Managing a Fishery Under Moratorium: Assessment Opportunities for Virginia's Stocks of American Shad

ABSTRACT

Virginia's river fisheries for American shad have been under moratorium since 1994. The moratorium is partial since the three stocks (in the James, York, and Rappahannock rivers) are harvested to an unknown degree in an offshore mixed-stock fishery. Current research efforts have three objectives: (1) to determine current status of the stocks relative to historical levels, (2) to determine appropriate target catch-rate levels for restoration, and (3) to develop new assessment tools so that a future moratorium can be avoided. Current status is being evaluated by monitoring catch rate of commercial fishers who are paid to fish with historical methods in historical locations; the contemporary catch rates are compared to those recorded in logbooks completed voluntarily by fishers prior to the closure. We propose to define restoration targets in terms of historic catch rates recorded in logbooks. This requires determination of relative catching power of historic (multifilament) and modern (monofilament) nets. Two novel assessment methods are being evaluated: index-removal and change-in-ratio methods. These are based on comparing the catch rate and catch composition, respectively, of ripening fish and spent fish near the mouth of the river. During a moratorium, the parameters should be the same for ripening and spent fish, thus providing a critical check on the model assumptions. Maturity information is needed to forecast recruitment but previous estimates of maturity-at-age schedules are biased. Improved estimates can be obtained using a new statistical method which requires that there be a moratorium. It is unfortunate for society when a fish population declines to the point where a moratorium must be declared but a moratorium can provide important opportunities for testing methods and estimating parameters.

The harvest of American shad (*Alosa sapidissima*) in Virginia's rivers and the Virginia portion of Chesapeake Bay has been prohibited since 1994, when a moratorium was declared by the Virginia Marine Resources Commission (VMRC) in response to declining harvest and catch rates. A moratorium was established in Maryland waters in 1980. There remains a mixed-stock fishery in the ocean for which a 40% reduction in effort is mandated by December 2002 with full closure scheduled by December 2004 (ASMFC 1999). Virginia landings in 1999 from the mixed-stock fishery offshore (104,000 kg, VMRC data) are low when compared to historic annual harvests of 175,000–325,000 kg from the York River alone in 1953–1959 (Nichols and Massmann 1963) or the 1980 harvest by staked gill nets in the York River (362,000 kg, unpublished logbook data, Virginia Institute of Marine Science). Thus, at present, the stocks in Virginia (the populations reproducing in Virginia rivers) present an unusual opportunity to study populations under moratorium that are relatively lightly exploited.

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In 1998, the Anadromous Fishes Program of the Virginia Institute of Marine Science (VIMS) was asked to provide advice on the status and management of the shad stocks. Our first priority was to determine the status of the three stocks (James River, York River, and Rappahannock River) relative to the levels occurring in the decade prior to the moratorium. The primary source of information on historical stock levels is logbooks that were voluntarily contributed by approximately 30 fishers who used staked gill nets in the years 1980 to 1992 in the rivers. To provide the information necessary for managing the stocks, we needed to recommend restoration targets and develop new methods for assessing stock status so that future fishery closures could be avoided. Although it was unfortunate for Virginia's citizens that the river shad fisheries had to be closed, the moratorium has provided important opportunities for research on management measures. This research is being conducted on all three Virginia shad stocks but, for brevity, we describe our work on one river, the York River.

Determining current status

The voluntary logbooks provide information on the number of 900-foot nets fished each day and the aggregate daily catch in weight of females in the nets for each year from 1980 through 1992. The locations of the nets are also known, but the catch is not available separately for each net. The daily catch rates can be converted into an index of run size by computing the area under the curve of daily catch rate (weight of females/m of net) versus day of the season.

We were able to enlist the help of one of the fishers who supplied logbooks from the York River (see sidebar). The fisher was contracted to fish for the entire season with the same kind of gill net used historically at one of his traditional sites. Scientists accompanied the fisher each time the net was hauled. Because of budgetary limitations, the net was fished for two consecutive nights and then was tied up out of the water for the remainder of the week. Prior to contracting with the fisher, we evaluated the chances for success of the program by examining the following questions. Were the cooperating fisher's catch rates similar to the catch rates observed over the entire collection of logbooks? How much fishing effort would be necessary to obtain a reliable catch rate? Did fishing activity downstream of the locations of the cooperating fisher's nets reduce his catch rates in the past? (If so, then the absence of current fishing effort would tend to inflate the current index of abundance.)

It appears that the cooperating fisher's historic performance was similar to the overall performance of the other logbook providers (Figure 1). We evaluated sampling strategies by repeatedly sampling the historical record. For example, to evaluate a two-consecutive-days-per-week sampling strategy, we compared the actual area under the curve of catch rate versus day to that obtained by considering only Sunday-Monday data, then compared the actual area with that obtained by considering only Monday-Tuesday data, and so on (seven comparisons). We concluded that curves based on two consecutive days of sampling were similar to those for each year of the historic data and that a two-day sampling scheme was in line with budgetary constraints.

The fishing location of the cooperating fisher was downstream of most of the historic fishing effort (Figure 2). Therefore, it is unlikely that the downstream fishing had much impact on the cooperating fisher's catch rates in the past and, consequently, the absence of other fishers today should not confound analysis. If the absence of other fishers today is inflating catches in current monitoring, the index of abundance will be too high and this should be considered if the current stock status appears to be on the borderline between depressed and recovered. The monitoring data for the first year (1998) suggested a run strength in the York River higher than any year in the historic record (Figure 3). In the next year, the index dropped substantially. It appears that variations in recruitment from year to year may be important in determining run size (see below).

Determining appropriate targets

It is reasonable to ask if the catch rate indices in the early 1980s represent an optimal or an overfished condition. Nichols and Massmann (1963) referred to logbooks voluntarily provided to VIMS in the 1950s, and we have recently found these records preserved on microfiche. The catch rates documented in these older logbooks (when runs of American shad were presumably larger) are grossly similar to those recorded in the logbooks from the 1980s. We obtained fishing gear used by one of these fishers (see sidebar) and determined that the nets used in the 1950s were of a different mesh and construction (multifilament nylon versus monofilament nylon). Comparison trials are required to determine an efficiency factor that can be used to make the data from the 1950s comparable to the later data. There is no guarantee that adjusted catch rates from the past will provide optimal targets but this appears to be the best approach available.

The Atlantic States Marine Fisheries Commission (ASMFC) has mandated that states establish numerical restoration targets before opening a shad fishery under moratorium. Discussions in the ASMFC American shad and river herring technical committee have focused on establishing target population sizes. However, given that the historic data available from Virginia pertains to catch rates, it makes sense to define targets in terms of the catch rate metric available. Catch rates have also been used by Hattala and Kahnle (1998) for Hudson River stock assessment of American shad.

Shad Nets from the 1950s

Finding microfilm records of daily commercial catch rates of American shad in the 1950s offers the opportunity to assess the status of the York River stock 40 years prior to the closure of the fishery in 1994. These data had been voluntarily donated to the Virginia Institute of Marine Science by a staked gill net fisher, Malvin Greene. However, without specific knowledge of the characteristics of Greene's fishing gear, we were unable to use the logbooks to develop a restoration target for shad recovery. By chance, we learned that Jimmy Greene (photo, left), a senior laboratory specialist at VIMS, was none other than Malvin's son. Jimmy kindly rooted through the barn on his family's property looking for the nets he used with his father many years ago. He finally found them in a barrel in the dismembered body of a 1954 Ford pickup. The fishing power of these multifilament nylon nets will be compared to that of modern monofilament nets in a comparative fishing trial to be conducted by commercial fisher Raymond Kellum (photo, right).

Developing new assessment tools

Improvements in assessment methodology are always desired but the need is especially acute when previous methods have not proven adequate and when there are pressures to open a fishery as soon as possible. We found a number of potentially useful techniques that require assumptions that can only be evaluated during a moratorium.

Index-removal Estimation—In the absence of a fishery, what goes up the river to spawn must come back down excepting losses due to natural mortality during the run. In the presence of fishing in the river, some of the fish heading upstream never come back down. This provides a way to estimate run size if an index of abundance of pre-spawning fish heading upstream can be compared to an index of spent fish heading downstream. For example, if the index of ripening fish is 400 (e.g., 400 pre-spawning fish caught over the course of the season at the river mouth) and the index of spent fish is 300, then the 25 % apparent reduction in abundance should be attributable to exploitation. This assumes that natural mortality is negligible during the run and that ripening and spent fish have the same catchability. Furthermore, if 500,000 fish were harvested, then the 500,000 represents one quarter of the run. More formally, the run size, N_f, and the exploitation rate, u_f, of females can be estimated by

$$\hat{N}_f = \frac{R_f c_1}{c_1 - c_2}$$

$$\hat{u}_f = \frac{c_1 - c_2}{c_1}$$

where the ^ symbol represents an estimate, R_f is the number of females removed by the fishery during the spawning run, and c_1 and c_2 are the indices of abundance of pre-spawning and spent females, respectively. This method is reviewed by Hoenig and Pollock (1998) and has been used by Dawe et al. (1993) and Frusher et al. (1998).

To evaluate the suitability of this method for shad, we examined catches from pound nets at the mouth of the York River during 1998 and 1999 while the fishery was closed in the river. If the assumptions of the method were met, we should have seen roughly equal numbers of pre-spawning and spent females in our monitoring. We found that designating maturity stage using gross morphological characteristics of gonads is not definitive since maturing and partially spent females can be confused. Therefore, we used standard histological methods to validate our macroscopic results based on characteristics described by Olney et al. in unpublished data.

The results indicated a problem in the use of the index-removal method. The number of spent females substantially exceeded the number of pre-spawning females (Figure 4). Two possibilities could account for these observations. First, spent fish may have a different catchability than pre-spawning fish. Second, at the mouth of the river there may be a mixture of river stocks present at the beginning of the run (as suggested by Nichols and Massmann 1963, who tagged fish at the mouth of the river and obtained an appreciable number of tag returns from other rivers). To deal with the potential problem of mixed stocks, we are evaluating the use of alternative methods for obtaining samples farther upstream.

Change-in-ratio methods—The gill-net fishery for American shad is selective for gravid ("roe")

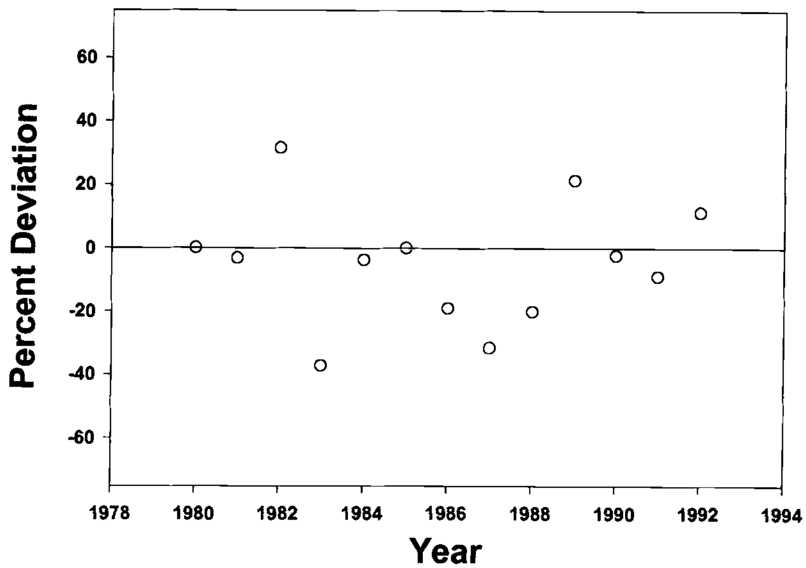

Figure 1. The percent deviation of the annual catch index of Raymond Kellum from that of all other commercial fishers combined who used staked gill nets in the York River, 1980–1992.

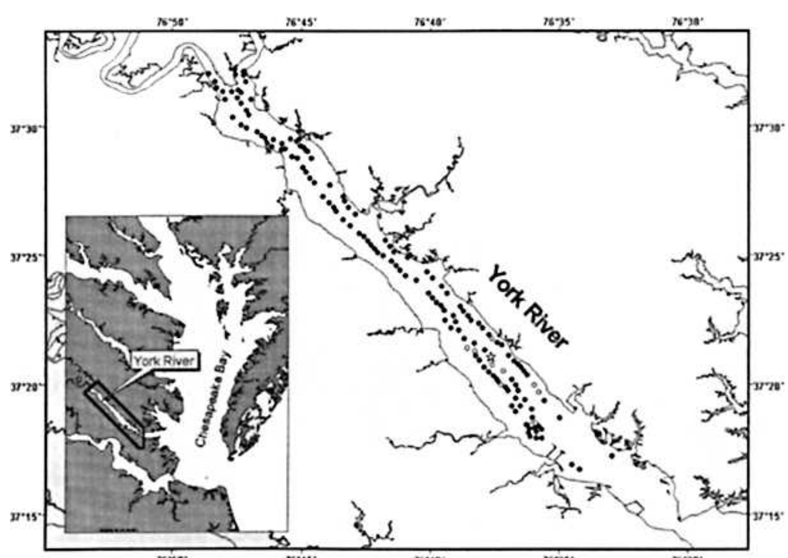

Figure 2. Historic locations of staked gill nets on the York River in 1983, locations of nets used historically by Raymond Kellum (open circles), and current monitoring location (star).

females. This suggests that in the presence of a commercial fishery, the sex ratio (females:males) of spent fish should be lower than that of pre-spawning fish. During the moratorium, we would expect the sex ratio of pre-spawning fish to be close to that of spent fish. The greater the change in the sex ratio from pre-spawning to spent fish, the higher the exploitation rate. This allows one to estimate the exploitation rate of females. If the harvest is also known, then the size of the run can also be estimated. More formally, the run size, N_f, and the exploitation rate, u_f, of females can be estimated by

$$\hat{N}_f = \frac{P_1(R_f - P_2R)}{P_1 - P_2}$$

$$\hat{u}_f = \frac{R_f}{\hat{N}_f}$$

where R_f is the number of females and R is the total number of fish harvested during the run, P_1 and P_2 are the proportion of the ripening and spent fish, respectively, that are female, and the other symbols are as defined previously. The method is reviewed by Pollock and Hoenig (1998), and has been used by Dawe et al. (1993) and Frusher et al. (1998).

We found that the sex ratio of both pre-spawning and spent fish approximated 1:1 in two consecutive years of monitoring pound nets at the mouth of the York River (1998 pre-spawning, 0.53 females:0.47 males; 1998 spent, 0.51:0.49; 1999 pre-spawning, 0.57:0.43; 1999 spent, 0.55:0.45). The change-in-ratio estimator is appropriate even if pre-spawning and spent fish have a different catchability (i.e., when the index-removal fails) because the relative catchability of females and males in the pound nets does not appear to be affected by spawning condition. However, the method would not be appropriate if the pound net catches at the river mouth represented a mixture of river stocks.

Determining maturity at age and forecasting recruitment—The river monitoring program samples the mature fish; an unknown fraction of the population that is immature remains in the ocean. If we could estimate the proportion mature at each age we could forecast the relative recruitment for the next year (and, if an absolute estimate of the run strength is available from, say, the index-removal method, we could forecast absolute recruitment to the next year's run.)

This leads to the question, "How can we estimate the maturity at age schedule when we only observe mature fish?" We developed a method (Maki et al., in press) that makes use of the fact that the scales record the spawning history of each mature fish (Judy 1961; Cating 1953). No fish above the age 7 in our samples are first-time spawners. Hence, we can look at the number of fish age 7 and above to determine the fractions maturing at each age. This is the approach used by Aprahamian and Lester (unpublished data). However, there are very few fish age 7 and above in the York River spawning run. If we look at a younger age, say age 5, we can observe the relative numbers maturing at ages 3, 4, and 5 but we cannot tell about those maturing at ages 6 or 7. The observed proportions p^*_i of five year old fish maturing at age i for i = 3, 4 and 5, are related to the true proportions p_i of five year olds maturing at age i by

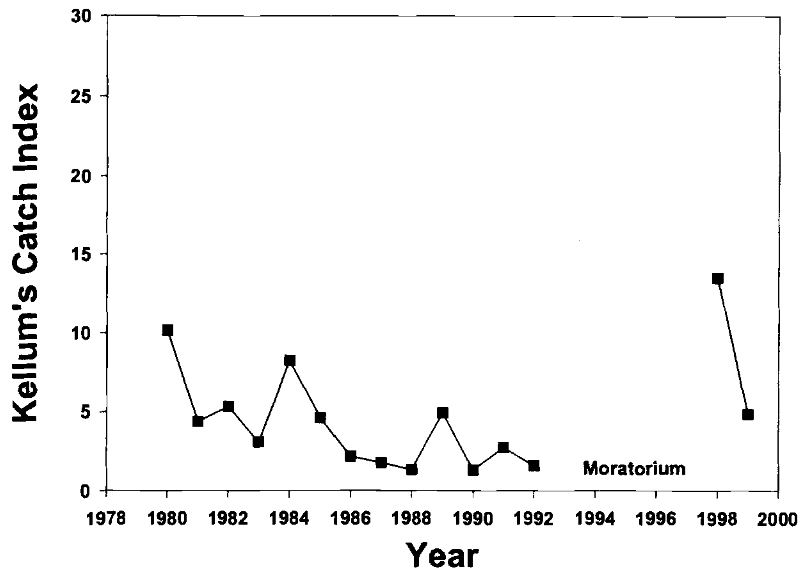

Figure 3. Recent (1998, 1999) and historic values of the catch index of female American shad on the York River.

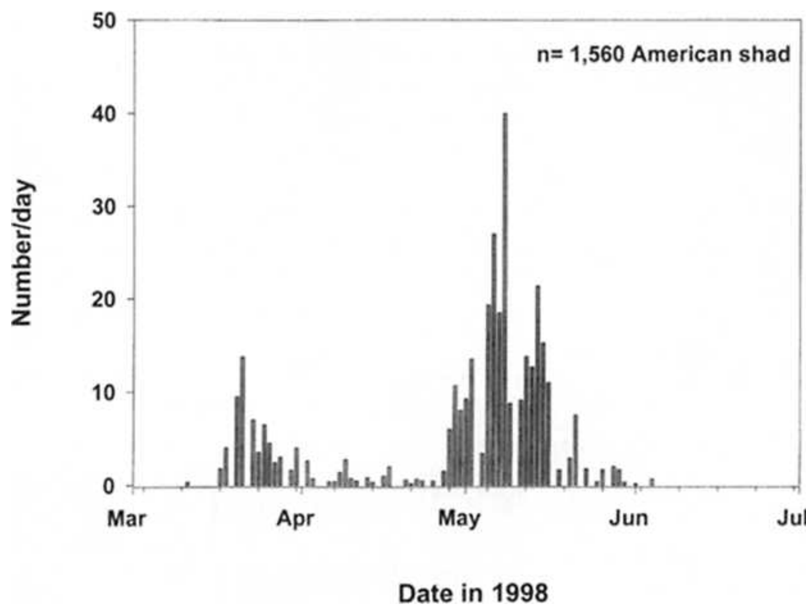

Figure 4. Catch rates of female American shad in the pound nets in 1998. All females captured prior to the middle of April 1998 were ripening while almost all females taken after that date had spawned. Overall, more spent females (downriver migrants) were caught than ripening females (upriver migrants). This could be due to ripening and spent fish having different catchabilities or to the pound nets catching a mixture of river stocks.

$$p_i^* = p_i/(1 - p_6 - p_7) .$$

Thus, given information on the proportion maturing at ages 6 and 7 (from fish captured at age 6, 7, and above), we can use information from fish of age 5 to infer proportions maturing at earlier ages. Our method combines the data from all of the ages to obtain estimates of the proportion maturing at each age. Previous studies failed to account for the unobservable immature fish at sea and thus produced maturity schedules that were biased towards earlier maturity.

The method of Maki et al. (in press) is based on the assumption that immature and mature fish of the same age have the same mortality rate. Because of the moratorium, the fishing effort on mature fish in the rivers is largely absent and the fishing mortality is presumably very low compared to historic levels (there is only a small native American harvest and some harvest for hatchery operations). Mature fish are subject to fishing in the offshore intercept fishery. Thus, the moratorium in the river and bay helps assure that this assumption is largely met by eliminating one source of differential mortality. Another possible source of differential mortality between immature and mature fish is the unknown stress associated with spawning. However, American shad in the York River spawn repeatedly, as do stocks farther north, and therefore do not appear to have high spawning induced mortality. York River shad undergo a relatively short migration to the spawning grounds (Bilkovic et al. in press) that may reduce energetic expenditure and spawning stress. Based on our samples, the percentages of females with at least one prior spawn were 40.2 % in 1998 and 67.3 % in 1999. Sensitivity analyses performed by Maki et al. (in press) demonstrate that the new method for estimating a maturity schedule is sensitive to differential mortality (as is the older, biased method) and this highlights the significance of conducting studies during a moratorium.

Discussion

Although it was unfortunate for society that a moratorium had to be imposed, the ban has been the impetus for developing a suite of new methods designed to answer the three principal questions of fishers and resource managers: At what point should fishery scientists declare the stocks recovered? What are the recovery targets? How will scientists prevent future collapse? The moratorium provided an opportunity for scientists to step back from day to day activities and develop a strategy for framing and answering key questions.

We believe there are several general lessons to be learned. First, a moratorium can provide an opportunity to examine historic data such as fishery-dependent logbook data. We suspect that most assessment programs have copious amounts of information that have not been analyzed or have not been reexamined since the first analysis of the data many years ago.

Second, a moratorium can provide opportunities to try new assessment methods. These may have critical assumptions that can only be checked during a moratorium. Our test of the assumptions of the index-removal method turned out to be critical because we found pound nets at the mouth of the river do not provide representative samples of the York River stock.

Third, a moratorium can provide opportunities to estimate parameters that otherwise could not be estimated, such as the maturity schedule of shad. Another example is the estimation of natural mortality rate. Brownie tagging models (Brownie et al. 1985) can be used to obtain robust estimates of survival rate. During a moratorium, few if any tag returns will be obtained; however, when the fishery is reopened the tag returns allow estimation of the total mortality occurring at the time of tagging, i.e., of natural morality (plus any mortality caused by bycatch).

It appears that a useful distinction can be made between a partial moratorium and a total one. For American shad, the moratorium on harvesting fish in Virginia rivers is technically a partial moratorium because the three river stocks are harvested to a variable degree in the offshore mixed-stock fishery (Brown et al. 1999). The partial moratorium provides opportunities to establish a time-series of relative strength of the runs in the rivers and to evaluate the use of index-removal and change-in-ratio methods. A total moratorium is necessary to get the best estimates of maturity-at-age schedules.

Hearn et al. (1998) described a tagging model that makes use of seasonal closures (i.e., a partial moratorium) to obtain estimates of fishing and natural mortality rates and tag reporting rate. This method is not suitable for American shad but it does serve to illustrate that useful techniques might be developed if attention is turned to learning how to take advantage of various kinds of moratoria. Opportunities provided by closed fisheries are important and should not be squandered.

Finally, our work with American shad highlights the importance of locating historic data and the dangers in using historic data uncritically. Efforts should be made to locate original logbooks and laboratory notebooks, to interview their authors when possible, and to look for methods to confirm the validity of the data (such as tracking down commercial fishers' nets and locating archival material.)

Acknowledgments

We thank commercial fishers Raymond and Tony Kellum, Marc Brown, James Sanders, and Donnie Green for providing the foundation for our monitoring program, Jimmy Greene for historical research, and the staff of the Anadromous Fishes Research program at VIMS for their prodigious efforts. Comments of reviewers improved our manuscript. This research is funded by the Wallop-Breaux Program of the U.S. Fish and Wildlife Service through the Marine Recreational Fishing Advisory Board of the Virginia Marine Resources Commission (Grant Numbers F-116-R-1 and F-116-R-2), and by the Anadromous Fish Conservation Act, Public Law 89-304 (Grant-In-Aid Project AFC-28, Grant Number NA86FA0261 and Project AFC-30, Grant Number NA96FA0229) from the National Marine Fisheries Service. This is VIMS Contribution No. 2357.

References

ASMFC (Atlantic States Marine Fisheries Commission). 1999. Amendment 1 to the Interstate Fishery Management Plan for shad and river herring. Atlantic States Marine Fisheries Commission, Fishery Management Report No. 35, Washington, DC.

Brown, B. L., P. E. Smouse, J. M. Epifanio, and **C. J. Kobak.** 1999. Mitochondrial DNA mixed-stock analysis of American shad: coastal harvests are dynamic and variable. Transactions of the American Fisheries Society 128:977–994.

Bilkovic, D. M., J. E. Olney, and **C. H. Hershner**. In press. Spawning of American shad (*Alosa sapidissima*) and striped bass (*Morone saxatilis*) in the Mattaponi and Pamunkey rivers, Virginia. Fishery Bulletin.

Brownie, C., D. R. Anderson, K. P. Burnham, and **D. S. Robson.** 1985. Statistical inference from band recovery data: a handbook. 2nd ed. U.S. Fish and Wildlife Service Resource Publication 156.

Cating, J. P. 1953. Determining age of Atlantic shad from their scales. U.S. Fishery Bulletin 54:187–199.

Dawe, E. G., J. M. Hoenig, and **X. Xu.** 1993. Change-in-ratio and index-removal methods for population assessment and their application to snow crab (*Chionoecetes opilio*). Canadian Journal of Fisheries and Aquatic Sciences 50:1467–1476.

Frusher, S. D., R. B. Kennedy, and **I. D. Gibson.** 1998. Preliminary estimates of exploitation rates in the Tasmanian rock lobster (*Jasus edwardsii*) fishery using the change-in-ratio and index removal techniques with tag-recapture data. Canadian Special Publication in Fisheries and Aquatic Sciences 125:63–71.

Hattala, K., and **A. Kahnle.** 1998. Stock status and definition of over-fishing rate for American shad of the Hudson River estuary. *In* American shad stock assessment peer review report, Atlantic States Marine Fisheries Commission, Attachment C, Washington, DC.

Hearn, W. S., K. H. Pollock, and **E. N. Brooks.** 1998. Pre- and post-season tagging models: estimation of reporting rate and fishing and natural mortality rates. Canadian Journal of Fisheries and Aquatic Sciences 55:199–205.

Hoenig, J. M., and **K. H. Pollock.** 1998. Index-removal methods. Pages 342–346 *in* S. Kotz, C. B. Read, and D. L. Banks, eds. Encyclopedia of statistical sciences update volume 2. John Wiley and Sons, Inc., New York.

Judy, M. H. 1961. Validity of age determination from scales of marked American shad. U.S. Fishery Bulletin 61:161–170.

Maki, K., J. M. Hoenig, and **J. E. Olney** in press. Estimating proportion mature at age when immature fish are unavailable for study, with application to American shad (*Alosa sapidissima*) in the York River, Virginia. North American Journal of Fisheries Management.

Nichols, P. R., and **W. H. Massmann.** 1963. Abundance, age, and fecundity of shad, York River, Vitginia., 1953–59. U.S. Fishery Bulletin 63:179–187.

Pollock, K. H., and **J. M. Hoenig.** 1998. Change-in-ratio estimators. Pages 109–112 *in* S. Kotz, C. B. Read and D. L. Banks, eds. Encyclopedia of statistical sciences update volume 2. John Wiley and Sons, Inc., New York.