VINEYARD NORTHEAST

CONSTRUCTION AND OPERATIONS PLAN
VOLUME II APPENDIX

MARCH 2024

PREPARED BY:

Epsilon
ASSOCIATES INC.

SUBMITTED BY:

VINEYARD NORTHEAST LLC

VINEYARD OFFSHORE

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Appendix II-N Zooplankton and Ichthyoplankton Entrainment Assessment

Prepared by:
RPS

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ZOOPLANKTON AND ICHTHYOPLANKTON ENTRAINMENT ASSESSMENT

Vineyard Northeast

Entrainment Assessment

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Prepared by:

RPS Group, Inc.

Joseph Zottoli,Gabriella DiPreta, and Alicia Morandi

Project Manager: Alicia Morandi

55 Village Square Drive

South Kingstown, RI 02879

T 401-789-6224

E alicia.morandi@rpsgroup.com

Prepared for:

Epsilon Associates, Inc.

Maria Hartnett

Principal

3 Mill & Main Place, Suite 250

Maynard, MA 01754

T **978-897-7100**

E **mhartnett@epsilonassociates.com**

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List of Acronyms

BOEM	Bureau of Ocean Energy Management
EcoMon	Ecosystem Monitoring
EPRI	Electric Power Research Institute
ESP	electrical service platform
LLC	Limited Liability Company
MMS	Minerals Management Service
NCEI	National Centers for Environmental Information
NOAA	National Oceanic and Atmospheric Administration
CWIS	Cooling Water Intake Structure
USCG	United States Coast Guard
WTG	wind turbine generator

1 Introduction

1.1 Background

Vineyard Northeast LLC (the "Proponent") proposes to develop, construct, and operate offshore renewable wind energy facilities in Bureau of Ocean Energy Management (BOEM) Lease Area OCS-A 0522 (the "Lease Area") along with associated offshore and onshore transmission systems. This proposed development is referred to as "Vineyard Northeast." Vineyard Northeast includes up to 160 total wind turbine generator (WTG) and electrical service platform (ESP) positions within the Lease Area. Offshore export cables installed within offshore export cable corridors (OECCs) will connect the renewable wind energy facilities to onshore transmission systems in Massachusetts and/or Connecticut.

Up to three ESPs are expected to be installed in the Lease Area. If the selected ESP includes high voltage direct current (HVDC) equipment, a cooling water intake structure (CWIS) may be required,[1] which is estimated to intake up to 8.75 million gallons (33.1 million liters) of seawater per day throughout the operational period. In addition, a jetting tools (such as a jet plow) may be used to install inter-array and export cables during the construction period and could withdraw up to 0.71 million gallons (2.7 million liters) of seawater per hour when in use. The entrainment of water by both the CWIS and jetting tools would be expected to result in the mortality of zooplankton, including ichthyoplankton (i.e., egg and larval fishes). Conservatively, 100% mortality is assumed for entrained zooplankton as applied in other recent marine entrainment assessments (Northeast Gateway 2005; MMS 2008; South Fork Wind Farm 2019).

This study was performed to provide estimates of the potential impacts to zooplankton with special focus on ichthyoplankton based on localized survey abundances and anticipated entrained water volumes. The results in context of regional abundances, species life histories, and other impacts are intended to provide insight on species and community level impacts.

1.2 Objectives

- Identify the ichthyoplankton and zooplankton taxa present within 15 km of the Lease Area (the Study Area) using Ecosystem Monitoring (EcoMon) plankton sampling data.
- Estimate seasonal ichthyoplankton density for each fish taxa using mean and 95th percentile EcoMon sampling data.

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[1] This analysis assumes an open-loop CWIS is required; however, the HVDC ESP(s) could potentially use closed-loop water cooling (where no water is withdrawn from or discharged to the sea) if such technology becomes technically and commercially feasible. Although this technology is not currently available in the offshore wind market, the Proponent is aware of a number of firms that are working to develop and test closed loop cooling systems for use in offshore wind HVDC ESPs.

- Estimate seasonal total zooplankton density using mean, 5th percentile, and 95th percentile EcoMon sampling data.
- Estimate losses (i.e., total mortality) from entrainment of zooplankton and ichthyoplankton into the Vineyard Northeast ESP(s) CWIS.
- Estimate losses of commercially important equivalent adult (age-one) fish based on entrainment of ichthyoplankton into the Vineyard Northeast ESP(s) CWIS.
- Compare results to other sources of entrainment and fishery removals.

2 Methods

2.1 Data

The zooplankton data for this study were derived from the NOAA Northeast Fisheries Science Center EcoMon survey data (NEFSC 2019). The EcoMon dataset includes multiple survey efforts on the continental shelf dating back to 1977 but only years 2000 to 2019 (most recently available year) were applied for this study because regular processing of ichthyoplankton samples has only been completed since 2000 (Northeast Gateway 2005). EcoMon data are collected during six to seven surveys per year covering roughly 120 randomly selected stations each trip between North Carolina and Nova Scotia. During the period analyzed for this study, zooplankton were collected with twin 60-cm Bongo nets with 333-micron mesh. Data and associated metadata are available online for both zooplankton (92 taxa) and ichthyoplankton (45 taxa) from the NOAA National Centers for Environmental Information (NCEI) as catch extrapolated to densities per 100 cubic meters (m^3).

For assessing potential impacts from the CWIS, data were limited to samples recorded within 15 km of the Lease Area boundary. By applying a buffer to the Lease Area, the dataset remains representative for ESP(s) CWIS located anywhere within the Lease Area and incorporates zooplankton data from areas where they could be easily transported to within the Lease Area by oceanographic processes.

After reducing the dataset to only include samples from within 15 km of the Lease Area taken between 2000 and 2019, there were 16 winter (Dec—Feb) tows, 53 spring (Mar—May) tows, 30 summer (Jun—Aug) tows, and 56 fall (Sep—Nov) tows for a total of 155 tows (Figure 1).

2.1.1 Ichthyoplankton Data

Density (# of individuals per 100 m^3) data for each fish taxa were pooled and averaged by season. The data for each taxa were zero-inflated and over dispersed so a log transformation was ruled out. Instead, the arithmetic mean was used as a conservative estimate because it is greater than the geometric mean in right skewed data. The 95th percentile catch value for each fish taxa were also calculated for each season as another estimate of density that is typically more conservative. In some cases, the 95th percentile catch value was less than the arithmetic mean due to one or a few outliers in the 95th to 100th percentile range. Therefore, both the arithmetic mean and 95th percentile values were used in this assessment with the greater value representing the most conservative estimate for each taxa and season.

Since ichthyoplankton eggs are not recorded in the EcoMon database, they were not included in this part of the analysis. Approximations can be made for taxa with pelagic eggs using a 10-fold multiplier assuming a 10% survival rate to the larval stage (Dahlberg 1979; Pepin 1991).

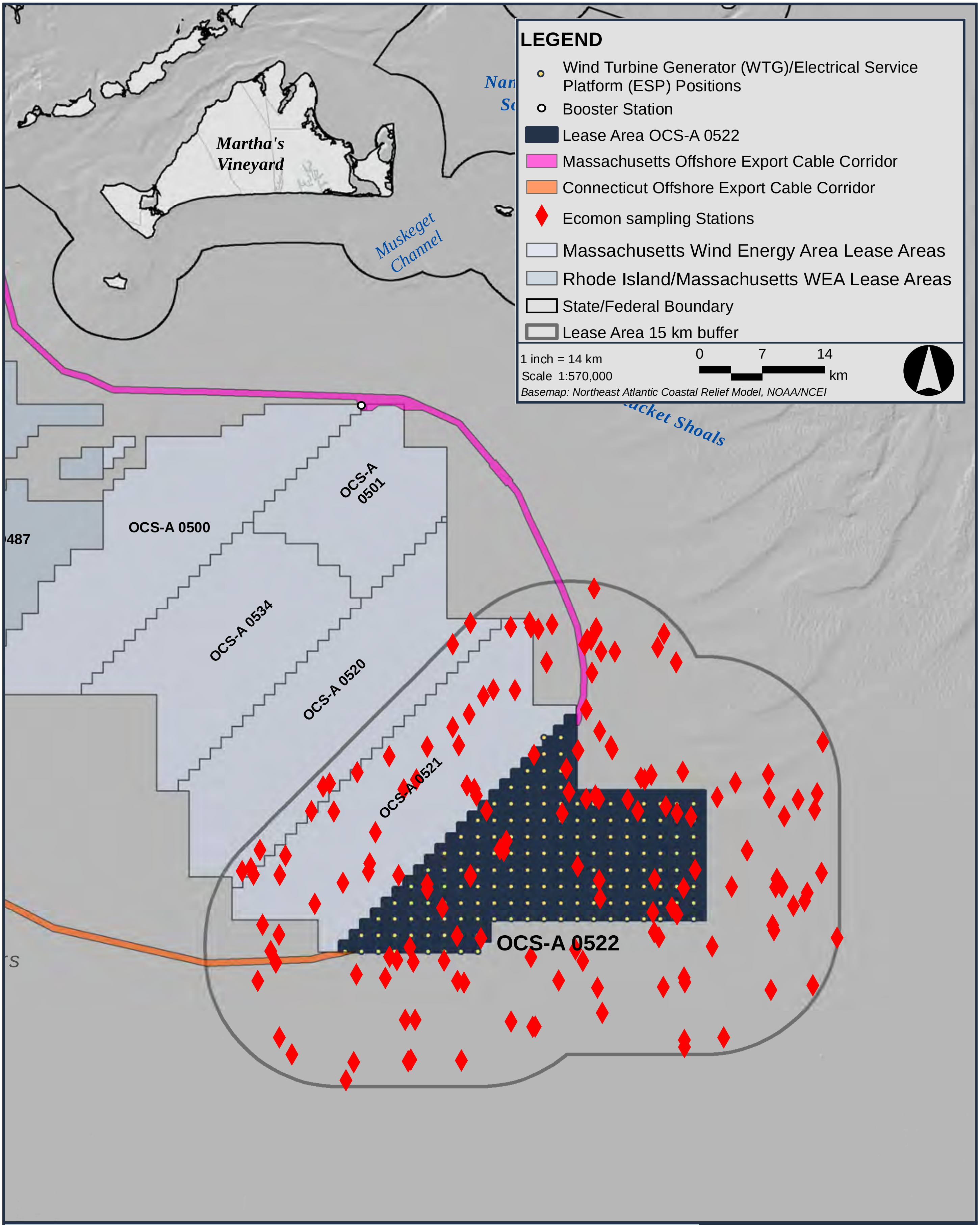

Figure 1

EcoMon Zooplankton Sampling Stations Within 15 km of the Lease Area Between 2000 to 2019

VINEYARD NORTHEAST
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2.1.2 Zooplankton (Non-Ichthyoplankton) Data

For non-ichthyoplankton zooplankton, the seasonal presence or absence of each taxa was recorded before pooling the density (# of individuals per 100 m^3) data by sample. Higher order taxa that could contain multiple other taxa already represented in the dataset, such as *Gastropoda, Copepoda,* and *Euphausiacea* categories, were excluded from the total density calculations to avoid overrepresentation. Instead, density values from individual species within those orders were used. Additionally, fish species captured in the zooplankton subsample were excluded from total zooplankton density counts because these species are presented individually in the ichthyoplankton results. The seasonal zooplankton data were over-dispersed but not zero-inflated like the ichthyoplankton data. To minimize the impacts of overdispersion, data were grouped by season and log-transformed, then averaged and retransformed using the inverse log to produce the mean value for each season. The 5th and 95th percentile seasonal sample values were selected from untransformed data.

2.2 Water Volume Calculations

The daily water withdrawal volume used for this study was the maximum expected flow rate of 8,749,377 gallons (33,120 m^3) per day. The seasonal average and selected percentile densities (per 100 m^3) of zooplankton and ichthyoplankton were multiplied by 25% of the total yearly intake volume to estimate the total number of entrained organisms in each of the four seasons. Mortality was assumed to be 100%.

2.3 Equivalent Adult Losses

For 12 managed or highly abundant fish taxa with available life-history information, the annual number of equivalent adults (age 1) lost to entrainment were calculated using the forward projection approach as described in EPRI (2004). Using the forward projection approach, the entrainment losses at the egg and larval stage were multiplied by the fraction of fish at that stage that would be expected to survive to the next life stage until the cohort reached age-one (i.e., age of equivalence):

$$EA = S_A N$$

Where: EA = equivalent adult loss;
N = number of fish lost due to entrainment; and
S_A = fraction of fish expected to survive from the age ($_A$) at which they are entrained to the next age group.

Regular and adjusted (meaning adjusted to account for the ages of eggs and larvae being different than day 0 when collected) survival rates were derived from Northeast Gateway (2005) as presented in Table 1. Larvae collected in the EcoMon trawl were conservatively assumed to be post-yolk-sac larvae due to their higher chance of survival to the age of equivalency. As described above, the number of eggs subjected to equivalent adult calculations were assumed to be 10 times greater than the number of larvae expected to be entrained. Therefore, losses from entrained larvae were calculated using the adjusted post-yolk-sac larvae survival rates followed by regular young-of-the year survival rates. Losses from entrained eggs were calculated by multiplying the entrained larvae estimate by 10 and then using the adjusted egg survival rate followed by regular survival rates at later life stages. However, Atlantic herring (*Clupea harengus*), sand lance (*Ammodytidae spp.*), and winter flounder (*Pseudopleuronectes americanus*) lay adhesive, demersal eggs so estimates of egg loss via entrainment and subsequent equivalent adults were not included for these species.

Average annual coastwide commercial landings in pounds were calculated for each species included in the equivalent adult loss calculations. These data were queried from NOAA Fisheries (2022) and averaged over the six-year span between 2016 and 2022.

Table 1 Survival Rates by Life Stage for Taxa with Calculated Equivalent Adult Losses

Taxa	Adjusted Egg S_A	Yolk-Sac Larvae S_A	Adjusted Post-Yolk-Sac Larvae	Post-Yolk-Sac Larvae S_A	Young-of-the-Year
Atlantic Herring	NA	NA	0.0783	0.0408	0.0041
Atlantic Cod	0.5989	0.3329	0.0492	0.0252	0.0006
Atlantic Mackerel	0.4424	0.1921	0.0506	0.0260	0.0028
Butterfish	0.3871	0.0870	0.0264	0.0134	0.5294
Haddock	0.3017	0.0023			0.0169
Silver Hake	0.4475	0.0738	0.0063	0.0031	0.0773
Pollock	0.5691	0.0058			0.0078
Red and White (Phycid) hakes	0.5705	0.5762	0.0048	0.0024	0.0063
Sand Lance	NA	NA	0.4206	0.2663	0.0551
Cunner	0.4123	0.6851	0.1487	0.0803	0.1145
Winter Flounder	NA	NA	0.7360	0.5822	0.0004
Yellowtail flounder	0.5738	0.0368			0.0491

Notes:
1. Table values are from Northeast Gateway (2005).

3 Results

3.1 EcoMon Data

Out of the 86 zooplankton taxa recorded by the EcoMon dataset, a total of 47 taxa from 9 phyla were present within the Study Area during one or more seasons from 2000 to 2019 (Table 2). A total of 37 taxa of ichthyoplankton were recorded as present at least once in the final dataset. Sampling abundances for most ichthyoplankton taxa peaked over a few weeks at different times of the year for different taxa (Figures 2a-2e).

Table 2 Zooplankton Taxa Presence (+) by Season within Study Area

Taxa	Fall	Winter	Spring	Summer
Arthropoda				
Centropages typicus	+	+	+	+
Calanus finmarchicus	+	+	+	+
Pseudocalanus spp.	+	+	+	+
Penilia spp.	+		+	+
Temora longicornis	+	+	+	+
Centropages hamatus	+	+	+	+
Paracalanus parvus	+	+	+	+
Acartia spp.	+	+	+	+
Metridia lucens	+	+	+	+
Evadne spp.	+		+	+
Oithona spp.	+	+	+	+
Cirripedia	+	+	+	+
Hyperiidea	+	+	+	+
Gammaridea	+	+	+	+
Calanus minor	+	+		+
Clausocalanus arcuicornis	+	+	+	+
Decapoda	+	+	+	+
Acartia longiremis	+	+	+	+
Eucalanus spp.	+			+
Podon spp.	+		+	+
Clausocalanus furcatus	+			+
Calanus spp.	+		+	
Oncaea spp.	+			+
Corycaeidae	+	+	+	+
Ostracoda	+	+		
Temora stylifera	+			+
Mysidacea	+	+	+	+
Temora spp.	+			

Table 2 Zooplankton Taxa Presence (+) by Season within Study Area (Continued)

Taxa	Fall	Winter	Spring	Summer
Arthropoda				
Tortanus discaudatus	+	+	+	+
Paracalanus spp.	+			+
Thysanoessa inermis		+		
Thysanoessa raschii	+			
Euphausia krohnii	+			
Thysanoessa gregaria	+			+
Mollusca				
Thecosomata	+	+	+	+
Spiratella spp.	+	+	+	+
Pelecypoda	+	+	+	+
Cnidaria				
Siphonophores	+		+	+
Coelenterates	+	+	+	+
Ctenophores	+		+	+
Chordata				
Appendicularians	+	+	+	+
Salpa	+	+	+	+
Echinodermata				
Echinodermata	+	+	+	+
Annelida				
Polychaeta	+	+	+	+
Bryozoa				
Bryozoa	+	+	+	+
Protozoa				
Protozoa	+	+	+	+
Chaetognatha				
Chaetognatha	+	+	+	+

Notes:
1. Zooplankton presence in the Study Area by season are derived from the EcoMon dataset.

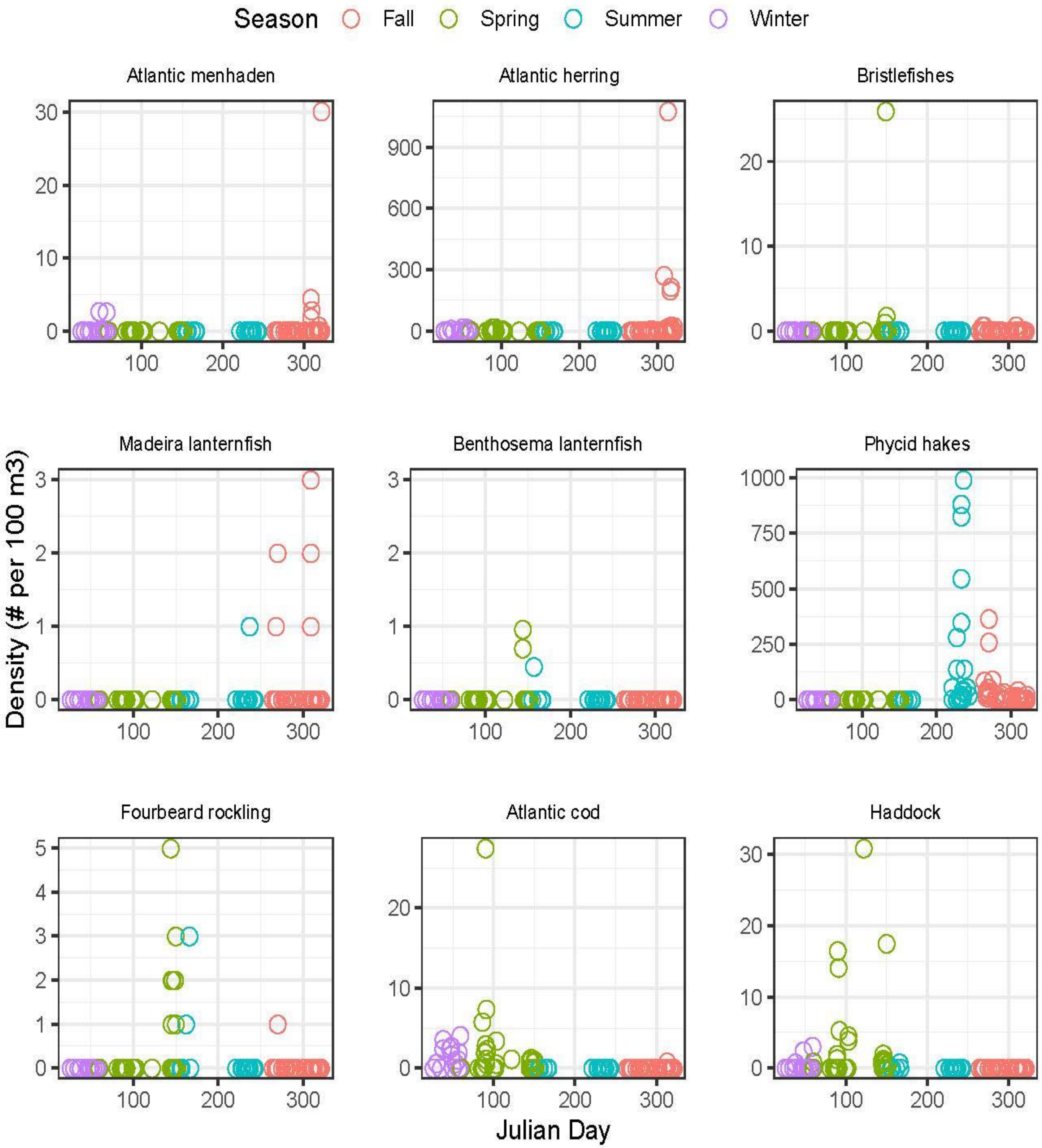

Figure 2a

Ichthyoplankton Sample Densities (Individuals per 100 m^3) Within the Study Area Throughout the Year

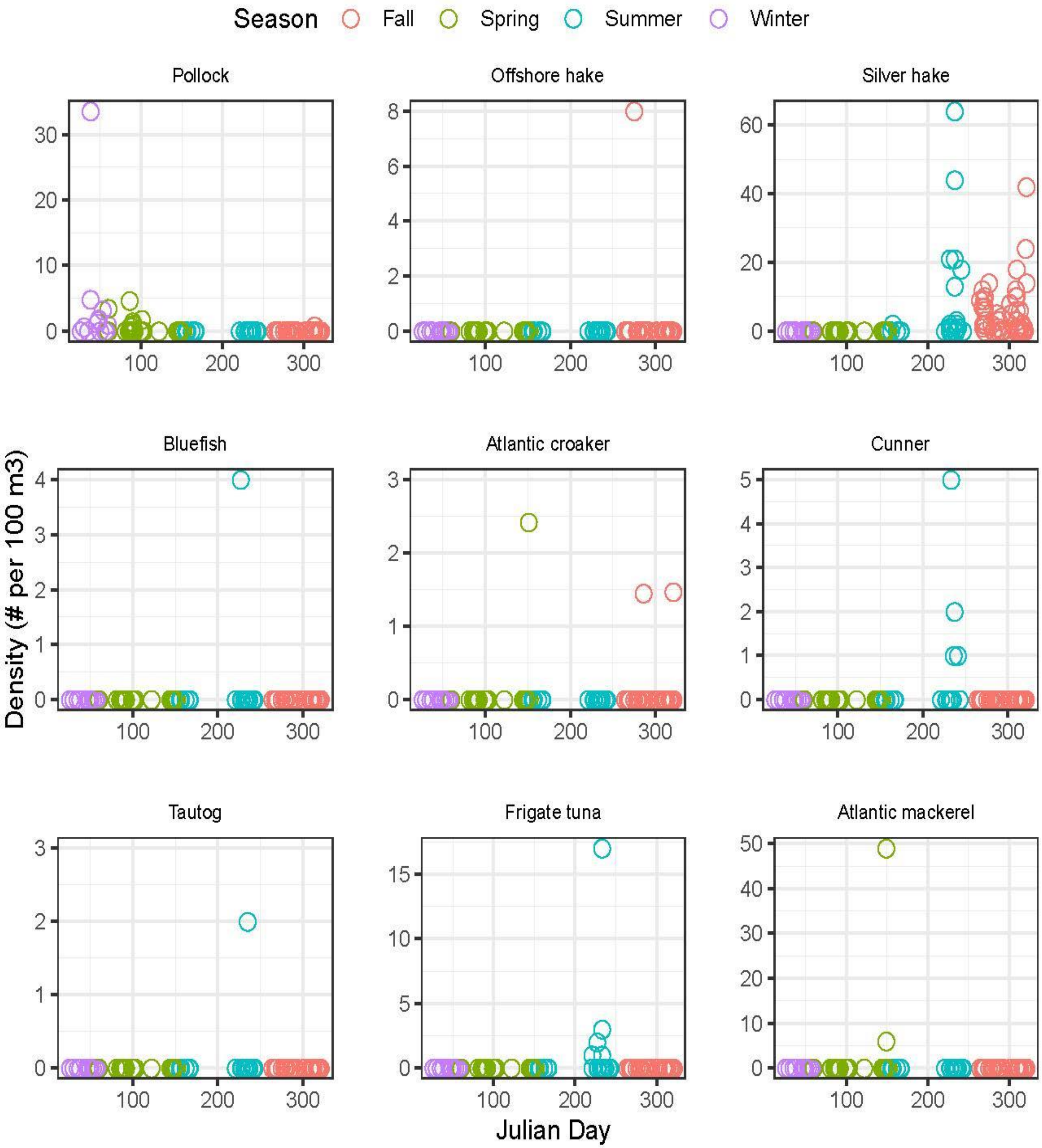

Figure 2b

Ichthyoplankton Sample Densities (Individuals per 100 m^3) Within the Study Area Throughout the Year

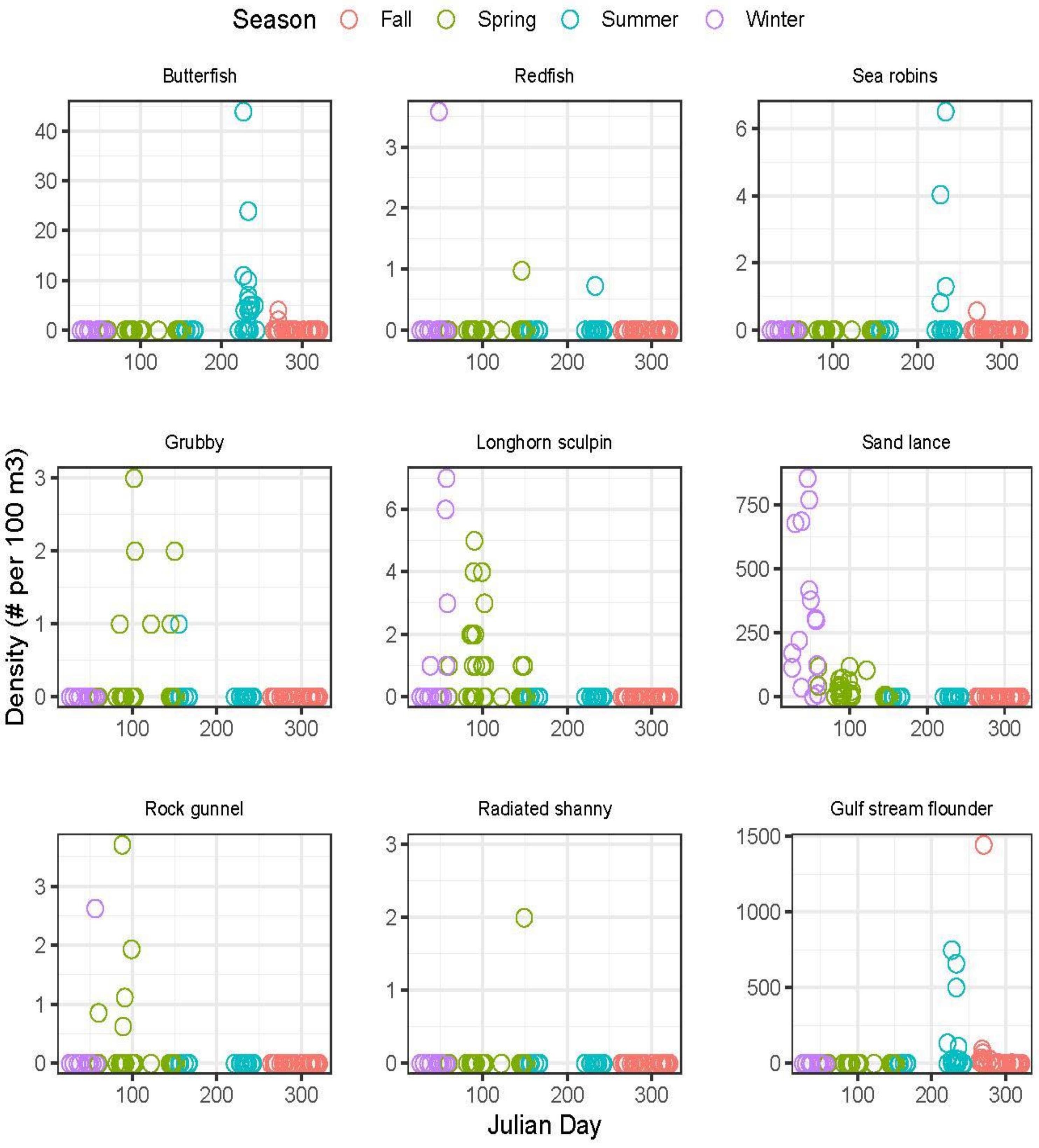

Figure 2c

Ichthyoplankton Sample Densities (Individuals per 100 m^3) Within the Study Area Throughout the Year

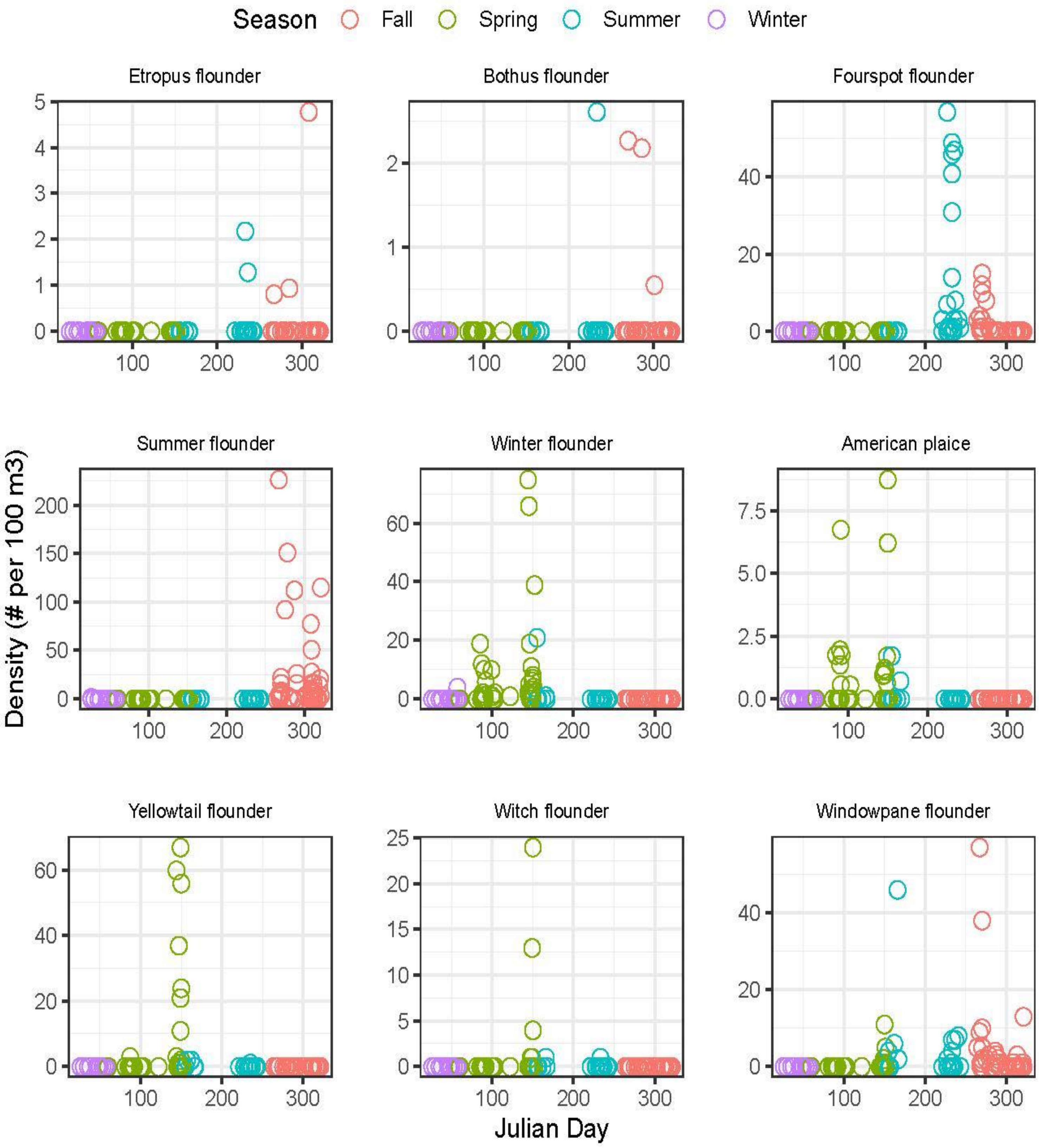

Figure 2d

Ichthyoplankton Sample Densities (Individuals per 100 m^3) Within the Study Area Throughout the Year

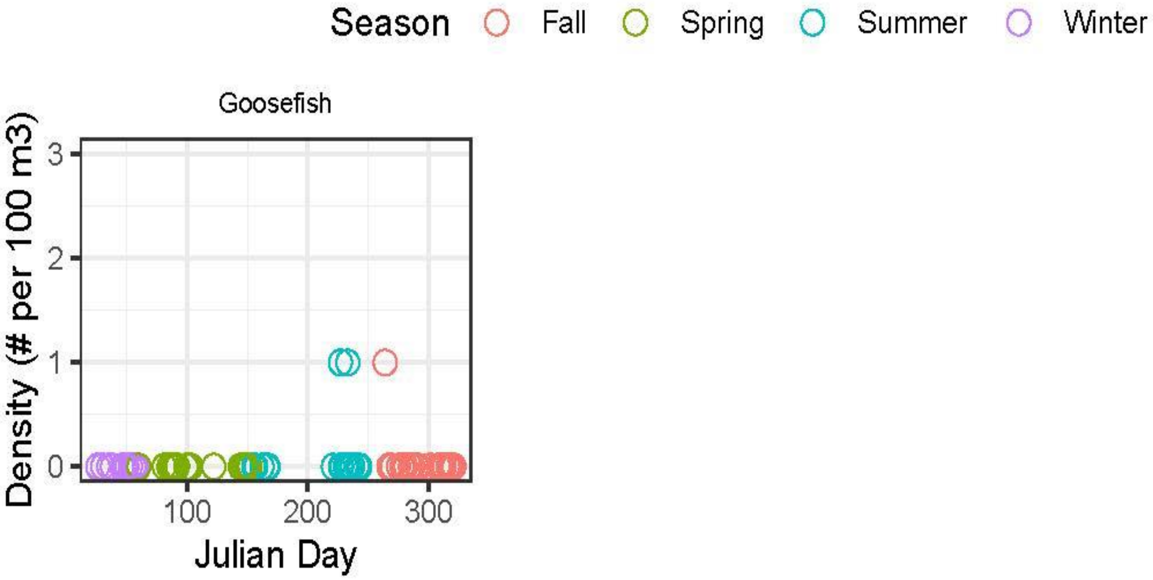

Figure 2e

Ichthyoplankton Sample Densities (Individuals per 100 m^3) Within the Study Area Throughout the Year

3.2 Entrainment Losses - Ichthyoplankton

Most ichthyoplankton taxa were only present in one or two seasons. Estimated seasonal densities of ichthyoplankton taxa ranged from a mode of 0 to 320 individuals per 100 m^3 (sand lances in winter) based on arithmetic mean values and from a mode of 0 to 826 individuals per 100 m^3 (phycid hakes in fall) based on 95th percentile values. Annual estimated ichthyoplankton losses from CWIS entrainment ranged from 0 to 10.2 million larvae (sand lance) based on arithmetic mean values and 0 to 27.5 million larvae (phycid hakes) based on 95th percentile values (Table 3).

Table 3 Presence and Estimated Larval Fish Entrainment Mortality Based on Seasonal Mean and 95th Percentile Catch Values

Taxa	Season[1]	Percent of Tows Present (%)	Estimated Mean Larval Density (# per 100 m^3)	Estimated 95th Percentile Larval Density (# per 100 m^3)	Estimated # of Entrained Larvae based on Mean Density	Estimated # of Entrained Larvae based on 95th Percentile Density
Atlantic menhaden (*Brevoortia tyrannus*)	Winter	12.5	0.33	2.62	10,030	79,182
	Spring	0	-	-	-	-
	Summer	0	-	1.86	-	56,213
	Fall	8.9	0.71	-	21,571	-
	Total	4.5	NA	NA	31,601	135,395
Atlantic herring (*Clupea harengus*)	Winter	43.8	2.87	13.00	86,888	392,886
	Spring	22.6	1.11	8.00	33,643	241,776
	Summer	0	-	199.00	-	6,014,178
	Fall	30.4	33.57	-	1,014,596	-
	Total	23.2	NA	NA	1,135,127	6,648,840
Bristlefishes (*Cyclothone spp*)	Winter	0	-	-	-	-
	Spring	5.7	0.54	-	16,326	-
	Summer	0	-	-	-	-
	Fall	5.4	0.03	-	955	-
	Total	3.9	NA	NA	17,281	-
Madeira lanternfish *(Ceratoscopelus maderensis)*	Winter	0	-	-	-	-
	Spring	0	-	-	-	-
	Summer	3.3	0.03	1.00	1,007	30,222
	Fall	8.9	0.16	-	4,857	-
	Total	3.9	NA	NA	5,865	30,222

Table 3 Presence and Estimated Larval Fish Entrainment Mortality Based on Seasonal Mean and 95th Percentile Catch Values (Continued)

Taxa	Season[1]	Percent of Tows Present (%)	Estimated Mean Larval Density (# per 100 m^3)	Estimated 95th Percentile Larval Density (# per 100 m^3)	Estimated # of Entrained Larvae based on Mean Density	Estimated # of Entrained Larvae based on 95th Percentile Density
Benthosema lanternfish *(Benthosema spp)*	Winter	0	-	-	-	-
	Spring	3.8	0.03	-	947	-
	Summer	3.3	0.01	-	453	-
	Fall	0	-	-	-	-
	Total	1.9	NA	NA	1,400	-
Phycid hakes *(Urophycis spp)*	Winter	0	-	-	-	-
	Spring	0	-	-	-	-
	Summer	73.3	147.01	82.83	4,443,027	2,503,288
	Fall	71.4	23.41	826.26	707,405	24,971,230
	Total	40.0	NA	NA	5,150,432	27,474,518
Fourbeard rockling *(Enchelyopus cimbrius)*	Winter	0	-	-	-	-
	Spring	15.1	0.36	2.00	10,834	60,444
	Summer	6.7	0.13	-	4,030	-
	Fall	1.8	0.02	-	540	-
	Total	7.1	NA	NA	15,404	60,444
Atlantic cod *(Gadus morhua)*	Winter	62.5	1.32	3.57	39,780	107,893
	Spring	34.0	1.17	3.41	35,457	103,057
	Summer	0	-	-	-	-
	Fall	1.8	0.01	-	410	-
	Total	18.7	NA	NA	75,647	210,950
Haddock *(Melanogrammus aeglefinus)*	Winter	18.8	0.39	2.41	11,654	72,835
	Spring	37.7	2.00	14.12	60,547	426,735
	Summer	3.3	0.02	-	725	-
	Fall	0	-	-	-	-
	Total	15.5	NA	NA	72,926	499,570
Pollock *(Pollachius virens)*	Winter	50.0	2.99	4.82	90,326	145,670
	Spring	13.2	0.26	1.37	7,744	41,404
	Summer	0	-	-	-	-
	Fall	1.8	0.01	-	410	-
	Total	10.3	NA	NA	98,480	187,074

Table 3 Presence and Estimated Larval Fish Entrainment Mortality Based on Seasonal Mean and 95th Percentile Catch Values (Continued)

Taxa	Season[1]	Percent of Tows Present (%)	Estimated Mean Larval Density (# per 100 m³)	Estimated 95th Percentile Larval Density (# per 100 m³)	Estimated # of Entrained Larvae based on Mean Density	Estimated # of Entrained Larvae based on 95th Percentile Density
Offshore hake *(Merluccius albidus)*	Winter	0	-	-	-	-
	Spring	0	-	-	-	-
	Summer	0	-	-	-	-
	Fall	1.8	0.14	-	4,317	-
	Total	0.7	NA	NA	4,317	-
Silver hake *(Merluccius bilinearis)*	Winter	0	-	-	-	-
	Spring	0	-	-	-	-
	Summer	46.7	6.47	14.00	195,436	423,108
	Fall	64.3	4.95	21.00	149,491	634,662
	Total	32.3	NA	NA	344,927	1,057,770
Bluefish *(Pomatomus saltatrix)*	Winter	0	-	-	-	-
	Spring	0	-	-	-	-
	Summer	3.3	0.13	-	4,030	-
	Fall	0	-	-	-	-
	Total	0.6	NA	NA	4,030	-
Atlantic croaker *(Micropogonias undulatus)*	Winter	0	-	-	-	-
	Spring	1.9	0.05	-	1,380	-
	Summer	0	-	-	-	-
	Fall	3.6	0.05	-	1,576	-
	Total	1.9	NA	NA	2,956	-
Cunner *(Tautogolabrus adspersus)*	Winter	0	-	-	-	-
	Spring	0	-	-	-	-
	Summer	13.3	0.30	-	9,067	-
	Fall	0	-	1.00	-	30,222
	Total	2.6	NA	NA	9,067	30,222
Tautog *(Tautoga onitis)*	Winter	0	-	-	-	-
	Spring	0	-	-	-	-
	Summer	3.3	0.07	-	2,015	-
	Fall	0	-	-	-	-
	Total	0.6	NA	NA	2,015	-

Table 3 Presence and Estimated Larval Fish Entrainment Mortality Based on Seasonal Mean and 95th Percentile Catch Values (Continued)

Taxa	Season[1]	Percent of Tows Present (%)	Estimated Mean Larval Density (# per 100 m^3)	Estimated 95th Percentile Larval Density (# per 100 m^3)	Estimated # of Entrained Larvae based on Mean Density	Estimated # of Entrained Larvae based on 95th Percentile Density
Frigate tunas *(Auxis spp)*	Winter	0	-	-	-	-
	Spring	0	-	-	-	-
	Summer	20.0	0.83	-	25,185	-
	Fall	0	-	2.00	-	60,444
	Total	3.9	NA	NA	25,185	60,444
Atlantic mackerel *(Scomber scombrus)*	Winter	0	-	-	-	-
	Spring	3.8	1.04	-	31,362	-
	Summer	0	-	-	-	-
	Fall	0	-	-	-	-
	Total	1.3	NA	NA	31,362	-
Butterfishes *(Peprilus spp)*	Winter	0	-	-	-	-
	Spring	0	-	-	-	-
	Summer	46.7	4.47	-	134,992	-
	Fall	3.6	0.11	11.00	3,238	332,442
	Total	10.3	NA	NA	138,230	332,442
Redfishes *(Sebastes spp)*	Winter	6.3	0.22	-	6,781	-
	Spring	1.9	0.02	-	559	-
	Summer	3.3	0.02	-	735	-
	Fall	0	-	-	-	-
	Total	1.9	NA	NA	8,075	-
Sea robins *(Prionotus spp)*	Winter	0	-	-	-	-
	Spring	0	-	-	-	-
	Summer	13.3	0.42	-	12,774	-
	Fall	1.8	0.01	1.30	308	39,289
	Total	3.2	NA	NA	13,081	39,289
Grubby *(Myoxocephalus aenaeus)*	Winter	0	-	-	-	-
	Spring	11.3	0.19	1.00	5,702	30,222
	Summer	3.3	0.03	-	1,007	-
	Fall	0	-	-	-	-
	Total	4.5	NA	NA	6,710	30,222

Table 3 Presence and Estimated Larval Fish Entrainment Mortality Based on Seasonal Mean and 95th Percentile Catch Values (Continued)

Taxa	Season[1]	Percent of Tows Present (%)	Estimated Mean Larval Density (# per 100 m^3)	Estimated 95th Percentile Larval Density (# per 100 m^3)	Estimated # of Entrained Larvae based on Mean Density	Estimated # of Entrained Larvae based on 95th Percentile Density
Longhorn sculpin *(Myoxocephalus octodecemspinosus)*	Winter	31.3	1.13	6.00	34,000	181,332
	Spring	30.2	0.60	3.00	18,247	90,666
	Summer	0	-	-	-	-
	Fall	0	-	-	-	-
	Total	13.5	NA	NA	52,247	271,998
Sand lances *(Ammodytes spp)*	Winter	93.8	320.46	771.37	9,685,037	23,312,344
	Spring	47.2	18.08	73.11	546,374	2,209,530
	Summer	0	-	-	-	-
	Fall	0	-	-	-	-
	Total	25.8	NA	NA	10,231,410	25,521,875
Rock gunnel *(Pholis gunnellus)*	Winter	6.3	0.16	-	4,968	-
	Spring	9.4	0.16	0.86	4,710	25,991
	Summer	0	-	-	-	-
	Fall	0	-	-	-	-
	Total	3.9	NA	NA	9,678	25,991
Radiated shanny *(Ulvaria subbifurcata)*	Winter	0	-	-	-	-
	Spring	1.9	0.04	-	1,140	-
	Summer	0	-	-	-	-
	Fall	0	-	-	-	-
	Total	0.6	NA	NA	1,140	-
Gulf Stream flounder *(Citharichthys arctifrons)*	Winter	0	-	-	-	-
	Spring	0	-	-	-	-
	Summer	50.0	75.97	36.00	2,295,865	1,087,992
	Fall	37.5	31.16	503.00	941,739	15,201,666
	Total	23.2	NA	NA	3,237,604	16,289,658
Etropus flounders *(Etropus spp)*	Winter	0	-	-	-	-
	Spring	0	-	-	-	-
	Summer	6.7	0.12	-	3,496	-
	Fall	5.4	0.12	-	3,524	-
	Total	3.2	NA	NA	7,020	-

Table 3 **Presence and Estimated Larval Fish Entrainment Mortality Based on Seasonal Mean and 95th Percentile Catch Values (Continued)**

Taxa	Season[1]	Percent of Tows Present (%)	Estimated Mean Larval Density (# per 100 m^3)	Estimated 95th Percentile Larval Density (# per 100 m^3)	Estimated # of Entrained Larvae based on Mean Density	Estimated # of Entrained Larvae based on 95th Percentile Density
Bothus flounders *(Bothus spp)*	Winter	0	-	-	-	-
	Spring	0	-	-	-	-
	Summer	3.3	0.09	-	2,629	-
	Fall	5.4	0.09	-	2,698	-
	Total	2.6	NA	NA	5,328	-
Fourspot flounder *(Hippoglossina oblonga)*	Winter	0	-	-	-	-
	Spring	0	-	-	-	-
	Summer	56.7	10.53	8.00	318,338	241,776
	Fall	19.6	1.05	47.00	31,841	1,420,434
	Total	18.1	NA	NA	350,179	1,662,210
Summer flounder *(Paralichthys dentatus)*	Winter	6.3	0.08	-	2,361	-
	Spring	0	-	-	-	-
	Summer	0	-	112.41	-	3,397,255
	Fall	67.9	19.65	-	593,803	-
	Total	25.2	NA	NA	596,164	3,397,255
Winter flounder *(Pseudopleuronectes americanus)*	Winter	6.3	0.25	-	7,556	-
	Spring	60.4	6.21	19.00	187,604	574,218
	Summer	6.7	0.73	-	22,163	-
	Fall	0	-	-	-	-
	Total	22.6	NA	NA	217,323	574,218
American plaice *(Hippoglossoides platessoides)*	Winter	0	-	-	-	-
	Spring	28.3	0.68	1.95	20,699	58,933
	Summer	6.7	0.08	-	2,458	-
	Fall	0	-	-	-	-
	Total	11.0	NA	NA	23,157	58,933
Yellowtail flounder *(Limanda ferruginea*	Winter	0	-	-	-	-
	Spring	22.6	5.40	37.00	163,085	1,118,214
	Summer	10.0	0.17	-	5,037	-
	Fall	0	-	1.00	-	30,222
	Total	9.7	NA	NA	168,122	1,148,436

Table 3 Presence and Estimated Larval Fish Entrainment Mortality Based on Seasonal Mean and 95th Percentile Catch Values (Continued)

Taxa	Season[1]	Percent of Tows Present (%)	Estimated Mean Larval Density (# per 100 m^3)	Estimated 95th Percentile Larval Density (# per 100 m^3)	Estimated # of Entrained Larvae based on Mean Density	Estimated # of Entrained Larvae based on 95th Percentile Density
Witch flounder *(Glyptocephalus cynoglossus)*	Winter	0	-	-	-	-
	Spring	9.4	0.81	1.00	24,520	30,222
	Summer	6.7	0.07	-	2,015	-
	Fall	0	-	-	-	-
	Total	4.5	NA	NA	26,535	30,222
Windowpane flounder *(Scophthalmus aquosus)*	Winter	0	-	-	-	-
	Spring	13.2	0.42	1.00	12,545	30,222
	Summer	33.3	2.90	10.00	87,644	302,220
	Fall	46.4	3.00	7.00	90,666	211,554
	Total	27.7	NA	NA	190,855	543,996
Goosefish *(Lophius americanus)*	Winter	0	-	-	-	-
	Spring	0	-	-	-	-
	Summer	10.0	0.10	-	3,022	-
	Fall	1.8	0.02	1.00	540	30,222
	Total	2.6	NA	NA	3,562	30,222

Notes:

1. Between 2000 and 2019 number of samples per season included 16 winter tows, 53 spring tows, 30 summer tows, and 56 fall tows.
2. Table data is from the EcoMon dataset.
3. Dashes indicate taxa was not present during that season. “NA” indicates that densities were calculated per season based on different numbers of tows so it was not appropriate to total them.

3.3 Entrainment Losses - Equivalent Adults

Losses of equivalent age-one fish were calculated using larval densities and survival rates. For ten of these fish taxa, it was estimated that less than 10,000 equivalent age-one fish would be lost annually via entrainment for most species based on both mean and 95th percentile estimates. Sand lance had much higher estimated annual losses at between 200,000 (mean) and 600,000 (95th percentile) equivalent age-one fish lost. Yellowtail flounder losses were second highest at 68,295 equivalent age-one fish based on the 95th percentile estimate (Table 4). Average commercial landings of each of these taxa were in the millions or tens of millions of pounds except for cunner and sand lance, which are not typically harvested in the United States because of their small size (Table 5).

Table 4 Estimated Annual Fish Larvae and Equivalent Age-One Fish Loss Based on Seasonal Mean and 95th Percentile Density Values

Taxa	Estimated Annual Larval Mortality - Mean Density	Estimated Annual Larval Mortality – 95th Percentile Density	Estimated Annual Equivalent Age-One Fish Loss – Mean Density	Estimated Annual Equivalent Age-One Fish Loss – 95th Percentile Density
Atlantic herring	1,135,127	6,648,840	364	2,134
Atlantic cod	75,647	210,950	5	13
Atlantic mackerel	31,362	0	6	-
Butterfish	138,230	332,442	2,262	5,440
Haddock	72,926	499,570	1,241	8,501
Silver hake	344,927	1,057,770	195	599
Pollock	98,480	187,074	4,372	8,304
Red and white (Phycid) hakes	5,150,432	27,474,518	412	2,196
Sand lance	10,231,410	25,521,875	237,114	591,471
Cunner	9,067	30,222	390	1,299
Winter flounder	217,323	574,218	64	169
Yellowtail flounder	168,122	1,148,436	9,998	68,295

Notes:

1. Table data is from the EcoMon dataset.

Table 5 **Average Commercial Landings Between 2016–2020 (Coastwide) of Species With Equivalent Age-One Fish Loss Estimates**

Taxa	Average Annual Commercial landings (pounds)
Atlantic herring	77,625,232
Atlantic cod	2,218,584
Atlantic mackerel	15,160,043
Butterfish	5,452,070
Haddock	15,836,543
Silver hake	11,974,195
Pollock	6,877,006
Red and white (Phycid) hakes	5,217,463
Sand lance	NA
Cunner	3,685
Winter flounder	1,671,993
Yellowtail flounder	1,362,602

Notes: Table data is from NOAA Fisheries 2022.

3.4 Entrainment Losses - Zooplankton

Pooled zooplankton densities varied seasonally. After applying the appropriate transformations to calculate mean the zooplankton densities, summer had the highest seasonal density with an estimated 369,086 individuals per 100 m^3 and winter had the lowest seasonal density with an estimated 39,122 individuals per 100 m^3. The spring had the highest 95th percentile density but not the highest mean indicating that very high densities are possible in the spring but not consistent. The estimated losses from entrainment by the CWIS are summarized in Table 6. Based on the mean estimates, the total number of zooplankton expected to be entrained by the CWIS is 13.5 billion individuals annually. Based on the extremely conservative 95th percentile estimates, the total number of zooplankton expected to be entrained by the CWIS is 54.6 billion individuals annually.

Table 6 Presence and Estimated Zooplankton Entrainment Mortality Based on Seasonal 5th Percentile, Mean, and 95th Percentile Density Values

Season	Number of Samples	Estimated 5th Percentile Density (# per 100 m3)	Estimated Mean Density (# per 100 m3)	Estimated 95th Percentile Density (# per 100 m3)	Estimated # of Entrained Larvae based on 5th Percentile Density (billions of individuals)	Estimated # of Entrained Larvae based on Mean Density (billions of individuals)	Estimated # of Entrained Larvae based on 95th Percentile Density (billions of individuals)
Winter	16	8,758	39,122	132,242	0.27	1.18	3.10
Spring	53	22,792	126,640	751,351	0.69	3.82	22.70
Summer	30	50,456	150,204	369,086	1.52	4.54	11.16
Fall	56	30,837	131,577	553,187	0.93	3.98	16.72
Total	155	NA	NA	NA	3.41	13.53	54.58

Notes:

1. Table data is from the EcoMon dataset.
2. "NA" indicates that densities were calculated per season based on different numbers of tows so it was not appropriate to total them.

4 Discussion

The purpose of this study was to characterize the existing zooplankton community and quantify potential impacts of entrainment from a single ESP CWIS; up to three ESP CWIS may be used for Vineyard Northeast. The zooplankton composition and ichthyoplankton taxa densities were comparable to those described in a nearby offshore wind project as part of a jet plow entrainment study (South Fork Wind Farm 2019). There is the potential for losses to other entrainment sources such as vessel cooling systems and jetting tool pumps, but these entrainment volumes are expected to be much lower than volumes from the ESP CWIS. Jetting tool intake rates are expected to be a maximum of 64,800,000 liters per day, if operated 24 hours per day at the maximum flow rate, which is about twice the daily CWIS flow. However, jetting tool operation is expected to be temporary during construction and the total volume of entrained water from a jetting tool is expected to be at least two orders of magnitude less than the volume entrained over the life of the CWIS. In addition, modeling at nearby South Fork Wind (2019) and Cape Wind (MMS 2008) found entrainment impacts from jet plow cable installation to be small relative to total zooplankton abundance. Therefore, jetting tool entrainment was not included in this assessment.

In the context of regional abundances and species life histories, estimated losses of zooplankton and ichthyoplankton from entrainment by the ESP CWIS are small. The CWIS is expected to remove less than 8.75 million gallons (33.1 million liters) per day, which is roughly 0.0001% of the volume of water within the Lease Area for one ESP and 0.0003% for up to three ESPs, assuming an average water depth of 50 m. As demonstrated by the equivalent adult calculations, tens to thousands of times fewer age-one equivalent fish are expected to be lost to entrainment when compared to larvae lost due to high early-life stage mortality. In addition, many of the fish species investigated here have not reached sexual maturity or legal harvest length by age-one so additional time (and therefore mortality) is expected in most cases before socioeconomic or future reproductive losses would be incurred.

In context of commercial fisheries removals, the equivalent one-year-old fish expected to be lost to entrainment only comprise a fraction of a percent of the annual commercial fisheries landings. For example, most taxa are expected to have less than 10,000 equivalent one-year-old individuals lost to entrainment with those same species typically experiencing between one million and twenty million pounds of landings annually (not including discard mortality or recreational landings). At one year of age, most fish species included in this analysis are expected to weigh less than one pound. For example, at age-one, Atlantic cod weigh about 0.6 pounds (NEFSC 2012) and yellowtail flounder weigh about 0.3 pounds (NEFSC 2011), and 10,000 individuals at these weights would constitute less than 0.5% of their annual commercial landings.

This study does not include commercially important invertebrates that may be impacted by entrainment such as sea scallops and squid because EcoMon data does not provide information for these species. However, similar results would be expected due to the relatively small volume of entrained seawater.

5 Conclusions

In the context of regional abundances and species life histories, estimated losses of zooplankton and ichthyoplankton from entrainment by an ESP CWIS are small. The CWIS is expected to remove less than 8.75 million gallons (33.1million liters) per day, which is roughly 0.0001% of the volume of water within the Lease Area for one ESP and 0.0003% for up to three ESPs. Based on seasonal mean densities and entrained water volumes, annual estimated ichthyoplankton losses from CWIS entrainment are expected to range from 0 to 10.2 million fish larvae depending on the species. Annual estimated zooplankton losses are expected to be 13.5 billion individuals. When considering the high mortality rates for fish early life stages, the number of equivalent age-one fishes lost to entrainment are expected to be typically less than 10,000 individuals per species annually, which is a fraction of one percent of annual commercial landings for most species. At this scale, ecological and socioeconomic effects from entrainment via the ESP CWIS will likely be undetectable.

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