Fishery Management Report No. 68
of the

Atlantic States Marine Fisheries Commission

ASMFC Breeding and Stocking Protocol for Cultured Atlantic Sturgeon

May 1996

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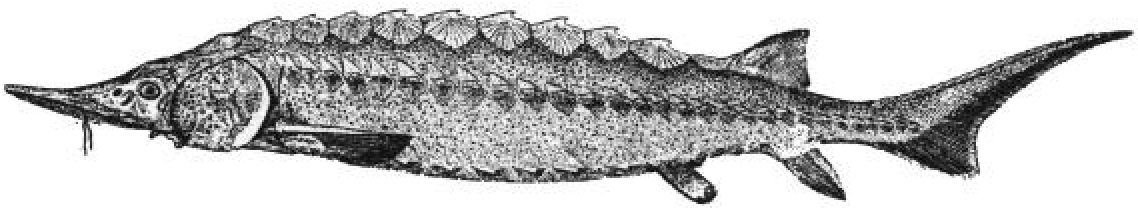

May 1996

This document was prepared by the Atlantic States Marine Fisheries Commission's Atlantic Sturgeon Aquaculture and Stocking Committee.

A report of the Atlantic States Marine Fisheries Commission pursuant to U.S. Department of Commerce, National Oceanic and Atmospheric Administration Award No. NA67 FGO 137.

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Whenever possible, use brood fish from the same river in which stocking will occur. When this is not possible, the source of brood fish used to culture progeny should be taken from the same regional grouping as the area being stocked.

Recommendation 2:

With regard to stocking programs, highest priority should be placed on populations perceived to be extirpated, and a secondary priority should be placed on populations exhibiting little, if any, natural reproduction.

Recommendation 3:

The minimum generation effective population size of brood fish to be used in culture for stocking programs should be 100 (with an inbreeding rate of 0.50%). Year class effective population sizes should be at least six (preferably 3 of each sex). However, year class effective population sizes of six or greater also maybe obtained using unbalanced sex ratios (see Table 1). Fishery agencies undertaking culture programs for Atlantic sturgeon should commit to the necessary number of years of stocking (given excepted year class effective population sizes, see Table 2) to achieve the targeted generation effective population size. For example, 10 years at year class effective population size of 10.

Recommendation 4:

If fewer breeding fish are available than prescribed by Recommendation 3, their progeny may be used for captive research (i.e., not released into public waters) or provided to private aquaculture interests for captive use.

Recommendation 5:

Any jurisdiction wishing to conduct Atlantic sturgeon stocking projects for research or restoration purposes should first provide a detailed proposal to ASMFC for review and approval. Such proposals should include goals and objectives, methodologies, monitoring programs, and timelines. Proposals shall be reviewed by the ASMFC Atlantic Sturgeon Aquaculture and Stocking committee and approved by the Atlantic Sturgeon Management Board.

Recommendation 6:

Jurisdictions involved in sturgeon culture and stocking programs should annually monitor the status of their populations and the effects of stocking. Monitoring results should be reported annually to ASMFC by July 1.

Recommendation 7:

Sturgeon brood fish should be spawned only once and healthy survivors should be externally marked and returned to their river of origin whenever feasible.

Recommendation 8:

Initial stockings of cultured Atlantic sturgeon should be limited to 50,000 fingerlings per breeding female per season for each receiving water, and sperm from multiple male spawners should not be mixed for artificial fertilization. All fish destined for stocking should be distinctively marked or ta2ged to at least d time and 12arental origin.

BREEDING AND STOCKING PROTOCOL FOR CULTURED ATLANTIC STURGEON

INTRODUCTION

Atlantic sturgeon populations on the East Coast of the United States are severely depressed. In 1992, the Atlantic States Marine Fisheries Commission (ASMFC) Policy Board accepted recommendations from the Atlantic Sturgeon Aquaculture and Stocking Committee which included preparation of a separate discussion paper to address possible inter-basin transfer of broodstock and/or hatchery produced progeny and other interjurisdictional problems related to stocking of sturgeon. The purpose of this document is to review and recommend culture and stocking strategies for Atlantic sturgeon.

BACKGROUND

The ASMFC adopted a Fishery Management Plan for Atlantic Sturgeon (ASMFC, 1990) which included numerous recommendations focused on rebuilding fisheries through harvest control, identification and protection of essential habitats, basic life history research, stock identification, and defining the role of aquaculture in restoration. Three recommendations specifically addressed the latter need:

- The ASMFC should encourage an expanded aquaculture effort to develop techniques to rear Atlantic sturgeon and evaluate fish for stock restoration.
- The ASMFC should encourage aquaculture research to identify and control early life stage diseases, synchronize spawning times of males and females, and reduce handling stress problems.
- The ASMFC should establish an aquaculture and stocking committee to provide guidelines for aquaculture and restoration stocking of sturgeon.

With this identified need to further evaluate the role of aquaculture in Atlantic sturgeon recovery, ASMFC established an Atlantic Sturgeon Aquaculture and Stocking Committee. This committee, comprised of eight states and federal biologists, defined six broad problem areas and developed numerous recommendations to address them. These were reported in "Recommendations Concerning the Culture and Stocking of Atlantic Sturgeon" which was accepted by the Policy Board (ASMFC, 1992).

Many of the culture recommendations in the cited report encouraged state and federal agencies to develop techniques for broodfish collection and holding, induced spawning and sperm preservation, incubation, hatching, and rearing of Atlantic sturgeon. However, recommendations related to stocking the cultured progeny or excess wild broodfish were necessarily cautious and included:

- If management units are defined by river then genetic integrity of stocks within river basins should be maintained by stocking only progeny of native broodstock.

- If genetic substructure exists then restoration programs should employ only genetically compatible stocking (i.e., reintroduction of progeny cultured from one stock into waters inhabited by that same stock).

- If native broodstock no longer exist, or are in such low abundance as to preclude effective collection, priority should be given to stocking fish from adjacent, hydrologically similar river systems.

- Broodstock should be collected at times and in numbers that do not unduly stress the native population yet adequately represent the inherent variation of that stock.

- An adequate effective breeding population size should be maintained to the extent possible in culturing Atlantic sturgeon for restoration purposes so that genetic integrity of the local recipient stock is maintained.

Achieving these conservative stocking strategies requires that (1) stock discrimination analysis should be completed for viable Atlantic sturgeon populations on the Atlantic Coast; (2) within river genetic variation should be described for potential donor and recipient waters; (3) the relative breeding population sizes of existing sturgeon stocks should be adequately assessed; and (4) consideration should be given to interbasin transplants from hydrologically similar river systems, or at least those from adjacent or nearby waters.

The first need expressed above is being addressed but is currently limited to a few systems. Based on frequencies of mitochondrial DNA restriction endonuclease analysis, Waldman et al. (1996) demonstrated geographic heterogeneity between the St. John River (New Brunswick), the Hudson River, and several Georgia rivers. In the Georgia analysis, it appeared that fish from the Altamaha differed from the Savannah, Ogeechee and Satilla for at least one restriction enzyme (Hinf I), but numbers of samples from the latter three rivers were very small. Final interpretation will require larger samples sizes. Waldman et al. (in press) addressed the second information need for two sites on the Hudson River and found that genotype frequencies for five restriction enzymes were homogenous. Similar results were found for lake sturgeon in the St. Lawrence River system (Guenette et al., 1993). An extensive 3-year study on sturgeon stocks of the Hudson River, funded by the Hudson River Foundation, is partially directed at the third need (population size) but no other rivers are being similarly assessed. Few efforts have yet been made to characterize and compare sturgeon habitat, behavioral preferences, or river similarities.

> ***Until sufficient numbers of sturgeon specimens can be collected and analyzed from additional rivers, we should assume that there exists at least regional, if not river-specific heterogeneity.***

It is recognized that ASMFC-recommended and state-imposed fishery restrictions and supplemental stocking alone will not rebuild populations if essential habitats remain degraded or unusable:

> ***None of the recommendations in this report are intended to replace the need to identify and protect essential spawning, nursery, riverine feeding/rearing, or ocean staging habitats, or to conduct research necessary to fill vital life history information gaps for this species. In some instances, resolution of habitat concerns may be a prerequisite to initiation of sturgeon stocking.***

CURRENT STURGEON CULTURE PROGRAMS

In cooperation with several states, experimental sturgeon culture is currently being conducted by the U. S. Fish and Wildlife Service (USFWS) and the National Biological Service at sites in Massachusetts, Pennsylvania, Virginia, South Carolina, and Florida (Gulf subspecies). Some of this work has resulted in broodfish collection, sperm preservation, induced spawning, hatching, and culture of 1+ year old sturgeon. Wild caught adult and sub-adult Atlantic sturgeon have been successfully held in captivity on artificial feeds for over 5 years.

Techniques are being refined for broodfish collection, holding and hauling; induced ovulation, fertilization, and sperm preservation; hatching and culture of progeny including larval and juvenile diet development, feeding rates, and rearing densities; wild and cultured fish disease assessment; juvenile tagging and tag retention analysis. Juvenile sturgeon are being held to determine if captive broodfish can be reared for future production. The USFWS intends to develop a culture manual for Atlantic sturgeon for use by interested states, the federal government, and private concerns.

Although the USFWS does not have a specific production or stocking goal, substantial numbers of juvenile Atlantic sturgeon could result from these studies. If this occurs, excess fish could either be provided to private aquaculture interests or used to test the concept of stock enhancement, or they may be destroyed. Thus, there is the need for development and approval of culture and stocking protocols for this species.

REASONS FOR CULTURE AND STOCKING

Atlantic sturgeon stocks appear to be at extremely low levels throughout most of their range and the species is highly susceptible to fishing and human-induced habitat perturbations (Smith and Clugston 1994). Most ASMFC jurisdictions have either closed their fisheries or imposed a 7-ft. TL minimum size limit to increase the likelihood that fish can spawn at least once prior to being exposed to harvest. In recent years, New York and New Jersey accounted for more than 90% of total landings with a 5-ft. minimum size limit, seasons, quotas and mandatory reporting. Continued declines in the Hudson River sturgeon population and general ineffectiveness of ASMFC plan recommendations prompted the Atlantic Sturgeon Management Board to request that, effective March 11, 1996, all jurisdictions should impose a two-year moratorium on sturgeon fishing while the FMP is amended.

Artificial propagation of Atlantic sturgeon has the potential for meeting basic needs related to stock conservation. A primary purpose may be to provide a means of reintroducing this species to waters which historically supported Atlantic sturgeon, but whose natural stock is either extirpated, or in extremely low abundance. Lack of fish may preclude effective genetic analysis of these stocks. Other purposes for artificial propagation might include production of fish for various research studies (e.g. environmental tolerance, toxicity evaluation, behavior, tag retention, etc.), as well as to provide fish to the private aquaculture community for production of sturgeon flesh and caviar. The research activities will help elucidate life history and ecological characteristics of the species while the private aquaculture aspect has the potential to reduce reliance on commercial fisheries and avoid the threat of introducing exotic sturgeons and their diseases to the East Coast.

GENETIC CONSIDERATIONS

Discrimination of stocks based on DNA analysis (Waldman et al. 1996), although incomplete for the Atlantic Coast, supports the concept that like other anadromous fish, Atlantic sturgeon have some genetic characteristics that are unique to individual rivers (e.g., Hudson, St. John) or at least regions (e.g., Georgia coastal rivers). Extreme care must be taken in culture and stocking programs to insure against excessive inbreeding, loss of genetic diversity, or diminished survival, yield, or reproduction of remnant wild stocks. Kapuscinski and Jacobson (1987) point out that reproduction of fish destined for slaughter (e.g., private aquaculture) is not important, but the fitness of fish used as broodstock or for production of progeny for stocking is extremely important because the fitness of future generations depends upon genetic characteristics of the present generation.

Selection Criteria

Fitness of stocked fish may be less than that of the wild population in a particular location. If the stocked fish are poorly adapted to their new environment and the numbers stocked are large compared to natural production, long-term fitness and adaptability of the population may be diminished. Krueger et al. (1981) suggest that the best way to insure that stocked fish will have high fitness for a particular environment is to use wild fish from the same environment as broodstock. If wild broodstock are too scarce to achieve minimum effective population sizes, then several options can be considered. These include using broodstock only from similar or nearby environments, crossing wild x hatchery strains, mixing gametes from many populations, or maximizing genetic differences between mated pairs based on DNA analysis of individual spawners. For each of these alternatives, Krueger et al. (1981) recommended that mature broodstock be randomly selected from wild populations to avoid inadvertent selection for body size, spawning time, or site-specific variations, and that the hatchery rearing period should be minimized to reduce domestication.

With regard to artificial selection and hybridization programs to enhance management of fisheries, Hynes et al. (1981) provided the following general cautions:

- It is difficult to increase fitness of a population that is already well adapted to its environment.
- Selection programs invariably reduce the effective population size and encourage inbreeding and loss of genetic diversity.
- Artificial selection is difficult and inefficient for species with complex life histories because they cannot be maintained in a hatchery during their entire life cycle.
- Detrimental effects due to culture in an artificial environment accumulate with time.
- It is hard to obtain large selection differentials and responses to selection when spawners must be obtained from relatively small populations.

Inbreeding

Inbreeding is the most important genetic concern in hatchery management, resulting in a loss of genetic diversity (inbreeding depression) and increased homozygosity (Kapuscinski and Jacobson, 1987). Under certain conditions, inbreeding may be cumulative because it can increase from one generation to the next. The rate of inbreeding in a population depends on the effective size of the population such that: ÿF = $1/(2N_e)$ where ÿF is the rate of inbreeding per generation and N_e is the effective population size (see below).

The principal factors affecting inbreeding and effective size of hatchery populations are the number of wild broodfish used for hatchery production, the sex ratio, variation in the reproductive success of individual spawners, and in the case of long-term captive broodstock, the size of the founding population.

Effective Population Size and Sex Ratios

Effective population size is the size of an ideal random mating population that would experience genetic drift and inbreeding at the same rate as the real population under consideration. In a large naturally self-sustaining population with no variation in reproductive success, non-overlapping generations, and balanced sex ratios, the effective population size is the total number of adult spawning individuals in that population. This idealized natural population probably does not exist for Atlantic sturgeon. Although it may be possible and certainly desirable to use large numbers of broodfish in hatchery production programs, unbalanced sex ratios reduce the effective population size and increase the rate of inbreeding such that:

$$1/N_e = 1/(4N_m) + 1/(4N_f) \qquad \text{and, ÿ}F = 1/(2N_e) = 1/(8N_m) + 1/(8N_f)$$

where N_m = number of males and N_f = number of females

When sex ratios are balanced ($N_m = N_f$), then $1/N_e = 1/N$ and ÿF = $1/(2N)$. Some sturgeon populations may show a preponderance of males on the spawning grounds (Doroshov and Van Eenennam 1994). Although artificial culture programs for this species should strive to use equal numbers of male and female broodfish whenever possible, use of sperm from multiple donors from populations where males are non-limiting will enhance the effective population size. Table 1 shows the effective population number based on small numbers of males and females used to produce <u>one</u> progeny year- class (Kincaid 1993).

The concept of effective population size (N_e) is used to determine the number of individuals transmitting genetic material from parent generation to progeny generation. In long-lived species such as Atlantic sturgeon multiple year-classes will contribute to the same progeny generation, and the generation N_e will be the sum of year-class increments ($N_{e,GI}$) over the generational interval for the population. Generation interval (GI) is the average age of females at first maturity, i.e. average age of females (in years) in the progeny (F_1) generation when they mature and begin to produce the next (F_2) generation. As a result, the generation N_e can be calculated as:

$$N_{e(GEN)} = \text{ÿ} (N_{e,1} + N_{e,2} + N_{e,3} + \text{- - - - - - -} \; N_{e,GI})$$

The assumptions are that (1) individuals spawn once per generation, (2) matings occur randomly within each year-class, (3) survival across year-classes is equal, and (4) there is no migration, mutation, or selection. Generation N_e is very important to the discussion of artificial sturgeon breeding populations since relatively small numbers of parents mated each year are additive to future year pairings (Table 2). For example, if researchers successfully mated only four females and four males each year over the course of a generation interval (say 15 years), the year-class N_e would only be 8 (ÿF = 6%), but the generation N_e would be 120 with ÿF = 0.42%.

Geneticists differ in their opinion as to the minimum effective population size for restoration stocking purposes but agree that N_e should be as large as possible to minimize loss of genetic diversity. Although domestic animals tolerate inbreeding at a rate of about 1% per generation (N_e = 50) without showing inbreeding depression (Kapuscinski and Jacobson 1987), Kincaid (1983) suggested a minimum effective size of a breeding population of at least 100 individuals (equivalent to ÿF = 0.5%) for enhancement of wild stocks. Moreover, Kapuscinski and Lannan (1986) recommended minimum effective population sizes of more than 100 for hatchery fish, and Gharrett and Shirley (1985) support values ranging from 60 to 200. Kincaid (1983) suggest two general approaches to minimizing inbreeding in captive hatchery populations; (1) random matings from large populations, and (2) rotational line crossing to minimize matings between related individuals.

STURGEON AVAILABILITY

Atlantic sturgeon are large, long-lived fish whose spawning populations are composed of many age classes. Riverine spawning and nursery habitat is poorly defined. Naturally occurring remnant stocks appear to be extremely depressed in relation to historic abundance and individual population sizes and sex ratios of wild stocks are generally unknown. Based on current research and commercial fisheries data, the largest U. S. breeding population appears to occur in the Hudson River. Mature fish are also taken from commercial fisheries and directed research netting in the Altamaha and Ogeechee Rivers in Georgia. State and federal sponsored research and incidental netting of juvenile and/or adult Atlantic sturgeon in recent years indicate that reproducing populations also occur in the Savannah River (GA/SC), the Winyah Bay system, the Ashepoo/Combahee/Edisto (ACE) system of South Carolina, the Cape Fear River of North Carolina, and the Androscoggin and Kennebec Rivers of Maine. Atlantic sturgeon are only rarely observed elsewhere along the coast including the Merrimack River, the Connecticut River, the Chesapeake Bay, and other coastal rivers of North Carolina. Although juvenile Atlantic sturgeon appear abundant in the upper Delaware Bay, mtDNA analysis (Waldman et al. in press) and tag returns from distant waters (Delaware DNR data) suggest that many of these may be migrants from a mixture of other systems, particularly the Hudson.

Literature cited in the Genetics section is compelling with regard to the desirability of using large effective population sizes and reducing inbreeding in culture situations. However, many pragmatic considerations affect achievement of this goal for Atlantic sturgeon including:

- Broodfish are often difficult to collect due to low abundance - lack of defined spawning areas.
- Adult fish collected are not necessarily mature.
- Both sexes are not necessarily available at the same time.
- Special (and expensive) hauling and holding facilities are needed.

- Development of captive broodstock populations may require 10 or more years.
- Maintaining large numbers of broodfish for each strain requires large and costly facilities.
- Long-term sperm preservation and spawning techniques are not yet refined.

With regard to artificial culture, the major conflict, which must be resolved by sturgeon managers, is to choose between what is genetically desirable as opposed to accepting logistical constraints regarding broodstock availability. Based on current knowledge of the various stocks, it is unlikely that individual year-class artificial breeding populations of more than 10 fish (e.g. 5 pairs) could be acquired for any given river system in any one season.

High inbreeding rates may occur over several generations from single year-class production. However, since males and female sturgeon mature at different ages, the probability of sibling matings is reduced from random as the numbers of spawning fish increase due to multiple year-class production and stocking. The key to reducing inbreeding while using small numbers of available brood fish each year is to commit to a long-term program (10+ years) of brood collection, spawning, and stocking to create a large generation effective population size. In this scenario, brood fish must only be used once.

STOCK CHARACTERIZATION

Atlantic sturgeon population sizes have not yet been estimated for any stock. Nevertheless, those stocks being considered for reintroduction or restoration stocking can be separated into two categories:

(1) Possibly extirpated (e.g., Susquehanna and other northern Chesapeake tributaries, St. Marys). This is the **re-introduction** category.

(2) Very small with only minimal (if any) natural reproduction (e.g., Gulf of Maine rivers, the Connecticut River and other southern New England tributaries, the Delaware River, southern Chesapeake Bay and North Carolina coastal tributaries). This is the **restoration** category.

It should be recognized that collection of sufficient numbers of sturgeon specimens for comparative genetic analysis may never be accomplished as these stocks continue to deteriorate, and that a culture and stocking initiative may be immediately warranted to avoid further extirpations. Because of regional genetic similarities noted by Waldman et al. (1996) and until a more comprehensive genetic analysis is completed, consideration should be given to grouping regional populations for artificial breeding purposes as follows:

- Gulf of Maine including St. John River, Maine rivers, and the Merrimack River

- Mid-Atlantic including the Hudson River and southern New England rivers draining into Long Island Sound, the Delaware River and Chesapeake Bay

- South Atlantic rivers of North and South Carolina, Georgia, and Florida

ECOLOGICAL CONSIDERATIONS

Genetic similarities between stocks do not necessarily indicate fitness for survival in waters targeted for inter-basin transplants of cultured sturgeon. It is likely that certain behavioral characteristics are adaptive to individual river environmental conditions. Factors such as migration distance, water depth, flow rates, substrate composition, and other spawning and nursery habitat conditions should be evaluated and considered in selection of donor stocks. Wherever possible, habitat limitations should be evaluated prior to initiation of reintroduction or restoration stocking.

BROODFISH SELECTION AND MINIMUM NUMBERS

Federal and state agencies with the capability to initiate culture and stocking of Atlantic sturgeon should be encouraged to proceed, but to follow recommendations in this Protocol.

Recommendation 1:

Whenever possible, use broodfish from the same river in which stocking will occur. When this is not possible, the source of broodfish used to produce fish for stocking should be taken from the same regional genetic grouping as the area being stocked.

Recommendation 2:

With regard to stocking programs, highest priority should be placed on populations believed to be extirpated with a lower priority placed on populations exhibiting little, if any, natural reproduction .

Recommendations above are not intended to preclude states from independently moving forward with sturgeon stock enhancement efforts in their waters. However, if stock size and natural reproductive capability are known to be adversely affected by habitat degradation and/or excessive fishing mortality, culture initiatives should be closely tied to measures aimed at remediating those problems. Suggested potential broodfish donor and progeny recipient locations are shown in Table 3. It is recognized that this listing is subject to change as information becomes available regarding status and genetics of specific stocks.

Fishery agencies which embark on sturgeon culture and stocking should recognize the desirability of either working with large numbers of broodfish to maximize N_e, or by continuing their effort with smaller numbers of broodfish for many years. Either way this will reduce the rate of inbreeding. Current status of stocks suggests that large numbers of broodfish from any source are likely not available in the near-term. Maximizing generation N_e by using smaller numbers of brood fish each year is, for many donor waters, achievable, desirable, and less costly on an annual basis, but requires a long-term commitment.

Recommendation 3:

The minimum effective population size of brood fish to be used in culture for stocking programs should be 100 (with an inbreeding rate of 0.50%). Year class effective population sizes should be at least six (preferably three of each sex). Year class effective population sizes of six or greater may be obtained using unbalanced sex ratios (see Table 1), but sperm from multiple male donors should not be mixed for artificial fertilization.

<u>Recommendation 4</u>:

Agencies involved with stocking programs for Atlantic sturgeon should commit to the necessary period of time to achieve the desired generation effective population size (see Table 2). For example, 10 years at an average year class effective population size of 10.

<u>Recommendation 5</u>:

If fewer breeding fish are available than prescribed in Recommendation 3, their progeny may be used for captive research (i. e. not released into public waters) or provided to private aquaculture interests for captive use.

<u>Recommendation 6</u>:

Broodfish should be spawned only once and after spawning they should be externally marked and returned to their river of origin whenever feasible.

Additional considerations may include using cryopreserved sperm from many different males each year to increase donor numbers (N_m), or possibly cross-breeding sturgeon from different stocks within the same regional groupings.

STOCKING NUMBERS AND SIZES

As noted above, to minimize inbreeding effects from small year-class breeding populations, stocking for re-introduction or restoration purposes should be planned as a long-term effort (10+ years). This lengthy commitment is also desirable due to life history characteristics of Atlantic sturgeon (long-lived, slow growing, late maturing, periodic spawning) which requires considerable time to evaluate success and because of large costs associated with establishing culture and holding facilities.

Basic information on natural reproduction parameters (fertilization rate, hatch rate, larval and juvenile mortality rates, etc.) are lacking for this species. Artificial production from even a few large female sturgeon could amount to hundreds of thousands of juveniles for release as small fingerlings. Since natural reproduction appears to be weak in most rivers targeted for restoration or enhancement, these stockings may substantially increase ultimate population sizes. Adverse impacts associated with potential inbreeding depression and alteration of reproductive fitness of the resultant mixed populations is minimized by multi-year stockings over the course of the generation interval.

There is no magic formula for determining the best number, size, or age of Atlantic sturgeon for stocking. Based on the recent experience at the USFWS Northeast Fishery Center (Mohler, et al. in prep.), 2-3" fish can be reared in about 60 days; 4-6" fish in 120 days; and yearlings achieved an average size of about 16-18". Stocking of fry reduces adverse impacts associated with domestication but exposes them to higher in-stream mortality (predation and food competition). Larger stocked juveniles may out-compete wild fish of the same age for food due to their greater average size, but this advantage may be offset by a relative lack of fitness for survival in the wild.

Information is not currently available regarding natural rates of egg deposition, fertilization, hatching, or survival of larvae and early juveniles. Stocking rates proposed assume that in the wild, an average sturgeon female may spawn 500,000 eggs with one or several males, and that natural mortality of eggs and progeny for the first 90-120 days may amount to 90%.

Although males may not mature for 8-10 years and females for 15-20 years, it is believed that survival of marked-stocked sturgeons and their relative abundance in the mixed populations can be adequately evaluated within about 10 years. Natal stream fidelity is implied but not yet proven. If this does occur, it is uncertain when or how fish become imprinted. Managers must determine preferred stocking locations (freshwater vs. estuarine) and seasons to coincide with habitat requirements and food availability.

In order to determine effectiveness of sturgeon stocking, tagging or marking and follow-up evaluation must be essential components of population enhancement programs. Large lots of small sturgeon in hatcheries can be marked with coded wire tags (CWT). Larger fingerlings could accommodate streamer tags and/or PIT tags, but substantially higher costs are involved with the latter. Although CWT's are inexpensive, they must be surgically removed for microscopic examination of codes. The USFWS is currently evaluating tag retention rates for these and other visible tag combinations and will recommend best marking strategies.

Recommendation 7:

In order to avoid gene swamping from small numbers of breeding pairs, numbers of progeny stocked from individual matings in any one year should be within 50% of each other, not to exceed 50,000 fish per pair. All fish stocked should be distinctively marked or tagged to at least indicate release location and time and parental origin.

PLANNING AND EVALUATION

Affected ASMFC states and federal agencies should work cooperatively in sturgeon culture, marking, stocking, evaluation, and research. Jurisdictions contemplating culture and stocking of Atlantic sturgeon should prepare stock reintroduction or restoration plans which specify measures of success. These 'goals' may include such factors as desired numbers of spawning adults, presence of numerous year classes, and specified improvement in rates of natural reproduction. Evaluation needs may include characterization of habitat requirements and availability, impacts of dams and pollution, food sources and preferences, predator-prey relations, juvenile mortality rates, relative survival and growth of stocked versus natural fish, and relative contribution of cultured fish to future spawning classes.

Recommendation 8:

Management jurisdictions involved in culture and stocking programs for Atlantic sturgeon should annually monitor the status of their populations and the effects of stocking. They should provide a detailed proposal to ASMFC for review which includes goals and objectives, methods, monitoring activities, and timelines. Monitoring results should be reported to ASMFC each year by July 1.

SUMMARY

Artificial culture and stocking of Atlantic sturgeon may play an important role in re-introduction or restoration of populations which are currently at or near all time low levels. Technology for such culture is being developed, but major difficulties exist in securing adequate numbers of broodfish from most populations.

Genetic differentiation of sturgeon populations on the East Coast should be completed so that natural breeding stocks can be fully defined. Until that time, donor and recipient rivers should be consolidated as regional geographic units.

Desirable minimum year-class effective population sizes for artificial culture will be difficult to achieve. Effective generational populations can be developed using relatively small numbers of brood fish each year for 10+ years. Highest emphasis should be placed on stocking of rivers having suitable spawning and nursery habitat but whose natural populations are presumed to be extirpated or at very low abundance. Intensive hatchery product evaluation must be an essential component of these stocking programs.

Recommendations provided in this Protocol should not be construed as replacing or precluding other management options including the closure of fisheries and monitoring the effects of such closures.

LITERATURE CITED

ASMFC, 1992. Recommendations concerning the culture and stocking of Atlantic sturgeon. Spec. Rep. No. 22. Dec. 1992: 20p.

ASMFC, 1990. Fishery management plan for Atlantic sturgeon. Fish. Mgmt. Rep. No. 17. Nov. 1990: 73p.

Doroshov, S., and J. Van Eenennam, 1994. Reproductive conditions of the Atlantic sturgeon stock in the Hudson River. Unpublished Year 2 Contract Report to the Hudson River Foundation, NY, Animal Sci. Dept., UCal. Davis.

Gharrett, A. J., and S. M. Shirley, 1985. A genetic examination of spawning methodology in a salmon hatchery. Aquaculture 47: 245-256.

Guenette, S., R. Fortin, and E. Rassart, 1993. Mitochondrial DNA variation in lake sturgeon From the St. Lawrence River and James Bay drainage basins in Quebec, Canada. Canadian Journal of Fisheries and Aquatic Sciences, Vol. 50: pp. 659-664.

Hynes, J. D., E. H. Brown Jr., J. H. Helle, N. Ryman, and D. A. Webster, 1981. Guidelines for The culture of fish stocks for resource management. Canadian Journal of Fisheries and Aquatic Sciences 38: 1867-1876.

Kapuscinski, A. R., and L. D. Jacobson, 1987. Genetic guidelines for fisheries management. Minnesota Sea Grant Research Rep. No. 17: 66p.

Kapuscinski, A. R. D., and J. E. Lannan, 1986. A conceptual genetic fitness model for fisheries management. Canadian Journal of Fisheries and Aquatic Sciences 43: 1606-1616.

Kincaid, H. L., 1993. Breeding plan to preserve the genetic variability of the Kootenai River white sturgeon. U. S. Dept. Energy/ Bonneville Power Admin. Rep. No. DOE/BP-02886-1, Dec. 1993: 18p. s

Kincaid, H. L., 1983. Inbreeding in fish populations used for aquaculture. Aquaculture 33: 215-227.

Krueger, C. C., A. J. Gharrett, T. R. Dehring, and F. W. Allendorf, 1981. Genetic aspects of fisheries rehabilitation programs. Canadian Journal of Fisheries and Aquatic Sciences 38:1877-1881.

Mohler, J. W., K. Fynn-Aikins, and R. Barrows. In prep. Development of spawning and culture technology for Atlantic sturgeon. USFWS Northeast Fishery Center, Lamar, PA.

Smith, T. I. J., and J. P. Clugston. 1994. Status and management of Atlantic sturgeon (*Acipenser oxyrinchus*, in North America. Proceedings of The International Conference on Sturgeon Biodiversity and Conservation, July 28-30, 1994, New York, NY.

Waldman, J. R., J. T. Hart, and I. I. Wirgin. 1996. Stock composition of the New York Bight Atlantic sturgeon fishery based on analysis of mitochondrial DNA. Transactions of the American Fisheries Society 125: 364-371. Waldman, J. R., K. Nolan, J. Hart, and I. I. Wirgin, In press. Genetic differentiation of three key Hudson River anadromo us fishes. Estuaries

Table 1. Effective population number based on the actual number of males and females used to produce the progeny generation for on year-class. Identify the number of females in columns and the number of males in rows, the calculated effective breeding number for this combination can be read at the column and row intersection.

	Number of Female Parents											
Number of Male Parents	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1	2.0	2.7	3.0	3.2	3.3	3.4	3.5	3.6	3.6	3.6	3.7	3.7
2	2.7	4.0	4.8	5.3	5.7	6.0	6.2	6.4	6.5	6.7	6.8	6.9
3	3.0	4.8	6.0	6.9	7.5	8.0	8.4	8.7	9.0	9.2	9.4	9.6
4	3.2	5.3	6.9	8.0	8.9	9.6	10.2	10.7	11.1	11.4	11.7	12.0
5	3.3	5.7	7.5	8.9	10.0	10.9	11.7	12.3	12.9	13.3	13.8	14.1
6	3.4	6.0	8.0	9.6	10.9	12.0	12.9	13.7	14.4	15.0	15.5	16.0
7	3.5	6.2	8.4	10.2	11.7	12.9	14.0	14.9	15.7	16.5	17.1	17.7
8	3.6	6.4	8.7	10.7	12.3	13.7	14.9	16.0	16.9	17.8	18.5	19.1
9	3.6	6.5	9.0	11.1	12.9	14.4	15.7	16.9	18.0	19.0	19.8	20.6
10	3.6	6.7	9.2	11.4	13.3	15.0	16.5	17.8	19.0	20.0	21.0	21.8
11	3.7	6.8	9.4	11.7	13.8	15.5	17.1	18.5	19.8	20.6	22.0	23.0
12	3.7	6.9	9.5	12.0	14.1	16.0	17.7	19.1	20.6	21.8	23.0	24.0

Table 2. Calculation of the number of years of culture at various year-class effective population sizes (N_e) to achieve a generational effective population size ($N_{e(GEN)}$) which will produce an inbreeding rate of 0.5% (i.e., sum of year-class N_e's equal 100 with ÿF = $1/2N_e$).

	Year-Class Effective Population (from Table 1)				
Years /	6	8	10	12	14
4	24	32	40	48	56
5	30	40	50	60	70
6	36	48	60	72	84
7	42	56	70	84	90
8	48	64	80	96	104
9	54	72	90	108	
10	60	80	100		
11	66	88			
12	72	96			
13	78	104			
14	84				
15	90				
16	96				
17	102				

$N_{e(GEN)}$ =ÿ ($N_{e,1} + N_{e,2} + N_{e,3}$ + - - - N_{eGI})

$N_{e(GEN)}$ = Generation effective population size

GI = Generation interval (age at first female spawning)

Table 3. Suggested Atlantic sturgeon donor broodfish populations for use in culture and stocking programs in select Atlantic Coast tributaries.

Donor Stocks	Receiving Rivers	Priority
St. John	Kennebec	High
	Androscoggin	High
	Other ME/NH rivers	High
	Merrimack	High
Hudson River	Hudson	Low
	Connecticut, LI tribs.	High
	Delaware River	High
	Chesapeake Bay	High
Delaware River	Chesapeake Bay and tribs.	High
	Delaware River	High
Cape Fear, Other NC,	Cape Fear River, Other NC	High
Altamaha, ACE basin,	St Marys, Savannah	High
Winyah Bay system	Altamaha, Ogeechee, Satilla	Medium
	Waccamaw/PeeDee	Medium
	Ashepoo, Combahee, Edisto	High
	Santee, St. John's River	High

APPENDIX 1

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