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Describing juvenile American shad and striped bass habitat use in the Hudson River Estuary using species distribution models

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ABSTRACT

Species distribution models (SDMs) are currently being used to identify essential fish habitat and guide fisheries management worldwide. We present SDMs based on generalized linear mixed models (GLMM) of the fall distribution or occurrence of juvenile American shad (*Alosa sapidissima*) and juvenile striped bass (*Morone saxatilis*) in the Hudson River estuary (HRE) based on data from a fishery-independent survey. The distribution of both species were modeled over a 6-year period (2000–2005) as a function of dissolved oxygen, salinity, water temperature, distance along the HRE denoted as river mile, time or Julian day, distance from submerged aquatic vegetation (SAV), and sediment characteristics. Salinity, river mile, and Julian day were the most important environmental determinants of juvenile American shad presence, and sediment type, salinity, river mile, and Julian day were the most important environmental determinants of juvenile striped bass presence. Calibration plots showed a high level of agreement between predictions generated by each model and actual observations of each species' occurrence. Based on this result, we mapped the predicted distribution of each species. We found the highest predicted probabilities of juvenile American shad presence in the upper HRE, but the highest predicted probabilities of juvenile striped bass presence were in the lower HRE. Our results suggest that habitat partitioning between these two species is present during the fall in this system but the mechanism is unclear.

1. Introduction

Identifying essential fish habitat has become a primary focus in fisheries management (NOAA, 1996; Bellido et al., 2008; Valvanis et al., 2008). Essential fish habitat has been defined by the National Oceanic and Atmospheric Administration (NOAA) and by the EU Scientific, Technical and Economic Committee for Fisheries (STECF) and applies to habitat used during all life stages of managed fish (Rosenberg et al., 2000; STECF, 2006). This policy has been indirectly applied to non-federally managed fishes through regional (e.g., Atlantic States Marine Fisheries Commission; ASMFC) and state (e.g., New York State Department of Environmental Conservation; NYSDEC) agencies. For example, the goals of the Hudson River Action Agenda for 2005–2009 are "to restore the signature fisheries to their full potential" and to conserve and protect critical river habitat to assure that these characteristic species are supported throughout their life stages. The Hudson River Estuary Management Plan (HREMP) states that currently declining species, including American shad (*Alosa sapidissima*), Atlantic sturgeon (*Acipenser oxyrhynchus*), river herring (*Alosa pseudoharengus* and *A. aestivalis*), American eel (*Anguilla rostrata*) and largemouth bass (*Micropterus salmoides*), and the recovering striped bass fishery (*Morone saxatilis*), need to be managed through an ecosystem approach. Evaluating fish habitat suitability for all life stages is a goal of the HREMP; however no procedures were described as to how this goal was to be achieved (NYSDEC, 2005). Species distribution models (SDMs), which relate species distribution data (occurrence or abundance at known locations) with information on the environmental and/or spatial characteristics of those locations (Elith and Leathwick, 2009), can be used to provide understanding and/or to predict species distributions across a landscape. Here we use SDMs to identify fish habitat use for two signature species in the HRE. Developing a process to describe habitat use is an important first step in identifying fish habitat suitability, a management goal of the HREMP.

American shad and striped bass are two anadromous species that as juveniles extensively use the Hudson River estuary (HRE). Both species spend most of their adult life in marine waters and enter the HRE in the spring to spawn in the freshwaters of the middle and upper estuary. Shad eggs, yolk sac larvae (YSL) and post yolk sac larvae (PYSL) are found mainly in the upper HRE. As juveniles

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they are found throughout the estuary and emigrate from the HRE at the end of the summer and early fall. This emigration is probably triggered by age (Limburg, 1996) and declining water temperature (Leggett, 1976; ASMFC, 2007). Striped bass eggs and YSL are found mainly in the mid HRE but YSL are sometimes found further upriver. Striped bass PYSL are most abundant in the mid to lower estuary but can be found throughout the HRE. As juveniles they are found primarily in the lower estuary but at the end of their first summer can also be found in New York Harbor, western Long Island Sound, and the south shore of Long Island. Striped bass usually emigrate from Atlantic coast estuaries at age-2 or 3 (Waldman et al., 1990; ASMFC, 2007).

American shad and striped bass are both managed by the ASMFC, but currently have very different population statuses. The HRE commercial and recreational fishery for American shad has been closed recently because abundances have been decreasing steadily since the late 1980s and have shown little evidence of recovery. The HRE also supports a fully recovered striped bass population demonstrating dramatic increasing abundances from the mid 1990s to the present (Limburg et al., 2006). Although much research has been conducted on American shad and striped bass in the HRE, our spatial approach describing their habitat use could directly aid fisheries managers to develop conservation plans for the HRE resource. We develop an SDM for the juvenile life stage for each species describing how habitat characteristics affect their presence/absence or occurrence and specifically test whether factors such as sediment type, distance to nearest SAV, specifically water celery beds (*Vallisneria Americana*) and water chestnut beds (*Trapa natans*), salinity, water temperature and dissolved oxygen influence the distribution of juvenile American shad and striped bass in the HRE.

2. Methods

To address our research question, we built SDMs, similar to Valvanis et al. (2008), for juvenile American shad (hereafter, simply 'shad') and juvenile striped bass (hereafter, simply 'striped bass'). We chose these two particular species because they provide an opportunity to compare species with similar life histories but differing abundance trends and management status, and because they are both listed as 'signature fisheries' in the HREMP. Signature fisheries are those fisheries that support a commercial and/or recreational fishery in the HRE. Identifying critical habitat for all their life stages is a goal of the HREMP (NYSDEC, 2005). We chose young-of-the-year or the juvenile age classes of these species because they are broadly distributed and well sampled in the Hudson River Monitoring Program's survey (described below).

2.1. Study area

The Hudson River, located in eastern New York State, USA, extends 315 miles from its source, Lake Tear of the Clouds in the Adirondack Mountains, to New York Harbor. It is tidally influenced up to a dam located at Green Island near Troy, NY (river mile = RM 155). After examining studies concerning spatio-temporal fish abundance trends in the HRE (Pace et al., 1993; Daniels, 1995; ASA, 2004; Hurst et al., 2004; Strayer et al., 2004) and evaluating extant spatial environmental data for the HRE, including sediment type (Nitsche et al., 2005), submerged aquatic vegetation characteristics (Nieder et al., 2004), and water quality parameters (ASA, 2004), we decided to focus our research on the entire Hudson River estuary. The study area or extent is specifically defined as the Battery (RM 0) north to Albany (RM 152).

2.2. Fish data

In the HRE, there has been an annual intensive multi-species survey since 1974 by the Hudson River Monitoring Program (HRMP), funded by the electric generators on the HRE. The goal of this survey is to determine the direct impact that these utility companies have on the HRE fish populations. Presence/absence shad and striped bass data were obtained from HRMP's Fall Juvenile Survey (FJS) which samples with beam trawls and Tucker trawls from RM 0 to RM 152; and the Beach Seine Survey (BSS) which samples with a 30.5 m beach seine from RM 20 to RM 152. The HRMP's fish survey data have been subjected to the rigors of complete QA/QC protocol and have been used in numerous analyses published in peer-reviewed journals (e.g., Pace et al., 1993; Strayer et al., 2004; Dunning et al., 2006; Heimbuch, 2008). For this study, we used presence or absence of shad and striped bass for the fall season (September 21–December 21) for each year, 2000–2005. We only examined the fall season because of the importance of this season on the juvenile life stage for both species. We chose the time period 2000–2005 because the sediment and submerged aquatic vegetation environmental data (see below) were collected during this time period only.

2.3. Environmental data

The environmental data were collected from two data sources, the New York State Department of Environmental Conservation (NYSDEC) and the HRMP's survey. The Euclidean distances (m) from the nearest water celery bed and nearest water chestnut bed to a fish sampling location were calculated using a map of SAV distribution derived from aerial photography conducted by the NYSDEC in 2002. The SAV distribution map was classified as water celery and water chestnut vegetation and exists as vector/polygon feature types. These variables were chosen because Ross et al. (1997) found a positive relationship between shad abundance and percent SAV cover in the upper Delaware River. Also, Price et al. (1985) provide compelling evidence for a relationship between declining juvenile striped bass and disappearing SAV in the Chesapeake Bay during the mid-1980s. However, the HRE has two major types of SAV, one indigenous, water celery, and one invasive, water chestnut and each may affect shad and striped bass differently. Water chestnut, found in the middle and upper HRE, is oxygen depleting due to its growth structure. Therefore the presence of water chestnut usually denotes hypoxic conditions. In comparison, water celery, found in distinct beds throughout the HRE, is oxygen enriching like most typical SAV species (Caraco and Cole, 2002).

The NYSDEC also mapped sediment type based primarily on sidescan sonar, subbottom profiling, and sediment grab or core samples collected from 1998 through 2003. Sediment type and bathymetry data were obtained from Cornell University Geospatial Information Repository (CUGIR) (http://cugir.mannlib.cornell.edu) (Nitsche et al., 2004; Bell et al., 2006). Six sediment types were identified in the HRE: mud, sandy mud, muddy sand, sand, gravelly sand and gravel (http://cugir.mannlib.cornell.edu). We realize shad and striped bass are not benthic fishes, but both species do prey on benthic organisms during the juvenile stage (Ross et al., 1997; Jordan et al., 2003). And Kennish et al. (2004) in Mullica Bay-Great Bay and Strayer et al. (2006) in the Hudson River found that sediment type and bottom structure strongly influences benthic invertebrate assemblages.

Three additional environmental variables, water temperature, salinity and dissolved oxygen were chosen based on known or plausible roles influencing shad and striped bass distributions (Munroe, 2002; Klein-MacPhee, 2002). These variables, obtained from the HRMP's survey, were not collected on-station or co-located with the fish samples and thus were not georeferenced. However, river mile, water depth and strata location (e.g. beach, channel or east or west of the channel) was recorded for each water sampling site. We created a thalweg for the HRE (according to Merwade et al., 2005) to measure north–south distance within the river. The thalweg in conjunction with the aforementioned spatial location information allowed us to assign approximate locations to the water sample locations.

Because the water samples were not co-located with the fish samples, we interpolated fall bottom temperature, salinity and dissolved oxygen values for each year (2000–2005) using universal kriging. Universal kriging is an interpolation procedure that uses a regression model as part of the kriging process, modeling the unknown local mean values as having a local linear or quadratic trend (Cressie, 1993). We modeled a linear longitudinal (or north–south trend) and a quadratic east–west trend for all water variables. Variogram modeling and subsequent universal kriging procedures were conducted with the automap package in R. Interpolated bottom temperature, salinity and dissolved oxygen were mapped in R and corresponding values were extracted for each fish sampling site.

All continuous explanatory variables (water temperature, salinity, dissolved oxygen, distance to nearest water celery and water chestnut bed, river mile and Julian day), were scaled to have zero mean and unit variance, which allows for a direct comparison of the relative importance of the explanatory variables (Gelman and Hill, 2006).

2.4. Analytical approach

We used generalized linear mixed models (GLMMs) with a binomial error distribution to model shad and striped bass occurrence during the fall over the time period 2000–2005. We used the environmental variables described above as fixed effects, as well as river mile to denote spatial dependence, and Julian day to denote specific time during the fall season. Second order polynomials were fit for Julian day, river mile, salinity, dissolved oxygen and water temperature because these predictors showed quadratic relationships to shad and striped bass occurrence. We used likelihood ratio tests (LRT) to compare the more complex models containing the quadratic terms with the simpler models that did not contain the quadratic terms, testing whether the extra goodness-of-fit to the data was worth the added complexity (Bolker, 2008). We built varying intercept GLMMs with two random effects, year and site location, to account for the repeated measure over time at each site. We modeled the response variable as a binomial variable only to denote presence/absence for that particular species and estimated the probability of shad or striped bass occurrence throughout the HRE. The final products are probability of occurrence maps or species distribution maps for shad and striped bass.

We evaluated the models using calibration plots that show the agreement between predictions generated by a model and actual observations. This is also considered the "goodness-of-fit" of the model. The calibration plots were produced by breaking the predicted probability range up into bins, and plotting the proportion of sampling sites that are recorded present within each of these bins against the mean or median predicted value of each bin. Because the models were to be used to produce probability of occurrence maps for each species, it was desirable that the predicted probability was well calibrated to the true probability.

All statistical analyses were conducted using R (R Development Core Team, 2009) using lme4, Presence/absence, lattice and Hmisc libraries and programs written by the authors. Final predicted probability of occurrence maps for shad and striped bass were projected in ESRI's ArcGIS 9.3.

3. Results

Strong correlations were present between many pairs of explanatory variables. Most notably, there were strong negative correlations between river mile and salinity ($r = -0.65$) and river mile and distance to nearest water chestnut bed ($r = -0.74$). Other strong correlations occurred between salinity and distance to nearest water celery bed ($r = 0.68$) and between salinity and distance to nearest water chestnut bed ($r = 0.76$). However, collinearity among the explanatory variables was not deemed sufficient to drop variables from the models, but will be considered in the interpretation of the model results. We examined collinearity further by assessing

Table 1
Parameter estimates and standard errors from the generalized mixed models (GLMM).

Fixed effects	Parameter estimates American Shad	Standard errors	Parameter estimates striped bass	Standard errors
Intercept	−0.36	0.23	0.61*	0.31
Julian day	9.34***	1.03	−1.71	0.83
Julian day^2	−9.66***	1.05	1.28	0.83
Salinity	−1.44***	0.21	0.46*	0.21
Salinity^2	1.14***	0.20	−0.84***	0.19
River mile	1.25***	0.44	−1.13**	0.47
River mile^2	−0.83**	0.36	−0.08	0.38
Water temperature	−0.27	0.47	1.35**	0.54
Water temperature^2	0.58	0.48	−1.54***	0.54
Dissolved oxygen	0.05	0.39	−0.12	0.47
Dissolved oxygen^2	−0.09	0.39	−0.09	0.47
Distance to WCe	0.18	0.11	0.25*	0.10
Distance to WCh		0.11	−0.26*	0.12
Sediment type				
Mud	0.07	0.11	0.33***	0.12
Sandy mud	−0.05	0.19	0.72***	0.20
Muddy mud	0.06	0.23	0.86***	0.24
Sand	−0.49	0.40	0.10	0.46
Gravelly sand	1.00	0.68	0.36	0.65
Gravel	−0.48	1.31	−1.58	1.37

WCe = water celery; WCh = water chestnut.
* $p < 0.05$.
** $p = 0.01$.
*** $p < 0.01$.

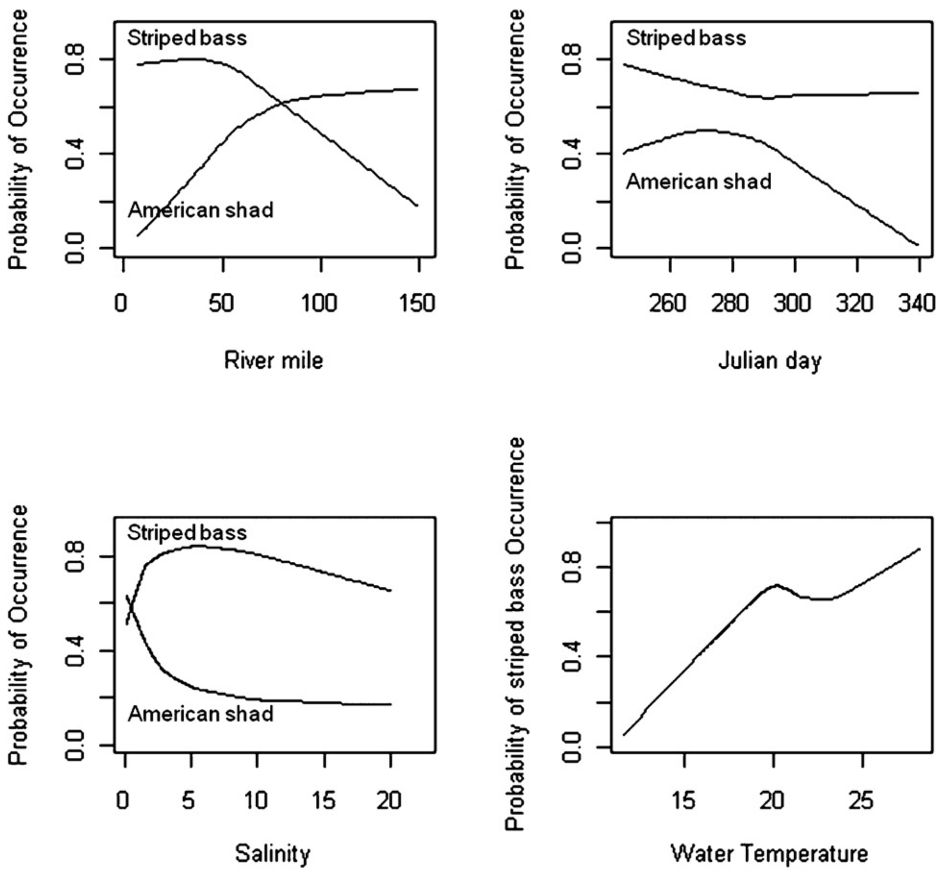

Fig. 1. Probability of juvenile American shad and juvenile striped bass occurrence versus Julian day, river mile, salinity and water temperature in the HRE based on the GLMMs.

the variance inflation factors (from the covariance matrix of parameter estimates) for the explanatory variables using the Design package in the R statistical program (R Development Core Team, 2009). The variance inflation factors were all <5.0 for both models, which indicates that they independently predict variance in the response variables (Kutner et al., 2004).

We chose to keep the more complex GLMM models with the quadratic terms for both species based on significant LRTs. Based on these models, the primary drivers for probability of shad occurrence were Julian day, river mile, and salinity (Table 1). Shad exhibited a unimodal relationship with Julian day; probability of occurrence was 0.4 at the start of the fall survey and rose to a peak of 0.5 in late September before sharply declining to near zero in late fall (Fig. 1). Shad exhibited a strong threshold-like relationship with river mile; probability of occurrence increased rapidly from near zero in the lower estuary to 0.6 in the mid estuary (RM 75) and then remained high, asymptotically approaching 0.7 in the upper estuary (Fig. 1). Lastly, shad exhibited a negative exponential-like relationship with salinity; probability of occurrence decreased rapidly from above 0.6 at near-zero salinity to approximately 0.2 at salinities above 5 (which occur mid-estuary during the fall season). The drivers for striped bass occurrence included virtually all of the predictors we considered, including Julian day, river mile, salinity, water temperature, distance to water celery, distance to water chestnut, and sediment type (Table 1). Striped bass exhibited a weak negative relationship with Julian day; probability of occurrence decreased from approximately 0.8 at the beginning of the fall to just above 0.6 at mid-fall and then remained at that level for the remainder of the fall (Fig. 1). Striped bass exhibited a threshold-like relationship with river mile; probability of occurrence was approximately 0.8 until river mile 50 and then decreased steadily upriver to roughly 0.2 at the upper most reach (Fig. 1). Striped bass exhibited a distinct unimodal relationship with salinity; probability of occurrence peaked at a salinity of around 5 (Fig. 1). Striped bass exhibited a generally positive relationship with temperature; probability of occurrence generally increased with temperature, but the relationship was not perfectly monotonic (Fig. 1). The inconsistent relationship at temperatures between 20 and 23 °C may have been due to differences in average temperatures among years. For example, temperatures above 23 °C were observed only in 2005 denoting a predominantly warmer year. Striped bass also exhibited a strong relationship with sediment type or grain size; probability of occurrence was greater where there was a predominance of fine-grained sediments (Table 1). Lastly, striped bass exhibited a weak positive relationship with distance to water celery beds and a weak negative relationship with distance to water chestnut beds.

Calibration or 'goodness-of-fit' plots showed a high level of agreement between predictions generated by each model and actual observations of shad and striped bass occurrence, which allowed us to confidently map the species' predicted distributions (Figs. 2 and 3). Not surprisingly given the model results, the highest predicted probabilities of shad occurrence are found in the upper HRE, whereas the highest predicted probabilities of striped bass occurrence are found in the lower HRE.

4. Discussion

In addition to meeting our primary goal, identifying shad and striped bass habitat use during the fall (2000–2005) throughout the HRE (Figs. 2 and 3), we outlined a method that can be used

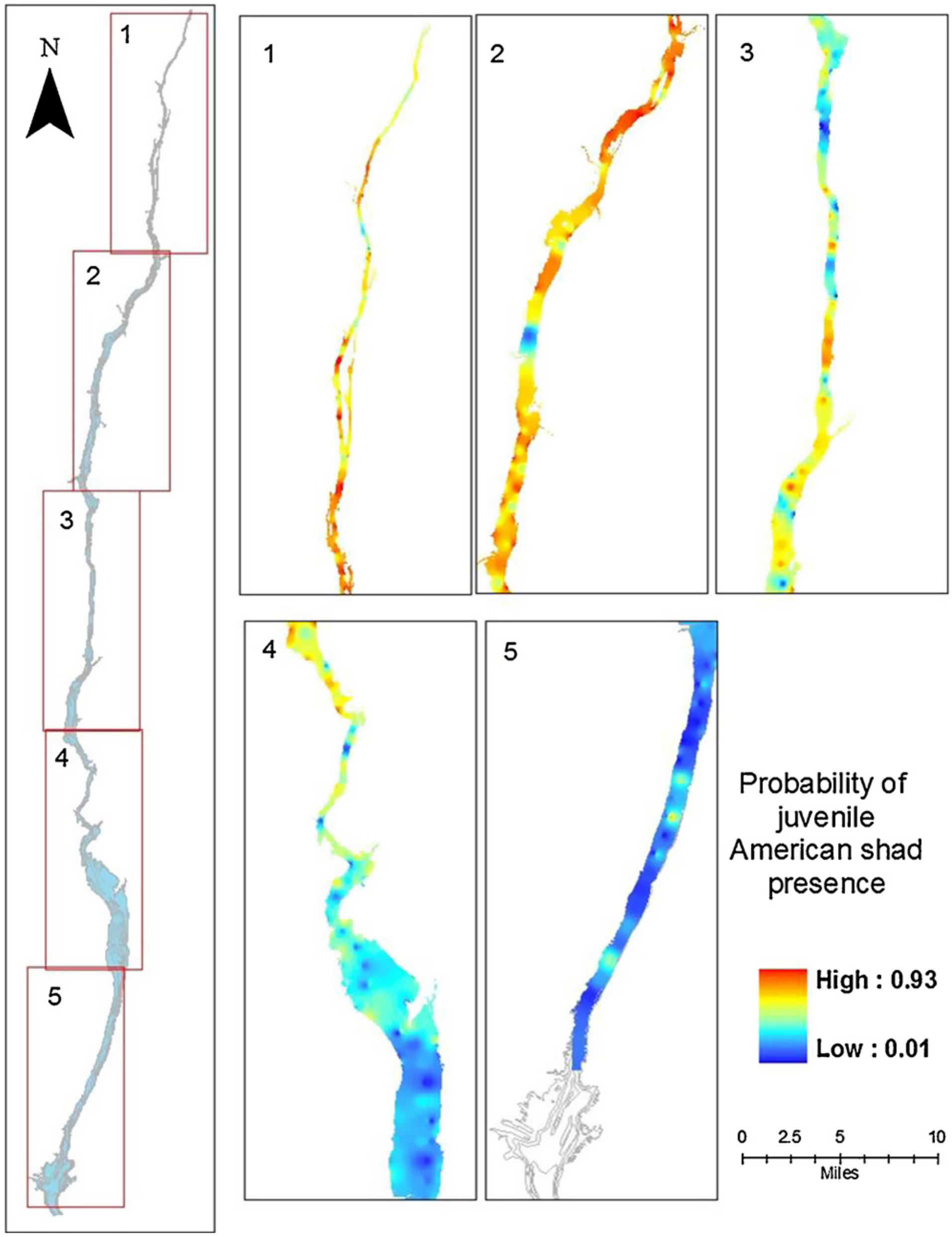

Fig. 2. Map of the probability of juvenile American shad occurrence in the HRE based on the GLMM (2000–2005). Higher probabilities are depicted in red and lower probabilities are depicted in blue. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

for developing SDMs for all signature species and life stages in the HRE. By applying GLMMs and interpreting the resulting parameter estimates, we are also able to describe the relationship between shad and striped bass and the environmental variables. Identifying habitat use for all life stages and seasons over varying time periods could be useful in management decisions such as identifying areas for habitat restoration and to identify additional research needs to support ecosystem management.

The spatial patterns of shad and striped bass probability of occurrence in the HRE during the fall from 2000 to 2005 were related to several predictor variables (Table 1). Julian day, river mile and salinity were the most important predictors of shad occurrence. Julian day, river mile and salinity, in addition to water temperature and to a lesser degree sediment type and distance to nearest water celery and water chestnut bed, were important predictors of striped bass occurrence. In the discussion below we will primarily focus on the common drivers found between the two species (Julian day, river mile and salinity) after discussing apparent collinearity among predictors.

As expected salinity and river mile have a strong negative correlation (−0.65) because salinity decreases as river mile increases. The location of the salt water/freshwater interface varies with season and can occur anywhere from RM 25 in the spring to RM 100 in the fall. But generally the HRE becomes a tidal freshwater environment mid-estuary near Kingston, New York (RM 125). Salinity is also highly correlated with both distance to nearest water celery bed (0.68) and distance to water chestnut bed (0.76). Water chestnut beds are found only in the freshwater region of the upper HRE and water celery beds are found throughout the HRE in all salinity environments. From this collection of intercorrelated variables, we were able to discern a general pattern of shad and striped bass occurrence for the entire HRE, although the collinearity among

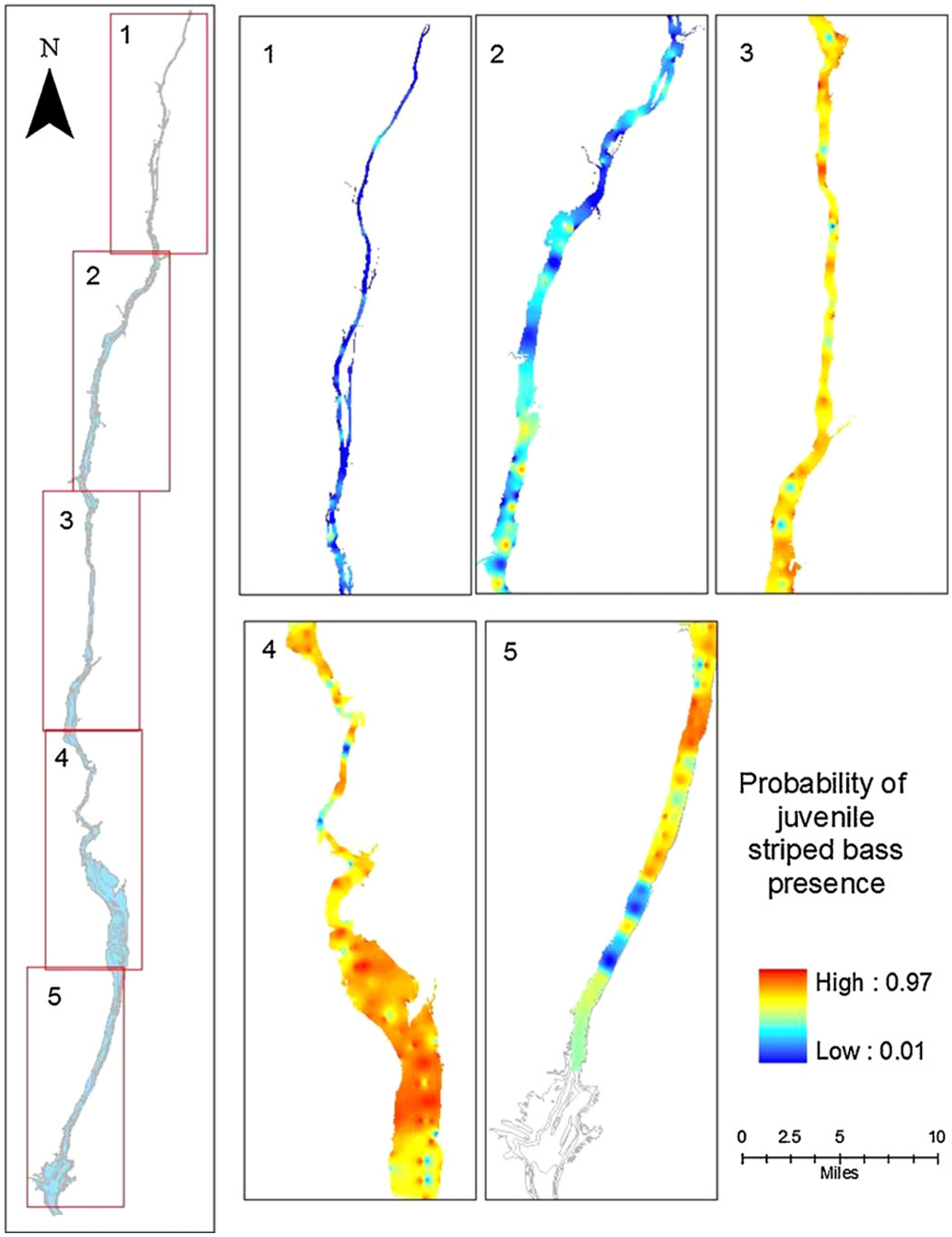

Fig. 3. Map of the probability of juvenile striped bass occurrence in the HRE based on the GLMM (2000–2005). Higher probabilities are depicted in red and lower probabilities are depicted in blue. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

predictors makes it difficult to ascribe independent effects to each of the variables.

In general, shad and striped bass exhibit an inverse relationship in their temporal and spatial occurrence based on Julian day, river mile and salinity (Fig. 1). Specifically, as the fall progresses striped bass probability of occurrence remains relatively unchanged while that of shad decreases markedly. These results suggest that striped bass remain in the HRE throughout the fall. The decrease in shad suggests that either they are emigrating from the system or largely dying. There is no indication that they are emigrating from the system; for example, probability of occurrence does not increase in the lower estuary later in the fall as we might expect if they were emigrating (Fig. 2). Instead, it seems more likely that they are experiencing mortality, which we discuss in further detail below. There is an equally strong inverse relationship in the spatial distribution of these two species during the fall, which is evident in the fitted relationships involving river mile and salinity (Fig. 1) and in the probability of occurrence maps (Figs. 2 and 3). Shad utilized the freshwater upper HRE and striped bass primarily utilized the more saline lower HRE, although it is impossible to discern the independent role of salinity in this relationship due to the collinearity with river mile. Bilkovic et al. (2002) also found that peak striped bass spawning activity in the York River system took place below areas of peak shad spawning, with little spatial overlap, so it seems likely that this relationship is general.

The movement of shad has been well studied in the HRE. Limburg (1996) conducted a fine-scale demographic study in the HRE of the 1990 year class of YOY shad using otolith microanalysis and found that migration was both size- and age-biased. Cohorts moved down the river as early as June, older cohorts tending to move earlier than younger ones. She found that by September most size classes of fish utilize the middle estuary, and by late October, fish move to the lower estuary (even in the face of higher predation risk), due to a combination of lower food resources and thermal risks in the upper and middle estuary. Limburg (2001) confirmed this bimodal first emigration pattern with respect to age and size for the 1989 and 1990 cohorts, also through otolith microanalysis, but was unable to validate this finding with actual YOY data collected in 1989 and 1990 thus suggesting differential mortality due to predation and hypoxia experienced in the lower HRE. Our results show that shad probability of presence is very low in the lower HRE and higher in the upper HRE during the fall (Fig. 2) and therefore does not illustrate successful migration. Also, shad probability of presence decreases through the season (Fig. 1) suggesting that they could be experiencing mortality. Based on the spatial partitioning we found between shad and striped bass, differential mortality due to predation could explain our findings.

Before we consider a predator-prey relationship between shad and striped bass, we present our findings of a positive relationship between finer-grained sediments and probability of striped bass occurrence, which may have to do with the distribution of their prey. Kennish et al. (2004) in Mullica Bay-Great Bay and Strayer et al. (2004) in the HRE both found that sediment type or grain size and bottom structure strongly influences benthic invertebrate assemblages. Howe et al. (2008) found that age-0 striped bass collected in the littoral zones of lower HRE (20–45 RM) selectively feed on invertebrates, specifically, gammarid amphipods, *Crangon* spp. shrimp, and chironomid larvae. They also found higher numbers of invertebrates and higher numbers of age-0 striped bass at sites with finer sediments (Howe et al., 2008). Similarly, Overton et al. (2009) while studying diets of striped bass in the Chesapeake Bay found that small sized (150–300 mm) striped bass primarily prey on benthic invertebrates. Juvenile or age-0 striped bass in the HRE feed primarily on invertebrates (Jordan et al., 2003; Howe et al., 2008) but age-1+ striped bass, also found in the lower HRE, diets vary and other important prey items should be considered for HRE striped bass based on additional findings discussed below and because they are considered to be opportunistic feeders (Klein-MacPhee, 2002; Hartman, 2003).

Limburg's (2001) suggestion of differential mortality due to predation supports our idea of a possible predator prey linkage between age-1+ striped bass or other predatory fish and shad in the mid and lower HRE. Juvenile shad are common prey for striped bass in other systems but this predator prey relationship has not been consistently observed in the HRE. Gardinier and Hoff (1982) reported finding shad in the stomachs of striped bass collected in the HRE over the period April through November. However, Dunning et al. (1997) and Kahnle and Hattala (2007) examined stomachs of adult striped bass collected in the lower HRE in the winter and spring, respectively, and did not find shad as a prey item suggesting that season may influence diet. Investigating age-1 or older striped bass diets in the HRE would be valuable in evaluating this potential predator-prey relationship. For example, Tuomikoski et al. (2008) found that age-1 striped bass in western Albemarle Sound, North Carolina preyed upon several commercially important species including juvenile American shad.

Limburg's (2001) suggestion of shad differential mortality due to hypoxia should also be considered in combination with other anthropogenic stressors affecting the HRE. Anthropogenic stressors can be classified into non-fishery related versus fishery related (e.g. overfishing). Non-fishery related stressors such as urbanization impacts fish resources throughout the HRE and exists in many forms such as chemical pollution (Wirgin et al., 2011), hypoxia, land-use changes (Limburg and Schmidt, 1990) and possible power plant impingement (ASA, 2004). Hypoxia caused by eutrophication exists in late summer in New York Harbor can be lethal to emigrating juvenile shad if they cannot avoid the hypoxic areas. It is also plausible that a combination of predation and the encountering of hypoxic water masses could have resulted in the patterns of differential mortality observed (Limburg, 2001). Fishery related stressors such as overfishing have historically impacted HRE striped bass population but the population has recovered (ASMFC, 2003). Commercial fishing and bycatch has been considered a stressor on shad populations (ASMFC, 2007) but Savoy and Crecco (2004) found no evidence that commercial fisheries have measurable influence in Connecticut River shad stocks.

In our attempt to identify habitat use for juvenile shad and striped bass in the HRE we developed SDMs for both species during the fall season. Based on the probability of occurrence maps we see a clear north–south partitioning of the estuary by the two species (Figs. 2 and 3) that could be due to habitat partitioning or a predator-prey relationship. This illustrates that single species management is probably an ineffective approach for managing these two species in the HRE (NYSDEC, 2005). Further investigation through temporal and spatial sampling of striped bass and other predatory diets will provide information for possible differential mortality due to predation contributing to the already low shad abundances in the HRE. More importantly, by identifying habitat use, a useful management application has been developed that can identify areas for habitat restoration (Miller et al., 2006). And because we created an approach to mapping fish habitat use in the HRE this can be applied to other species and life stages and aid managers in identifying areas for additional habitat restoration or focused ecosystem level research.

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