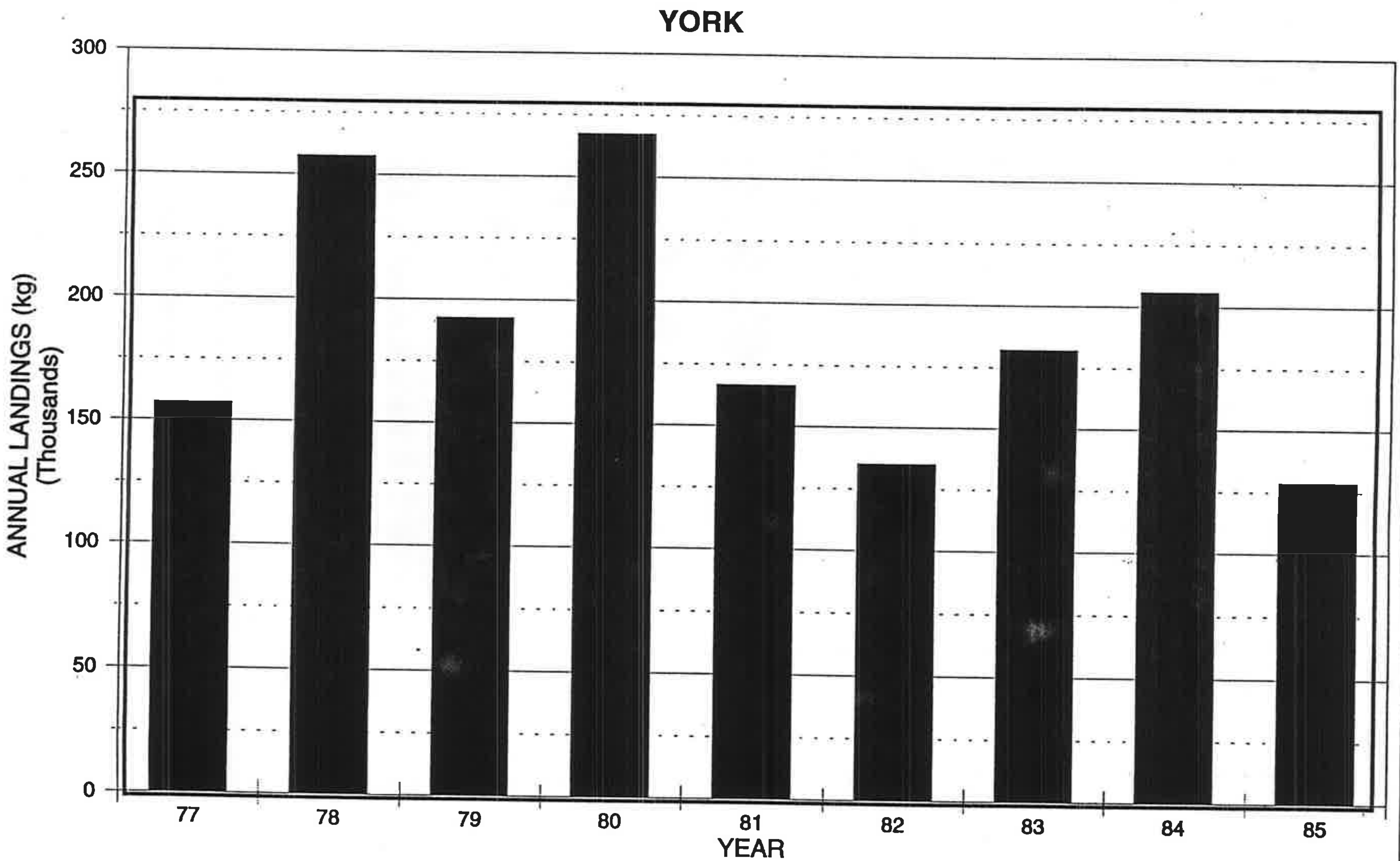

Figure 7. Commercial landing of female American shad for the York River. Solid box = years selected for population estimate.

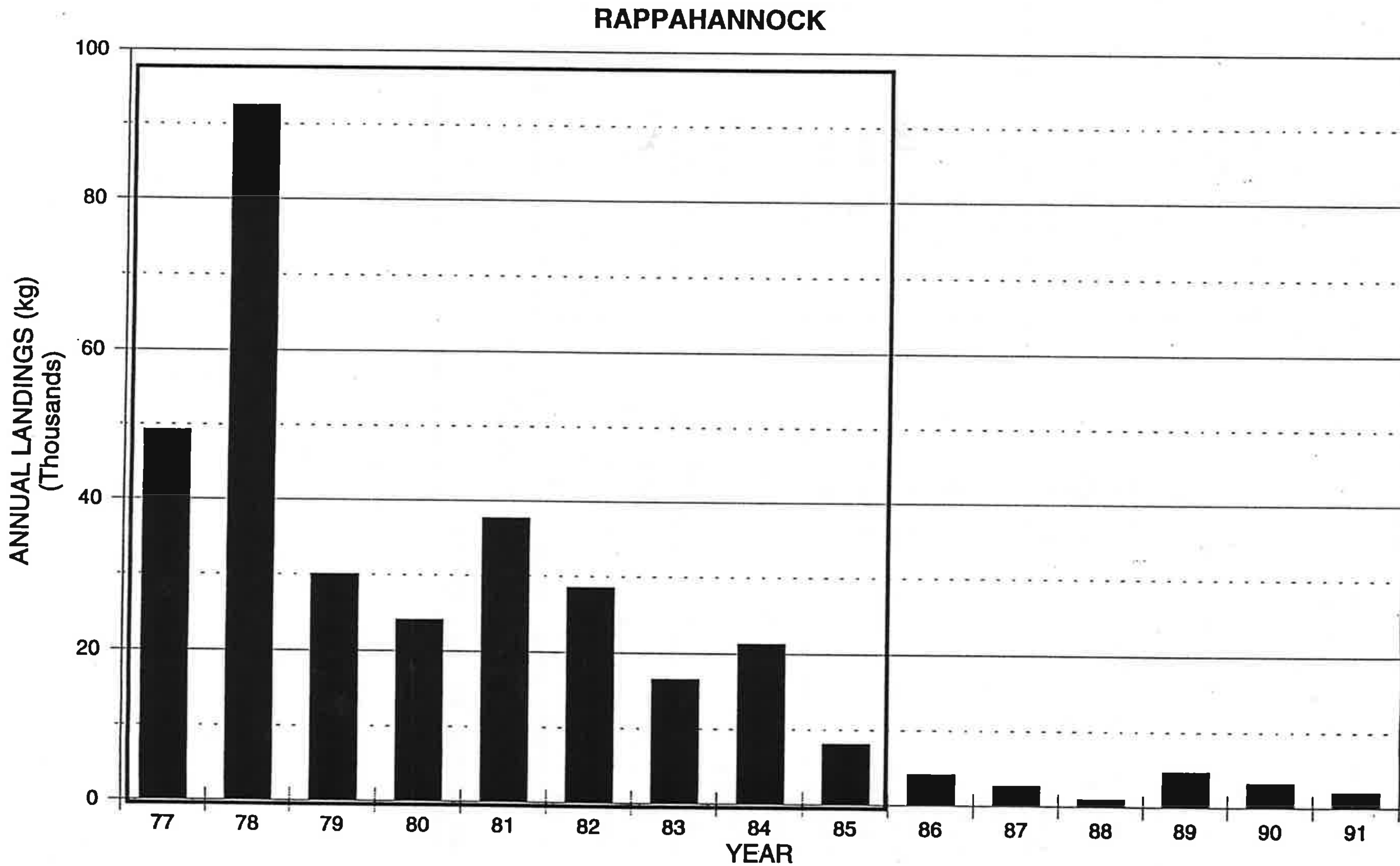

Figure 8. Commercial landing of female American shad for the Rappahannock River. Solid box = years selected for population estimate.

Table 6. Estimated annual landings (kg) of American shad by stake gill nets in the James River, 1977-1991

Year	Males	Females
1977*	11,612	186,495
1978*	116,348	574,935
1979*	17,238	263,203
1980*	59,003	343,026
1981*	12,056	105,550
1982*	21,811	37,731
1983*	46,822	146,715
1984*	35,531	169,990
1985*	16,922	71,232
1986	11,772	17,977
1987	913	7,052
1988	1,625	10,354
1989	2,663	6,476
1990	1,167	3,401
1991	223	1,176

* Years selected for population estimate

Source: Blumberg et al. (1991)

Table 7. Estimated annual landings (kg) of American shad by pound nets and stake gill nets in the York River, 1977-1991

Year	Stake Gill Net		Pound Net	
	American Shad		American Shad	
	Male	Female	Male	Female
1977*	3,376	137,748	48,887	19,487
1978*	31,666	174,780	59,535	82,641
1979*	23,460	186,074	4,213	6,487
1980*	25,012	246,719	7,840	20,575
1981*	23,453	158,905	55,220	7,788
1982*	23,811	134,676	22,017	542
1983*	45,717	167,590	26,830	14,495
1984*	58,104	196,550	14,682	9,414
1985*	36,786	120,951	22,470	7,806
1986	32,886	72,542		
1987	12,362	88,237		
1988	20,758	88,380		
1989	24,071	94,611		
1990	16,230	50,257		
1991	4,740	51,951		

* Years selected for population estimate

Source: Blumberg et al. (1991)

Table 8. Estimated annual landings (kg) of American shad by pound nets and stake gill nets in the Rappahannock River, 1977-1991

	Stake Gill Net		Pound Net	
	American Shad		American Shad	
Year	Male	Female	Male	Female
1977*	2,298	22,053	71,012	27,224
1978*	10,909	45,870	53,918	46,643
1979*	2,199	21,619	12,762	8,485
1980*	1,366	8,831	16,303	15,288
1981*	2,621	10,015	27,041	27,720
1982*	2,616	5,256	38,418	23,262
1983*	2,113	4,969	22,917	11,604
1984*	5,043	12,949	12,535	8,327
1985*	3,284	6,152	4,910	1,995
1986	888	1,958	4,485	2,235
1987	927	1,771	1,715	1,001
1988	404	878	728	193
1989	794	4,211	339	570
1990	490	2,832	920	483
1991	212	1,595	267	517

* Years selected for population estimate

Source: Blumberg et al. (1991)

- Commercial shad landings in Maryland are approximately 85% female (MDNR 1986); therefore, we multiplied the total number of adults by 0.85 to obtain the number of females (we ignored the weight difference between males and females in this calculation).

- We considered an annual exploitation rate to represent the percentage of a shad run that was harvested each year. Historical shad exploitation rates have been estimated for several major shad runs along the East Coast, including the Upper Bay (Gibson et al. 1988). Walburg and Sykes (1957) calculated exploitation rates for the Potomac River (58%) and the James River (73%) based on a 1952 tagging study. To our knowledge, the only other exploitation rate estimate available for any other Chesapeake Bay shad stocks is the 61% value for the Upper Bay stock reported in Gibson et al. (1988). We averaged the historical exploitation rates for 10 river systems presented in Gibson et al. (1988) and used maximum for a range[4]) in our calculations. In addition, we developed independent target values for the Upper Bay, James, and Potomac rivers using the river-specific exploitation rates in the literature for those spawning areas.

- In most years, males will make up more than 50% of the spawning run, typically comprising about 60% to 70% of the total (based on Virginia pound net data). Assuming a male/female sex ratio of 1.5:1, multiplying the number of females by 2.5 produces an annual adult abundance estimate that includes both sexes.

- Under-reporting of commercial harvests in Maryland has been estimated to be as high as 40% (Watermen's Association, 1978), although later studies have suggested that the amount of under-reporting may be less when harvests are lower. To account for suspected underreporting during the time periods when shad harvests were substantial, we selected a correction factor consistent with the assumption that watermen did not report 30% of their harvest each year.

For Virginia rivers, shad commercial landings were reported separately for males and females (Tables 6 through 8); therefore, only the percent exploitation rate, a kilogram/pound conversion, the pound per fish conversion factor, and the 2.5 multiplier representing the sex ratio and the 30% estimate of underreporting were necessary to estimate shad abundance in Virginia rivers. Table 9 summarizes the calculations used to derive stock abundance estimates. Table 10 presents annual population abundance estimates (and a range calculated using the minimum and maximum exploitation rates) over the reference periods for both Maryland and Virginia tributaries. Also included are population abundance estimates calculated using the tributary-specific exploitation rates available for the Upper Bay, Potomac and James rivers.

We note that the Upper Bay restoration target presented here represents the expected stock abundance with no shad production in the riverine portion of the Susquehanna River; i.e., it represents our estimate of the abundance of the Upper Bay shad stock before upstream passage facilities were present at Conowingo Dam and before any active alosid restoration program had been undertaken in the Susquehanna River. The Susquehanna River restoration program has established a goal of two million shad produced in the river upstream of Conowingo Dam (personal communication with R. St. Pierre, USFWS, and R. Hoopes, Pennsylvania Fish and Boat Commission). Shad population estimates for the upper Bay generated from the ongoing MDNR tag and recapture study clearly include fish destined for the riverine portion of the Susquehanna and present as a result of the restoration program that has been underway since the late 1970s. Thus, we have also included in Table 10, an Upper Bay restoration target value <u>inclusive</u> of the potential riverine Susquehanna River production of two million adult shad.

Table 9. Summary of calculations used to develop adult stock abundance estimates for American shad from commercial landings data
Maryland
Tributary-specific average annual commercial landings (1955-1970) ÷ 4 (lbs) = Number of fish harvested
Number of fish harvested x 0.85 = Number of <u>females</u> harvested
Number of females harvested ÷ Annual Exploitation Rate (Table 10) = Female population size
Female population size x 2.5 = Total population size
Total population size ÷ 0.70 = Total population size <u>corrected for</u> assumed under-reporting
Virginia
Tributary-specific average annual commercial harvest <u>of female shad</u> (1977-1985) ÷ 4 (lbs) = Number of females harvested
Number of females harvested ÷ Annual Exploitation Rate (Table 10) = Female population size
Female population size x 2.5 = Total Population sizep
Total population size ÷0.70 = Total population size <u>corrected for</u> assumed under-reporting

One approach that could be used to track the progress of the Susquehanna River restoration program independent of the progress toward increasing the abundance of the Upper Bay shad stock would be to treat the Upper Bay stock size estimates derived from the ongoing tag and recapture program as the combined total of Susquehanna River and Upper Bay fish, and then subtract out the number of fish lifted at Conowingo Dam passage facilities to provide an estimate of adult shad numbers for only the Upper Bay. Such an approach assumes that all fish destined for the Susquehanna River upstream of Conowingo Dam actually enter the Conowingo fish lifts and are counted, rather than either spawning at the base of the dam or leaving the area without spawning. Resolution of how these data should be used for tracking restoration progress is appropriately the responsibility of the multi-agency groups overseeing the Susquehanna River alosid restoration effort (e.g., SRAFRC) and will not be addressed further in this document.

Table 10. Population estimates for American shad in several regions and tributaries of the Chesapeake Bay

Body of Water	Commercial Landings (lbs)	Annual Assumed Exploitation (%)		Estimated Population Size (N)
Patuxent River Basin[a]	7,333	Mean	37	15,042
		Minimum	13	42,811
		Maximum	61	9,124
Choptank River Basin[a]	67,834	Mean	37	139,139
		Minimum	13	396,010
		Maximum	61	84,396
Lower Eastern Shore (primarily Nanticoke River)[a]	144,069	Mean	37	295,508
		Minimum	13	841,061
		Maximum	61	179,242
Upper Bay,[a] not including Susquehanna upstream of Conowingo Dam	989,713	Reported[c]	61	1,231,347
		Mean	37	2,030,058
		Minimum	13	5,777,859
		Maximum	61	1,231,347
Susquehanna River and upper Bay, combined	Not applicable	Reported[c]	61	3,231,347
Potomac River Basin[a]	474,501	Reported[d]	58	620,884
		Mean	37	973,277
		Minimum	13	2,770,097
		Maximum	61	590,349
James River[b]	Males - 82,836 Females - 466,280	Reported[d]	73	570,303
		Mean	37	1,125,193
		Minimum	13	3,202,471
		Maximum	61	682,494
York River[b]	Males - 130,901 Females - 415,782	Mean	37	1,003,334
		Minimum	13	2,855,642
		Maximum	61	608,580
Rappahannock River[b]	Males - 71,767 Females - 75,695	Mean	37	182,663
		Minimum	13	519,886
		Maximum	61	110,795

(a) Commercial landings and estimated population size values are averaged over the years 1955-1970.
(b) Commercial landings and estimated population size values are averaged over the years 1977-1985.
(c) Gibson et al. (1988)
(d) Walburg and Sykes (1987)

Uncertainty about the accuracy of the commercial landings data and the simplistic nature of the assumptions underlying the calculations described above raise the question of whether these adult abundance estimates have any value as restoration targets for Chesapeake Bay American shad stocks. We therefore sought some means of evaluating the potential validity of these estimates. Although no adult abundance estimates for historical time periods are available to validate our calculations (except for Walburg and

Sykes' Potomac River and James River estimates), it is reasonable to assume that the abundance of a shad population in any given tributary of the bay should be related to the area or volume of the spawning and nursery habitat in that tributary. The American shad literature documents the strong role that environmental variability plays in establishing year-class success in individual river systems such as the Connecticut River, a factor that might preclude such a quantitative relationship. However, within a single geographical region such as the Chesapeake Bay, it is reasonable to assume that the magnitude of environmental variability among Bay tributaries may be less important than the role of habitat availability in establishing tributary stock abundance.

To explore the relationship, if any, between our derived adult shad population estimates and the amount of spawning and nursery habitat in each major Bay tributary, we estimated the surface area currently used by American shad for spawning and the volume associated with that habitat. Approximate spawning area for the major river systems in the Bay was calculated based on volume and areal statistics reported by Cronin (1971). American shad generally spawn in the mainstem rivers, beginning near the salt/fresh water interface and extending upriver until restricted by barriers (e.g., dams) or shallow water. The salt/fresh water borders used in spawning habitat calculations were obtained from correspondence with biologists who had conducted research in the particular river systems, and salinity profile maps (e.g., Environmental Atlas of the Potomac Estuary). Cronin (1971) calculated surface areal and volume estimates of the river systems to the head of tide; therefore, we were restricted to using these values as the upper river boundary for spawning habitat estimates, even though American shad may spawn farther upriver. Table 11 presents the river mile segment, area and volume estimates for assumed shad spawning habitats in the major river systems of the Chesapeake Bay. These estimates do not include the Susquehanna River upstream of Conowingo Dam and those portions of other tributaries upstream from recently impassable migration barriers.[4]

Figures 9 and 10 present plots of our estimated adult stock abundance versus spawning habitat volume and area. There appears to be a positive association between both area and volume and our abundance estimates, except both area and volume and our estimate of stock abundance is lower than would be expected based on amount of habitat. In our view, the uncertain nature of the adult abundance estimates does not merit rigorous statistical correlation

[4] We used Maryland shad landings data from 1955 to 1974 and Virginia data from 1977 to 1985 to develop our stock abundance estimates. No significant measures that would have provided access to portions of the tributaries upstream of blockages were in place then; therefore, the shad landings data represent production in segments of the tributaries below major migration blockages.

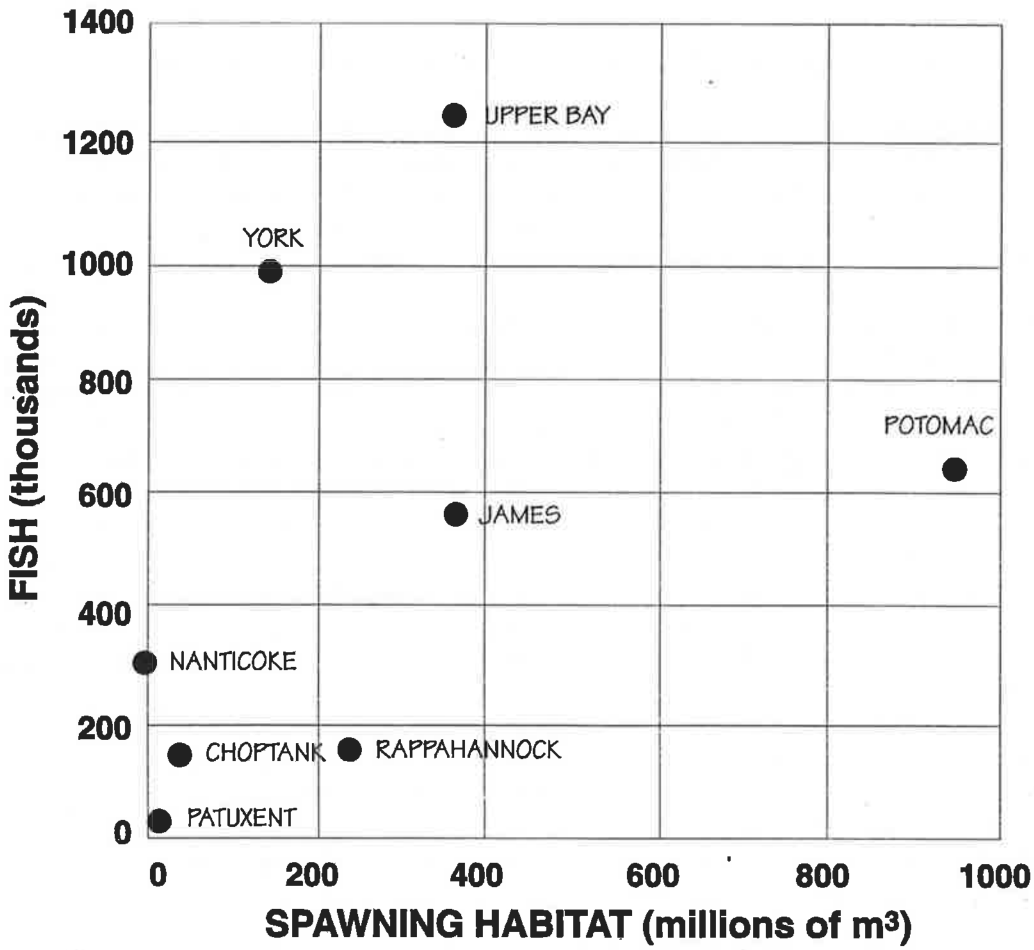

Figure 9. Plot of stock abundance estimates (see Table 10) versus volume of habitat (see Table 11).

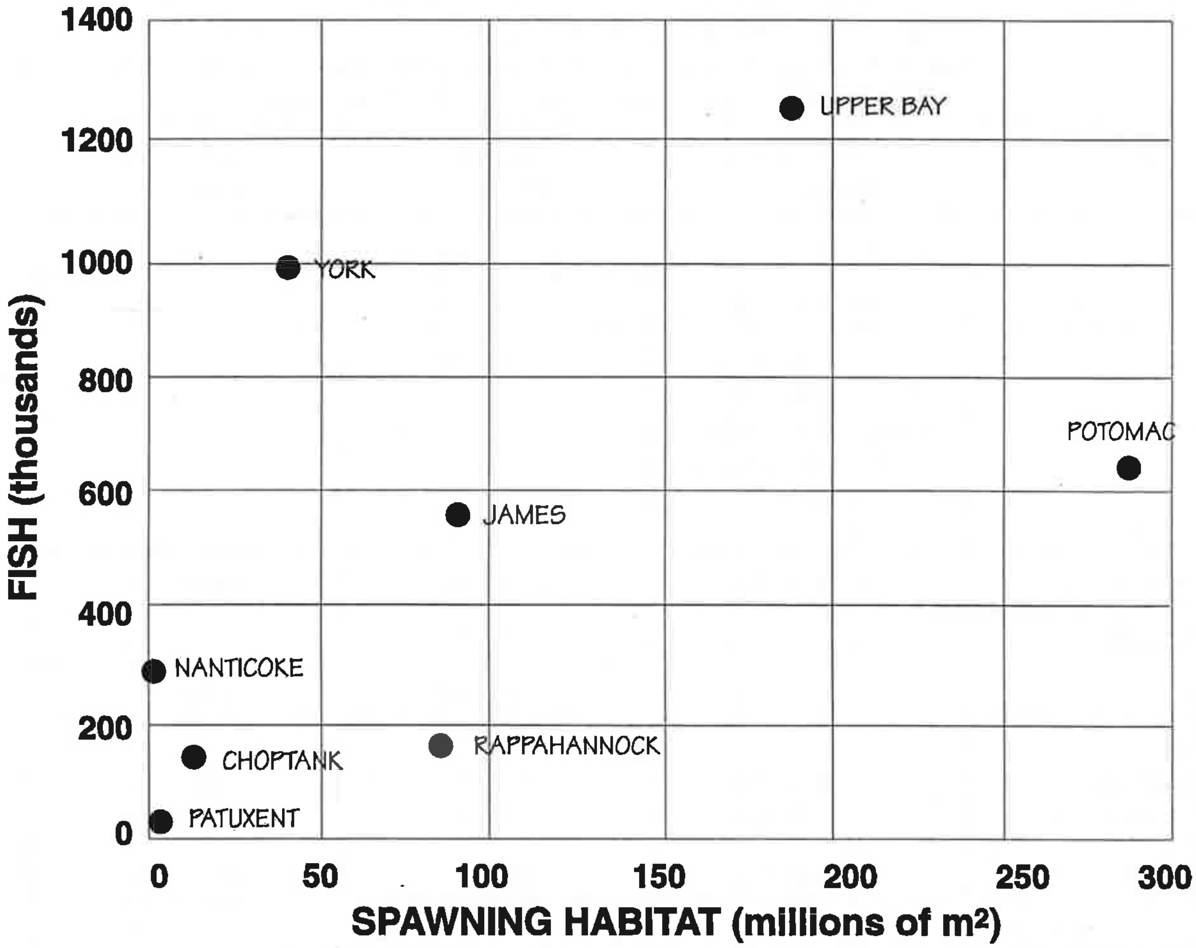

Figure 10. Plot of stock abundance estimates (see Table 10) versus area of habitat (see Table 11).

analysis (i.e., the statistical result would be only as meaningful as the assumptions that went into our stock abundance estimation calculations). However, the reasonable association for shad in most of the Bay tributaries offers some support for the validity of the approach that we applied to develop those adult abundance estimates.

Table 11. Area and volume estimates of American shad spawning habitat up to the head of tide in major rivers of the Chesapeake Bay. Area and volume were measured at mean low water.

River	River Mile Segment	Area ($10^6 M^2$)	Volume ($10^6 M^3$)
Patuxent	30 to 34	3.28	9.43
Choptank	40 to 58	10.14	28.02
Upper Bay	149 to 156 includes NE, Elk, Bohemia, and lower Susquehanna River	185.96	347.63
Potomac	55 to 98	280.93	964.78
Nanticoke	29 to 34	1.98	6.06
James	40 to 84	92.62	334.76
York			
Pamukey	35 to 69	23.88	81.34
Mattaponi	35 to 59	11.62	43.84
Rappahannock	35 to 93	85.20	229.90

Source: Cronin (1971)

Occurrence of Juvenile American Shad in Seine Surveys

There were few studies designed to assess juvenile American shad abundance in Chesapeake Bay tributaries before the 1980s; however, juvenile shad were collected and recorded as ancillary data as part of several juvenile striped bass seine surveys dating back to the 1950s. This historic seine data provide at least some information about juvenile abundances during time periods when shad stocks are believed to have been at relatively "healthy" levels, or at least much more abundant than they are in 1954. As on the case of commercial landings records, the representativeness of the quantitative juvenile shad seine data is questionable for a number of reasons:

- seining locations were selected based on juvenile striped bass habitat suitability, not to represent preferred nursery areas for American shad;
- American shad and other alosids are more likely to school than striped bass, and thus catch-per-unit-effort (CPU) values in seines probably reflect contagious distributions of the fish being sampled; and
- seines are not the optimal sampling gear for juvenile shad; Virginia (J. Loesch, VIMS) has developed a push-net sampling program that may provide reliable abundance estimates for juvenile alosids; however, the time series record for that program does not extend back to periods when American shad were present in substantial numbers and is therefore not useful for developing quantitative targets for restored stock levels.

Despite these limitations, using the existing seine survey data to either establish stock restoration targets for American shad or track progress toward targets based on adult abundance estimates offers one key advantage over other possible approaches: several seining programs are operating currently and provide a cost-effective means of monitoring changes in the status of shad stocks caused by fisheries or habitat management actions that are being or may be implemented.

Given the non-normal distribution of juvenile shad CPUE data from the historical seine surveys (statistical distributions are highly skewed to zero values), the sporadic pattern of occurrence of juvenile shad in seine haul catches, and the relatively small number of juvenile shad taken in the surveys even during years when shad stocks appeared to be at relatively abundant levels, it did not appear likely that the simple mean CPUE of juvenile shad would have a quantitative, consistent relationship to adult shad stock abundance. These characteristics of the available data sets also preclude application of the types of statistical analyses that could be expected to produce meaningful stock recruitment relationships. For example, the sparse data (i.e., frequent zero values) and the uncertain validity of the quantitative catch data (i.e., because beach seines are not the most efficient sampling gear for juvenile shad) indicate to us that these seine survey data sets are unsuitable for the time-lagged correlation analyses between juvenile abundance and commercial catch that were used extensively in developing striped bass population dynamics models.

We believe, however, that some potentially useful information could be drawn from the seine same data sets, namely presence and absence information on juvenile shad, that might lead to the development of a metric of value for establishing or tracking a restoration target. Mangel and Smith (1990) explored the application of presence-absence sampling to fisheries management, and Uphoff (1993) used it with striped bass ichthyoplankton as an indicator of stock status in the Choptank and Nanticoke rivers.

Using the Maryland and Virginia juvenile fish survey data, we calculated, the number of seine hauls that captured one or more juvenile American shad over time (Appendix B). Using a three-year running average to smooth the trends, we then plotted the percent of seine hauls that captured one or more shad over time for each river system (Figures 11 through 18). All data for the Virginia systems were used, whereas only primary site data were used to develop the running three-year average plots for Maryland systems (auxiliary sites were not sampled in all years; thus, only data from primary sites provided a consistent year to year sampling effort).

The time series of percent of seine hauls that took one or more juvenile shad clearly reflect what is generally believed to be the pattern of decline of shad stocks throughout the Bay. For example, in the Upper Bay, where annual spawning runs of American shad are believed to have declined from at least a million fish in the 1960s to a few thousand in the 1970s, juveniles literally disappeared from the seine survey catches during the mid-1970s. Conversely, in the Potomac River, shad stocks continued to persist at levels supporting some harvest well into the 1980s, and juveniles continued to be present in the annual seine survey through the present, albeit at lower percent occurrence rates in the late 1970s and early-1980s than during the mid 1960s and early-1970s (figure 15).

Because of the consistent manner in which the striped bass juvenile seine surveys have been and continue to be conducted, it appears reasonable to assume that the probability of capture of one or more juvenile shad in those surveys is related to their abundance in the river systems being sampled. The abundance of juveniles clearly is related to future spawning stock size, and is also likely to be associated to some degree, to size of the spawning stock in the same year. These types of relationships cannot be rigorously established in the absence of year-class or spawning stock abundance estimates. The only data that can be used, in some cases, for such validation is the tributary-specific commercial landings records. Comparisons between the percent juvenile occurrence and commercial harvest records are possible for some river systems in the Chesapeake Bay.

These comparisons, however, are limited by the degree of overlap of the two time series, in the case of the Virginia river systems, and by the fact that the Maryland commercial shad fishery was closed in 1980, thus significantly truncating the commercial landings time series record. In addition, the regionally specific commercial landings records have some gaps; for example, some of the Maryland tributary-specific data are not available or incomplete for years between 1962 and 1966.

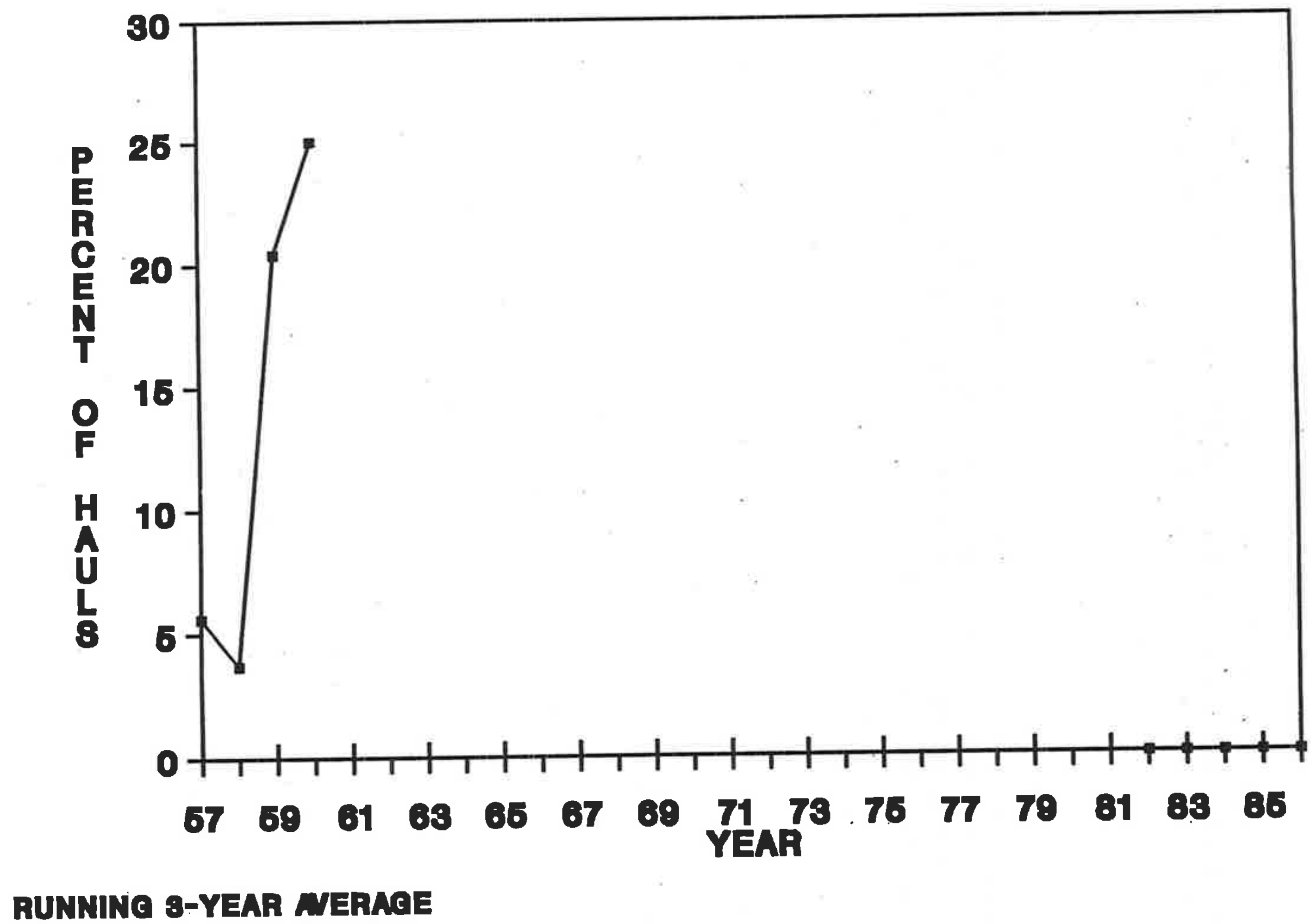

Figure 11. Percent of seine hauls containing juvenile American shad in the Patuxent River, the year indicated represents the last of the three-years averaged

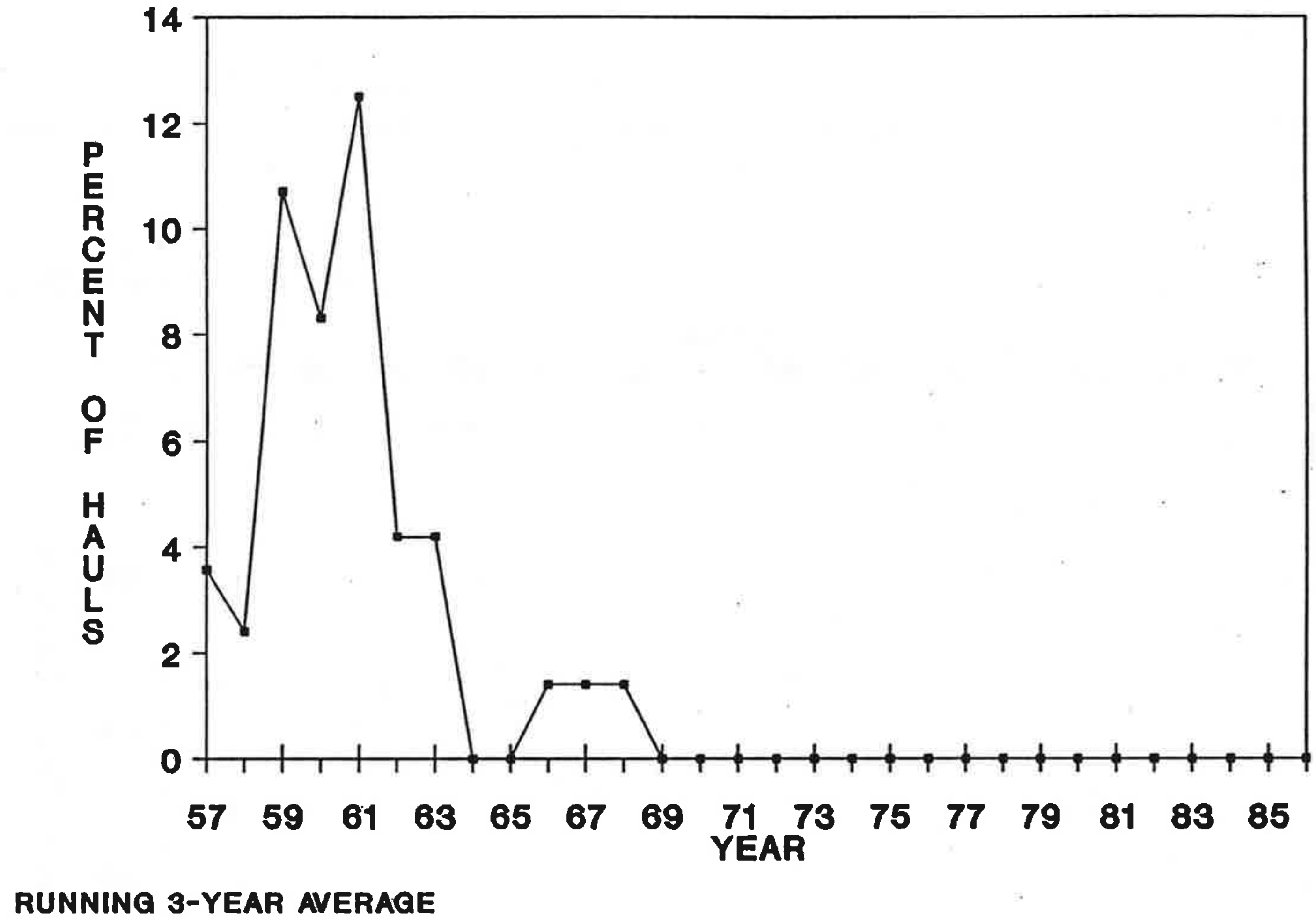

Figure 12. Percent of seine hauls containing juvenile American shad in the Choptank River (primary sites), the year indicated represents the last of the three-years averaged

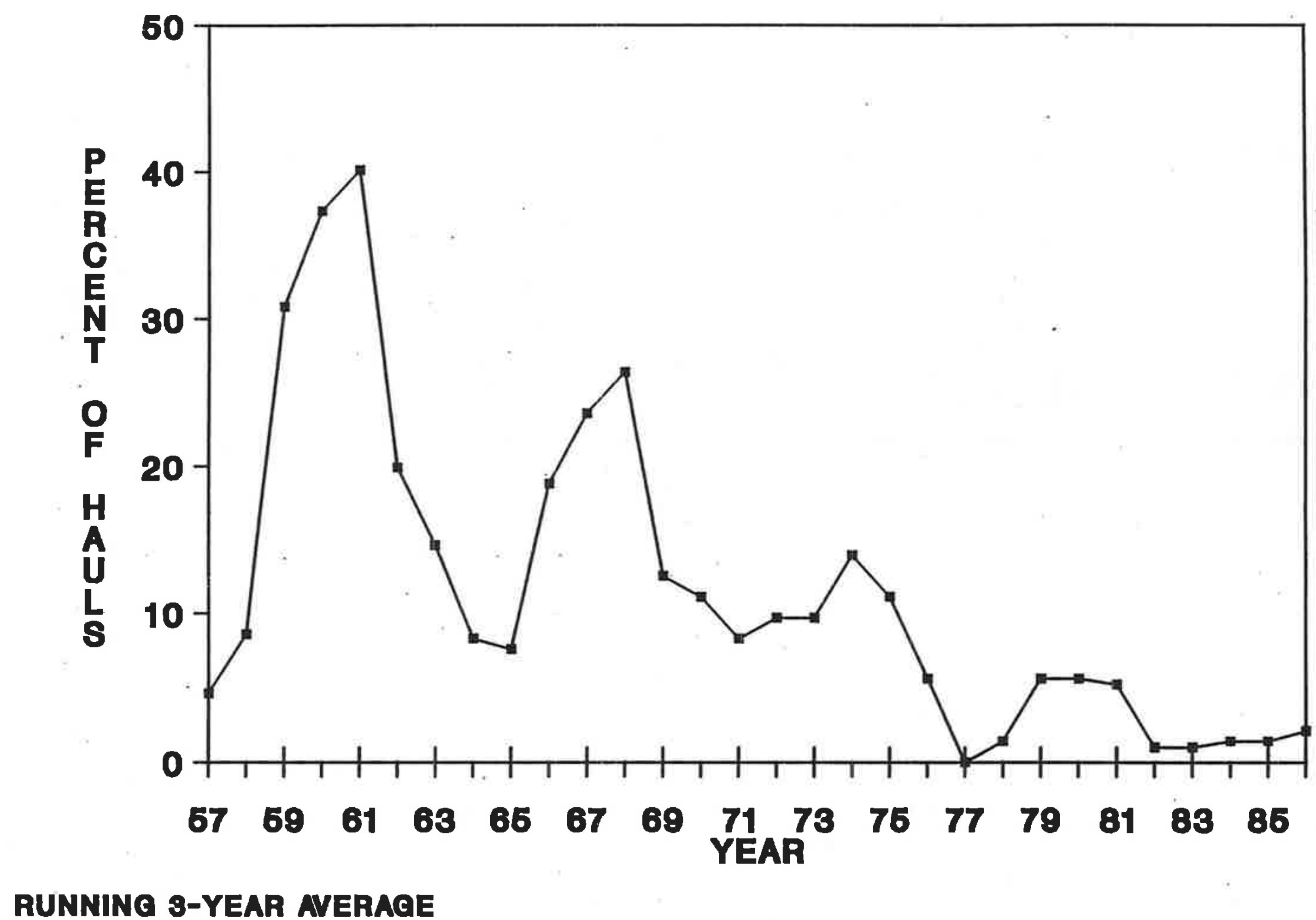

Figure 13. Percent of seine hauls containing juvenile American shad in the Nanticoke River (primary sites), the year indicated represents the last of the three-years averaged

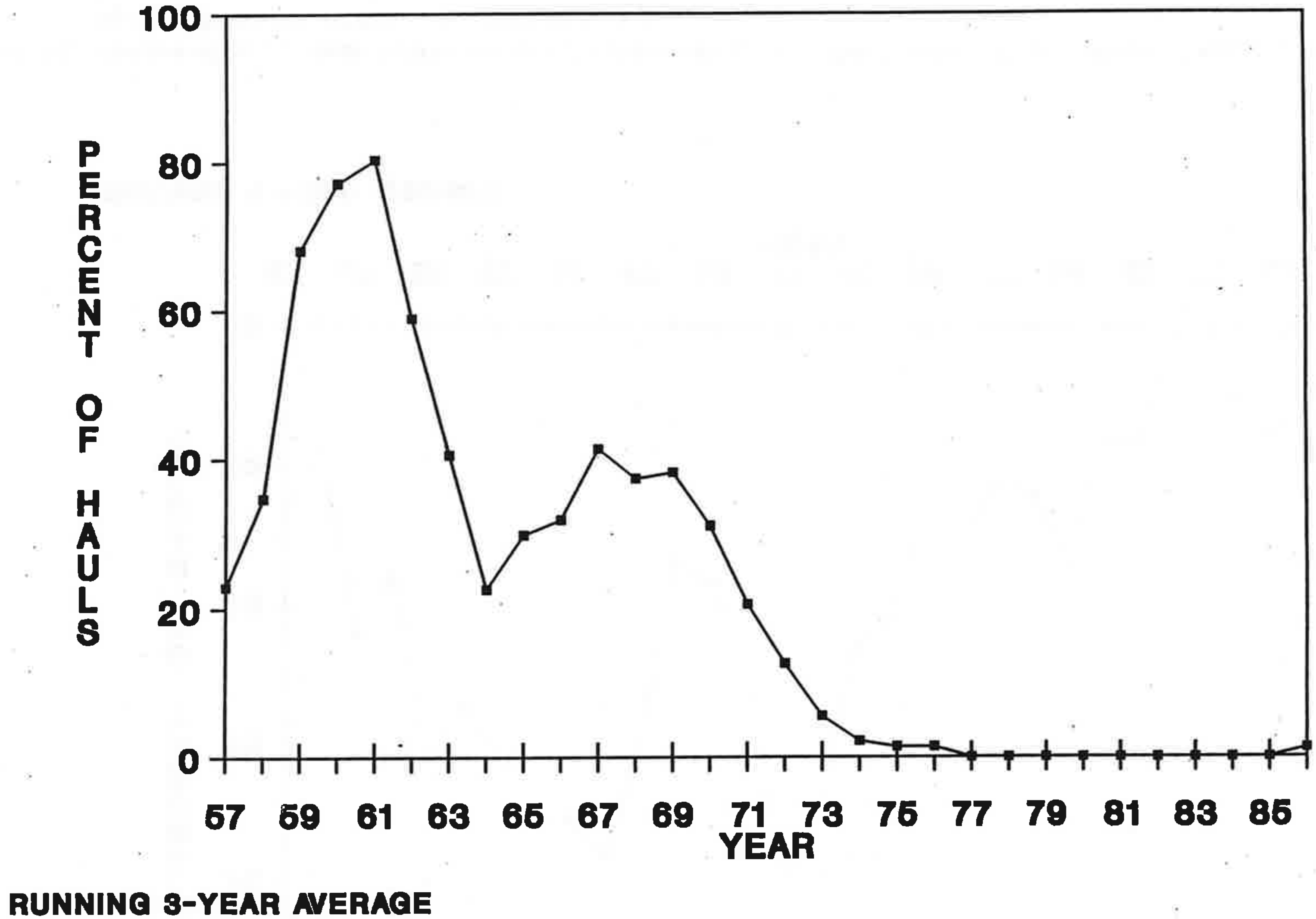

Figure 14. Percent of seine hauls containing juvenile American shad in the Upper Bay region (primary sites), the year indicated represents the last of the three-years averaged

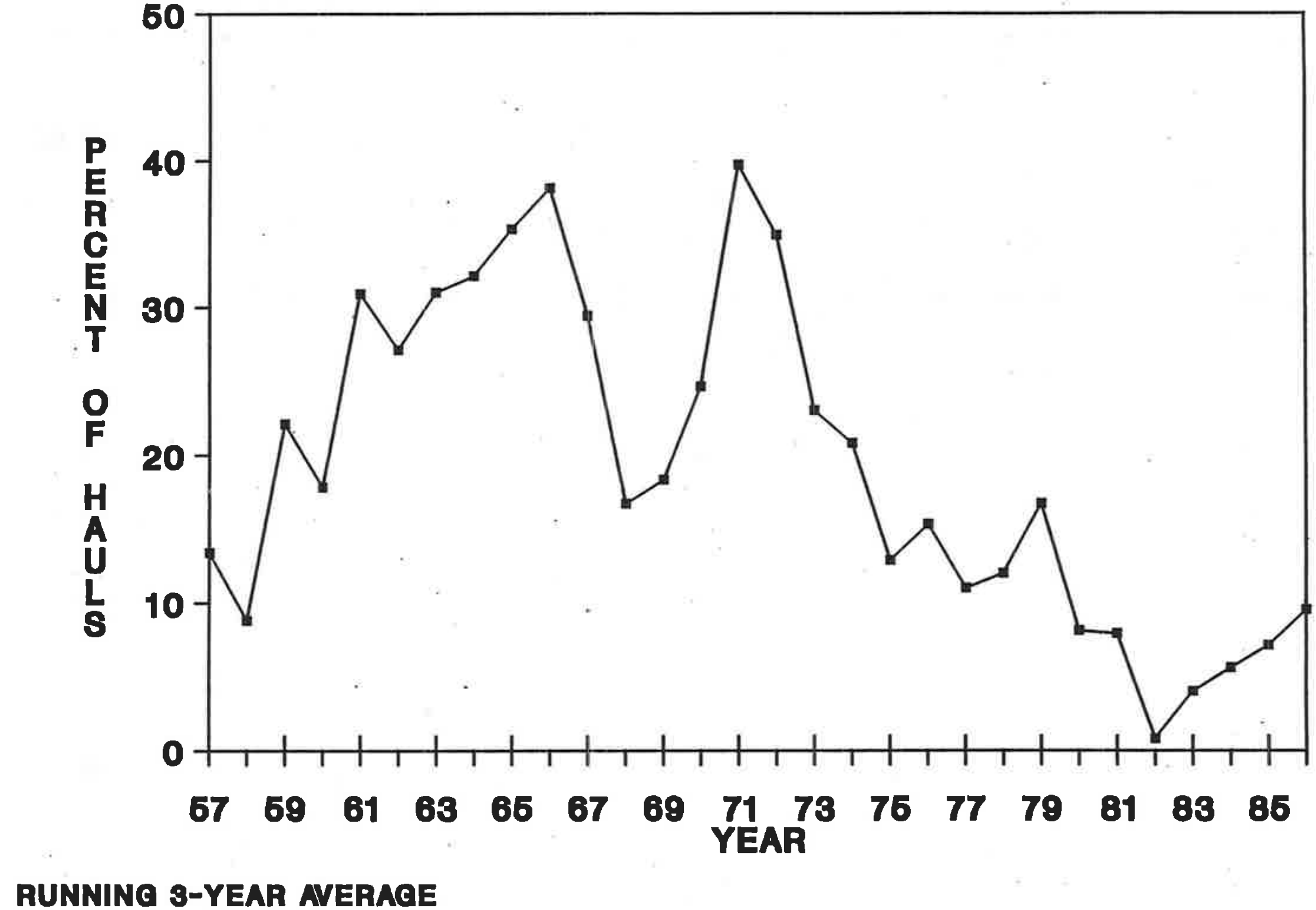

Figure 15. Percent of seine hauls containing juvenile American shad in the Potomac River (primary sites), the year indicated represents the last of the three-years averaged

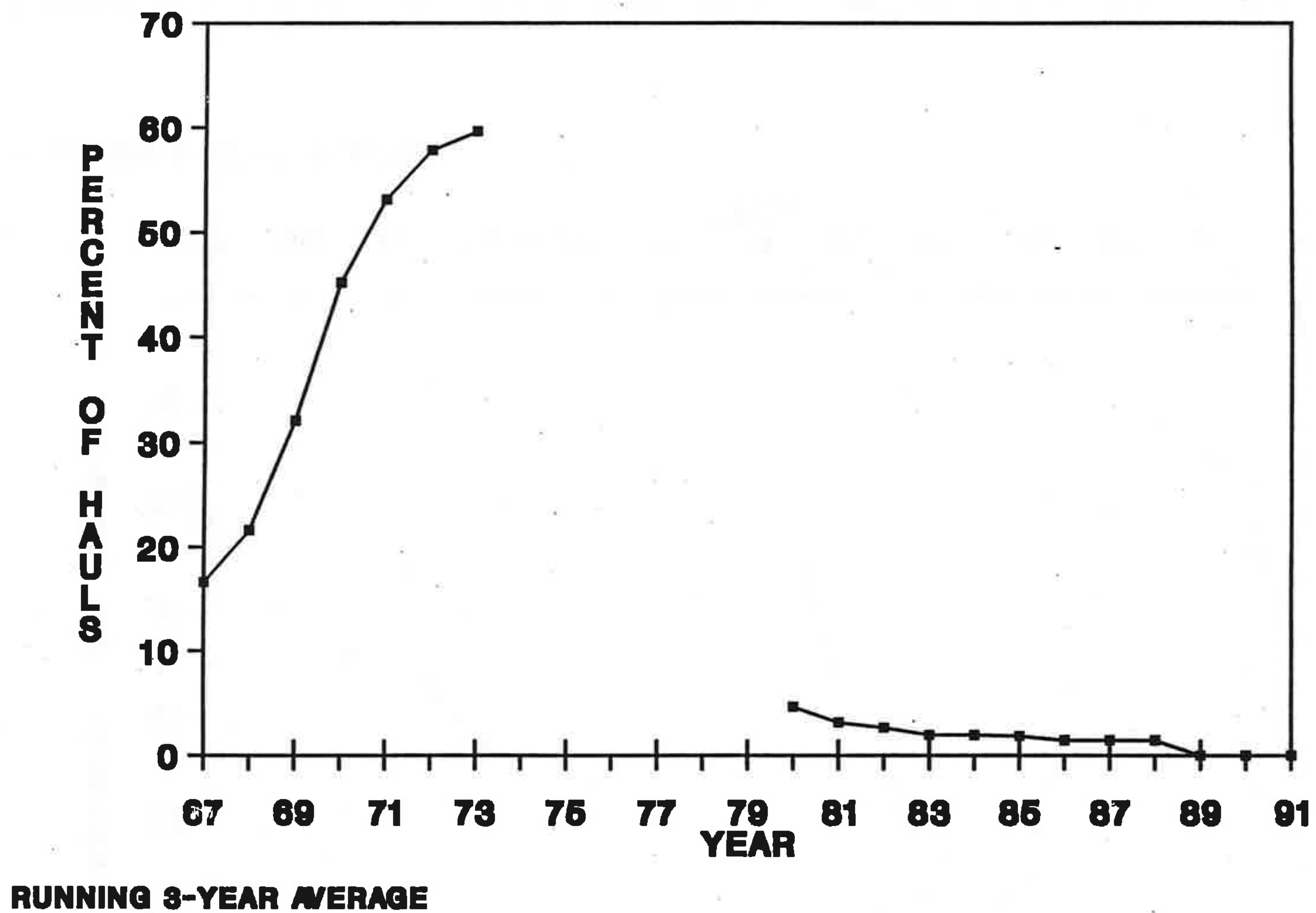

Figure 16. Percent of seine hauls containing juvenile American shad in the James River, the year indicated represents the last of the three-years averaged

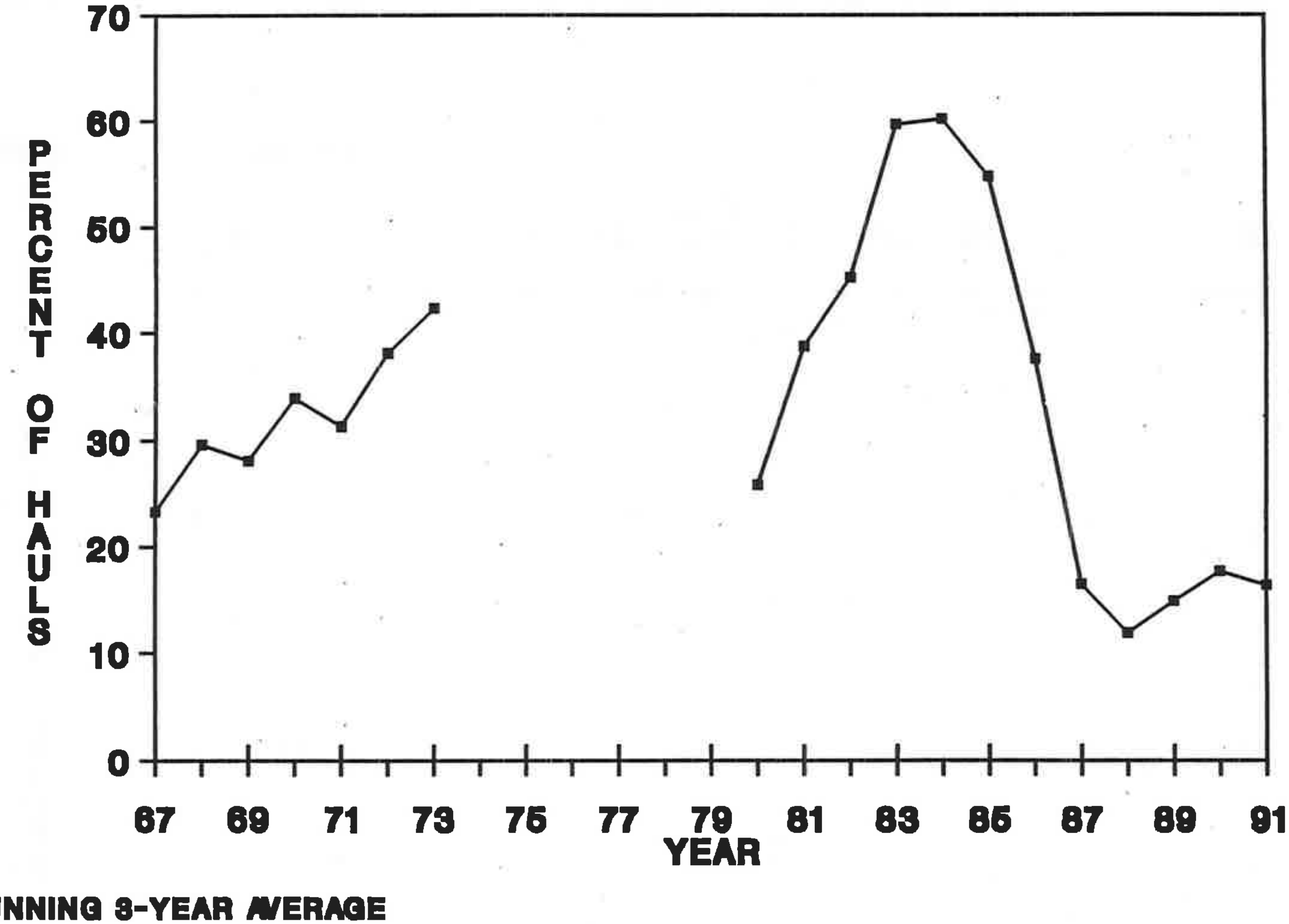

Figure 17. Percent of seine hauls containing juvenile American shad in the York River, the year indicated represents the last of the three-years averaged

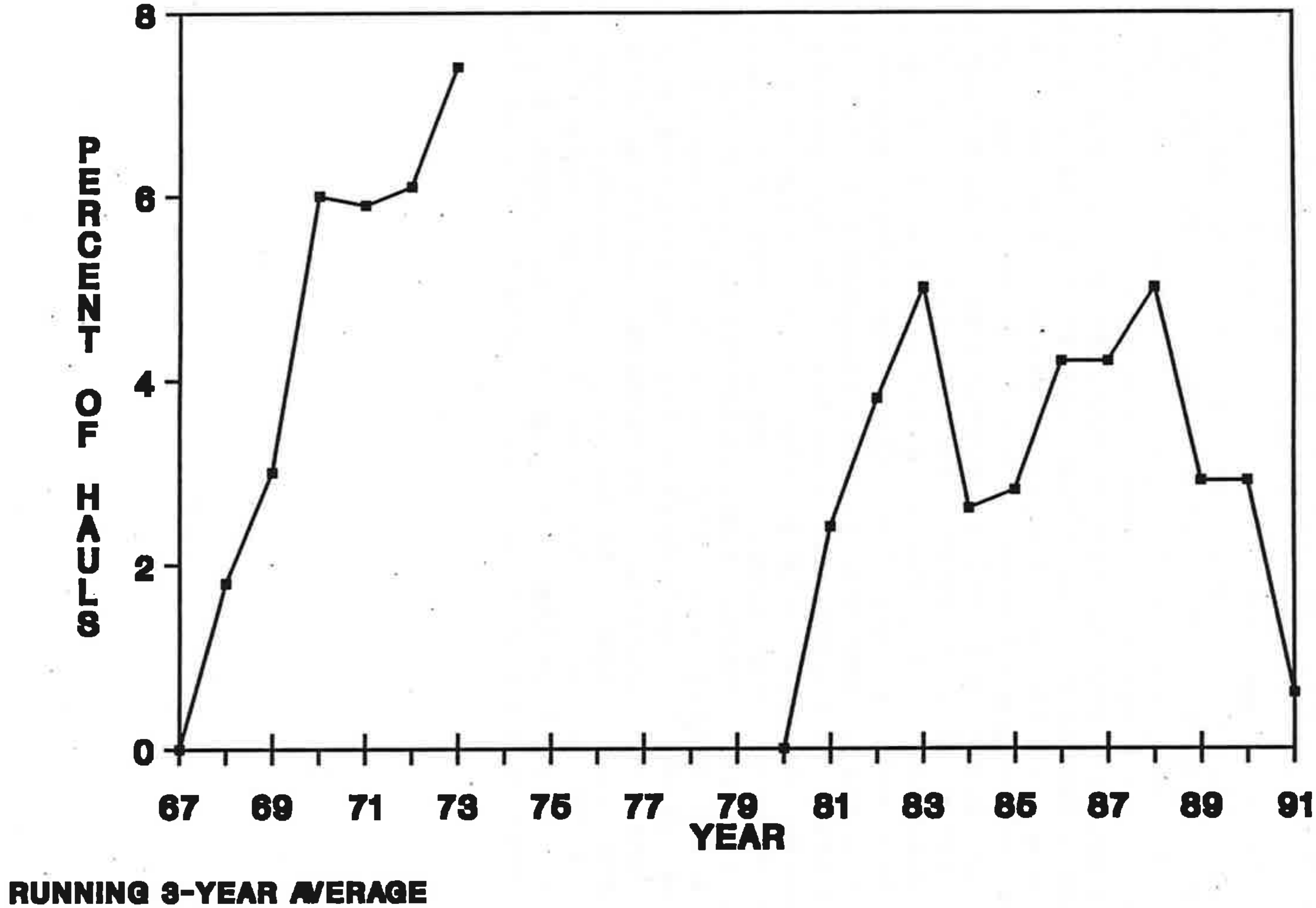

Figure 18. Percent of seine hauls containing juvenile American shad in the Rappahannock River, the year indicated represents the last of the three-years averaged

Despite these severe limitations, the time series records of reported commercial landings and percent juvenile occurrence for some systems (e.g., Patuxent, Upper Bay) appear to correspond. The tributary-specific plots in Figure 19 show reasonably good associations between frequency of occurrence of juvenile shad in seine hauls and commercial landings in the same year for a number of the tributaries, including Upper Bay, Potomac, Choptank and Nanticoke Rivers. No associations or relatively weak associations are suggested by the plots for other river systems. As in the case of the apparent association between stock abundance and spawning habitat volume, the uncertainty associated with the numbers being examined here does not support the use of rigorous statistical analyses to test the association. The existence of some association suggests however, that if juvenile American shad again begin to appear in juvenile striped bass seine survey hauls with a frequency similar to that during the periods of relatively high stock abundance (i.e., the late 1960s and early 1970s), it would be reasonable to conclude that the adult stocks have increased and perhaps recovered to some reasonable level. Simply tracking the trend in percent of seine hauls taking juvenile shad from standardized surveys would provide an indication of progress in stock restoration over time, as Uphoff (1993) has shown for striped bass ichthyoplankton. The historical degree of decline in percent of hauls taking shad might also be interpreted as an indication of which Bay tributaries have experienced the most significant shad stock declines. For example, the change over time for the Potomac River (Figure 15; decline in occurrence from peaks on the order of 40% to lows on the order of 10%) suggests that this stock has not declined to the same degree as the Upper Bay stock (Figure 14; decline in occurrence from a peak of 80% to lows of 0%).

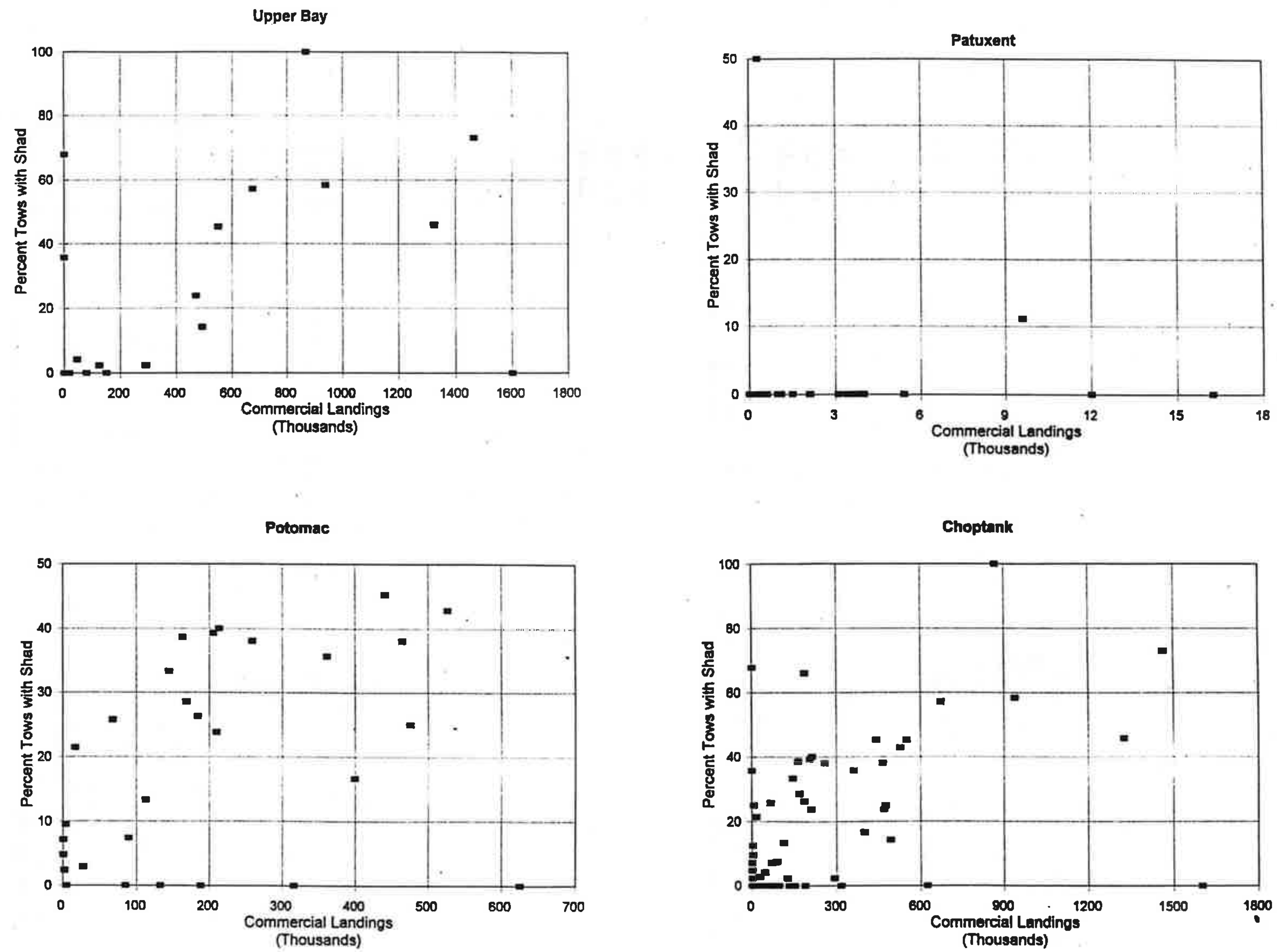

Figure 19. Plots of total annual commercial landings versus percent of seine hauls capturing at least one juvenile shad, including all years for which complete commercial landings data were available, for each of the Bay tributaries

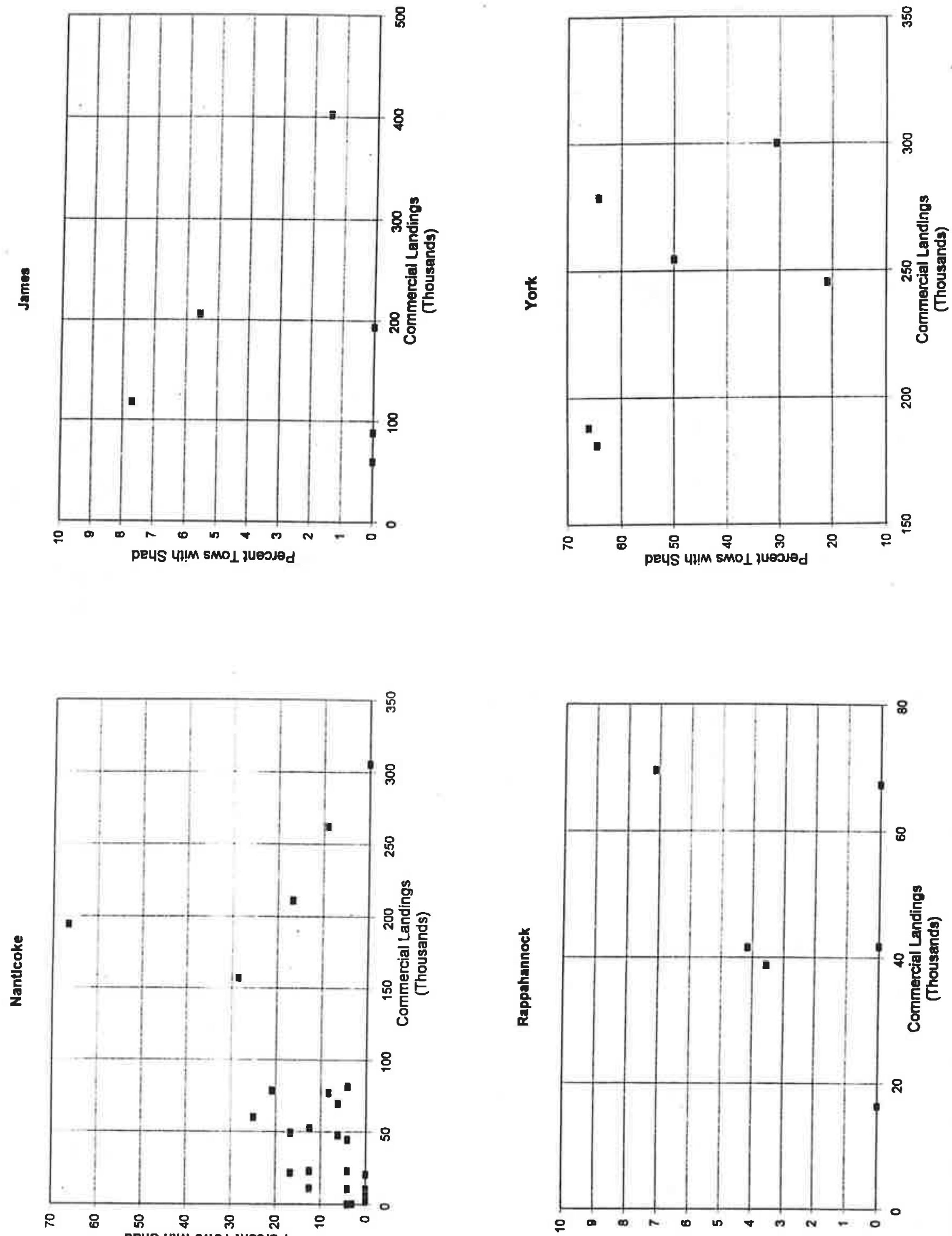

Figure 19. (Continued)

Presence/Absence of American Shad Eggs or Larvae in Ichthyoplankton Surveys

Similarly to the previous approach with juvenile catches in seine surveys, ichthyoplankton data may also be useful in developing shad stock restoration targets or in tracking progress toward an adult abundance targets, based on occurrence of eggs or larvae. Uphoff (1993) applied this approach to an assessment of striped bass stock status in the Choptank and Nanticoke rivers and demonstrated its potential utility. Uphoff dealt with a species that declined significantly and has recovered over the period for which ichthyoplankton data are available. The decline in striped bass, however, was probably not as severe as that exhibited by American shad stocks in Chesapeake Bay.

The presence-absence approach with eggs or larvae would be most useful for tracking progress in restoration of severely depressed fish stocks. Once spawning stocks reach some modest level of recovery, the frequency of capture of eggs or larvae (i.e., the number of plankton net tows in which one or more eggs or larvae would be found) may reach a relatively high and consistent level that would not necessarily increase with further increases in stock size. After some point, the density of eggs and larvae may not consistently change. We do not believe that estimating stock abundance from ichthyoplankton density is a feasible or reasonable approach because it requires all of the rigorous sampling design characteristics necessary for reliable quantitative estimation of eggs and larval abundance, as well as valid estimates of such biological factors as fecundity as a proportion of body weight and size and age composition of the spawning stock.

The key to the utility of an ichthyoplankton presence-absence approach for monitoring progress toward shad stock restoration targets beyond detecting if any shad are spawning in a particular tributary would appear to be the identification of the relative stock level at which egg-larval "saturation" occurs in ichthyoplankton samples. To establish whether such a level exists, it would be necessary to examine ichthyoplankton data collected during periods when shad stocks were believed to be at widely different levels of abundance.

We investigated several ichthyoplankton data sources. Two data sets available from MDNR were examined; these data were collected on the Nanticoke River from the late 1950s through 1960 and in the Choptank River from 1980 through 1990. Unfortunately, these data sets proved to be of no use for this target setting exercise because all clupeids collected (i.e., river herring and shad) were combined into one category and not identified to species. Because of the difficulty associated with separating larval clupeid species, the same limitation was present in a fouryear (1974-77) ichthyoplankton data set collected in the Potomac River by the University of Maryland as part of the Potomac River Fisheries Program funded by the Maryland Power Plant Research Program. Except for the data collected during 1975, all river herring, gizzard shad, and American shad eggs were grouped into one category. No American shad eggs or larvae were reported in the 1975 survey. These data sets, although not useful for American shad, might prove useful for developing stock restoration or protection targets for other important species, such as white perch.

The absence of useful American shad ichthyoplankton data for several different years precludes further evaluation of whether this approach is feasible or useful for developing stock restoration targets in Chesapeake Bay. However, the rationale for considering this approach appears compelling for several reasons:

- the approach appears most viable when stocks are very low, as is the case with American shad in Chesapeake Bay;
- shad eggs are large and easily identifiable in the field, and quantification of volume filtered by the collection gear is not a critical aspect of establishing presence/absence; therefore, simplified field protocols and no laboratory sample processing would be necessary, allowing for relatively low costs for implementation; and
- a time series of percent occurrence of eggs or larvae would provide a basis for tracking progress over time in a stock restoration program.

Pound Net Monitoring of Stock Status

We used commercial landings data collected in pound nets from Maryland and Virginia tributaries of the Bay to develop the historical shad abundance estimates presented above, but we did not use these catch data to independently develop alternative stock abundance estimates. Some Bay fisheries scientists and resource managers have suggested that a pound net sampling program would be one feasible means of monitoring the status of shad spawning stocks in major Bay tributaries. A pound net program has merit because the deployment and fishing of pound nets is much less expensive than intensive mark and recapture studies for establishing stock status.

Pound nets offer several advantages over other stock status monitoring methods:

- Although setting a pound net is labor-intensive (e.g., planting the support posts), monitoring catches after the net is set requires minimal effort, pound nets fish continuously, and watermen could be paid a modest amount to report shad catch per net per sampling interval throughout the entire shad season while retaining the legal catch of other species for sale.

- Because pound nets fish continuously until removed from the water, effort is simply quantified as the number of days fished.

- Pound nets are non-lethal, so captured fish can be released unharmed.

- Pound nets are particularly well suited for harvesting schooling species, such as shad.

Pound nets also have a number of disadvantages as shad monitoring tools:

- Because the nets are stationary, capture of shad is a function of whether fish encounter the net (i.e., what percentage of all fish migrating up a tributary are likely to encounter the pound net lead) and how they behave once in the vicinity of the net (i.e., what percentage of fish encountering the lead will eventually enter the pound); therefore, catchability (in terms of percent of fish passing the net that are actually captured) may vary as a function of migratory behavior, which in turn will vary in response to fluctuations in environmental parameters, such as current speed and direction and light intensity.

- Because of the schooling characteristics of shad, the magnitude of pound net catches over any given time interval may reflect the number of schools and size of schools that encounter the net; consequently, knowledge of schooling characteristics (e.g., average number of fish present in a school) may be required to accurately estimate catch efficiencies based on the number of individual shad captured.

- Because the gear is stationary, its placement is critical in establishing the probability of capturing shad. Watermen traditionally fish certain locations in a given river system based on their familiarity with these locations, past harvest history or anecdotal information. Because of numerous fishery closures during the past decades and the significant decline in the number of watermen who still fish pound nets in Chesapeake Bay tributaries, sites where shad harvest is highly likely may not be known for all tributaries. To the extent possible, good sites may be selected by hiring retired watermen who are familiar with the tributaries of interest to either operate the pound nets or at least give advice to resource management agency staff on where the pound nets should be set. In the absence of such knowledge, extensive trial-and-error sampling may be required to establish the best pound net locations. With small shad stocks, the absence of catch at a particular site could result either from the net being set in an inappropriate location or from a lack of fish; an independent documentation of shad stock size abundance (e.g., a gill netting effort) would have to be conducted concurrently to distinguish between these alternative interpretations of lack of catch. It may also be possible to obtain harvest and effort information for past years from active and retired watermen who kept records of their pound net catches.

We have been unable to locate in the literature any instance where catch in stationary gear (e.g., pound nets, floating fish traps) has been used in conjunction with measured catch efficiency to estimate fish stock abundance directly (many studies employed such gear in stock status monitoring or as sampling gear for tag and recapture studies). We see no precedent for using pound nets to estimate stock size; however, because pound nets are a good gear for catching shad, some measure of catch rate (e.g., average catch/day over the season; total catch per season; number of days fished on which any shad were captured) might be useful for monitoring changes in stock status. The most recent data relating to this issue was presented in Markham and Weinrich (1994). They reported that pound net CPUE in the Upper Bay showed no linear trend over the time period during which their Peterson population estimates increased dramatically, and that there was only a weak correlation (Kendall's coefficient of rank correlation = 0.524, $p = 0.099$) between the pound net CPUE and the population abundance resulting from their tag and recapture program.

For such metrics to be most useful, some means of validating or establishing ordinal value (i.e., double the metric equates to what change in stock size) would be necessary. The single current means of establishing American shad stock size in Chesapeake Bay is through tag and recapture programs, such as the current one for the place for the Upper bay shad stock. The high cost of this type of abundance estimation program makes the implementing of such efforts in all Bay tributaries infeasible each year. Tag and recapture studies conducted occasionally in a random sample of tributaries, in conjunction with regular annual pound net monitoring programs in all tributaries, could, over a period of years, provide the basis for developing meaningful pound net-based adult abundance metrics for each Bay tributary.

We propose that all eight tributaries included in this document be monitored by pound nets, and that costly tag and recapture studies be conducted in a randomly-selected subset of tributaries (*n*). To take into account the high cost associated with tag and recapture studies, a suitable choice of sample size within a year may be *n* = 2 tributaries. The tag and recapture studies should yield relatively accurate estimates of the absolute adult shad abundance (*y*) for each of the *n* tributaries. Furthermore, the random selection of tributaries (*Y*) in which to conduct tag and recapture studies will allow the estimation of the average adult abundance for all eight tributaries (*Y*). However, for a sample of two tributaries, this estimate is likely to be fairly imprecise. It may be possible to improve on this estimate by using the auxiliary data from the pound net monitoring program. For each tributary *i*, the pound net cpue (x_i) provides an estimate of relative adult shad abundance. An estimator for *Y* is (see Jessen, 1978, p. 139).

$$\bar{y}_L = \bar{y} + b\ (\bar{X} - \bar{x})$$

where

$\bar{y}$ = the mean of the *y*'s in the small sample of *n* tributaries

$\bar{x}$ = the mean of the *x*'s in the small sample of *n* tributaries

$\bar{X}$ = the mean of the *x*'s for all tributaries.

b = a parameter

The parameter *b* may be pre-assigned from previous knowledge (or intelligent guess-work) about the relationship between pound net and tag-recapture estimates of abundance. In simple random sampling with pre-assigned $b = b_0$ (<u>not</u> necessarily representing the true slope of the relationship), the estimator is unbiased, with variance

$$Var(\bar{y}) = \frac{1-f}{n}\ (S_{yy} - 2b_0 S_{xy} + b_0^2 S_{xx})$$

where

S_{yy} = the variance of the *y*'s

S_{xx} = the variance of the *x*'s
S_{xy} = the co-variance between *x* and *y*

If the parameter *b* (i.e., the slope of the regression) is estimated from the sample, then this estimator is usually biased for $\overline{Y}$ since the regression of *y* on *x* seldom is perfectly linear. For very small values of *n*, the bias may be appreciable. A variance estimator for *y* is given by

$$\text{var}\ (\overline{y}) = \left(\frac{N - n}{N}\right) \left\{ S_y^2 (1 - R^2) \left[\frac{1}{n} + \frac{(\overline{X} - \overline{x})}{\sum (X_i - \overline{x})^2}\right] + \frac{R^2 S_y^2}{n} \right\}$$

where $\sum (X_i - \overline{x})^2$ is summed over *n*, and

N = total number of tributaries (8 for this study)

n = the number of tributaries selected for tag and recapture studies

S_y = the variance of the abundance estimates *(y)* from tag recapture studies

R = the correlation between *y* (tag recapture estimates) and *x* (catch rates from pound nets).

If the correlation is high between tag and recapture estimates of adult shad abundance (*y*) and catch rates for pound nets (*x*), then the regression approach may result in a significant improvement in estimates of overall adult abundance. In practice, however, the estimation of the slope (*b*) from the samples would only be feasible if a relatively large number of tag and recapture studies are conducted.

Suggested Further Development of American Shad Restoration Targets

The adult shad abundance estimates developed from commercial harvest data appear to be one useful option for developing stock restoration targets. The calculations performed for this technical memorandum could be refined; for example, more detailed sex-specific average weight data or more detailed sex ratios could be used. Variability of the various data inputs could be used. Variability of the various data inputs could be incorporated to generate the restoration targets in a probabilistic manner. Given that no other alternatives exist for setting population abundance targets, such refinement and its accompanying documentation should be considered, completed and evaluated.

With regard to the juvenile presence-absence analyses, tracking of stock status and progress toward restoration targets using such a metric can be initiated immediately, because the data are drawn from current field programs. Using these data for this purpose does, however, requires a consistent study design is maintained over the entire monitoring period, which could extend well into the next century. The consequences of changing sampling locations or frequency on probability of occurrence of juvenile shad probably could not be estimated or corrected for.

The absence of any usable Chesapeake Bay ichthyoplankton data for American shad (current or past) precludes further empirical analysis of this option. Ichthyoplankton programs in other mid-Atlantic tidal estuaries (e.g., the Hudson River, New York), however, have collected species-specific densities of American shad eggs and larvae. A statistical evaluation of those data may provide some insight regarding the levels of sampling required and levels of sampling required and levels of shad egg occurrence that would represent particular stock sizes.

A second means of evaluating the ichthyoplankton approach further could be derived from a theoretical perspective. Areas and volumes of shad spawning habitats in Chesapeake Bay tributaries were estimated as part of this task. Spawning stock abundance was also estimated. Fecundity estimates for shad are available in the literature and could be used to estimate the numbers of eggs that would be released into a spawning area for any given spawning stock abundance. The probability of capture of an egg, when the spawning habitat volume and egg density are known, would be a function of the temporal and spatial distribution of eggs and the temporal and spatial distribution and intensity of sampling. It may be possible to develop a model, based on these inputs and assumptions, that could predict the probability of capture of eggs as a function of stock abundance and sampling intensity. It might also be possible to validate the output of such a model against actual ichthyoplankton data from the Hudson River. A validated model of this type could then be used to develop an ichthyoplankton monitoring programs in Chesapeake Bay tributaries specifically aimed at establishing a presence-absence index of shad abundance as another means of tracking progress toward stock restoration targets.

Regarding a pound net monitoring program for adult shad, we do not believe that any further analysis would contribute to development of meaningful restoration targets (expressed as stock size) using historical data. However, a statistically rigorous study design could be developed using historical catch rates and other available data, taking into account costs of pound net placement, catch rates, catch monitoring protocols and feasibility of supplemental tag and recapture studies. Such a design could incorporate an implementation strategy that would also take into account results of ongoing studies. For example, a substantial increase in the frequency of occurrence of juvenile shad in the striped bass seine survey in a tributary where no shad had been taken for many years could serve as a trigger for implementing a pound net survey, either by itself or in conjunction with a tag and recapture study, to estimate adult abundance. Such a design could also allow for iterative modification, in which the design could be modified as data are collected and findings analyzed.

The data sets employed to explore these stock restoration target options would also provide data about several other key fish species in the Bay. It might be useful to apply these same procedures and evaluate the results if stock restoration or protection targets are developed for these species.

Utility and Application of American Shad Restoration Targets to Management

The focus of this Technical Memorandum has been on the development of quantitative measures of shad stock status in Chesapeake Bay tributaries that could be used to develop restoration targets. Such measures are intended to serve as metrics to track progress over time in the restoration of these shad stocks. Targets developed from those metrics are intended to indicate restoration status. We have attempted to develop quantitative targets that, if achieved at some time in the future, would suggest that shad stocks are at levels comparable to those that occurred in the relatively recent past when shad stocks were generally considered to be at more "healthy" abundance levels than they are today.

Shad stock status metrics and restoration targets provide a basis for assessing the extent to which resource management activities and water quality improvement programs in Chesapeake Bay and its tributaries have had quantifiable beneficial effects on this important anadromous fish species. The development of comparable metrics and targets for other important fish species would contribute to assessing the overall success of management actions and water quality improvements in enhancing major exploited living resources. These metrics and targets could also contribute to the development and implementation of appropriate management strategies for each species.

By far the most detailed stock status information ever developed for any fish species in the Bay has been for striped bass. A wide array of stock status, composition and abundance surveys have been conducted, beginning as early as 1954. As a result, a meaningful recruitment index and spawning stock composition and biomass measures have been developed and used to track changes in stock status. These measures have, in turn, provided quantitative milestones which, when attained, triggered changes in management measures controlling exploitation (ASMFC 1990). For example, under Amendment 4 to the ASMFC Interstate Striped Bass Management Plan, severe restrictions on striped bass harvest, including moratoria in some states and very large size limits in others, were lifted when the juvenile index (catch per unit effort of juvenile striped bass in a standardized seine survey conducted in striped bass spawning areas) reached a certain level. At that point, the stock was considered to have increased to a size that could sustain a limited level of fishing mortality (the instantaneous exploitation rate target was set at 0.25). The fishery permitted at that point was designed to allow for harvest levels that would result in an exploitation rate not exceeding 0.25. At a fully-restored stock level, population modeling suggested that the striped bass stock could experience an instantaneous exploitation rate of 0.50 without a resultant decline in stock abundance. Although the east coast (including Chesapeake Bay) striped bass stock was officially declared to be "fully restored" by ASMFC as of 1 January 1995, proposed relaxation of harvest restrictions are being approached very cautiously to ensure that exploitation rates will not exceed the ultimate target level of 0.50. An increase in the instantaneous exploitation rate to an interim level of 0.375 is being considered.

In the case of American shad, the ASMFC Fishery Management Plan for Anadromous Alosid Stocks of the Eastern United States (1985) established target exploitation rates for shad stocks at different abundance levels: no exploitation should be allowed of "severely depleted" stocks; a maximum annual exploitation rate of 25% was established for stock considered "depleted" or "newly established"; and, a maximum annual exploitation rate of 40% was specified for stocks exhibiting "no perceived decline"(i.e., those considered to be at "healthy" levels). The 40% rate was based on analysis of all historical data on exploitation rates experienced by stocks that remained at stable levels over long periods of time and it thus has a relatively strong scientific basis. The 25% allowable exploitation rate for depleted stocks was selected subjectively as an intermediate rate that would likely allow for continued population growth and stock recovery, based on the opinions of the fisheries biologists contributing to development of the management plan. This intermediate target exploitation rate was not derived from quantitative analysis or population modeling. Chesapeake Bay shad stocks are clearly in the severely depleted category.

While this Technical Memorandum was not prepared for the purpose of recommending changes in the current management strategies for Chesapeake Bay American shad, we believe that the stock status metrics and restoration targets developed here could be applied to shad management in much the same manner that comparable stock status indicators have been used in the management of striped bass. That is, attainment of a "fully restored" stock status target level (whatever that level may be), whether it be adult abundance or some specified frequency of occurrence of shad juveniles in the striped bass seine survey, could be considered as at least one trigger for reopening the fishery and allowing an initial annual exploitation rate of 10 or 25%, and an ultimate annual exploitation rate not exceeding 40%. Given Maryland's and Virginia's experiences in striped bass management, it is clear that lifting the current moratoria on shad harvests would have to be accompanied by rigid control of the newly opened fishery in order to ensure that the prescribed exploitation rates are not exceeded and further stock expansion is not impeded.

There are a number of limitations on the application of stock restoration targets described in this document to management of Chesapeake Bay shad in this manner. We have addressed Bay shad as consisting of individual tributary stocks, yet historical fisheries for this species have taken place throughout the Bay and have been exercised in many locations at which several tributary stocks are likely to have been vulnerable to capture at the same locations. Thus, newly opened shad fisheries may have to be restricted to specific tributary waters (based on tributary-specific stock status metrics), which poses significant enforcement problems (e.g., it would be difficult to document the waters from which shad in possession had been taken). Monitoring exploitation rates on a tributary-specific basis would also be very difficult, especially given the high natural mortality (i.e., low repeat spawning percentage) typical of Chesapeake Bay shad stocks[5]. In contrast, striped bass stocks are managed on a coast-wide basis, thus simplifying regulation and enforcement. Despite these potential difficulties, protection of specific Bay tributary stocks of shad that remain in very depleted condition will require continued closure of any fisheries to which those stocks might be exposed (including the coastal intercept fisheries) and limiting any initial lifting of moratoria on harvesting to main bodies of specific tributaries.

By far the greatest potential complications for management of Chesapeake Bay shad stocks will likely occur in the Upper Bay area, where adult shad destined for the riverine portion of the

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[5]Because striped bass are long-lived and spawn many times, exploitation rates are established by tracking the changes in relative abundance of different year=classes as they pass through the fishery over many years; such an approach would be difficult to apply to American shad, for which repeat spawners historically have made up less than 20% of any annual run.

Susquehanna River, upstream of Conowingo Dam are already and will continue to be mixed with adult shad spawned in the Upper Bay, downstream of Conowingo Dam. Kahn and Weinrich (1994) suggested that 20% to 50% of the adult shad present in or passing through the Upper Bay during the spring spawning migration may currently be of Upper Bay origin. Presumably, the rest are of riverine Susquehanna River origin. Any shad fishery opened in the Upper Bay and in the Maryland portion of the Susquehanna River below Conowingo dam will exploit both stocks. Thus, any restoration targets used to trigger changes in management strategies must account for the status of both stocks. Our estimate of about 1.2 million adults as a Tier 2 mostly restored stock level in the Upper Bay (Table 10) must be considered in combination with the separate restoration target of 2 million fish established by the Susquehanna River alosid restoration program for the riverine Susquehanna River shad stock. Thus, the combined "fully restored" stock level for the Upper Bay and Susquehanna River, at which an annual exploitation rate of 40% would be acceptable would be at least 3.2 million fish (and probably higher) with much more restricted harvest levels being appropriate at lower stock abundance levels. Detailed population modeling and stock assessment calculations will be required to establish the consequences of lower annual exploitation rates (e.g., 25%) on the potential growth rates of partially or mostly restored shad stocks still undergoing recovery.

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