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Historical Trends in Abundance of American Shad and River Herring in Albemarle Sound, North Carolina

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Abstract.—The Albemarle Sound basin once supported large fisheries for American shad *Alosa sapidissima* and river herring (alewife *Alosa pseudoharengus* and blueback herring *Alosa aestivalis* combined); however, current landings of both stocks are extremely low. We used catch-per-unit-effort (CPUE) data from an 1845–1907 haul-seine fishery to estimate the historical abundance and productivity of these stocks. These historical data are valuable because we can measure (1) the response of the stocks to a period of no fishing during the Civil War and (2) stock productivity before significant changes in water quality and habitat. We found that biomass-based models fitted the historical haul-seine CPUE data reasonably well, but the models appeared to be unreliable for forecasting. For river herring, an analysis that included 1977–1993 pound-net CPUE data appeared to provide better management advice. Estimates of the population growth rate (r) ranged from 0.5 to 0.9 for American shad and 0.3 to 0.5 for river herring. We estimated that maximum sustainable yield was roughly 1–2 million kilograms for American shad, compared to 5–6 million kilograms for river herring. If the stocks can be restored and current productivity is similar to historical levels, both stocks should support much higher landings than are currently being made.

American shad *Alosa sapidissima* and river herring (alewife *Alosa pseudoharengus* and blueback herring *Alosa aestivalis* combined) once supported large fisheries in Albemarle Sound, but landings have declined substantially from historical levels (Figure 1; Chestnut and Davis 1975; S. Winslow, North Carolina Division of Marine Fisheries, personal communication). For example, 1994 landings of river herring (253,000 kg; Winslow, personal communication) were only 5% of the average 1880–1970 landings (5.4 million kilograms; Chestnut and Davis 1975). Landings of American shad have declined almost continuously from a peak of 3.3 million kg in 1897. The current low landings have led to concern about the status of these stocks, but adequate recent data are not available to evaluate the factors responsible for the decline (Winslow 1990).

The objective of this study was to estimate the historical abundance and productivity of these stocks. We analyzed catch-per-unit-effort (CPUE) data from the Greenfield fishery, which was a haul-seine fishery that operated with the same gear and procedures from 1845 to 1907 (University of North Carolina 1980). Our goal was to compare estimates of sustainable yields during the 1800s with current landings to assess the potential production of these stocks.

Fishery Development and Catch Analysis

Development of the Historical Fishery

American shad and river herring were among the first fish to be exploited commercially in North Carolina because their oily flesh allowed them to be salt preserved without ice or refrigeration. The fishery was an established industry by the time of the American Revolution. Between 1771 and 1776, the Edenton, North Carolina, custom house cleared 851 vessels carrying 24,432 barrels of fish destined for the British West Indies, the Azores, the Canary Islands, southern Europe, and the New England colonies (Taylor 1992).

By 1846, there were 15 large haul-seine operations in Albemarle Sound employing about 1,000 people (Taylor 1992). These operations marketed their most valuable product, American shad, in Baltimore, Maryland, whereas river herring were shipped to markets in Richmond, Petersburg, and Norfolk, Virginia (Taylor 1992).

New markets were established after the completion of the Albemarle and Chesapeake Canal from Currituck to Norfolk, Virginia, in 1869. The

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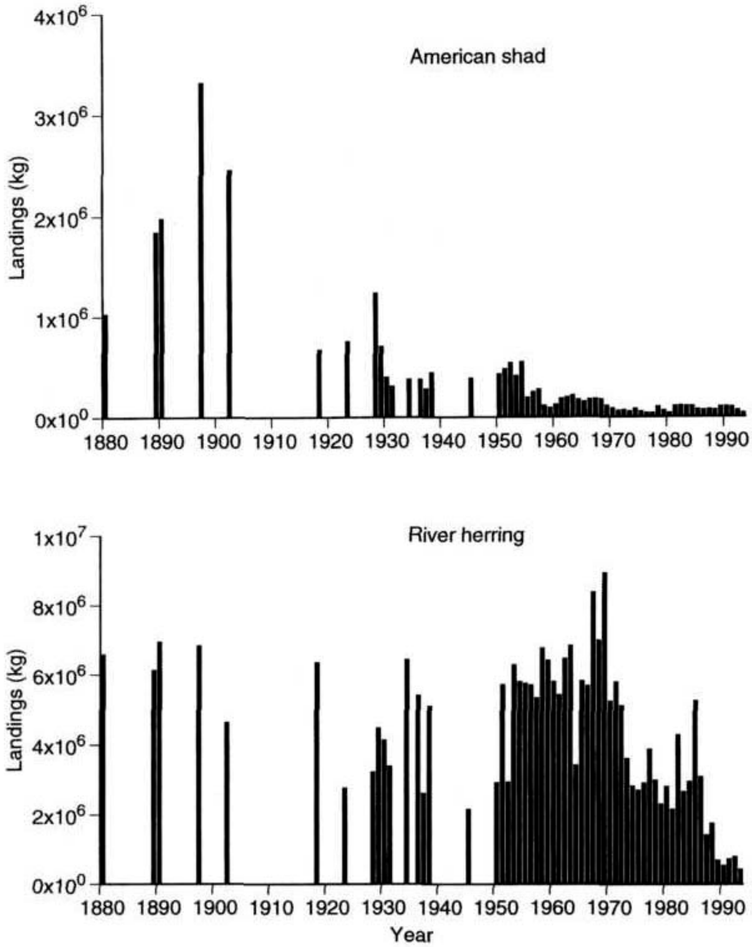

FIGURE 1.—Total reported landings of American shad and river herring for Albemarle Sound from 1880 to 1993.

canal enabled steamboat transportation to Norfolk, Baltimore, Philadelphia, and New York (Taylor 1992). Ice also became available during this period, allowing fresh American shad to be transported to northern markets at premium prices (Boyce 1917). In response to the developing fresh fish market, the fishery was expanded with the introduction of pound nets in 1870 (Earll 1887). The number of pound nets increased from 117 in 1880 to 950 in 1890 (North Carolina Board of Agriculture 1896). By 1896, there were 1,125 pound nets in Albemarle Sound and its tributaries, resulting in an estimated total of 242,210 m of netting from 3.7 to 7.3 m deep (North Carolina Board of Agriculture 1896). Use of pound nets and stake nets proliferated to such an extent that, by 1905, North Carolina found it necessary to pass the Vann Law, which required a channel through the sound for the passage of migrating fish (Taylor 1992). Apparently, before passage of this law, spawning runs were completely blocked by panels of netting.

Haul-seine operations rapidly disappeared after the introduction of pound nets because haul seines were very expensive to operate and could be fished on only a few sites that were free of snags. In comparison, pound nets were relatively inexpensive to operate and could be fished anywhere. Many were near the ocean inlet, whereas the haul seines were primarily in western Albemarle Sound near the mouths of the Roanoke and Chowan rivers (Figure 2; McDonald 1887). Also, the haul seine industry had focused on salt processing of American shad, which became obsolete with the availability of ice and the establishment of daily railroad and steamboat connections to northern mar-

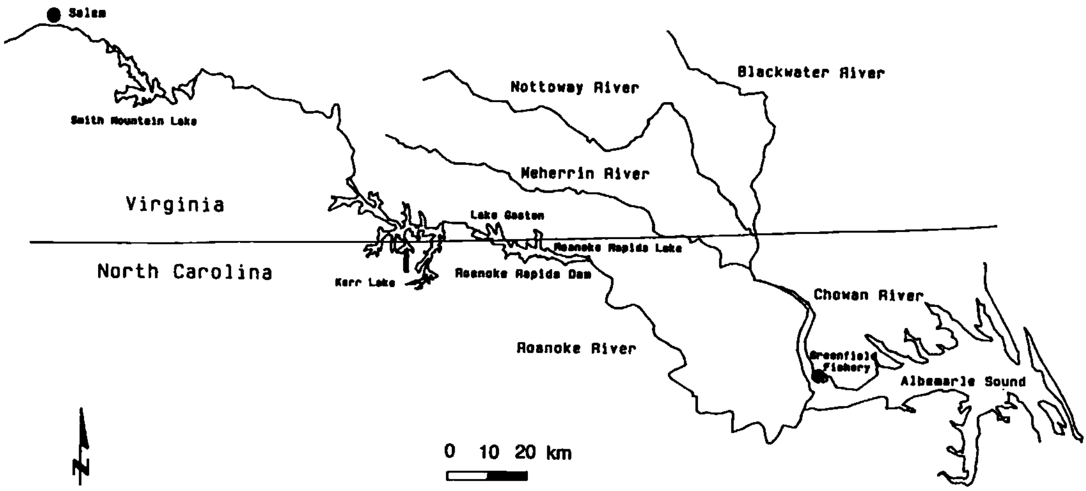

FIGURE 2.—Location of the Greenfield haul-seine fishery, which operated on Albemarle Sound from 1845 to 1907, and historical range for the spawning migration of American shad.

kets. Fifteen haul-seine operations were on Albemarle Sound in 1846 (Taylor 1992), 12 operated in 1880 (Boyce 1917), 4 were functional in 1896 (Stevenson 1899); by 1902 only the Greenfield fishery remained, and it closed by 1907.

Another factor that may have affected landings of American shad was the loss of spawning habitat. McDonald (1884a) reported that migration up the Roanoke River was blocked at Weldon, North Carolina, whereas the natural limit to migration was over 250 km further upstream near Salem, Virginia (Figure 2). The obstruction at Weldon may have been a fish slide, which was described by Yarrow (1874) as a solid, substantial structure that captured all American shad attempting to migrate further upstream. Later, the Roanoke River was dammed by the Roanoke Navigation, Water Power and Manufacturing Company. The specific date is unknown, but the dam would have been constructed after property and water rights were purchased in 1882 (State of North Carolina, Halifax County Superior Court 1907). The dam was on the site that is now occupied by the Roanoke Rapids Dam (Figure 2) and averaged 3.6 m high, creating an 18-ha reservoir (U.S. Army Corps of Engineers 1943). McDonald (1884b) believed that loss in American shad spawning habitat would result in a corresponding reduction in productive capacity. Any loss to the fishery attributable to a loss of spawning habitat would not have been evident in the fishery for 3–9 years, because that is the number of years it takes for adult American shad to return from the ocean to spawn (Winslow 1990). Direct effects of the fish-slide harvest at Weldon are unknown, but Yarrow (1874) suggested that the harvest was so substantial that American shad would disappear from those waters within a few years if that method of fishing was continued.

TABLE 1.—Number of American shad fry stocked in Albemarle Sound and its tributaries from 1877 to 1881 (North Carolina Department of Agriculture 1881). No records are available for 1882–1884, the final 3 years of the stocking program (Winslow 1990).

	Number of American shad fry stocked in:				
Location	1877	1878	1879	1880	1881
Roanoke River		389,000	350,000	150,000	
Meherrin River		150,000	230,000		
Nottoway River		111,000	275,000		
Blackwater River			220,000	550,000	675,000
Chowan River		200,000			
Salmon Creek		1,508,000	210,000	1,075,000	1,860,000
Albemarle Sound	600,000	185,000	110,000	875,000	1,570,000
All	600,000	2,543,000	1,395,000	2,650,000	4,105,000

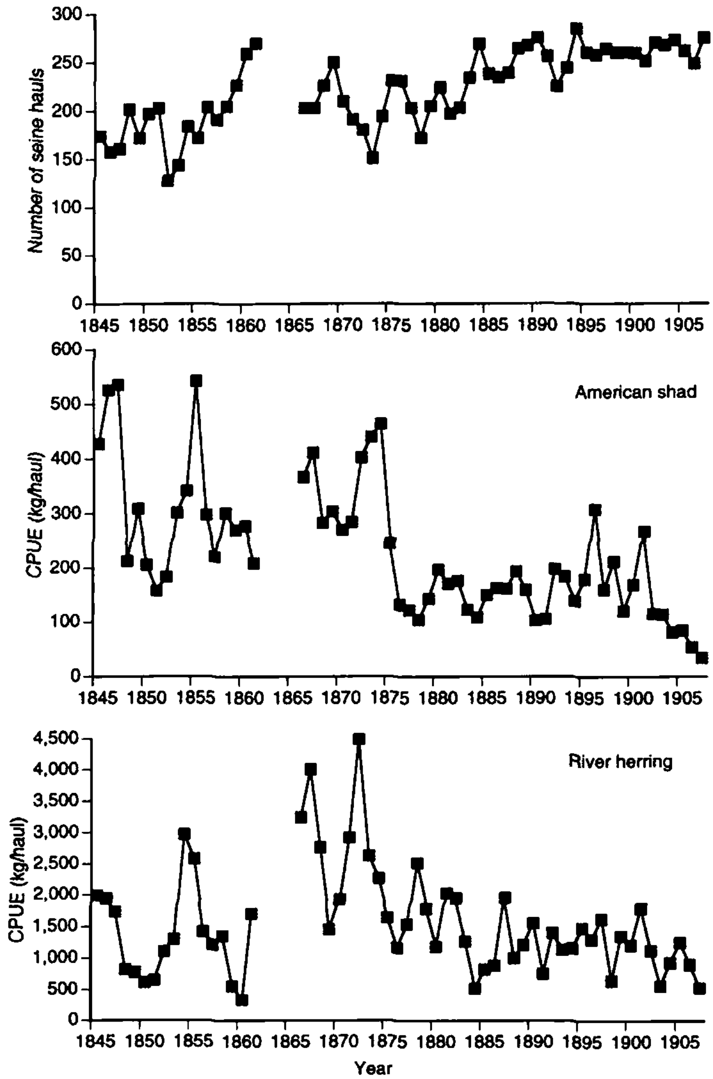

FIGURE 3.—Haul-seine effort and CPUE for American shad and river herring in the Greenfield fishery, 1845–1907.

Concern about the effect of fishing on American shad was first expressed in the mid-1800s (Taylor 1951). One approach for addressing that concern was a program for stocking American shad fry into Albemarle Sound (Winslow 1990). The stocking program was implemented from 1877 to 1884 by the state of North Carolina and the U.S. Fish Commission. Numbers of fry stocked in Albemarle Sound, the Roanoke River, or one of its tributaries ranged from 600,000 in 1877 to 4,105,000 in 1881 (North Carolina Department of Agriculture 1881; Table 1). Although it is not possible to separate the effects of stocking from the effects of the expanded pound-net fishery, stocking may have contributed to the increase in landings in the late 1800s (Winslow 1990).

Description of the Greenfield Haul Seine Operation

The Greenfield fishery was 22.5 km west of Edenton along the north shore of Albemarle Sound (Figure 2; Stevenson 1899; University of North Carolina 1980). It was owned by Edward Wood, who also owned and operated 2,025 ha of farmland, served as president of the Albemarle Sound Navigation Company that owned steamboats and schooners, and invested in the Chesapeake Canal Company and the Seaboard and Roanoke Railroad

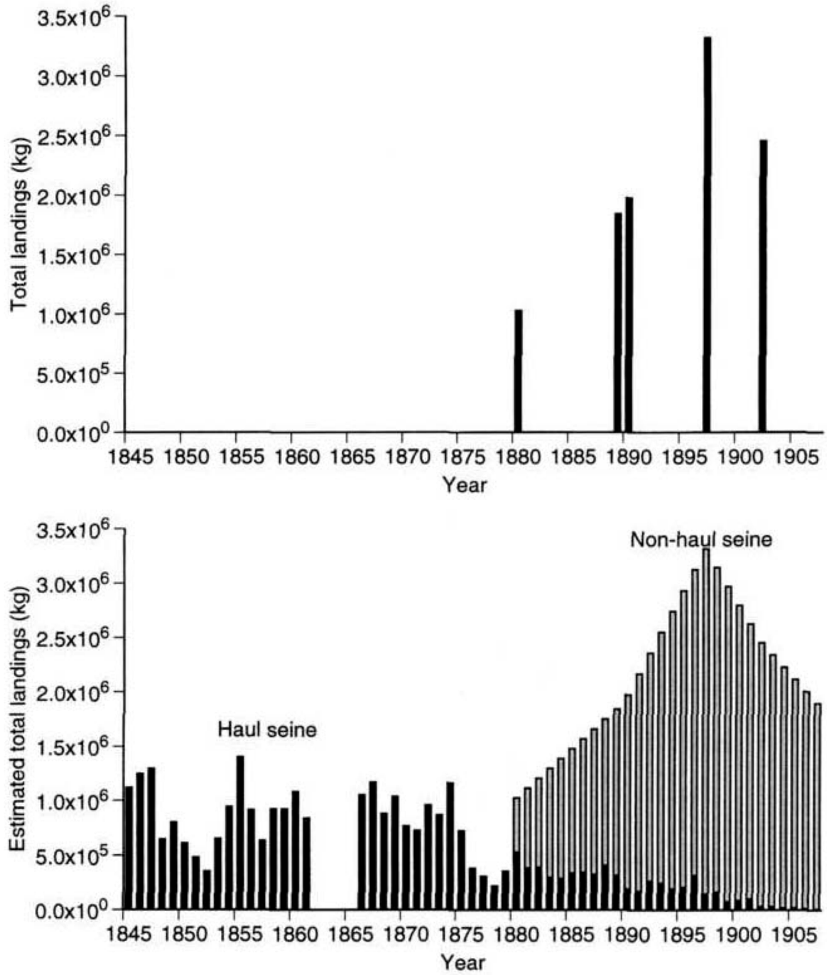

FIGURE 4.—Total reported landings (upper panel) and estimated landings (lower panel) of American shad in Albemarle Sound, 1845–1907.

Company. After Wood's death in 1872, the Greenfield fishery was operated by his son Frank, a prominent businessman who maintained interests in farming, banking, and manufacturing. Thus, the Greenfield fishery records presented in this paper are those of a large, integrated industry that was well maintained from 1845 to 1907. Also, the Greenfield records were made before income tax was instituted, so they would not reflect any effort to avoid taxation.

Microfilm copies of the original fisheries ledgers, made available by the Southern Historical Collection of the University of North Carolina at Chapel Hill, were examined to determine the number of fishing hauls (Figure 3) and annual catch in number of fish. We calculated CPUE (kg/haul) by dividing the total annual catch in number by the number of hauls and multiplying by an estimate of mean weight per individual (American shad: Stevenson 1899; river herring: Smith 1907) (Figure 3).

The fish were caught with a 2,285 m × 7.3-m haul seine with 3,290 m of hauling line (University of North Carolina 1980). The seine was laid out by two steam-powered flatboats starting from a fixed location offshore and hauled in by two steam-powered engines on shore. The fishery employed about 80 people to work the seine and process the catch. Seines were operated for 6 days and nights per week during the run, which was generally from April 1 to May 10. Typically, four to six pulls of the haul seine were made each working day. The number of American shad and river herring were

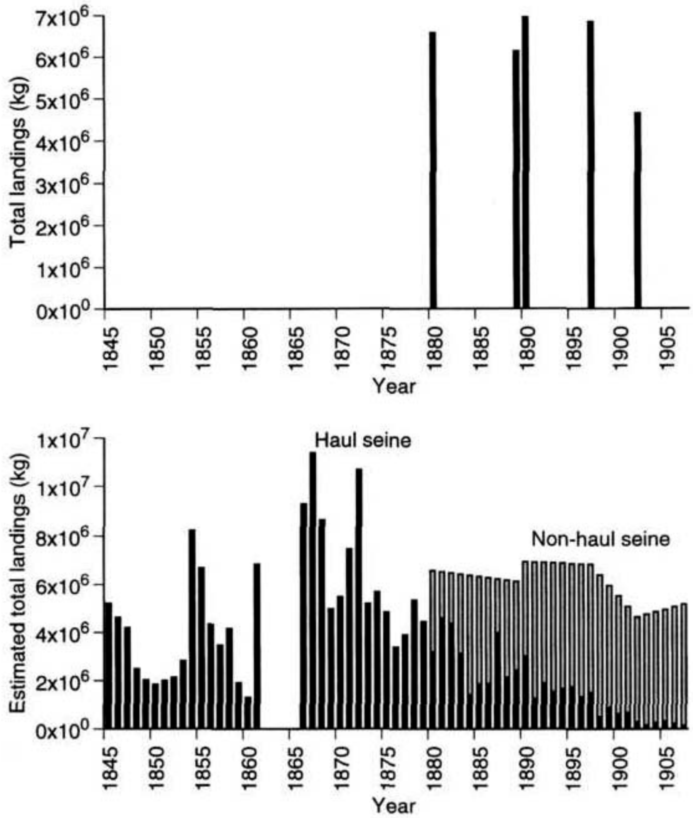

FIGURE 5.—Total reported landings (upper panel) and estimated landings (lower panel) of river herring in Albemarle Sound, 1845–1907.

recorded for each pull. Records of American shad landings did not include hickory shad *Alosa mediocris*, which are similar in appearance, because hickory shad were considered inferior in taste and were not marketed (McDonald 1884b). Alewife and blueback herring records were not kept separately because the two species were (and still are) sold collectively under the name river herring. On the basis of analyses for several Atlantic coast rivers, alewives and blueback herring have very similar estimated growth and natural mortality rates, maximum sizes, ages at first spawning, mean fecundities, and population growth rates (Crecco and Gibson 1990), so a combined analysis may not be a significant source of error.

Analysis of the CPUE Data

We analyzed the historical CPUE data using a biomass-based model (Hilborn and Walters 1992). The standard model assumes logistic population growth (Schaefer 1954) and can be written as a difference equation,

$$B_{t+1} = B_t + rB_t(1 - B_t/K) - C_t, \quad (1)$$

B_t represents biomass at time t, r is the intrinsic rate of population growth, K is unfished equilibrium stock size, and C_t is the catch at time t (Hilborn and Walters 1992).

We modified this standard model to account for the effect of the developing pound net fishery on haul-seine CPUE. In the difference equation for biomass, we included separately the catch from haul seines (C_{th}) and other gears (C_{to}, primarily pound nets, but including staked gill nets):

$$B_{t+1} = B_t + rB_t(1 - B_t/K) - C_{th} - C_{to}. \quad (2)$$

Because most pound nets operated downstream of the Greenfield haul-seine operation, haul-seine CPUE (U_t) at time t was assumed to be proportional to biomass remaining after harvest by other gears was accounted for,

$$U_t = q(B_t - C_{to}); \quad (3)$$

the parameter q was a proportionality factor rep-

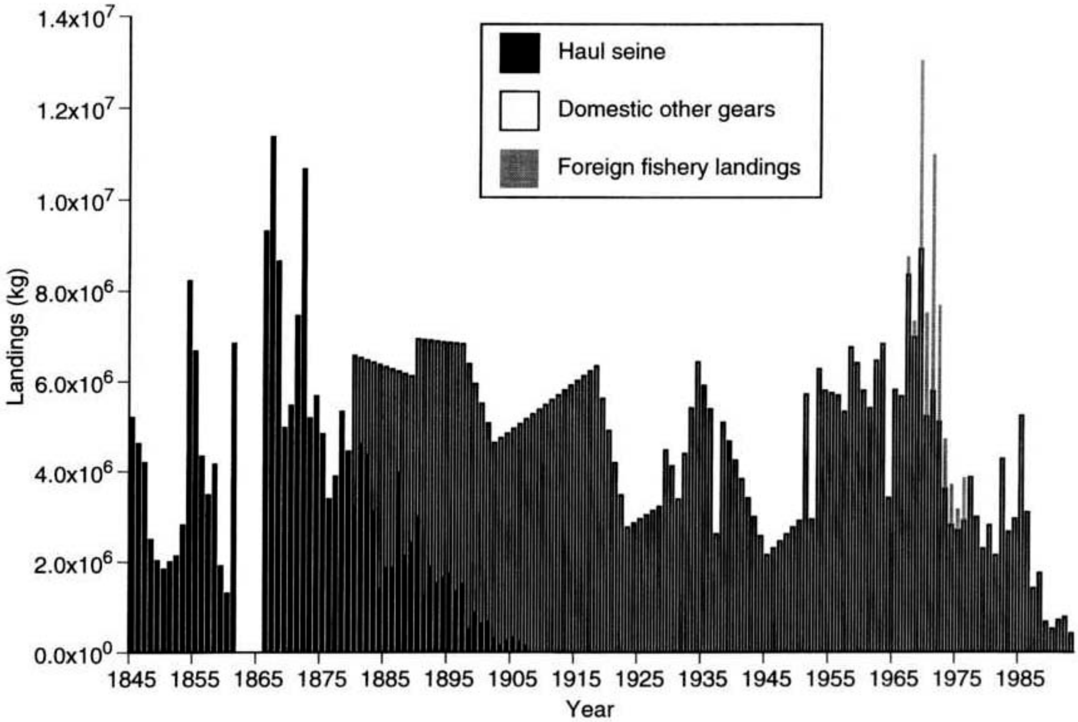

FIGURE 6.—Estimated total Albemarle Sound river herring landings by gear category, 1845–1993.

resenting haul-seine catchability. By solving equation (3) for B_t and substituting in equation (2), we could express the difference equation for biomass in terms of CPUE:

$$\hat{U}_t = \hat{U}_{t-1} + rq\left(\frac{\hat{U}_{t-1}}{q} + C_{t-1,o}\right) \cdot \left(1 - \frac{\hat{U}_{t-1}}{qK} - \frac{C_{t-1,o}}{K}\right) - q(C_{t-1,h} + C_{t,o}). \qquad (4)$$

In addition to the logistic model parameters r, K, and q, we also required an estimate of $\hat{U}_1$, the predicted CPUE level in year one. Approaches for obtaining $\hat{U}_1$ include estimating it as a fourth parameter or setting $\hat{U}_1$ equal to U_1 or an average of the first few Us (Hilborn and Walters 1992). Although estimating an additional parameter is difficult when parameter confounding is high (Hilborn and Walters 1992), we obtained better fits by estimating all four parameters. We used nonlinear least squares to estimate the four model parameters by minimizing

$$\sum (U_t - \hat{U}_t)^2 \qquad (5)$$

(Hilborn and Walters 1992). We also obtained additional least-squares estimates for q, K, and $\hat{U}_1$ by fixing r at a range of values. This approach, sometimes termed profiling, illustrated how well the parameter r was determined by the data and the objective function, and how sensitive the other parameters were to changes in r (Mittertreiner and Schnute 1985; Prager 1994).

The biomass-based models required estimates of annual landings by gear category. Records of total annual landings were available occasionally between 1880 and 1950 and annually thereafter (Figure 1). We used linear interpolation to estimate total annual landings for those years when data were unavailable. We estimated landings from haul seining for 1845–1907 by multiplying Greenfield landings in number by mean weight per individual and by linearly interpolated estimates of the number of haul seines operating. We assumed that non-haul-seine landings were negligible before 1880 (Milner 1880; Earll 1887) and equal to the difference between estimated total landings and haul-seine landings between 1880 and 1907 (Figures 4, 5).

We tested the reliability of the 1845–1907 model for river herring by predicting abundance and

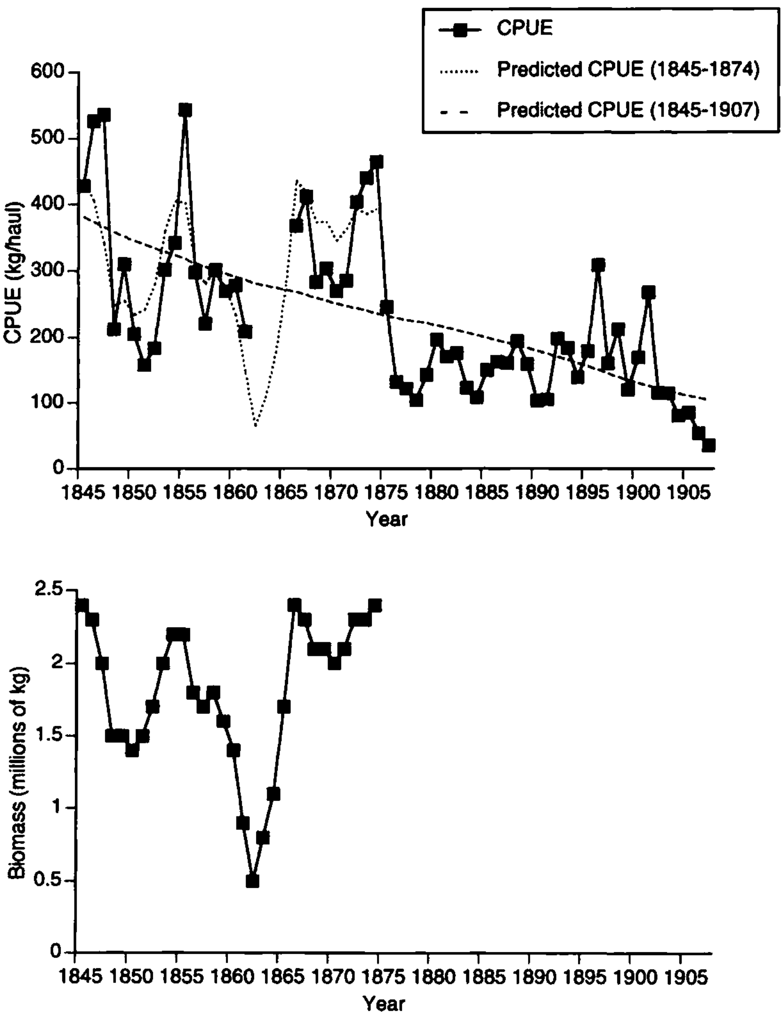

FIGURE 7.—Observed and predicted CPUE for American shad in Albemarle Sound, 1845–1907 (upper panel) and predicted biomass from the 1845–1874 model (lower panel).

CPUE after 1907. Because model predictions were poor (see Results), we also fitted a model to the entire 1845–1993 time series, using 1977–1993 pound-net CPUE data (Winslow, personal communication) as an additional index of relative abundance. A separate pound-net catchability (q) was estimated for 1908–1993, and the sum-of-squares criterion was modified to include both 1845–1907 and 1977–1993. Because offshore foreign fishing has been suggested as the cause of the recent decline in river herring landings, we included estimates of those landings (Loesch et al. 1981; Figure 6). Offshore catches were apportioned between Virginia and North Carolina on the basis of inshore landings.

Maximum sustainable yield (MSY) was estimated with the standard formula for a logistic model, $(Kr)/4$ (Hilborn and Walters 1992). In addition to the estimates of MSY, we have also included our estimates of historical biomass. Those estimates must be viewed with considerable caution, however, because of the tendency for absolute biomass estimates to be less reliable than the estimate of MSY (Prager 1993).

Results

American Shad

American shad CPUE in the Greenfield fishery exhibited a variable but generally decreasing trend from 1845 to 1907 (Figure 3). The decline in CPUE was not gradual as would be expected if

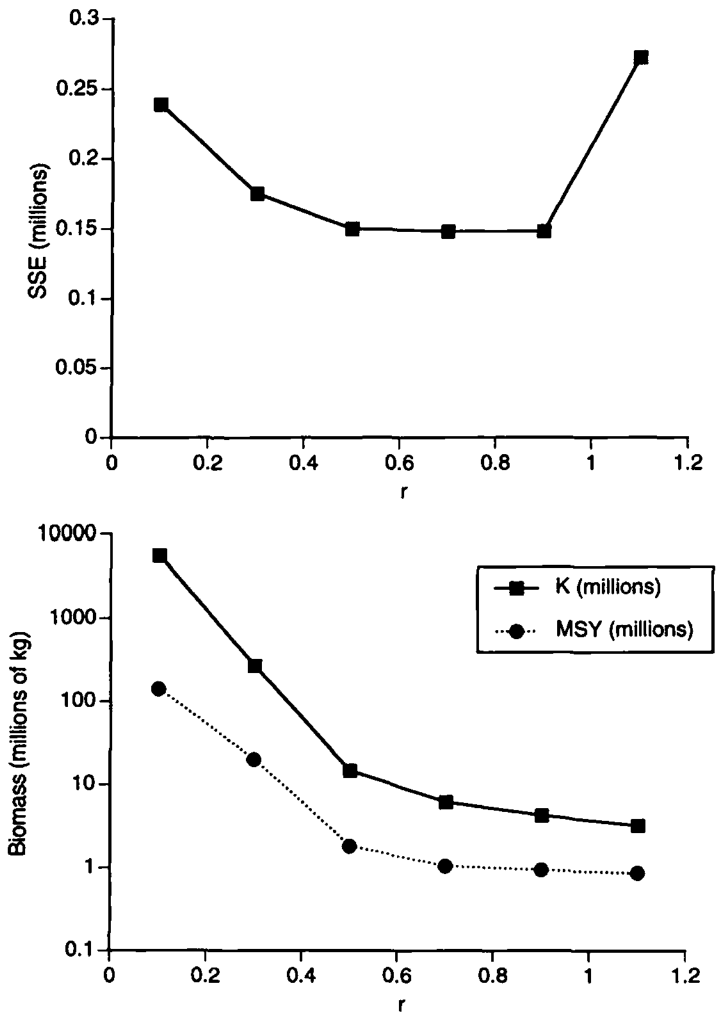

FIGURE 8.—Population growth rate (*r*) versus error sum of squares (SSE; upper panel) and versus estimates of *K* and maximum sustainable yield (MSY; lower panel) for American shad, based on the 1845–1874 model.

resulting from fishing, but occurred primarily during two periods: 1874–1876 and 1901–1907. There appeared to be a moderate increase in CPUE after the Civil War (1861–1865). Haul seining was prohibited during the war because North Carolina authorities feared that the foodstuffs would be acquired by Federal factions (Taylor 1992).

The biomass-based model did not provide an acceptable fit to the entire CPUE time series (Figure 7). A much better fit was obtained for the period between 1845 and 1874 (Figure 7). The model for that reduced period adequately captured the fluctuations in CPUE before the Civil War and predicted a sharp increase in CPUE after the Civil War. For the range of *r* values examined, the error sum of squares was least for $r = 0.7$, but very similar results were obtained for *r* values of 0.5–0.9 (Figure 8). For $r = 0.5$–0.9, estimates of MSY ranged from 0.9 to 1.8 million kilograms (Figure 8).

River Herring

Similar to CPUE for American shad, CPUE for river herring varied considerably from year to year (Figure 3). Some of the fluctuations in CPUE corresponded to those for American shad, which suggested that the cause could be similar fluctuations in year-class strength or changes in flow or water clarity that affected catchability of both (Figure 3). There was a sharp increase in CPUE for river herring after the temporary closure during the Civil War, then a decline to a level similar to that of the pre-war period (Figure 3).

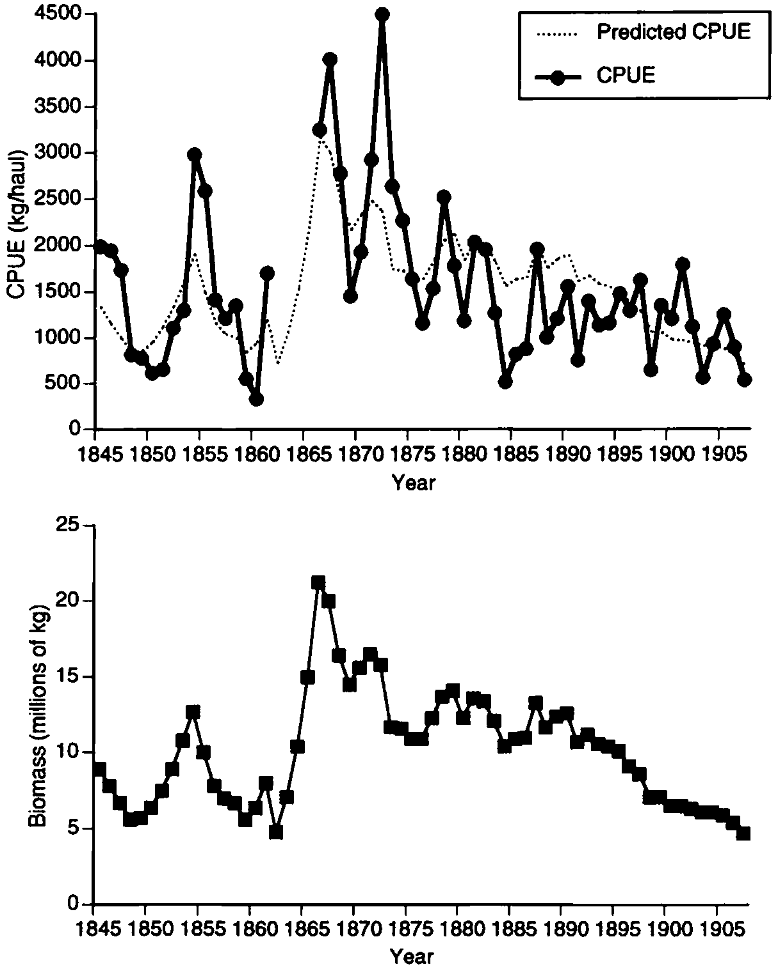

FIGURE 9.—Observed and predicted CPUE (upper panel) and predicted biomass (lower panel) for river herring in Albemarle Sound, 1845–1907.

The biomass-based model provided a good fit to the 1845–1907 CPUE data for river herring (Figure 9). The model predicted a sharp increase in CPUE after the Civil War, then gradually declining CPUE afterwards. The best fit was obtained for r = 0.5, for which the estimate of MSY was 11.3 million kilograms (Figure 10). The model had poor predictive power, however, as CPUE was forecast to decline to 0 by 1911 (Figure 11). Therefore, we refitted the model using 1845–1993 landings data to account for the continued existence of the fishery.

Predicted CPUE for the 1845–1993 model was similar to that for the 1845–1907 model for the period up to 1907 (Figure 11). After 1907, the 1845–1993 model predicted substantial fluctuations in CPUE, including a sharp increase in the late 1940s. No data are available to evaluate the reliability of the 1908–1976 CPUE predictions. The model predicted a sharp decline in CPUE after the high landings in the 1970s, which agreed well with the available CPUE data. Parameter estimates for this model were considerably different from those for the 1845–1907 model. The best fit was achieved at an r of 0.3, for which the estimate of MSY was 5.7 million kilograms (Figure 12).

Discussion

One key stock assessment question is what sort of analysis is warranted, given the available data. For American shad and river herring, we consider the haul seine CPUE data to be of high quality. The annual values represent a large number of hauls with consistent gear and methods. The values

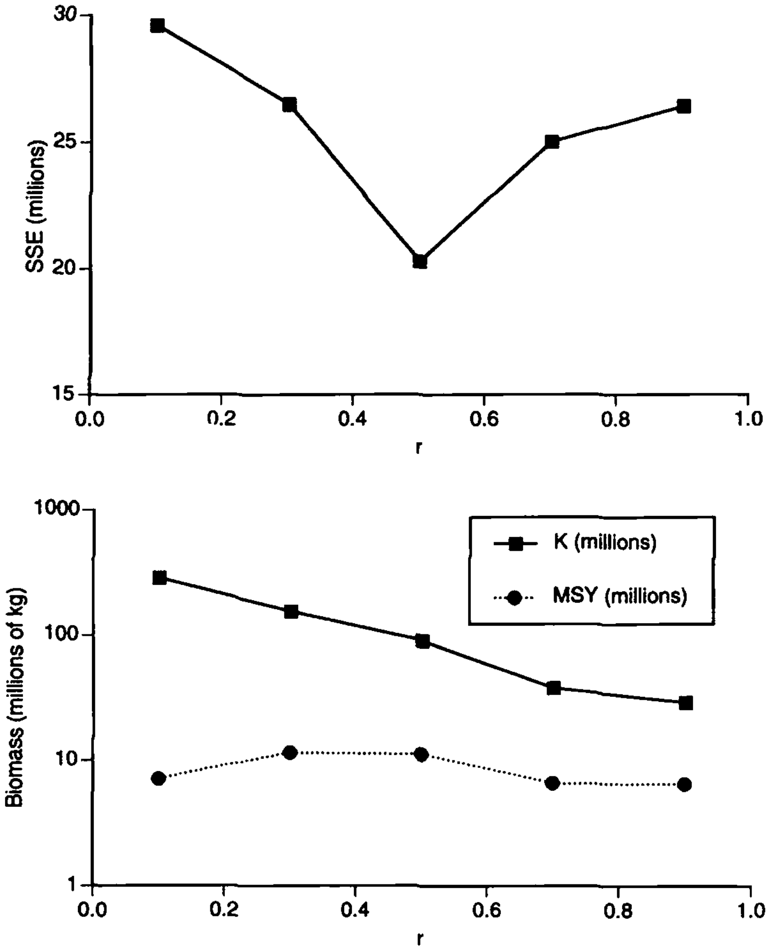

FIGURE 10.—Population growth rate (r) versus error sum of squares (SSE; upper panel) and versus estimates of K and maximum sustainable yield (MSY; lower panel) for river herring, based on 1845–1907 CPUE data.

vary considerably, but the changes from year to year appear to reflect not only sampling error but also a serially correlated process.

Of much poorer quality are the landing records, and we made numerous assumptions and interpolations to generate the annual landing estimates. The effect of these manipulations is unknown, so we have relied on the long history of the fishery to provide some management guidance. For example, the estimate of MSY for river herring, based on the 1845–1993 model, was 5.7 million kilograms. That is similar to the average reported landings from 1880 to 1970 (5.4 million kilograms), which was clearly a sustainable harvest under historical conditions of stock productivity. Thus, the only remaining question is whether habitat has been lost or degraded to such a degree that historical levels of harvest are no longer possible.

For American shad, an adequate fit of our biomass-based model to the CPUE data could not be obtained for the period 1845–1907. We attributed the difficulty in fitting to the sharp decline in haul-seine CPUE observed in 1874–1876. That occurred at about the same time as a reported decline in catch rates of American shad migrating up the Roanoke River to spawn. John Emry, the owner of the fish slide at Weldon, reported a decrease in American shad abundance "of at least one-half in the last ten years" (Yarrow 1874). Similar declines in CPUE were reported at that time for several southern river systems, including the Savannah, Congaree, Wateree, and Cape Fear rivers (Yarrow 1874). Yarrow (1874) suggested that intensive fishing throughout the south was responsible for the declines in abundance. He further suggested that continued use of the fish slide at Weldon

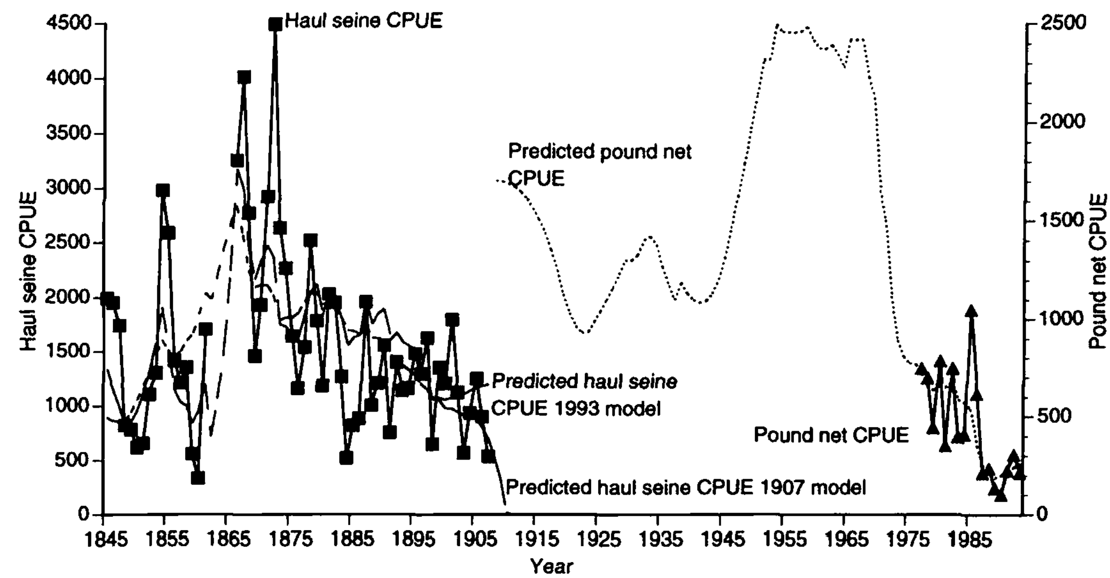

FIGURE 11.—Observed and predicted river herring CPUE for the haul-seine and pound-net fisheries.

would result in overharvest of American shad within a few years; unfortunately, landing data that could be included in our model were not available.

Also, we have no recent CPUE data for American shad because they are taken primarily by gillnetting, rather than by the pound nets used to obtain recent river herring CPUE. The model fitted the historical American shad CPUE data reasonably well for the 30-year period 1845–1874, but the reliability of that model is difficult to judge. The MSY estimates thought to be most feasible (0.9–1.8 million kilograms) were greater than the estimated landings during the haul-seine fishery but less than peak landings from the pound-net fishery (which were clearly not sustainable). Better estimates of sustainable harvest may be possible if an index of current abundance can be developed for this species.

Experience with fitting biomass-based models has shown that the best fits are obtained when there is considerable contrast in stock size and fishing effort (Hilborn and Walters 1992). In that regard, one advantage of our historical data set is the period without fishing during the Civil War. We believe that the temporary closure was important in establishing how resilient the stocks were to fishing. For river herring, we also believe that the long series of landings is valuable because it includes an extended period of relatively constant landings and a recent rapid decline in landings.

Prager et al. (1994) proposed two quantitative measures of the contrast in stock size and fishing effort within a data series. The first is a nearness index ($\hat{N}$), which ranges from 0 (least reliable) to 1 (most reliable) and indicates how closely a modeled stock has approached the biomass level producing MSY (B_{MSY}). It is defined as

$$\hat{N} = 1 - \frac{|\hat{B}_{MSY} - \hat{B}^*|}{\hat{B}_{MSY}}; \qquad (6)$$

B^* is the smaller of K or the estimated stock biomass closest to B_{MSY}. If biomass is estimated to have crossed B_{MSY}, the index is defined to equal 1. The second measure is a coverage index ($\hat{C}$), which ranges from 0 (least reliable) to 2 (most reliable) and indicates how widely stock biomass has varied between 0 and K. The coverage index is defined as

$$\hat{C} = \frac{\hat{B}^{+} - \hat{B}^{-}}{\hat{B}_{MSY}}; \qquad (7)$$

B^{+} is the smaller of K or the largest estimated stock biomass, and B^{-} is the smallest estimated value. Our estimated nearness index was 1.0 for river herring, compared to 0.7 for American shad. Estimated coverage indices were 1.6 for river herring and 0.6 for American shad. These values suggest that the river herring results are likely to be more reliable than those for American shad. Of course, these indices are only one indication of reliability; for example, they do not take into account the gaps in the landings data used to generate our biomass estimates.

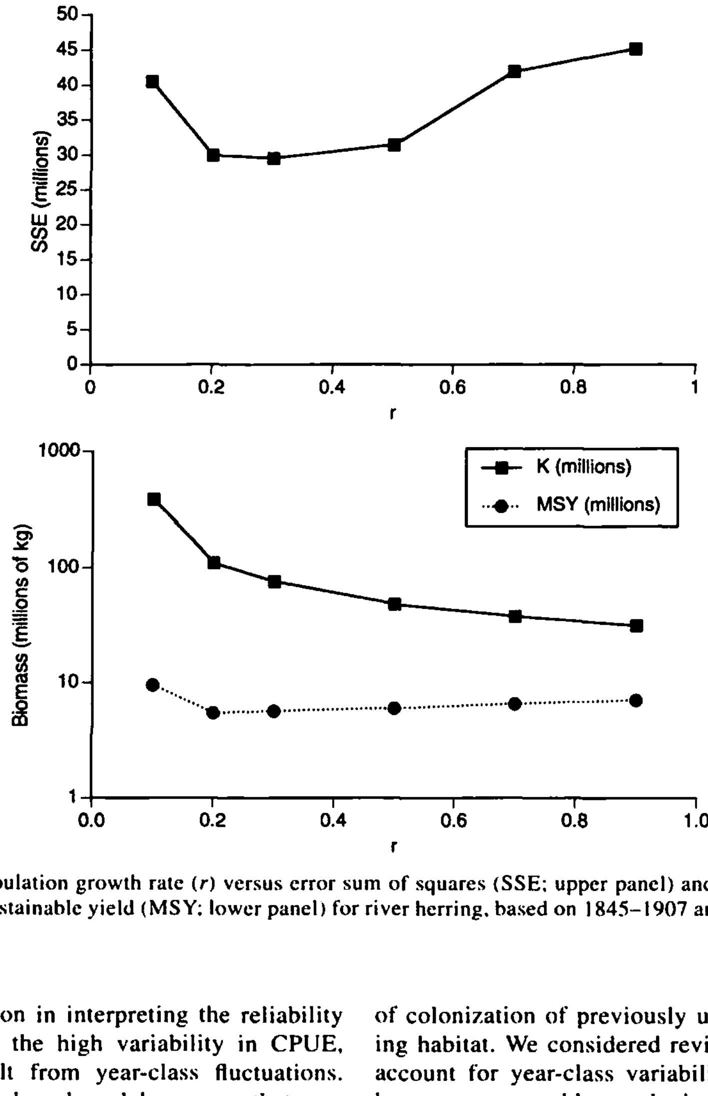

FIGURE 12.—Population growth rate (r) versus error sum of squares (SSE; upper panel) and versus estimates of K and maximum sustainable yield (MSY; lower panel) for river herring, based on 1845–1907 and 1977–1993 CPUE data.

Another question in interpreting the reliability of our results is the high variability in CPUE, which may result from year-class fluctuations. Standard biomass-based models assume that systematic changes in CPUE result from the population's response to fishing. For that reason, our model may be misinterpreting year-class variation as an indicator of high population growth. That type of error seems more likely for American shad ($\hat{r}$ = 0.5–0.9) than for river herring ($\hat{r}$ = 0.3). We had expected a lower estimated r for American shad than for river herring because of the shorter average life span for river herring in Albemarle Sound (Winslow et al. 1983). Our best estimate of r for river herring was similar to estimates for New England and New Brunswick stocks (range, 0.303–0.540 for alewives; 0.437–0.550 for blueback herring: Crecco and Gibson 1990). The Crecco and Gibson (1990) estimates were based on observed increases in population size in the first 8–10 years of colonization of previously unavailable spawning habitat. We considered revising our model to account for year-class variability (Prager 1993), but we were unable to obtain auxiliary data on flow or temperature from the 1800s that might have been related to fluctuations in year-class strength.

We hope that the results of this study will provide an impetus for restoration of the Albemarle Sound stocks of American shad and river herring. These populations supported longstanding traditional fisheries that were once of considerable economic importance to the region. The populations are estimated to have relatively rapid growth and were shown to rebound quickly in response to a period without fishing. Restoration programs for American shad and river herring have been initiated in Maine, New Hampshire, Rhode Island, Massachusetts, Pennsylvania, Delaware, Maryland, Virginia, and South Carolina, and some populations have increased dramatically (Crecco and

Gibson 1990; ASMFC 1993). Measures used to rebuild those populations include stocking (fry and adults), restrictions on harvest (including closures), construction and operation of fish passage facilities at dams (including fish lifts), and habitat improvement (ASMFC 1993; Cooper et al. 1994; Rulifson 1994).

Our results suggest that relatively short periods of very high harvest initiated the declines of the Albemarle Sound stocks of American shad and river herring. For river herring, our results are consistent with those from studies linking the declining fishery to excessive offshore catches by foreign vessels during the 1970s (Street and Davis 1976; Rulifson et al. 1987; Crecco and Gibson 1990). For American shad, harvests were well above our estimated MSY around 1900, and landings have declined more or less continuously since then. Reports from the late 1800s attributed the disappearance of vast runs of East Coast anadromous fish to intensive fishing and loss of spawning habitat because of dam construction (Worth 1882; McDonald 1887). Smith (1907) suggested that excessive fishing on or near the ocean during that time seriously threatened the fishery by limiting the supply of fish on the spawning grounds.

What remains to be determined is the degree to which current landings affect these stocks. Current harvests are well below historical levels and the estimates of MSY, but the exploitation rates could still be excessive because population sizes are thought to be low. We have no information about current exploitation rates or population size, but our estimated r for river herring (0.3) suggests that the exploitation rate (u) should be low ($u_{MSY} = r/2$: Hilborn and Walters 1992). For American shad, our estimates of r (0.5–0.9) correspond to a recommended exploitation rate of 0.25–0.45. Tagging studies could be done to estimate current rates of exploitation (Crecco and Gibson 1988). Those studies would need to also address ocean harvest of American shad and river herring, which has been increasing and, for American shad, represents a substantial fraction of the total harvest (Harris and Rulifson 1989).

The first step toward restoring these stocks could be to assess the effect of fishing (including ocean fisheries) on survival, and the effects of water quality and loss of spawning habitat (including the Roanoke Rapids Dam for American shad) on reproduction. If overfishing is occurring, our estimates of MSY and the historical landings data suggest that there is much to be gained by restricting harvest over the short term to rebuild the Albemarle Sound stocks. For example, on the basis of current prices, the river herring fishery would increase in value from less than U.S. $100,000 to about $1,000,000 if landings could be restored to the average level reported for 1880–1970. Although water quality has generally improved over the past 20 years (Eades and Cooper 1994), the question of whether that long-term average harvest is sustainable given the current habitat quality remains to be answered.

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