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

Spatial and Temporal Marine Wildlife Distributions in the New York Offshore Planning Area, Summer 2016–Spring 2019

Final Report
Volume 5: Results (Sharks and Rays)

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APEM

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Abstract

NYSERDA tasked Normandeau Associates, Inc., and their teaming partner APEM Ltd. to collect aerial digital imagery over the New York Offshore Planning Area during 12 surveys spaced seasonally over three years between 2016 and 2019. Imagery was captured at a resolution of 1.5 cm at the sea surface and provides information on spatial and temporal abundances of birds, marine mammals, turtles, rays, sharks, large bony fishes, and fish shoals. Spatial patterns were analyzed within distance from shore and water depth zones and reference the proposed Call Areas within the surveyed planning area identified by BOEM at the time of writing. Seasonal density comparisons highlight the differences among zones for each species group. Except for turtles, densities were generally lower in the zone containing the identified BOEM Call Areas. Full Summary and Final Reports can also be found on remote.normandeau.com https://remote.normandeau.com/aer_docs.php?pj=6

Keywords

Marine mammals; Birds; Turtles; Rays; Sharks; Aerial Digital Surveys; NYSERDA; Normandeau; APEM; Call Area; Density; Distribution; Abundance; Marine Wildlife; Offshore Wind

Acknowledgments

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Normandeau would also like to thank Dr. Greg Skomal, Dr. Robert Kenney, Calusa Horn, Jessica Pate, and Dr. Nick Farmer for their taxonomic expertise and for their interest in the data generated by these surveys. Special thanks to Greg Lampman of NYSERDA for his help and support throughout the project. Normandeau would also like to thank the Project Advisory Committee for their interest and advice throughout the project.

All aerial images were collected by APEM Ltd., and flight height calculation methodology information was provided by APEM Ltd.

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1 Introduction

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 were conducted on a quarterly basis and timed to coincide with periods of abundance of bird and marine species that could be vulnerable to impacts from offshore wind activities.

Each survey collected images covering at least 7% of the OPA. All survey data have been summarized and are freely available at https://remote.normandeau.com/nys_aer_overview.php

This report summarizes the results of the 12 surveys for all shark and ray species. It is volume 5 of five volumes:

- Volume 1: Methods, General Results, Limitations, and Discussion
- Volume 2: Results (Birds)
- Volume 3: Results (Turtles)
- Volume 4: Results (Marine Mammals)
- Volume 5: Results (Sharks and Rays)

2 Results (Sharks and Rays)

There were 15 species of sharks and six species of rays identified in imagery during surveys of the OPA (Table 1). Over 12 surveys, 26,121 sharks were recorded with most encounters in the Spring 2018 survey, and 21,539 rays were recorded with most encountered during the Summer surveys (Table 2). Example images from each survey are in Appendix A.

Table 1. Shark and Ray Species Identified in Imagery Captured over 12 Surveys in the New York OPA

Common Name	Scientific Name
SHARKS AND RAYS	Chondrichthyes
Sharks	
Whale Shark [a]	*Rhincodon typus*
Sand Tiger Shark	*Carcharias taurus*
Thresher Shark	*Alopias vulpinus*
Basking Shark	*Cetorhinus maximus*
White Shark	*Carcharodon carcharias*
Shortfin Mako [a]	*Isurus oxyrinchus*
Blue Shark	*Prionace glauca*
Dusky Shark	*Carcharhinus obscurus*
Oceanic Whitetip Shark	*Carcharhinus longimanus*
Sandbar Shark	*Carcharhinus plumbeus*
Tiger Shark	*Galeocerdo cuvier*
Great Hammerhead	*Sphyrna mokarran*
Smooth Hammerhead	*Sphyrna zygaena*
Scalloped Hammerhead [a]	*Sphyrna lewini*
Spurdog	*Squalus acanthias*
Rays	
Bluntnose Stingray	*Dasyatis say*
Giant Manta Ray [a]	*Manta birostris*
Giant Devil Ray	*Mobula mobula*
Chilean Devil Ray	*Mobula tarapacana*
Bullnose Ray	*Myliobatis freminvillii*
Cownose Ray	*Rhinoptera bonasus*

[a] Listed under the Endangered Species Act

Table 2. Number of Sharks and Rays per Survey Identified in Imagery Captured over 12 Surveys in the New York OPA

Species	Total	Summer			Fall			Winter			Spring		
		2016	2017	2018	2016	2017	2018	2016–2017	2017–2018	2018–2019	2017	2018	2019
Shark	**26,121**	**643**	**1,382**	**413**	**4**	**13**	**2**	**26**	**11**	**1**	**180**	**22,934**	**512**
Whale Shark [a]	14	1	10	3	-	-	-	-	-	-	-	-	-
Sand Tiger Shark	1	-	1	-	-	-	-	-	-	-	-	-	-
Thresher Shark	7	2	5	-	-	-	-	-	-	-	-	-	-
Basking Shark	740	1	133	6	-	1	-	14	9	1	99	46	430
White Shark	19	1	13	1	-	1	1	-	-	-	2	-	-
Shortfin Mako [a]	7	1	4	2	-	-	-	-	-	-	-	-	-
Blue Shark	103	5	21	1	2	3	-	2	2	-	34	15	18
Carcharhinidae (unid.)	563	132	320	106	-	2	-	-	-	-	3	-	-
Dusky Shark	3	1	2	-	-	-	-	-	-	-	-	-	-
Oceanic Whitetip Shark	1	1	-	-	-	-	-	-	-	-	-	-	-
Sandbar Shark	21	-	21	-	-	-	-	-	-	-	-	-	-
Tiger Shark	15	4	8	2	-	1	-	-	-	-	-	-	-
Great Hammerhead	10	8	1	1	-	-	-	-	-	-	-	-	-
Smooth Hammerhead	73	9	56	7	-	1	-	-	-	-	-	-	-
Scalloped Hammerhead [a]	240	18	213	7	-	2	-	-	-	-	-	-	-
Hammerhead (unid.) [a]	472	123	232	115	1	1	-	-	-	-	-	-	-
Spurdog	22,936	-	-	-	-	-	-	2	-	-	-	22,871	63
species unknown	896	336	342	162	1	1	1	8	-	-	42	2	1
Ray	**21,539**	**8,103**	**7,624**	**5,797**	**4**	**2**	**8**	**0**	**0**	**0**	**0**	**0**	**1**
Bluntnose Stingray	1	1	-	-	-	-	-	-	-	-	-	-	-
Giant Manta Ray [a]	7	4	2	1	-	-	-	-	-	-	-	-	-
Giant Devil Ray	186	156	17	12	-	1	-	-	-	-	-	-	-
Chilean Devil Ray	131	70	48	13	-	-	-	-	-	-	-	-	-
Bullnose Ray	98	-	87	11	-	-	-	-	-	-	-	-	-
Cownose/Bullnose Ray	8,026	3,464	1,979	2,575	1	-	6	-	-	-	-	-	1
Cownose Ray	10,003	3,275	4,229	2,499	-	-	-	-	-	-	-	-	-
species unknown	3,087	1,133	1,262	686	3	1	2	-	-	-	-	-	-
Totals	**47,660**	**8,746**	**9,006**	**6,210**	**8**	**15**	**10**	**26**	**11**	**1**	**180**	**22,934**	**513**

[a] Listed under the Endangered Species Act

2.1 Species Identification

2.1.1 Sharks

Over all surveys, the identification success for sharks varied among taxonomic groups (Table 3). Of the 26,121 sharks found in the 12 surveys, 88% (n=22,936) were spurdog species, most of which were found in the Spring 2018 survey (Table 2; Figure 1). Of the remaining sharks, 4% (n=896) were identified as shark-species unknown, 2% (n=563) were Carcharhinidae (unid.), and 2% (n=472) were hammerhead (unid.), making 1,931 unidentified sharks and an identification success rate of 93% to species (Table 2). Many of these species are difficult to distinguish even at close quarters. There were 316 (56%) of the Carcharhinidae (unid.), 250 (53%) of the hammerhead (unid.), and 530 (59%) of the shark-species unknown that were significantly submerged (Table 4).

At the species group level for sharks there was 99.9% agreement between the original identification and the QC identification; of 5,579 targets initially identified as sharks, only 10 were assigned as "unknown." Shark species accuracy was >80% for most species (Table 3).

Figure 1. Spurdogs Found in the Spring 2018 Survey

2.1.2 Rays

Across all surveys, 48% of rays (n=10,426) were ascribed to species (Table 2). There were 8,026 rays ascribed to the species blend cownose/bullnose ray and 3,087 as ray-species unknown (Table 2). Of the cownose/bullnose ray group, 69% (n=5,557) were rated as significantly submerged as were 84% (n=2,578) of the ray-species unknown (Table 4).

At the species group level for rays there was 99.9% agreement between the original identification and the QC identification; of 4,088 targets initially identified as rays, three were assigned as "other." Species accuracy for individual ray species was also high (>98%) except for the initial identifications of giant devil ray and Chilean devil ray, which were around 10–12% and went through further review by additional taxonomic experts (Table 5).

Table 3. Initial Identification Accuracy and QC ID Accuracy for Shark Species

Species	Initial ID Success	QC ID Success	n (initial ID)	n (QC ID)
Whale Shark [a]	100.0%	100.0%	3	3
Thresher Shark	100.0%	100.0%	3	3
Basking Shark	94.2%	98.5%	137	131
White Shark	100.0%	100.0%	2	2
Shortfin Mako [a]	100.0%	100.0%	4	4
Blue Shark	94.1%	100.0%	17	16
Carcharhinidae (unid.)	85.1%	89.9%	94	89
Dusky Shark	50.0%	100.0%	2	1
Sandbar Shark	100.0%	100.0%	4	4
Tiger Shark	83.3%	100.0%	6	5
Great Hammerhead	100.0%	50.0%	2	4
Smooth Hammerhead	83.3%	90.9%	12	11
Scalloped Hammerhead [a]	89.7%	97.6%	224	206
Hammerhead (unid.) [a]	94.2%	94.2%	362	362
Spurdog	100.0%	100.0%	4,564	4,564
Shark-species unknown	88.1%	76.8%	143	164
unknown object	NA [b]	0.0%	0	10

[a] Listed under the Endangered Species Act

[b] An NA value means that no individuals of that species group were identified by the respective observer.

Table 4. Number of Significantly Submerged Shark and Ray Individuals per Survey

Species	Total	Summer			Fall			Winter			Spring		
		2016	2017	2018	2016	2017	2018	2016–2017	2017–2018	2018–2019	2017	2018	2019
Shark	**1,567**	**1**	**995**	**287**	**3**	**2**	**1**	**15**	**5**	**0**	**111**	**74**	**73**
Whale Shark [a]	**6**	0	4	2	0	0	0	0	0	0	0	0	0
Sand Tiger Shark	**0**	0	0	0	0	0	0	0	0	0	0	0	0
Thresher Shark	**4**	0	4	0	0	0	0	0	0	0	0	0	0
Basking Shark	**290**	0	125	0	0	0	0	8	4	0	68	14	71
White Shark	**8**	0	5	1	0	0	0	0	0	0	2	0	0
Shortfin Mako [a]	**0**	0	0	0	0	0	0	0	0	0	0	0	0
Blue Shark	**19**	0	9	0	1	1	0	0	1	0	6	0	1
Carcharhinidae (unid.)	**316**	1	255	59	0	0	0	0	0	0	1	0	0
Dusky Shark	**0**	0	0	0	0	0	0	0	0	0	0	0	0
Oceanic Whitetip Shark	**0**	0	0	0	0	0	0	0	0	0	0	0	0
Sandbar Shark	**2**	0	2	0	0	0	0	0	0	0	0	0	0
Tiger Shark	**0**	0	0	0	0	0	0	0	0	0	0	0	0
Great Hammerhead	**1**	0	1	0	0	0	0	0	0	0	0	0	0
Smooth Hammerhead	**13**	0	11	2	0	0	0	0	0	0	0	0	0
Scalloped Hammerhead [a]	**70**	0	70	0	0	0	0	0	0	0	0	0	0
Hammerhead (unid.) [a]	**250**	0	174	75	1	0	0	0	0	0	0	0	0
Spurdog	**58**	0	0	0	0	0	0	0	0	0	0	58	0
species unknown	**530**	0	335	148	1	1	1	7	0	0	34	2	1
Ray	**11,674**	**4,382**	**4,229**	**3,053**	**1**	**1**	**8**	**0**	**0**	**0**	**0**	**0**	**0**
Bluntnose Stingray	**1**	1	0	0	0	0	0	0	0	0	0	0	0
Giant Manta Ray [a]	**3**	2	1	0	0	0	0	0	0	0	0	0	0
Giant Devil Ray	**86**	74	6	6	0	0	0	0	0	0	0	0	0
Chilean Devil Ray	**36**	14	17	5	0	0	0	0	0	0	0	0	0
Bullnose Ray	**16**	0	14	2	0	0	0	0	0	0	0	0	0
Cownose/Bullnose Ray	**5,557**	2,172	1,758	1,620	1	0	6	0	0	0	0	0	0
Cownose Ray	**3,397**	1,405	1,180	812	0	0	0	0	0	0	0	0	0
species unknown	**2,578**	714	1,253	608	0	1	2	0	0	0	0	0	0
Totals	**13,241**	**4,383**	**5,224**	**3,340**	**4**	**3**	**9**	**15**	**5**	**0**	**111**	**74**	**73**

[a] Listed under the Endangered Species Act

Table 5. Initial Identification Accuracy and QC ID Accuracy for Ray Species

Species	Initial ID Success	QC ID Success	n (initial ID)	n (QC ID)
Giant Manta Ray [a]	100.0%	4.8%	3	62
Giant Devil Ray	10.7%	100.0%	28	3
Chilean Devil Ray	12.5%	100.0%	16	2
Bullnose Ray	100.0%	100.0%	6	6
Cownose/Bullnose Ray	97.7%	98.6%	1,758	1,742
Cownose Ray	98.7%	98.4%	1,904	1,910
Ray-species unknown	93.3%	96.7%	373	360
unknown object	NA [b]	0.0%	0	3

[a] Listed under the Endangered Species Act

[b] An NA value means that no individuals of that species group were identified by the respective observer.

2.2 Species Composition and Density per Survey

2.2.1 Sharks

Fifteen species of sharks were identified among the 12 surveys. The highest species richness occurred during Summer surveys when 10 (2018) to 14 (2017) species were recorded. Most (88%) shark observations (spurdog) occurred during the Spring 2018 survey (7.31 sharks/km^2) with that species also found in the Spring 2019 survey but in much lower numbers (0.02 per km^2) (Table 6). The remaining shark observations were mainly in the Summer surveys across the OPA. Only blue sharks, basking sharks, white sharks, Carcharhinidae (unid.), scalloped hammerheads, smooth hammerheads, tiger sharks, hammerheads (unid.), and shark-species unknown were observed during the Fall surveys, and abundances of these species were typically one to two orders of magnitude lower than during Summer surveys (Table 6). During the Winter surveys, only basking sharks, blue sharks, spurdogs, and shark-species unknown were found, and abundances were generally low (Table 6). Basking sharks, white sharks, blue sharks, Carcharhinidae (unid.), spurdogs, and shark-species unknown were found in the Spring surveys (Table 6). Basking sharks and blue sharks were the only species found in all seasons, although not in every survey. White sharks occurred in every season except Winter. Tiger sharks, smooth hammerheads, scalloped hammerheads, and hammerhead (unid.) were found in Summer and Fall surveys. All other species occurred only in Summer (Table 6).

2.2.2 Rays

Rays were mostly observed in the OPA during the Summer surveys with a few individuals in Fall surveys (Table 7) and one ray in the Spring 2019 survey. Densities were two to three orders of magnitude greater in the Summer surveys than the Fall when only <1% of ray observations occurred (Table 7). Of the 6.8 rays/km^2 recorded in the Summer surveys, 47% (3.2 rays/km^2) were cownose rays, 49% (3.3 rays/km^2) were identified as cownose/bullnose rays, <1% bullnose rays, 1% giant devil rays, <1% Chilean devil rays, <1% giant manta rays, and <1% bluntnose stingrays (Table 7); there were five species identified in the each of the Summer surveys. The remaining 14% (0.98 rays/km^2) were not ascribed to species or species group (Table 7). Of the 14 rays recorded during the Fall surveys, one giant devil ray and seven cownose/bullnose rays were identified (Table 7). The one ray species recorded in the Spring 2019 survey was in the cownose/bullnose ray species group. The remaining rays were not ascribed to species or species group (Table 7).

Table 6. Density (per km^2) and Percent of Total for Shark Species in the OPA from the Summer 2016 through Spring 2019 Surveys

Species	Summer						Fall						Winter						Spring						Total
	2016		2017		2018		2016		2017		2018		2016–2017		2017–2018		2018–2019		2017		2018		2019		
	Density	%	Density	%	Density	%	Density	%	Density	%	Density	%	Density	%	Density	%	Density	%	Density	%	Density	%	Density	%	
Whale Shark [a]	0.0003	7.14	0.0032	71.43	0.0010	21.43	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0045
Sand Tiger Shark	-	-	0.0003	100.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0003
Thresher Shark	0.0006	28.57	0.0016	71.43	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0022
Basking Shark	0.0003	0.14	0.0424	17.97	0.0019	0.81	-	-	0.0003	0.14	-	-	0.0035	1.89	0.0029	1.22	0.0003	0.14	0.0301	13.38	0.0147	6.22	0.1363	58.11	0.2328
White Shark	0.0003	5.26	0.0041	68.42	0.0003	5.26	-	-	0.0003	5.26	0.0003	5.26	-	-	-	-	-	-	0.0006	10.53	-	-	-	-	0.0060
Shortfin Mako [a]	0.0003	14.29	0.0013	57.14	0.0006	28.57	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0022
Blue Shark	0.0016	4.85	0.0067	20.39	0.0003	0.97	0.0005	1.94	0.0009	2.91	-	-	0.0005	1.94	0.0006	1.94	-	-	0.0103	33.01	0.0048	14.56	0.0057	17.48	0.0320
Carcharhinidae (unid.)	0.0412	23.45	0.1021	56.84	0.0336	18.83	-	-	0.0006	0.36	-	-	-	-	-	-	-	-	0.0009	0.53	-	-	-	-	0.1785
Dusky Shark	0.0003	33.33	0.0006	66.67	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0010
Oceanic Whitetip Shark	0.0003	100.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0003
Sandbar Shark	-	-	0.0067	100.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0067
Tiger Shark	0.0012	26.67	0.0026	53.33	0.0006	13.33	-	-	0.0003	6.67	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0048
Great Hammerhead	0.0025	80.00	0.0003	10.00	0.0003	10.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0031
Smooth Hammerhead	0.0028	12.33	0.0179	76.71	0.0022	9.59	-	-	0.0003	1.37	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0232
Scalloped Hammerhead [a]	0.0056	7.50	0.0680	88.75	0.0022	2.92	-	-	0.0006	0.83	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0764
Hammerhead (unid.) [a]	0.0384	26.06	0.0740	49.15	0.0365	24.36	0.0003	0.21	0.0003	0.21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.1495
Spurdog	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.01	-	-	-	-	-	-	7.3147	99.72	0.0200	0.27	7.3352
species unknown	0.1049	37.50	0.1091	38.17	0.0514	18.08	0.0003	0.11	0.0003	0.11	0.0003	0.11	0.0020	0.89	-	-	-	-	0.0128	4.69	0.0006	0.22	0.0003	0.11	0.2821
Total	**0.2007**	**2.46**	**0.4410**	**5.29**	**0.1311**	**1.58**	**0.0010**	**0.02**	**0.0041**	**0.05**	**0.0006**	**0.01**	**0.0066**	**0.10**	**0.0035**	**0.04**	**0.0003**	**0.00**	**0.0547**	**0.69**	**7.3349**	**87.80**	**0.1623**	**1.96**	**8.3408**

[a] Listed under the Endangered Species Act

Table 7. Density (per km^2) and Percent of Total for Ray Species in the OPA from the Summer 2016 through Spring 2019 Surveys

Species	Summer						Fall						Winter						Spring						Total
	2016		2017		2018		2016		2017		2018		2016–2017		2017–2018		2018–2019		2017		2018		2019		
	Density	%	Density	%	Density	%	Density	%	Density	%	Density	%	Density	%	Density	%	Density	%	Density	%	Density	%	Density	%	
Bluntnose Stingray	0.0003	100.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0003
Giant Manta Ray [a]	0.0012	57.14	0.0006	28.57	0.0003	14.29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0022
Giant Devil Ray	0.0487	83.87	0.0054	9.14	0.0038	6.45	-	-	0.0003	0.54	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0582
Chilean Devil Ray	0.0218	53.44	0.0153	36.64	0.0041	9.92	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0413
Bullnose Ray	-	-	0.0278	88.78	0.0035	11.22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0313
Cownose/Bullnose Ray	1.0811	43.16	0.6316	24.66	0.8174	32.08	0.0003	0.01	-	-	0.0019	0.07	-	-	-	-	-	-	-	-	-	-	0.0003	0.01	2.5325
Cownose Ray	1.0222	32.74	1.3496	42.28	0.7932	24.98	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.1650
species unknown	0.3536	36.70	0.4027	40.88	0.2178	22.22	0.0008	0.10	0.0003	0.03	0.0006	0.06	-	-	-	-	-	-	-	-	-	-	-	-	0.9758
Total	**2.5290**	**37.62**	**2.4331**	**35.40**	**1.8401**	**26.91**	**0.0010**	**0.02**	**0.0006**	**0.01**	**0.0025**	**0.04**	**-**	**--**	**-**	**--**	**-**	**--**	**-**	**--**	**-**	**--**	**0.0003**	**0.00**	**6.8067**

[a] Listed under the Endangered Species Act

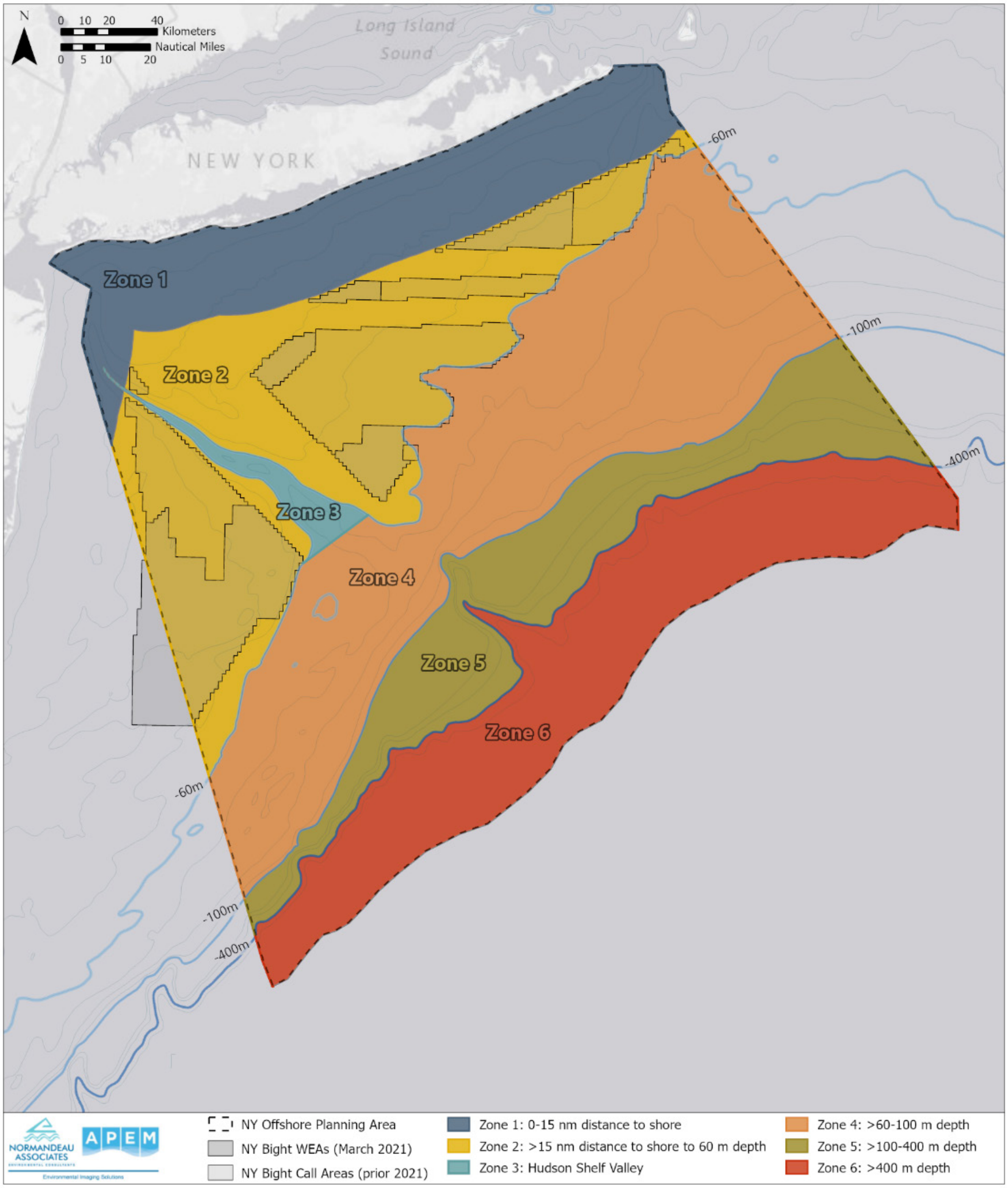
2.3 Spatial Distribution and Direction of Travel

To account for spatial variation more effectively within the OPA, six discrete zones were considered (Figure 2).

- Zone 1: Coastal Zone
- Zone 2: Area for Consideration Zone
- Zone 3: Hudson Shelf Valley Zone
- Zone 4: Shelf Zone
- Zone 5: Shelf Slope Zone
- Zone 6: Shelf Break Zone

Density was quantified for species with 30 or more total observations by dividing the total count of individuals of a species within the strip transect by the strip transect area. Densities are presented as individuals per square kilometer (km^2) surveyed plus or minus standard error of the mean. On the resulting heat maps, density is scaled to the maximum density across all seasons for each taxon. For species with fewer than 30 total observations, a single point map shows the occurrence record spatially and temporally. To gain a deeper understanding of direction of travel, a Rao spacing test was used for species and seasons with greater than 30 occurrences to test the hypothesis that the underlying direction of travel distribution is uniform and report the test statistic as t and the p-value as p where appropriate.

Figure 2. Zones Defined in the Analyses and Location of the Call Areas



2.3.1 Sharks

Throughout the OPA, 26,121 sharks were observed (Table 2). Considering all sharks, mean density was greatest during Spring (n=23,626; $\bar{x}$ = 1.20 ± 0.77 sharks/km^2), nearly four times that of Summer (n=2,438; $\bar{x}$ = 0.33 ± 0.09 sharks/km^2) and a magnitude of order greater than density during Winter (n=38) and Fall (n=19) when shark density was relatively extremely low (Table 2, Figure 3, Figure 4). The disparity in observations was driven wholly by 22,934 spurdogs observed during Spring surveys. During Spring, density in Zone 4 was four times higher than the mean density of the OPA (n=21,939; $\bar{x}$ = 4.68 ± 3.95 sharks/km^2), and during Summer, Zone 1 had above-average density, but density was also variable (n=576; $\bar{x}$ = 0.75 ± 0.41 sharks/km^2) (Figure 4). During Fall and Winter, travel direction was mixed (Figure 5). During Spring, travel direction was non-uniform ($t = 287.6$, $p < 0.001$), and sharks exhibited a slight preference for travel to the northeast. During Summer, travel direction was non-uniform ($t = 304.6$, $p < 0.001$), and sharks exhibited a bimodal pattern of travel either to the west or east (Figure 5).

2.3.1.1 Shark Species with Fewer than 30 Observations

Shark species with fewer than 30 observations included whale shark (n=14), sand tiger shark (n=1), thresher shark (n =7), white shark (n=19), shortfin mako (n=7), dusky shark (n=3), oceanic whitetip shark (n=1), sandbar shark (n=21), tiger shark (n =15), and great hammerhead (n=10) (Table 2, Figure 6, Figure 7). Only five observations of these species occurred outside of Summer surveys. During Summer, observations were widely distributed throughout the OPA (Figure 6, Figure 7).

Figure 3. Spatial Distribution of Sharks During Fall and Winter by Zone and Proximity to Call Areas

Heat map density maximum is scaled to the maximum density for the species/species group across all seasons. Inset figure shows estimated densities within each Zone ± standard error of the mean.

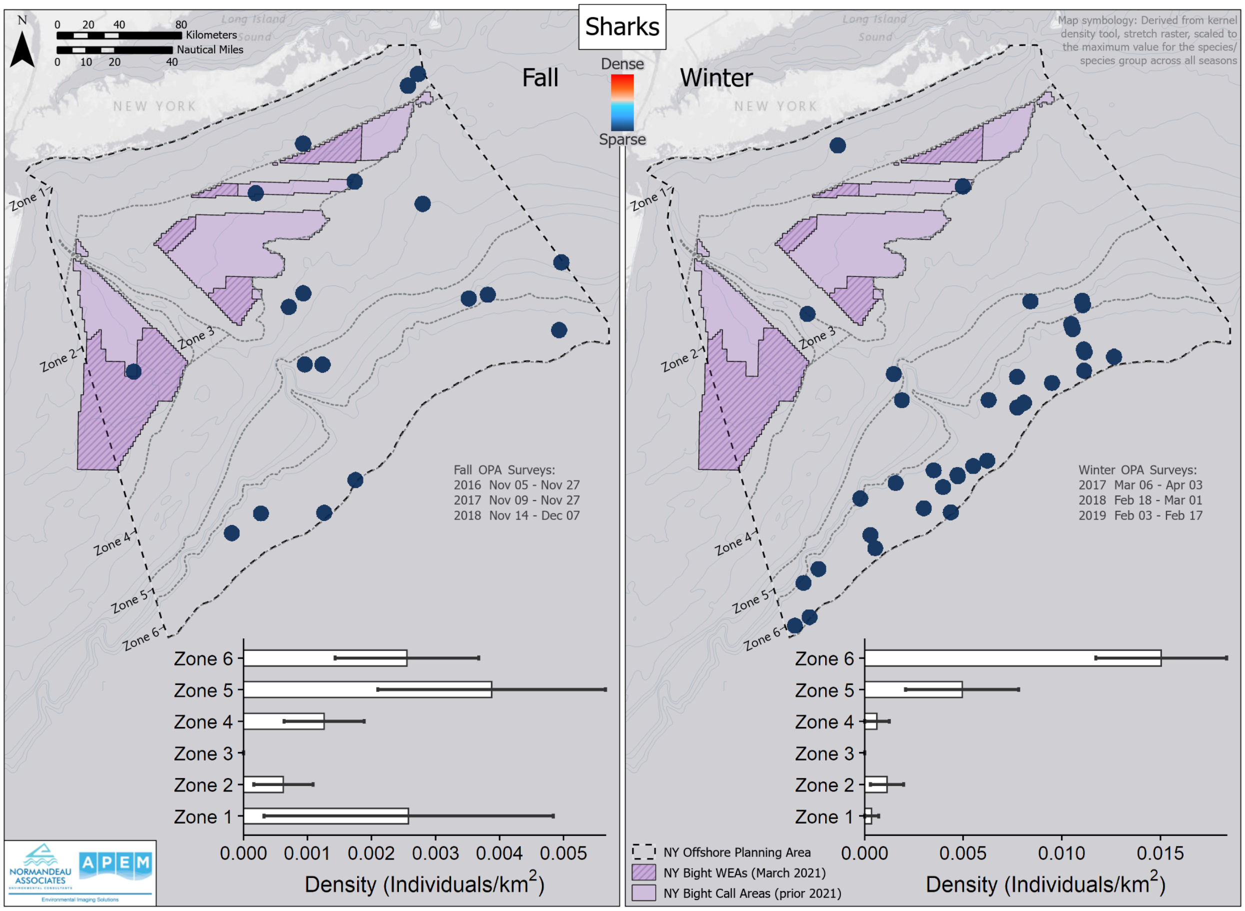


Figure 4. Spatial Distribution of Sharks During Spring and Summer by Zone and Proximity to Call Areas

Heat map density maximum is scaled to the maximum density for the species/species group across all seasons. Inset figure shows estimated densities within each Zone ± standard error of the mean.

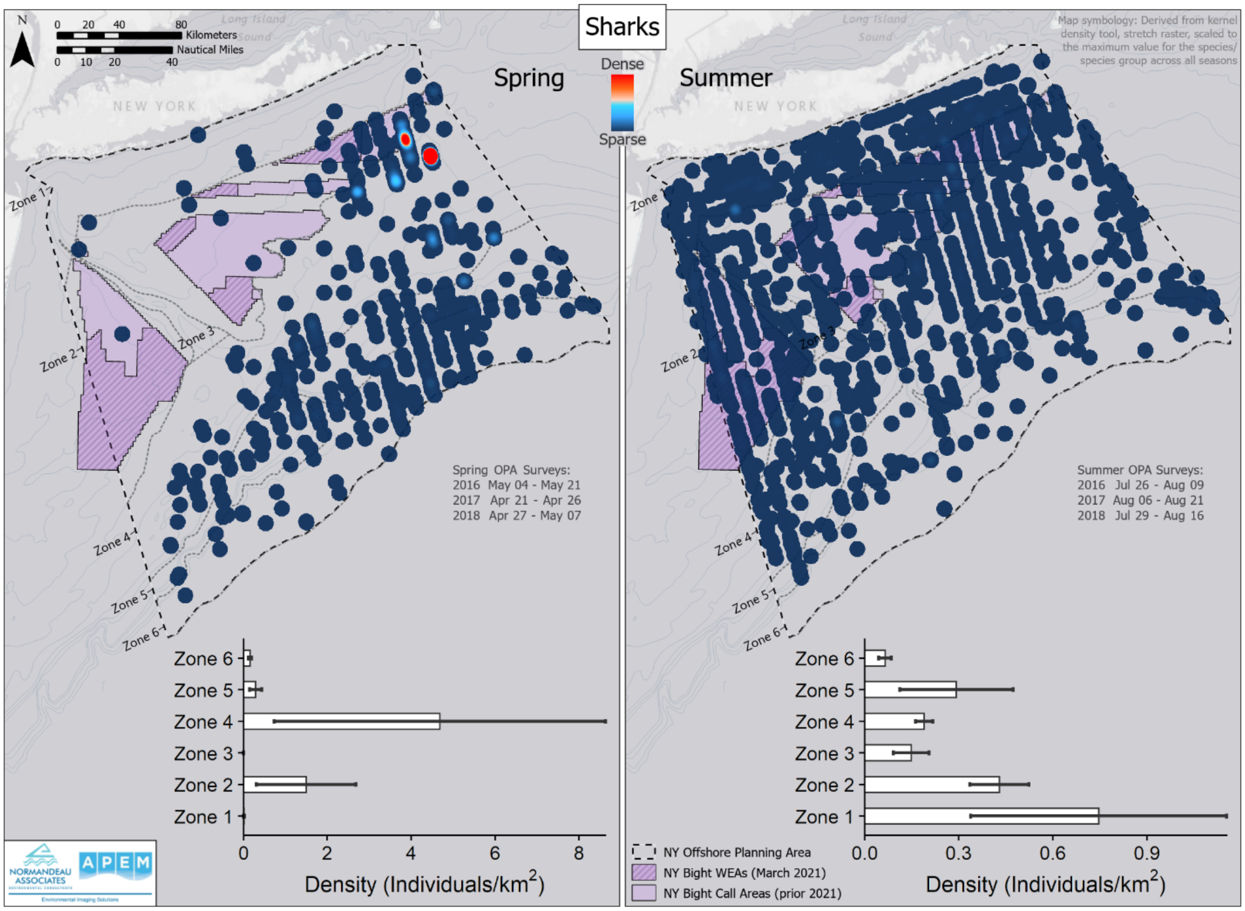


Figure 5. Direction of Travel of All Sharks for All Surveys

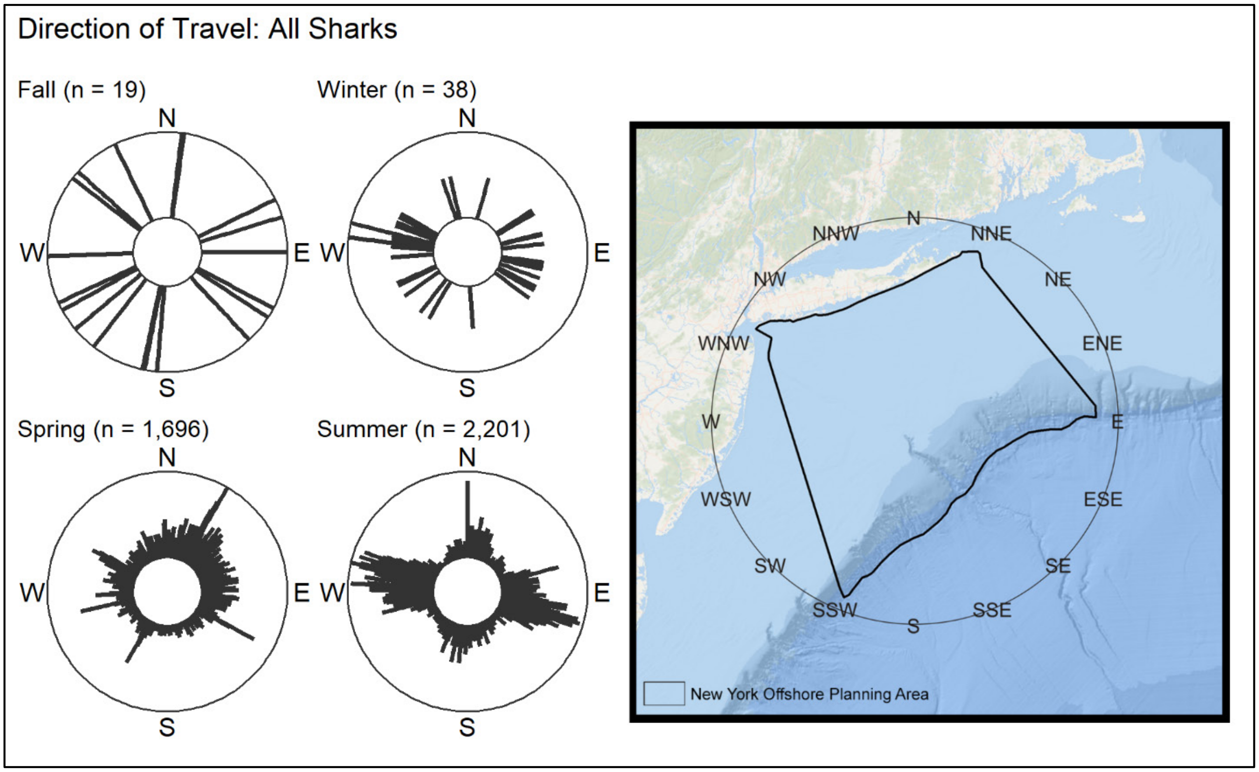


Figure 6. Spatial Distribution of Shark Species with Fewer than 30 Occurrences Across All Surveys

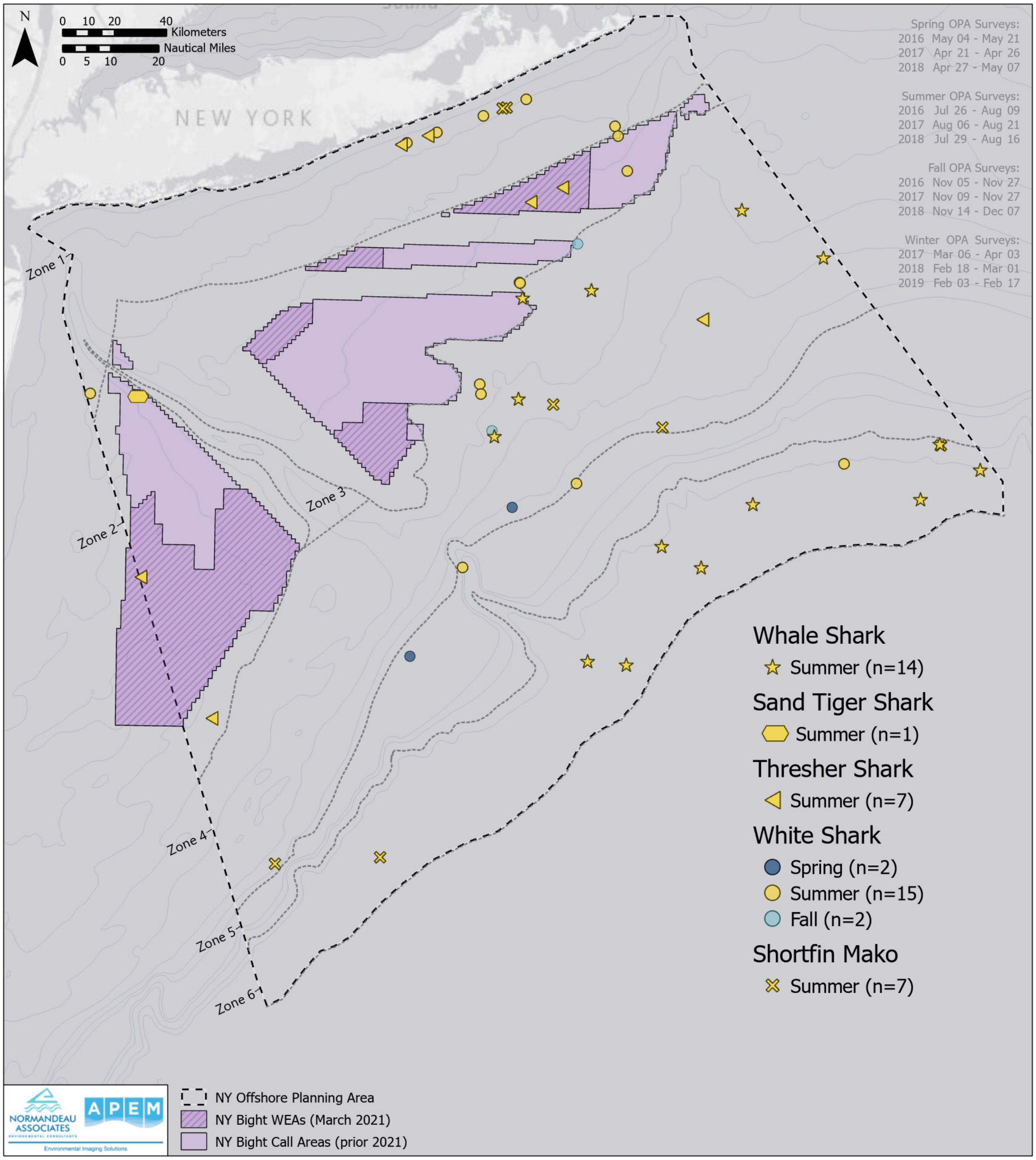
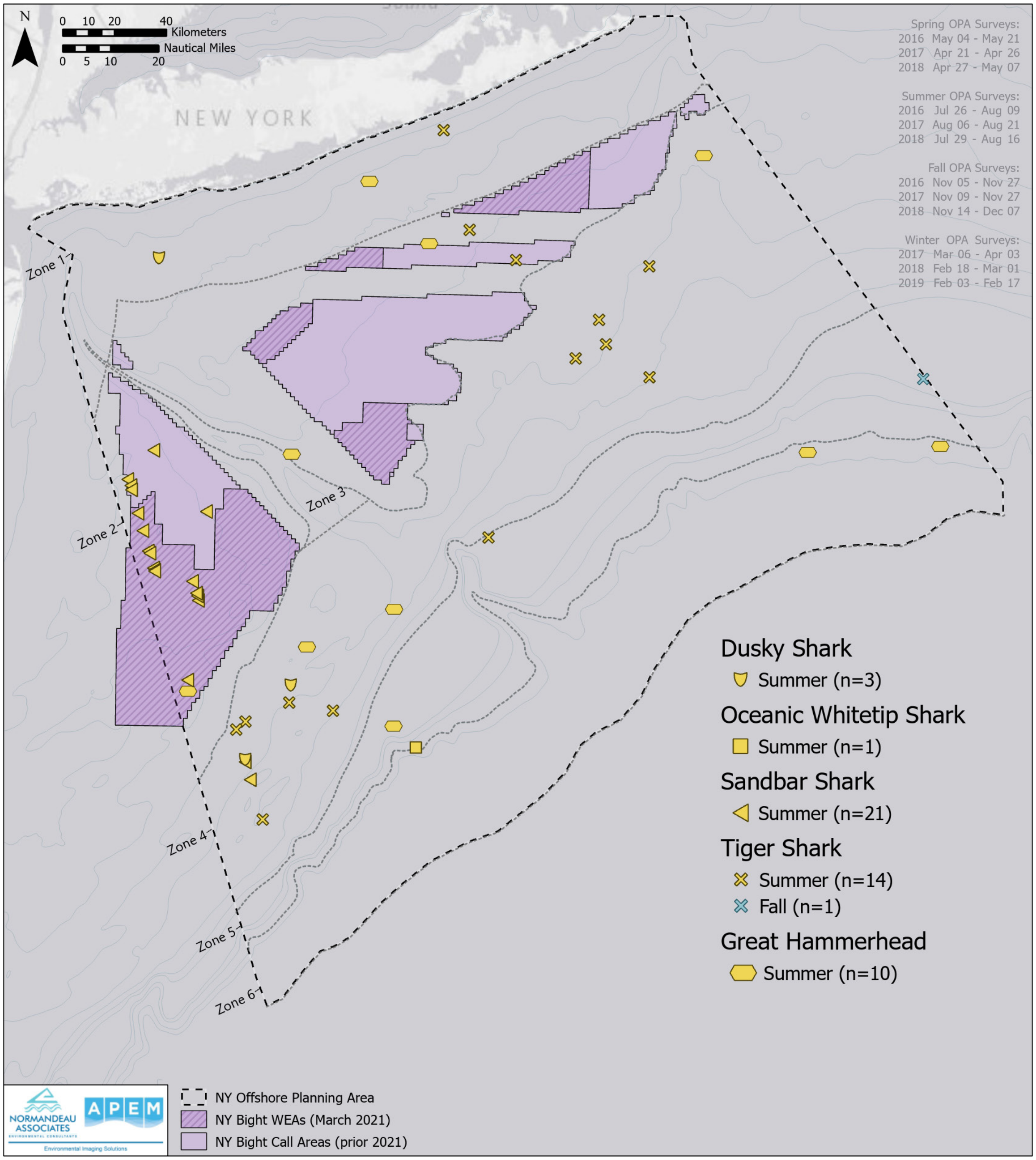


Figure 7. Spatial Distribution of Shark Species with Fewer than 30 Occurrences Across All Surveys



2.3.1.2 Non-hammerhead Shark Species

Non-hammerhead shark species (n=23,867) accounted for most shark observations, 96% of which were spurdogs (n=22,936) (Table 2). Mean density was greatest during Spring (n=23,578; $\bar{x}$ = 1.20 ± 0.76 sharks/km^2) followed by Summer (n=250; $\bar{x}$ = 0.02 ± 0.006 sharks/km^2), Winter (n=30), and Fall (n=9) (Table 2, Figure 8, Figure 9). During Fall, Winter, and Summer surveys, travel direction was non-uniform, and no distinct patterns of travel direction were observed. However, during the Spring, travel direction was non-uniform ($t = 285.5$, $p < 0.001$), and there was an observable preference for travel to the northeast—a pattern driven by spurdog (Figure 10).

Basking Shark

Basking shark (n=740) density was greatest during Spring (n=575; $\bar{x}$ = 0.06 ± 0.01 sharks/km^2) followed by Summer (n=140; $\bar{x}$ = 0.01 ± 0.006 sharks/km^2). Relatively low densities were observed during the Winter (n=24) and Fall (n =1) (Table 2, Figure 11, Figure 12). During Spring, basking shark density was greatest within Zones 5 and 6, and during Summer, density was greatest within Zone 2 (Figure 12). During Fall, Winter, and Summer surveys, there were no clear patterns associated with direction of travel (Figure 13). During Spring, travel direction was non-uniform ($t = 204.6$, $p < 0.001$), and basking sharks exhibited a multimodal distribution with peaks of travel direction to the northeast, southeast, southwest, and northwest (Figure 13).

Blue Shark

Blue shark (n=103) density was greatest during Spring (n=67; $\bar{x}$ = 0.008 ± 0.002 sharks/km^2) followed by Summer (n=27; $\bar{x}$ = 0.002 sharks/km^2). There were few observations during Fall (n=5) and Winter (n=4) (Figure 14, Figure 15). During Spring, Zones 5 and 6 had the greatest densities, and during Summer, density was relatively even throughout the OPA (Figure 14, Figure 15). Across all seasons, travel direction was non-uniform and there were no clear patterns of direction of travel (Figure 16).

Spurdog

During the Springs surveys, 22,934 spurdog were observed (Table 2, Figure 17). There were two spurdogs observed during Winter and no observations during Fall and Winter (Table 2, Figure 17). Spurdog observations were concentrated within the northernmost portion of Zone 4 where the individuals exhibited a predominantly direction of travel to the northeast (Figure 17, Figure 18).

Figure 8. Spatial Distribution of Non-Hammerhead Sharks During Fall and Winter by Zone and Proximity to Call Areas

Heat map density maximum is scaled to the maximum density for the species/species group across all seasons. Inset figure shows estimated densities within each Zone ± standard error of the mean.

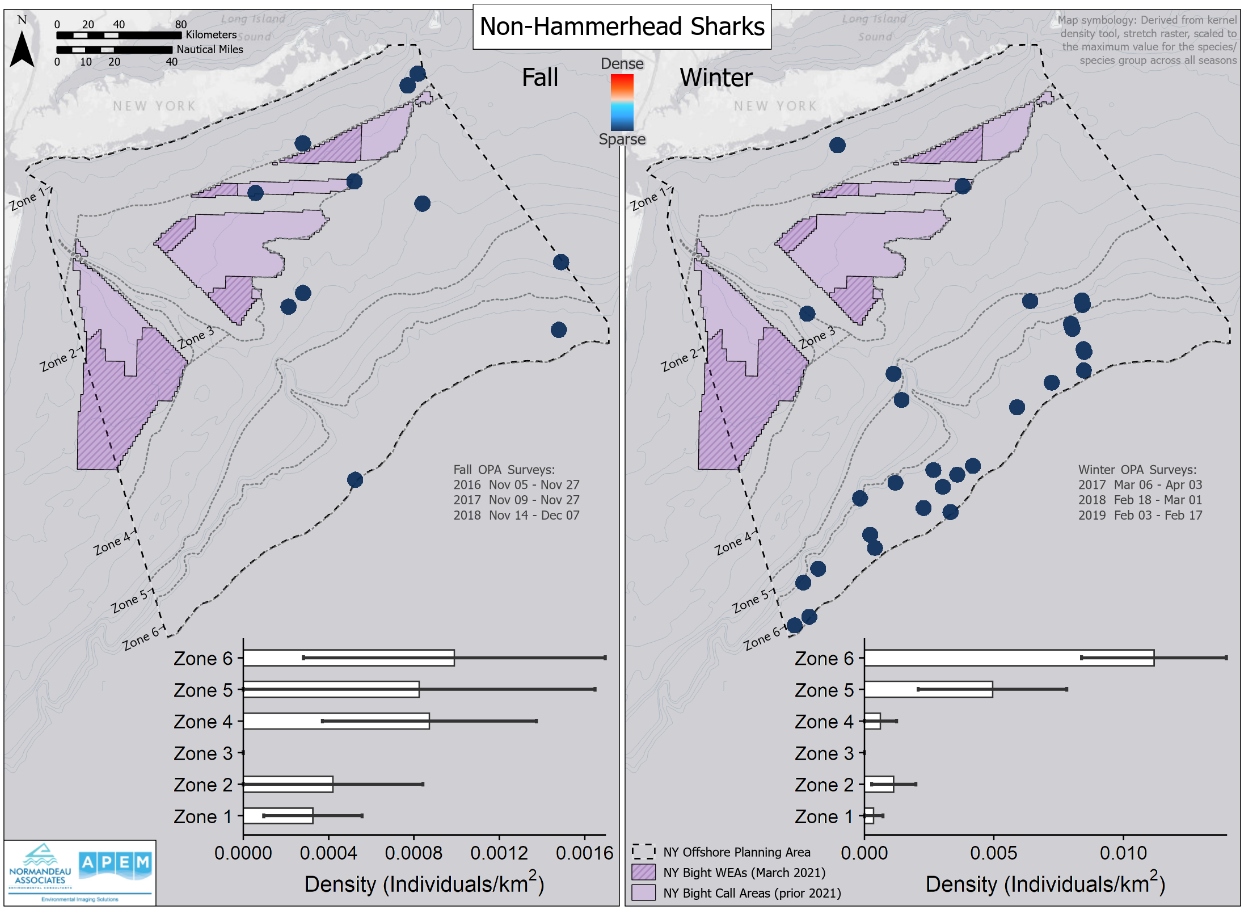


Figure 9. Spatial Distribution of Non-Hammerhead Sharks During Spring and Summer by Zone and Proximity to Call Areas

Heat map density maximum is scaled to the maximum density for the species/species group across all seasons. Inset figure shows estimated densities within each Zone ± standard error of the mean.

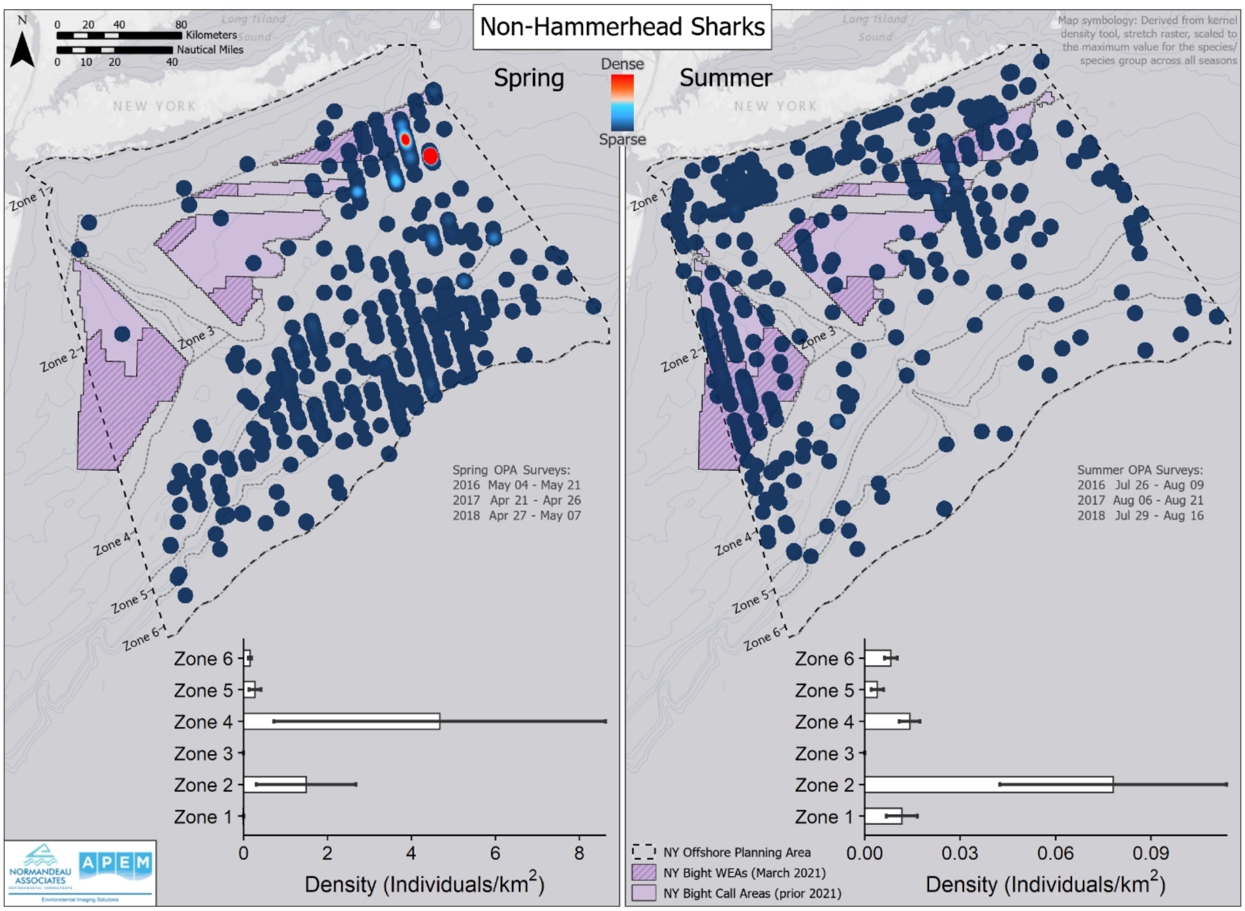


Figure 10. Direction of Travel of Non-hammerhead Sharks for All Surveys

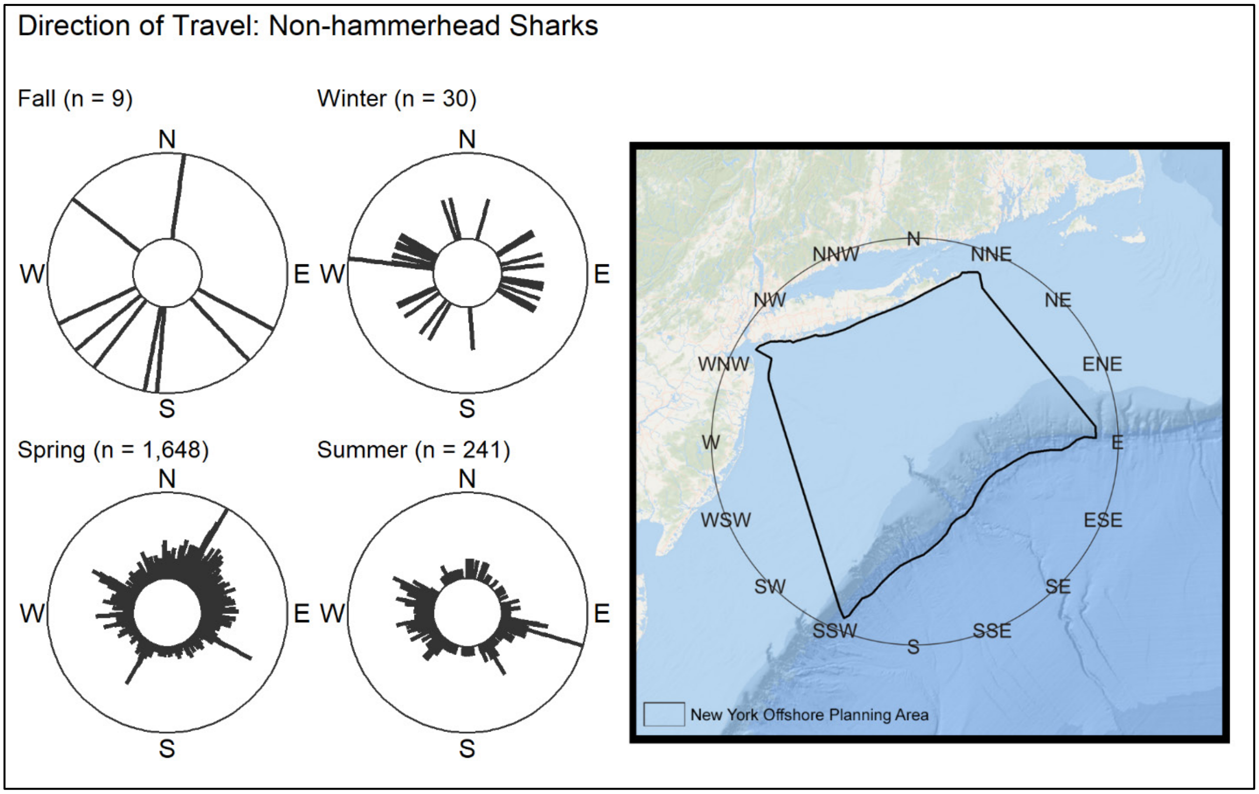


Figure 11. Spatial Distribution of Basking Sharks During Fall and Winter by Zone and Proximity to Call Areas

Heat map density maximum is scaled to the maximum density for the species/species group across all seasons. Inset figure shows estimated densities within each Zone ± standard error of the mean.

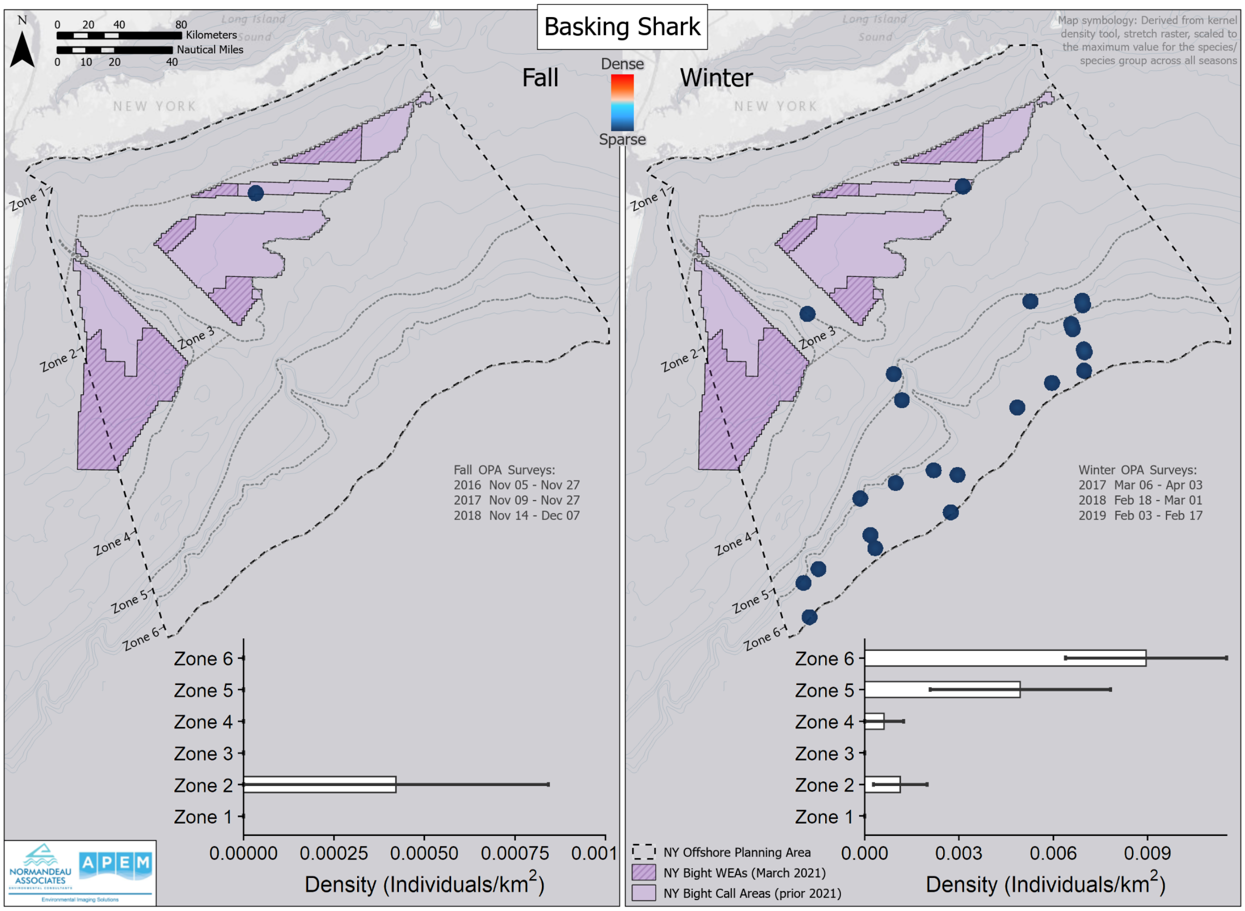


Figure 12. Spatial Distribution of Basking Sharks During Spring and Summer by Zone and Proximity to Call Areas

Heat map density maximum is scaled to the maximum density for the species/species group across all seasons. Inset figure shows estimated densities within each Zone ± standard error of the mean.

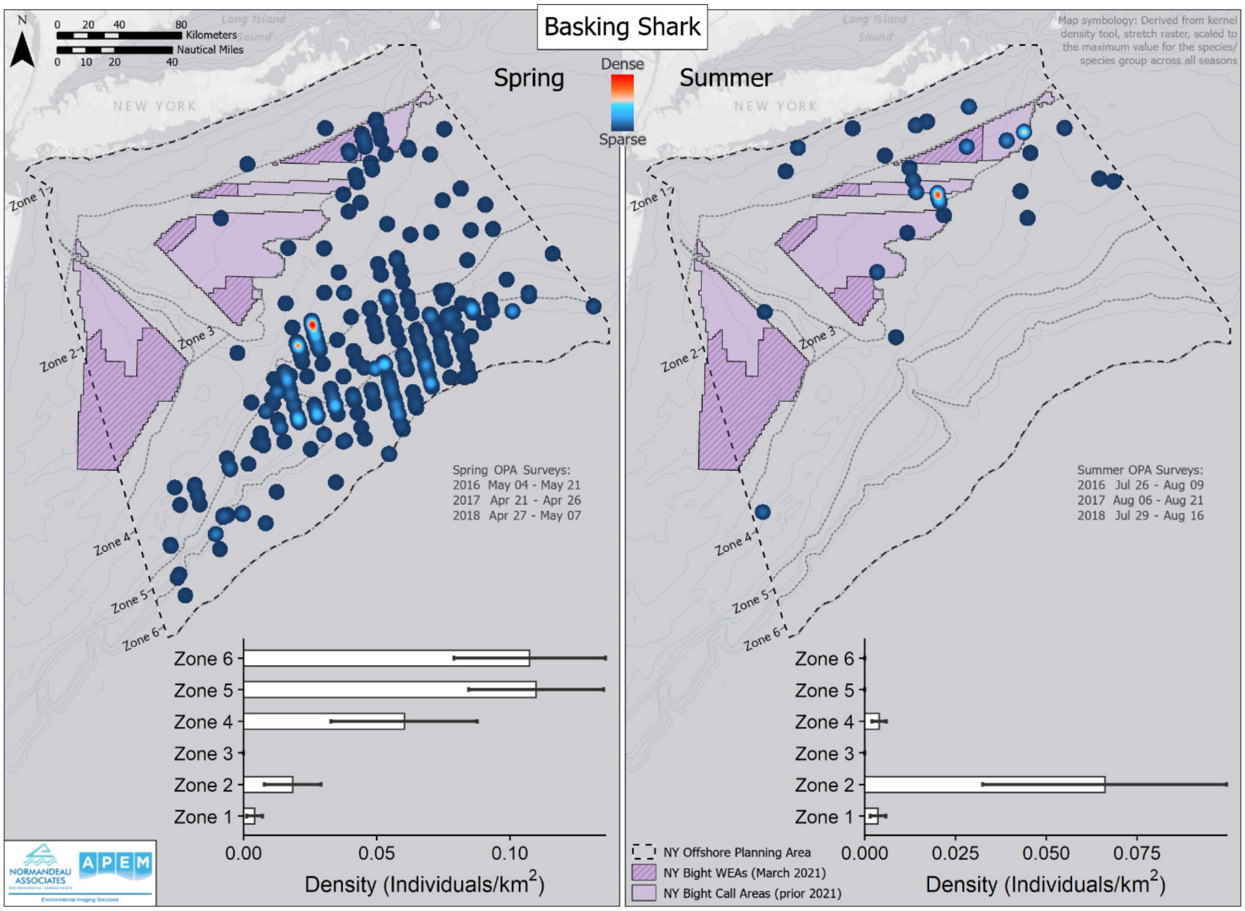


Figure 13. Direction of Travel of Basking Sharks for All Surveys

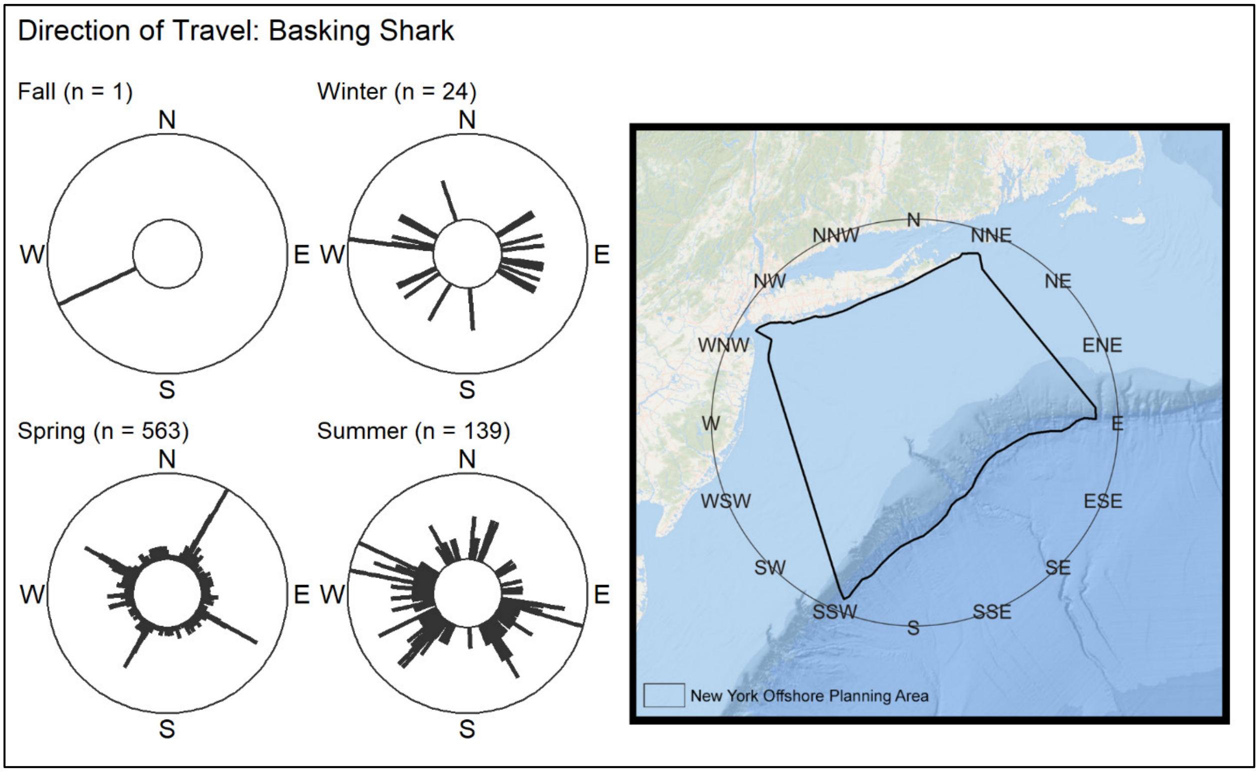


Figure 14. Spatial Distribution of Blue Sharks During Fall and Winter by Zone and Proximity to Call Areas

Heat map density maximum is scaled to the maximum density for the species/species group across all seasons. Inset figure shows estimated densities within each Zone ± standard error of the mean.

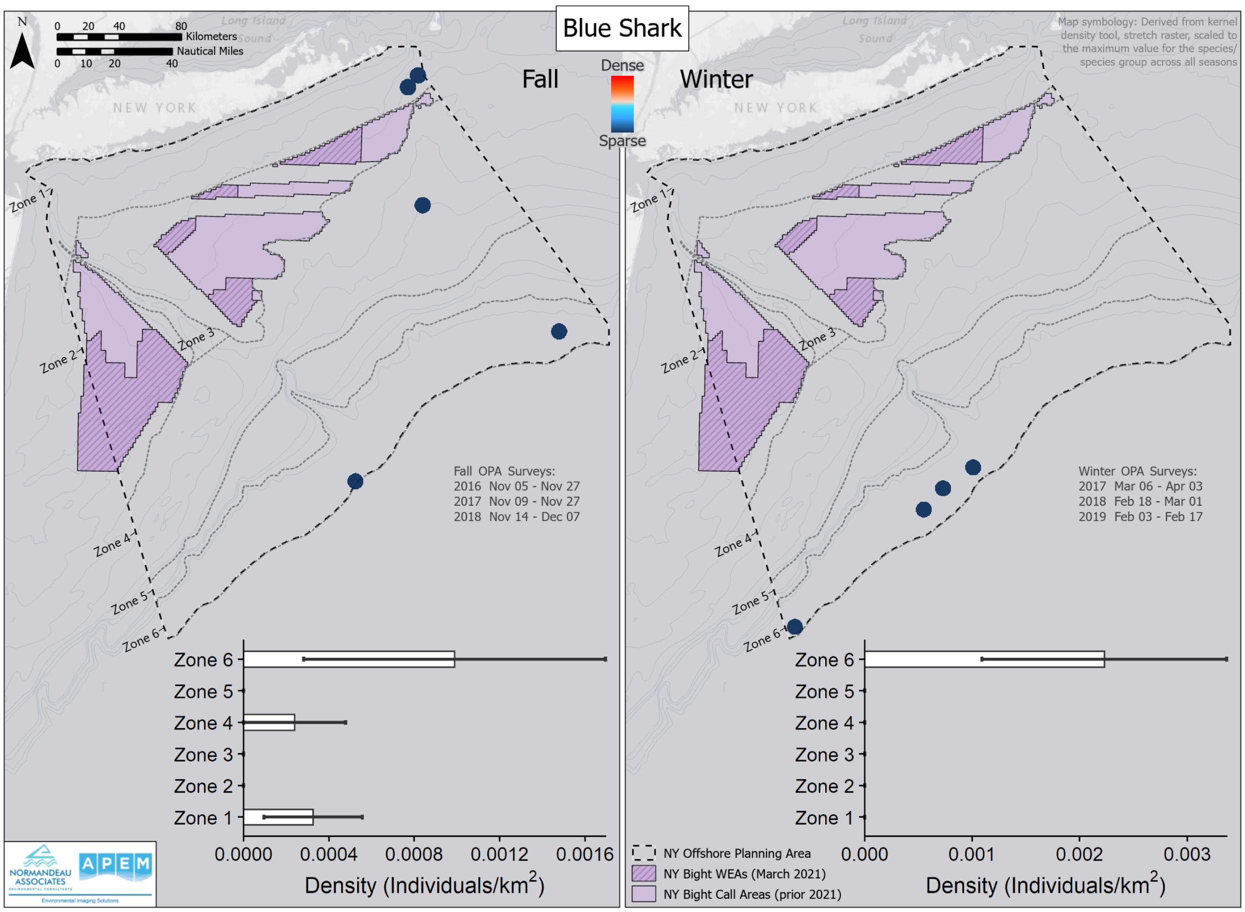


Figure 15. Spatial Distribution of Blue Sharks During Spring and Summer by Zone and Proximity to Call Areas

Heat map density maximum is scaled to the maximum density for the species/species group across all seasons. Inset figure shows estimated densities within each Zone ± standard error of the mean.

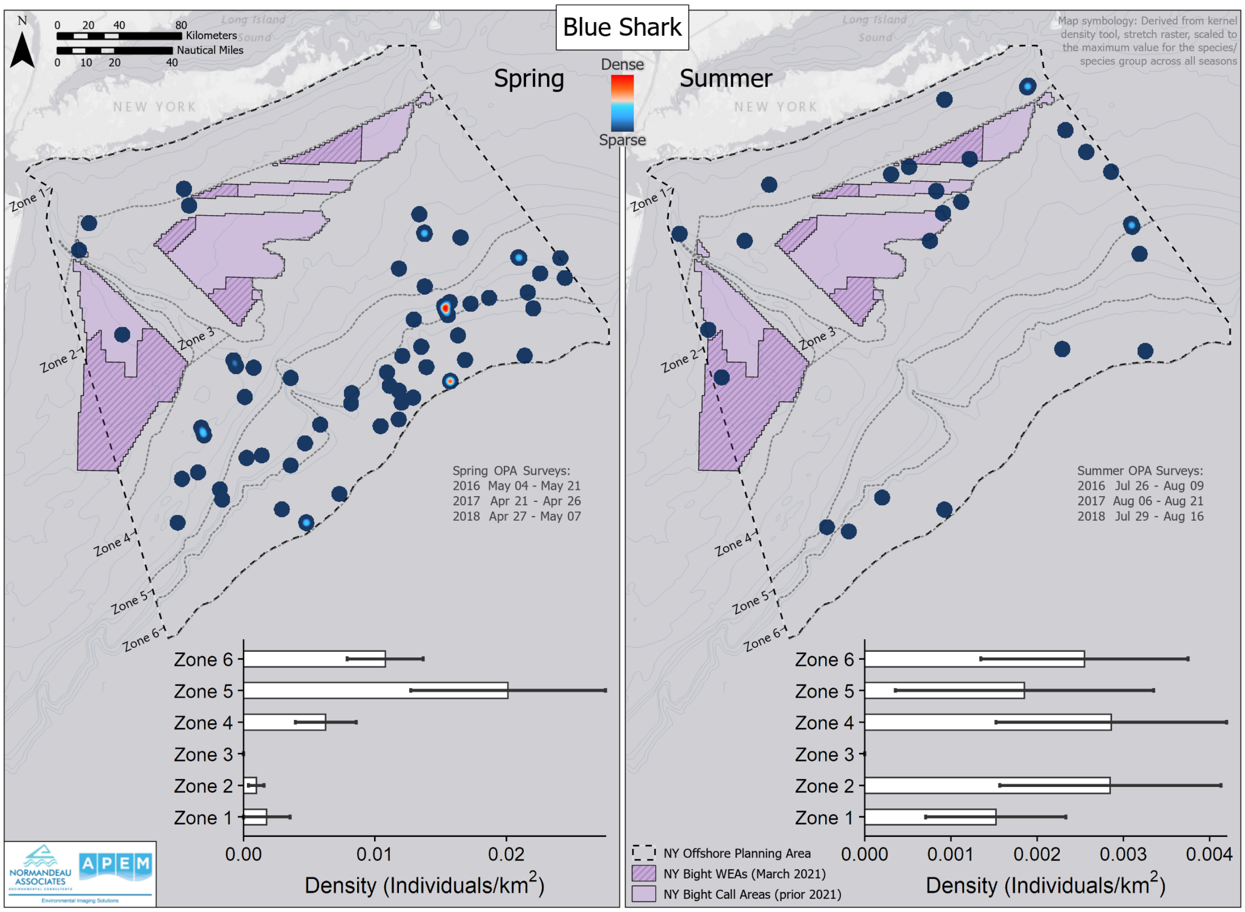


Figure 16. Direction of Travel of Blue Sharks for All Surveys

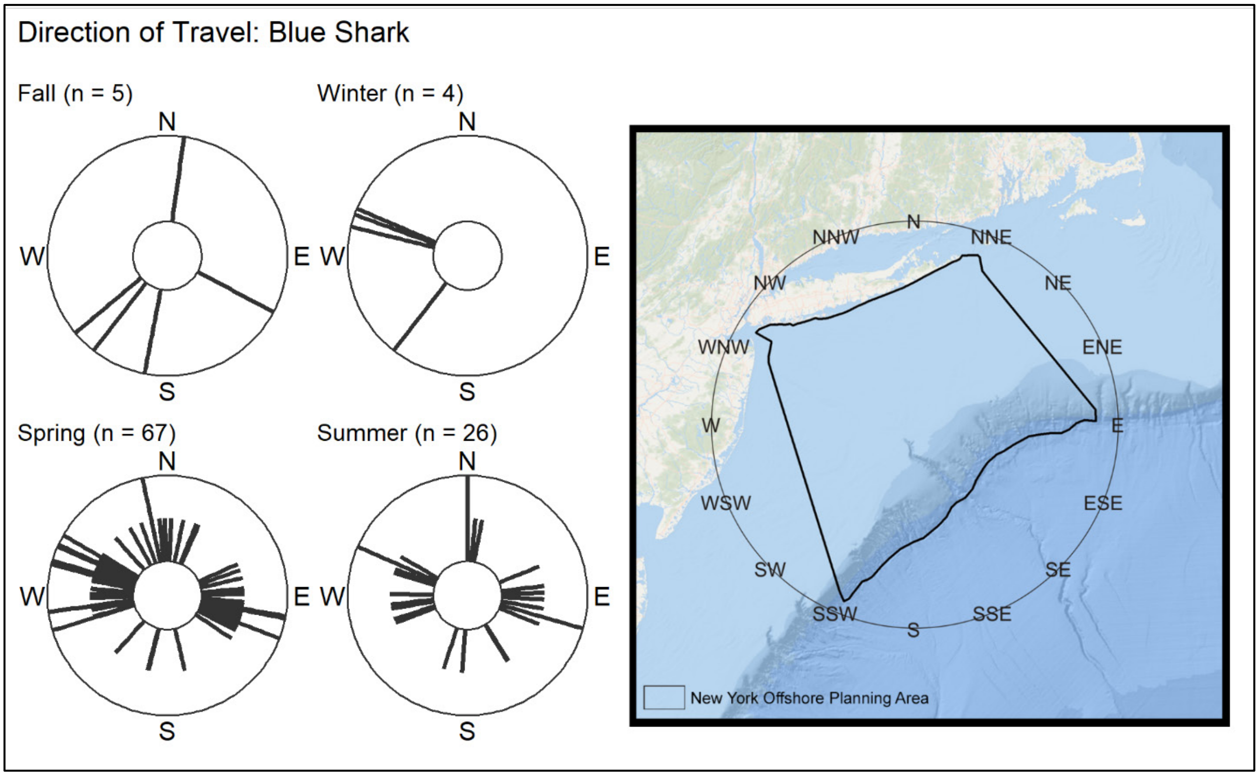


Figure 17. Spatial Distribution of Spurdogs During Spring and Winter by Zone and Proximity to Call Areas

Heat map density maximum is scaled to the maximum density for the species/species group across all seasons. Inset figure shows estimated densities within each Zone ± standard error of the mean.

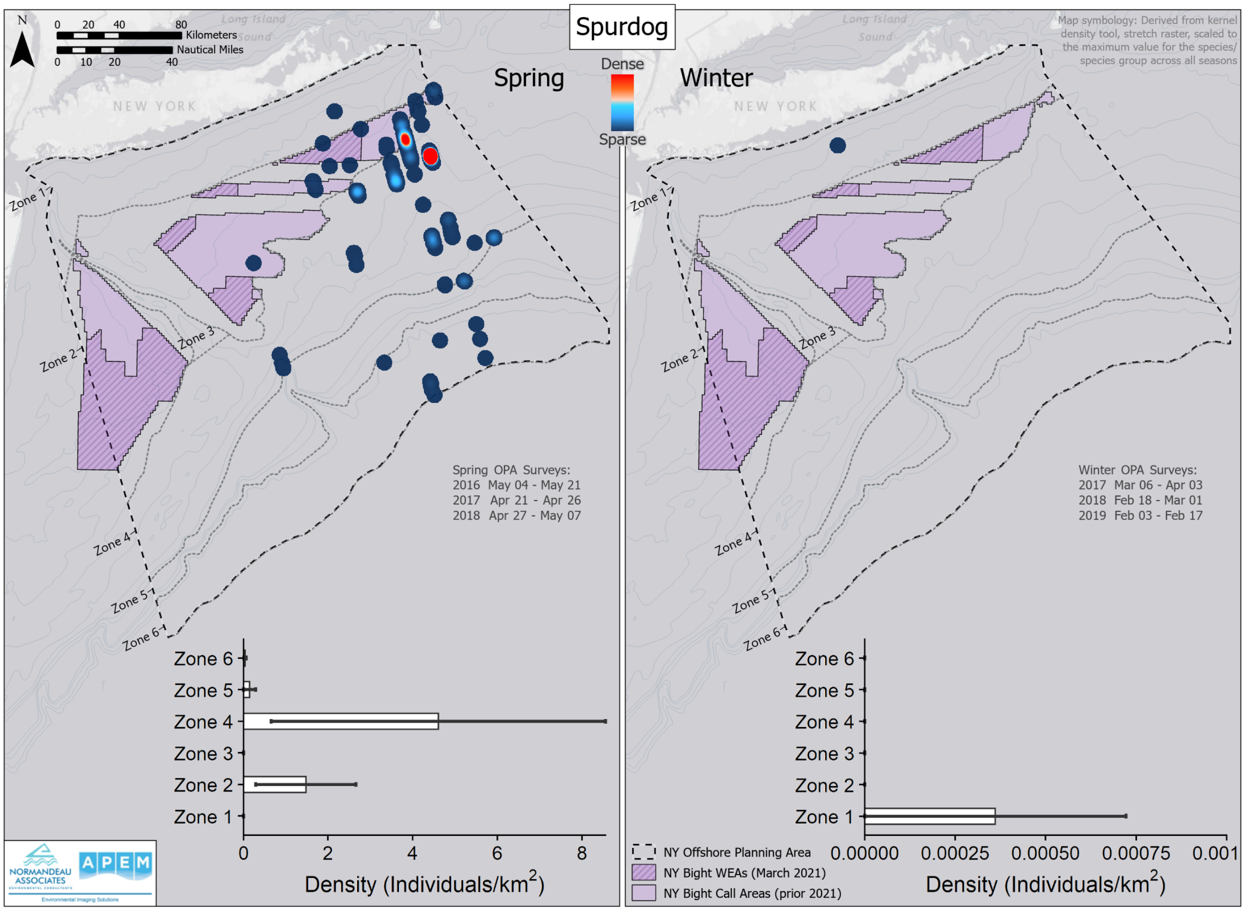
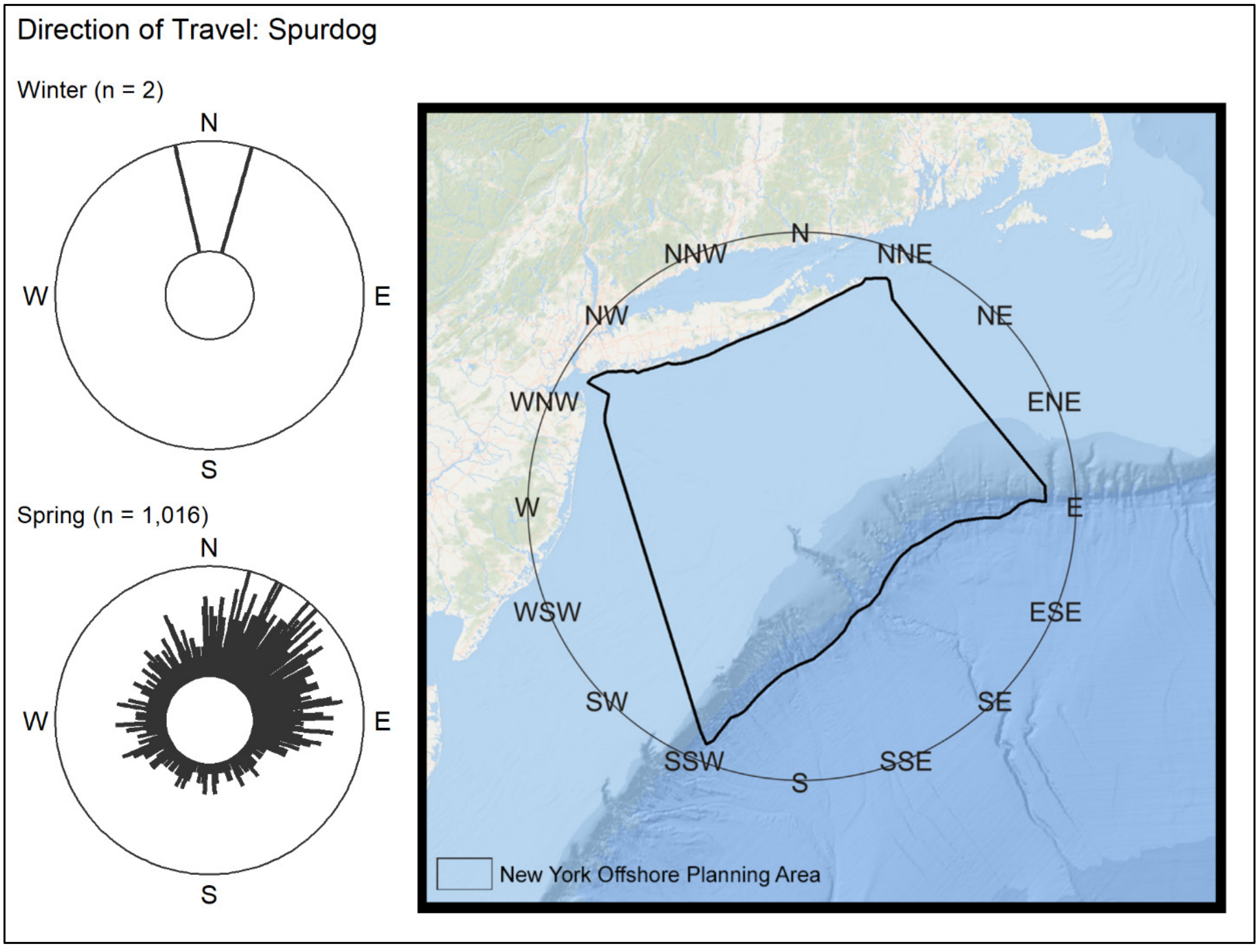


Figure 18. Direction of Travel of Spurdogs for All Surveys



2.3.1.3 Hammerhead Shark Species

Of 795 hammerhead observations, 790 occurred during Summer surveys and five occurred during Fall; there were no observations during Winter or Spring (Table 2, Figure 19). During Summer, observations were widely distributed with a mean OPA density of $\bar{x} = 0.09 \pm 0.01$ sharks/km^2 (Figure 19). Summer density was greatest within Zone 2 ($\bar{x} = 0.15 \pm 0.05$ sharks/km^2) and Zone 5 ($\bar{x} = 0.12 \pm 0.04$ sharks/km^2) (Figure 19). During Summer, travel direction was non-uniform ($t = 244.7$, $p < 0.001$), and hammerhead sharks exhibited a direction of travel to the west or east (Figure 20).

Smooth Hammerhead Shark

Smooth hammerhead shark density was greatest during Summer surveys (n=72; $\bar{x} = 0.007$ sharks/km^2), and Fall surveys produced one observation (Table 2, Figure 21). During Summer, Zones 1, 2, and 4 had marginally above-average density estimates relative to the whole OPA (Figure 21). During Summer, travel direction was non-uniform (t = 189.6, $p < 0.001$), and smooth hammerhead sharks exhibited a slight direction of travel to the east and west (Figure 22).

Scalloped Hammerhead Shark

Scalloped hammerhead sharks were distributed throughout the OPA during Summer (n=238; $\bar{x} = 0.02 \pm 0.005$ sharks/km^2) and observed on two occasions within Zone 5 during the Fall (Table 2, Figure 23). During Summer, density was greatest within Zone 5 (Figure 23). During Summer, travel direction was non-uniform (t = 222.5, $p < 0.001$), and scalloped hammerhead sharks exhibited a bimodal pattern of travel direction where individuals were more often observed traveling either east or west (Figure 24).

Figure 19. Spatial Distribution of Hammerhead Sharks During Fall and Summer by Zone and Proximity to Call Areas

Heat map density maximum is scaled to the maximum density for the species/species group across all seasons. Inset figure shows estimated densities within each Zone ± standard error of the mean.

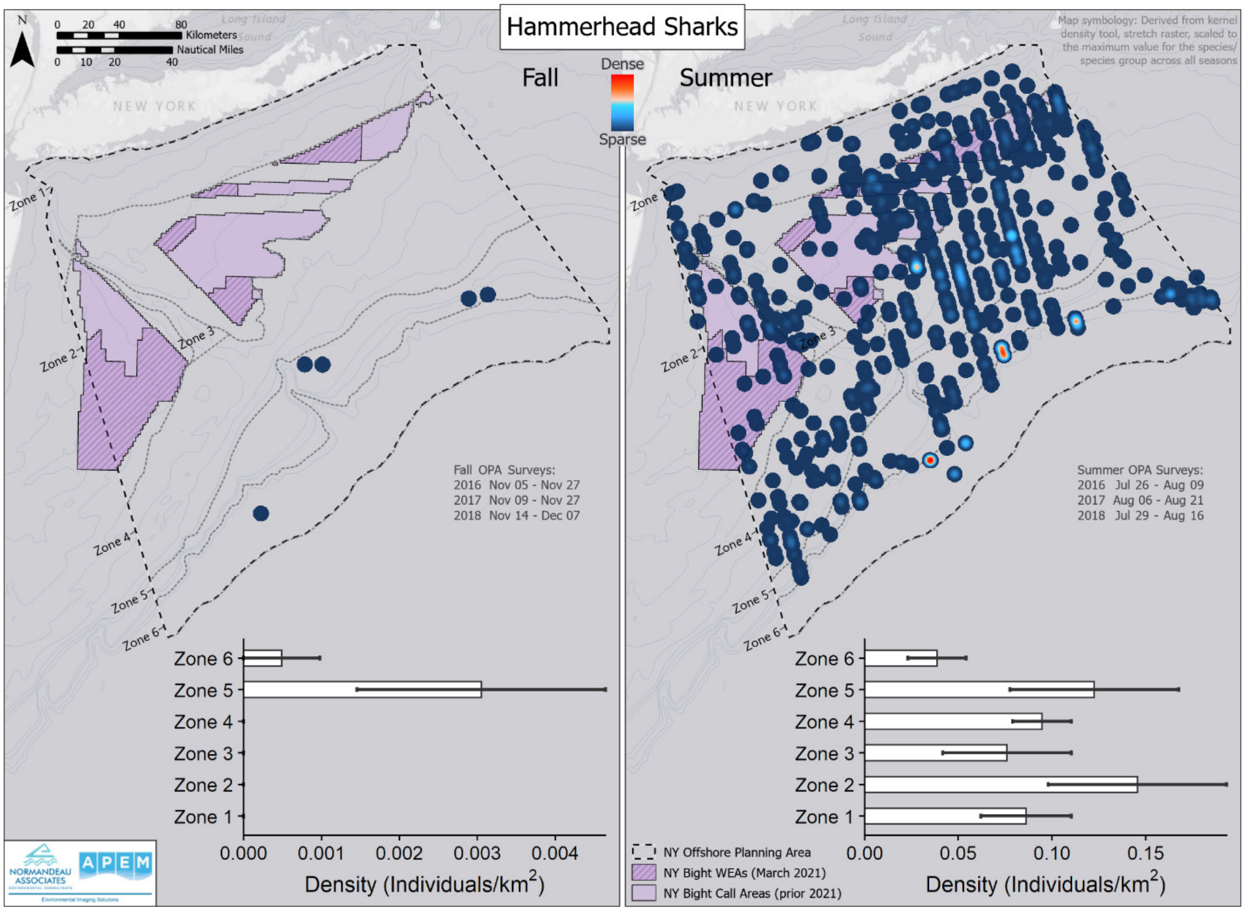


Figure 20. Direction of Travel of All Hammerhead Sharks for All Surveys

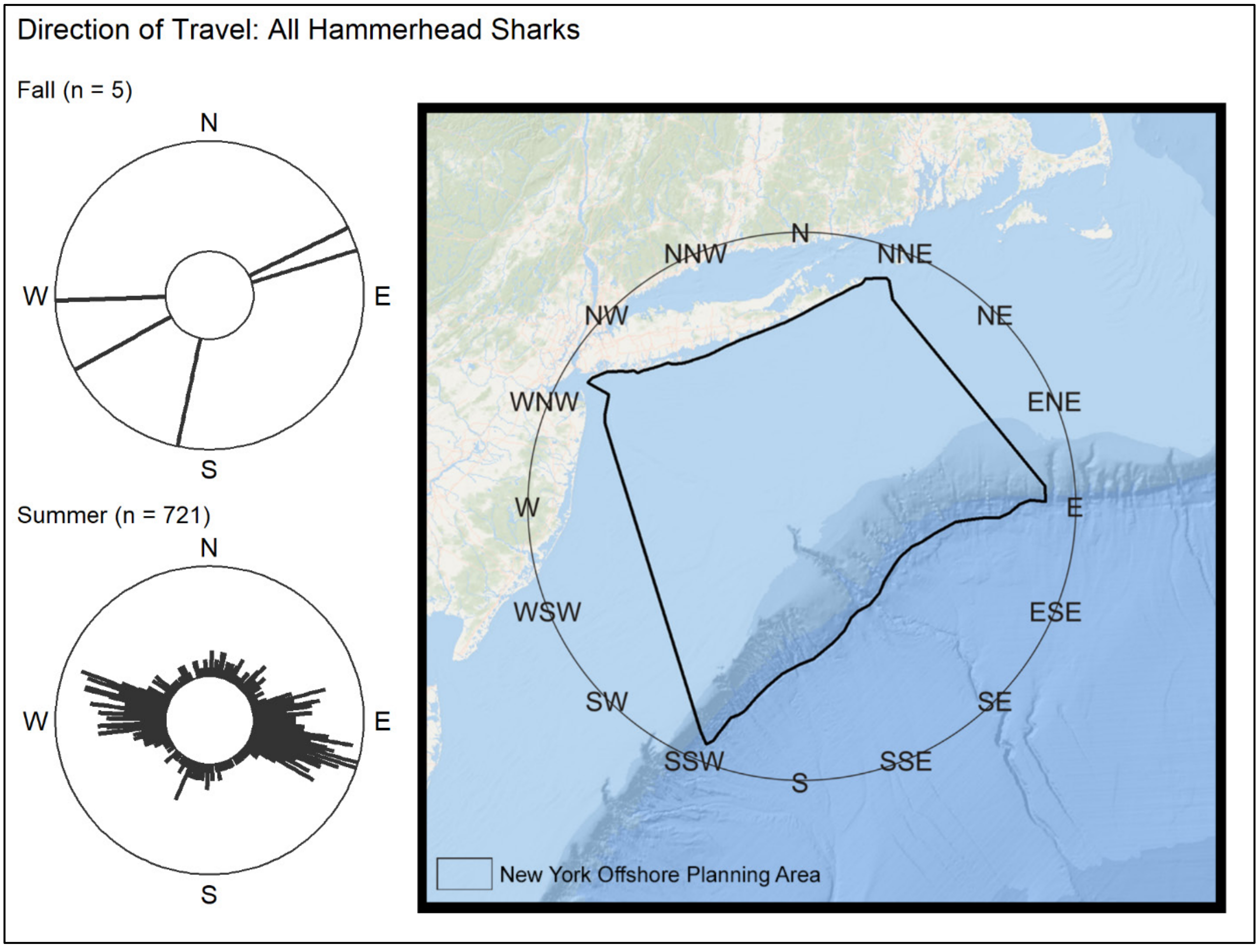


Figure 21. Spatial Distribution of Smooth Hammerhead Sharks During Fall and Summer by Zone and Proximity to Call Areas

Heat map density maximum is scaled to the maximum density for the species/species group across all seasons. Inset figure shows estimated densities within each Zone ± standard error of the mean.

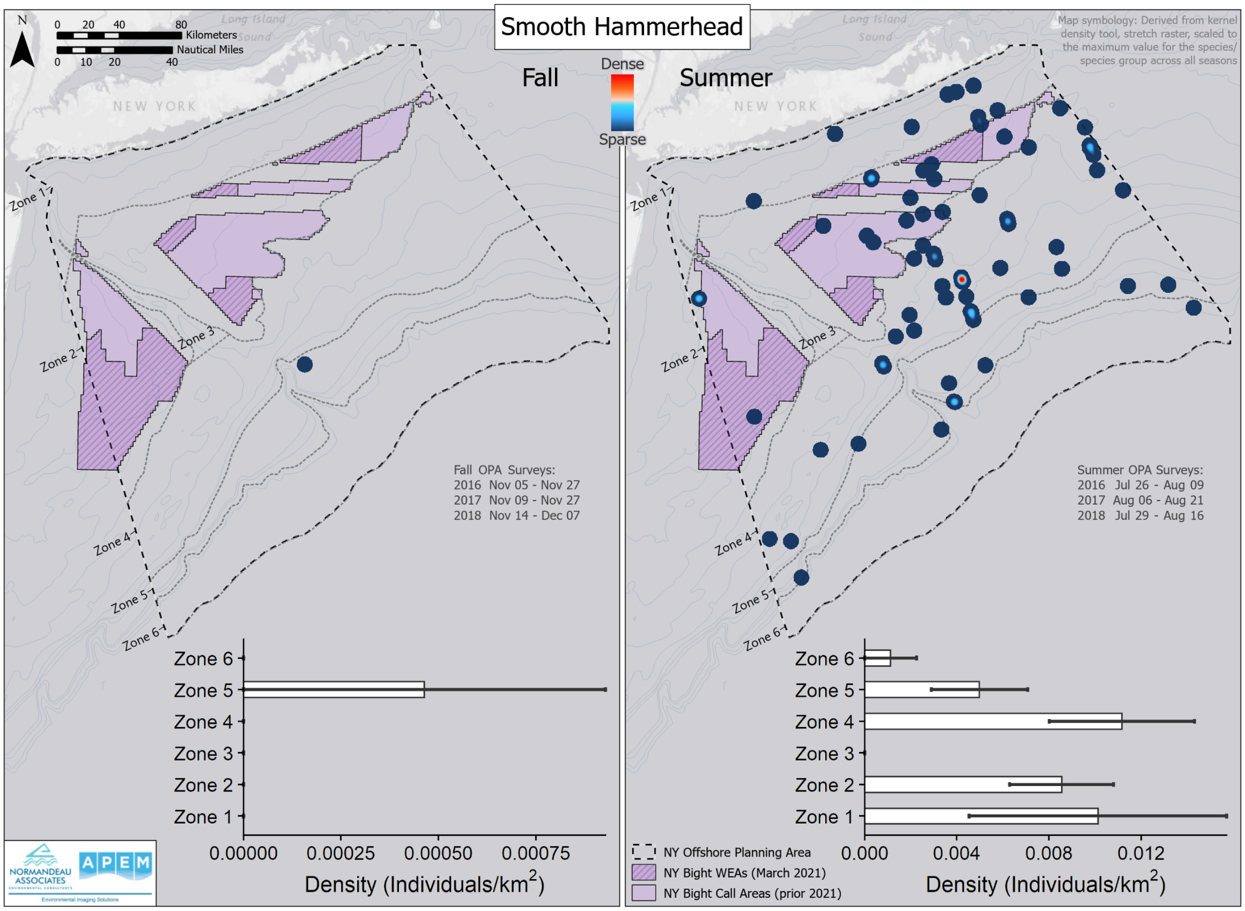


Figure 22. Direction of Travel of Smooth Hammerhead Sharks for All Surveys

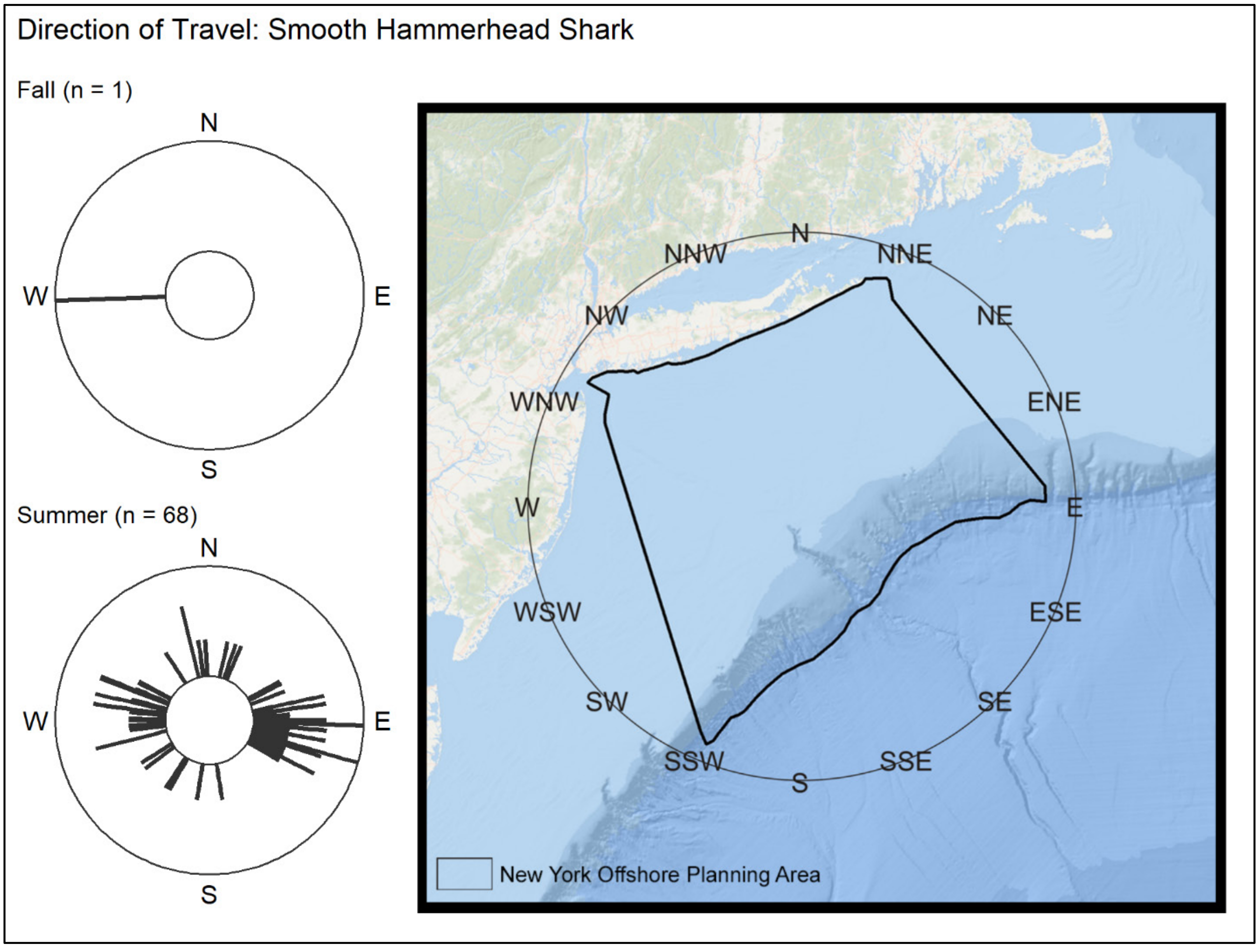


Figure 23. Spatial Distribution of Scalloped Hammerhead Sharks During Fall and Summer by Zone and Proximity to Call Areas

Heat map density maximum is scaled to the maximum density for the species/species group across all seasons. Inset figure shows estimated densities within each Zone ± standard error of the mean.

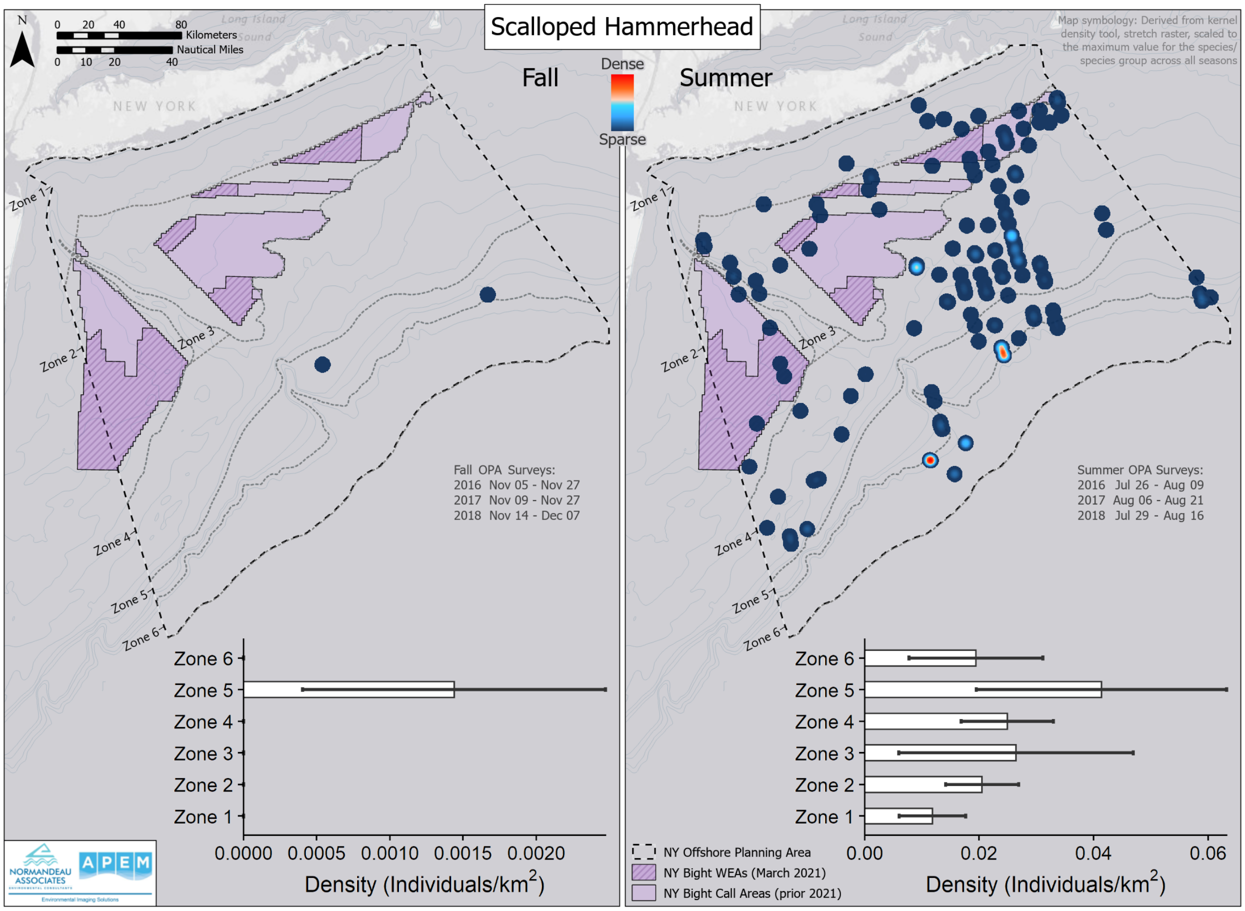
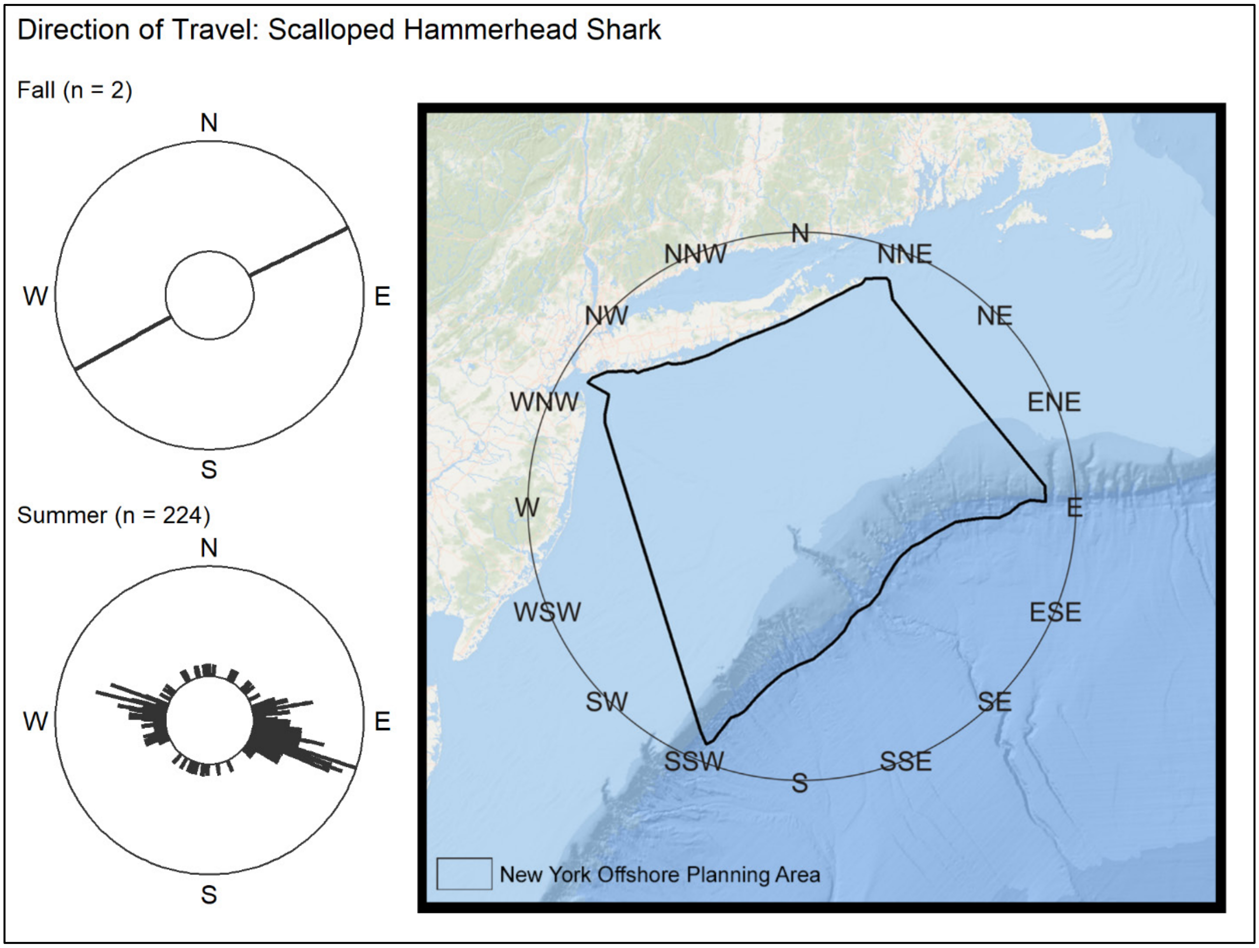


Figure 24. Direction of Travel of Scalloped Hammerhead Sharks for All Surveys



2.3.2 Rays

Throughout the OPA, 21,539 rays were observed consisting of six confirmed species: giant devil ray, Chilean devil ray, bullnose ray, cownose ray, giant manta ray, and bluntnose stingray (Table 2). Eighty-four percent of the rays were cownose, bullnose, or cownose/bullnose rays (n=18,127). Rays were almost exclusively observed during the Summer (n=21,524) with Fall having 14 occurrences, Spring having one occurrence, and Winter having none (Table 2, Figure 25, Figure 26). During Summer, rays were widely distributed with a mean OPA density of $\bar{x} = 0.96 \pm 0.25$ rays/km^2 yet exhibited variable above-average densities within Zones 1 and 2—a result of high concentrations in the westernmost sections of these zones (Figure 26). During Summer, travel direction was non-uniform ($t = 319.3$, $p < 0.001$), and most frequently travel was to the southeast (Figure 27).

2.3.2.1 Giant Devil Ray

Except for a single observation within Zone 6 during the Fall, giant devil rays were observed exclusively within Zones 5 and 6 during Summer surveys (Figure 28). Density was greatest within Zone 5 (n=117; $\bar{x} = 0.12 \pm 0.03$ rays/km^2), yet concentrations within Zone 5 were right on the border of Zone 6 (Figure 28). During Summer, travel direction was non-uniform ($t = 214.6$, $p < 0.001$) with a slight pattern of travel to the west and east (Figure 29).

2.3.2.2 Chilean Devil Ray

Chilean devil rays were only observed during Summer (n=131) surveys (Table 2). Most observations occurred within Zones 5 and 6 with Zone 6 having the greatest estimated density (n=131; $\bar{x} = 0.02 \pm 0.005$ rays/km^2) (Figure 30). Like other species predominantly observed within Zones 5 and 6 during the Summer, travel direction was non-uniform ($t = 203.0$, $p < 0.001$) with a slight pattern of travel to the west and east (Figure 31).

2.3.2.3 Cownose/Bullnose Ray

There were 8,026 targets that lacked species resolution but were positively classified as either cownose or bullnose ray (Table 2, Figure 32, Figure 33), 10,003 targets classified as cownose ray (Table 2, Figure 34), and 98 targets classified as bullnose ray (Table 2, Figure 35), with all but seven (Fall) and one (Spring) observations during the Summer surveys. For all three groups a similar pattern emerged in that density was greatest within Zone 2, where observations were concentrated in the west (Figure 32, Figure 33, Figure 34, Figure 35). Cownose rays had a non-uniform travel direction distribution ($t = 291.2$, $p < 0.001$) and a more predominant travel direction to the southeast than was observed by either cownose/bullnose rays or bullnose rays (Figure 36, Figure 37, Figure 38).

2.3.2.4 Ray Species with Fewer than 30 Observations

Bluntnose stingray (n=1) and giant manta ray (n=7) were observed fewer than 30 times and were only observed during Summer (Table 2, Figure 39). The single bluntnose stingray observation occurred within Zone 1, and all seven giant manta ray observations occurred within either Zone 5 or 6 (Figure 39).

Figure 25. Spatial Distribution of All Rays During Fall and Winter by Zone and Proximity to Call Areas

Heat map density maximum is scaled to the maximum density for the species/species group across all seasons. Inset figure shows estimated densities within each Zone ± standard error of the mean.

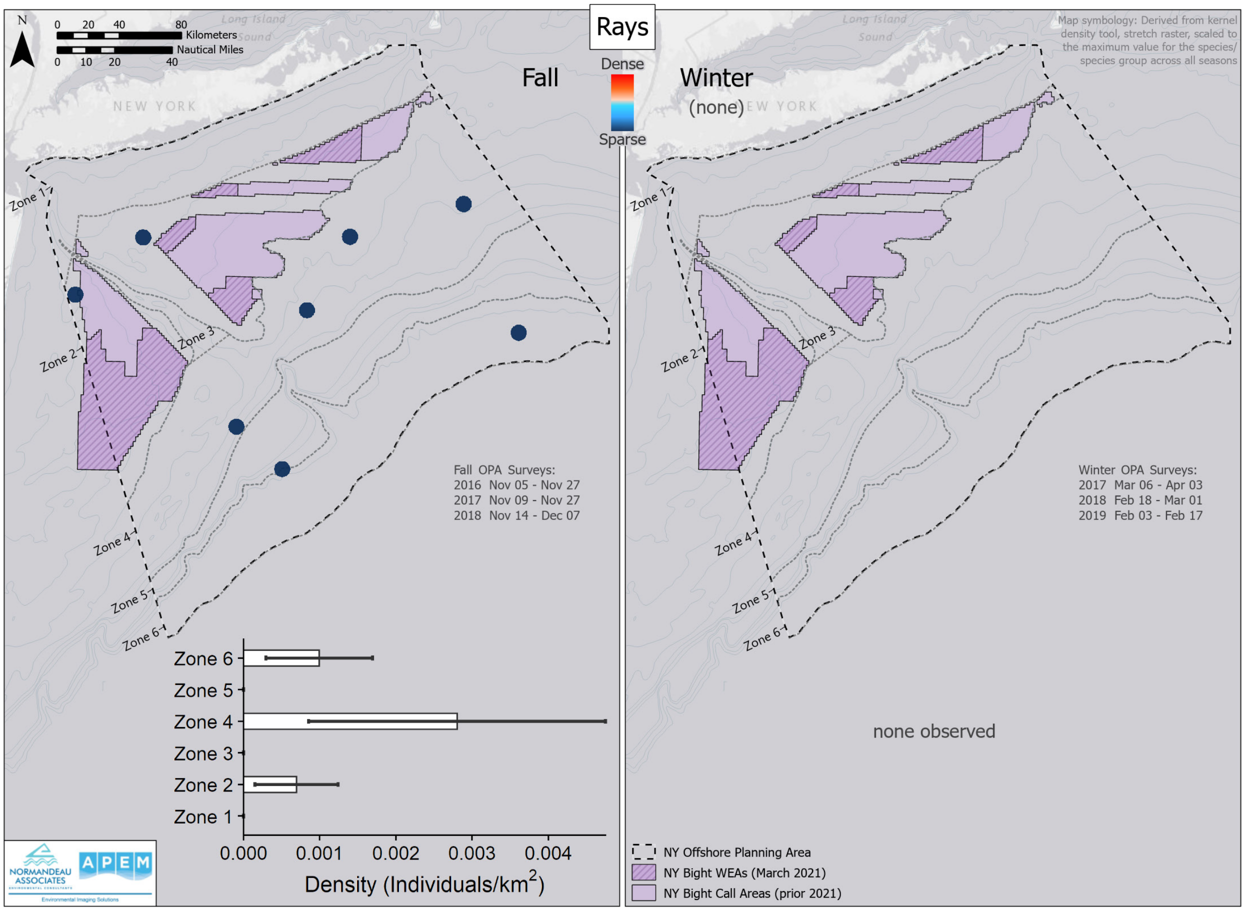


Figure 26. Spatial Distribution of All Rays During Spring and Summer by Zone and Proximity to Call Areas

Heat map density maximum is scaled to the maximum density for the species/species group across all seasons. Inset figure shows estimated densities within each Zone ± standard error of the mean.

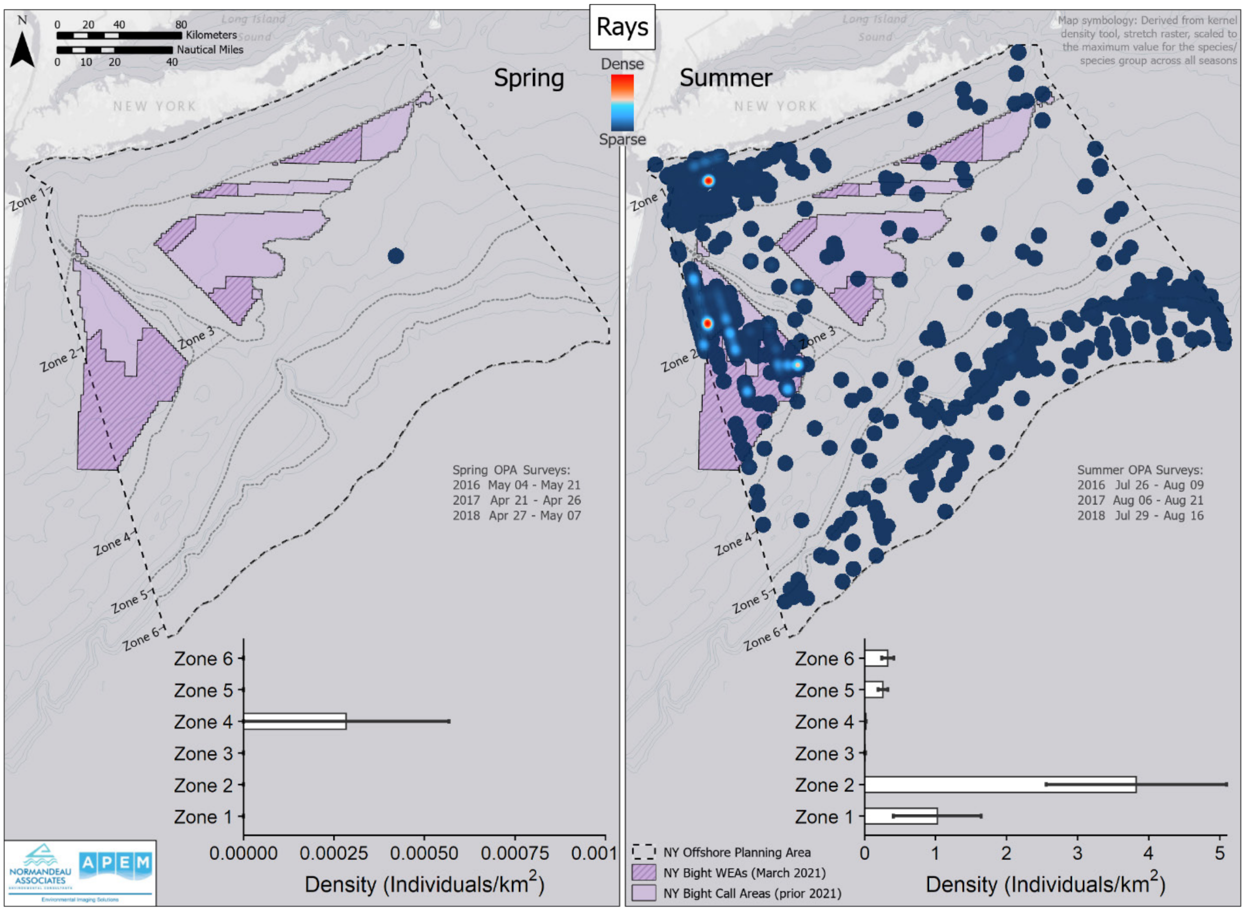


Figure 27. Direction of Travel of All Rays for All Surveys

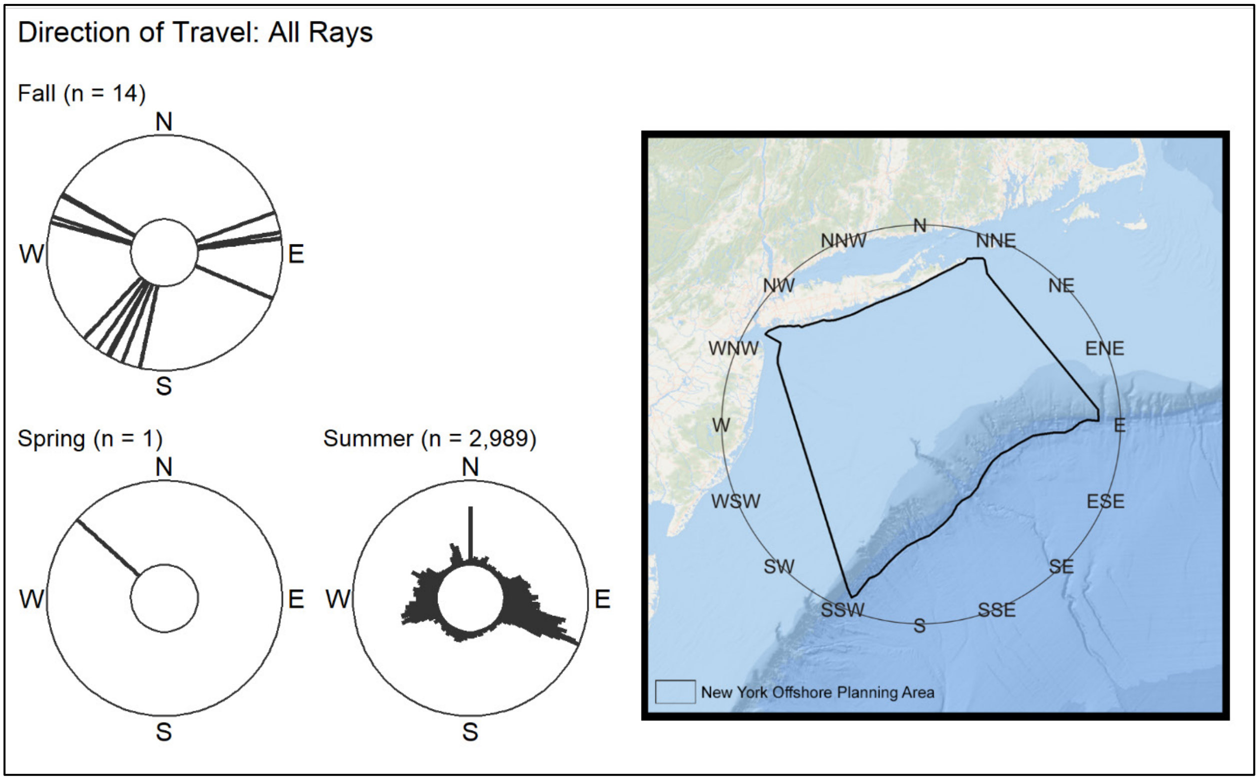


Figure 28. Spatial Distribution of Giant Devil Rays During Fall and Summer by Zone and Proximity to Call Areas

Heat map density maximum is scaled to the maximum density for the species/species group across all seasons. Inset figure shows estimated densities within each Zone ± standard error of the mean.

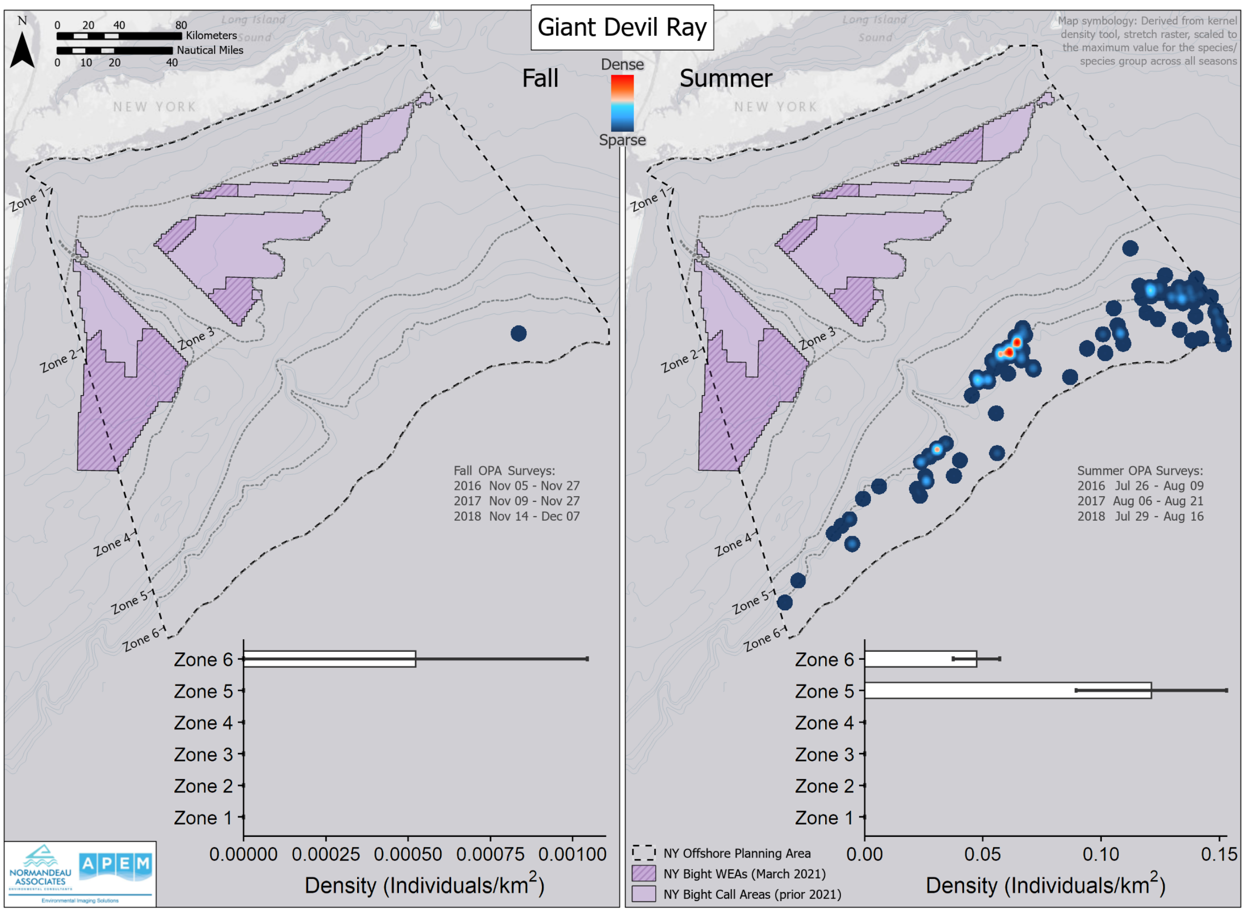


Figure 29. Direction of Travel of Giant Devil Rays for All Surveys

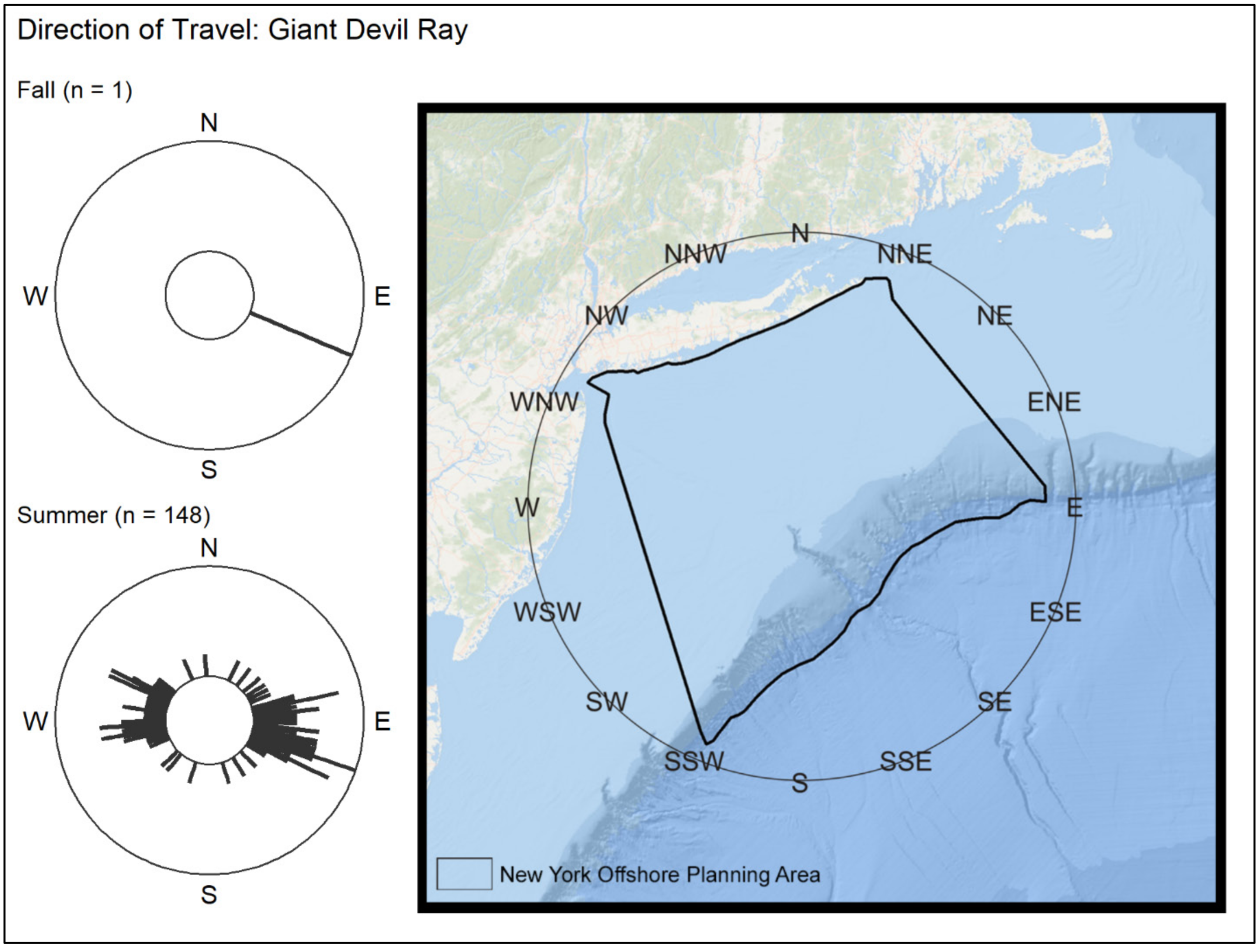


Figure 30. Spatial Distribution of Chilean Devil Rays During Spring and Summer by Zone and Proximity to Call Areas

Heat map density maximum is scaled to the maximum density for the species/species group across all seasons. Inset figure shows estimated densities within each Zone ± standard error of the mean.

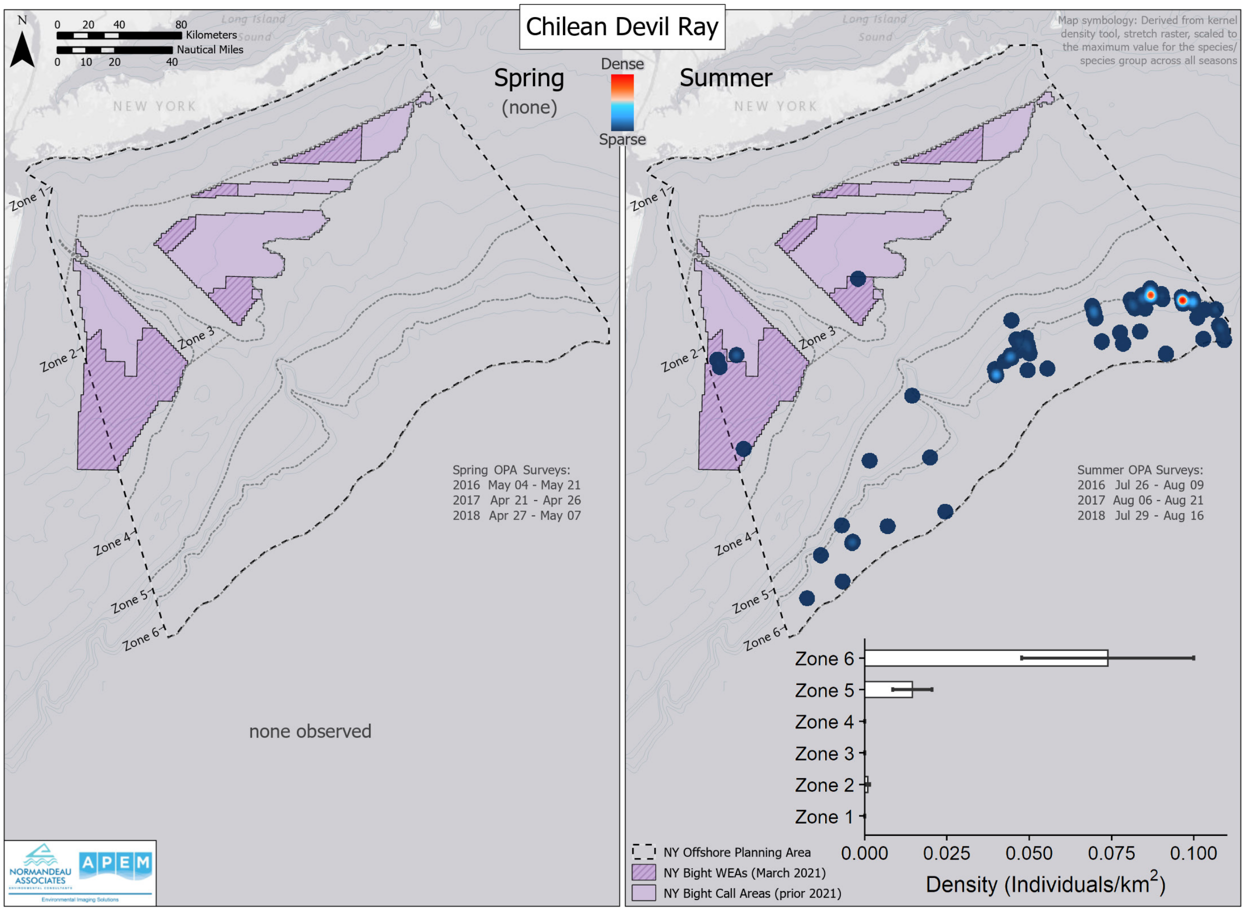


Figure 31. Direction of Travel of Chilean Devil Rays for All Surveys

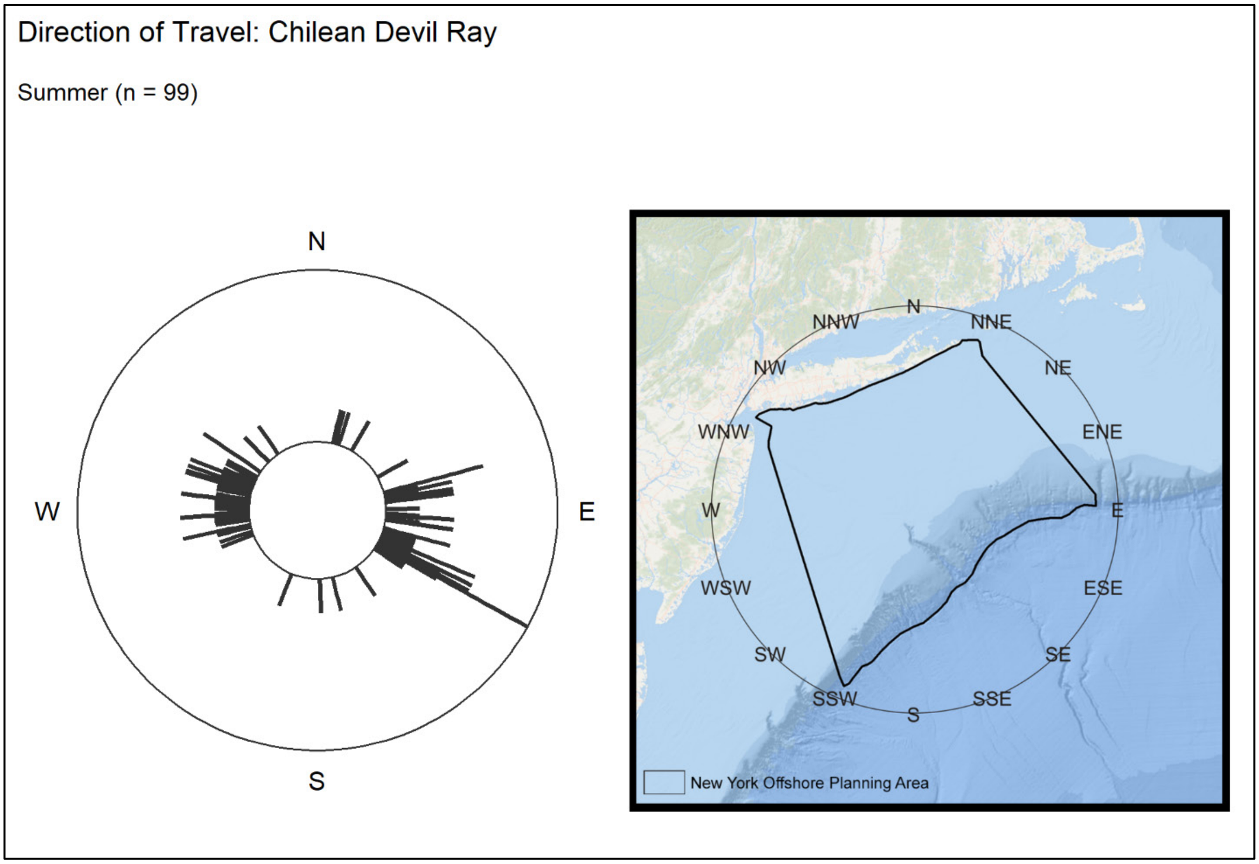


Figure 32. Spatial Distribution of Cownose/Bullnose Rays During Fall and Winter by Zone and Proximity to Call Areas

Heat map density maximum is scaled to the maximum density for the species/species group across all seasons. Inset figure shows estimated densities within each Zone ± standard error of the mean.

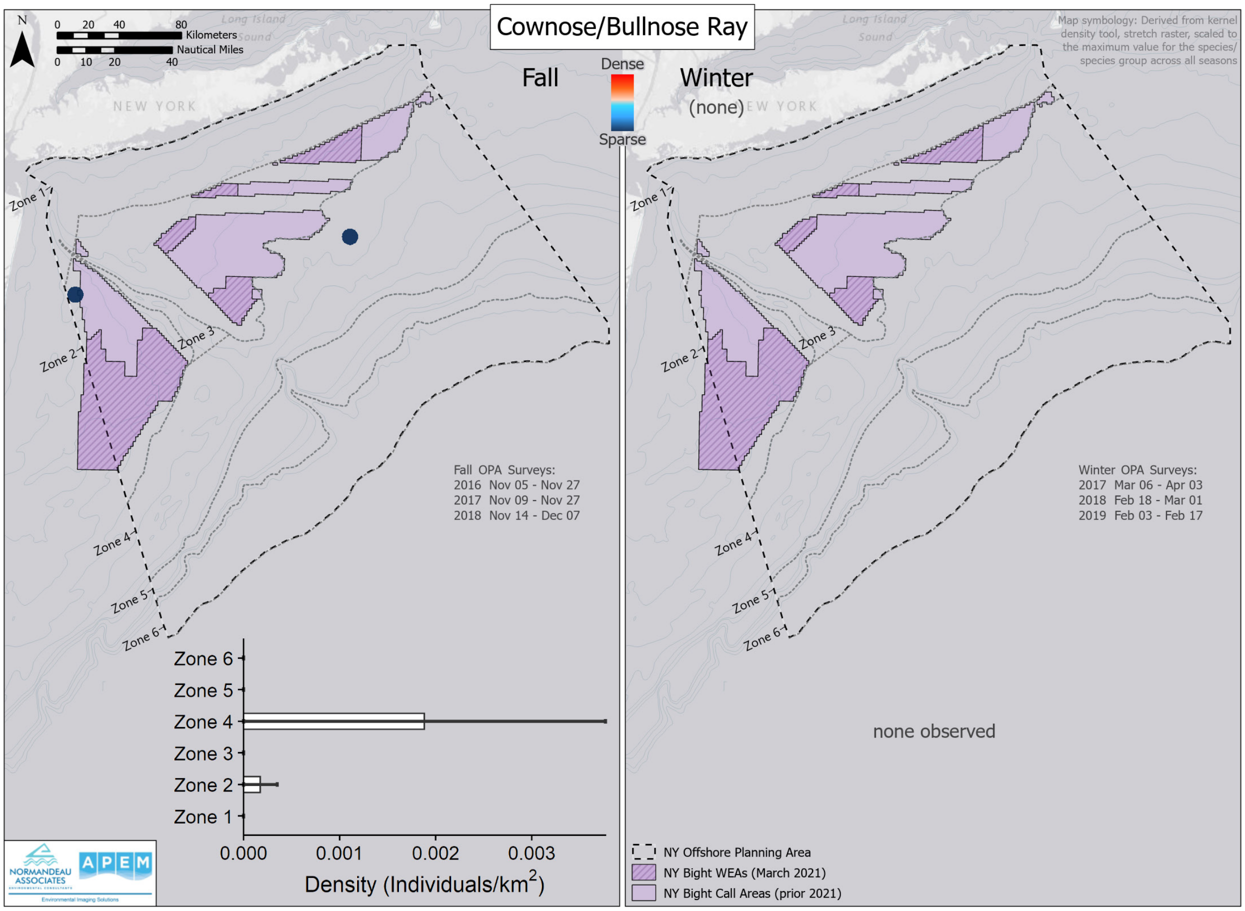


Figure 33. Spatial Distribution of Cownose/Bullnose Rays During Spring and Summer by Zone and Proximity to Call Areas

Heat map density maximum is scaled to the maximum density for the species/species group across all seasons. Inset figure shows estimated densities within each Zone ± standard error of the mean.

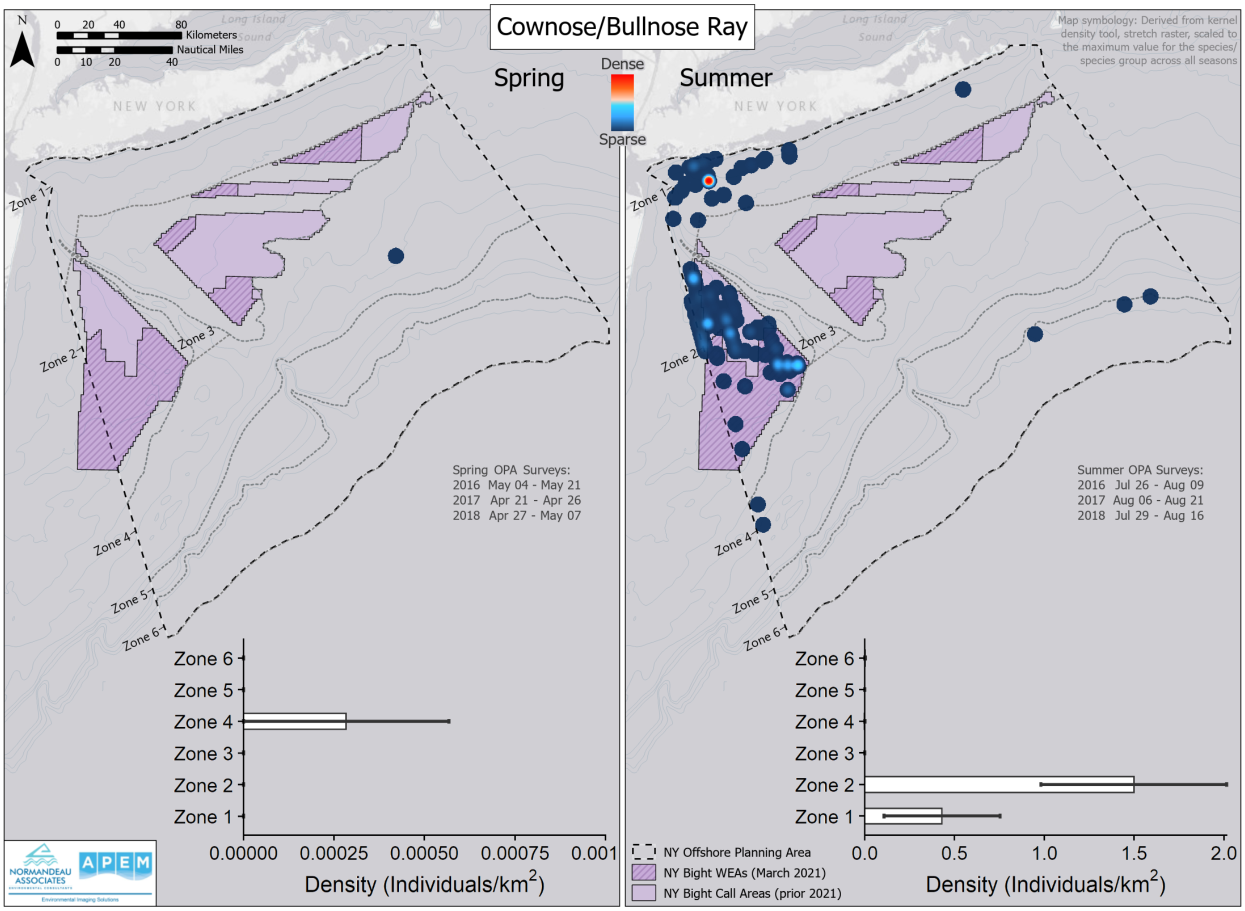


Figure 34. Spatial Distribution of Cownose Rays During Spring and Summer by Zone and Proximity to Call Areas

Heat map density maximum is scaled to the maximum density for the species/species group across all seasons. Inset figure shows estimated densities within each Zone ± standard error of the mean.

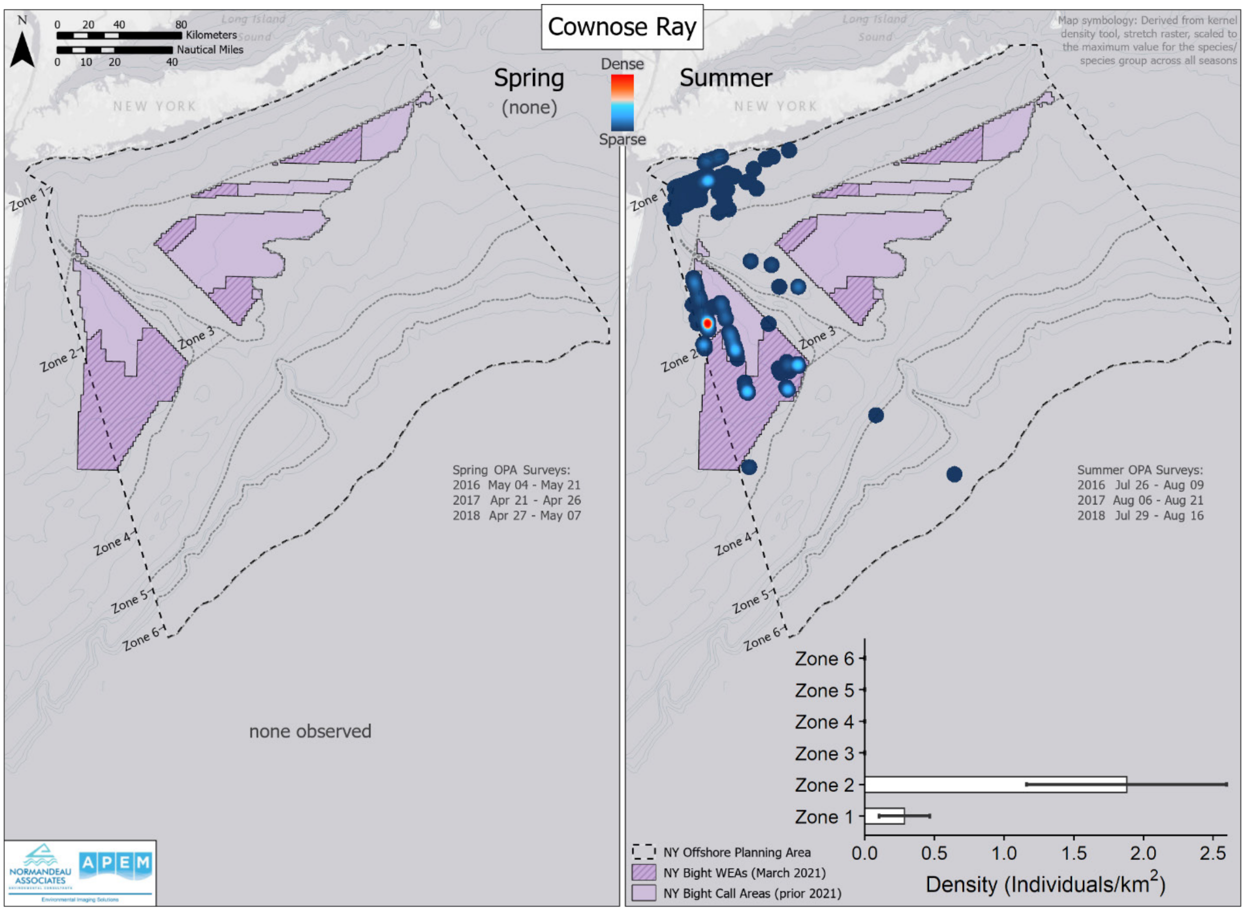


Figure 35. Spatial Distribution of Bullnose Rays During Spring and Summer by Zone and Proximity to Call Areas

Heat map density maximum is scaled to the maximum density for the species/species group across all seasons. Inset figure shows estimated densities within each Zone ± standard error of the mean.

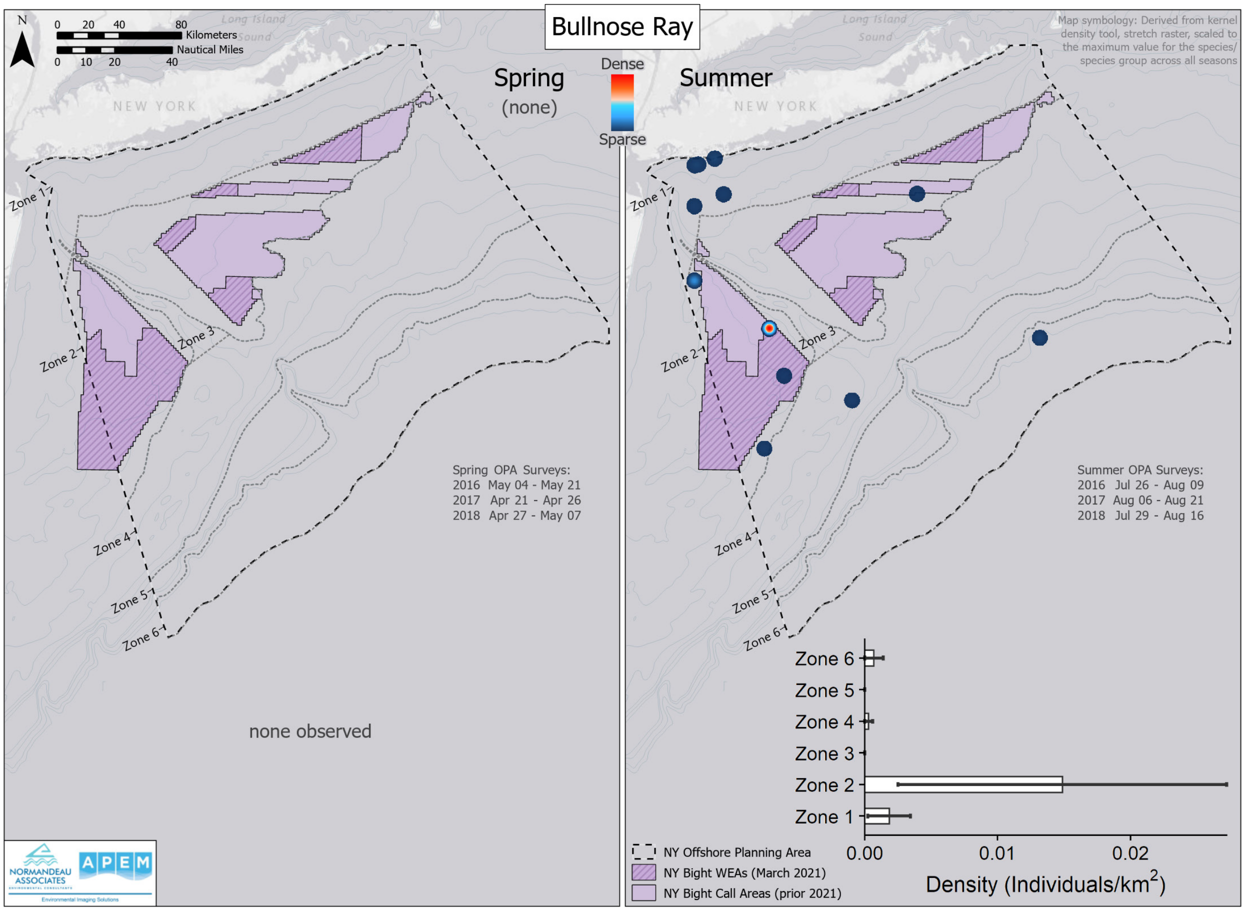


Figure 36. Direction of Travel of Cownose/Bullnose Rays for All Surveys

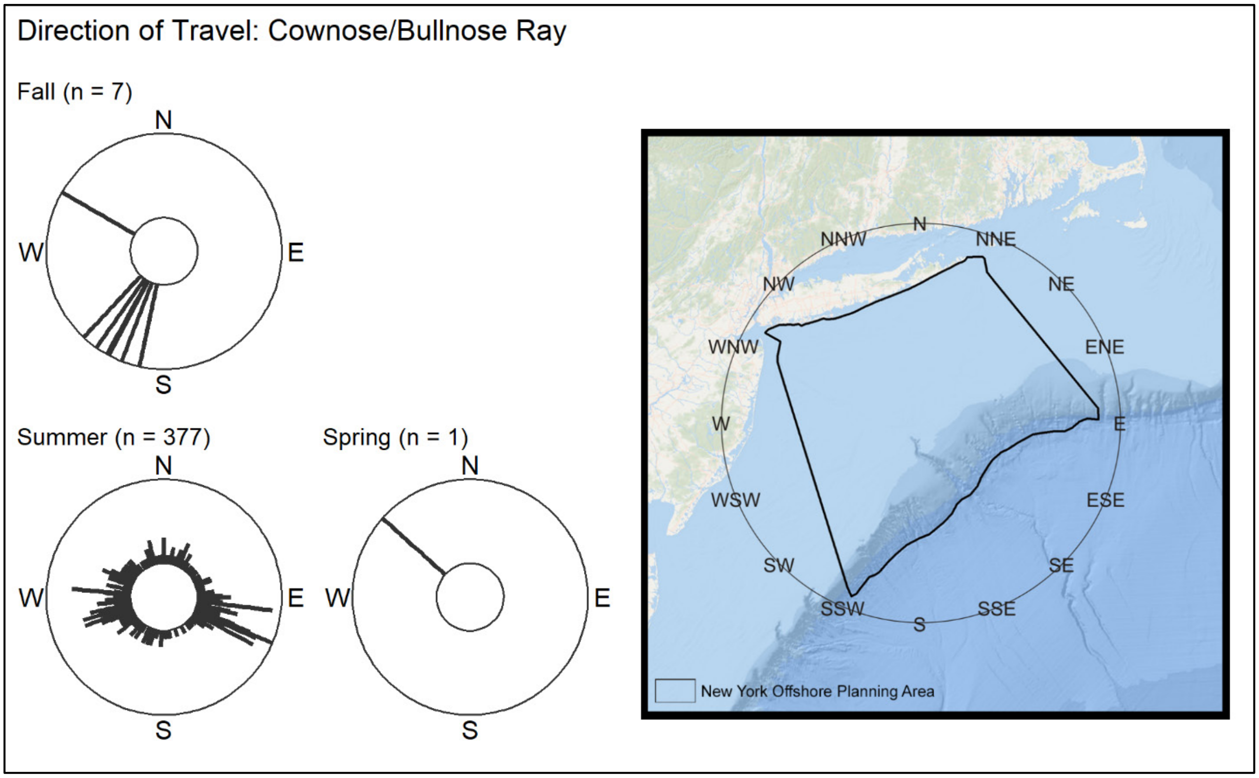


Figure 37. Direction of Travel of Cownose Rays for All Surveys

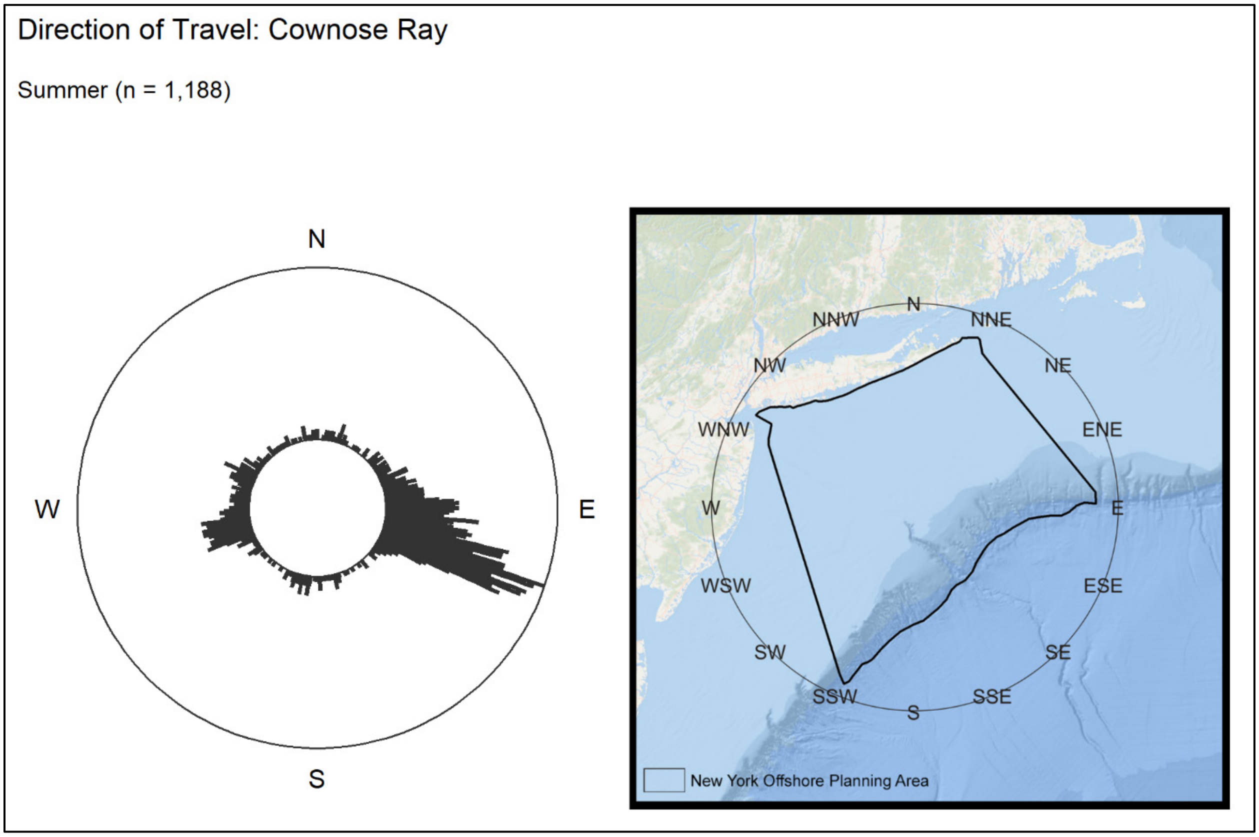


Figure 38. Direction of Travel of Bullnose Rays for All Surveys

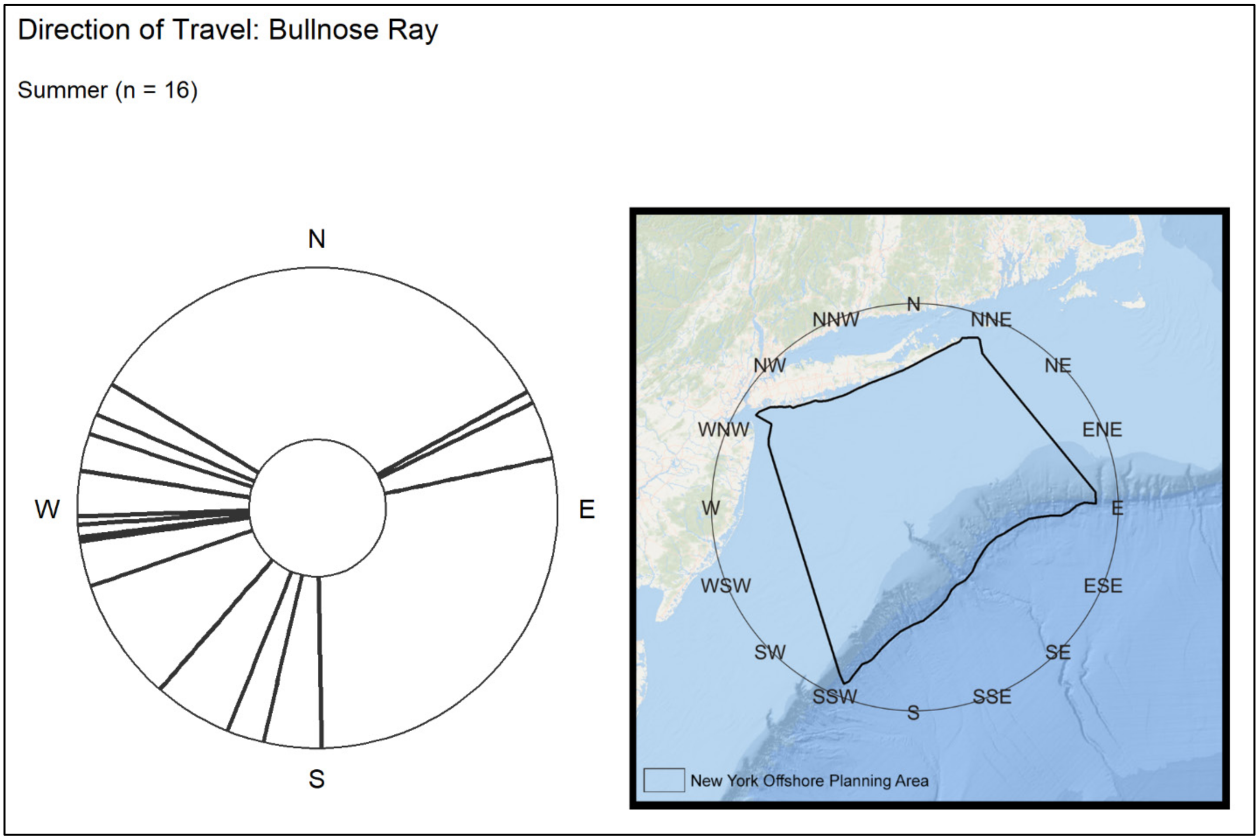
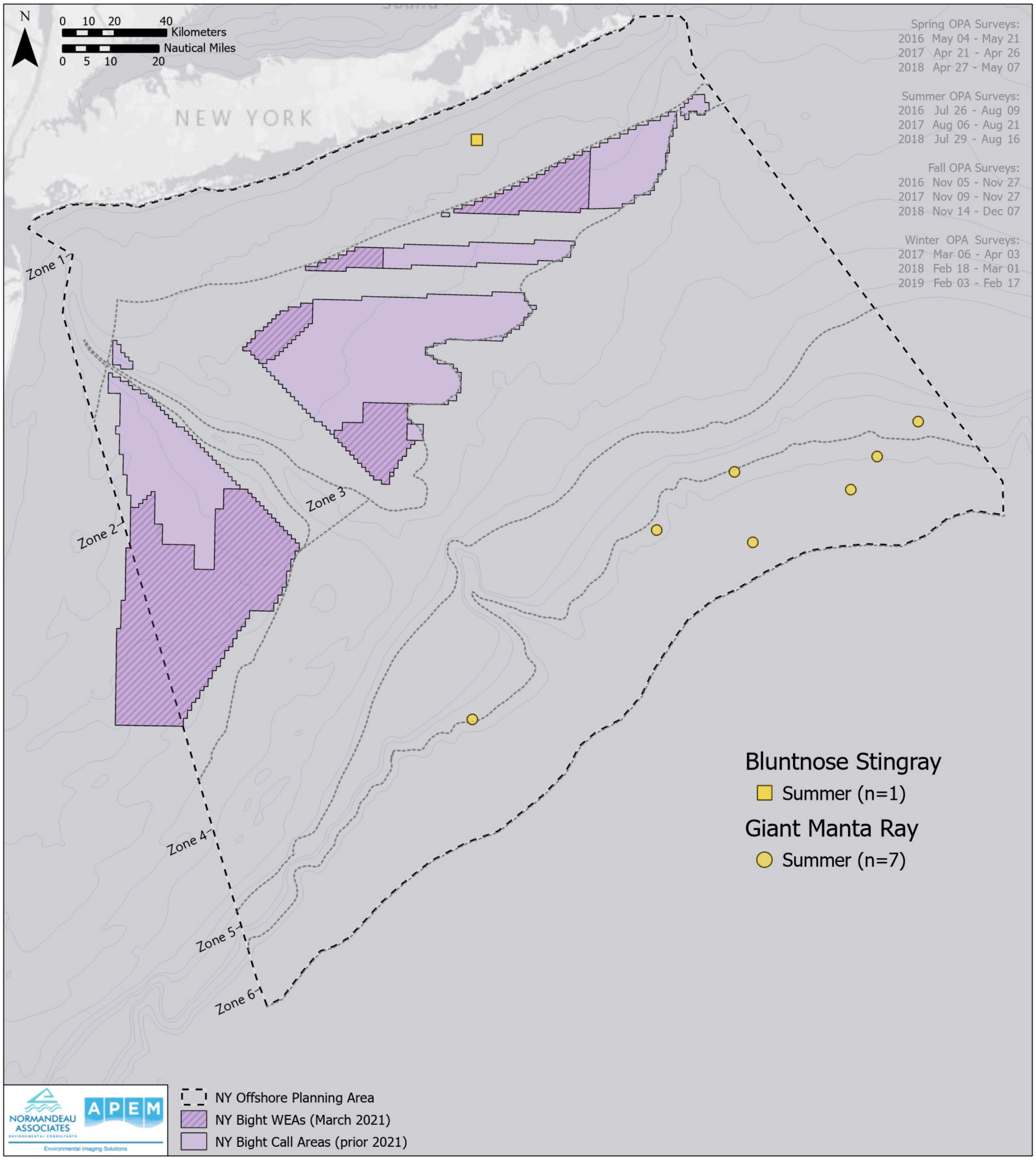


Figure 39. Spatial Distribution of Ray Species with Fewer than 30 Occurrences Across All Surveys



Appendix A. Representative Shark and Ray Images from Each Survey

Summer 2016


Smooth Hammerhead


Basking Shark


Giant Manta Ray


Chilean Devil Ray

Fall 2016

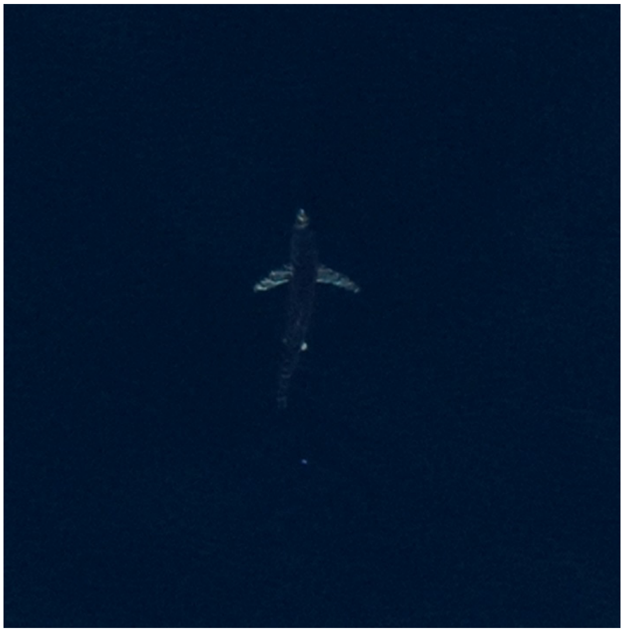
Blue Shark

Winter 2016–2017

Spurdog

Basking Shark

Spring 2017


Blue Shark


Basking Shark

Summer 2017


Whale Shark


Scalloped Hammerhead


Cownose Ray


Giant Devil Ray

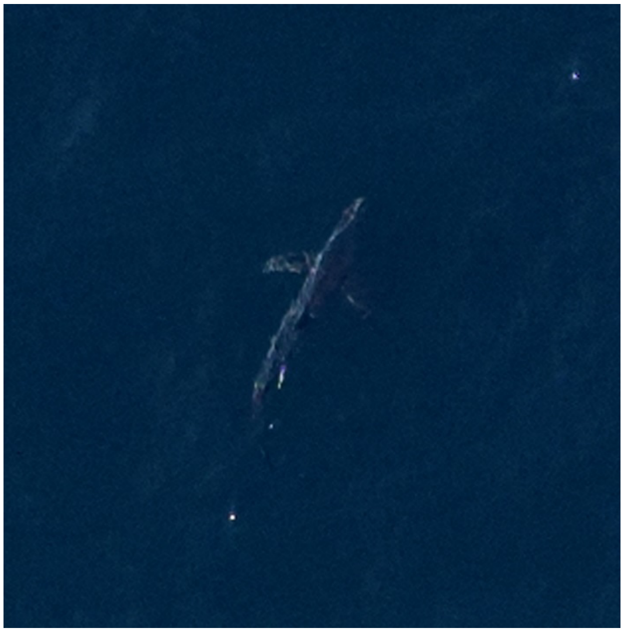
Fall 2017


Tiger Shark


Scalloped Hammerhead


Giant Devil Ray

Winter 2017–2018



Blue Shark

Basking Shark

Spring 2018


Spurdog


Basking Shark

Summer 2018

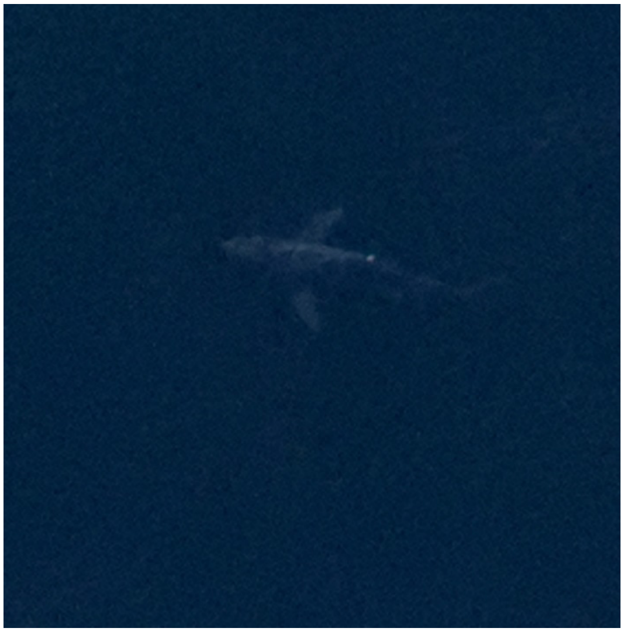

Whale Shark


Shortfin Mako


Cownose Ray


Chilean Devil Ray

Fall 2018


White Shark


Cownose/Bullnose Ray

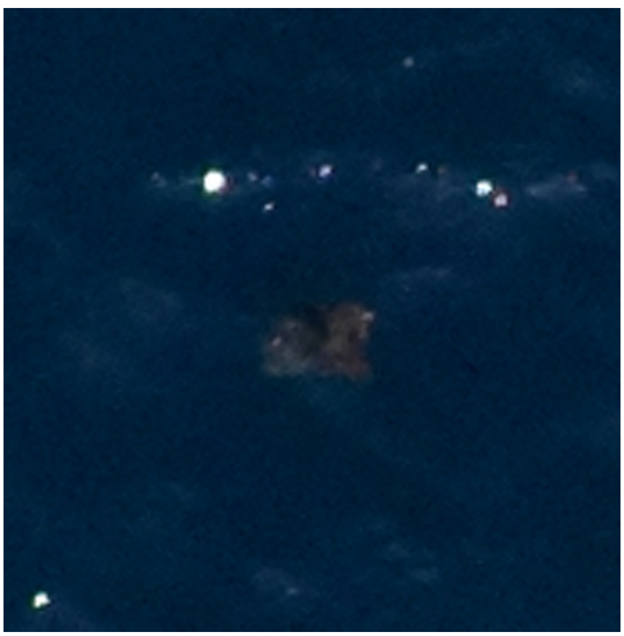
Winter 2018–2019

Basking Shark

Spring 2019

Blue Shark

Basking Shark



Cownose/Bullnose Ray