Spatio-temporal patterns of the oceanic conditions and nearshore marine community in the Mid-Atlantic Bight (New Jersey, USA)

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Oceanic environmental conditions influence, shape, and control the geographical range, spatial distribution, abundance, and size composition of marine fauna. Water temperature, salinity, dissolved oxygen, depth, and sediment type influence select fish life-history characteristics and community structure. Marine communities are vulnerable to major changes in environmental conditions, but the response and severity depends on various biological or ecological factors, such as resilience to stress or adaptation. Researchers around the world have predicted and documented numerous alterations in fish communities caused by ongoing significant physicochemical shifts associated with natural and potentially unnatural sources, but published studies describing the historical conditions are lacking for most regions around the world, including the coastal waters off New Jersey. Given the need to understand these processes, a multifaceted investigation was undertaken to describe, evaluate, and compare the oceanic conditions and nearshore marine fauna community off New Jersey during 1988 through 2015. Findings showed the oceanic conditions varied over time and space. Mean surface water temperature increased significantly about 0.6°C per decade, mean salinity decreased about 1.3 psu per decade, and dissolved oxygen increased 0.09 mg/l per decade. Over 20.4 million fish and invertebrates (1,338.3 mt) representing 214 (water temperature preference classified) species (*not including unidentified species*) were collected within 15 strata (areas: 12−26) off the coast of New Jersey from 1988 to 2015. Three marine fauna water temperature preference groups (coldwater-adapted, warmwater-adapted, and subtropic-adapted) were identified in the study area. The main coldwater-adapted species collected were longfin squid (*Loligo pealei*) (*n* = 2,225,975), Atlantic herring (*Clupea harengus*) (*n* = 544,032), and little skate (*Leucoraja erinacea*) (*n* = 316,356), while Atlantic butterfish (*Peprilus triacanthus*) (*n* = 2,873,138), scup (*Stenotomus chrysops*) (*n* = 1,318,569), and northern searobin (*Prionotus carolinus*) (*n* = 503,230) represented the warmwater-adapted group.

Bay anchovy (*Anchoa mitchilli*) (n = 9,227,960), striped anchovy (*Anchoa hepsetus*) (n = 245,214), and Atlantic moonfish (*Vomer setapinnis*) (n = 38,691) denoted the subtropic-adapted group. Subtropic-adapted species were the most abundant and coldwater-adapted were the least abundant water temperature preference group. The estimated abundance of coldwater-adapted species declined, warmwater-adapted species slightly increased, and subtropic-adapted species decreased with time, which suggest the environmental conditions are influencing and thereby shifting the marine community.

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2   **community in the Mid-Atlantic Bight (New Jersey, USA)**
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12
13   **ABSTRACT**
14
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16   distribution, abundance, and size composition of marine fauna. Water temperature, salinity,
17   dissolved oxygen, depth, and sediment type influence select fish life-history characteristics and
18   community structure. Marine communities are vulnerable to major changes in environmental
19   conditions, but the response and severity depends on various biological or ecological factors, such
20   as resilience to stress or adaptation. Researchers around the world have predicted and documented
21   numerous alterations in fish communities caused by ongoing significant physicochemical shifts
22   associated with natural and potentially unnatural sources, but published studies describing the
23   historical conditions are lacking for most regions around the world, including the coastal waters
24   off New Jersey. Given the need to understand these processes, a multifaceted investigation was
25   undertaken to describe, evaluate, and compare the oceanic conditions and nearshore marine fauna
26   community off New Jersey during 1988 through 2015. Findings showed the oceanic conditions
27   varied over time and space. Mean surface water temperature increased significantly about 0.6°C
28   per decade, mean salinity decreased about 1.3 psu per decade, and dissolved oxygen increased
29   0.09 mg/l per decade. Over 20.4 million fish and invertebrates (1,338.3 mt) representing 214
30   (water temperature preference classified) species (*not including unidentified species*) were
31   collected within 15 strata (areas: 12−26) off the coast of New Jersey from 1988 to 2015. Three
32   marine fauna water temperature preference groups (coldwater-adapted, warmwater-adapted, and
33   subtropic-adapted) were identified in the study area. The main coldwater-adapted species
34   collected were longfin squid (*Loligo pealei*) (n = 2,225,975), Atlantic herring (*Clupea harengus*)
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36   (*Peprilus triacanthus*) (n = 2,873,138), scup (*Stenotomus chrysops*) (n = 1,318,569), and northern
37   searobin (*Prionotus carolinus*) (n = 503,230) represented the warmwater-adapted group. Bay
38   anchovy (*Anchoa mitchilli*) (n = 9,227,960), striped anchovy (*Anchoa hepsetus*) (n = 245,214),
39   and Atlantic moonfish (*Vomer setapinnis*) (n = 38,691) denoted the subtropic-adapted group.
40   Subtropic-adapted species were the most abundant and coldwater-adapted were the least abundant
41   water temperature preference group. The estimated abundance of coldwater-adapted species
42   declined, warmwater-adapted species slightly increased, and subtropic-adapted species decreased
43   with time, which suggest the environmental conditions are influencing and thereby shifting the
44   marine community.
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48

49   **INTRODUCTION**

50   Oceanic environmental conditions influence, form, and control the geographical range,

51   spatial distribution, abundance, and size composition of marine fauna. Fish life-history and

52   community structure characteristics are shaped by water temperature, salinity, dissolved oxygen

53   (DO), depth, and sediment type (Horne et al., 1989). For many open-water coastal species (non-

54   estuary dependent), water temperature is usually the most important environmental factor

55   influencing fish distribution (e.g., Hoese and Moore, 1977; Wood et al. 2009; Howell and

56   Auster, 2012). Based on a species' physiology, marine fauna have an optimal temperature range

57   that effect their behavior, distribution, abundance, and other life-history characteristics. In most

58   regions, water temperature varies with season, which influences migratory behavior (Parker and

59   Dixon, 1998).

60   In addition to effecting the distribution, mean size, and life span (Mucoid et al. 2011) of

61   fishes, fluctuations in the physicochemical conditions can also impact the regional community

62   structure (Reash and Pigg, 1990; Vinebrooke et al., 2004; Krishnakumar and Bhat, 2008;

63   Azzurro et al., 2011; Aschan et al., 2013), and the associated food-chain length (e.g., Bondavalli

64   et al., 2006). According to Ficke et al., (2007), a major change in the environment conditions

65   causes fish to either "adapt, migrate, or perish". Marine communities are vulnerable to changes

66   in environmental conditions, which can have direct and indirect impacts.

67   Researchers worldwide have predicted and documented numerous changes in marine

68   communities caused by ongoing physicochemical shifts associated with natural and potentially

69   unnatural sources (Rijnsdorp et al., 2009; Crozier and Hutchings, 2014; Pinksky and Mantua,

70   2014), but fundamental information describing marine communities are lacking for most regions

71   (Johnson, 2012), including the nearshore waters off New Jersey; New Jersey is located within the

72   middle or Mid-Atlantic Bight (MAB) in the western North Atlantic Ocean.

73   In spite of the economic value of New Jersey's fisheries resources, only partial

74   information about the nearshore marine community and environmental conditions is available.

75   As such, the main goal of this study was to elucidate the trends in the environmental conditions

76   and the nearshore marine fauna community off New Jersey over the past 28 years (1988−2015).

77   The primary purpose was to provide resource managers and others with a description of the

78   environmental conditions and marine fauna in the nearshore waters off New Jersey so they can

79   make knowledgeable management decisions about marine resources, predict future changes in

80   populations, and potentially reconstruct the past historical baseline conditions given the shifting

81   baseline syndrome. Establishing the "relative" baseline conditions will help resource managers

82   and researchers evaluate potential future impacts to the biological community associated with

83   natural and anthropogenic disturbances in the nearshore waters off New Jersey.

84
85   **MATERIAL AND METHODS**
86
87   *Study Area and Survey Design*
88
89   To evaluate marine community dynamics, the survey area (**Fig. 1**) was divided into 15

90   sampling strata (12−26) by depth and geographical location (latitude and longitude). To be

91   consistent with established federal marine resource field-sampling programs, the designers of the

92   New Jersey Ocean Stock Assessment (OSA) survey incorporated the same latitudinal boundaries

93   defined by the National Marine Fisheries Service (NMFS), Northeast Fishery Science Center

94   (NEFSC), Northeast Atlantic Groundfish Survey Program; exceptions were those strata at the

95   northern and southern ends of the New Jersey coastline where NMFS extended its survey into

96   New York and Delaware waters (ASMFC, 1994). The boundaries were also truncated in the

97   northern and southern strata to include only the waters adjacent to the New Jersey coastline and

98   the ocean waters off Delaware Bay. The longitudinal boundaries consisted of the 9.1 (30 ft.),

99   18.3 (60 ft.), and 27.4 m (90 ft.) isobaths. The bottom contours were somewhat irregular, so the

100   stratum boundaries were smoothed using GIS techniques (ASMFC, 1994).

101   To reduce potential sampling bias, each sampling area was divided into smaller blocks.

102   Mid-shore blocks (9.1−18.3 m) and offshore (18.3−27.4 m) blocks were 2.0 minute longitude by

103   2.5 minute latitude, whereas nearshore (5.5−9.1 m) blocks were 1.0 minute longitude by 1.0

104   minute latitude. Nearshore block dimensions were smaller because the strata were narrower and

105   encompassed a smaller area than the mid and offshore strata; thus, the smaller block size

106   permitted a greater number of potential sampling sites than would be possible with larger

107   dimensions. It should be noted the blocks truncated by stratum boundaries encompassed a

108   smaller area (> 50%) than the whole blocks (Byrne, 1994; 2008).

109   *Experimental Field Sampling Approach*
110
111   Field sampling was conducted bimonthly (every two months: February, April, June,

112   August, October, and December) from 1988 to 1989. From 1990 to date, the December and

113   February surveys were replaced by a single winter survey in January, followed by surveys in

114   April, June, August, and October (ASMFC, 1994). The annual sampling survey effort during

115   1988 through 1990 varied slightly because of the limited budget (e.g., high charter vessel costs),

116   but annual sampling generally consisted of two hauls per stratum. Overall, the sampling effort

117   averaged 39 hauls (i.e., two samples from each strata plus one additional haul in each of the nine

118   larger strata) per survey. The average number of stations sampled each year was around 182.

119   *Station Selection*
120

121   Constrained randomization was used to select unique sampling stations for each survey

122   trip. Sampling stations (survey site location) were randomly selected by the NJDEP program

123   leader during 1988 through 1991, but this method was replaced in 1992 by a computer generated

124   random number selection program. Because stratum shapes were elongate and the sampling

125   effort was limited, a station selection procedure was used to reduce any spatial distribution

126   sampling bias. The station selection procedure consisted of limiting the first station to only the

127   top half of the block numbers and the second station to the bottom half; however, if a third

128   station was selected then these limitations were not imposed in the procedure process. For

129   instance, haul one would be selected from blocks 1 to 25, haul two from blocks 26 to 50, and

130   haul three from blocks 1 to 50 for a stratum with 50 blocks. For each station, three additional

131   alternate sites were also pre-selected using the same procedures described above to account for

132   any fixed fishing gear (e.g., traps or nets), bottom obstructions, or other impediments that

133   prevented sampling at the initial station (Byrne, 1994; 2008).

134   *Field Sampling Gear*

135
136   Field sampling was conducted with a tapered (forward to rear netting) three-in-one

137   bottom otter trawl. The forward (i.e., wings and belly) and rear netting was constructed with

138   #3/20 twisted polyethylene twine. The forward and rear netting was constructed with 12 cm and

139   8 cm stretch mesh, respectively. The cod-end was constructed with 7.6 cm stretch mesh 4 mm

140   polyethylene twine and lined with #147 style (6.4 mm stretch mesh) white knitted nylon netting.

141   The round and drop-mesh corners were hung to yield a 50 percent hanging ratio. The trawl

142   doors were 2.44 m x 1.27 m (3.1 m^2) constructed with marine grade wood and steel shoes that

143   weighed approximately 453.5 kg. Based on hydroacoustic sensors, the average wing spread was

144   around 13 m. The headrope was 25 m and the footrope was 30.5 m. The top and bottom bridles

145   were 36.6 m and constructed with a 1.27 and 1.91 cm wire rope, respectively. The groundwire

146   was 18.3 m. The bottom bridle and groundwire were covered with 6.03 cm rubber cookies. The

147   rigging (sweep) consisted of 7.62 cm rubber cookies on 14.3 mm wire rope, 9.5 mm long drop

148   chains (six link long), and 32 center-hole floats (20.32 cm). The extension chain was a 1.27 cm

149   Trawlex chain. (Byrne, 1994; 2008).

150   *Field Sampling Procedures*

151   All tows were conducted between sunrise and sunset. The trawl tow duration was

152   standardized at 20 minutes and the vessel speed was between 4.7 and 5.6 kilometers per hour

153   (2.5 and 3.0 knots). The swept area (a) was estimated with the following equation: a = D*hr*X2,

154   D =V*t; where V is the velocity of the trawl over the ground when trawling, hr is the length of

155   the head-rope, and t is the time spent trawling. X2 is that fraction of the head-rope length, hr,

156   which is equal to the width of the path swept by the trawl, the "wing spread", hr*X2. Based on

157   vessel speed, one 20 minute tow generally covered a distance of 1.85 km. Given the trawl

158   dimensions and distance towed, the total swept area was around 24,050 m^2. The cardinal

159   direction of the tow was determined by the oceanic conditions (wind, waves, and current) at the

160   time of deployment; tows were generally made in the direction of the waves, wind, and current.

161   A 91.5 m wire was used to maintain a tow depth ratio of approximately 3:1 (Byrne, 1994; 2008).

162   Survey replicates (tow) were considered independent of one another given the random station

163   selection process, and the distance between sampling sites and time between tows; each tow was

164   considered a random sample of the population.

165   *Data Collection Protocol*
166
167   At each sampling station the surface and bottom environmental conditions (water

168   temperature (degrees Celsius [°C], salinity (parts per thousand [psu], and dissolved oxygen

169   (milligrams per liter [mg/l]) were measured with a CTD and recorded before deploying the trawl.

170   After the 20 minute tow was completed, the trawl was retrieved and the catch (fish and

171   macroinvertebrates) was rough sorted into plastic buckets. Afterwards, the entire catch was

172   identified to species, enumerated, and the length (fork and/or total, as appropriate) was measured

173   to the nearest cm for fish (20 individuals randomly selected); the disk width (cm) was measured

174   for skates and rays. All species were identified to the lowest taxa. The total weight was taken

175   using either a hanging or floor scale. The individual weights of every species were determined

176   by weighing individual baskets (total weight) of every species collected and dividing by the total

177   count of individuals in the basket. Various other measurements were recorded depending on the

178   macroinvertebrate species. For example, the carapace width (mm) was measured for crabs, the

179   carapace length (mm) for lobsters and mantle length (mm) for squids. Because some catches

180   were too large to sort in the field, a representative thoroughly mixed sub-sample was randomly

181   selected and weighed. After the sub-sample was sorted, species composition was extrapolated to

182   determine the total catch (Byrne, 1994; 2008).

183   *Data Treatment/Processing*

184

185   To minimize any potential spatial non-independence, data were pooled among stations

186   within each individual sampling area. Before initiating statistical hypothesis tests, environmental

187   and biological data were transformed (e.g., logarithmic, square root, fourth root, or arcsine) to

188   meet normality assumptions, and down-weight the statistical effects (i.e., reduce skewness) of

189   abundant taxa, while allowing less common taxa to contribute to sample discernment (Thorne et

190   al., 1999; Korsman, 2013). Normal probability plots were examined, and Kolmogorov-Smirnov

191   and Bartlett tests were used to assess normality and homoscedacity (Zar, 1999). Outlier

192   observations were investigated to determine whether the outlier occurred by chance; all outliers

193   were retained for these analyses.

194   To evaluate the nearshore marine community and oceanic conditions, 28 years

195   (1988−2015) of fishery-independent monitoring data (environmental and biological) were

196   compiled, sorted (time [year and month] and space [area and zone]), and summarized. After

197   pooling the data by stations sampled within each area, the marine community (catch

198   characteristics [total number, estimated abundance, and estimated biomass]) was evaluated using

199   two approaches: a single dataset (pooling all the data) and segregating the data in various time-

200   series datasets. The data were segregated into six 5-year time-series periods to help discern

201   patterns and test for potential differences among time and space. This approach was driven from

202   the perspective that most available time-series data for nearshore/offshore fisheries are only two

203   to five years in duration. Data were pooled by stations and segregated by individual sampling

204   areas (12−26) and geographical north/south zones defined as the following: 1 (sampling areas

205   12−17), 2 (sampling areas 18−23), and 3 (sampling areas 24−26). Data was also segregated by

206   west/east zones defined as the following: 1 (sampling areas 12, 15, 18, 21, and 24), 2 (sampling

207   areas 13, 16, 19, 22, and 25), and 3 (sampling areas 14, 17, 20, 23, and 26). It should be noted

208   the amount of area for each designated geographical zone was a different size in terms of km^2.

209   Following Howell and Auster (2012), marine species were classified a priori as

210   coldwater-adapted species (primarily distributed in cold temperate regions), warmwater-adapted

211   species (primarily distributed in warm temperate regions), or subtropic-adapted species

212   (primarily distributed in subtropical and tropical regions). Classification followed Froese and

213   Pauly (2018) and published life-history literature (e.g., Murdy et al., 1997; Collette and Klein-

214   MacPhee 2002; Able and Fahay 2010) describing a species' distribution relative to the MAB,

215   water temperature tolerance (minimum and maximum), preferred water temperature range, and

216   preferred spawning water temperature. In general, the mean preferred water temperature was

217   used to select the best water temperature preference group for each species. Species preferring

218   water temperature <15°C were generally classified as coldwater-adapted, while those preferring

219   water temperatures 15−29°C were classified as warmwater-adapted. Species preferring

220   temperatures >30°C were classified as subtropic-adapted.

221   The statistical significance level was defined as $P < 0.05$. In the presence of significance

222   at the 95 percent confidence level, a Tukey *post-hoc* multiple pairwise comparison tests were

223   used to differentiate the specific differences among the population means. Data were evaluated

224   using various software, including Microsoft Access®, Microsoft Excel®, and Statgraphics

225   Centurion XVI®.

226   *Statistical Analyses*
227   *Physicochemical Conditions*
228
229   A two-fold approach was taken to analyzing variation over time. Interannual variation of

230   numerous factors was examined by treating observations from individual stations and months as

231   independent, generating a sensitive Analysis of Variance (ANOVA) test of the null hypothesis of

232   no variation due to the high degrees of freedom. To examine trends, annual averages were

233   regressed against time (year), generating a conservative test with low degrees of freedom and a

234   weaker independence assumption of no serial correlation between annual averages. The

235   physicochemical conditions were evaluated by univariate procedures to discern patterns over

236   space and time. Descriptive statistics and graphical plots were generated for each individual

237   defined sampling area (12−26; **Fig. 1**). Student's *t*-tests were used to test the null hypothesis that

238   the annual average surface and bottom oceanic conditions (water temperature, salinity, and

239   dissolved oxygen [DO]) were equal among years (1988−2015). One-way ANOVAs were used

240   to test the null hypothesis that annual and bimonthly oceanic conditions (water temperature,

241   salinity, and DO) were equal among years and sampling areas. To characterize the

242   physicochemical conditions within the study area (1988−2015), the annual mean surface and

243   bottom water temperature, salinity, and DO readings were individually examined for spatial and

244   interannual patterns using linear regression to categorize the trend as stable, increasing, or

245   decreasing. The strength of the association was examined using the coefficient of determination

246   (r^2). One-way ANOVAs were also used to test the null hypothesis that annual and bimonthly

247   bottom oceanic conditions (water temperature, salinity, and DO) were equal among zones and

248   depth boundaries. Regression was also used to evaluate the association between space (latitude

249   and longitude) and time.

250   *Marine Community*

251

252   To evaluate the biological patterns and trends, the marine community (catch

253   characteristics [total number, estimated abundance, and estimated biomass]) was examined using

254   various univariate procedures. The total number marine fauna collected by individual taxa were

255   tabulated, summarized, and plotted by time and space. Descriptive statistics, histograms,

256   frequency distribution, and cumulative frequency polygon plots were generated to evaluate

257   central tendency, dispersion, and variability. To evaluate seasonal (bimonthly) and annual

258   variability in the estimated abundance (density [number of fauna collected per 100 m^2]), the total

259   number of individuals collected by species were standardized, transformed into nominal catch

260   per unit effort (CPUE) indices, and evaluated using several analytical approaches. For analyses

261   and interpretation of the abundance indices, it was assumed there was a simple direct positive

262   relationship between CPUE and abundance. To estimate abundance as a function of effort,

263   CPUE was calculated by taking the product of the area swept, which was computed from the

264   trawl net width at the wingtips and the distance towed; the trawl wing or horizontal spread was

265   determined using hydroacoustic sensors. Abundance (N_t number per 100 m^2) was estimated

266   using the CPUE, the trawl dimensions, and the vessel speed in the following equation:

267

268         $N_t = \frac{C}{AL} \times 100$

269

270   where C is catch of species (i) at time $_t$, A is the mouth area of the trawl (24,076 m^2), and L is the

271   distance towed (~1.85 km), which was the product of the vessel speed (92.5 m s^{-1}) and the trawl

272   time (20 min). To estimate biomass (g 100 m^{-3}), W (catch in weight) was substituted for C in

273   each tow.

274

275   The annual estimated abundance and biomass index (mean number/weight per tow) were

276   computed, compared, and regressed over the 28-year time series to examine change in estimated

277   abundance and biomass over time and space. To examine annual variability in species

278   composition, ANOVA tests were conducted to test the null hypothesis that the total number,

279   estimated abundance and biomass were equal over time and space. Regression was also used to

280   examine the association between catch characteristics and time and space using the fitted slope to

281   indicate increasing or decreasing trends.

282   Biological data (abundance and biomass) were segregated by individual sampling area

283   (12−26) and geographical zones. North/south zones were defined as the following: 1 [sampling

284   areas 12−17], 2 [sampling areas 18−23], and 3 [sampling areas 24−26]. West/east zones were

285   defined as the following: 1 [sampling areas 12, 15, 18, 21, and 24], 2 [sampling areas 13, 16, 19,

286   22, and 25], and 3 [sampling areas 14, 17, 20, 23, and 26]. Regression was used to evaluate the

287   association between space (latitude and longitude) and time. One-way ANOVAs were used to

288   test the null hypothesis that annual and bimonthly catch characteristics (total number, estimated

289   abundance and biomass) were equal among zone and depth boundary. Spatial and temporal

290   patterns were evaluated using regression to categorize the slope of the fitted trend.

291   Descriptive statistics were generated to examine the number of warmwater, coldwater,

292   and subtropic-adapted species. ANOVAs were used to test the null hypothesis that the catch

293   characteristics (total number, estimated abundance and biomass) by temperature preference

294   category were equal over time and space. Descriptive statistics were also generated to evaluate

295   the ratio of warmwater to coldwater-adapted species. Spatial and temporal patterns were

296   evaluated using regression to categorize the slope of the fitted trend.

297   Individual descriptive statistics of the catch, and temperature preference category were

298   calculated and plotted by time-series. To examine annual variability in the marine fauna,

299   separate ANOVA tests were conducted to test the null hypothesis that the catch characteristics

300   ([total number, estimated abundance, and biomass]) were equal among time-series, month, and

301   area. Two-way ANOVA tests were conducted to test the null hypothesis that the catch

302   characteristics ([total number, estimated abundance, and biomass]) by individual temperature

303   preference category were equal among time and space. Regression was used to examine the

304   potential association between catch characteristics and time-series, month, and area. Spatial and

305   temporal patterns were evaluated using regression to categorize the slope of the fitted trend.

306   General Linear Models (GLM) were calculated for each time-series (overall and temperature

307   preference category) to examine the pattern of interactions and associations of time and space on

308   the catch characteristics.

309
310 **RESULTS**
311
312 *Physicochemical Conditions*
313 *Water Temperature*
314
315 The overall mean annual surface water temperature off the coast of New Jersey within the

316 15 strata (areas: 12−26) during 1988 through 2015 ranged from 13.39°C in 2003 to 16.12°C in

317 2002 with a mean of 14.81°C (± 6.6°C). A paired *t*-test showed the mean surface water

318 temperature was significantly warmer (2.3°C) than the bottom water temperature (t (5096) =

319 3.72; $P < 0.05$). The mean surface water temperature varied significantly among years

320 (ANOVA, **Table 1**), and there was a weak positive association between the surface water

321 temperature and time. The mean (0.06°C per year) and maximum (0.02°C per year) surface

322 water temperature increased about 0.6°C and 0.2°C per decade, respectively. Averaging over

323 years, the mean monthly surface water temperature increased from January (4.46°C) to August

324 (22.74°C), and decreased from September (22.24°C) to December (5.65°C). The surface water

325 temperature varied significantly among months (F [11, 5084] = 5942.1, $P < 0.05$).

326 The mean surface water temperature ranged from 13.8°C in sampling area 12 to 15.52°C

327 in sampling area 23. In general, the mean surface water temperature was colder in the northern

328 than the southern sampling areas (**Table S1**); the 15 sampling areas were numbered in numerical

329 order from north to south (12−26). However surface water temperature in sampling areas 21 and

330 24 did not follow this pattern; the surface water temperature in these areas was slightly cooler.

331 The mean water temperature in sampling area 21 was cooler than the water temperature in

332 sampling area 24. A linear model showed a strong positive (significant) association between the

333 mean annual surface water temperature and the sampling area (**Table S1**).

334   The mean bottom water temperature off the coast of New Jersey within the 15 strata

335   (areas: 12−26) during 1988 through 2015 ranged from 10.44°C in 1994 to 14.57°C in 2002 with

336   a mean of 12.53°C (± 5.6°C). The bottom water temperature also varied significantly with time,

337   and there was a weak positive association between bottom water temperature and year (**Table 1**).

338   Averaging over years, the bottom water temperature varied significantly among months (F [11,

339   5084] = 1637.8, P < 0.05) with the coldest (4.96°C) in January and the warmest (20.51°C) in

340   September.

341   The mean bottom water temperature ranged from 10.67°C in sampling area 14 to 14.25°C

342   in sampling area 24. The mean bottom water temperature varied significantly among sampling

343   areas (**Table S2**), and there was a weak positive association between bottom water temperature

344   and the sampling area (**Table S2**). Segregating the sampling areas into zones (*See Methods*), the

345   mean bottom water temperature was significantly colder in the northern zones than the southern

346   zones (F [2, 5093] = 23.08, P < 0.05); a *post-hoc* test showed the mean water temperature varied

347   significantly between zones 1 and 2 (-0.89), 1 and 3 (-1.36), and 2 and 3 (-0.47). The warmest

348   bottom water temperature was in the sampling areas closest to shore, and the coldest bottom

349   water temperature was detected in sampling areas furthest from shore (F [2, 4828] = 42.11, P <

350   0.05); a *post-hoc* test showed the mean water temperature varied significantly between eastern

351   and western zones 1 and 2 (0.52), 1 and 3 (1.74), and 2 and 3 (1.22).

352   *Salinity*
353
354   The mean annual surface salinity off the coast of New Jersey within 15 strata (areas:

355   12−26) during 1988 through 2015 ranged from 29.94 in 1996 to 32.11 psu in 1998 with a mean

356   of 30.75 psu (± 2.06 psu). Overall, the mean salinity decreased about 0.13 psu per year or 1.3

357   psu per decade. The surface salinity varied significantly among years, and there was a weak

358   negative (non-significant) association between the surface salinity and time (**Table 1**).

359   Averaging over years, the mean monthly surface salinity ranged from 30.25 in April to 31.48 psu

360   in November with a mean of 30.73 psu (± 2.07 psu). The surface salinity varied significantly

361   among months (F [11, 5084] = 31.46, $P < 0.05$).

362   The mean surface salinity ranged from 28.92 in sampling area 14 to 31.45 psu in

363   sampling area 26 with a mean of 30.74 psu (± 2.07 psu). The surface salinity varied significantly

364   among sampling areas (**Table S1**), and there was a strong positive (significant) association

365   between the surface salinity and sampling area (**Table S2**). The surface salinity was generally

366   lower in the northern sampling areas than the southern sampling areas (Table S1**)**. The surface

367   salinity ranged from 28.13 psu in sampling area 12 to 31.49 psu in sampling area 26. The lowest

368   surface salinity levels were found in the areas closest to shore, and the highest surface salinity

369   levels were detected in areas furthest from shore.

370   A paired t-test showed the mean annual bottom salinity level was higher than the mean

371   annual surface salinity (t (5095) = -34.25; $P < 0.05$). The lowest (30.52 psu) bottom salinity was

372   in 2005 and the highest (32.87 psu) was in 1988 with a mean of 31.66 psu (± 1.4 psu). The

373   bottom salinity varied significantly with time (F [27, 5069] = 50.12, $P < 0.05$), and there was a

374   weak negative (significant) association between the surface salinity and time (**Table 1**). The

375   bottom salinity ranged from 31.09 in December to 31.94 psu in November. Averaging over

376   years, the bottom salinity also varied significantly among months (F [11, 5085] = 5.13, $P <$

377   0.05).

378   The mean bottom salinity ranged from 30.33 in sampling area 12 to 32.32 in sampling

379   area 23 with a mean of 31.66 psu (± 1.4 psu). The bottom salinity varied significantly among

380   sampling areas (**Table S2**), and there was a weak negative association between the bottom

381   salinity and the sampling area (**Table S2**). Segregating the sampling areas into zones (*See*

382   *Methods*), the mean bottom salinity varied significantly among northern and southern zones (F

383   [2, 5094] = 14.31, $P < 0.05$); a *post-hoc* test showed mean bottom salinity varied significantly

384   between zones 1 and 2 (-0.18), and 2 and 3 (0.15). The mean bottom salinity level increased

385   from northern to middle sampling areas, and then decreased in the southern sampling areas. The

386   mean bottom salinity varied significantly among eastern and western zones (F [2, 4829] = 373.5,

387     $P < 0.05$); a *post-hoc* test showed mean bottom salinity varied significantly between zones 1 and

388   2 (-0.54), 1 and 3 (-1.07), and 2 and 3 (-0.52). Mean bottom salinity increased from eastern to

389   western zones.

390   *Dissolved Oxygen*

391

392   The mean surface DO off the coast of New Jersey within 15 strata (areas: 12−26) during

393   1988 through 2015 ranged from 7.9 in 1995 to 8.98 in 1998 mg/L with a mean of 8.54 mg/L (±

394   1.52 mg/L), and there was a weak positive association between the surface DO and time (**Table**

395   **1**). Overall, the mean DO increased about 0.009 mg/L per year or 0.09 mg/L per decade.

396   Averaging over years, the mean monthly surface DO ranged from 7.17 in September to 10.27

397   mg/L in December. The surface DO varied significantly among months (F [11, 5080] = 608.75,

398     $P < 0.05$).

399   The mean surface DO ranged from 8.20 in sampling area 24 to 9.06 mg/L in sampling

400   area 14. The surface DO varied significantly among sampling areas (**Table S2**), and there was a

401   strong negative association between the surface DO and the sampling area (**Table S2**). In

402   general, the surface DO decreased from northern to southern sampling areas, but no pattern was

403   evident for the sampling areas closest and furthest from shore (**Table S1**).

404   A paired *t*-test showed the annual bottom DO levels were significantly lower (t (5091) =

405   132.17; $P < 0.05$) than the annual surface DO levels suggesting a strong water column

406   stratification. The mean bottom DO off the coast of New Jersey within 15 strata (sampling

407   areas: 12−26) during 1988 through 2015 ranged from 6.64 in 1988 to 8.35 mg/L in 1993 mg/L

408   with a mean of 7.58 mg/L (± 1.84 mg/L), and there was a weak positive association between the

409   bottom DO and time (**Table 1**). The mean monthly bottom DO ranged from 5.55 in August to

410   9.87 mg/L in January. Averaging over years, the bottom DO varied significantly among months

411   (F [11, 5081] = 1121.85, $P < 0.05$).

412   The mean bottom DO ranged from 7.09 in sampling area 16 to 8.13 mg/L in sampling

413   area 24. The surface DO varied significantly among sampling areas (**Table S2**), and there was a

414   strong positive association between the bottom DO and sampling area (**Table S2**). Segregating

415   the sampling areas into zones (*See Methods*), the mean bottom DO varied significantly among

416   northern and southern zones (F [2, 5090] = 54.78, $P < 0.05$); a *post-hoc* test showed mean

417   bottom DO varied significantly between zones 1 and 2 (-0.42), 1 and 3 (-0.69), and 2 and 3 (-

418   0.27). The bottom DO generally increased from northern to southern sampling areas. The mean

419   bottom DO also varied significantly among western and eastern zones (F [2, 4825] = 2.77, $P <$

420   0.05); a *post-hoc* test showed mean bottom DO varied significantly between zones 1 and 3

421   (0.15). The mean DO generally decreased from nearshore to offshore sampling areas.

422   *Marine Fauna Community*
423   *Annual and Spatial Dynamics*
424
425   Over 20.4 million fish and invertebrates (1,338.3 mt) representing 214 (water temperature

426   preference classified) species (*not including unidentified species*) were collected within 15 strata

427   (areas: 12−26) off the coast of New Jersey from 1988 to 2015. Three marine fauna water

428   temperature preference groups (coldwater-adapted, warmwater-adapted, and subtropic-adapted)

429   were identified in the study area (**Fig. S1**). The total number of individuals collected ranged

430   from 4.0 million (coldwater-adapted) to 6.8 million (subtropic-adapted). In each temperature

431   preference category, three species represented the majority of the catch. The main coldwater-

432   adapted species collected were longfin squid (*Loligo pealei*) (n = 2,225,975), Atlantic herring

433   (*Clupea harengus*) (n = 544,032), and little skate (*Leucoraja erinacea*) (n = 316,356), while

434   Atlantic butterfish (*Peprilus triacanthus*) (n = 2,873,138), scup (*Stenotomus chrysops*) (n =

435   1,318,569), and northern searobin (*Prionotus carolinus*) (n = 503,230) represented the

436   warmwater-adapted group. Bay anchovy (*Anchoa mitchilli*) (n = 9,227,960), striped anchovy

437   (*Anchoa hepsetus*) (n = 245,214), and Atlantic moonfish (*Vomer setapinnis*) (n = 38,691)

438   denoted the subtropic-adapted group.

439   The most abundant water temperature preference group was the subtropic-adapted and

440   the coldwater-adapted group was the least abundant group in the study area. The number of

441   individuals collected per group varied over time with the coldwater-adapted group slightly

442   decreasing since 2004 (**Fig. 2**). In terms of percent composition, coldwater-adapted group

443   declined over time, but in some years (1989, 1990, 1991, 1993, 1995, 1997, 2006, and 2012) it

444   was the second most dominant group (**Fig. S2**). In 1998, the coldwater-adapted group was the

445   most abundant group. Overall, the coldwater to warmwater-adapted ratio declined over time,

446   and there was a weak negative association between the coldwater: warmwater-adapted ratio and

447   time (F [1, 26] = 10.71, P = 0.003; r^2 = 29.2%) (**Fig. 3**)

448   Pooling all samples, the lowest (0.1784 individuals per m^2) mean estimated abundance (#

449   individuals/m^2) was the warmwater-adapted group and highest (0.2340 individuals per m^2) was

450   the subtropic-adapted group (F [2, 100201] = 618.47, P < 0.05).   The lowest mean estimated

451   biomass (kg/m^2) was the subtropic-adapted group and the highest was the coldwater-adapted

452   group (F [2, 100201] = 687.35, P < 0.05).

453   The mean estimated abundance of the coldwater-adapted group was consistently lower

454   than the estimated abundance of the warmwater-adapted group over time (**Fig. 4**). The mean

455   annual estimated abundance varied significantly by water temperature preference category (F [2,

456   100203] = 587.86, P < 0.05), time (F [27, 100203] = 11.93, P < 0.05), and the interaction

457   between the water temperature group and time (F [54, 100203] = 9.33, P < 0.05). Overall,

458   pooling the six 5-year time-series, the mean annual estimated abundance of the coldwater-

459   adapted (F [5, 39039] = 8.82, P < 0.05) and subtropic-adapted (F [5, 7382] = 8.16, P < 0.05)

460   groups decreased, and the warmwater-adapted group slightly increased (F [5, 39039] = 14.10, P

461   < 0.05) over time.

462   The mean estimated abundance of the water temperature groups significantly varied by

463   time (F [2, 100203] = 600.08, P < 0.05), space (F [14, 100203] = 3.93, P < 0.05), and the

464   interaction between time and space (F [28, 100203] = 3.82, P < 0.05). The highest mean

465   estimated abundance for the coldwater-adapted group was in the northern sampling areas

466   (sampling areas 13, 14, and 12), while the highest mean estimated abundance for the warmwater-

467   adapted (sampling areas 20, 18, and 19) and subtropic-adapted (sampling areas 22, 20, and 19)

468   groups was in mid and southern sampling areas.

469   Similarly, the mean annual estimated biomass varied significantly by water temperature

470   preference category (F [2, 100203] = 705.8, P < 0.05), time (F [27, 100203] = 6.49, P < 0.05),

471   space (F [14, 100203] = 2.92, P < 0.05), and the interaction between time and space (F [54,

472   100203] = 3.79, P < 0.05). The mean annual estimated biomass for all three water temperature

473   preference groups (coldwater-adapted [F [5, 39039] = 38.84, P < 0.05]; warmwater-adapted [F

474   [5, 39039] = 44.03, $P < 0.05$]; and subtropic-adapted [F [5, 7382] = 10.35, $P < 0.05$] increased

475   with time, but the mean annual estimated biomass of the subtropic-adapted group increased the

476   most and coldwater-adapted group increased the least. The interaction pattern between the mean

477   annual estimated biomass and space was less clear than the mean annual estimated abundance

478   and time; there was no pattern in the mean annual estimated biomass of the coldwater-adapted

479   [sampling areas 18, 13, and 23], warmwater-adapted [sampling areas 20, 12, and 19], and

480   subtropic-adapted [sampling areas 18, 12, and 22] groups.

481   Pooling the data (1988−2015), GLMs showed that year and sampling area were

482   significant predictors of the total number and estimated abundance of the coldwater and

483   warmwater-adapted groups. The total number and estimated abundance of the subtropic-adapted

484   group were significantly predicted by the year, month, and sampling area, whereas the estimated

485   abundance was only significantly predicted by the year and sampling area (**Tables 2-4**).

486   *Segregated Spatial Dynamics*
487   *North/South Spatial Dynamics*
488
489   Subtropic-adapted species were the most abundant category and coldwater-species were

490   the least abundant category in every north/south zones; north/south zones were designated as the

491   following: north (sampling areas 12−17); mid (sampling areas 18−23), and south (sampling areas

492   24−26). The total number of coldwater and warmwater-adapted species decreased from north to

493   south, but the mean annual estimated abundance of coldwater (F [2, 40368] = 0.21, $P = 0.81$)

494   and warmwater-adapted groups (F [2, 40368] = 2.35, $P = 0.0957$) did not vary significantly

495   among north and south zones.

496   A two-way ANOVA showed the mean annual estimated abundance of coldwater-adapted

497   species varied significantly by time and space (F [54, 40368] = 1.87, $P = 0.0001$). The mean

498   annual estimated abundance of coldwater species was highest in zone 1 during a few years

499 (1994, 1997, 2004-2006, 2008, 2011, and 2012). In contrast, the mean annual estimated

500 abundance of coldwater species was highest in zone 3 during 1988-1990, 1992, and 2003.

501 The mean annual estimated abundance of warmwater species also varied significantly by

502 time and space, including the interaction between time and space (F [42, 40368] = 2.71, $P <$

503 0.05). The highest mean annual estimated abundance in Zone 1 occurred in 1994, 2003, and

504 2004. In Zone 3, the highest mean annual estimated abundance occurred in 1988, 1992 and

505 1999.

506 The mean annual estimated abundance of subtropic-adapted species varied significantly

507 by time (F [27, 7474] = 1.74, P = 0.01) and space (F [2, 7471] = 4.54, P = 0.01). The highest

508 mean annual estimated abundance of subtropic-adapted species was in Zone 2 (F [2, 7471] =

509 4.15, P = 0.0158) followed by Zone 1 and Zone 3. The highest mean annual estimated

510 abundance in Zone 1 occurred in 1997, 2001, 2003, 2004, 2007, 2008, 2011, and 2015. In Zone

511 3, the highest mean annual estimated abundance occurred in 1990 and 2005.

512 The estimated biomass of coldwater-adapted species peaked in Zone 1 during 2000 and

513 2007, but it did not vary significantly by time (F [27, 40368] = 0.58, P = 0.95) or space (F [2,

514 40368] = 2.21, P = 0.11). Similarly, the estimated biomass of warmwater-adapted species

515 peaked in Zone 2 during 2005, but it did not vary significantly by time F [27, 40368] = 0.85, P =

516 0.65) or space (F [2, 40368] = 0.61, P = 0.82). The estimated abundance of subtropic-adapted

517 species peaked in Zone 3 during 2012, but it did not vary significantly by time F [27, 7471] =

518 0.89, P = 0.62) or space (F [2, 7471] = 0.86, P = 0.42). The estimated biomass of subtropic-

519 adapted species increased in Zone 2 during 2012 through 2015.

520 *West/East Spatial Dynamics*
521

522   The mean annual estimated abundance of subtropic-adapted species was highest and the

523   coldwater-adapted species were lowest in every west/east zone; west/east zones were designated

524   as the following: west (sampling areas 12, 15, 18, 21, and 24); mid (sampling areas 13, 16, 19,

525   22, and 25), and east (sampling areas 14, 17, 20, 23, and 26). The mean annual estimated

526   abundance of subtropic-adapted species decreased from west (Zone 1) to east (Zone 2) Zones,

527   and coldwater and warmwater-adapted species increased from west to east zones.

528   The mean annual estimated abundance of coldwater-adapted species varied significantly

529   by time (F [27, 40368] = 2.07, P = 0.0009) and space (F [2, 40368] = 4.81, P = 0.008). The

530   mean annual estimated abundance in Zone 1 was the highest in 1993 and 2004. In Zone 3, the

531   mean annual estimated abundance peaked in 1990 and 2011.

532   The mean annual estimated abundance of warmwater-adapted species varied significantly

533   by time (F [27, 40368] = 2.09, P = 0.002) and interaction between time and space (F [42, 40368]

534   = 1.64, P = 0.005). The mean annual estimated abundance peaked in Zone 3 during 1992. In

535   Zone 2, the mean annual estimated abundance peaked in 1994, 1996, 1999, 2002, 2004, and

536   2006.

537   The mean annual estimated abundance of subtropic-adapted species varied significantly

538   over time (F [27, 7471] = 1.90, P = 0.003). The mean annual estimated abundance in Zone 1

539   peaked in 1990, 2000, 2002, and 2014. The mean annual estimated abundance in Zone 2 peaked

540   1992, 1995, 2008, and 2013. In Zone 3, the mean annual estimated abundance peaked in 1993,

541   2009, and 2011.

542   Overall, the highest mean annual estimated biomass was warmwater-adapted species, but

543   there was no evidence to suggest the mean annual estimated biomass among temperature

544   preference categories significantly changed from western to eastern areas.

545   The mean annual estimated biomass of coldwater-adapted species did not vary

546   significantly by time (F [27, 40368] = 1.21, P = 0.21) or space (F [2, 40368] = 2.90, P =

547   0.0552). The mean annual estimated biomass in Zone 3 peaked in 2000, and in Zone 2 it peaked

548   during 2007; the mean annual estimated biomass in Zone 1 was relatively low throughout the

549   time period.

550   Similarly, the mean annual estimated biomass of warmwater-adapted species did not vary

551   significantly by time (F [27, 40368] = 1.09, P = 0.35) or space (F [2, 40368] = 0.35, P = 0.89).

552   In Zone 1, the mean annual estimated biomass peaked in 2012, and peaked in Zone 2 in 2005. In

553   Zone 3, the mean annual estimated biomass peaked in 1992, 2001, and 2007.

554   The mean annual estimated biomass of subtropic-adapted species did not vary

555   significantly by time (F [27, 7471] = 0.31, P = 0.99) or space (F [2, 7471] = 0.03, P = 0.97). In

556   Zone 1, the estimated biomass peaked in 1991, and increased from 2012 to 2015. In Zone 2, the

557   mean annual estimated biomass peaked in 2004 and 2012. The mean annual estimated biomass

558   in Zone 3 was relatively low during most of the years, but it peaked in 1997 and 2014.

559
560   **DISCUSSION**
561

562   *Physicochemical Conditions*
563
564   Identifying the annual and seasonal variability in the oceanic conditions and the response

565   of community and component populations within the ecosystem is critical for predicting long-

566   term community dynamics, trends, and evaluating disturbance. Given the broad oceanographic

567   hydrodynamics off New Jersey (Kohut et al., 2004), the water temperature, salinity, and DO

568   levels significantly varied over time and space in the study area. The mean oceanic conditions

569   were highly variable over the 28-year period, but various alternating or cyclic patterns were

570   evident, along with increasing or decreasing trends. In general, water temperature increased and

571   the salinity decreased over time. The rising water temperature and falling salinity trends echoed

572   previous studies for the region (Howell and Auster, 2012; Geiger et al., 2013; Thomas et al.,

573   2017). The trend rates for mean (0.06°C per year) and maximum (0.02°C per year) surface water

574   temperature were similar to published rates (Thomas et al., 2017).

575   The nearshore waters off New Jersey are a dynamic hydrological system influenced by

576   summer stratification and winter mixing, which are associated with the prevailing wind and

577   buoyancy factors (Glenn et al., 2004; Kohut et al., 2004). Northeast wind often causes

578   downwelling, while southwest wind causes upwelling (Kohut et al., 2004). The physicochemical

579   conditions varied not only by year and season, but among specific sampling areas within the

580   study area. Besides the southeast corner of the study area (sampling areas 21 and 24), water

581   temperature (surface and bottom), salinity (surface), and DO increased from northern to southern

582   sampling areas, and salinity increased from western to eastern sampling areas. Bottom salinity

583   decreased from middle to southern areas, and the surface DO decreased from northern to

584   southern areas. Bottom DO increased from northern to southern sampling areas, and decreased

585   from eastern to western sampling areas.

586   Upwelling and downwelling off New Jersey are frequent events given the wide

587   continental shelf and gently sloping topography; the continental shelf extends about 200 km off

588   the coast of New Jersey (Song et al., 2001; Kohut et al., 2004). It is possible the relatively

589   warmer water temperature and higher salinity in sampling areas 21 and 24 was influenced by the

590   nearby underlying topography (i.e., topographic bump and oblique sand ridges) or seasonal

591   upwelling events. The nearshore waters (~ 40 m) are more stratified than the offshore waters in

592   June because of the influence of lower salinity water from the Hudson River (Schofield et al.,

593   2008), which could be causing the decreasing salinity trend off the New Jersey coast, noted here.

594   The warmwater period in the MAB is longer now than in the past and this environmental change

595   has influenced the stratified period (June−September) thereby altering the timing of spring and

596   fall phytoplankton blooms. Over the past decade, the warming period is beginning earlier each

597   year (Thomas et al., 2017).

598   The surface and bottom DO varied significantly over time and the positive association

599   between DO and time was explained adequately by regression, but a low correlation coefficient

600   value (0.08) indicated a weak association. It is difficult to explain why the DO slightly increased

601   (0.009 mg/L per year) with time given research has shown several recurrent hypoxia events

602   (1994, 1996, and 2001) occurring along the southern New Jersey coast (Glenn et al., 2004).

603   Hypoxia is relatively common along the New Jersey coast, but these events are somewhat short-

604   term and related to coastal upwelling, which sometimes occurs in summer when the wind is from

605   the southwest (Glenn et al., 2004). The hypoxia centers (~ 150 km^2) are spatially isolated in

606   duration (~ 1 week), frequency (~ 5 times in 9 years), and space (Barnegat Inlet, Mullica River

607   Estuary, and Townsend/Hereford Inlets). The hypoxia locations are downstream of a series of

608   topographic highs associated with ancient river deltas in the southern waters off New Jersey.

609   The most significant upwelling events occurred after the most severe cooling seasons in 1994,

610   1996, and 2001 (Glenn et al., 2004). Researchers hypothesized that severe cooling seasons often

611   causes colder and larger Cold Pools, which produce more significant summer upwelling events

612   by summertime wind-driven forces. Upwelling also depends upon wind, precipitation, and storm

613   frequency. Given that water temperature is increasing in the study area, it is possible that

614   summer upwelling events could be less severe than in the past, which is reducing the magnitude

615   of hypoxia events in specific areas within the study area. This hypothesis might explain the

616   slight increase in DO over time. Then again, it might be related to the ongoing water quality

617   improvements (less pollution) in nearby New York and New Jersey waterbodies (HydroQual,

618   2010).

619   *Marine Fauna Community*
620
621   The nearshore coastal waters off New Jersey provide year-round and seasonal habitat for

622   three temperature preference groups (subtropic-adapted, warmwater-adapted, and coldwater-

623   adapted), which complemented previous findings in the MAB (Wood et al., 2009; Howell and

624   Auster, 2012). However, different than Howell and Auster (2012), subtropic-adapted species

625   were the most abundant and coldwater-adapted species were the least abundant in the study area.

626   Bay anchovy was the most abundant subtropic-adapted species and butterfish was the most

627   abundant warmwater-adapted species. These findings did not agree with Howell and Auster

628   (2012) who reported more coldwater-adapted species than warmwater-adapted and subtropic-

629   adapted species in Long Island Sound. New Jersey waters are not only located south of Long

630   Island Sound, but anecdotal information from local fishermen suggest warmwater eddies and

631   whorls spinning off the Gulf Stream Current can provide habitat to subtropic-adapted marine

632   fauna, which could explain why there were more subtropic-adapted species in New Jersey than

633   New York.

634   The estimated abundance of warmwater-adapted species is increasing, coldwater and

635   subtropic-adapted species is decreasing, and the coldwater to warmwater-adapted ratio is

636   decreasing over time. This ongoing pattern for marine fauna seems to be becoming more

637   common in the MAB (Nye et al., 2009; Wood et al., 2009; Howell and Auster, 2012), and

638   throughout the world (e.g., Polovina et al., 2011). Most researchers attribute this shift in species

639   distribution and composition to climate variability (Cheung et al., 2011; Jang et al., 2011;

640   Polovina et al., 2011; Brander et al., 2013). The abundance of warmwater-adapted species is

641   also increasing with time in Narragansett Bay (Wood et al., 2009). In nearby Long Island Sound,

642   Howell and Auster (2012) reported a shift from a coldwater to warmwater-adapted dominated

643   species community, and an increase in subtropic-adapted species over a 25-year duration

644   (1984−2008). It is possible the present study did not show this same trend for subtropic-adapted

645   species because the environmental conditions off New Jersey are more variable than in the Long

646   Island Sound (a semi-enclosed estuary) given the frequency of upwelling and downwelling

647   events (Glenn et al., 2004; Kohut et al., 2004). Though the mean water temperature is rising, the

648   frequency of upwelling/downwelling is also increasing in the MAB (Kohut et al., 2004), which

649   could explain the decline in estimated abundance of subtropic-adapted species over time. It is

650   also possible subtropic-adapted species cannot tolerate abrupt changes in water temperatures

651   caused by these events. Thus, these oceanographic events could be negatively impacting some

652   subtropic-adapted species since the influx of cold water/warm water ($\pm$ 1−4°C) can often occur

653   in a short (~ 3 or 4 weeks) period (Kohut et al., 2004).

654   The highest estimated abundance of coldwater-adapted species was in northern sampling

655   areas (12−17), and the highest estimated abundance for warmwater and subtropic-adapted

656   species was in mid and southern sampling areas (18−26). The total number of coldwater and

657   warmwater-adapted species decreased from north to south, but the estimated abundance did not

658   vary significantly among the study area. Explaining the distribution of species is not

659   straightforward in terms of water temperature (Wood et al., 2009), as it appears to vary by time,

660   space and season given the oceanographic dynamics in the study area. Despite this variable

661   pattern, the estimated abundance of coldwater-adapted species was generally higher in the

662   southern sampling areas (24−26) during earlier years (1990s) and higher in the northern

663   sampling areas (12−14) during later years (2000s). The estimated abundance of warmwater-

664   adapted species was more variable, but it was higher in the southern sampling areas during a few

665   earlier years (1990s) and higher in the northern sampling areas during a few later years (2000s).

666   The estimated abundance of subtropic-adapted species was highest in the middle sampling areas

667   (18−23), followed by the northern (12−17) and southern sampling (24−26) areas. In general, the

668   highest estimated abundance was higher in the southern sampling areas (24−26) during a few

669   earlier years, and higher in the northern sampling areas (12−17) during later years. In some

670   ways, the findings suggest the distribution of species, based on their temperature preference, is

671   currently in a transitional phase; the period when some individuals can still tolerate the mean

672   water temperature. For instance, the water temperature preference classification for this study

673   was based on the mean preferred water temperature, which means 50 percent of the individuals

674   can tolerate either a lower or higher water temperature. Assuming the water temperature

675   continues to rise with time, then a full transition from a coldwater dominated community to a

676   warmwater community will occur over time.

677   The estimated abundance of coldwater and warmwater-adapted species increased from

678   nearshore to offshore and subtropic-adapted species decreased from nearshore (12, 15, 18, 21,

679   24) to offshore (14, 17, 20, 23, 26) sampling areas. The increase in the estimated abundance of

680   warmwater-adapted species from nearshore to offshore sampling areas suggests the

681   environmental conditions are ideal for a geographical range expansion within the study area

682   given the rising water temperature. In general, the estimated abundance of coldwater-adapted

683   species was higher in the nearshore sampling areas in a few earlier years (1990s) and higher in

684   the offshore sampling areas in a few later years (2000s). These findings suggest the distribution

685   of coldwater and warmwater-adapted species is shifting north, which agrees with other findings

686   in the MAB (Nye et al., 2009; Howell and Auster, 2012).

687   The estimated abundance for all three temperature preference categories has changed

688   over time. The estimated abundance of subtropic-adapted species decreased from nearshore to

689   offshore sampling areas, and coldwater and warmwater-adapted species increased from

690   nearshore to offshore sampling areas. Despite these general patterns, inter-annual patterns were

691   challenging to decipher given their high annual population and habitat selection variability. For

692   instance, coldwater-adapted species had high abundance in the nearshore sampling areas during

693   1993 and 2004, and high abundance in the offshore zone during 1990 and 2011. The findings

694   partially support the hypotheses that the estimated abundance and biomass of warmwater and

695   subtropic-adapted assemblages increased from offshore to nearshore sampling areas, and the

696   estimated abundance and biomass of coldwater-adapted assemblage increased from nearshore to

697   offshore sampling areas with time. Overall, it appears that biomass trends are idiosyncratic to

698   specific areas within the overall study area, but these findings could be more related to how the

699   sampling was spatially segregated rather than to biological reasons.

700   The estimated biomass for all three water temperature preference categories is increasing

701   with time in the study area; however, the estimated biomass of coldwater-adapted species is

702   increasing the most even though they are decreasing in abundance throughout the study area.

703   Larger individuals seem to be replacing smaller individuals, or less abundant larger individuals

704   are more common in the study area, such as bullnose sting ray (*Dasyatis sayi*). It is difficult to

705   explain why the estimated biomass of subtropic-adapted species is increasing the most since their

706   estimated abundance is decreasing with time. Smaller or younger (juvenile life-stage) coldwater-

707   adapted individuals could be declining, moving away, or maybe the larger less abundant

708   subtropic-adapted species are moving into the study area to feed. Actually, it is possible that

709   juvenile/sub-adults are moving offshore to deeper colder waters, while adults are moving

710   nearshore in pursue of prey. Another potential explanation is that rising water temperature is

711   causing coldwater-adapted species to grow faster (Duffy et al., 2016). It is often difficult to

712   explain or generalize the response of fish populations to climate change given the number of

713   influential factors and individual species broad responses (Rijnsdorp et al., 2009).

714   The estimated biomass of coldwater and warmwater-adapted species was influenced by

715   month and sampling area, whereas subtropic-adapted species were generally more influenced by

716   the sampling area. This observation seems reasonable since the estimated abundance of most

717   species in the coldwater and warmwater-adapted groups is correlated with season (i.e. water

718   temperature). However, it was somewhat surprising that the subtropic-adapted group was not

719   influenced by season, but it is possible that certain sampling areas have ideal and less fluctuating

720   water temperatures given the oceanic dynamics (upwelling/downwelling and eddies) in the study

721   area (Kohut et al., 2004). The total number and estimated abundance of coldwater-adapted and

722   warmwater-adapted species in recent years (2013−2015) were influenced more by month and

723   sampling area than the previous years (2008−2012) suggesting the seasonal water temperature

724   could be rising and falling faster depending on the sampling area. Actually, the warming period

725   is occurring earlier and lasting longer (Thomas et al., 2017), which could explain the decreasing

726   and increasing abundance in coldwater-adapted and warmwater-adapted groups, respectively.

727

728   **CONCLUSION**

729

730   The nearshore waters off New Jersey provide habitat for a variety of marine fauna,

731   including various warmwater and subtropic-adapted species. Overall, the findings indicate the

732 abundance and distribution of coldwater, warmwater, and subtropic-adapted species is changing

733 with time. In particular, the coldwater-warmwater-adapted ratio is declining with time, which

734 appears to be linked to the rising water temperature. Despite these findings, it should be

735 acknowledged this study was limited in scope in terms of examining wide-ranging potential

736 disturbances or stressors (i.e., fishing impacts). Thus, future researchers should consider

737 evaluating other known stressors besides the environmental conditions, such as fisheries

738 (commercial and recreational), habitat loss, and poor water quality. Although researchers have

739 investigated some of these stressors individually, and the impacts of individual stress on specific

740 species, it is recommended future research examine various stressors in synchronicity since they

741 are not independent of each other; cumulative effects are known to impact natural resources

742

756   Finally, I thank Sophia Passy, Laura Mydlarz, Arne Winguth, and Sandy Diamond-Tissue for

757   their assistance, guidance, and patience. I especially thank James Grover for his support,

758   dedication, and asking the tough questions. His detailed technical review improved the overall

759   document. Lastly, I thank Jeff Gearhart and Blake Price for reviewing and making various

760   editorial changes that improved the document. The views, opinions, conclusions, or proposals

761   expressed are mine and do not necessarily reflect the views of the University of Texas at

762   Arlington, the New Jersey Department of Environmental Protection, or Environmental Resources

763   Management, Inc.

764
765   **REFERENCES**
766

767   Able, K.W., and Fahay, M.P. 2010. Ecology of estuarine fishes: temperate waters of the western

768   north Atlantic. Baltimore: The Johns Hopkins University Press.

769   ASMFC (Atlantic States Marine Fisheries Commission). 1994. Proceedings of the workshop on

770   saltwater fishing tournaments. U.S. Fish and Wildlife Service, Atlantic States Marine

771   Fisheries Commission Special Report Number 46.

772   Bondavalli, C., Bodini, A., Rossetti, G., and Allesina, S. 2006. Detecting stress at a whole

773   ecosystem level. The case of a mountain lake: Lake Santo (Italy). Ecosystems 9: 1–56.

774   Brander, K. 2013. Climate and current anthropogenic impacts on fisheries. Climatic Change 119:

775   9−21. doi 10.1007/s10584−012−0541−2.

776   Byrne, D. 2008. Ocean trawling survey. New Jersey Department of Environmental Protection,

777   Division of Fish and Wildlife, Marine Fisheries Administration, Bureau of Marine

778   Fisheries.

779   Byrne, D. 1994. Stock assessment of New Jersey's nearshore recreational fisheries resources. In

780   Proceedings of the workshop on the collection and use of trawl survey data for fisheries

781   management, ed. T. Berger, 36–42. Washington: Atlantic States Marine Fisheries

782   Commission.

783 Cheung, W. W. L., Dunne, J., Sarmiento, J. L., and Pauly, D. 2011. Integrating ecophysiology

784   and plankton dynamics into projected maximum fisheries catch potential under climate

785   change in the Northeast Atlantic. ICES Journal of Marine Science, 68: 1008–1018.

786 Collette, B.B. and Klein-MacPhee, G. (eds.). 2002. Bigelow and Schroeder's fishes of the Gulf

787   of Maine, third ed. Caldwell, N.J. Blackburn Press, 577 pp.

788 Crozier, L.G., and Hutchings, J.A. 2014. Plastic and evolutionary responses to climate change in

789   fish. Evolution Applications ISSN 1752–4571.

790 Duffy, J.E., Lefcheck, J.S., Stuart-Smith, R.D., Navarrete, S.A., and Edgar, G.J. 2016.

791   Biodiversity enhances reef fish biomass and resistance to climate change. PNAS 113

792   (22): 6230–6235.

793 Ficke, A.D., Myrick, C.A., and Hansen, L.J. 2007. Potential impacts of global climate change on

794   freshwater fisheries. Reviews in Fish Biology and Fisheries 17: 581–613.

795 Froese, R. and D. Pauly. 2018. https://www.fishbase.de/search.php. 2018. FishBase. World Wide

796   Web electronic publication.www.fishbase.org, version (10/2018).

797 Geiger, E.F., Grossi, M.D., Trembanis, A.C., Kohut, J.T., and Oliver, M.J. 2013. Satellite-

798   derived coastal ocean and estuarine salinity in the Mid-Atlantic. Continental Shelf

799   Research 63: S235–S242. DOI: https://doi.org/10.1016/j. csr.2011.12.001.

800 Glenn, S., Arone, R., Bermann, K., Bissett, P.W., Crowley, M., Cullen, J., Gryzmski, J.,

801   Haidvogel, D., Kohut, J., Moline, M., Oliver, M., Orrisco, C., Sherrell, R., Song, T.,

802   Weidemann, A., Chang, R., and Schofield, O. 2004. Biogeochemical impact of

803　　　summertime coastal upwelling on the New Jersey Shelf. Journal of Geophysical Research

804　　　109, C12S02, doi:10.1029/2003JC002265.

805　Hare J.A, Wuenschel M.J., and Kimball M.E. 2012. Projecting Range Limits with Coupled

806　　　Thermal Tolerance − Climate Change Models: An Example Based on Gray Snapper

807　　　(Lutjanus griseus) along the U.S. East Coast. PLoS ONE 7(12):

808　　　e52294.doi:10.1371/journal.pone.0052294.

809　Hoese, H.D. and Moore, R.H. 1977. Fishes of the Gulf of Mexico, Texas, Louisiana and adjacent

810　　　waters. Texas A. & M. University Press, College Station. 327 pp.

811　Horne, J.K., and Campana, S.E. 1989. Environmental factors influencing the distribution sf

812　　　juvenile groundfish in nearshore habitats of southwest Nova Scotia. Canadian Journal of

813　　　Fish and Aquatic Science 46: 1277−1286.

814　Howell, P., and Auster, P.J. 2012. Phase Shift in an Estuarine Finfish Community Associated

815　　　with Warming Temperatures. Marine and Coastal Fisheries: Dynamics, Management, and

816　　　Ecosystem Science 4: 481–495.

817　HydroQual, Inc. 2010. Narrative description of historical dissolved oxygen improvements in

818　　　NY/NJ harbor related to previous nutrient reduction activities. 49 pp.

819　Jang, C. J., Park, J., Park, T., and Yoo, S. 2011. Response of the ocean mixed layer depth to

820　　　global warming and its impact on primary production: a case for the North Pacific Ocean.

821　　　– ICES Journal of Marine Science, 68: 996–1007.Johnson CA. (eds) Climate change

822　　　2001: the scientific basis. Cambridge University Press, Cambridge, UK, pp 101–181.

823　Kratz, T.K., Deegan, L.A., Harmon, M.E., and Lauenroth, W.K. 2003. Ecological Variability in

824　　　Space and Time: Insights Gained from the US LTER Program. Bioscience 53 (1): 57−67.

825   Kohut, JT., Glenn, SM., and Chant, R.J. 2004. Seasonal current variability on the New Jersey

826   inner shelf. Journal of Geophysical Research 109: C07S07. doi:

827   10.1029/2003JC001963,2004.

828   Korsman, B. 2013. The Spatial and Temporal Community Structure of Ichthyoplankton in a

829   Northeast Florida Estuary: A Study of Ingress at a Faunal Boundary. UNF Theses and

830   Dissertations. Paper 452.http://digitalcommons.unf.edu/etd/452.

831   Krishnakumar, P.K., and Bhat, G.S. 2008. Seasonal and interannual variations of oceanographic

832   conditions off Mangalore coast (Karnataka, India) in the Malabar upwelling system

833   during 1995–2004 and their influences on the pelagic fishery. Fisheries Oceanography 17

834   (1): 45–60.

835   Murdy, E., R. Baker, and Musick, J. 1997. Fishes of Chesapeake Bay. Washington, D.C.:

836   Smithsonian Institution Press.

837   Muyodi, F.J., Mwanuzi, F.L., and Kapiyo, R. 2011. Environmental quality and fish communities

838   in selected catchments of Lake Victoria. The Open Environmental Engineering Journal 4:

839   54−65.

840   Nye, J.A., Link, J.S., Hare, J.A., and Overholtz, W.J. 2009. Changing spatial distribution of fish

841   stocks in relation to climate and population size on the Northeast United States

842   continental shelf. Marine Ecology Series 393: 111−129. doi: 10.3354/meps08220.

843   Parker, R.O., Jr., and Dixon, R.L. 1998. Changes in a North Carolina reef−fish community after

844   15 years of intense fishing: Global−warming implications. Transactions of the American

845   Fisheries Society 127(6): 908–920.

846   Pinsky, M.L., Worm, B., Fogarty, M.J., Sarmiento, J.L., and Levin, S.A. 2013. Marine taxa track

847   local climate velocities. Science 341: 1239−1242.

848   Pinsky, M.L., and Mantua, N.J. 2014. Emerging adaptation approaches for climate ready

849   fisheries management. Oceanography 27(4):146–159, http://dx.doi.org/10.5670/

850   oceanog.2014.93.

851   Polovina, J. J., Dunne, J. P., Woodworth, P. A., and Howell, E. A. 2011. Projected expansion of

852   the subtropical biome and contraction of the temperate and equatorial upwelling biomes

853   in the North Pacific under global warming. – ICES Journal of Marine Science 68: 986–

854   995.

855   Reash, R.J., and Pigg, J. 1990. Physicochemcial factors affecting the abundance and species

856   richness of fishes in the Cimarron River. Proceedings Oklahoma Academic Science 70:

857   23−28.

858   Rijnsdorp, A.D., Peck, M.A., Engelhard, G.H., Mo¨llmann, C., and Pinnegar, J.K. 2009.

859   Resolving the effect of climate change on fish populations. ICES Journal of Marine

860   Science, 66: 1570–1583.

861   Schofield, O., Chant, R., Cahill, B., Castelao, R., Gong, D., Kahl, A., Kohut, J., Montes-Hugo,

862   M., Ramadurai, R., Ramey, P., and Glenn, S. 2008. The Decadal View of the Mid-

863   Atlantic Bight from the COOLroom: Is Our Coastal System Changing? Oceanogrpahy 21

864   4: 108-117.

865   Song, T.Y., Haidvogel, D.B., and Glenn, S.M. 2001. Effects of topographic variability on the

866   formation of upwelling centers off New Jersey: A theoretical model, Journal of

867   Geophysical Research 106: 9223– 9240.

868   Thomas, A.C, Pershing, A.J., Friedland, K.D., Nye, J.A., Mills, K.E., Alexander, M.A., Record,

869   N.R., Weatherbee, R., and Henderson, E.M. 2017. Seasonal trends and phenology shifts

870   in sea surface temperature on the North American northeastern continental shelf. Elem

871   Sci Anth, 5: 48. doi: https://doi.org/10.1525/elementa.240.

872   Thorne, R.St., J. W.P. Williams and Cao, Y. 1999. The influence of data transformations on

873   biological monitoring studies using macroinvertebrates. Water Resources. 33(2):

874   343−350.

875   Vinebrooke, R., K. Cottingham, J.N Orberg, M.S Cheffer, S.Dodson, S. Maberly, and Sommer,

876   U. 2004. Impacts of multiple stressors on biodiversity and ecosystem functioning: The

877   role of species co−tolerance. Oikos104:451–457.doi:10.1111/j.0030−1299.2004.13255.x.

878   Wood, A.J.M, Collie, J.S., and Hare, J.A. 2009. A comparison between warm-water fish

879   assemblages of Narragansett Bay and those of Long Island Sound waters. Fishery

880   Bulletin 107: 89−100.

881   Zar, J.H. 1999. Biostatistical analysis, 4th Ed. Prentice Hall, Upper Saddle River, NJ.

Table 1(on next page)

The annual physicochemical conditions in the study area (1988−2015).

1 **Table 1**. The annual physicochemical conditions in the study area (1988−2015).

2

Environmental Parameter	Hypothesis Test for Interannual Variation	Test Results	Regression Model	Regression Equation for Time Trend	F-test	r^2
Surface Water Temperature	ANOVA	F [26, 5068] = 3.13, P < 0.05)	Linear	Surface Temperature = -37.0457 + 0.0259257*Year	F [1, 26] = 1.77, P = 0.1945	6.4%
Bottom Water Temperature	ANOVA	F [26, 5068] = 6.35, P = < 0.05	Linear	Bottom Temperature = -22.9444 + 0.0177299*Year	F [1, 26] = 0.54, P = 0.4678	2.0%
Surface Salinity	ANOVA	F [26, 5068] = 18.97, P < 0.05	Linear	Surface Salinity = 90.1532 - 0.0296713*Year	F [1, 26] = 4.20, P = 0.0505	13.9%
Bottom Salinity	ANOVA	F [26, 5069] = 26.97, P < 0.05	Linear	Bottom Salinity = 90.0402 - 0.0291552*Year	F [1, 26] = 6.87, P = 0.0144	20.9%
Surface Dissolved Oxygen	ANOVA	F [26, 5066] = 5.20, P <0.05	Linear	Surface DO = -10.5943 + 0.0095525*Year	F [1, 26] = 2.74, P = 0.11	9.5%
Bottom Dissolved Oxygen	ANOVA	F [26, 5067] = 6.42, P < 0.05	Linear	Bottom DO = -15.1643 + 0.0113536*Year	F [1, 26] = 2.17, P = 0.1526	7.8%

3

Table 2(on next page)

General Linear Model and associated ANOVA Type III Sums of Squares. Coldwater-adapted species Temperature Preference. 5-yr Time-series (1988-2015). CW = Coldwater-adapted species.

1   **Table 2.** General Linear Model and associated ANOVA Type III Sums of Squares. Coldwater-adapted species Temperature
2   Preference. 5-yr Time-series (1988-2015). CW = Coldwater-adapted species.

Dependent Variable	Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value	Fitted Model	R^2
Total Number (Coldwater-adapted)	Time Series (CW)	11.3453	1	11.3453	7.99	0.0047	$\sqrt{\sqrt{}}$ Total Number (CW) = 6.3662 - 2.13748E-7*Time Series (CW) + 0.0192003*Month (CW) - 0.0104509*Area (CW)	0.41%
	Month (CW)	136.547	1	136.547	96.15	0.0000		
	Area (CW)	74.3637	1	74.3637	52.36	0.0000		
	Residual	55435.6	39036	1.42011				
	Total (corrected)	55663.8	39039					
Estimated Abundance (Coldwater-adapted)	Time Series (CW)	0.0292921	1	0.0292921	2.38	0.1229	$\sqrt{\sqrt{}}$ Estimated Abundance (CW) = 0.413077 - 1.0861E-8*Time Series (CW) + 0.00168064*Month (CW) - 0.000971917*Area (CW)	0.36%
	Month (CW)	1.0462	1	1.0462	85.01	0.0000		
	Area (CW)	0.643144	1	0.643144	52.26	0.0000		
	Residual	480.408	39036	0.0123068				
	Total (corrected)	482.161	39039					
Estimated Biomass (Coldwater-adapted)	Time Series (CW)	0.0336629	1	0.0336629	6.63	0.0100	$\sqrt{\sqrt{}}$ Estimated Biomass (CW) = -0.0790099 + 1.16431E-8*Time Series (CW) - 0.00145997*Month (CW) - 0.00139156*Area (CW)	1.06%
	Month (CW)	0.789501	1	0.789501	155.47	0.0000		
	Area (CW)	1.31841	1	1.31841	259.62	0.0000		
	Residual	198.236	39036	0.00507829				
	Total (corrected)	200.357	39039					

3

Table 3(on next page)

General Linear Model and associated ANOVA Type III Sums of Squares. Warmwater-adapted species Temperature Preference. 5-yr Time-series (1988-2015). WW = Warmwater-adapted species.

1 **Table 3.** General Linear Model and associated ANOVA Type III Sums of Squares. Warmwater-adapted species Temperature
2 Preference. 5-yr Time-series (1988-2015). WW = Warmwater-adapted species.

Dependent Variable	Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value	Fitted Model	R^2
Total Number (Warmwater-adapted)	Time Series (WW)	60.3819	1	60.3819	40.24	0.0000	$\sqrt{\sqrt{}}$ Total Number (WW) = -8.22361 + 4.92926E-7*Time Series (WW) + 0.0550105*Month (WW) - 0.00515665*Area (WW)	1.66%
	Month (WW)	922.387	1	922.387	614.75	0.0000		
	Area (WW)	18.0308	1	18.0308	12.02	0.0005		
	Residual	58570.3	39036	1.50042				
	Total (corrected)	59559.4	39039					
Estimated Abundance (Warmwater-adapted)	Time Series (WW)	0.780301	1	0.780301	60.04	0.0000	$\sqrt{\sqrt{}}$ Estimated Abundance (WW) = -0.967161 + 5.6035E-8*Time Series (WW) + 0.00501172*Month (WW) - 0.000490182*Area (WW)	1.64%
	Month (WW)	7.65589	1	7.65589	589.07	0.0000		
	Area (WW)	0.162928	1	0.162928	12.54	0.0004		
	Residual	507.331	39036	0.0129965				
	Total (corrected)	515.812	39039					
Estimated Biomass (Warmwater-adapted)	Time Series (WW)	0.800626	1	0.800626	164.43	0.0000	$\sqrt{\sqrt{}}$ Estimated Biomass (WW) = -1.0566 + 5.67601E-8*Time Series (WW) + 0.00400921*Month (WW) + 0.000216194*Area (WW)	2.91%
	Month (WW)	4.89938	1	4.89938	1006.22	0.0000		
	Area (WW)	0.0316933	1	0.0316933	6.51	0.0107		
	Residual	190.069	39036	0.00486908				
	Total (corrected)	195.747	39039					

3

Table 4(on next page)

General Linear Model and associated ANOVA Type III Sums of Squares. Subtropical-adapted species Temperature Preference. Pooled 5-yr Time-series (1988-2015). ST = Subtropical-adapted species.

Table 4. General Linear Model and associated ANOVA Type III Sums of Squares. Subtropical-adapted species Temperature Preference. Pooled 5-yr Time-series (1988-2015). ST = Subtropical-adapted species.

Dependent Variable	Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value	Fitted Model	R^2
Total Number (Subtropic-adapted)	Time Series (ST)	135.366	1	135.366	19.51	0.0000	$\sqrt{\sqrt{}}$ Total Number (ST) = 34.9198 - 0.00000161118*Time Series (ST) + 0.0682713*Month (ST) - 0.0374255*Area (ST)	0.88%
	Month (ST)	139.303	1	139.303	20.08	0.0000		
	Area (ST)	168.857	1	168.857	24.34	0.0000		
	Residual	51187.0	7379	6.93685				
	Total (corrected)	51642.8	7382					
Estimated Abundance (Subtropic-adapted)	Time Series (ST)	0.992579	1	0.992579	16.37	0.0001	$\sqrt{\sqrt{}}$ Estimated Abundance (ST) = 3.01224 - 1.37966E-7*Time Series (ST) + 0.00626256*Month (ST) - 0.00351368*Area (ST)	0.83%
	Month (ST)	1.17216	1	1.17216	19.33	0.0000		
	Area (ST)	1.48837	1	1.48837	24.54	0.0000		
	Residual	447.466	7379	0.0606405				
	Total (corrected)	451.214	7382					
Estimated Biomass (Subtropic-adapted)	Time Series (ST)	0.203569	1	0.203569	42.11	0.0000	$\sqrt{\sqrt{}}$ Estimated Biomass (ST) = -1.19149 + 6.24808E-8*Time Series (ST) - 0.0000933727*Month (ST) + 0.00143838*Area (ST)	1.23%
	Month (ST)	0.00026057	1	0.00026057	0.05	0.8164		
	Area (ST)	0.249422	1	0.249422	51.59	0.0000		
	Residual	35.6733	7379	0.00483444				
	Total (corrected)	36.1178	7382					

Figure 1

Study Area; New Jersey Ocean Stock Assessment Program.

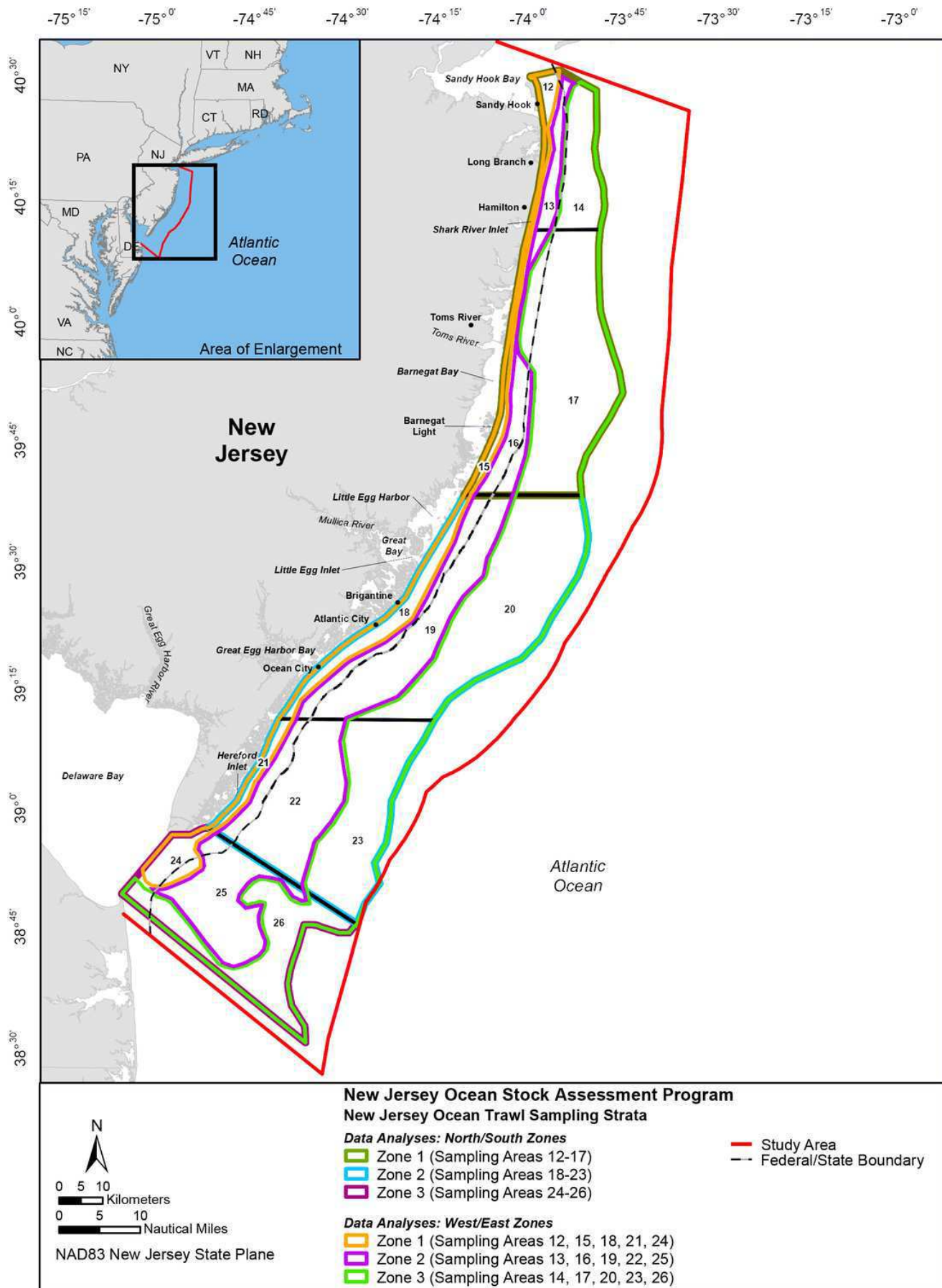The colored lines depict different zones (Figure Credit: Casey Gomez, 2019).

New Jersey Ocean Stock Assessment Program
New Jersey Ocean Trawl Sampling Strata

Data Analyses: North/South Zones
- Zone 1 (Sampling Areas 12-17)
- Zone 2 (Sampling Areas 18-23)
- Zone 3 (Sampling Areas 24-26)

— Study Area
--- Federal/State Boundary

Data Analyses: West/East Zones
- Zone 1 (Sampling Areas 12, 15, 18, 21, 24)
- Zone 2 (Sampling Areas 13, 16, 19, 22, 25)
- Zone 3 (Sampling Areas 14, 17, 20, 23, 26)

NAD83 New Jersey State Plane

Figure 2

The total number of individuals collected per water temperature preference group within the study area (1988−2015). Error bars represent the standard error.
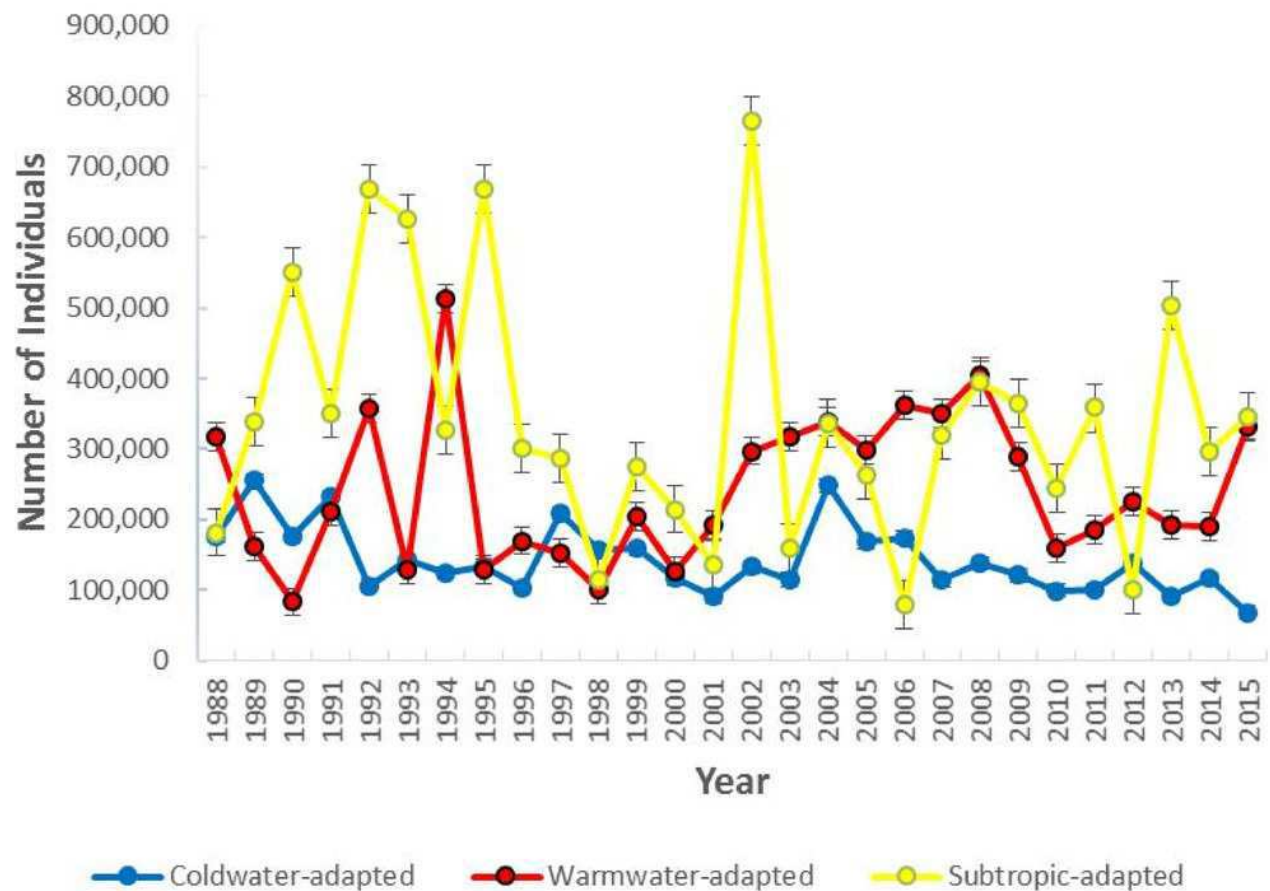
Figure 3

The coldwater to warmwater-adapted ratio of species collected within the study area (1988–2015). Error bars represent the standard error.
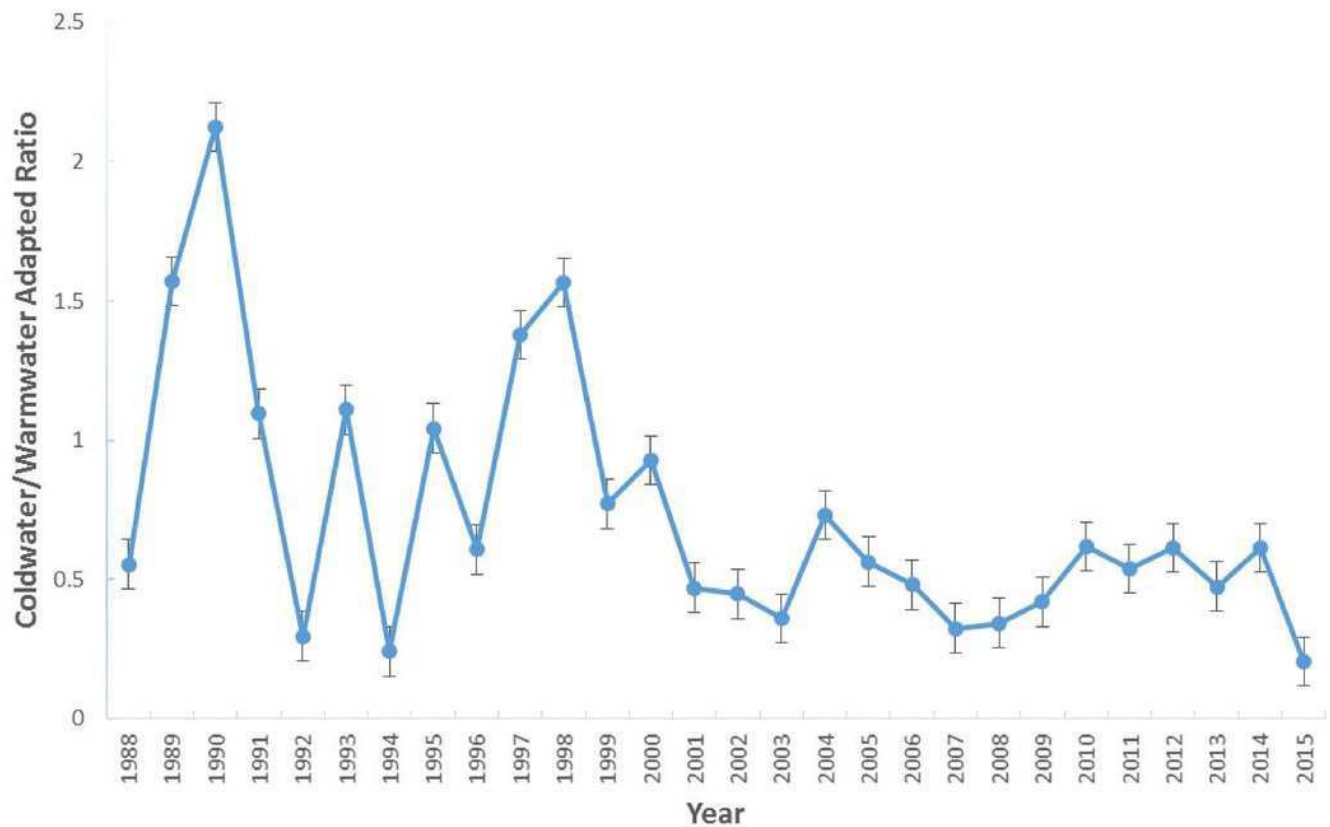
Figure 4

The mean annual estimated abundance (individuals/m^2) by water temperature preference collected within the study area (1988−2015).