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[Article]

Comparing Historical Catch Rates of American Shad in Multifilament and Monofilament Nets: A Step Toward Setting Restoration Targets for Virginia Stocks

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Abstract.—Recreational and commercial harvest of American shad *Alosa sapidissima* in the Virginia waters of the Chesapeake Bay and its tributaries has been prohibited since 1994. The Atlantic States Marine Fisheries Commission Shad and River Herring Management Plan requires that Virginia develop restoration targets for its shad populations, but estimates of their sizes are not available and there is little information about historic population levels. Thus, establishing restoration targets based on population size is problematic. A current spawning stock monitoring program yields catch rate information that can be compared with historic catch rate information recorded in commercial fishery logbooks from the 1950s and the 1980s. However, multifilament gill nets were used in the 1950s and monofilament nets were used in the 1980s (as well as in the current monitoring program). A Latin square design was employed to test the differences in relative fishing power of the two gear types over 2 years of seasonal sampling on the York River, Virginia. Estimates are that the monofilament nets are roughly twice as efficient as the multifilament nets. Reported catch rates in the 1950s and 1980s are roughly equivalent. However, when adjustments are made for the differences in fishing gear, catch rates for the 1950s are twice as high as those during the 1980s. These results provide valuable information for setting restoration targets for Virginia stocks of American shad.

A complete moratorium on fishing for American shad *Alosa sapidissima* in Virginia's rivers and the lower Chesapeake Bay was imposed by the Virginia Marine Resources Commission in 1994 in response to severe declines in commercial harvest and catch rates. The closure applied to both recreational and commercial fisheries and remains in effect. In addition to the prohibition on fishing, Virginia's plan to restore depleted stocks includes supplementation by annual releases of hatchery-reared larvae in the James and York rivers, construction of fish passage facilities, and removal of dams to restore historic spawning habitat (Olney et al. 2003; Weaver et al. 2003; Hendricks 2003). As part of the Atlantic States Marine Fisheries Commission (ASMFC) Shad and River Herring Management Plan (ASMFC 1999) and interstate agreements of the Chesapeake Bay Program, Virginia is required to develop appropriate targets for restoration of the York, Rappahannock, and James River stocks. The establishment of these targets should provide state fishery managers with measurable benchmarks to relax the fishing moratorium and stop releases of hatchery fish. One possibility is to define these restoration targets in terms of population size. However, there is little information available about historic population levels and no estimates of current population size. Historic data available from Virginia pertain to catch rates, and catch rates form the basis for current spawning stock monitoring (Olney 2004). Thus, it makes sense to define targets in terms of the catch rate metric available. The ASMFC accepted the proposition that restoration targets and current stock status could be expressed in terms of catch rates in the absence of information on absolute population sizes.

Catch-per-unit-effort data have been compiled from commercial logbooks of landings and effort by fishers using staked gill nets at various locations on the James, York, and Rappahannock rivers. These logbooks were voluntarily provided to the Virginia Institute of Marine Science (VIMS) from 1980 to 1992 and provide information on the number of nets fished each day and the daily catch of females in the nets for each year. (The shad fishery was largely a roe fishery; hence the fishers' interest was focused on females.) Additionally, archived VIMS microfilms contain records of daily commercial catch rates of American shad from the

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1950s and 1960s. Some of these logbooks were first compiled and analyzed by Nichols and Massmann (1963) in their study of the American shad fishery in the York River.

In 1997, commercial fishers asked the Virginia Marine Resources Commission to consider opening the shad fisheries. The Commission asked VIMS for advice and in 1998 VIMS began a monitoring program for American shad in the James, York, and Rappahannock rivers. This monitoring program consists of sampling techniques (staked gill nets) and locations that are both consistent and comparable with those that generated the historical logbook data from 1980 to 1992. Indeed, two of the three fishers contracted by VIMS were authors of logbooks in the 1980s. The monitoring program allows the comparison of current relative abundance (as measured by catch rate) with historic levels recorded in the logbooks (for details of the monitoring program, see Olney and Hoenig 2001).

Initial catch rates in the monitoring program were as low as those recorded in the commercial fishery just before the moratorium was imposed. This led the commission to decide the moratorium should remain in place. Questions remained, however, as to what catch rate would be appropriate for reopening the fishery and what level of harvest or effort would be allowed.

Landings data compiled by Nichols and Massmann from 1953 to 1959 averaged around 253,000 kg. Nichols and Massmann also provided information on the effort and catch rates. However, while the logbook data are available from the 1950s, it was not clear whether the fishing gear (mesh size and material) used in the 1950s was the same as that used in the 1980s and during the current monitoring program. Fortunately, the son of one of the 1950s fishers was able to locate the fishing gear utilized by his father (Malvin Green) during that period (Olney and Hoenig 2001). Our inspection of Green's 1950s gear revealed that the older nets were constructed of multifilament nylon with a 12.06-cm stretched mesh in contrast to the 12.40-cm stretched mesh monofilament nets used in the 1980s and in the VIMS monitoring program. Thus, to compare catch rates among periods it is necessary to determine the relative fishing power of the two kinds of nets.

Previous studies have compared catch results from monofilament nylon nets with those from nets made using other materials (e.g., cotton, twined nylon). The terminology can be ambiguous (e.g., twined nylon versus multifilament nylon), and it is often unclear how the tested materials compare with those used historically in the York River (e.g., twine thickness, color, and mesh size may also differ in addition to material). While these studies may not have compared exactly the same mesh materials as those utilized in Virginia waters, there appears to be a general consensus that monofilament nets fish more efficiently than the other net types examined. For example, Pristas and Trent (1977) reported that catches in monofilament nets fished in St. Andrew Bay, Florida, were greater than those in multifilament nets for 8 of the 12 most abundant species caught. Additionally, monofilament nets were reported to incur less net damage, were fished more easily, caught fewer blue crabs *Callinectes sapidus* (perhaps leading to less net damage), tangled less, and were set and retrieved faster than multifilament nets. Test fishing in Swedish lakes showed that monofilament nylon nets caught on average approximately four times as many fish as twined nylon nets (Molin 1953). Catches for all six principal species in a comparison of mono- and multifilament gill nets in Lake Erie were higher in monofilament nets (Henderson and Nepszy 1992). The ratio of catches in mono- and multifilament nets ranged from 1.23:1 for white suckers *Catostomus commersonii* to 2.93:1 for freshwater drums *Aplodinotus grunniens*. Catch comparisons between the two net types showed that monofilament nets were 1.8 times more efficient (but varied seasonally) than multifilament nets for lake whitefish *Coregonus clupeaformis* (Collins 1979).

Since it seemed catch rates were likely to change for American shad after monofilament was introduced, we set out to determine an equivalence factor relating the fishing power or efficiency of the old nets to that of the modern nets. The only way we can see to relate current population status to biological benchmarks is to compare catch rates with historical levels.

Methods

The study design consisted of 2×2 Latin squares (Cochran and Cox 1957) replicated in time. A staked gill net consisting of ten 30-ft panels of multifilament net (12.06-cm stretched mesh) adjacent to 10 equally sized panels of monofilament net (12.40-cm stretched mesh) was fished for each of two consecutive days each week of the season. On the first day, we randomly chose the location (shore side or channel side) to be fished by the old net type. The locations of the two nets were switched the next day by removing the nets and hanging them in reverse order. There were two factors that could affect the catches of female American shad: the net type position (i.e., the north, channel end or the south, shore end of the net) and the day. With the 2×2 Latin square design (Figures 1, 2), each net type was fished on each of 2 d and at each of two positions. The nets were fished during the peak of the spawning run over a 7-week period during spring 2002 and a 5-week period during spring 2003.

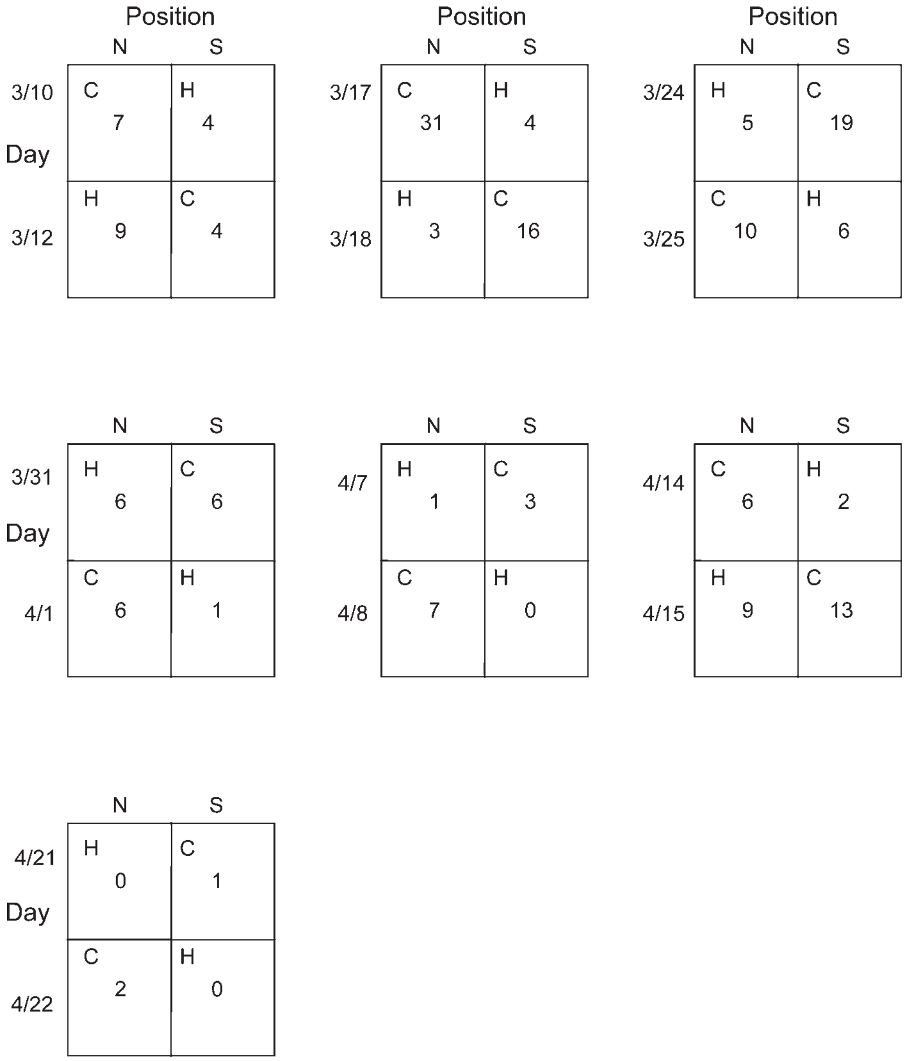

FIGURE 1.—Latin square design for the 2002 study and the number of female American shad captured in each respective treatment on particular days in March and April. The letters N (for north) and S (for south) are used to specify the two positions where the nets can be hung; C = contemporary mesh type (monofilament), H = historical mesh type (multifilament).

A generalized linear main effects model was fit for each year of sampling using the SAS procedure GENMOD with a Poisson error and log link. The null hypothesis was that the mean catch of female American shad per standard set of the new net type (monofilament) is equal to the mean of the old net type (multifilament). We used a two-tailed test because we recognized that factors other than catch rate of female shad may also enter into a fisher's decision about net type. For example, a net that produces significantly less bycatch may be attractive to a fisher because the net can be emptied of fish more quickly. We also fitted a model with interactions. None of the interactions with the type of net were significant, so this model was not considered further.

As an event-in-time model, the Poisson model assumes that events (catches) are independent of one another. A tendency for fish to associate could result in a violation of this assumption, which results in an inflated variance (overdispersion). In the original model, the Pearson chi-square statistic and the deviance, divided by their degrees of freedom, were much larger than one. Thus the data exhibited overdispersion (e.g., McCullagh and Nelder 1983). To correct for overdispersion, the covariance matrix was multiplied by an estimated dispersion parameter that adjusted the

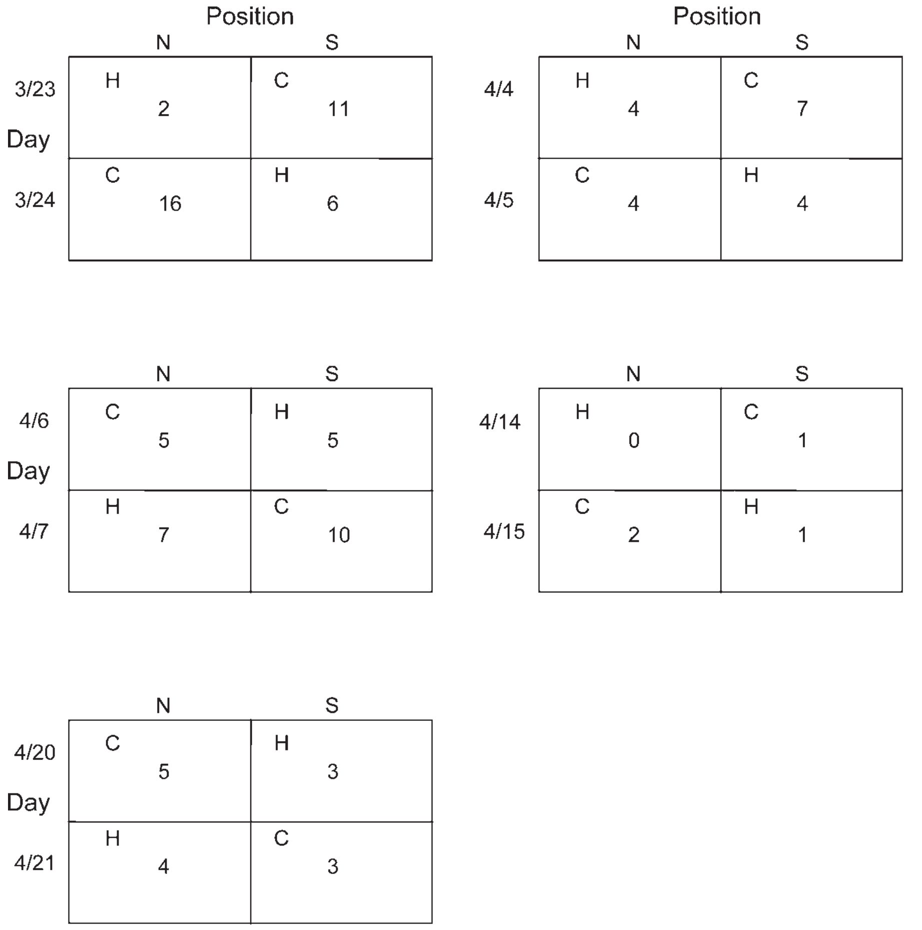

FIGURE 2.—Latin square design for the 2003 study and the number of female American shad captured in each respective treatment. See Figure 1 for more details.

deviance to match the degrees of freedom. All further analyses were conducted utilizing the parameter estimates from the model corrected for overdispersion.

The coefficients (β) estimated by the linear model are logarithmic relative risks. The relative fishing power of the new net was determined by exponentiating the estimated log relative risk of the new type of net relative to the old. Ninety-five percent confidence intervals on the relative fishing power were determined as

$$\exp(\beta \pm 2 \times \mathrm{SE}).$$

Since the sampling protocol was essentially the same for 2002 and 2003, we combined the data from both years of sampling to increase sample size and, in turn, create a more precise estimate of fishing power. This was completed by merging the individual data sets together and coding 2002 as weeks 1–7 and 2003 as weeks 8–12. Thus, the combined yearly samples yielded 12 replicated 2×2 Latin squares.

We compared mean seasonal catch rates in staked gill nets constructed of multifilament (1950s) and monofilament meshes (1980s) in the York River, Virginia. Data from the 1950s were taken from the logbooks of Malvin Green, Aberdeen Creek, Virginia, because we knew the net type and mesh size used by Green and because his logbooks were the most extensive of any of the cooperating fishers. Data from the 1980s were taken from the logbooks of Raymond Kellum, Bena, Virginia, who fished near Green's site. The 1950s data were originally recorded as numbers of female American shad per day because the fishery was primarily a roe fishery. To be comparable with logbook data from the 1980s, numbers were converted to weight using an estimate of average female weight of 1.45 kg

(Nichols and Massmann 1963). Mean catch rates are expressed as female kg/m/d.

Results

Sampling in 2002 produced 215 fish, of which 156 were female (Figure 1). The Poisson main effects model yielded significant differences in female catch between the two net types (Table 1; $P = 0.0004$). The estimated effect of the new type of net relative to the old was 0.8966. The expected ratio of catches (current : historical) is

$$\exp(0.8966) = 2.45.$$

The standard error was 0.25, and the 95% confidence interval on the relative fishing power was (1.47, 4.06).

A total of 126 fish were collected during the 2003 season; 100 were females (Figure 2). Again, the model yielded a significant difference in catch between the two net types (Table 2; $P = 0.0040$). The estimated effect of the new net type (monofilament) relative to the old (multifilament) was 0.5766, which yields an expected ratio of catches (current : historical) equal to 1.78. With a standard error of 0.20, the 95% confidence interval on the relative fishing power was (1.19, 2.66).

As expected, the Poisson main effects model also yielded a significant difference in catch between the two net types for the combined yearly data sets (Table 3; $P < 0.0001$). The expected ratio (current : historical) of catches for the combined data were 2.16 with a 95% confidence interval of (1.52, 3.07).

Discussion

The basic data collection scheme is consistent with two randomized designs: a crossover design and a replicated 2 × 2 Latin square design. Cochran and Cox (1957:127–131) provide a detailed explanation.

The difference between the two designs is that the Latin square imposes more control over the design than the crossover design. With the crossover design, the number of days the new net is fished at the north position is equal to the number of times it is fished in the south position; the replicated Latin squares design imposes the additional control that in each week the nets are fished 2 d and in exactly one of those 2 d the new net is fished in the north position. With the crossover design you could therefore have, by chance, the new net being fished in the north position in the first half of the season and in the second half being fished in the south position; with the replicated Latin square design both nets are fished in the north each week.

The historical catch rates of multifilament nets (when runs of American shad were presumably larger) documented on the microfilm records appeared similar to those recorded in the logbooks from the 1980s. Mean seasonal catch rates (female kg/m/d) varied from 0.125 to 0.309 in the 1950s and from 0.028 to 0.268 in the 1980s. However, the results of our comparison study indicate that this is likely not the case when differences in fishing gear are taken into account. While the confidence limits surrounding the fishing power estimates were large, the results suggest that current fishing gear (monofilament) is roughly twice as

TABLE 1.—Parameter estimates for 2002 data from the Poisson main-effects model (females only).

Parameter	DF	Estimate	SE	χ^2	*P*
Intercept	1	−1.1723	0.8605	1.86	0.1731
Week					
1	1	1.8315	0.8877	4.26	0.0391
2	1	2.6173	0.8526	9.82	0.0017
3	1	2.3026	0.8649	7.09	0.0078
4	1	1.8458	0.8874	4.33	0.0375
5	1	1.2993	0.9303	1.95	0.1625
6	1	2.2883	0.8652	6.99	0.0082
Position	1	0.4861	0.2366	4.22	0.0399
Day	1	0.1428	0.2315	0.38	0.5374
Net	1	0.8966	0.2526	12.59	0.0004

TABLE 2.—Parameter estimates for 2003 data from the Poisson main-effects model (females only).

Parameter	DF	Estimate	SE	χ^2	*P*
Intercept	1	1.1495	0.3053	14.18	0.0002
Week					
1	1	0.8494	0.2968	8.19	0.0042
2	1	0.2385	0.3322	0.52	0.4728
3	1	0.5878	0.3096	3.60	0.0577
4	1	−1.3197	0.5411	5.95	0.0147
Position	1	−0.0528	0.1927	0.07	0.7843
Day	1	−0.2842	0.1944	2.14	0.1438
Net	1	0.5766	0.2004	8.28	0.0040

TABLE 3.—Parameter estimates for 2002–2003 combined data from the Poisson main-effects model (females only).

Parameter	DF	Estimate	SE	χ^2	*P*
Intercept	1	0.7155	0.3794	3.56	0.0593
Week					
1	1	0.2364	0.4513	0.27	0.6004
2	1	1.0761	0.3906	7.59	0.0059
3	1	0.6929	0.4132	2.81	0.0936
4	1	0.2361	0.4513	0.27	0.6009
5	1	−0.3104	0.5187	0.36	0.5495
6	1	0.6931	0.4132	2.81	0.0934
7	1	−1.6097	0.8264	3.79	0.0514
8	1	0.8470	0.4033	4.41	0.0357
9	1	0.2361	0.4513	0.27	0.6009
10	1	0.5878	0.4207	1.95	0.1624
11	1	−1.3220	0.7353	3.23	0.0722
Position	1	0.2832	0.1650	2.95	0.0860
Day	1	−0.0057	0.1636	0.00	0.9724
Net	1	0.7704	0.1756	19.25	<0.0001

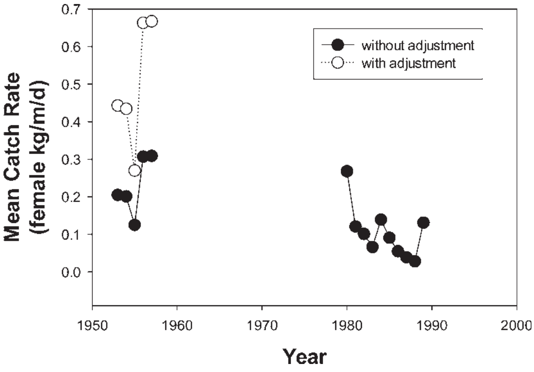

FIGURE 3.—Mean seasonal catch rates obtained by Green in the 1950s with multifilament nets and by Kellum in the 1980s with monofilament nets (see text for more details). The adjusted catch rates were calculated by multiplying the reported catch rates from the 1950s by the relative fishing power of 2.16.

efficient as the historical (multifilament) gear (Figure 3). Such comparisons should provide important guidance in setting restoration targets for Virginia stocks.

Thus, initial monitoring efforts on the York River focused on comparing current catch rates with those recorded in the logbooks from the early 1980s (Olney and Hoenig 2001). It was unknown whether the catch rate indices during the 1980s represented optimal or overfished conditions. The discovery of microfilm records of daily commercial catch rates of American shad in the 1950s offered the opportunity to assess the status of the York River stock 40 years prior to the closure of the fishery. During the 1950s landings of American shad in the York River were high (Table 4) compared with those recorded in the previous decades (1930–1940), 1950s landings totaling 175,000–325,000 kg annually and averaging 253,000 kg over the 7-year period (Nichols and Massmann 1963). In 1980, total York River harvest was also large (362,000 kg) but declined precipitously thereafter (Olney and Hoenig 2001). It is not our place to set restoration targets. But, it could be argued that York River harvests around 250,000 kg annually in the 1950s were sustainable and might be a suitable target provided abundance equaled that of the 1950s. This could be judged on the basis of comparison of current monitoring catch rates with Green's catch rates in the 1950s after suitable adjustment for relative gear efficiency.

TABLE 4.—Historic catches of female American shad from the York River (from Nichols and Massmann 1963).

Year	Catch (kg)
1953	251,000
1954	275,000
1955	245,000
1956	325,000
1957	290,000
1958	175,000
1959	210,000
Average	253,000

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