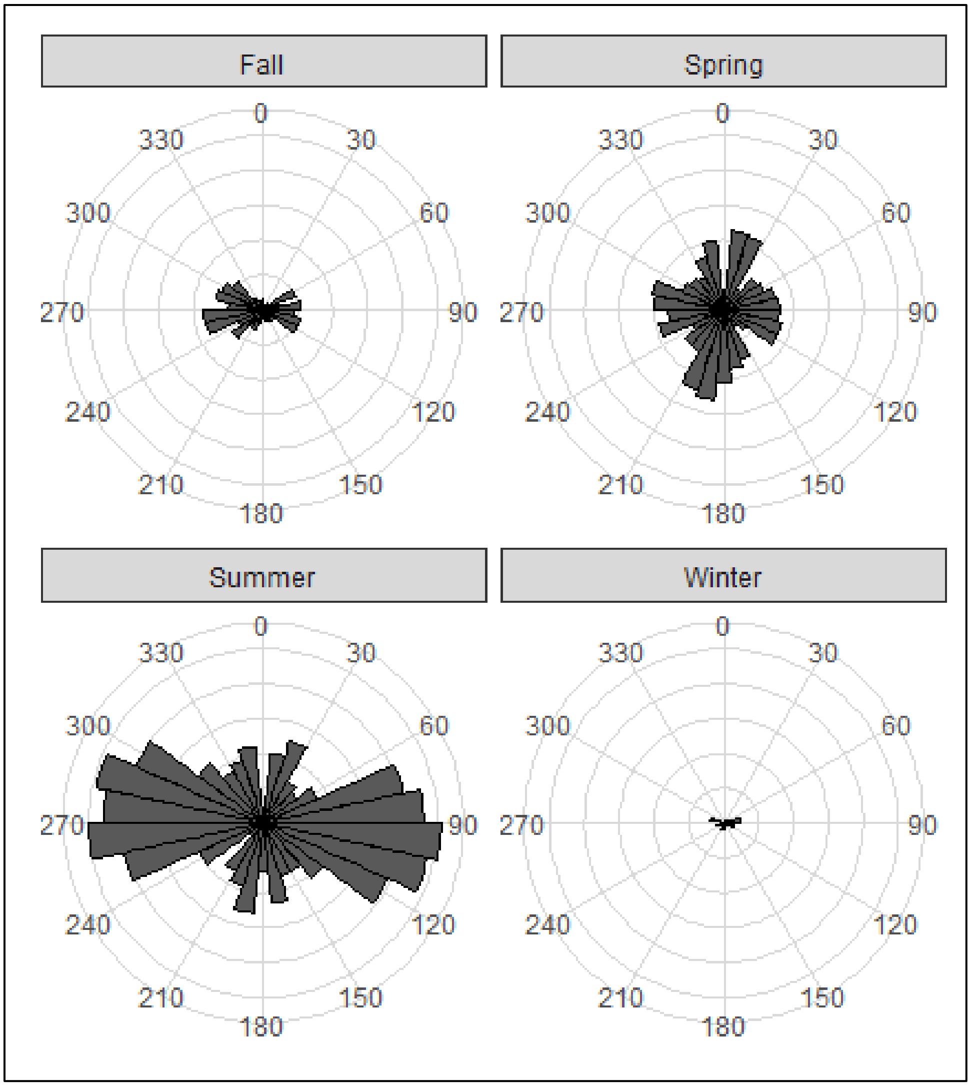

Figure 43. Relative abundance and distribution of headings (degrees) observed for all bony fishes in the OPA during the Summer 2016 through Spring 2019 surveys.

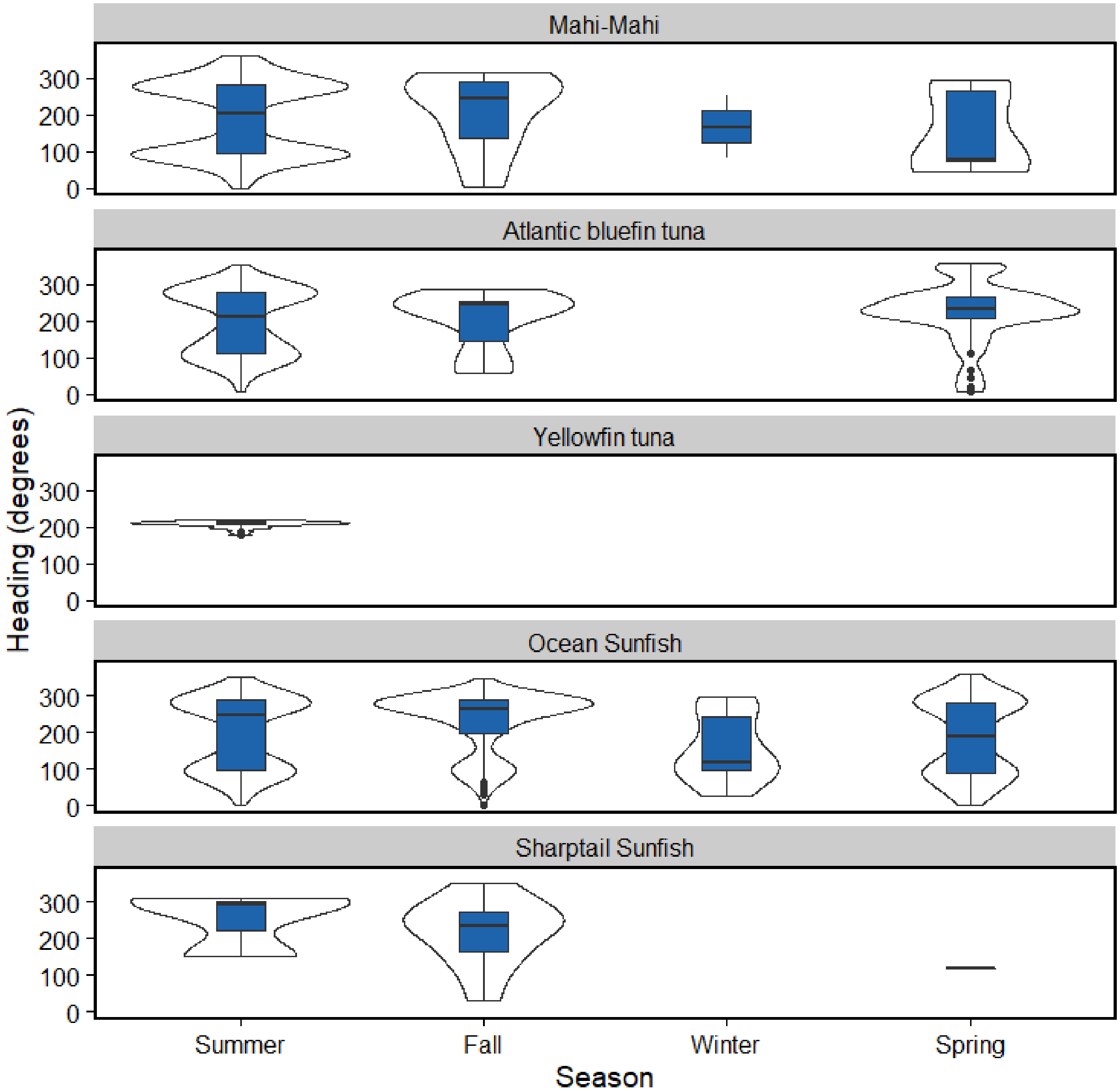

Figure 44. Heading and density by bony fish species observed in the OPA for each season across the Summer 2016 through Spring 2019 surveys.

Boxplots represent minimum, maximum, 25th percentile, 75th percentile and median (50th percentile) with points representing outliers. Outlines around boxplots are violin plots representing the density of data points within each season. Larger bulge equates to more observations of individuals at that particular heading.

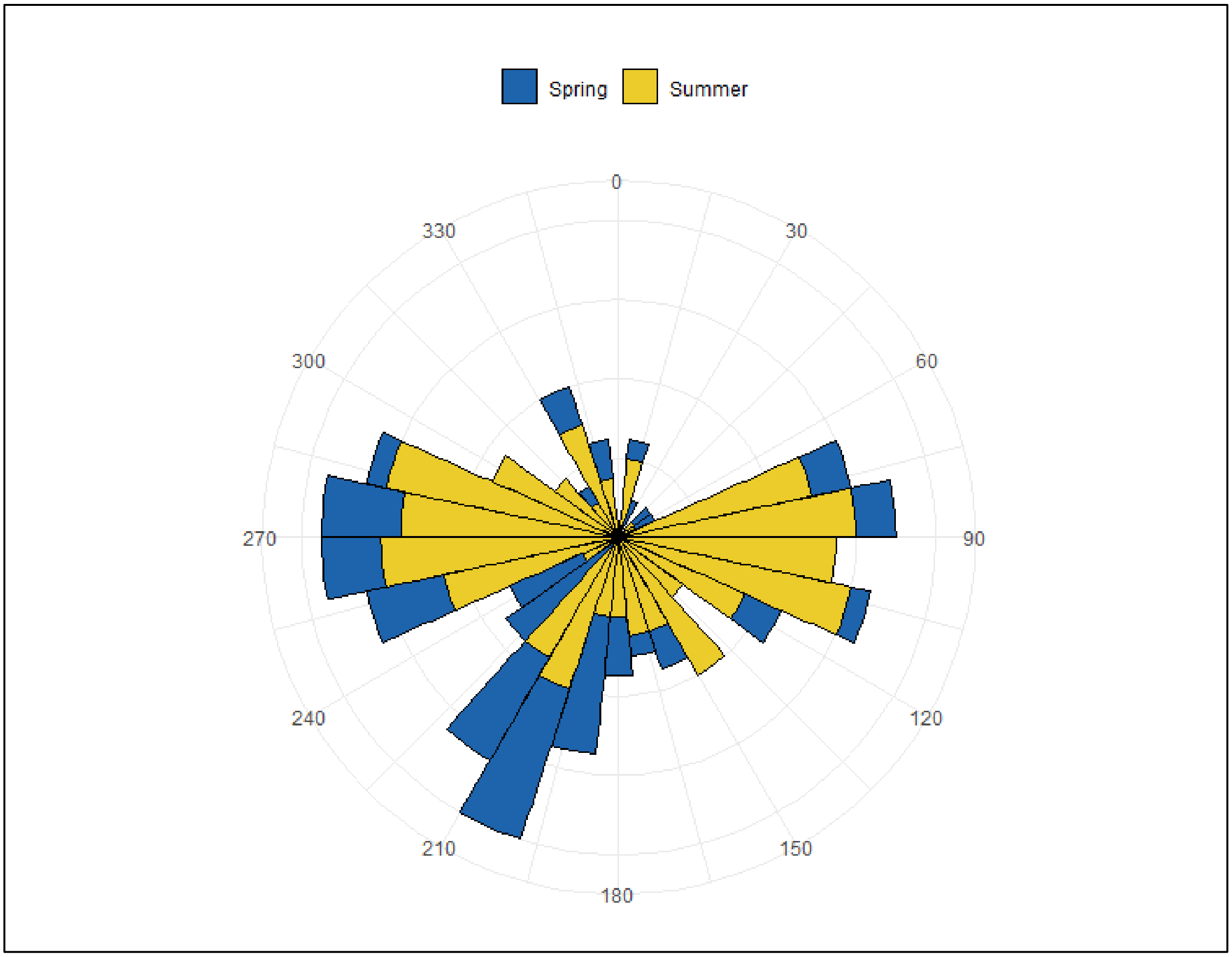

Figure 45. Relative Spring and Summer abundance and distribution of headings (degrees) observed for Tuna fishes in the OPA during the Summer 2016, 2017, and 2018 and the Spring 2017, 2018, and 2019 surveys.

Seasons with fewer than 25 observations are omitted.

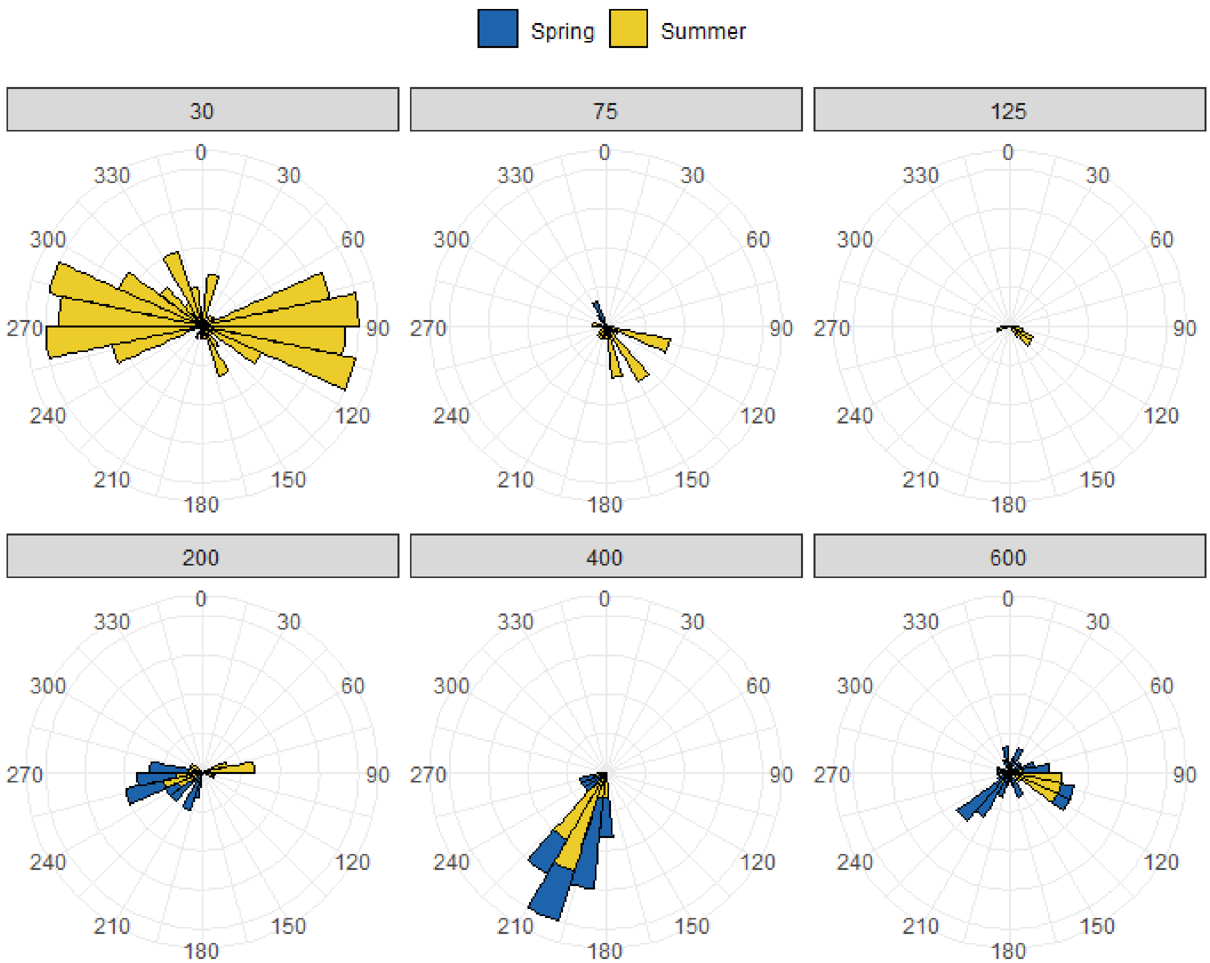

Figure 46. Headings (degrees) documented for all observed Tuna fishes during the Summer 2016, 2017, and 2018 and the Spring 2017, 2018, and 2019 surveys in the OPA presented for each estimated ocean depth (30–600 m).

Seasons with fewer than 25 observations are omitted.

Figure 47. Relative Spring and Summer abundance and distribution of headings (degrees) observed for Atlantic Bluefin and Yellowfin Tuna in the OPA during the Summer 2016, 2017, and 2018 and the Spring 2017, 2018, and 2019 surveys.

Seasons with fewer than 25 observations are omitted.

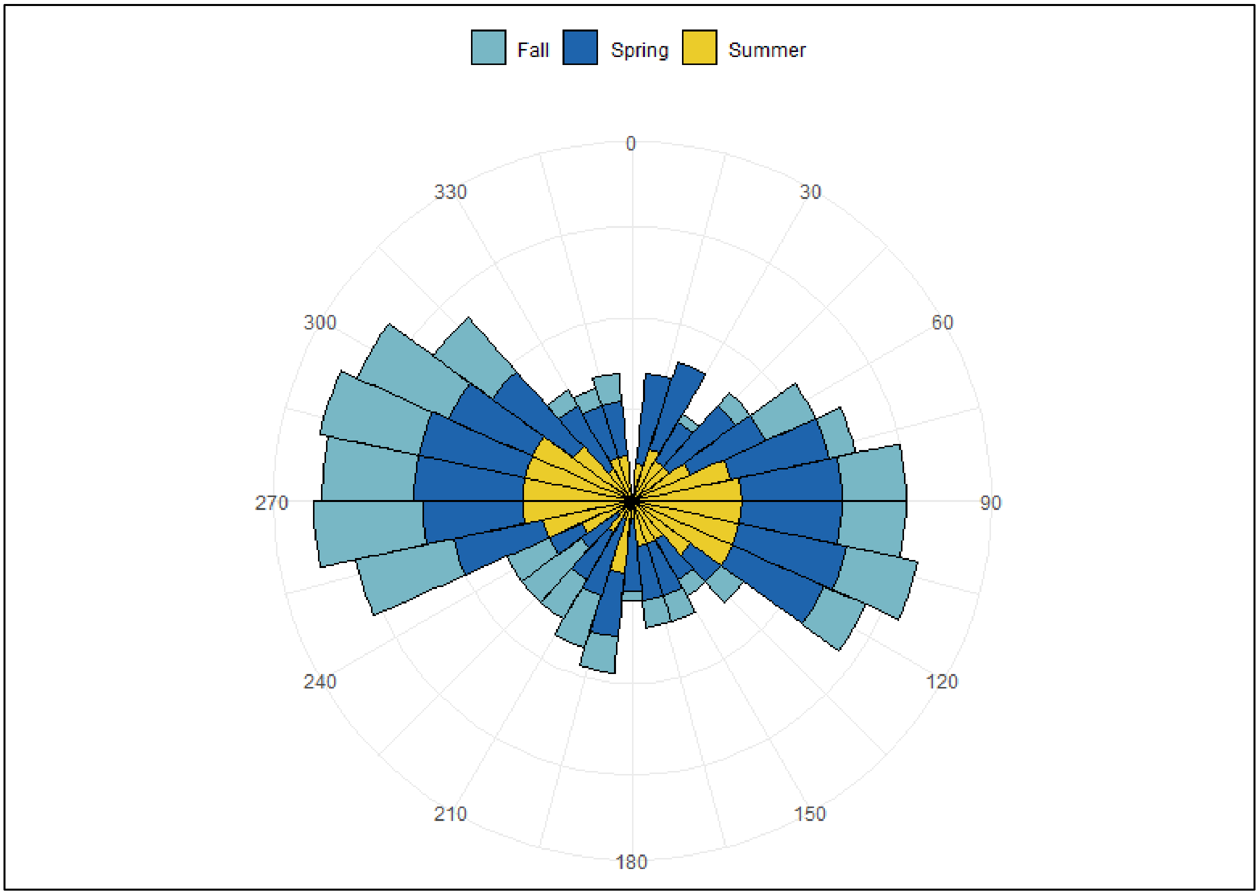

Figure 48. Relative abundance and distribution of headings (degrees) observed for Sunfishes in the OPA during the Fall 2016 through Spring 2019 surveys.

Seasons with fewer than 25 observations are omitted.

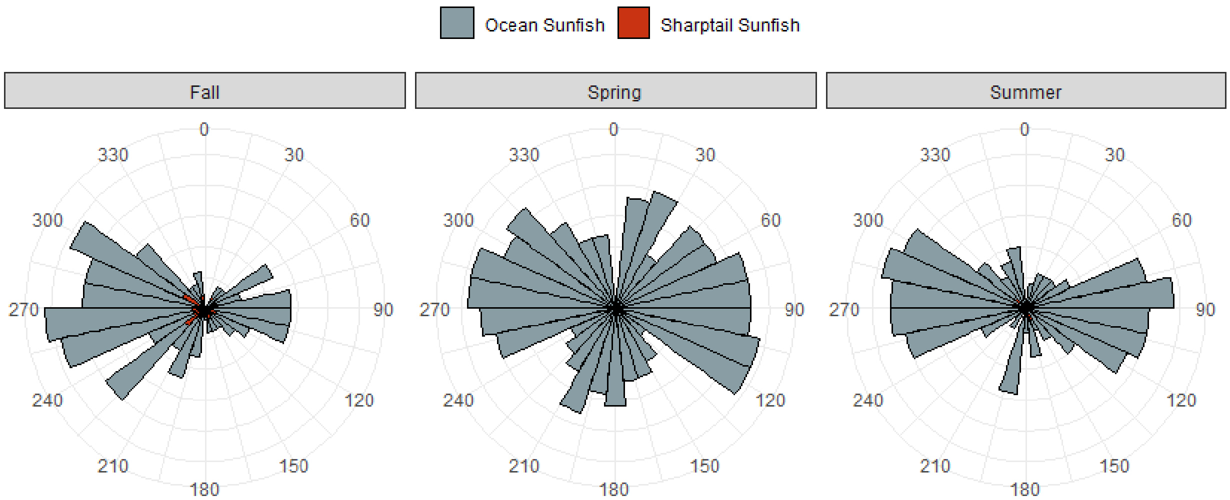

Figure 49. Relative Fall, Spring, and Summer abundance and distribution of headings (degrees) observed for Ocean and Sharptail Sunfish in the OPA during the Summer 2016 through Spring 2019 surveys.

Seasons with fewer than 25 observations are omitted. The vast majority of identified sunfishes were Ocean Sunfish.

3.7 Fish Shoal Area

All fish shoals were measured for areal extent using a custom designed measuring tool created on NYSERDA’s remote.normandeau.com data management system. Shoal area ranged from an area of 1 m^2 to 8,651 m^2 (Figure 50). Most shoals had areas of less than 20 m^2 (55.6%), and 88.3% of shoals had an area of less than 100 m^2. Despite a substantial difference in maximum observed shoal areas between Summer and Spring, there were relatively small differences in mean and standard deviation of shoal areas (Table 17, Figure 50). Conversely, both mean shoal area and standard deviation were much higher in the Fall relative to the Summer and Spring (Table 17, Figure 50). Area measurements may be underestimates of the actual size of the shoals as an unknown portion of each shoal was likely submerged.

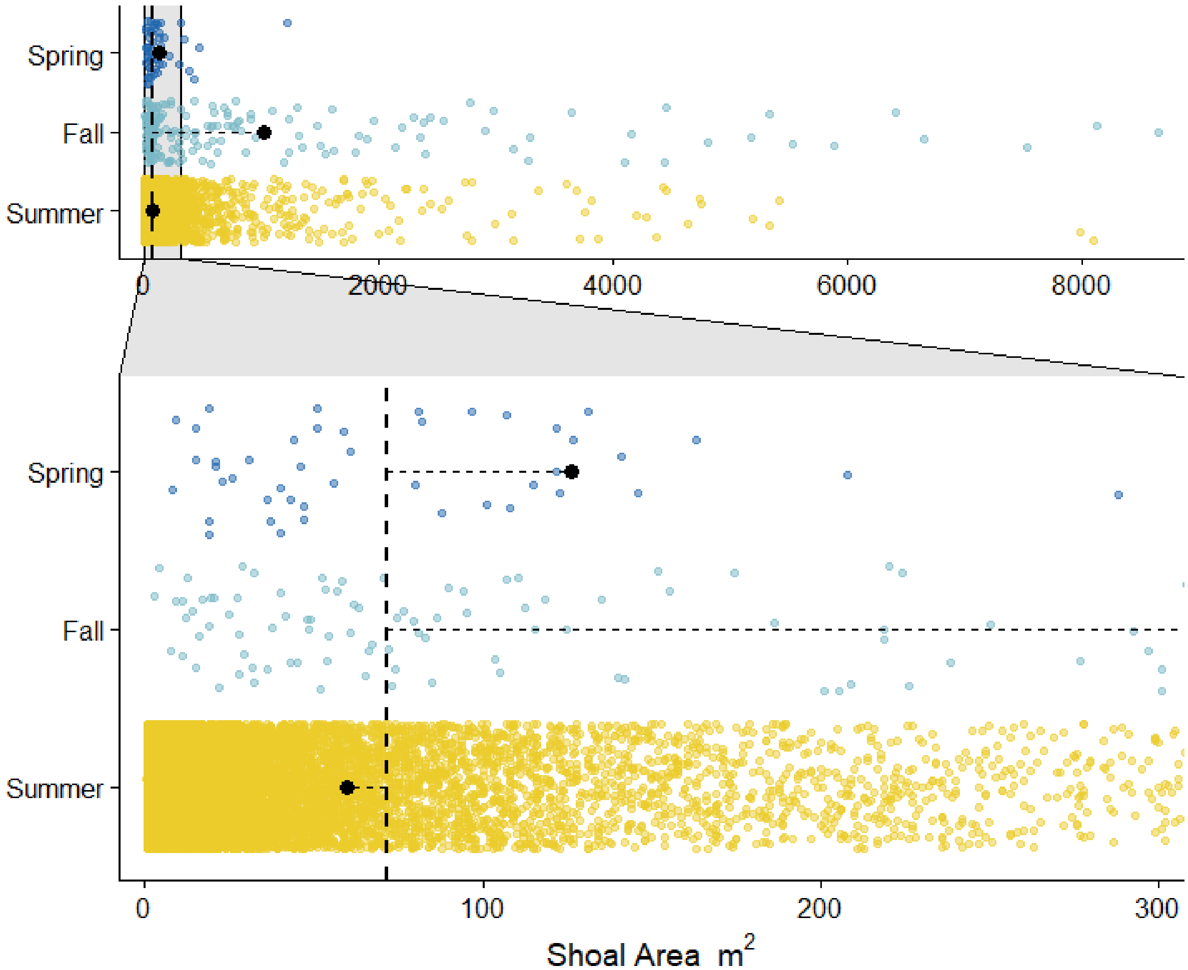

Figure 50. Total count by areal extent (m²) for each fish shoal observed in the OPA during the Summer 2016 through Spring 2019 surveys.

Vertical dashed line represents the mean shoal area across seasons and black points represent the group means for each season. Top panel shows the variance and maximum shoal sizes observed in Fall and summer and the lower panel is a zoom on the small shoal areas showing the large quantity of small shoals in the Summer. Winter is omitted because n = 1.

Table 17. Mean Area and Sum Area (m²) for all Fish Shoals Observed in the OPA

Survey	Season	n	Mean Area m²	Sum Area m²
1	Summer 2016	12,025	51.67	621,310.88
2	Fall 2016	171	1031.25	176,344.35
3	Winter 2016–2017	1	13.53	13.53
4	Spring 2017	51	126.25	6439.00
5	Summer 2017	617	92.42	57,026.00
6	Fall 2017	2	106.00	212.00
9	Summer 2018	1,422	115.51	164,258.07

3.7.1 Shipping Lanes and Fish Shoals

Greater than 72% of all fish shoals were observed within the perimeter of a shipping lane (Figure 51). The greatest percent of shoals (96%) within shipping lanes occurred during the Fall, while Spring had the lowest percent of occurrences with only 16% (Figure 51; Table 18).

Table 18. Percent of Shoals occurring within Shipping Lanes for each Season Pooled across the Summer 2016 through Spring 2019 Surveys

Summer	Fall	Spring	Winter	Total
72	96	16	0	72

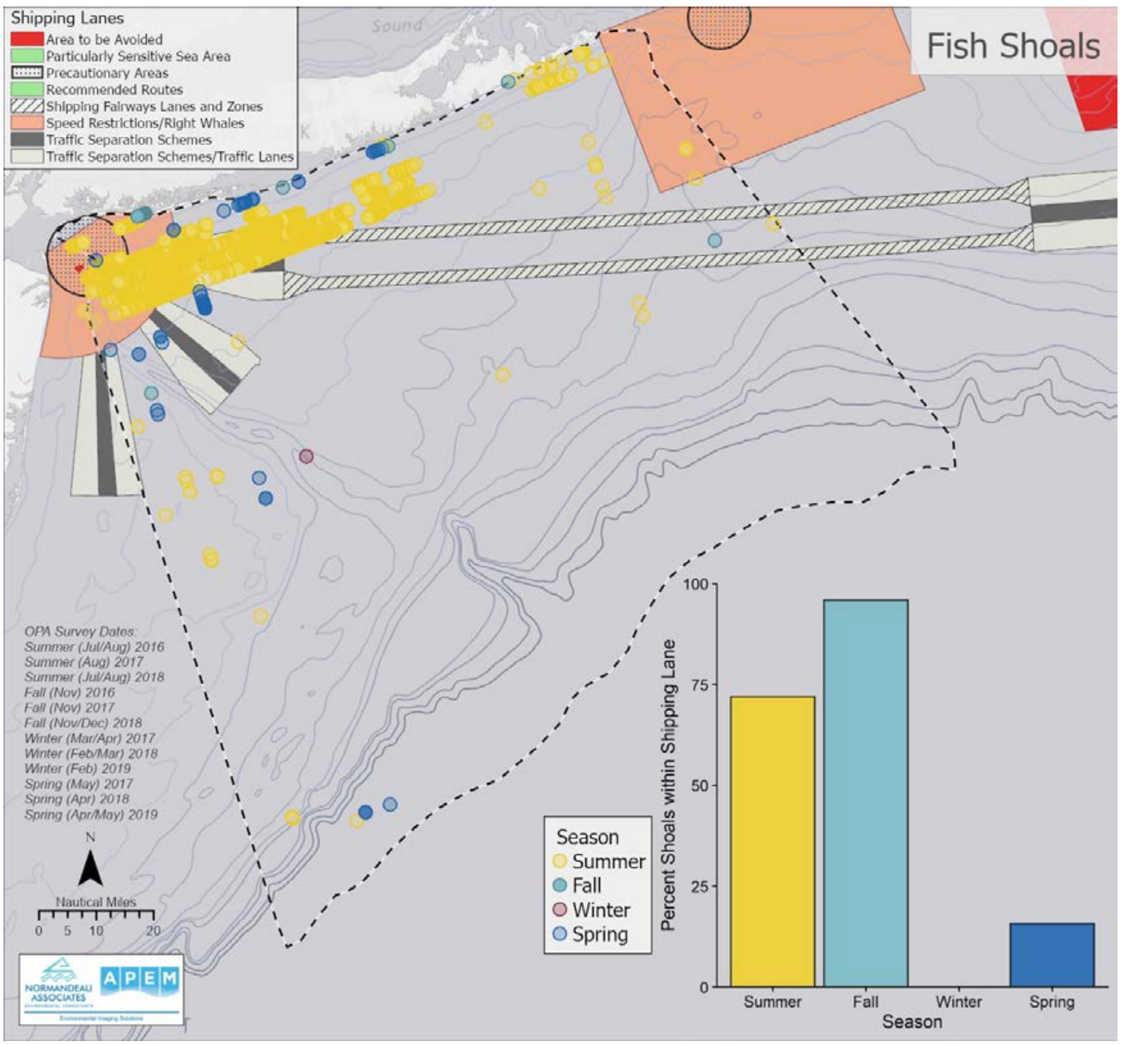

Figure 51. Percent of shoals within shipping lanes for Summer 2016, 2017, and 2018; Fall 2016, 2017, and 2018; and Spring 2017, 2018, and 2019 in the OPA, as well as the total across all seasons excluding the single Winter fish shoal observation (5 nautical miles = 9.26 km).

Shipping lane data provided by Office of Coast Survey, 2018: Shipping Fairways, Lanes, and Zones for US waters, https://www.fisheries.noaa.gov/inport/item/39986

3.7.2 Observation Rates of Bony Fish and Fish Shoals near the Hudson Canyon

The Hudson Canyon is a 2,080-km^2 landscape feature within the OPA. Because of its prominence within the OPA and the way that it influences the overall bathymetric patterns, we investigated whether the canyon was associated with different surface observation rates relative to the rest of the OPA. To do this, counts were corrected by dividing the total number of counts by survey by the total area surveyed within the Hudson Canyon. This process was repeated to quantify the observation rates of the whole OPA (excluding the trench) for comparison.

Observation rates varied within the canyon relative to the rest of the OPA. Bony fishes were observed most frequently in the Summer with an average observation rate 3.54 times greater within the canyon relative to the rest of the OPA. In the Fall, observation rates in the canyon were 2.34 times that of rates outside of the canyon despite a general decrease in overall detections (Figure 52, Table 19). In the Spring, bony fishes concentrated in Zone 4 beyond the 400-m depth zone and thus only two bony fish occurrences were documented in the canyon.

On average, Summer observation rates for shoals were 2.89 times higher within the trench boundary than outside (Figure 53). Observation rates were so low in the other seasons for fish shoals that patterns beyond the Summer did not emerge.

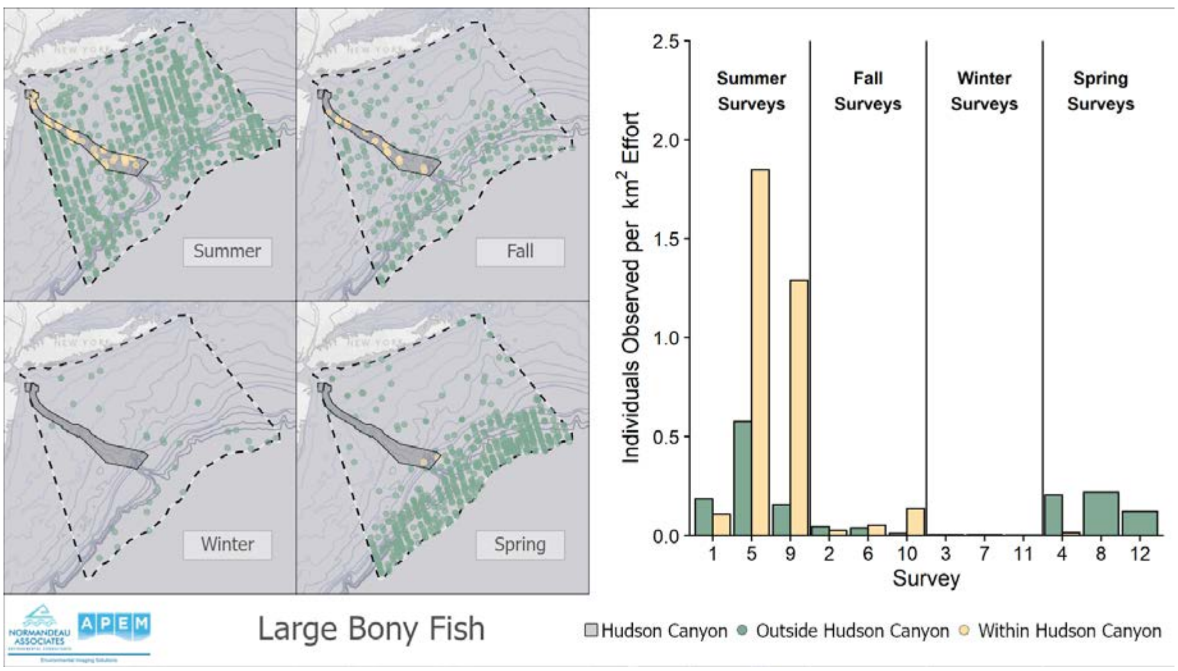

Figure 52. Left: Map showing all bony fish within (pale yellow) and outside (green) the drowned river valley leading to the Hudson Canyon by season. Right: Individuals observed per km^2 of effort within and outside of the Hudson Canyon valley for each survey by season.

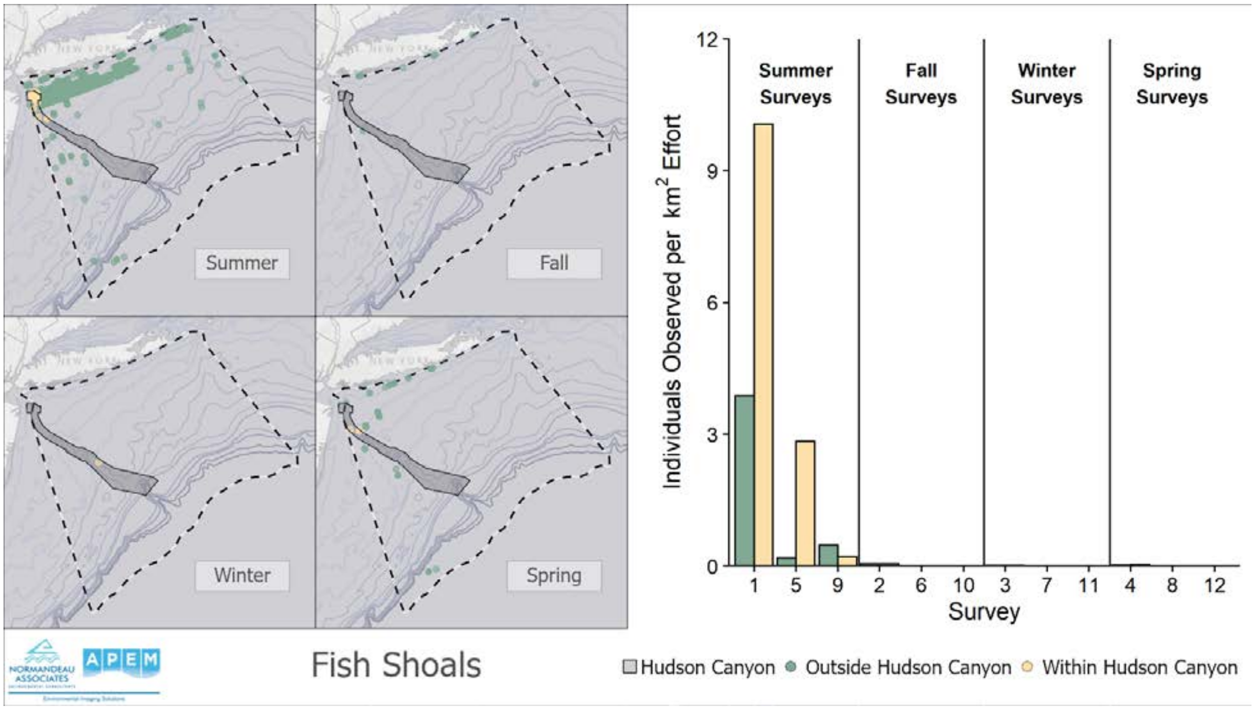

Figure 53. Left: Map showing all fish shoals within (pale yellow) and outside (green) the drowned river valley leading to the Hudson Canyon by season. Right: Number of shoals observed per km^2 of effort within and outside the Hudson Canyon valley for each survey by season.

Table 19. Mean Observation Rates (per km^2) Within and Outside of the Hudson Canyon Valley Boundary for each Season

Season	Mean Observation Rate (no./km^2)	
	Within Trench	Outside Trench
Bony Fish		
Summer	1.08	0.31
Fall	0.07	0.03
Winter	0	0.003
Spring	0.01	0.18
Fish Shoals		
Summer	4.37	1.51
Fall	0	0.02
Winter	0.005	0
Spring	0.03	0.02

3.8 Camera Performance

Results for two different camera performance metrics are presented here to investigate potential inherent and environmental biases in the detection probabilities/capacities for all captured images. This was done by first determining if all cameras of the array are equally likely to produce positive images and thus account for trades-offs in footprint and resolution inherent to the array design, and second by determining if positive images were negatively correlated with wind speed. Analyses of both metrics were constrained to only include bony fishes and further by omitting data from Summer 2016 because a different camera system was used.

3.8.1 Trade-Offs in Image Footprint and Image Resolution Across the Camera Array

First, to determine if each camera on the camera array was equally likely to capture positive images (image containing an animal), a series of proof of concept analyses were conducted considering the bony fishes data set beginning with the second survey. These analyses were conducted to investigate any biases in the camera array due to an inherent image size resolution trade-off as cameras will have different image characteristics depending on where it is positioned on the camera array system. The farther a camera is positioned away from the array centroid, the larger the area captured in the image (image footprint) but the lower the total resolution of the image, leading to a negatively correlated relationship. We wanted to ensure that the camera array system design was not inherently biasing cameras with larger footprints to detect an increased number of bony fishes or fish shoals or conversely that cameras with the greatest footprint were not under-performing and detecting fewer individuals due to low image resolution (i.e., more likely to generate false negatives).

The range of image footprints across the array is not large, however, over time there could be some bias associated with these differences. If the footprint of a camera biases the number of times it is able to detect an animal, we would expect that, on average, cameras with larger areal extent would be more likely to capture an image containing an animal. Thus, we would predict that over time the cameras with the larger footprints would have a greater proportion of images containing a boney fish. To determine if camera footprint (i.e., the image coverage area) influences the number of bony fishes imaged, the total number of times each camera detected one or more bony fishes was quantified (Figure 54). When comparing the proportion of images with one or more bony fishes present across all cameras on the array, we found no difference in the relative number of bony fishes imaged across the Fall 2016 through Spring 2019 surveys ($F_{8,77} = 0.23$, $p = 0.98$), suggesting that each camera is just as likely to detect bony fishes independent of camera footprint.

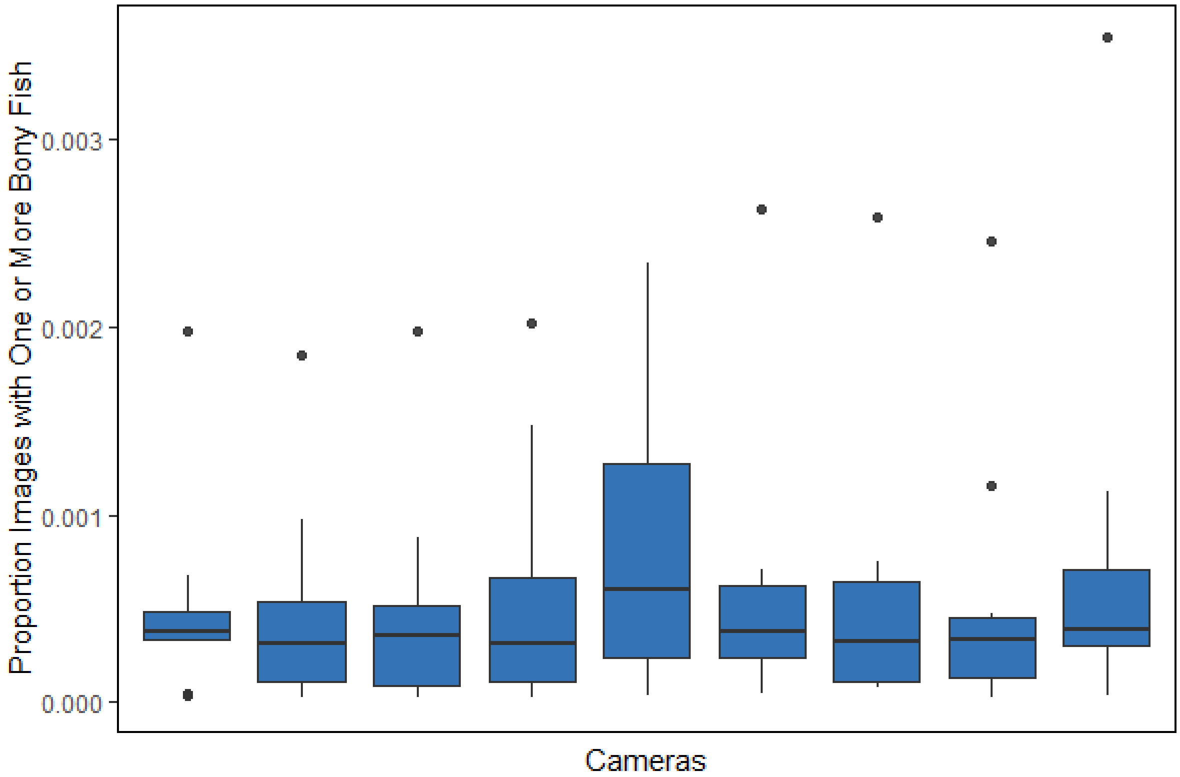

Figure 54. Proportion of times a camera captured an image of one or more bony fishes over the total number of times a camera took a picture during a given survey.

The order of data does not reflect the location of each camera in the array. Boxplots represent minimum, maximum, 25th percentile, 75th percentile and median (50th percentile) with points representing outliers.

It is possible that slightly higher resolution cameras are more proficient at detecting multiple objects within an image that has been flagged. It could be imagined that both computer software and human image inspectors would be able to pick out the hardest to see bony fishes only when photo resolution is highest, leading to a higher total count of bony fishes. To determine if resolution was correlated with total number of animals imaged, the proportion of bony fishes associated with each camera was quantified over the total number of photos imaged per camera (Figure 55). We find that total number of bony fishes imaged by each camera does not differ by cameras throughout the Fall 2016 through Spring 2019 surveys ($F_{8,77} = 0.19$, $P = 0.99$), suggesting that camera resolution does not bias detection probability.

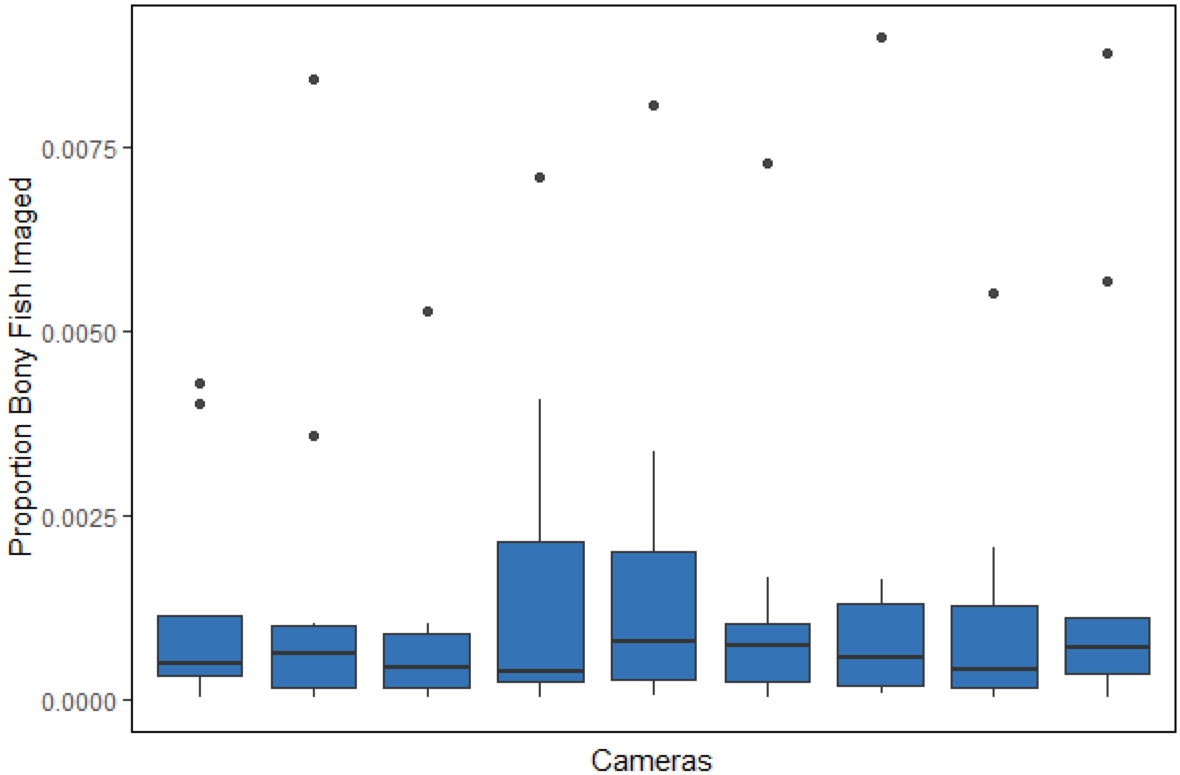

Figure 55. Proportion of bony fishes imaged by each camera across the Fall 2016 through Spring 2019 surveys.

The order of data does not reflect the location of each camera in the array. Boxplots represent minimum, maximum, 25th percentile, 75th percentile and median (50th percentile) with points representing outliers.

Although no resolution bias appears to be present across the array, we wanted to determine if cameras with the highest resolution had a higher species identification success rate. Identifying imaged animals to species could be made more difficult with slight changes in resolution. We constrained our dataset to include only bony fishes that were successfully identified to species and compared the proportion of species-identified individuals across all cameras (Figure 56). We found that positively identified images were not correlated with camera resolution ($F_{8,75} = 0.14$, $P = 0.99$), suggesting that the differences in image resolution are not severe enough to bias the dataset.

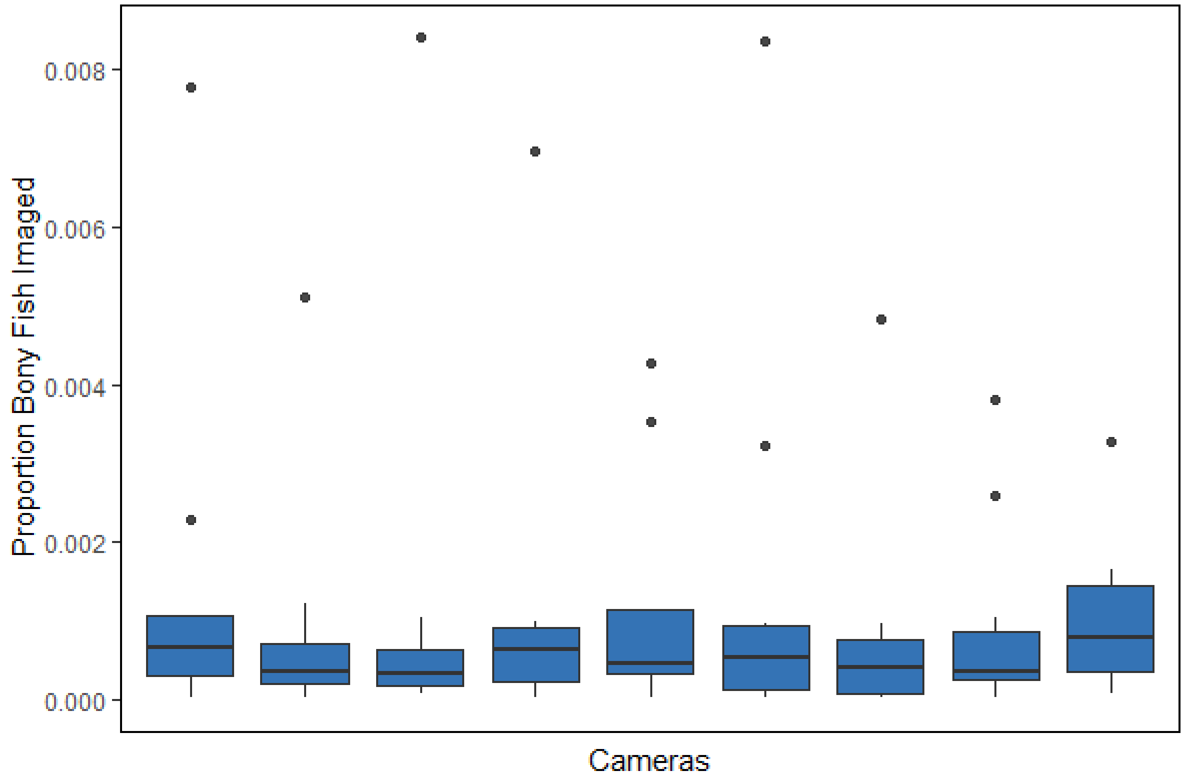

Figure 56. Proportion of instances a camera captured an image of a species-identified bony fish.

The order of data does not reflect the location of each camera in the array. Boxplots represent minimum, maximum, 25th percentile, 75th percentile and median (50th percentile) with points representing outliers.

3.8.2 Wind Speed

Surveys were recommended to be conducted when wind speeds were below 30 knots. On occasion, logistical constraints led the flight team to conduct surveys or parts of surveys when wind speed was greater than 30 knots (Figure 57). To determine if wind speed influenced the number of total bony fishes imaged, the total number of individuals imaged at each recorded wind speed were quantified and the proportion was calculated to control for differences in the number of total images pooled across all cameras captured at each wind speed (Figure 58).

There was a very weak negative correlation between camera performance and wind speed ($F_{1,99}$ = 5.095, P = 0.026, Adj. R^2 = 0.039; Logistic regression), possibly driven by rougher water surface conditions (Figure 58). However when the data set is constrained to images that were captured at wind speeds of 35 knots and less, there was no statistical relationship between proportion of animals imaged and wind speed ($F_{1,91}$ = 3.849, P = 0.053, Adj. R^2 = 0.030; Logistic regression), suggesting that overall, surveys that occur 5 knots above the recommended survey wind speed of 30 knots are not less likely to image bony fishes.

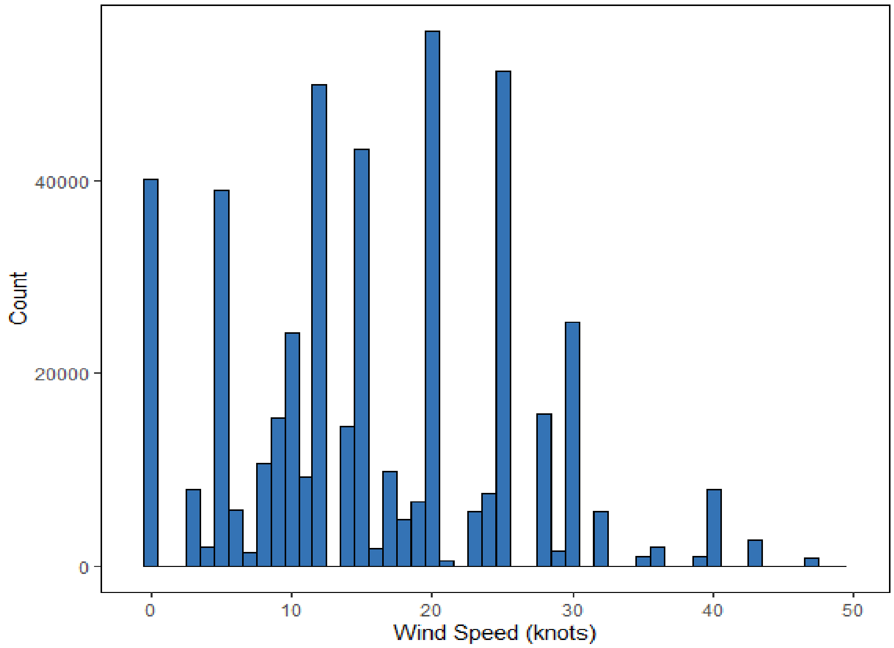

Figure 57. Total number of images obtained at each wind speed.

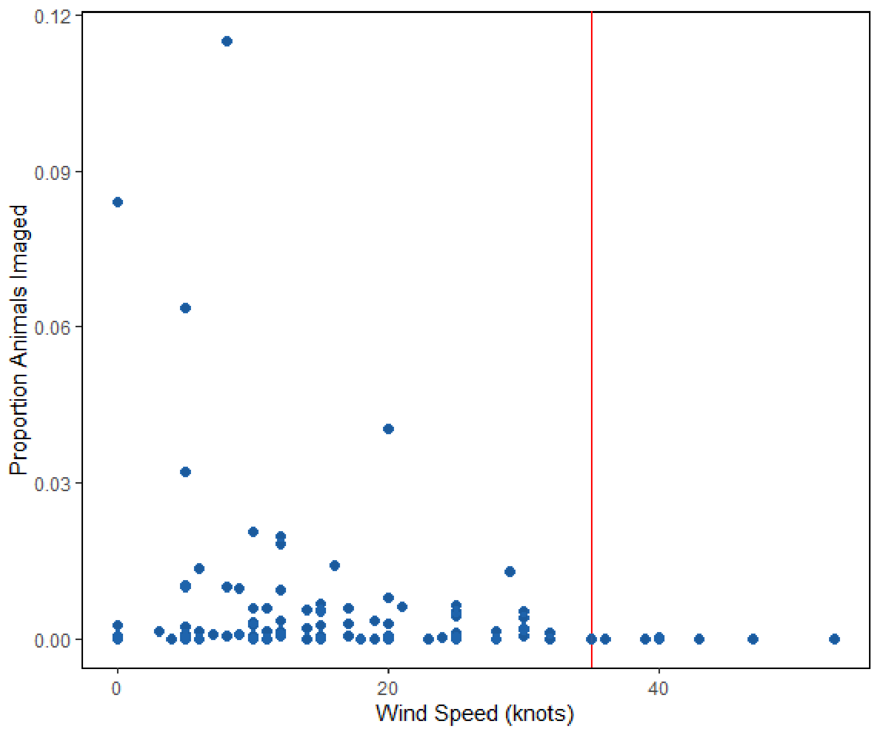

Figure 58. Proportion of bony fishes imaged at each wind speed (knots) experienced across the Fall 2016 through Spring 2019 surveys.

The red vertical line represents the maximum wind speed (35 knots) at which there is no significant statistical relationship between the wind and the probability of imaging an individual bony fish.

4 Discussion

The findings of this survey suggest that spatial distribution of bony fishes and fish shoals are strongly influenced by season. This project originally did not consider bony fishes and shoals from the survey efforts but later included them once their prevalence within the images became apparent. This project was designed with avian species and other marine organisms such as marine mammals, sharks, and rays. Future surveys may consider shifting the survey times to coincide with bony fishes and/or fish shoal life history patterns more directly if the primary target of such a survey is bony fishes and fish shoals. It is perhaps most important to note the immense disparity in imaged fish shoals between survey one and all subsequent surveys. As mentioned above, the Summer 2016 survey fish shoal abundance exceeds all subsequent surveys combined. Our results make it difficult to conclude or speculate about what might have driven such high numbers during this survey, but future surveyors should be aware of such differences while planning surveys, particularly if fish shoals are the target. Despite potentially missing peak shoaling periods during the remaining surveys, the survey periods used for this baseline data survey were adequate indicators of the temporal and spatial variation occurring in the OPA.

In general, this study highlights the challenge of making accurate species-specific predictions of bony fish and fish shoal abundance in part because of the extreme variance in their sighting rates from transect to transect. Post stratification of the area based on metrics of depth and distance from shore seem to be one effective way to aid our understanding of the spatial and temporal distribution of bony fishes and shoals. Future studies should consider additional covariates such as patterns of primary productivity as a way to refine models and identify other important factors driving fish behavior in pelagic environments.

4.1 Large Bony Fish

Species of large bony fishes imaged in this survey occur globally, and populations migrate substantial distances annually. Most are known or thought to reproduce in tropical or near-tropical waters but move to higher latitudes during warmer temperatures to take advantage of rich feeding opportunities. While we identified seven species of large bony fishes, only three species occurred in high enough numbers to discern either spatial or seasonal patterns. Review of the ecology of these frequently observed species provides us with a basis for understanding their use of the OPA.

Ocean Sunfish was the most frequently observed large bony fish in the surveys and it was present in every survey; although, it most abundant in Spring (522 observations), Summer (363 observations), and Fall (249 observations). Its association with the depth/distance zones defined in Section 3.5 varied seasonally (Figure 59). In the Summer it was most abundant in Zone 2B, in water depths of 50–100 m and around 30–60 km from shore. In Spring and Fall, highest abundances were farther offshore and in deeper waters (Zones 3 and 4). This seasonal distribution pattern was consistent with summer “residence” in shallower waters and seasonal migrations along the shelf break as observed by Potter et al. (2011) using tagged fish and Kenney (1996) using aerial survey data from the 1970s. The largest bony fish in the ocean, the Ocean Sunfish, was thought to float passively at the surface, controlled by ocean currents. Recent studies have shown, however, that it is a powerful swimmer, achieving speeds comparable to pelagic sharks and is fully capable of controlling its horizontal position even in strong currents (summarized in Pope et al. 2010). Tagging studies have documented migrations as long as 2,500 km (Potter et al. 2011).

Ocean Sunfish are also capable of large vertical movements for feeding. Potter and Howell (2011) and Sims et al. (2009) observed a pattern of frequent deep dives over the day. The deepest dives occurred during daylight hours and shallower dives were at night, consistent with diel vertical migration of gelatinous zooplankton, thought to be the primary prey. In addition, Potter and Howell (2011) found that in cooler temperatures (<24°C) mean depth of fish was generally around 10–40 m below the surface, and in warmer temperatures (>24°C) mean depth of fish was around 150–400 m below the surface. This pattern may be related to the presence of a thermocline that affected depth distribution of prey. This suggests that the observations from the NYSERDA survey represent an underestimate of the number of Ocean Sunfish in the OPA in every season.

Mahi-Mahi was the second most frequently observed large bony fish occurring during the aerial digital surveys of the OPA. Its presence was highly seasonal, with 98% of the observations occurring during Summer surveys. Although it was observed throughout the survey area, highest abundances were found in Zone 2B (50–100 m depth, more than 60 km from shore) and Zone 4 (>400 m depth on the continental slope) (Figure 60). This probably reflects a combination of schools foraging in the shallower portions and schools migrating along the shelf break. While Mahi-Mahi can be found as far north as Massachusetts, it is a tropical to subtropical species whose distribution is related primarily to surface temperature and chlorophyll-*a* concentrations (Farrell et al. 2014). They are frequently found associated with *Sargassum*. Although Mahi-Mahi move north during the spring, highest concentrations tend to be found offshore of the OPA until July and August (Farrell et al. 2014).

Numbers of Mahi-Mahi were considerably higher in 2017 than 2016 or 2018. This could be the result of several things, including the fact that they are generally found in schools so their distribution would be expected to be highly patchy. However, it is interesting to note that during 2017 there was an abnormally high number of warm core rings emanating from the Gulf Stream in the region between 70° and 75°W that includes the OPA (Gangopadhyay et al. 2019). Perhaps this attracted this warm-water species shoreward at an above average rate. No data on warm core rings are available for 2018 at this time.

While Mahi-Mahi are known to dive above and below the thermocline for food, their dives tend to be of short duration and were most frequent at night (Merten et al. 2014; NOAA undated). Tagged individuals spend the majority of time (66%) in the upper 10 m of the water column (Merten et al. 2014), and NOAA describes them as surface feeders. This behavior suggests that the abundances extrapolated from the aerial digital survey are a reasonable estimate of the seasonal population of this species in the OPA.

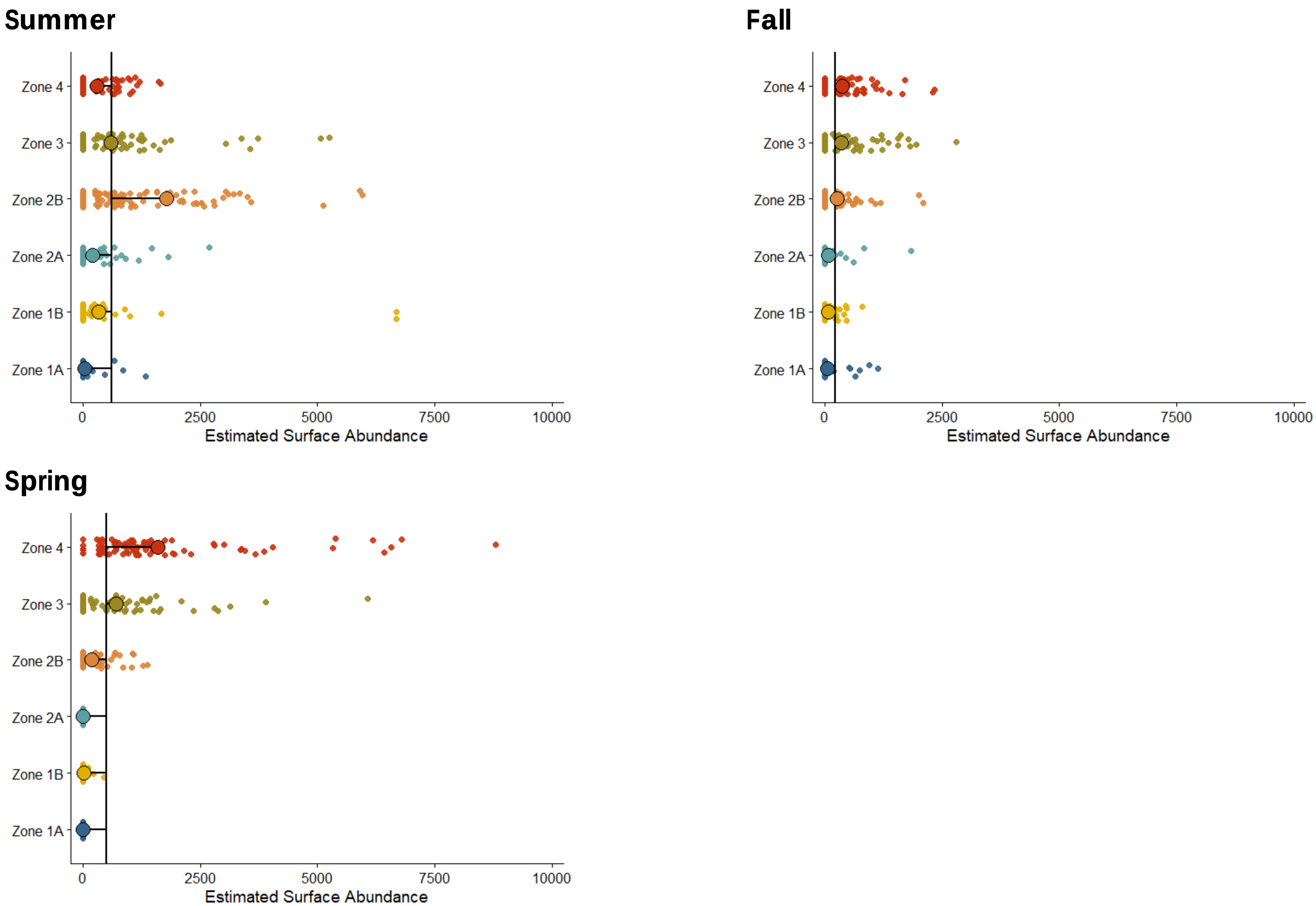

Figure 59. Estimated abundance for Sunfishes in the Summer, Fall, and Spring. In the Summer, Sunfishes were most abundant in Zone 2B; in the Fall and Spring, Sunfishes were most abundant in Zones 4 and 3.

Black vertical bar in the OPA is mean estimated abundance, and large circles with black outline represent the mean estimated abundance for each zone.

A highly migratory species, Atlantic Bluefin Tuna was observed nearly as frequently as Ocean Sunfish during the Summer and slightly more frequently in the Spring surveys. This Tuna species was absent from the Winter surveys and nearly so from the Fall surveys. This seasonal pattern conforms to long-term data acquired from individuals tagged off North Carolina (Walli et al. 2009). Tracking Atlantic Bluefin Tunas over a ten-year period, Walli et al. (2009) identified four areas of high residency (167 ± 33 days) in the north Atlantic. Two high-use areas were off the North American coast: off the Carolinas and off New England and the Scotian Shelf. Seasonal use of these two areas corresponded to periods of high primary and secondary productivity, in particular, periods with high abundances of forage fish such as Atlantic Mackerel (winter in North Carolina and summer off New England). While it is impossible to determine how long individuals observed using aerial digital photography remained in the OPA, the differences in seasonal distribution of sightings suggest possible differences in habitat use. In the Summer sightings, Atlantic Bluefin Tuna were found most frequently in the shallower, closer-to-shore Zone 2B (Figure 62), possibly an indication of foraging. The sightings in the Spring were concentrated in offshore Zone 4 (the continental shelf), which suggests these were fish in transit.

As with Ocean Sunfish, Atlantic Bluefin Tuna spend most of their time below the surface. Lutcavage et al. (2000) reported that adult Atlantic Bluefin Tuna spent less than 8% of the time within one meter of the surface and less than 19% of the time within four meters of the surface. Deeper than that, it would be extremely difficult to detect, let alone identify a fish. Thus, the abundances determined by this survey of the OPA are likely to be substantial underestimates of the number of Atlantic Bluefin Tuna occurring there.

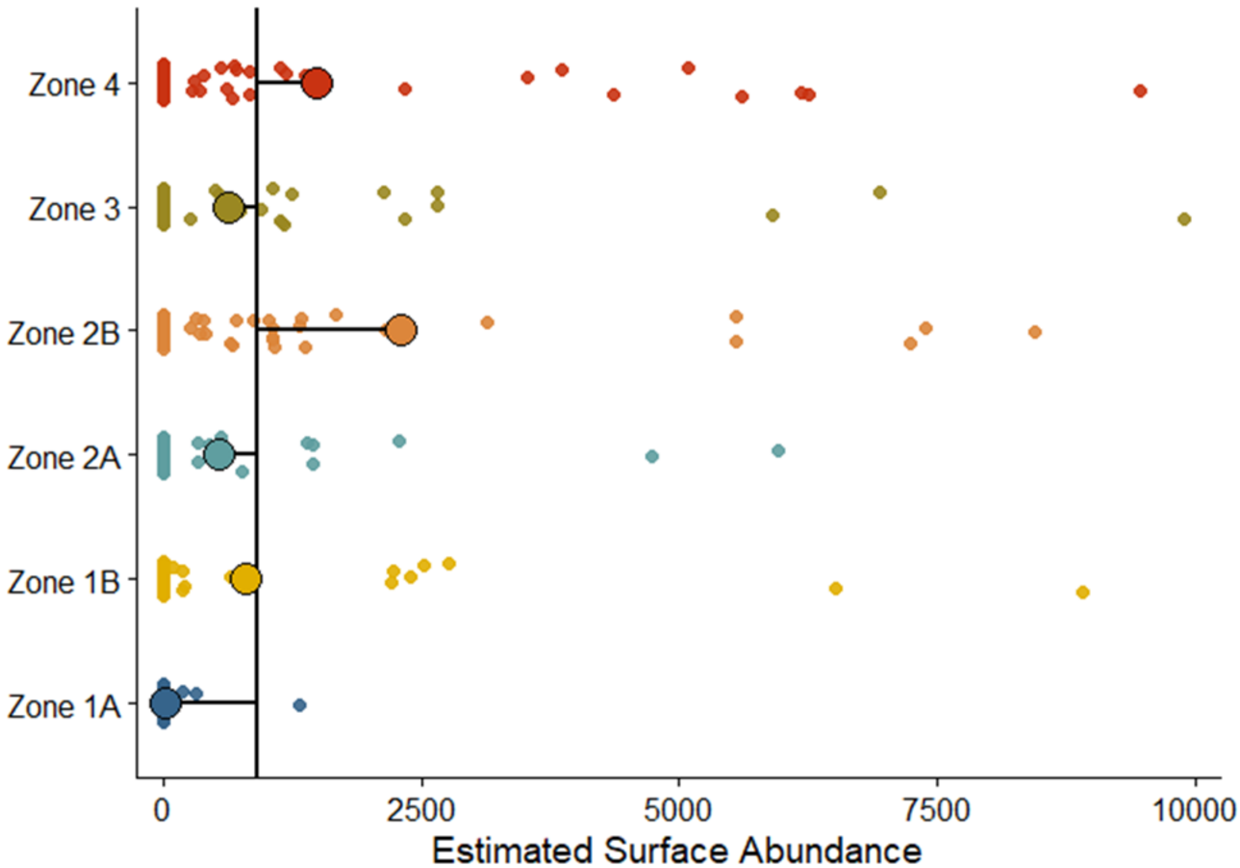

Figure 60. Estimated abundance for Mahi-Mahi in the Summer. Mahi-Mahi were most abundant in Zone 4 and Zone 2B.

Black vertical bar in the OPA is mean estimated abundance, and large circles with black outline represent the mean estimated abundance for each zone.

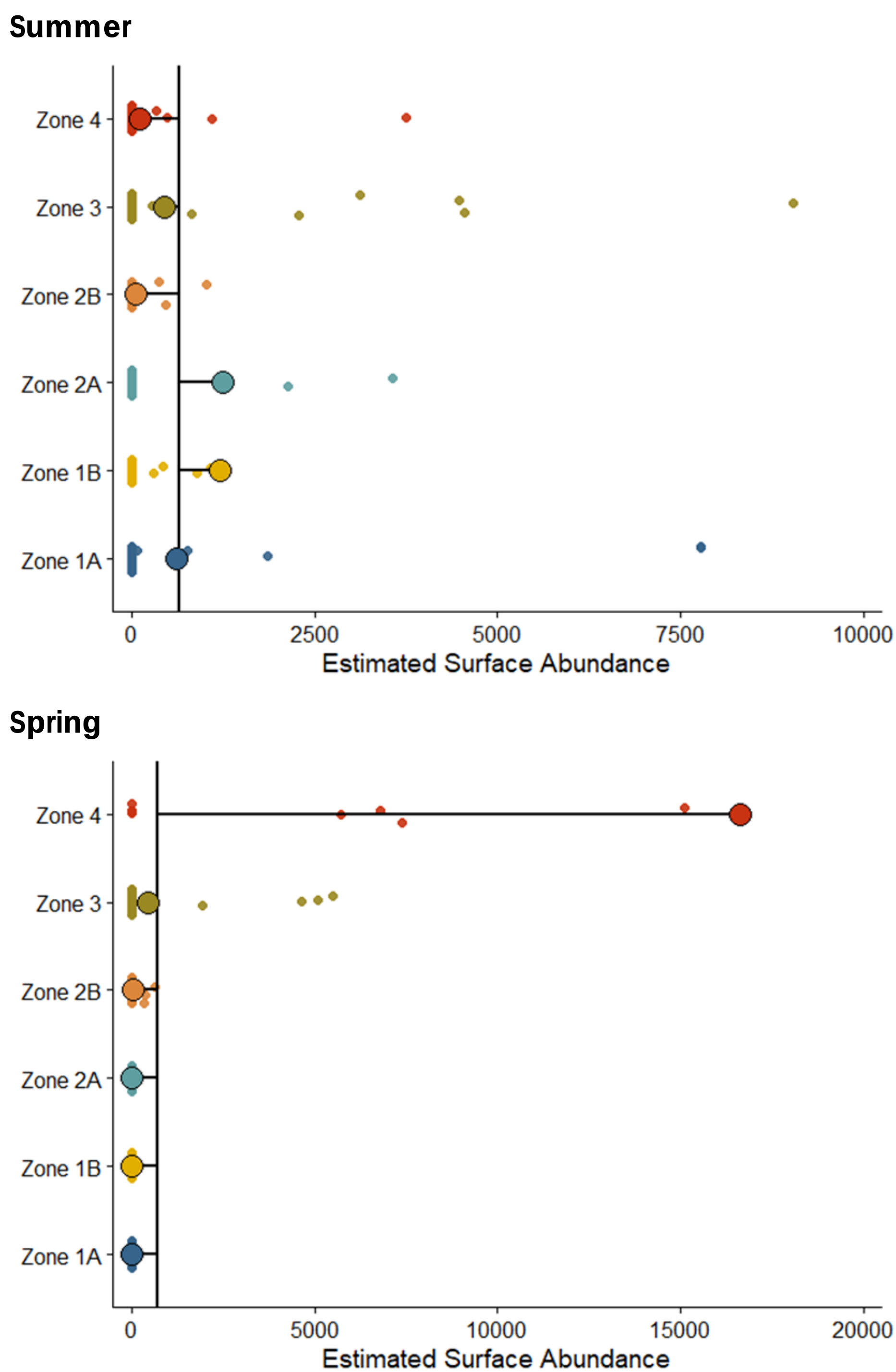

Figure 61. Estimated abundance for Tuna spp. in the Summer and Spring. In the Summer, Tuna were most abundant in Zone 2A and Zone 1B and in the Spring, abundance was greatest in Zone 4.

Black vertical bar in the OPA is mean estimated abundance, and large circles with black outline represent the mean estimated abundance for each zone.

4.2 Shoals

It was not possible to identify the fish occurring within the shoals to species for a number of reasons (large numbers, relatively small size, crowding, and even slight submergence combine to obscure distinctive characteristics). However, several schooling species are known to occur in the project area (NYSDEC 2007), and it is likely that the shoals observed in this survey were each assemblages of one of these species, including Atlantic Herring, Atlantic Mackerel, Atlantic Menhaden, or Hickory Shad. Winter shoals, found farther offshore than during other seasons, are more likely to be made up of Atlantic Herring, a planktivore and forage species with high commercial value. NEFSC (2018b) reported that spawning stock for Atlantic Herring has declined since around 2014, and that may partially account for the limited number of shoals observed in the Winter. In addition, with the absence of a pycnocline in the Winter, Atlantic Herring schools would not necessarily be located near enough to the surface to be observed.

Atlantic Menhaden, Atlantic Mackerel, and Hickory Shad would be expected to occur in warmer water from the spring through the fall. These species exhibit slightly different peaks in abundance in New York coastal waters (NYSDEC 2007). Populations of these three species extend both north and south of the OPA. Atlantic Menhaden and Atlantic Mackerel both range north into the Gulf of Maine whereas Hickory Shad ranges only to southern New England. All perform north-south migrations. It is likely that the numerous schools observed in the Summer 2016 survey were adult Atlantic Menhaden, a planktivore and important forage species for predators such as Striped Bass (ASMFC 2020). Nature Conservancy (2020) attributed the recent increase in marine mammals in New York Bight to increased populations of Atlantic Menhaden.

Fall shoals could have included some Atlantic Menhaden but could also have been made up of Atlantic Mackerel, another planktivore and important forage species that overwinters on the continental shelf between Long Island and Chesapeake Bay (Studholme et al. 1999). Atlantic Mackerel may also have been represented in the shoals observed in Spring surveys. Studholme et al. (1999) reported that this species moves inshore before moving north in late spring. NEFSC (2018a) reported two observations that would suggest Atlantic Mackerel are likely a smaller component of the fish shoals observed in this survey than Atlantic Menhaden: Atlantic Mackerel was being overfished, indicating a population that is not sustaining itself and fewer Atlantic Mackerel are migrating southward from New England in the early winter, suggesting a response to changing thermal conditions or observed changes in primary and secondary production in the Mid-Atlantic Bight.

Some of the shoals observed in Spring surveys may have been made up of Hickory Shad, an anadromous species, as adults congregate during their upriver spawning migration (Greene et al. 2009). Although Hickory Shad ranges from Florida to the Gulf of Maine, the largest populations occur between the Chesapeake Bay and North Carolina. As Atlantic Menhaden fishing begins in the spring in the Mid-Atlantic, it is also reasonable to assume that some of the shoals observed in the Spring surveys are made up of menhaden.

Results of this three-year survey indicate that there is a high degree of interannual variability in the number of shoals, particularly in the Summer. SEDAR (2020) noted, however, that in the region from Connecticut to Delaware, Atlantic Menhaden attained high abundances in 2014 through 2016 followed by a decline in 2017, matching the pattern observed in the aerial digital surveys.

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Appendix A. Distance (km) from Shore Data for Bony Fish by Season for Each Species

Season/Species	n	Distance from Shore (km)					
		Mean	Median	Min	Max	Standard Deviation	Standard Error of mean
Summer							
Atlantic bluefin tuna	319	48	44	21	151	28.4	1.6
Atlantic swordfish	22	129	128	73	161	22.6	4.8
Billfish-species unknown	19	116	129	8	185	49.2	11.3
Cobia	10	40	31	18	120	31.8	10.1
Mahi-Mahi	971	95	98	5	182	44.4	1.4
Ocean Sunfish	363	96	93	6	159	30.0	1.6
Sharptail Sunfish	3	111	93	92	146	31.1	17.9
Sunfish-species unknown	425	89	82	13	177	32.0	1.6
Tuna-species unknown	259	61	53	6	140	31.8	2.0
Unid. Fish-species unknown	434	81	84	2	166	31.9	1.5
Yellowfin tuna	22	140	140	140	140	0.0	0.0
Fall							
Atlantic bluefin tuna	18	96	100	78	100	7.2	1.7
Mahi-Mahi	14	127	162	21	166	54.2	14.5
Ocean Sunfish	249	119	130	13	187	40.0	2.5
Sharptail Sunfish	12	117	140	45	171	47.9	13.8
Sunfish-species unknown	15	101	115	43	151	37.6	9.7
Tuna-species unknown	5	28	13	13	90	34.5	15.4
Unid. Fish-species unknown	17	118	106	63	168	27.9	6.8
Winter							
Mahi-Mahi	2	74	74	43	105	43.7	30.9
Ocean Sunfish	19	146	158	20	180	38.1	8.7
Sunfish-species unknown	3	126	120	116	143	14.1	8.1
Tuna-species unknown	1	108	108	108	108	*NA*	*NA*
Unid. Fish-species unknown	5	46	18	14	127	48.8	21.8
Spring							
Atlantic bluefin tuna	537	154	156	72	159	6.4	0.3
Atlantic swordfish	1	158	158	158	158	*NA*	*NA*
Cobia	1	119	119	119	119	*NA*	*NA*
Mahi-Mahi	7	96	128	30	158	62.8	23.7
Ocean Sunfish	522	147	148	30	188	19.2	0.8
Sharptail Sunfish	1	153	153	153	153	*NA*	*NA*
Sunfish-species unknown	21	139	137	78	176	22.0	4.8
Tuna-species unknown	126	165	158	85	183	14.4	1.3
Unid. Fish-species unknown	441	39	2	1	173	61.7	2.9

Appendix B. Ocean Depth (m) Data for Bony Fish by Season by Season by Species

Season/Species	n	Estimated Ocean Depth (m)					
		Mean	Median	Min	Max	Standard Deviation	Standard Error of mean
Summer							
Atlantic bluefin tuna	319	77	30	30	600	121.7	6.8
Atlantic swordfish	22	259	125	75	600	240.2	51.2
Billfish-species unknown	19	256	125	30	600	243.5	55.9
Cobia	10	40	30	30	125	30.0	9.5
Mahi-Mahi	971	194	75	30	600	225.9	7.3
Ocean Sunfish	363	126	75	30	600	140.4	7.4
Sharptail Sunfish	3	183	75	75	400	187.6	108.3
Sunfish-species unknown	425	128	75	30	600	152.2	7.4
Tuna-species unknown	259	54	30	30	600	70.3	4.4
Unid. Fish-species unknown	434	97	75	30	600	116.4	5.6
Yellowfin tuna	22	400	400	400	400	0.0	0.0
Fall							
Atlantic bluefin tuna	18	75	75	75	75	0.0	0.0
Mahi-Mahi	14	403	600	30	600	274.8	73.4
Ocean Sunfish	249	261	125	30	600	235.0	14.9
Sharptail Sunfish	12	331	363	30	600	283.1	81.7
Sunfish-species unknown	15	100	125	30	200	56.8	14.7
Tuna-species unknown	5	39	30	30	75	20.1	9.0
Unid. Fish-species unknown	17	227	75	30	600	248.6	60.3
Winter							
Mahi-Mahi	2	53	74	30	75	31.8	22.5
Ocean Sunfish	19	504	158	30	600	203.0	46.6
Sunfish-species unknown	3	283	120	125	600	274.2	158.3
Tuna-species unknown	1	75	108	75	75	*NA*	*NA*
Unid. Fish-species unknown	5	64	18	30	200	76.0	34.0
Spring							
Atlantic bluefin tuna	537	584	600	75	600	79.8	3.4
Atlantic swordfish	1	600	600	600	600	*NA*	*NA*
Cobia	1	75	75	75	75	*NA*	*NA*
Mahi-Mahi	7	232	200	75	600	199.9	75.5
Ocean Sunfish	522	459	600	30	600	205.6	9.0
Sharptail Sunfish	1	600	600	600	600	*NA*	*NA*
Sunfish-species unknown	21	358	400	75	600	245.4	53.5
Tuna-species unknown	126	451	600	75	600	173.7	15.5
Unid. Fish-species unknown	441	139	30	30	600	217.6	10.4