Spatial-Explicit Growth Rate Model of Young Striped Bass in Albemarle Sound: Implications on Essential Fish Habitat (EFH) Using GIS

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Abstract*-Production dynamics of fish may depend on local processes and can be strongly influenced by the physical habitats which they live. These habitats are often patchy which inhibits the use of system-wide models to examine fish production. We examined the growth rate potential of juvenile striped bass *Morone saxatilis* in Albemarle Sound, North Carolina, to identify essential fish habitat (EFH) for striped bass during the summer and early-fall months. Growth rate potential integrates a physiological-based model (bioenergetics) of fish growth with the physical environment. We integrated the growth rate potential model with Global Information Systems (GIS) to spatially map the growth gate potential of individual juvenile striped bass in Albemarle Sound. Water temperatures during the modeled period were within the "preferred" range 19 and 27°C, of juvenile striped bass except during June when water temperatures were above 28°C. Dissolved oxygen and salinity levels were at levels suitable for striped bass throughout the modeled period. Mean growth rate (g/g/d) was 0.023 during the modeled period. Our model predicted that the modeled areas all produced positive growth in the north Albemarle Sound, particularly in the Chowan and North rivers, the mouth of the Roanoke River provided physical habitats (based on water temperature) to support high growth rates of striped bass. These areas may be defined as EFH areas. Our approach shows the usefulness of integrating two technologies to predict fish production.

Introduction

The Albemarle Sound in North Carolina supports a major commercial and recreational striped bass *Morone saxatilis* fishery [1]. During 1970 through the early 1980s, the striped bass population declined because of collectively over fishing, loss of spawning habitat, and changes in river flow [2] and [3].

Fisheries managers are often concerned with the factors that effect the production of fish. Fish production often depends on the number of individuals through time, recruitment, and growth rates of individuals within the population. Fish production can be limited by biological and physical factors that occur. In the past, fish production models have considered the modeled system to be homogenous and do not incorporate the spatial environment.. However, abiotic factors such as food supply and water quality may differ spatially.

The Albemarle Sound serves as a nursery area for young-of-year striped bass [4]. The production of young fish may depend on the amount of available habitat particularly during the summer periods that will protect them from high levels of predation and capable of providing suitable feeding conditions. Favorable habitat is especially crucial for striped bass because the juvenile stage is relatively long compared to other life stages. The optimal temperature range for juvenile striped bass is 14-16°C [5]; [6] but can tolerate ranges from 10-27°C [7]. Dissolve oxygen is also a major component of suitable habitat. Reference [6] reported little to no survival at 1 mg/l and moderate to high survival at 3 and 5+ mg/l, respectively. These environmental conditions must be available to juvenile striped bass to increase survivorship probabilities.

The production, recovery and subsequent maintenance of fishes may in large part depend on the quality and quantity of habitat, especially for young fishes. Habitat degradation, alteration and destruction of habitat is ongoing and there is a lack of sufficient information to identify the most important habitat or nursery areas to conserve and restore. Essential fish habitat (EFH) can be defined as those waters and substrates necessary to fish for spawning and growth to maturity. We examined the growth rate potential of juvenile striped bass *Morone saxatilis* in Albemarle Sound, North Carolina, to identify essential fish habitat (EFH) for striped bass during the summer and early-fall months.

Advances in ecology have shown the relationship of spatial patterns of biotic and abiotic components of the environment and their importance [8]; [9] [10]). Geographic information systems (GIS) allows for the presentation and analysis of distributional patterns and spatial modeling with a spatially explicit data base [11]. In our approach, GIS provided the necessary platform for mapping spatial data and for conducting spatially explicit modeling. Growth rate potential integrates a physiological-based model (bioenergetics) of fish growth with the physical environment. In our analysis we used the growth rate potential as a bioenergetics measure of habitat quality, thus predicting the growth of a fish in this environment.

We integrated the growth rate potential model with Global Information Systems (GIS) to spatially map the growth gate potential of individual juvenile striped bass in the Albemarle Sound.

Methods

Water quality data (temperature, dissolved oxygen, and salinity) were obtained from North Carolina Department of Marine Fisheries (NCDMF) juvenile seine survey from 2002-2004. Routine monitoring of juvenile fishes in Albemarle Sound is conducted annually by NCDMF in shallow areas at 30 fixed stations from July through October (Fig 1).

Fig 1. Juvenile seine survey stations of the North Carolina Department of Marine Fisheries (NCDMF) in Albemarle Sound

Advances in ecology have shown the relationship of spatial patterns of biotic and abiotic components of the environment and their importance (Risser et al. 1984; Turner 1989; Turner and Gardner 1991). Geographic information systems (GIS) allows for the presentation and analysis of distributional patterns and spatial modeling with a spatially explicit data base (Haslett 1990). In our approach, GIS provided the necessary platform for mapping spatial data and for conducting spatially explicit modeling.

The juvenile striped bass model used bioenergetics parameters derived and listed for this species by Hartman 1993. We started the modeling period on June first (day 152) using a striped bass weighing 5g. We assumed that juvenile striped bass would consume 100 percent invertebrates and set the prey energy density as 950 cal/g. The "Wisconsin" bioenergetics model (Kitchell et al. 1977; Hewett and Johnson 1992) was adapted for use with spatial data in a geographic information system (Pazner et al. 1989). An energy budget equation was used to calculate growth (Winberg 1956): growth = consumption - (egestion+ excretion + respiration+ specific dynamic action). We modeled growth rates at 10-day intervals from July through October for the 30 sample sites used by NCDMF and the input water quality data from each of the site was also used. We assumed that juvenile fish would feed at their maximum rate (C_{max}) and set the p-value at 1.

We used geostatistical methods to extend the spatially explicit bioenergetics model into a dynamic environment. Ordinary kriging was used to interpolate the data into two-dimensional transects. Kriging tends to produce smooth interpolation results and is well suited to continuous variables.

Results

The mean water temperatures in the Albemarle Sound from Mat through October ranged from 26.4 to 19.7^{o}C (Fig 2). For most of the period, the mean temperature was within the preferred temperature range and during October was in the optimal range. The dissolved oxygen concentrations and salinity levels throughout Albemarle Sound were within the tolerance level for juvenile striped bass (Figs 3 and 4). Dissolved oxygen was higher in areas closer to the Atlantic Ocean while the salinity levels followed a very similar trend.

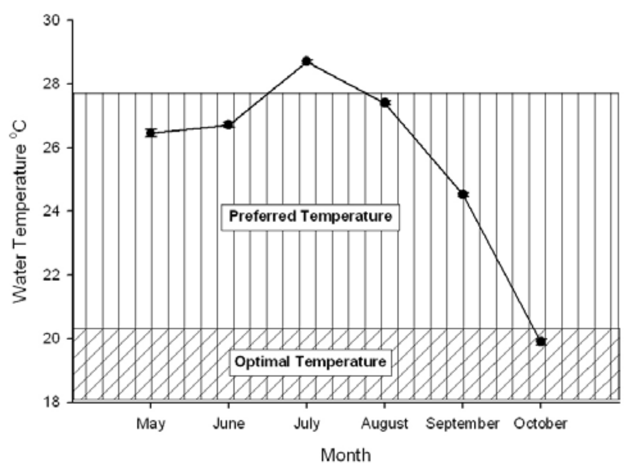

Fig 2. Mean water temperature in Albemarle Sound from May to October. The vertical lines represent the "preferred" temperatures of juvenile striped bass and the diagonal area represents the "optimal" temperatures.

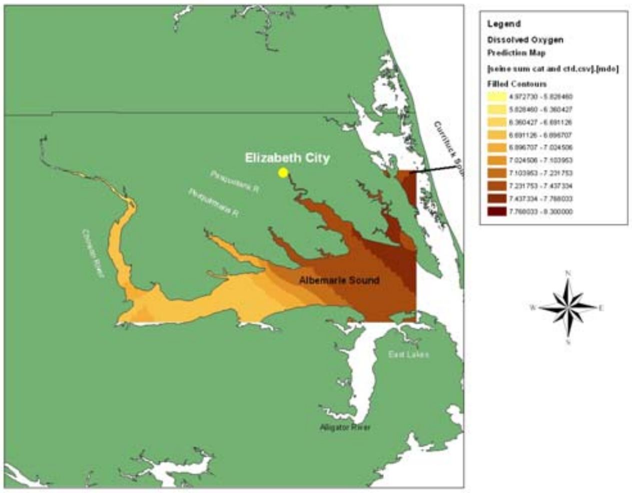

Fig 3. Dissolved oxygen (mg/l) concentrations from 2003-2004 in Albemarle Sound, North Carolina

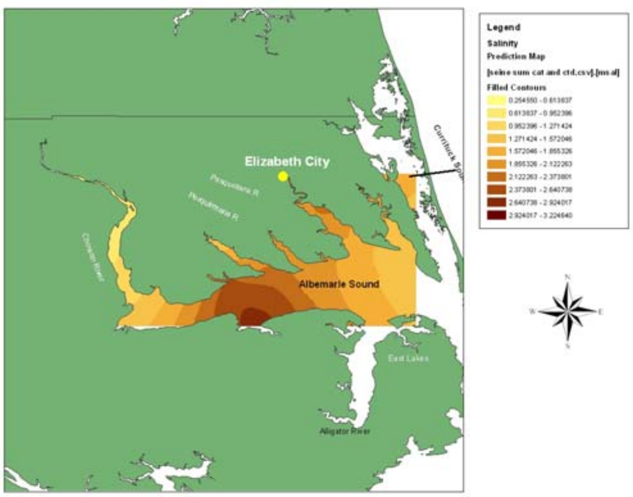

Fig 4. Salinity (ppt) concentrations from 2003-2004 in Albemarle Sound, North Carolina

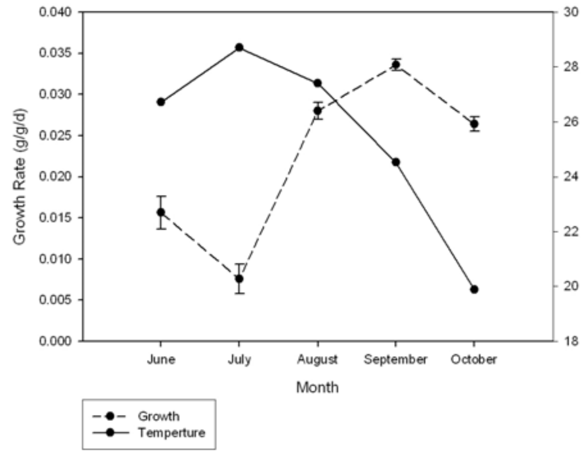

Fig 5. Predicted mean growth rate potential of juvenile striped bass and mean water temperature in Albemarle Sound, North Carolina

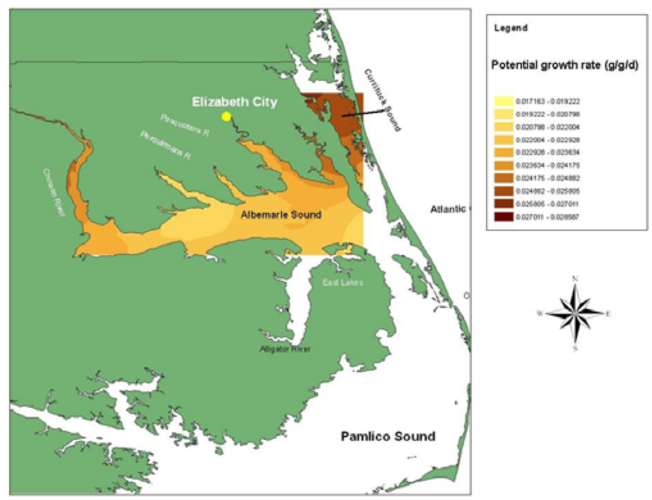

Fig 6. Map of growth rate potential (g/g/d) from June to October of juvenile striped bass in Albemarle Sound, North Carolina

Predicted mean growth rate potential was 0.26 g/d (Fig 5). The highest potential growth rate occurred during September and the lowest during July. As the water temperature cooled during the early fall (October) the potential growth declined as well. The spatial patterns in the predicted growth rates are shown in fig 6. Our models estimated higher growth rates primarily in the northern areas of the Sound. Other areas including the Chowan River, the mouth of the Roanoke River, and the North River had the highest growth rates among the tributaries.

Discussion

Our modeling approach shows how spatially heterogeneous biological factors affect fish growth. The distributions water temperatures are all spatially discontinuous and have nonlinear effects on fish growth rates. This shows how averaging over large areas may not be valid.

The distribution of water temperature may likely influence the distribution of juvenile striped bass in the Albemarle Sound. There are no physical barriers to prevent the movement of fish in Albemarle Sound. Our modeling approach assumed that an individual fish would remain in a general area over the modeled period. Hence was based our discussion on this assumption. However, predators and food concentrations may also influence their distributions as well. The monthly differences in our predicted growth rates were primarily because of water temperature; thus the slow growth during July was because of water temperature.

A large area of Albemarle Sound provided habitat suitable for positive growth for juvenile striped bass. From our analysis, it appears that the Albemarle Sound does provide suitable habitat to support positive growth for juvenile striped bass. Areas such as the Chowan River and the mouth of the Roanoke River supported some of the highest growth rates. Larval striped bass are common in both river systems and settle into these areas as they reach the juvenile stage. We did not attempt to determine the abundance of juveniles in these areas so it is unclear if they are routinely used by juveniles.

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