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Salmon PVA: A Population Viability Analysis Model for Atlantic Salmon in the Maine Distinct Population Segment

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Executive Summary

A population viability analysis (PVA) model has been developed for Atlantic salmon (*Salmo salar*) in Maine. This model incorporates uncertainty in juvenile and adult survival rates, direct and indirect linkages among populations in different rivers, and accounts for a number of sources of potential human removals or stocking in a flexible, modular Fortran program named SalmonPVA. The structure of the model is based on a state-space approach with a detailed life history cycle. Multiple cohorts in multiple rivers progress through their life history based on stage-specific survival rates and fecundity, with limits imposed by riverine habitat capacity. The model projects the populations forward in time (usually 100 years) numerous times, with stochastic variables selected based on a Monte Carlo approach to calculate the probability of extinction. This model is being developed with input from scientists and policy makers from NOAA Fisheries, US Fish and Wildlife Service, Atlantic Salmon Commission, and the University of Maine. Results from this model will form the basis for informing the selection of delisting criteria in the Recovery Plan for the Maine Distinct Population Segment, which was listed as endangered in 1999.

The SalmonPVA model is structured to represent Atlantic salmon life history characteristics in the US. For example, most fish spend three years in the river and two years at sea before returning to the river to spawn. However, the model allows for the possibility to return from sea after one or three years, and for some spawners to survive (termed kelts) and spawn again two years later. Inputs to the model allow for a wide range of simulations incorporating various combinations of mechanisms and parameter variability. The number of rivers is a dynamic variable limited only by the capacity of the computer running the program. Linkages among rivers are determined as input and allow for various straying hypotheses as well as for linkages among juvenile survival rates due to year effects. Habitat capacity limits are input and combined with the approach used for fecundity cause a Beverton and Holt type spawner-recruitment relationship. This underestimates the probability of extinction when populations are large relative to a Ricker type spawner-recruitment relationship. However, the salmon populations in Maine are currently so low that this concern is not of immediate consequence. A number of sources of human-induced removals from the populations are allowed (but not required) by the model including interception fisheries at sea, in river fishing, and broodstock removals of either returning adults or parr. Stocking of any life stage during any year of the simulation is also allowed within the model. Stocked fish are followed in a separate matrix in the program from the natural fish to allow for different survival rates or removals. The offspring from the hatchery fish are added to the natural population so that hatchery populations disapper if stocking is discontinued. The model allows direct examination of specific simulations as well as aggregate summary results from all of the simulations. The probability of extinction is the most important output, but trends in adult returns can also be examined. Population trend information is useful in combination with risk of extinction because a five percent chance of extinction in one hundred years has different implications if the overall trend for the population is increasing or decreasing over the projected time series.

1. Introduction

In November 2000, the Gulf of Maine Distinct Population Segment (DPS) of Atlantic salmon was listed as endangered under the Endangered Species Act (ESA) by the Fish and Wildlife Service and the National Marine Fisheries Service (Fed. Regist. 65(223):69459-69483). Eight coastal rivers in Maine contained extant populations of Atlantic salmon within the DPS covered by the ESA listing (Figure 1). This listing brought additional protections for the species as well as requirements for creating objective and measurable delisting criteria. One approach to developing delisting criteria is by using a population viability analysis (PVA), a stochastic modeling technique for predicting changes in population abundance given uncertain biological parameters (Beissinger 2002). This approach was selected for the Atlantic salmon in the Gulf of Maine DPS to project future abundance and to provide information for establishing recovery criteria. PVA can also be used to help direct research by quantifying the relative improvement in population viability due to different management decisions or the reduction of uncertainty in key biological parameters. This document describes the PVA developed for the Atlantic salmon DPS in terms of the modeling decisions as well as the available input data.

Decisions made in constructing the PVA and in evaluating which data to use were made by a Working Group comprised of experts of salmon biology. This group consisted of representatives from the National Marine Fisheries Service (NMFS), US Fish and Wildlife Service (FWS), and Maine Atlantic Salmon Commission (ASC) (see Appendix for participant list). The group met as needed to discuss model development and input data selection and reached agreement through consensus. This activity benefitted greatly from the many years of experience of the Working Group members and the collegial atmosphere at these meetings.

2. Theory

Population viability analysis is a technique to estimate the probability of a stock attaining given sizes, usually zero or very low, sometime in the future (Gilpin and Soulé, 1986). A wide range of modeling approaches are used in PVA, from simple extrapolation of current trends to complex individual based models (Beissinger and McCullough, 2002). Software to conduct PVAs is widely available, e.g. RAMAS and Vortex, but models built specifically for a given species have also been utilized (Nickelson and Lawson, 1998; Reed et al., 2002). Whatever approach is taken, the purpose is the same, to predict the probability of the population persisting into the future. Because predictions are difficult, PVA results should not be taken as absolute truth. Rather, the forecasts should be used to explore potential consequences of management actions in the light of an uncertain future and variation in input assumption and data.

A life history modeling approach was selected for the Atlantic salmon Gulf of Maine DPS due to the large amount of data available for the species. This approach has the benefit of higher biological realism but requires many more input parameters and distributions relative to simpler PVA models. Complex features of Atlantic salmon biology (such as anadromy, precocious parr, kelting, and hatchery supplementation) are captured in the model, but at the cost of having to make many assumptions (such as how survival in riverine life stages is related among the DPS rivers). These features and assumptions are described below. Verification of the model and input assumptions was conducted using historical data for the Narraguagus river. The status of the DPS was projected under the most likely input assumptions, and sensitivity analyses were conducted for a number of input parameters. Finally, recovery criteria were explored with the model.

3. Program SalmonPVA

SalmonPVA, written in Fortran90 using IMSL numerical routines wherever possible, uses a modular approach to track the fate of populations from multiple rivers separately through time. The core structure is based on Atlantic salmon life history characteristics in Maine, but is flexible in terms of number of rivers and years as well as survival rates, stocking, fishing rates, straying, and other components. The program consists of input and output sections with two main loops: a simulation loop that builds the resulting distributions of extinction probability, number of spawners, habitat limitation, etc., and a year loop that projects the multiple populations into the future (Figure 2).

SalmonPVA is a state-space model in which the number of fish alive in a cohort is simulated based on the number in the previous life history stage and time step and the rates of removals between steps (Figure 3). The structure of the model is fixed, but vital rates are input as distributions and Monte Carlo sampling is utilized to simulate many realizations of the populations forward in time. Summary statistics from these realizations are used to generate the probability of events such as extinction in a river or group of rivers, or the distribution of response variables such as the replacement rate. Populations are considered unique to rivers, with fish that stray from one river to another taking on all the vital rates of the fish found in the latter river.

Life history stages in this model were set such that year time steps could advance cohorts through most stages (Table 1). Eggs are laid in October of year 1 and become fry 8 months later in June of year 2. Two months later, the exception to the year advancement per life stage, the fish become parr0+. In August of the following year the fish advance to parr1+ and then become smolts in May of year 4. Adults return to the rivers in June of years 5, 6, and 7 as 1 sea winter, 2 sea winter and 3 sea winter adults, respectively. Eggs are laid in the same year as the adults return to the rivers, completing the life cycle. Atlantic salmon are iteroparous, surviving adults become kelts which move to the sea and return to spawn two years later. Only integer values of fish and eggs are allowed in the simulation.

For bookkeeping purposes, SalmonPVA uses six separate matrices (arranged in two sets of three matrices) to store the number of fish in each life stage for each river and year. The two sets are for the natural and hatchery populations while the three matrices are for the different life history stages. In the model, natural fish are hatched from eggs in the rivers and spend their entire life either in the river or at sea. In contrast, the hatchery population consists of fish stocked at some life stage. Note that the progeny of hatchery fish are considered natural fish in this model, and the same survival rates are applied to both the natural and hatchery populations. The juvenile matrices contain the egg through smolt life stages. The adult matrices keep track of the number of fish of each sea winter age group (1 through 3) in four separate locations or states within a given year: at sea, return to river prior to straying, return to river after straying, and spawners. The kelt matrices keep track of which fish have just become kelts and which are returning to spawn. The kelt matrices are the only ones which keep track of the sex of the fish. The progression of fish through life stages, along with linkages among rivers, are described below and shown schematically in Figure 4.

3.1 Juvenile Survival

Juvenile survival is modeled for each of the four life cycle transitions: egg to fry, fry to parr0+, parr0+ to parr1+, and parr1+ to smolt. For each transition, a minimum and maximum main effect is input along with a noise level. The minimum and maximum values for the main effect define a uniform distribution for survival at that stage. The noise level is assumed to be a uniform distribution centered on zero with width two times the noise level (i.e., from negative NL to positive NL, where NL is the input noise level). To create a survival rate for a specific juvenile transition, river, and year, a random value is selected from both the main effect and noise level distributions and these two values added together.

The number of fish that pass from one stage to the next is randomly selected from a binomial distribution, with initial population abundance as the number of events and the survival rate as the probability of success. Thus, the number of fish at the next life stage in the next time step is bounded by zero and the initial population abundance, with the expected value equal to the product of the initial population abundance and the survival rate. This assumes that each fish has an equal and independent probability of surviving through the time step. When the number of fish in the starting life stage is large (thousands), then the number of fish in the next life stage at the next time step approximately follows a normal distribution. However, when the population abundance in the starting population is low (tens), then the variability due to the binomial process critically affects the persistence of the stocks.

The random survival values for each life stage within a realization are generated prior to the year loop from one call to the IMSL routine DRNUN which returns a vector of uniform random numbers of length equal to the number of years being simulated. These random numbers are then scaled by the range of survival for that life stage. This is just a time saving feature relative to calling the random number generator within the year loop. The survival rate is independent of population abundance for all juvenile life stages, and so can be generated at the start of the simulation. However, the application of the survival rate through the binomial distribution must occur within the year loop as it depends upon the population abundance at that life stage. The application of the binomial distribution both here and elsewhere is accomplished using the IMSL routine RNBIN. For example, in Figure 3 the uniform distribution for survival of eggs to fry is (0,25, 0.35). A value for the year effect would be chosen randomly from this distribution, say 0.31, and then the random noise for the river effect, say -0.01, would produce the value of 0.30 shown. Thus, the survival rate for the particular year and river is formed from the sum of the year effect and the river effect, both of which are uniformly distributed random values. Application of this 30% survival rate to the 15,000 eggs would be expected to produce 4,500 fish (15,000 * 0.30 = 4,500), but the use of the binomial distribution instead produced 4,417 fry as survivors in year 2 in this example. For large sample sizes, the binomial distribution is similar to the normal distribution, but for small sample sizes skewed distributions can be generated because only integer values are possible. The added noise at the river effect level can cause the selected survival value to fall outside the original range, as in this example for year 3 egg to fry survival. The program checks to ensure that the survival rate is bounded by zero and one and exits with an error message during input if a survival rate outside of zero and one is possible.

Survival rate linkages are allowed both among juvenile stages and among rivers, but these linkages are not required. The linkages are defined by the main effect. In the case of the juvenile stage linkages, the same proportional value from within the two main effect distributions is used. For example, if the egg survival rate main effect is the interval (0.15,0.35) and the fry survival rate main effect is the interval (0.43,0.60) then linking these stages could produce an egg survival rate of 0.20 and a fry survival rate of 0.4725, as both are 25% from the start of the interval. The program allows none, all, or some of the juvenile stages to be linked. The none and all options require only a single input flag, while the some option requires definition of the linkages. This is accomplished by entering the number of linkages followed by the pairs of linked life stages. For example, if only the two parr stage survivals were desired to be linked, then the user enters the flag for some linkages followed by the number 1 for one linkage followed by the set of numbers 3, 4 for the third and fourth juvenile survivals. Any linkages among life stages are applied to all rivers. In a similar manner, linkages are allowed among the rivers; none, all, or some. The survival rate main effects for the linked rivers are all the same. If river 1 and river 2 are linked and river 2 and river 3 are linked, then rivers 1 and 3 will be linked whether or not this linkage is explicitly input.

The relative level of noise to main effect can overcome any linkages among rivers. The linkages allow “good” and “bad” years to occur for linked life stages and rivers, but the linkages must be combined with the noise level to determine the specific survival rate for a stage, river, and year. By varying the relative levels of main effects and noise, various life stages and rivers can vary between completely linked to completely independent (Figure 5).

3.2 Marine Survival

Marine survival was modeled assuming a cyclic pattern (sine wave) that varies in mean, period, amplitude, and phase over time. The first year at sea is assumed to have a lower survival rate than subsequent years at sea, with the difference between the two annual rates established through an input variable. The lower marine survival during the first year at sea is thought to be due to additional mortality caused during the transition from freshwater to the marine environment, but the actual mechanism is unknown. A component of random noise is added to the expected survival rate from the sine waves to more closely match the non-smooth variability observed in marine survival rates throughout the world. These cycles may be related to environmental cycles, such as the North Atlantic Oscillation, but no causal mechanism has been demonstrated for this relationship and there are still not enough data to adequately judge long term correlations.

Cycles of marine survival are modeled in SalmonPVA by assuming an empirical distribution for the cycle period, and uniform distributions for the cycle mean, amplitude, and phase. The empirical distribution for the cycle period is used to generate a generic cumulative distribution function from which values are sampled. A sufficient number of periods are collected during each realization to cover the range of years simulated. For each cycle, random realizations from the uniform distributions of the cycle mean, amplitude and phase are selected and applied to that cycle for the appropriate period of years. In this way, marine survival cycles between high and low values but for random durations, at random levels, with random ranges, and in random sequences that match the variability observed in the environment. By varying both the relative ranges assumed for the cycles and the additional noise, marine survival can be modeled as noise about a fixed mean, a constant sine wave, a near chaotic series, or any intermediate pattern.

As in the juvenile population, the marine survival rate in any year and sea winter age combination is applied using a binomial distribution, with the probability of success determined by the survival rate. The survival rates for all years and for both the first and later sea winters are computed for each realization prior to the year loop, but the application of the survival rates through the binomial distribution occurs for each year. Note that the initial number of 2 and 3 sea winter fish at sea is the number of these cohorts in the sea during the previous year minus the number of these fish that returned to rivers the previous year. The marine survival rate is the same for all stocks as they all inhabit the same environment. However, the use of the binomial distribution to determine the actual number of survivors means that two rivers with the same number of emigrating smolts in a given year can produce different numbers of one sea winter adults at sea.

3.3 Habitat Limitations

The capacity of rivers to support Atlantic salmon is limited by the amount of appropriate habitat. The abundance of all juvenile life stages, except smolts, may be limited by habitat. Smolts are not limited because they leave the rivers. Within the simulation, the habitat limitation occurs after natural mortality and human induced removals have occurred. All four juvenile stages can have a habitat cap, but a cap is not required for each stage. Data availability and mechanistic hypotheses should determine which stage(s) are limited. Elliot (2001) presented evidence of density-dependence in Atlantic salmon, but the stage at which the limitation occurred was not defined. Elson (1975) found a linear relationship between egg density and fry but found a density-dependent relationship between egg density and smolts. The habitat capacity approach used in SalmonPVA is equivalent to a Beverton and Holt type stock-recruitment relationship. The use of a Ricker type stock-recruitment relationship would be more pessimistic in terms of recovery potential, but there are no observations for recruitment levels at high stock sizes for Atlantic salmon in Maine upon which to base a Ricker type relationship.

The habitat capacity for a given juvenile stage in a particular river is determined from a mean level for each river, a random year effect applied to all rivers, and a random river specific effect. Both the year and river effects are multiplicative and defined by uniform distributions such that if set to zero cause no change from the mean. For example, if the year effect is desired to change the habitat capacity by plus or minus 10%, the entered range for the uniform distribution would be -0.1, 0.1. In this way, all rivers can experience "good" and "bad" years or fluctuate independently, depending upon the relative variability in the year and river effects. For each realization, the habitat limitations for each year and river are derived prior to the year loop as they are independent of the salmon population dynamics. These "good" and "bad" years of habitat limitation are independent of the "good" and "bad" years of juvenile survival. The habitat caps for each stage are chosen independently such that "good" and "bad" years can occur simultaneously for different stages within a river.

Habitat limitation for any juvenile stage can occur in one of three ways: hatchery fish are removed first, natural fish are removed first, or the two sets of fish are removed in proportion to their relative abundance. As such, hypotheses related to ecological effects can be examined. For example, it has been hypothesized that hatchery fish are more susceptible to predation than are naturally spawned fish. In all cases, the total number of fish that will become smolts in a given year and river are summed from the hatchery and natural populations. If this sum is less that the corresponding habitat limitation, then nothing happens. However, if this sum is greater than the habitat limitation then the number of fish that are removed is the difference between the sum and the cap. If one set of fish, hatchery or natural, is selectively removed then the number of fish in this set is compared to the number to be removed. If the number to be removed exceeds the number of fish in this set, then the rest of the removals are taken from the other set. The proportional option reduces each set by the ratio of the number to be removed and the number present. For example, if 60 hatchery fish and 500 natural fish are present in a river that has a habitat limitation of 400 fish that year then under the three options there could be 0 hatchery and 400 natural fish (hatchery first), 60 hatchery and 340 natural fish (natural first), or 42 hatchery and 358 natural fish (proportional) that remain after application of the habitat limitation.

3.4 Population Initializations

Two options exist for initializing the populations in each river: entering a number of years of data for a specific life stage, or entering all life stages in a single year. Both options utilize uniform distributions to reflect the uncertainty in the abundance estimates of most life stages. Different options can be used for different rivers. All life stages are projected forward to the last year with initialization data using all the processes described in this section, with the exception of straying which is not used during the initialization. Input data should be sufficient to ensure fish are present at all life stages in the first true year for projections. However, if there are uninitialized life stages, these values will be set to zero by the program. If enough data are entered such that a cohort is projected into an initialized life stage, then the initialized value will be used for the natural population. In contrast, previously stocked life stages are additive when projected forward into an initialized life stage because hatchery input is the number stocked not a population estimate. Note that since the fry to parr0+ transition occurs within a year time step, and this time step is done during the projection part of the time loop, if annual fry values are entered for initialization, then one more year than expected will be required to fill the cohorts. If adult stages are input, then ranges for each sea winter age should be input. Also note that when the second option for initialization is chosen, all life stages in a single year, the program will not allow the number of returns to be greater than the number of fish at sea for any of the sea winter ages. This is to ensure that the calculation of fish at sea in the next year does not start at a negative value.

3.5 Human Induced Removals

3.5.1 Interception Fisheries

Fish at sea can be caught in directed or non-directed fisheries. The interception fisheries remove fish from the river-specific populations randomly in proportion to their relative abundance. The input for interception fishery removals is a uniform distribution for each year, which reflects the uncertainty in estimating the number of Maine salmon caught in the mixed fisheries of Greenland or St. Pierre et Miquelon. The number of fish caught in a year is selected randomly from this range and if it exceeds the total number of fish at sea from all rivers, then all these fish are removed. If the total removal is less than the sum of the population currently existing in the run, then random fish are selected from the populations of natural and hatchery fish. The removal occurs temporally prior to the return of fish to the rivers in a given year.

3.5.2 Broodstock

Some adults that return to rivers to spawn are collected as broodstock for restoration efforts. These collections are based on two rules applied in the model: the number desired and the maximum percent of the run that can be removed as broodstock. The number of returning fish to a river is first compared to the desired total collection. The smaller of these two values becomes the first check. The second check is calculated as the maximum percentage of the returning fish allowed for broodstock collection. The lower value of these two checks is taken as the broodstock for that river, year and sea winter age. Note that since each sea winter age is treated separately, the total broodstock collection may be less than if all sea winter fish were aggregated. However, broodstock collection focuses on certain sea winter ages normally, and so the model treats them separately. Only natural fish are collected for broodstock.

In a similar manner, natural parr1+ are collected from some rivers through electrofishing for raising in hatcheries to serve as broodstock for future restoration efforts. In this case, only a maximum number of fish are entered and it is assumed that electrofishing operations occur only in stream reaches where natural fish are expected to occur. If the value entered is larger than the natural population size in a particular river for a given year, then all the natural fish are removed. Note that for projections, this option should only be used when a restoration stocking program is employed.

3.5.3 River Adults

When salmon return to a river to spawn, there is the potential for fishery removals to occur, through a directed fishery, as bycatch in a non-directed fishery, or through poaching. In the model, these in river removals are assumed to occur before broodstock collection. The river fishery removals are entered for each sea winter age separately to allow for directed fishing on different age classes or poaching of different age classes at different rates. The input for river adult removals is from a uniform distribution of the probability of a fish being caught. This probability is used with the binomial distribution to randomly remove a fraction of fish due to fishing. This approach mimics the expectation that larger returns will have larger removals, but at a given rate determined by management (for a directed fishery) or bycatch/poaching (for non-directed or illegal fisheries). The catch of natural and hatchery fish are treated separately to allow for a directed fishery on stocked fish.

3.6 Straying

Although Atlantic salmon have a remarkable ability to return to their natal river, there are occasions when fish return to a different river, termed straying. The model uses two input values to determine the proportion of natural and hatchery fish that stray (these can be set to different values). Two separate input values determine the fraction of natural and hatchery strays that will die, respectively. Finally, a single input matrix determines to which other rivers the fish will stray and in what expected proportions. In the model, the stray rate is defined as the proportion of fish from the total that is expected to return to a specific river that instead returns to a different river. For example, if 10 of 100 Narraguagus fish return to the Pleasant river, the stray rate for the Narraguagus river is 10% independent of the number of fish returning to the Pleasant river. The stray rate is applied to all fish within the population, natural or hatchery, but applied to each sea winter age separately using a binomial distribution to determine the number of strays from each river. This initial number of strays is then decreased according to the stray mortality fraction through the use of the binomial distribution. Once the number of strays that will survive is determined for each river, the river of return for these fish is determined by the straying matrix. The straying matrix has river of origin as the rows and river of return as the columns. The diagonal of the matrix should always be zero because the stray rate assumes that an actual stray occurs and the diagonal would put the fish back into the river of origin. However, the program will allow positive values along the diagonal such that stray rates can be made different among the rivers. The program checks that the sum of each row in the stray matrix is equal to one, and rescales to sum to one if not. In this way, physical distance or some other measure of straying can be used during input, and the program will calculate the straying matrix. The allocation of strays from a given river to all other rivers is done randomly but is based on the probability associated with the transfer in the straying matrix. Straying occurs after fish return to the river, but before any broodstock collection or fishing mortality occur, and before the counting of returns to the river.

3.7 Maturity and Fecundity

Atlantic salmon first return from the sea to spawn after spending from one to three years at sea. The maturity rate (proportion of fish at returning at each sea winter age) is stock dependent, with DPS fish predominantly returning as 2SW fish. A maturity vector is input that is held constant throughout the simulation, but applied through a binomial distribution to incorporate variability in the maturity rate.

Spawning fish are determined to be either male or female based on an input probability by sea winter age. For spawning to occur, both males and females must be present in the river. Males can be either adults or precocious parr (parr 1+) but females must be adults. The females spawn a quantity of eggs that is chosen randomly from an input normal distribution, with mean and variance set by sea winter age. Each female is treated independently, such that the resulting average number of eggs per female will be close to the mean when the number of females is large, due to the central value theorem, but will be more variable when the number of females is low. Hatchery fecundity for each female spawner is multiplied by an input constant that allows for either decreased or increased fecundity relative to natural spawners. The eggs produced by both natural and hatchery adults are placed into the natural population. Thus, after one life cycle of the ending of stocking, the hatchery populations will consist only of surviving kelts.

3.8 Stocking

Restoration efforts for Atlantic salmon have used stocking of hatchery reared fish to supplement natural populations. Different life stages of fish have been stocked in different rivers and at different times. The model allows user input of fish into the hatchery population at any stage and in any year. The numbers of fish stocked can also be varied over time, although the input format is designed for blocks of years with the same number of fish stocked at a given life stage. As noted above in the fecundity section, the hatchery population is not self-sustaining, fish only remain in this population until they spawn at which point their progeny are considered natural. There is not a random component to the stocking. This is because the levels of stocking are considered to be so high and discrete that any randomness would be artificial. Basically the questions are whether or not to stock, or which life stage to stock, but not variation in how many fish are stocked.

3.9 Counters

Given the large number of inputs, with imprecise estimation, to the Atlantic salmon population viability analysis, the model has to be run many times to produce distributions of response variables under different parameter combinations. The variables of interest collected from each realization are primarily related to population size and extinction, although habitat limitation effects and replacement rates are also evaluated. The number of realizations in which a given river went extinct or was limited by the habitat capacity is counted and reported in the program output. The average number of spawners over an input defined number of years is also computed and reported for each realization. This averaging allows the effect of cyclic marine survival to be mitigated in terms of expected numbers of spawners in the future, as using just a single year would induce more variability because the output would then depend upon where in the marine cycle the observation of survival was taken. Similarly, the replacement rate for a realization is calculated as the median of the last twenty years in the simulation. The replacement rate for year t is defined as the sum of adult offspring for that cohort in years t+4 to t+7 divided by year t adult returns (Rago, 2001). The rivers can be grouped into any number of geographical or size combinations to examine patterns in extinction, habitat capacity, and average number of spawners. A river can also be included in multiple groups.

The complete output from individual realizations can also be reported by the model including: natural and hatchery population abundance for all rivers, years, and life stages; removals due to intercept fishing, river fishing, and broodstock; and habitat limitations for each river and year and whether or not the cap was utilized for each river and year. Since a given random number seed will always produce the same output, multiple realizations from a single scenario can be collected by using the same random number seed and changing which realization is output.

3.10 Components Currently Not Included in Model

Catastrophic mortalities are currently not included in the model. This phenomenon could be added, but would require many more model realizations due to being, by definition, a low probability event. It is easier to consider the impacts of catastrophic events *a posteriori*, by taking the results and increasing the probability of extinction by some small amount corresponding to the hypothesized probability of catastrophic events.

Genetics are not considered at all in the model and would be difficult to incorporate unless a qualitative aspect is used. For example, decreasing fecundity if the population size goes below a certain limit.

Mortality associated with dam passage is not included directly in the model but can be aliased using the river fishing removals. The user would have to ensure that these removals were attributed to dams and not fishing when describing results.

Disease is not included directly in the model. It would be difficult to incorporate this as a transmissible vector, but disease might be considered as more of a catastrophic effect.

The impact of aquaculture escapees is also not included directly in the model but could be approximated using river fishing removals. Again, when describing results the user would have to ensure that these removals were attributed to aquaculture interactions and not fishing.

Predation is not modeled directly, but rather as a consequence of the survival rates. Although many predators of Atlantic salmon have been identified, the ability to predict future predator abundance, or that of alternative prey, makes direct incorporation into the model difficult.

4. Input for Base Case

4.1 Juvenile Survival

Estimates of survival rates for the juvenile life stages of Atlantic salmon were obtained from the literature and combined using an objective process that accounted for the uncertainty in each study. Some subjectiveness entered the process through decisions to include or exclude specific results in the process. The combination process first standardized survival values for all studies for a particular life stage to the same time interval assuming that the reported survival rate would be constant in the new time period. For example, if the reported survival was 20% over 10 months, then a standardized survival for 12 months would be 14.5%, calculated as $0.2^{(12/10)}$. This conversion was done to the mean as well as the minimum and maximum survival rates from each study. The standardized triplets of minimum, mean, and maximum survival for each study were then combined assuming triangular distributions with zero probability at the minimum and maximum values and the probability associated with the mean fixed to give an unit area under the curve, calculated as 2/(maximum-minimum). The triangles from studies selected for inclusion in the final estimate were then simply added together and rescaled to form a new distribution of the probability of each survival value for that life stage. This new probability distribution function was then converted to a cumulative distribution function and the 10^{th} and 90^{th} percentiles selected as the limits of a uniform distribution to describe the uncertainty associated with survival of that life stage.

The studies included in the generation of the uniform distribution for survival were based on group discussions involving representatives from NMFS, FWS, and ASC. The choices made for each life stage are detailed below.

The survival rates for egg to fry life stages came directly from a study conducted on Maine DPS Atlantic salmon (Jordan and Beland, 1981). The resulting uniform distribution for survival is 15-35% which was taken directly from the study instead of applying the objective process described above. This range in survival covers most other estimates available in the literature (Table 2) and is thought to best represent survival of Atlantic salmon in Maine.

The survival rates for fry to parr0+ life stages were derived using the objective process described above, with the standard time period of two months. There were 13 studies found in the literature for this life stage transition which were used to generate a total of 24 possible survival triangles (Table 3). Of these 24 possibilities, five were selected for use in the objective procedure to create the uniform distribution of 43-60% survival. The 19 other possibilities were not considered representative of survival of Atlantic salmon in Maine for a variety of reasons. The duration of a number of studies could not be determined, which was deemed too important to overlook for this life stage (Stewart, 1963; Mills, 1969; Greenwood, 1981; Knight et al., 1982; Kennedy, 1984). One study was conducted specifically as part of a low competition experiment (Heggenes and Borgstroem, 1991). Some studies were conducted in low productivity streams in Vermont (Whalen and LaBar, 1994; Whalen and LaBar, 1998) that are not considered representative of Maine DPS rivers. The two parts of the McMenemy (1995) study were averaged after adjusting for the different time periods to prevent this one study from having too much influence on the overall calculation of survival for this stage. The five selected studies had mean standardized survival rates ranging from 48.6-59.2% (Egglishaw and Shackley, 1973; Egglishaw and Shackley, 1980; Gardiner and Shackley, 1991; Orciari et al., 1994; McMenemy, 1995). The range of survival rates in these studies were quite similar and resulted in a relatively narrow distribution of survival rates for this life stage (Figure 6).

The survival rates for parr0+ to parr1+ life stages were derived using the objective process described above with a standard time period of twelve months. Ten studies were found in the literature for this life stage transition, and these were used to generate 12 possible survival triangles (Table 4). Of these 12 possibilities, seven were selected for use in the objective procedure to create a uniform distribution of 12-58% survival. One study was conducted specifically as part of a low competition experiment (Heggenes and Borgstroem, 1991). The unknown duration of two studies precluded their selection (Symons, 1979; Knight et al., 1982). The survival rates from the two time periods in the Orciari et al. (1994) study were averaged after standardization. The seven selected studies had mean standardized survival rates ranging from 11.3-50.2% (Meister, 1962; Egglishaw and Shackley, 1980; Kennedy and Strange, 1980; Kennedy and Strange, 1986; Gardiner and Shackley, 1991; Orciari et al., 1994; Cunjak et al., 1998). The range of survival rates in these studies was quite large, resulting in a wide distribution of survival for this life stage (Figure 7).

The survival rates for parr1+ to smolt life stages were derived using the objective process described above with a standard time period of nine months. Eight studies were found in the literature for this life stage transition and together with one set of data from the Narraguagus river (J. Kocik, NOAA Fisheries, pers. comm.) were used to generate 16 possible survival triangles (Table 5). Of these 16 possibilities, five were used to create a uniform distribution of 17-50% survival. The unknown duration of two studies obviated their selection (Elson, 1957; Symons, 1979). The both used Average standardized survival rates were calculated from the different sets of fish in the Myers (1984) and Orciari et al. (1994) studies to prevent one study from having too much affect in the overall calculations. Two studies were conducted in Vermont rivers, not considered to be representative of Maine DPS rivers (Whalen, 1998; Whalen et al., 2000). The five selected studies had mean standardized survival rates ranging from 16.8-45.8% (Meister, 1962; Myers, 1984; Orciari et al., 1994; Cunjak et al., 1998; Kocik pers. comm.). The range of survival rates in these studies was quite large and resulted in a relatively wide distribution of survival for this life stage (Figure 8).

Combining these survival rates produced a possible range of egg to smolt survival of 0.13-6.09% (Table 6). However, the distribution of egg to smolt survival is not uniform, but approximates a lognormal distribution (Figure 9). This is because the sum of random values from any distribution is approximately normal for large sample sizes and egg to smolt survival can be expressed as the sum of the natural logs of each survival rate. Survival values between 0.5 and

3.5% occur within the 90% confidence interval of this distribution, which corresponds to the general impression expressed by the working group and found in the literature (Bley and Moring 1988) that egg to smolt survival should be around 1-2%.

Linkages in survival rates were assumed to occur among all rivers and between the two parr life stages. The noise level for each life stage was set at 0.05 to generate relatively tight linkages, relative to the variability in the main effects. Relatively tight linkages among rivers are justified based on hydrological studies where, for example, data for the Machias River are used to supplement and extend the record for the Dennys River. The relatively tight linkage between the two parr survival rates is based on the similarity in habitat requirements of these two stages.

4.2 Marine Survival

Correlations exist between sea surface temperature and marine survival of Atlantic salmon (Scarnecchia 1984; Martin and Mitchell 1985; Scarnecchia et al. 1989; Friedland et al. 1993; Friedland et al. 1996; Friedland 1998; Friedland et al. 2003). One possible causal mechanism for these relationships for Maine DPS Atlantic salmon is the North Atlantic Oscillation (NAO). Although no direct link has yet been established between the NAO and Atlantic salmon marine survival, a cyclic pattern in marine survival is common to many species of salmon throughout the world. For example, marine survival of various species of Pacific salmon has been shown to vary with El Niño Southern Oscillation (ENSO) events (Johnson 1988; Beamish and Bouillon 1993; Francis and Hare 1994).

The NAO is defined as the normalized pressure difference between the Azores and Iceland. Monthly averages are computed and the deviations from December to March are averaged to create an annual winter value. NAO values from 1824 to 2001 have been estimated to contain thirteen cycles of length 7 to 23 years (Figure 10).

The NAO cycle lengths were used to generate a cumulative distribution function from which random cycle lengths were resampled, as described in section 3.2. The random cycle lengths were scaled to cover the range of marine survival through the use of the mean, amplitude and added noise. Marine survival from smolt to 2 sea winter adults of Maine Atlantic salmon has been estimated to be on the order of 0.5 - 4% based on tagging studies (Baum, 1983) and returns of stocked hatchery smolts (USASAC, 2002). Survival is hypothesized to be lower during the first year at sea due to the stress of moving from freshwater to a fully marine environment. In the SalmonPVA program, survival during the first sea winter is randomly selected from a uniform distribution ranging from 0.08 to 0.10 and the survival during that year for two sea winter and older fish is set to the random value plus 0.10. This produces an expected survival of 1.71% from smolt to 2 SW adult. Combining this expected survival with the average egg to smolt survival of 1.51% and an expected fecundity of a 2 SW female (described below) of 7,560 eggs yields an expectation of 1.95 adults surviving from the eggs of one female to their second sea winter. Given that Atlantic salmon can spawn in multiple years due to kelting, approximately

2.02 spawning adults would be expected to survive from the eggs of one 2SW female and thus, the populations are sustainable on average if there are no human induced removals. However, variability in survival rates at different life stages could still cause populations to decline and small populations to go extinct.

Variability in marine survival is produced by both the cycles and added random noise. Amplitudes of the marine survival cycles are randomly selected from a uniform distribution ranging from 0.02 to 0.05. The shift parameter (timing of the cycle) for the marine cycles is randomly selected from a uniform distribution ranging from -0.3 to -0.2 to reflect the decreasing trend in marine survival observed in recent years. The mean, amplitude, and shift values produce survival rates for smolt to 1 SW adults of 3% to 15%, and for 2 SW adults and older of 13% to 25%. The added noise is randomly selected from a uniform distribution ranging from -0.04 to 0.04. The survival rate of a smolt through to the 2 SW stage covers the range 0.05% to 4%, suggested by the working group as an appropriate level, with a few values outside of this range (Figure 11). Note that periods of good and poor marine survival are present in this approach and exhibit some of the same characteristics as the NAO, such as variable period length, large sudden spikes, and changes in the amount of variability at different times (compare Figure 10 with Figure 11).

4.3 Habitat Limitations

The base case habitat limitation in SalmonPVA operates on the survivors of the parr 1+ stage, those fish that will be smolts in that year. Insufficient data are available to reliably estimate habitat limits for other juvenile life stages. The amount of juvenile rearing habitat for parr1+ salmon in each river is calculated based upon habitat surveys (Table 7). These surveys determined the amount of suitable habitat based upon river characteristics such as flow, stream width, bottom type and aquatic vegetation. Following standard practice it was assumed that each unit of suitable juvenile rearing habitat was capable of producing seven large parr. Thus, multiplying the number of units of juvenile rearing habitat from the surveys by seven generates the average habitat limitation for each river (Table 7). Variability is introduced into the simulations through a year effect of plus or minus 20% and a river noise effect of plus or minus 5%. These variability levels are considered appropriate given the geographic proximity of the Maine river systems (Figure 1) and the annual variations in water levels and temperatures experienced in recent years. One possible exception is the Dennys River in which flows can be controlled to some extent and therefore may not be as tightly linked to good and bad years as the other rivers.

4.4 Population Initializations

The numbers of returning Atlantic salmon for years 1995 to 2002 were derived from either trap counts or a regression between trap counts and redd counts (Kocik and Trial, pers. comm.). Fish counted at weirs were identified for sea winter age, and the average sea winter age distribution from all available returns in a year were applied to those rivers which only had redd counts (USASAC, 2002). The 90% confidence interval from the regression between trap counts and redds was used to derive the variability in these initializations. The trap counts were assumed to be minimum estimates and a 10% increase, rounded to the nearest integer, was used as the upper bound for the actual run sizes of each sea winter age. For Cove Brook, neither weir nor redd counts exist for the years 1995 to 1999, so an assumption was made that the data from 2000 were applicable to these years as well. The initial populations produced a full population structure, including kelts, in 2003, the beginning of the projection period.

As returning fish produce natural eggs in the year of their return, both hatchery and natural origin fish were combined in the population initialization. Aquaculture escapees are not included in these totals because these fish would be stopped at the weirs and cannot be estimated at those rivers without weirs. Thus, the initial populations are entered as returning adults, after straying, by sea winter age with a range of possible abundance values from which a random selection is made (Table 8). The overall trend during this period has been declining (Figure 12).

4.5 Human Induced Removals

4.5.1 Interception Fisheries

Maine DPS Atlantic salmon while at sea can potentially be caught in the Greenland mixed-stock fishery or in the St. Pierre et Miquelon fishery. The Greenland fishery is currently small and captures salmon primarily from European and Canadian rivers. Genetic analysis of salmon caught off Greenland suggests that the number of DPS fish caught in 2002 was no greater than one to two fish (Sheehan et al. 2003). Assuming an equally small catch in the St. Pierre et Miquelon fishery produces a range of zero to four fish caught. The Working Group agreed that this removal range of DPS fish by the interception fisheries would be used as the base case for the years 2003 through 2012. The river and sea age composition of these fish depends upon the relative size of the runs from each river and sea winter age, implying that mainly 1SW fish will be caught.

4.5.2 Broodstock

Currently, there are no broodstock removals of returning adults from any of the Maine DPS rivers. Instead, electrofishing for parr is used to gather juvenile fish which are then raised in a hatchery to become broodstock. Returning adults are removed from the Penobscot river for broodstock. The annual number of parr1+ removed by electrofishing for broodstock has been 300 fish from both the Machias and Narraguagus River and 200 fish apiece from the East Machias, Sheepscot, Dennys, and Pleasant Rivers. In the model, these collections occur for years 2003 through 2014 to allow for the stocking of the rivers (see Section 4.8).

4.5.3 River Adults

No directed river fisheries occur on any of the Maine DPS rivers. Although illegal fishing may occur, it is totally unquantified. For the base case, removal of river adults due to legal or illegal fishing is set to zero for all rivers.

4.6 Straying

Straying in Atlantic salmon is thought to occur at a low rate, but is higher for hatchery fish than wild fish (Quinn 1993). In the base case simulations, stray rates of 1% for natural fish and 2% for hatchery fish are assumed. No mortality is assumed to occur because of straying for either natural or hatchery fish. To create the straying matrix, three separate components were combined: distance between river mouths, relative river size, and order of encounter. Each of the three components has an associated straying matrix. These matrices are combined in a simple spreadsheet application using weights to scale the relative importance of each factor.

The distance between river mouths straying matrix was computed using cost weighted distances between rivers estimated from a bathymetric scale in GIS (Marty Anderson, NOAA Fisheries, pers. comm.). A bathymetric grid for the Gulf of Maine was obtained from the Maine Office of GIS and stratified into three depth intervals: intertidal, 0-30 feet, and greater than 30 feet. These depth intervals were assigned a cost, related to the perceived ability of Atlantic salmon to navigate through these depths given the amount of obstructions expected. Overlaying the DPS rivers on the bathymetry grid allowed the calculation of the minimum cost path to travel from one river mouth to another using ARC VIEW GIS Spatial Analyst. For example, in Figure 13 Cove Brook is the starting river and the shades of color denote increasing cost as a fish travels to the other rivers. The inverse of each cost weighted distance was computed and the sum of the inverse distances was used to scale each river of origin such that the sum of each row was one (Table 9a).

The straying matrix for river size is computed by taking the inverse of the difference between river sizes and rescaling to sum to one (Table 9b). Since all the rivers in the DPS are small coastal river, the relative differences in size are magnified. If a much larger river, such as the Penobscot, was included in the analysis, the stray rates among the DPS rivers would be much more similar. For this reason, river size was downweighted relative to the other two components when constructing the overall straying matrix.

Returning Atlantic salmon stage south of their natal river and are more likely to stray into rivers located to the south than to the north (Collette and Klein-MacPhee 2002). The straying matrix for river order is thus created by assuming a linear relationship between probability of straying and order of encounter, and then rescaling to sum to one (Table 9c).

The final base case straying matrix for SalmonPVA was created by giving equal weight to the distance between river mouths and river order components and only half weight to the river size component. Each matrix was multiplied by its weighting factor and the matrices summed, element by element, and then rescaled to sum to one (Table 9d).

4.7 Maturity and Fecundity

The maturity rate for DPS Atlantic salmon was calculated based on the observed sea age composition of returns (USASAC 2002) and reflects the predominance of 2SW fish (Table 10).

The proportion of male and female spawners varies by sea winter age, with 1 SW spawners mainly males and older fish more evenly split between the sexes (Baum 1997; Table 10). The expected number of eggs produced per female increases with sea winter age (Baum 1997; Table 10). The mean eggs per female for kelts is an approximate average from multi-sea winter females. The variability in numbers of eggs per female was assumed to follow a constant coefficient of variation of 15%. The hatchery fecundity multiplier is set to one, meaning no difference between natural and hatchery fecundity.

4.8 Stocking

In the base case simulations, the rate of stocking in 2001 was assumed to continue during the years 2000 to 2015 (USASAC 2002; Table 11). Stocked fish remain in the appropriate hatchery matrix (juvenile, adult, or kelt) throughout their life, but their eggs get transferred to the natural juvenile matrix (Figure 4).

5. Testing and Verification

A number of types of testing and verification were conducted for SalmonPVA, not all of which are reported herein. The first tests compared the use of the point estimates (mid-points of the uniform distributions described above for the base case) for a single river, the Narraguagus, using the full range of uncertainty in the parameters. The point estimates case should show a self-sustaining population if the initial population size is not too small, based on the average survival calculations described above. The second set of tests expanded the comparison to include all eight DPS rivers. The impact of including multiple rivers was also assessed by comparing the results of the Narraguagus River runs to the runs with the eight DPS rivers. The third set of tests were run multiple times with different seed values for the random number generator to determine how many realizations are sufficient to get a consistent result. The fourth test was a verification approach that used historical data for the Narraguagus River to initialize the population. This single population was followed to determine if the model could produce a confidence interval for returning adults in years 1975 through 2002 that contained the observed point estimates. In this verification test, the appropriate number of realizations determined from the previous test were run and the full range of uncertainty in the base case input parameters was used.

5.1 Single Population Parameter Point Estimates vs Range

The midpoint of each range of uncertain parameter inputs for the Narraguagus River was simulated 1,000 times. In none of the 1,000 simulations did the population go extinct. The average number of natural spawners during the years 2082 to 2102 ranged from 112 to 575, with a median of 287 (Figure 14). In all 1,000 simulations the habitat limitation constrained the number of fish that became smolts. The habitat limitation was reached due to the stocking of 353,000 fry in the years 2000 to 2015, but could also be reached in later years when stocking was no longer conducted. The population was replacing itself, with a median replacement rate of 1.057 and range of 0.7 to 1.5 (Figure 15). When the ranges of uncertainty from the base case, described above, were input for the Narraguagus River and simulated 1,000 times, in 89 of the 1,000 simulations the population went extinct. The average number of natural spawners during the years 2082 to 2102 ranged from zero to 572 with a median of 36 (Figure 14). A large shift in the frequency distribution of average spawners was induced by the addition of uncertainty to the input parameters. Although all the uncertainties were evenly distributed about the midpoint, the response of the number of spawners is skewed and shifted. Decreasing the range of uncertainty in survival rates would therefore be expected to decrease the probability of extinction even if the average survival rate remained constant. In all 1,000 simulations, the habitat limitation was used to reduce the number of fish that became smolts, mostly due to stocking in the early years of the projections. In this case the population was not replacing itself, with a median replacement rate of 0.653 and range from zero to 1.6 (Figure 15). However, some of the zero replacement rates were due to the stock going extinct. Discounting the zero replacement rates, the median is between 0.7 and 0.8, indicative of a stock still not replacing itself.

5.2 Multiple Populations Parameter Point Estimates vs Range

The base case parameter inputs for all eight DPS rivers were simulated 10,000 times under two scenarios; (1) the parameter point estimates and (2) the full range of uncertainty. The output was generated for each river separately, all eight rivers combined, and as two special groups: Downeast rivers (DE, EM, MC, PL, and NG) and Southwest rivers (CB, DT, and SHP). Additional groupings are possible, but were not done for these tests. As in the single population example, inclusion of uncertainty in the parameters increased the probability of extinction, decreased the average numbers of spawners in years 2082 to 2102, and decreased the replacement rate (Table 12). The estimates from the single population examples were quite similar to those for the same river in the multiple population examples. For example, the median replacement rates from the single population and multiple population examples for the Narraguagus River were within 0.02 (3%) of each other.

5.3 Determination of the Appropriate Number of Realizations

When performing Monte Carlo simulations, the appropriate number of simulations to conduct must be found by trial and error. One method to accomplish this is to conduct multiple trials using a different number of realizations. For example, one might conduct ten trials of 1,000, 10,000, and 100,000 realizations and compare the variability in results among the three levels. Conducting more simulations would produce more consistent results but take more computation time. The tradeoff between consistency and time must be made for each study, but once determined can usually be used for all sensitivity analyses and changes in input parameters.

Ten trials were made using three levels of number of realizations: 1,000, 10,000 and 100,000. Each trial used a different random number generator seed value. Using 1,000 realizations, the ten trials had: (a) relatively large river specific ranges (one to five percent) for the probability of extinction; (b) one to three percent probability of habitat limitation for those rivers not always limited; and (c) zero to seven mean spawners for years 2082 to 2102 (Table 13a). Given the base case settings, 1,000 simulations were insufficient to adequately capture the amount of variability in the model. Increasing the number of simulations to 10,000 decreased the range of the ten results to less than two for all rivers and all three outputs described for the 1,000 simulations

(Table 13b). Further increasing the number of simulations to 100,000 decreased the range of the ten results to less than one in almost all cases (Table 13c). Both the 10,000 and 100,000 simulation cases sufficiently captured the uncertainty in results. The additional time needed to run the 100,000 simulations compared to the 10,000 simulations does not seem to be justified by the relatively minor decrease in variability. Thus, 10,000 simulations was used as the standard for the base case and all further sensitivity runs.

5.4 Narraguagus River Verification

Historical numbers of adult Atlantic salmon returning annually to the Narraguagus River, measured either through rod catches or at adult traps, were estimated for the years 1967 to 2002 and compared to model predictions (Table 14). The Cherryfield adult trap was used to count returning Atlantic salmon to the Narraguagus River from 1962 to 1974, and from 1991 to the present (Baum 1997). In the early period fish could bypass the trap by jumping over the dam. A modification to the spillway was made in 1991 and video monitors added to eliminate this undercount. Approximately 25% of the returning fish in the first period were thought to bypass the trap, so the trap records were divided by 0.75 to produce expanded trap catch estimates. Rod catch was collected during the period 1967 to 1995 by state agencies (Baum 1997). The average ratio of rod to expanded trap catch in the early period was applied to years without trap catch data to estimate the number of fish expected at the trap for years 1975 to 1990. These values represent escapement as spawners for each year and were considered to be of the correct order of magnitude, based on occasional redd counts. There were a few years when complete redd counts were made, and these values were used instead of the rod to trap ratio estimates. Ratios of hatchery and natural fish in the catch or trap were calculated from the US Atlantic Salmon Assessment Committee database for each year and applied to the predicted number of fish at the trap to allow comparison with model estimates of hatchery and natural fish passing the trap. The simulated populations were initialized based on the expanded catch using a range of 15% to 35% bypass of the trap and then applying the proportion at each sea winter age from the US Atlantic Salmon Assessment Committee database.

Three sources of removals were modeled in the verification test: (1) parr1+ for broodstock; (2) adult river fishing; and (3) the adult interception fisheries at sea. Each year 300 parr1+ salmon were collected by electrofishing for use as broodstock, a minor removal relative to the parr population abundance. In contrast, the adult removals have been large relative to abundance. In river fishing for adults was assumed to remove between 15% and 25% of the annual returns during 1967 to 1992. Based on catch at age information collected from the rod fishery, approximately 90% of the catch was 2 sea winter fish. This targeting of 2 sea winter fish was modeled by assuming only 2 sea winter fish were caught by the in river fishery. The interception fisheries were modeled by assuming that catches occurred in proportion to relative abundance. The number of fish caught in the interception fisheries was assumed to be equal to the run size for years 1967 to 1975 based on tag recapture data (range of 45% to 55% of total run caught) and then was linearly reduced over time to the current low levels (range of 0 to 10% of total run caught) (Table 15).

The Narraguagus River has been stocked with all juvenile life stages of Atlantic salmon at some point in its history (Table 16). In the years 1967 through 1982, only smolts were stocked. During 1983 through 1991, all life stages were stocked, although smolt stocking predominated. No stocking occurred in 1992, 1993, or 1994. Since 1995, fry have been the predominant life stage stocked, with relatively minor stocking of other juvenile life stages. As fry stocked fish cannot be distinguished from natural fish based on scale readings, simulated returns of hatchery fish for the years 1998 through 2002 were added to the natural returns for comparison to the predicted trap data. The returns from fry stocking in years 1985 though 1989 could not be distinguished from the larger expected returns of parr and smolt stocked fish for these cohorts. Thus, the plots of model natural + hatchery fry stocked returns for years 1988 through 1995 are slight underestimates and the associated plots of model hatchery (non fry stocked) will be overestimated for this period.

The model reports the median and 80% confidence intervals of the number of returns in each year for the natural population, hatchery population, and total. These confidence intervals were compared to the observations of predicted returns at the Cherryfield trap. For the verification test, only the Narraguagus River was simulated, so no straying was included.

The annual medians and 80% confidence intervals from 10,000 simulations are plotted with the observed returns in Figure 16. These SalmonPVA results did not mirror the observations of total returns; more than half of the observed points are outside the 80% confidence intervals and the trends are not similar. The observed data show a clear decline in total returns from the mid 1980s to 2002 while the model predictions show an overall increase during that period. The returns in the early part of the series are underestimated by the model while the returns from the later part of the series are overestimated. The early underestimation could be due to lower interception fishery catches than assumed or higher marine survival during this time period. Reducing the interception fishery catch by 90% did not substantially improve the predictions for the early part of the time series, and still produced large overestimates of more recent returns (results not shown). A possible explanation for the overestimation of recent returns is that stocked fish may have significantly lower survival than natural fish. Overestimation of hatchery returns impacts not only the hatchery population estimates in any year, but also the natural population return estimates in subsequent years, because the offspring of hatchery returns are classified as natural. Reducing the number of fish stocked by 50%, but using the original interception fishery catches, reduced the estimates of recent returns, but still produced a larger underestimation of returns early in the series and the increasing trend in run size for recent years remained (Figure 17). Reducing the number of fish stocked by 90% caused the predicted returns to be quite similar to those observed in the recent years, but still produced an increasing trend in recent years and greatly underestimated returns in the early part of the time series (Figure 18).

These results imply that something changed during the 1967 - 2002 period to cause the survival rate to decrease. Early in the time series large catches, both at sea and in the river, were supported and returns to the trap were high. In contrast, the fisheries in recent years have been almost completely eliminated, but the number of returns continues to decline. Marine survival of hatchery marked smolts has declined in many rivers during this time period. Thus, the assumption of stationarity in marine survival is probably not applicable over the 35 year period. It is likely that there has been a protracted downward trend in marine survival. Using SalmonPVA with the base case inputs does not allow for non-stationarity in survival rates. Although marine survival is cyclic, it will average the same level at the start and end of the projection over many realizations.

While the model can predict the correct order of magnitude of returns, the trend is not matched under the scenarios examined. The questions remain, what has changed and what are the appropriate levels for use in forecasts? The verification test is limited in that a model used for long-term projections is compared to a limited set of actual observations. Even if all the model processes and data inputs were correct, there is a chance that a single realization will fall outside the confidence intervals. Furthermore, there are many ways that model processes and data input can be changed to produce similar confidence intervals. No attempts were made to tune the model to Narraguagus River data.

6. Output for Base Case

The sections of the output file are described here with some examples (see Figure 19). The first part of the SalmonPVA output file is a record of the input file formatted so that the output file can be used directly as an input file to confirm results. This also allows confirmation of input selections to identify any input errors.

Following the input is an optional section containing the results from any one of the realizations, determined by user input. This section can be quite large, approximately 5,000 lines for the base case, but can be skipped by entering an integer less than 1 or greater than the number of simulations. This output serves two purposes: 1) it allows for quick troubleshooting of input when results are obviously different from those expected and 2) it allows for a detailed evaluation of one of the simulation trajectories. Using the same random number generator seed value allows the user to examine multiple simulation trajectories from a single set of results. In this section of output, the number of natural fish at each life stage and year are reported by river and as a total over all rivers (Table 17). The population matrix shows how the number of fish in a cohort decreases as it ages and passes through the different life stages. The hatchery population numbers are presented next in the same format as the natural populations. A matrix of habitat capacity follows with years as rows and rivers as columns. These values are the randomly chosen habitat limitations imposed for each river in each year. Whether or not these habitat capacity values were limiting follows as a similar matrix with entries of 1 when habitat was limiting and 0 when it was not. If even one year is limited for a given river in a simulation, then that simulation is recorded as having been limited by habitat. The next set of matrices output are the interception fishery removals (the number of fish caught in the Greenland and St. Pierre et Miquelon fisheries) presented by river with years as rows and classified by natural, hatchery, and total, each of which is further stratified by sea winter age. The next set of matrices output are the river adult fishery removals, presented in the same format as the interception fishery removals. These are followed by a set of matrices of natural fish removed for broodstock, one for adult and another for parr1+. The adult matrices have years as rows and sea winter age as columns, while the parr1+ matrices have years as rows and stock as columns. Using this output, the populations of fish can be tracked in conjunction with human induced removals to determine the impact of human activity on the populations. The impact of straying can also be derived by comparing the number of fish at each sea winter age before and after straying, for example 1SWret and 1SWstray, to assess the net gain or loss from each river.

Following the specific results from one realization is an optional section that lists the occurrence of extinction or habitat limitation for each stock and group for every realization, together with the average number of spawners for each stock and group in every realization. This section can quickly become huge as it grows at the rate of three times the number of realizations. For the base case, this section would contain over 30,000 lines. This section can be used to create histograms of outputs or to determine in which realization a certain stock went extinct. Combined with the optional realization specific results, these outputs can show why the salmon population in a river went extinct.

The remaining output is always provided. The river names and components of river groups are defined first, followed by the probability of extinction and habitat limitation for each stock and group, along with the minimum, median, and maximum number of years of habitat limitation for each stock and group (Table 18). These tables are followed by the average number of natural spawners in the specified years for each stock and group and the spawner exceedence tables (Table 19). The time series of returns are next given as medians and 80% confidence intervals for the natural, hatchery, and total populations (not shown here). Finally, the median replacement rate and table of replacement rate distributions are reported (Table 20).

The output in this section contains the bottom line values of interest from the SalmonPVA model. Here it can be seen that under the base case assumptions, the probability of salmon becoming extinct in the next 100 years ranges from less than 10% (Narraguagus and Machias rivers) to over 50% (Cove Brook and Ducktrap). As a group, salmon in the Downeast rivers have a 3% chance of all going extinct while the Southwest rivers have approximately a 15% chance of going extinct. The probability of the entire DPS going extinct in the next 100 years is less than 3%. Conversely, habitat limitations occur frequently for all rivers, with only three rivers having less than 98% occurrence of habitat capacity limitations (Cove Brook, Pleasant, and Ducktrap). The salmon populations in these rivers have the highest probability of extinction, the smallest initial population sizes, and no stocking, but are also the smallest rivers with the lowest habitat capacity. The effect of stocking is seen in the number of years when habitat is limiting, with the medians for stocked rivers corresponding to the approximate length of stocking. The average number of spawners in years 2082 to 2102 reflect this with Cove Brook, Pleasant, and Ducktrap having the lowest medians and maximums.

Although the entire DPS has less than 5% probability of going extinct in the next 100 years, the time trend and replacement rate results counter this suggestion of viability. Using only 1,000 simulations (due to computer memory limitations with 10,000 simulations) the trajectories of returns were examined as in the Narraguagus verification test (Figures 20-22). All the rivers and groups of rivers showed the same pattern of an increase in returns due to stocked fish, followed by an overall decrease during 2020 to 2102. Even rivers that were not stocked, such as Cove Brook, were impacted by the stocking of other rivers, due to straying. More importantly, the arbitrary threshold of 5% probability of extinction in 100 years may not be appropriate due to the continued downward trend in run sizes during 2020 to 2102. The trajectories also show the overly optimistic impact of stocking in the base case scenario; projected returns under stocking are much higher than currently observed at these stocking levels.

The median replacement rates for all rivers and river groups are all below 0.75 and there is at least an 85% probability that the replacement rate for each river and river group is less than one. This indicates that the populations are not viable, based on the definition provided in the Viable Salmonid Populations document (McElhany et al. 2000). The replacement rates are mainly determined by the survival rates assumed in the base case, but the low initial population sizes are also a decisive factor because in a number of rivers salmon go extinct early in the projection of many simulations, causing a replacement rate of zero (as manifest by unusually high frequencies of zero in the replacement rate distributions) (Figure 23). Even discounting the simulations with zero replacement rates, the distributions reveal that base case survival rates will not produce viable populations.

7. Sensitivity Analyses

7.1 Increased Survival

A series of five sensitivity analyses was conducted in which survival rates of certain life stages were increased by 20%. For each of the four juvenile life stages, the midpoint of the survival range was increased by 20% but the range of uncertainty held constant. This shifts the survival rates without a change in variability. In a similar fashion, the midpoint of the average marine survival was increased by 20% with the range remaining constant. The amplitude, frequency, and phase of the marine cycle were not changed in the sensitivity analyses. As expected, probability of extinction decreased, the median value of the average spawners for years 2082 to 2102 increased, and replacement rate increased (Table 21). The more unexpected result was that all four juvenile life stage sensitivity results were virtually identical. Furthermore, the magnitude of response was much greater than 20% (the amount of change in the survival rate) demonstrating the non-linear response of the model to differences in survival rates. Changing the marine survival rate had a larger effect than changes in any of the juvenile survival rates for all three response variables. This is not unexpected because the marine survival rate affects multiple years of an individual cohort, as opposed to a single year in applying the juvenile life stage survival rates. The increase in marine survival has a larger impact on the total returns to the rivers than the increase in juvenile survival of any one stage (Figure 24). However, all five sensitivity analyses produced declining populations (as seen in the figure and in the table of replacement rates). The consistent fluctuations in the median returns, especially for the increased marine survival scenario, reflect the interaction of the marine cycles with the cyclic nature of Atlantic salmon returns; a good return year frequently produces good returns six years later. The fluctuations are not caused by the simulated trajectories all following the same path, as evidenced by comparing three trajectories selected at random with the median and 80% confidence interval generated from 10,000 simulations (Figure 25).

7.2 Stocking

When stocking did not occur in any rivers, the probability of extinction increased to high levels for all rivers and groups of rivers (Table 22). This demonstrates the importance of stocking in perpetuating the currently small stocks, the more so given that the stocking projections are optimistic, as noted above. When stocking did not occur, the probability of habitat limitation dropped below 50% for all eight rivers. Both the average number of spawners in the years 2080 to 2100 and the replacement rate dropped to zero for many of the rivers due to the high probabilities of extinction. These results suggest that if the survival rates input to the model are correct, there is a low probability of Atlantic salmon persisting in the DPS rivers without hatchery supplementation.

7.3 Straying

The impact of straying on probability of extinction and replacement rates was examined under two scenarios. The first sensitivity run eliminated straying. The second sensitivity run maintained the stray rate matrix as in the base case, but increased the straying rates for both natural and hatchery populations five fold, from 1% and 2% to 5% and 10%, respectively. As expected, straying caused the rivers with smaller initial populations to have lower probabilities of extinction at the expense of the larger rivers (Table 23). The smaller rivers also had a higher probability of being limited by habitat when straying occurred. The overall effect of straying is a reallocation of fish from large populations to small populations, as seen in the DPS totals. This component of the model is important for the rivers with small populations, but less so for the rivers with large populations. However, this dependence upon strays in the small river populations is not seen in genetic analyses, where Cove Brook (the smallest of the DPS river) has consistently been found to be the most genetically distinct river in the DPS (King et al. 2000). The recent low abundance in all the DPS rivers makes drawing a conclusion regarding straying rates difficult.

7.4 Habitat Limitation

The sensitivity of results to the habitat limitation was examined by changing the number of large parr per unit of habitat to reflect potential changes in riverine productivity. The productivity of all rivers was either decreased from 7 to 3 large parr per unit, or increased to 11 large parr per unit, as approximate 50% changes in habitat limitation. As expected, increasing the number of large parr that the river can hold decreases the probability of extinction, decreases the probability of habitat limitation, increases the average number of spawners in years 2082 to 2102, and increases the replacement rate (Table 24). The changes are not linear; the change from 7 parr/unit to 3 parr/unit has a larger impact than the change from 7 parr/unit to 11 parr/unit. This is because the habitat cap prevents Malthusian growth, and the smaller the cap the more likely the population is to decrease back to zero. The changes in replacement rate are due to the higher probability of extinction because the juvenile and marine survival rates are the same among these runs. These results show the potential for habitat restoration to decrease the probability of extinction by allowing larger populations during periods of good survival.

7.5 Survival Linkages Among Rivers

As noted previously, SalmonPVA allows the user to determine the strength of the juvenile survival linkages among rivers. The full range of possibilities include no linkages (where each river has the survival value for that year drawn independently from all the others) through complete linkages (where only one survival rate is drawn for a year and applied to all rivers). These two extremes were simulated and compared to the base case assumption of relatively strong linkages among the rivers and a noise level of 0.05. Each scenario had the same maximum range of survival values for a given juvenile life stage, from the minimum minus noise to maximum plus noise. Surprisingly, the base case analysis did not, in general, produce results intermediate to the two extreme cases (Table 25). The probability of extinction was lower for all the individual rivers in the base case compared with both the complete linkage and complete independence among rivers. The entire DPS probability of extinction in the base case was intermediate to the two extremes. This apparent contradiction between individual rivers and all rivers combined arises because all rivers must be extinct for the DPS to become extinct. When juvenile survival rates are completely linked among rivers, there is no difference among the rivers in terms of good years and bad years. A period of bad years will cause all the rivers to simultaneously go extinct because there is no population unaffected by the poor survival rates that could otherwise provide strays. At the other extreme, when juvenile survival is completely independent among rivers, there are almost always some rivers with poor survival preventing the populations in all the rivers from rebuilding together. So although the probability of extinction over all rivers is lowered, the probability of extinction for any given river is increased because of the loss of strong cohorts spread over many rivers. These effects can also be seen in both the average numbers of spawners and replacement rates.

7.6 Initial Population Abundance

The initial population abundance for each river from 1995 through 2002 was doubled to examine the sensitivity of results. Both the lower and upper bounds of the input ranges were doubled, which also increased the variance of the input ranges. This approach was chosen to avoid the need to round to whole fish, as would be required by doubling the average of the range while maintaining the spread of the input range. Doubling the initial populations had almost no effect on: (a) the probabilities of extinction or habitat limitation; (b) the number of average spawners in years 2082 to 2102; or (c) the replacement rate (Table 26). The differences between the two scenarios were within the range of noise expected using 10,000 simulations (as shown above) which explains the counter-intuitive increases in some probabilities of extinction under larger starting population abundances.

7.7 Sensitivity Analyses Summary
Considering both the sensitivity analyses conducted in section 7 and the tests conducted in sections 5.1 and 5.2, the survival rates are the most influential parameters determining probability of population persistence. Both the level and amount of uncertainty in the survival rates determine the equilibrium condition to which the population proceeds when projected many years into the future. This is not surprising as the exploitation rates on these stocks are currently thought to be close to zero and are expected to remain low. The importance of stocking appears to be exaggerated by the model, with more returns per stocking event than have been observed historically. Some discounting of the amount of fish stocked therefore seems appropriate. Straying and survival linkages among rivers are not important for the DPS as a unit, but can be quite important for individual rivers with small populations. Habitat capacity does cause a limiting effect and increases the probability of extinction, but does not appear to have a major impact in the base case conditions. The potential for habitat restoration to improve the probability of population persistence, even under the same survival rates, demonstrates the utility of this restoration work. Initial population abundance is the least influential of the input parameters, but is obviously important for rivers with very small populations.

8. Viability Analyses

8.1 Relative Population Sizes
River size is a major factor in determining the number of Atlantic salmon that can be supported. Population viability analysis requires that relative sizes of populations reflect differences in river size. Given that adult returns are the most easily measured life stage, it is desirable to conduct viability analyses in terms of numbers of returning adults. One way to integrate river size and population size is to compute the number of adults that would fully seed the available juvenile habitat. These calculations have been performed for all the DPS rivers and are reported by the US Atlantic Salmon Assessment Committee where they are denoted Conservation Spawning Escapement (CSE) levels (USASAC 2002; Table 27). The viability analyses presented here used these values (or some multiple), expressed as the number of 2 sea winter returns during 1995 through 2002 to initialize population sizes used in the model.

8.2 Replacement Rate
One of the conditions necessary for a viable population is that it at least replace itself (McElhany et al. 2000). Using the CSE levels as initial population sizes, but with no stocking, the base case scenario results in replacement rates well below one for all rivers and combinations of rivers (Table 28). In a highly parameterized model, such as SalmonPVA, numerous inputs can be changed that will affect the replacement rate. Based on the sensitivity analyses, increases in survival rates are most likely to be required to achieve a replacement rate of one. Since increases in each of the four juvenile life stage survival rates produced identical percent results in the sensitivity analyses, only one of the survival rates (the parr1+ to smolt transition) was modified,

under the assumption that a similar percentage change in any of the other juvenile life stage survival rates would produce a similar change in replacement rate. Average marine survival rate was also examined to determine the amount of change in this parameter needed to generate a replacement rate of one. The replacement rate for the entire DPS was chosen as the DPS is the entity protected under the Endangered Species Act. An alternative approach would be to determine the survival rates that produced a minimum replacement rate of one for all the rivers.

The PVA results showed that the median replacement rate for the DPS responded more quickly to relative changes in marine survival than juvenile survival (Figure 26). A 21% increase in marine survival or a 35% increase in juvenile survival each produced a median replacement rate of one for the DPS. The median replacement rates for all the individual rivers were slightly below one but the distributions were normal and centered near one (Table 28; Figure 27). Due to the effect of population abundance on the replacement rate calculations and the effect of grouping rivers (a group of rivers has a lower probability of extinction than any individual river in the group), it is not possible to have all the rivers produce the same replacement rate.

8.3 Minimum Viable Population Abundances

How small can the initial populations be and still have a low probability of going extinct? SalmonPVA results using multiples of CSE levels of initial population abundance (10%CSE to 50%CSE) and the marine and juvenile survival scenarios that produced a replacement rate of 1.0 for the DPS (see above) reveal that small populations (10-20% CSE) can have low probabilities of extinction but that the smallest rivers have the highest probability of extinction (Table 29). These extinction risks are true extinction, not quasi-extinction of dropping below a certain number of returns over a given number of generations. Managers need to decide how much risk is acceptable when setting the recovery targets for these endangered populations.

8.4 Recovery Criteria

When setting recovery criteria for endangered species, other features besides population abundance and replacement rates must be considered. For Atlantic salmon, the distribution of fish among rivers is an important attribute which mitigates against catastrophic risks and provides diversity within the DPS. Genetic bottlenecks should also be considered in establishing recovery criteria, although these factors cannot be addressed directly with the current version of SalmonPVA. However, the model can be used to guide management decisions when setting recovery criteria by depicting the consequences of different management actions under various assumptions about future environmental conditions.

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Table 1. SalmonPVA life history stages modeled.

Life Stage	Year	Month
Egg	2001	Oct
Fry	2002	Jun
Parr 0+	2002	Aug
Parr 1+	2003	Aug
Smolt	2004	May
1 Sea Winter Adult Return	2005	Jun
2 Sea Winter Adult Return	2006	Jun
3 Sea Winter Adult Return	2007	Jun
First Kelt Return 2 Years After Spawn		Jun
Second Kelt Return 2 Years Later		Jun

Table 2. Egg to fry survival values from the literature assuming 8 months for standardization of survival rates. Bold values used to describe egg to fry survival.

			# Years	Duration	Reported Percent Survival			Converted % Survival		
Author	**Region**	**Origin**	**of Data**	**(months)**	**Mean**	**Lower**	**Upper**	**Mean**	**Lower**	**Upper**
Cunjak et al. 1998	New Brunswick	wild	6	6	30.67	9.20	61.0	20.68	4.15	51.73
Egglishaw & Shackley, 1980	Scotland	hatchery	2	6	12.92	11.10	14.8	6.53	5.33	7.83
Elson, 1957a	New Brunswick	wild	unk	unk	17.60	NA	NA	17.60	NA	NA
Elson, 1957a	New Brunswick	wild	unk	unk	NA	1.70	8.00	NA	1.70	8.00
Jordan & Beland, 1981	**Maine**	**wild**	**unk**	**8**	**25.00**	**15.00**	**35.00**	**25.00**	**15.00**	**35.00**

Table 3. Fry to Parr0+ survival values from the literature assuming 2 months for standardization of survival rates. Bold values used in objective process to calculate uniform distribution.

Author	Region	Origin	# Years of Data	Duration (months)	Reported Percent Survival Mean	Reported Percent Survival Lower	Reported Percent Survival Upper	Converted % Survival Mean	Converted % Survival Lower	Converted % Survival Upper
Egglishaw & Shackley, 1973	**Scotland**	**wild**	**4**	**5**	**24.00**	**18.00**	**30.00**	**56.50**	**50.36**	**61.78**
Egglishaw & Shackley, 1980	**Scotland**	**hatchery**	**5**	**5**	**19.50**	**9.40**	**31.00**	**52.00**	**38.84**	**62.60**
Gardiner & Shackley, 1991	**Scotland**	**wild**	**6**	**5**	**16.50**	**2.80**	**33.00**	**48.64**	**23.93**	**64.18**
Greenwood, 1981	New Hampshire	hatchery	3	unk	21.30	15.30	25.80	21.30	15.30	25.80
Heggenes & Borgstroem, 1991	Norway	hatchery	1	2	77.50	NA	NA	77.50	NA	NA
Kennedy, 1984	Ireland	hatchery	unk	unk	16.70	NA	NA	16.70	NA	NA
Knight et al., 1982	New Hampshire	hatchery	5	unk	25.00	11.00	46.00	25.00	11.00	46.00
Orciari et. al., 1994	**New England**	**hatchery**	**3**	**5**	**27.00**	**18.00**	**35.00**	**59.23**	**50.36**	**65.71**
McMenemy, 1995, 32	Vermont	hatchery	5	4	42.40	31.70	53.00	65.12	56.30	72.80
McMenemy, 1995, 109	Vermont	hatchery	3	6	15.00	5.70	21.00	53.13	38.49	59.44
McMenemy, 1995, average	**Vermont**	**hatchery**	**3**					**59.12**	**38.49**	**72.80**
Mills, 1969	Scotland	hatchery	7	unk	8.00	1.00	30.00	8.00	1.00	30.00
Stewart, 1963, unfed	England	hatchery	unk	unk	1.73	NA	NA	1.73	NA	NA
Stewart, 1963, fed	England	hatchery	unk	unk	8.80	NA	NA	8.80	NA	NA
Stewart, 1963, average	England	hatchery	unk					5.27	1.73	8.80
Whalen & LaBar, 1994, 12	Vermont	hatchery	1	3	33.33	24.00	44.00	48.07	38.62	57.85
Whalen & LaBar, 1994, 25	Vermont	hatchery	2	3	31.33	7.00	55.00	46.13	16.98	67.13
Whalen & LaBar, 1994, 50	Vermont	hatchery	2	3	16.33	7.00	29.00	29.88	16.98	43.81
Whalen & LaBar, 1994, 75	Vermont	hatchery	1	3	24.00	16.00	39.00	38.62	29.47	53.38
Whalen & LaBar, 1994 average	Vermont	hatchery	2	3	25.44	7.00	55.00	40.15	16.98	67.13
Whalen & LaBar, 1998, unfed	Vermont	hatchery	2	3	14.00	6.00	23.00	26.96	15.33	37.54
Whalen & LaBar, 1998, fed	Vermont	hatchery	2	3	23.00	11.00	64.00	37.54	22.96	74.27
Whalen & LaBar, 1998, average	Vermont	hatchery	2	3	18.00	6.00	64.00	31.88	15.33	74.27
Whalen & LaBar overall average	Vermont	hatchery	2	3	21.72	6.00	64.00	36.14	15.33	74.27

Table 4. Parr0+ to Parr1+ survival values from the literature assuming 12 months for standardization of survival rates. Bold values used in objective process to calculate uniform distribution.

Author	Region	Origin	# Years of Data	Duration (months)	Reported Percent Survival Mean	Lower	Upper	Converted % Survival Mean	Lower	Upper
Cunjak et al. 1998	**New Brunswick**	**wild**	**6**	**12**	**34.17**	**15.00**	**75.00**	**34.17**	**15.00**	**75.00**
Egglishaw & Shackley, 1980	**Scotland**	**hatchery**	**6**	**12**	**51.00**	**22.00**	**88.00**	**51.00**	**22.00**	**88.00**
Gardiner & Shackley, 1991	**Scotland**	**wild**	**5**	**12**	**11.30**	**3.30**	**18.70**	**11.30**	**3.30**	**18.70**
Heggenes & Borgstroem, 1991	Norway	hatchery	1	6	47.80	NA	NA	22.85	NA	NA
Kennedy & Strange, 1980	**Ireland**	**hatchery**	**2**	**12**	**23.00**	**14.30**	**31.70**	**23.00**	**14.30**	**31.70**
Kennedy & Strange, 1986	**Ireland**	**hatchery**	**2**	**12**	**47.00**	**24.00**	**78.00**	**47.00**	**24.00**	**78.00**
Knight et al., 1982	New Hampshire	hatchery	unk	unk	45.00	18.00	64.00	45.00	18.00	64.00
Meister, 1962	**Maine**	**wild**	**2**	**12**	**50.25**	**41.10**	**59.40**	**50.25**	**41.10**	**59.40**
Orciari et. al., 1994, 9	New England	hatchery	3	9	53.30	45.00	68.00	43.22	34.48	59.80
Orciari et. al., 1994, 12	New England	hatchery	3	12	32.40	27.00	42.00	32.40	27.00	42.00
Orciari et. al., 1994, average	**New England**	**hatchery**	**3**					**37.81**	**27.00**	**59.80**
Symons, 1979; data from Elson 1975	New Brunswick	hatchery	4	unk	15.30	5.00	26.00	15.30	5.00	26.00

Table 5. Parr1+ to smolt survival values from the literature assuming 9 months for standardization of survival rates. Bold values used in objective process to calculate uniform distribution.

			# Years	Duration	Reported Percent Survival			Converted % Survival		
Author	Region	Origin	of Data	(months)	Mean	Lower	Upper	Mean	Lower	Upper
Cunjak et al. 1998	**New Brunswick**	**wild**	**6**	**12**	**32.92**	**25.00**	**47.50**	**43.46**	**35.36**	**57.22**
Elson, 1957a	unknown	hatchery	unk	unk	11.00	2.00	30.00	11.00	2.00	30.00
Kocik pers. comm.	**Maine**	**wild**	**7**	**9**	**16.80**	**11.50**	**27.30**	**16.80**	**11.50**	**27.30**
Meister, 1962	**Maine**	**wild**	**1**	**18**	**8.90**	**NA**	**NA**	**29.83**	**19.83***	**39.83***
Myers 1984, precocious	Newfoundland	wild	4	12	27.25	12.00	41.00	37.72	20.39	51.24
Myers 1984, immature	Newfoundland	wild	4	12	43.75	30.00	72.00	53.79	40.54	78.16
Myers 1984, average	**Newfoundland**	**wild**	**4**					**45.75**	**20.39**	**78.16**
Orciari et. al., 1994, 7.5	New England	hatchery	3	7.5	31.20	24.00	37.00	24.72	18.04	30.33
Orciari et. al., 1994, 10.5	New England	hatchery	3	10.5	19.00	14.00	23.00	24.09	18.54	28.37
Orciari et. al., 1994, average	**New England**	**hatchery**	**3**					**24.40**	**18.04**	**30.33**
Symons, 1979, wild	New Brunswick	wild	4	unk	46.10	14.00	81.00	46.10	14.00	81.00
Symons, 1979, hatchery	New Brunswick	hatchery	1	unk	44.20	29.00	79.00	44.20	29.00	79.00
Symons, 1979, average	New Brunswick	both	1					45.15	14.00	81.00
Whalen, 1998, observed	Vermont	hatchery	2	9	17.50	8.90	24.00	17.50	8.90	24.00
Whalen et al, 2000, modeled	Vermont	hatchery	2	9	18.00	9.00	37.00	18.00	9.00	37.00
Whalen average	Vermont	hatchery						17.75	8.90	37.00

* assumed uncertainty centered on mean estimate

Table 6. Summary of life stage survival rates used in base case runs of SalmonPVA.

Life Stage		**Survival (%)**		
Begin	End	Min	Max	Mean
Egg	Fry	15	35	25
Fry	Parr 0+	43	60	51.5
Parr 0+	Parr 1+	12	58	35
Parr 1+	Smolt	17	50	33.5
Egg	Smolt	0.13	6.09	1.51

Table 7. Estimated amount of juvenile habitat and corresponding large parr potential (assuming 7 large parr per habitat unit) used in base case runs of SalmonPVA.

River	Abbrev.	Juvenile Habitat	Large Parr Potential
Dennys	DE	2,414	16,898
East Machias	EM	3,006	21,042
Machias	MC	6,156	43,092
Pleasant	PL	1,220	8,540
Narraguagus	NG	6,014	42,098
Cove Brook	CB	235	1,645
Ducktrap	DT	845	5,915
Sheepscot	SHP	2,797	19,579

Table 8. Population initializations (low and high values used as uniform distribution) for each sea winter age and river in base case runs of SalmonPVA.

	1SW		2SW		3SW	
Dennys						
Year	Lower	Upper	Lower	Upper	Lower	Upper
1995	3	8	18	51	1	4
1996	2	6	13	37	1	3
1997	2	6	14	41	1	3
1998	2	6	13	38	1	3
1999	2	5	11	31	1	2
2000	1	1[a]	1	1[a]	0	0[a]
2001	2	2[a]	0	0[a]	0	0[a]
2002	4	5[a]	13	16[a]	0	0[a]
East Machias						
Year	Lower	Upper	Lower	Upper	Lower	Upper
1995	0	0	0	0	0	0
1996	2	7	15	46	1	4
1997	1	3	7	20	1	2
1998	3	10	23	66	2	5
1999	2	5	11	32	1	2
2000	1	3	7	18	1	1
2001	1	2	4	11	0	1
2002	1	2	4	11	0	1
Machias						
Year	Lower	Upper	Lower	Upper	Lower	Upper
1995	2	4	11	29	1	2
1996	4	12	29	81	2	6
1997	3	9	20	57	2	4
1998	3	10	23	66	2	5
1999	3	7	17	49	1	4
2000	2	5	11	31	1	2
2001	2	5	11	30	1	2
2002	0	1	3	8	0	1
Pleasant						
Year	Lower	Upper	Lower	Upper	Lower	Upper
1995	1	2	6	15	0	1
1996	2	7	15	46	1	4
1997	0	1	2	4	0	0
1998	1	3	6	17	0	1
1999	0	0	0	0	0	0
2000	0	0[a]	2	2[a]	0	0[a]
2001	1	1[a]	9	11[a]	1	1[a]
2002	0	0[a]	0	0[a]	0	0[a]

	1SW		2SW		3SW	
Narraguagus						
Year	Lower	Upper	Lower	Upper	Lower	Upper
1995	0	0[a]	51	61[a]	5	6[a]
1996	10	12[a]	49	59[a]	5	6[a]
1997	1	1[a]	32	38[a]	4	5[a]
1998	1	1[a]	18	22[a]	3	4[a]
1999	6	7[a]	25	30[a]	1	1[a]
2000	13	16[a]	9	11[a]	0	0[a]
2001	5	6[a]	24	29[a]	3	4[a]
2002	4	5[a]	3	4[a]	1	1[a]
Cove Brook		(copied 2000 for previous years because no counts)				
Year	Lower	Upper	Lower	Upper	Lower	Upper
1995	0	1	2	4	0	0
1996	0	1	2	4	0	0
1997	0	1	2	4	0	0
1998	0	1	2	4	0	0
1999	0	1	2	4	0	0
2000	0	1	2	4	0	0
2001	0	0	0	0	0	0
2002	0	0	0	0	0	0
Ducktrap						
Year	Lower	Upper	Lower	Upper	Lower	Upper
1995	1	4	8	24	1	2
1996	2	7	16	47	1	4
1997	0	1	2	7	0	1
1998	1	3	6	17	0	1
1999	2	5	12	36	1	3
2000	0	1	2	7	0	1
2001	0	0	0	0	0	0
2002	0	0	0	0	0	0
Sheepscot						
Year	Lower	Upper	Lower	Upper	Lower	Upper
1995	0	1	2	7	0	1
1996	1	3	7	20	1	2
1997	1	2	6	15	0	1
1998	0	1	3	10	0	1
1999	2	4	11	29	1	2
2000	1	4	8	24	1	2
2001	0	1	3	10	0	1
2002	0	1	3	10	0	1

[a] These upper limits were formed assuming a 20% increase in the observed trap count.

Table 9a. Straying matrix based on distance between river mouths using cost weighted distances. In all four straying matrices river of origin is given in the first column and river of return in subsequent columns.

	DE	EM	MC	NG	PL	CV	DT	SHP
DE	0.0000	0.2227	0.2151	0.1488	0.1522	0.0872	0.1013	0.0726
EM	0.0927	0.0000	0.5620	0.1005	0.1043	0.0467	0.0568	0.0371
MC	0.0907	0.5696	0.0000	0.0981	0.1017	0.0465	0.0564	0.0370
NG	0.1091	0.1771	0.1706	0.0000	0.2646	0.0921	0.1151	0.0714
PL	0.1083	0.1783	0.1715	0.2568	0.0000	0.0941	0.1191	0.0720
CV	0.0814	0.1047	0.1029	0.1173	0.1234	0.0000	0.3483	0.1220
DT	0.0801	0.1080	0.1057	0.1242	0.1325	0.2951	0.0000	0.1545
SHP	0.0938	0.1151	0.1134	0.1257	0.1308	0.1688	0.2524	0.0000

Table 9b. Straying matrix based on relative river size.

	DE	EM	MC	NG	PL	CV	DT	SHP
DE	0.0000	0.0364	0.0178	0.7322	0.0590	0.0518	0.0650	0.0378
EM	0.0298	0.0000	0.0286	0.0284	0.0779	0.0175	0.0191	0.7987
MC	0.1138	0.2229	0.0000	0.1111	0.1631	0.0847	0.0893	0.2152
NG	0.7308	0.0346	0.0174	0.0000	0.0545	0.0557	0.0712	0.0359
PL	0.1481	0.2389	0.0641	0.1371	0.0000	0.0693	0.0776	0.2648
CV	0.1158	0.0478	0.0296	0.1246	0.0616	0.0000	0.5718	0.0488
DT	0.1341	0.0482	0.0289	0.1472	0.0638	0.5284	0.0000	0.0494
SHP	0.0306	0.7904	0.0273	0.0291	0.0854	0.0177	0.0194	0.0000

Table 9c. Straying matrix based on river order of encounter.

	DE	EM	MC	NG	PL	CV	DT	SHP
DE	0.0000	0.1039	0.1169	0.1299	0.1429	0.1558	0.1688	0.1818
EM	0.1000	0.0000	0.1143	0.1286	0.1429	0.1571	0.1714	0.1857
MC	0.0952	0.1111	0.0000	0.1270	0.1429	0.1587	0.1746	0.1905
NG	0.0893	0.1071	0.1250	0.0000	0.1429	0.1607	0.1786	0.1964
PL	0.0816	0.1020	0.1224	0.1429	0.0000	0.1633	0.1837	0.2041
CV	0.0714	0.0952	0.1190	0.1429	0.1667	0.0000	0.1905	0.2143
DT	0.0571	0.0857	0.1143	0.1429	0.1714	0.2000	0.0000	0.2286
SHP	0.0357	0.0714	0.1071	0.1429	0.1786	0.2143	0.2500	0.0000

Table 9d. Combined straying matrix, used in base case analysis of SalmonPVA.

	DE	EM	MC	NG	PL	CV	DT	SHP
DE	0.0000	0.1379	0.1364	0.2579	0.1298	0.1077	0.1210	0.1093
EM	0.0830	0.0000	0.2762	0.0973	0.1144	0.0852	0.0951	0.2488
MC	0.0971	0.3169	0.0000	0.1123	0.1304	0.0991	0.1102	0.1340
NG	0.2255	0.1206	0.1217	0.0000	0.1739	0.1123	0.1317	0.1143
PL	0.1056	0.1599	0.1304	0.1873	0.0000	0.1168	0.1367	0.1633
CV	0.0843	0.0895	0.0947	0.1290	0.1284	0.0000	0.3298	0.1443
DT	0.0817	0.0871	0.0938	0.1363	0.1343	0.3037	0.0000	0.1631
SHP	0.0579	0.2327	0.0937	0.1133	0.1408	0.1568	0.2048	0.0000

Table 10. Maturity, range for uniform distribution of proportion of returns that are female, and the mean and standard deviation for normal distribution of number of eggs per female by sea winter age. The standard deviations for eggs per female were derived assuming a 15% coefficient of variation.

Age	Maturity	Proportion Female Lower	Proportion Female Upper	Eggs per Female Mean	Eggs per Female St Dev
1SW	0.017	0.5%	2.5%	3040	456
2SW	0.939	50.0%	55.0%	7560	1134
3SW	1.000	50.0%	55.0%	10200	1530
Kelt				20000	3000

Table 11. Stocking assumed to occur for base case simulations in years 2000 to 2015 by river and juvenile life stage.

River	Fry	Parr0+	Parr1+	Smolt
Dennys	59,000	16,500	1,400	49,800
East Machias	242,000			
Machias	267,000			
Pleasant				
Narraguagus	353,000			
Cove Brook				
Ducktrap				
Sheepscot	171,000			

Table 12. Probabilities of extinction and habitat limitation along with medians of the average number of spawners in years 2082 to 2102 (denoted Spawners) and median replacement rate (denoted Rep Rate) from multiple rivers under base case inputs with parameter point estimates or full ranges of uncertainty. Downeast rivers are DE, EM, MC, PL, and NG. Southwest rivers are CB, DT, SHP.

Parameter Point Estimates				
	Percent Chance of			
	Extinction	Habitat Lim	Spawners	Rep Rate
DE	0.0	100.0	109.3	1.026
EM	0.0	100.0	146.7	1.043
MC	0.0	100.0	272.7	1.054
PL	0.0	13.4	32.3	1.000
NG	0.0	100.0	267.9	1.054
CB	0.3	99.1	14.6	1.000
DT	0.0	45.5	29.7	1.000
SHP	0.0	100.0	132.4	1.038
DPS	0.0	100.0	1010.5	1.077
Downeast	0.0	100.0	831.2	1.074
Southwest	0.0	100.0	177.5	1.059
Parameter Ranges				
	Percent Chance of			
	Extinction	Habitat Lim	Spawners	Rep Rate
DE	18.9	100.0	14.5	0.502
EM	14.4	100.0	19.0	0.571
MC	9.4	98.7	32.9	0.639
PL	47.2	47.5	2.7	0.000
NG	8.9	99.8	34.0	0.636
CB	68.4	83.5	0.5	0.000
DT	50.6	63.1	2.1	0.000
SHP	16.6	99.8	16.7	0.544
DPS	2.7	100.0	135.1	0.734
Downeast	3.1	100.0	111.3	0.726
Southwest	14.9	99.8	21.7	0.583

Table 13a. Probability of extinction, probability of habitat limitation, and median number of spawners in years 2082 to 2102 for ten different random number generator seed values with associated mean, standard deviation, coefficient of variation, and range when 1000 simulations are conducted. River groups defined as in Table 12.

1000 Simulations														
	Probability of Extinction													
River	A	B	C	D	E	F	G	H	I	J	Mean	Stdev	CV	Range
DE	19.7	18.8	17.3	21.9	19.3	17.5	20.4	18.9	21.6	17.6	19.30	1.63	8%	4.6
EM	15.3	13.7	15.1	15.4	16.1	14.3	15.5	14.3	15.5	13.7	14.89	0.83	6%	2.4
MC	8.5	7.6	9.9	9.6	10.0	8.4	9.4	8.4	9.5	8.8	9.01	0.79	9%	2.4
PL	49.8	43.0	47.9	48.1	47.2	46.2	46.3	47.4	50.0	47.0	47.29	1.98	4%	7.0
NG	9.5	8.1	7.5	10.3	10.1	8.2	10.0	8.7	9.6	7.9	8.99	1.03	11%	2.8
CB	69.8	66.7	67.4	70.2	70.8	68.6	67.8	67.9	69.1	70.7	68.90	1.44	2%	4.1
DT	51.9	51.2	49.8	52.6	52.5	49.2	52.3	49.5	52.5	51.7	51.32	1.33	3%	3.4
SHP	18.2	14.6	16.9	19.7	17.2	16.6	18.8	15.4	18.6	17.1	17.31	1.57	9%	5.1
All	3.0	2.8	3.3	3.3	2.3	2.1	3.1	1.9	2.6	2.9	2.73	0.49	18%	1.4
Down	3.3	3.4	3.6	4.2	2.7	2.8	3.5	2.1	2.6	3.4	3.16	0.61	19%	2.1
South	15.9	13.0	15.0	16.8	16.2	15.1	17.3	14.4	16.8	14.7	15.52	1.32	9%	4.3
	Probability of Habitat Limitation													
River	A	B	C	D	E	F	G	H	I	J	Mean	Stdev	CV	Range
DE	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.00	0%	0.0
EM	100.0	100.0	100.0	100.0	100.0	100.0	99.9	100.0	100.0	100.0	99.99	0.03	0%	0.1
MC	99.0	98.7	98.3	99.3	98.9	98.5	99.2	98.7	98.7	98.3	98.76	0.34	0%	1.0
PL	47.7	49.5	48.3	48.3	47.8	48.5	47.7	47.1	48.1	50.9	48.39	1.09	2%	3.8
NG	99.9	99.7	99.9	99.6	99.9	99.9	99.8	99.8	99.9	99.9	99.83	0.11	0%	0.3
CB	82.7	82.0	84.6	83.7	82.4	82.5	86.4	82.6	81.9	84.6	83.34	1.46	2%	4.5
DT	60.2	62.8	62.4	64.1	60.9	63.5	62.9	63.8	63.0	65.4	62.90	1.51	2%	5.2
SHP	100.0	99.6	99.8	99.8	99.9	99.9	99.8	99.9	99.9	99.9	99.85	0.11	0%	0.4
All	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.00	0%	0.0
Down	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.00	0%	0.0
South	100.0	99.7	99.8	99.8	100.0	99.9	99.8	99.9	100.0	99.9	99.88	0.10	0%	0.3
	Median of Average Spawners for Years 2082 to 2102													
River	A	B	C	D	E	F	G	H	I	J	Mean	Stdev	CV	Range
DE	13.5	15.1	15.5	12.6	14.2	15.2	13.7	14.2	13.0	13.0	14.00	1.02	7%	2.9
EM	18.2	20.2	20.4	18.6	17.0	20.5	19.7	19.7	18.7	17.0	19.00	1.31	7%	3.5
MC	32.5	34.3	36.1	30.2	31.0	34.0	31.3	32.9	31.7	32.1	32.61	1.77	5%	5.9
PL	2.5	3.6	3.0	2.3	2.9	3.0	2.7	2.8	2.2	2.7	2.77	0.40	14%	1.4
NG	33.0	37.1	34.9	29.4	30.2	35.6	33.1	34.7	31.7	33.1	33.28	2.40	7%	7.7
CB	0.5	0.6	0.6	0.4	0.4	0.5	0.5	0.5	0.4	0.4	0.48	0.08	16%	0.2
DT	1.8	2.1	2.0	1.8	1.7	2.4	1.9	2.1	1.9	1.9	1.96	0.20	10%	0.7
SHP	15.2	18.1	18.5	14.8	15.3	16.8	16.1	17.4	14.4	15.4	16.20	1.43	9%	4.1
All	132.0	146.8	142.6	128.4	120.2	142.4	131.1	140.3	130.1	124.4	133.8	8.75	7%	26.6
Down	110.8	121.0	117.4	105.6	101.9	117.5	111.5	114.0	107.2	104.3	111.1	6.36	6%	19.1
South	20.5	22.9	24.5	19.3	19.7	23.3	21.7	22.5	20.0	19.3	21.37	1.86	9%	5.2

Table 13b. Probability of extinction, probability of habitat limitation, and median number of spawners in years 2082 to 2102 for ten different random number generator seed values with associated mean, standard deviation, coefficient of variation, and range when 10,000 simulations are conducted. River groups defined as in Table 12.

10,000 Simulations														
	Probability of Extinction													
River	A	B	C	D	E	F	G	H	I	J	Mean	Stdev	CV	Range
DE	18.9	19.1	18.4	18.6	19.8	18.9	19.5	19.1	19.3	19.3	19.09	0.41	2%	1.4
EM	14.4	14.7	14.5	14.6	14.9	14.9	15.4	15.0	15.0	15.3	14.87	0.33	2%	1.0
MC	9.4	9.3	9.2	8.7	9.4	9.2	9.8	9.0	9.6	9.1	9.27	0.31	3%	1.1
PL	47.2	46.6	46.9	46.5	47.5	46.7	47.4	47.9	47.0	47.1	47.08	0.44	1%	1.4
NG	8.9	9.0	8.6	8.5	9.2	9.1	9.0	9.1	8.7	9.0	8.91	0.23	3%	0.7
CB	68.4	67.7	68.2	67.9	69.0	68.0	69.1	69.0	69.2	68.3	68.48	0.55	1%	1.5
DT	50.6	51.3	50.6	50.5	51.4	50.7	51.0	51.2	51.2	51.1	50.96	0.33	1%	0.9
SHP	16.6	17.0	16.7	16.5	17.3	16.7	16.9	17.1	16.5	17.6	16.89	0.36	2%	1.1
All	2.7	2.6	2.4	2.5	2.7	2.7	2.5	2.5	2.6	2.6	2.58	0.10	4%	0.3
Down	3.1	3.1	3.0	2.9	3.1	3.0	3.0	2.9	3.0	3.0	3.01	0.07	2%	0.2
South	14.9	15.2	15.0	14.7	15.6	15.1	15.1	15.4	15.2	15.7	15.19	0.31	2%	1.0
	Probability of Habitat Limitation													
River	A	B	C	D	E	F	G	H	I	J	Mean	Stdev	CV	Range
DE	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.00	0%	0.0
EM	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.00	0%	0.0
MC	98.7	98.5	98.5	98.5	98.7	98.7	98.7	98.3	98.6	98.7	98.59	0.14	0%	0.4
PL	47.5	47.5	47.4	48.0	46.9	47.9	47.0	46.6	47.5	47.6	47.39	0.44	1%	1.4
NG	99.8	99.8	99.8	99.8	99.8	99.8	99.8	99.8	99.8	99.8	99.80	0.00	0%	0.0
CB	83.5	83.0	83.7	83.6	83.0	83.1	83.2	83.2	83.0	82.8	83.21	0.30	0%	0.9
DT	63.1	61.9	63.1	63.2	62.6	62.4	61.5	61.9	63.1	62.2	62.50	0.61	1%	1.7
SHP	99.8	99.9	99.8	99.8	99.9	99.8	99.9	99.8	99.9	99.8	99.84	0.05	0%	0.1
All	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.00	0%	0.0
Down	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.00	0%	0.0
South	99.8	99.9	99.9	99.8	99.9	99.8	99.9	99.8	99.9	99.9	99.86	0.05	0%	0.1
	Median of Average Spawners for Years 2082 to 2102													
River	A	B	C	D	E	F	G	H	I	J	Mean	Stdev	CV	Range
DE	14.5	14.1	14.3	14.5	13.7	14.4	13.5	14.0	14.1	14.0	14.11	0.33	2%	1.0
EM	19.0	19.3	19.5	19.4	18.0	19.1	18.4	18.5	19.0	18.7	18.89	0.48	3%	1.5
MC	32.9	34.0	33.7	34.6	31.8	33.5	32.6	32.0	33.1	32.7	33.09	0.88	3%	2.8
PL	2.7	2.9	2.8	2.9	2.6	2.9	2.6	2.6	2.7	2.7	2.74	0.13	5%	0.3
NG	34.0	34.5	34.4	34.2	33.0	33.6	33.8	33.6	33.5	33.0	33.76	0.53	2%	1.5
CB	0.5	0.5	0.5	0.5	0.4	0.5	0.5	0.4	0.5	0.5	0.48	0.04	9%	0.1
DT	2.1	2.0	2.1	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.02	0.04	2%	0.1
SHP	16.7	16.8	16.6	16.9	16.1	16.4	16.5	16.4	16.6	16.3	16.53	0.24	1%	0.8
All	135.1	137.4	136.7	139.0	130.8	135.3	131.0	132.9	134.2	134.5	134.7	2.64	2%	8.2
Down	111.3	114.0	113.5	114.6	107.8	111.8	109.3	109.8	111.7	110.9	111.5	2.16	2%	6.8
South	21.7	22.0	21.5	22.2	21.0	21.3	21.3	21.2	21.3	21.2	21.47	0.38	2%	1.2

Table 13c. Probability of extinction, probability of habitat limitation, and median number of spawners in years 2082 to 2102 for ten different random number generator seed values with associated mean, standard deviation, coefficient of variation, and range when 100,000 simulations are conducted. River groups defined as in Table 12.

100,000 Simulations														
	Probability of Extinction													
River	A	B	C	D	E	F	G	H	I	J	Mean	Stdev	CV	Range
DE	19.4	19.3	19.3	19.4	19.6	19.4	19.6	19.5	19.3	19.3	19.41	0.12	1%	0.3
EM	14.9	14.9	14.9	15.0	15.0	15.0	15.1	15.2	14.9	15.0	14.99	0.10	1%	0.3
MC	9.3	9.4	9.4	9.4	9.4	9.3	9.6	9.6	9.4	9.4	9.42	0.10	1%	0.3
PL	47.2	46.9	47.3	47.2	47.1	47.1	47.4	47.3	46.9	47.2	47.16	0.16	0%	0.5
NG	9.1	9.0	9.0	9.1	9.1	9.0	9.2	9.1	9.0	9.1	9.07	0.07	1%	0.2
CB	68.8	68.4	68.9	68.6	68.5	68.6	68.9	68.7	68.6	68.8	68.68	0.17	0%	0.5
DT	51.0	50.7	51.1	51.1	50.9	50.9	51.1	51.1	50.7	51.1	50.97	0.16	0%	0.4
SHP	17.2	16.9	17.2	17.0	17.1	17.1	17.1	17.2	17.0	17.0	17.08	0.10	1%	0.3
All	2.6	2.6	2.6	2.6	2.7	2.6	2.7	2.7	2.7	2.7	2.65	0.05	2%	0.1
Down	3.1	3.1	3.0	3.1	3.1	3.0	3.2	3.2	3.2	3.1	3.11	0.07	2%	0.2
South	15.4	15.1	15.4	15.3	15.3	15.3	15.4	15.4	15.3	15.2	15.31	0.10	1%	0.3
	Probability of Habitat Limitation													
River	A	B	C	D	E	F	G	H	I	J	Mean	Stdev	CV	Range
DE	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.00	0%	0.0
EM	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.00	0%	0.0
MC	98.6	98.6	98.6	98.7	98.6	98.6	98.6	98.6	98.7	98.6	98.62	0.04	0%	0.1
PL	47.6	47.7	47.8	47.7	47.6	47.8	47.3	47.7	48.0	47.5	47.67	0.19	0%	0.7
NG	99.8	99.8	99.8	99.8	99.8	99.8	99.8	99.8	99.8	99.8	99.80	0.00	0%	0.0
CB	83.2	83.5	83.4	83.4	83.6	83.3	83.1	83.4	83.6	83.5	83.40	0.16	0%	0.5
DT	62.8	62.9	62.8	62.8	62.8	62.6	62.5	62.6	63.1	62.6	62.75	0.18	0%	0.6
SHP	99.9	99.9	99.8	99.9	99.9	99.9	99.9	99.8	99.9	99.9	99.88	0.04	0%	0.1
All	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.00	0%	0.0
Down	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.00	0%	0.0
South	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.90	0.00	0%	0.0
	Median of Average Spawners for Years 2082 to 2102													
River	A	B	C	D	E	F	G	H	I	J	Mean	Stdev	CV	Range
DE	14.0	14.2	13.9	14.0	14.0	13.9	13.9	14.0	14.1	14.0	14.00	0.09	1%	0.3
EM	19.0	19.1	18.7	19.0	18.9	18.8	18.8	18.8	19.1	18.6	18.88	0.17	1%	0.5
MC	33.0	33.5	32.9	33.0	33.2	33.1	33.0	32.9	33.4	33.0	33.10	0.21	1%	0.6
PL	2.8	2.8	2.7	2.8	2.8	2.8	2.7	2.8	2.8	2.7	2.77	0.05	2%	0.1
NG	33.6	34.1	33.3	33.6	33.9	33.7	33.8	33.5	34.2	33.5	33.72	0.28	1%	0.9
CB	0.4	0.5	0.4	0.5	0.5	0.5	0.4	0.5	0.5	0.4	0.46	0.05	11%	0.1
DT	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.00	0.00	0%	0.0
SHP	16.4	16.7	16.4	16.4	16.4	16.3	16.4	16.4	16.7	16.4	16.45	0.14	1%	0.4
All	134.2	136.2	133.6	134.9	134.6	134.4	133.9	134.1	136.4	134	134.6	0.95	1%	2.8
Down	111.5	112.7	110.4	111.6	111.6	111.6	110.8	111.0	112.6	111.0	111.5	0.74	1%	2.3
South	21.4	21.7	21.2	21.2	21.3	21.3	21.3	21.2	21.6	21.2	21.34	0.18	1%	0.5

Table 14. Estimated number of fish that passed the Cherryfield Trap on the Narraguagus river.

Year	Trap Catch	Expanded Trap Catch	Rod Catch	average 0.3189 Rod/Trap	Est Trap	Redd Counts	Predicted at Trap Total	Hatchery	Natural
1962	197	263	62	0.2360			263		
1963	147	196	47	0.2398			196		
1964	221	295	32	0.1086			295		
1965	197	263	38	0.1447			263		
1966	259	345	76	0.2201			345		
1967	309	412	56	0.1359			412	118	294
1968	232	309	109	0.3524			309	199	110
1969	122	163	22	0.1352			163	18	145
1970	86	115	75	0.6541			115	11	104
1971	76	101	33	0.3257			101	33	68
1972	199	265	139	0.5239			265	71	194
1973	97	129	75	0.5799			129	21	108
1974	101	135	66	0.4901			135	21	113
1975			111		348		348	6	342
1976			32		100		100	13	88
1977			124		389		389	22	367
1978			133		417		417	110	307
1979			58		182		182	28	154
1980			115		361		361	0	361
1981			73		229		229	69	160
1982			79		248		248	38	210
1983			90		282		282	60	223
1984			68		213	259	259	38	221
1985			57		179		179	0	179
1986			45		141	345	345	153	192
1987			37		116	210	210	62	148
1988			35		110		110	32	78
1989			39		122		122	38	85
1990			51		160	201	201	91	110
1991	74		22				74	21	53
1992	56		17				56	20	36
1993	87		7				87	19	68
1994	52		0				52	1	51
1995	56		0				56	0	56
1996	64		0				64	8	56
1997	37		0				37	2	35
1998	22		0				22	0	22
1999	32		0				32	2	30
2000	23		0				23	1	22
2001	32		0				32	2	30
2002	8						8	1	7

Table 15. Estimated catch of Narraguagus river salmon by interception fisheries.

Year	Returns	Proportion of Total Run low	high	Interception Fisheries Catch Lower	Upper
1967	263	0.45	0.55	215	321
1968	196	0.45	0.55	160	240
1969	295	0.45	0.55	241	360
1970	263	0.45	0.55	215	321
1971	345	0.45	0.55	283	422
1972	265	0.45	0.55	217	324
1973	129	0.45	0.55	106	158
1974	135	0.45	0.55	110	165
1975	348	0.45	0.55	285	425
1976	100	0.4	0.5	67	100
1977	389	0.4	0.5	259	389
1978	417	0.4	0.5	278	417
1979	182	0.4	0.5	121	182
1980	361	0.35	0.45	194	295
1981	229	0.35	0.45	123	187
1982	248	0.35	0.45	133	203
1983	282	0.35	0.45	152	231
1984	259	0.3	0.4	111	173
1985	179	0.3	0.4	77	119
1986	345	0.25	0.35	115	186
1987	210	0.25	0.35	70	113
1988	110	0.2	0.3	27	47
1989	122	0.2	0.3	31	52
1990	201	0.15	0.25	35	67
1991	74	0.15	0.25	13	25
1992	56	0.1	0.2	6	14
1993	87	0.1	0.2	10	22
1994	52	0.05	0.15	3	9
1995	56	0.05	0.15	3	10
1996	64	0	0.1	0	7
1997	37	0	0.1	0	4
1998	22	0	0.1	0	2
1999	32	0	0.1	0	4
2000	23	0	0.1	0	3
2001	32	0	0.1	0	4
2002	8	0	0.1	0	1

Table 16. Stocking history for the Narraguagus river by life stage.

Year	fry	parr0+	parr1+	smolt
1967	0	0	0	34,900
1968	0	0	0	23,600
1969	0	0	0	25,800
1970	0	0	0	11,800
1971	0	0	0	2,900
1972	0	0	0	15,700
1973	0	0	0	5,600
1974	0	0	0	0
1975	0	0	0	5,000
1976	0	0	0	8,400
1977	0	0	0	0
1978	0	0	0	0
1979	0	0	0	10,100
1980	0	0	0	20,400
1981	0	0	0	4,100
1982	0	0	0	5,200
1983	0	7,800	0	0
1984	0	0	0	5,200
1985	10,000	0	0	4,500
1986	0	0	0	7,500
1987	15,000	0	0	9,000
1988	20,000	13,000	5,600	15,700
1989	29,000	9,500	7,000	27,000
1990	0	0	0	16,800
1991	0	0	0	15,200
1992	0	0	0	0
1993	0	0	0	0
1994	0	0	0	0
1995	105,000	0	0	0
1996	196,000	0	0	0
1997	207,000	0	2,000	700
1998	274,000	14,400	0	0
1999	155,000	18,200	0	1,000
2000	252,000	0	0	0
2001	353,000	0	0	0
2002	353,000	0	0	0

Table 17. Section of output from realization 39 of SalmonPVA base case run showing number of fish at each life stage in the Dennys river for years 1996 to 2002. Note that in the actual output file all life stages are given in one row.

year	eggs	fry	parr0+	parr1+	smolts
1996	101893	0	0	0	0
1997	73512	14792	9298	0	0
1998	137947	17694	8746	4506	0
1999	109945	36298	23153	5308	2319
2000	0	25085	15057	2784	1261
2001	197466	0	0	5134	328
2002	84388	63017	31855	0	480

year	1SWatsea	2SWatsea	3SWatsea	1SWret	2SWret	3SWret
1996	0	0	0	0	0	0
1997	0	0	0	0	0	0
1998	0	0	0	0	0	0
1999	0	0	0	0	0	0
2000	269	0	0	2	0	0
2001	84	41	0	2	37	0
2002	24	25	0	0	24	0

year	1SWstray	2SWstray	3SWstray	1SWspawn	2SWspawn	3SWspawn
1996	2	20	2	2	20	2
1997	6	17	2	6	17	2
1998	5	31	1	5	31	1
1999	4	22	1	4	22	1
2000	1	1	0	3	1	0
2001	5	13	0	7	50	0
2002	2	24	0	2	24	0

year	KeltFout	KeltMout	KeltFret	KeltMret
1996	0	0	0	0
1997	3	0	0	0
1998	2	3	1	0
1999	2	3	0	1
2000	1	0	0	1
2001	0	0	1	0
2002	2	3	0	0

Table 18. Section of SalmonPVA output from base case run using 10,000 simulations. River names and river group definitions are given first. Next, the percent chance of extinction by stock/groupID are provided. This table is followed by tables of habitat limitation for all the stages where this option is utilized, only the parr1+ stage in the base case.

```
    1 = DE
    2 = EM
    3 = MC
    4 = PL
    5 = NG
    6 = CB
    7 = DT
    8 = SHP
    9 = group   1 => DE      EM      MC      PL      NG      CB      DT      SHP
   10 = group   2 => DE      EM      MC      PL      NG
   11 = group   3 => CB      DT      SHP

 ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
 summary results
                  percent chance of
 stock/groupID    extinction
      1                18.9
      2                14.4
      3                 9.4
      4                47.2
      5                 8.9
      6                68.4
      7                50.6
      8                16.6
      9                 2.7
     10                 3.1
     11                14.9

 Habitat Limitation for PARR1+ stage

                  percent chance of             # years habitat limiting
 stock/groupID    habitat limitation            min        med       max
      1               100.0                     14.        21.        56.
      2               100.0                      0.        14.        43.
      3                98.7                      0.         8.        44.
      4                47.5                      0.         0.        32.
      5                99.8                      0.        10.        45.
      6                83.5                      0.         4.        39.
      7                63.1                      0.         1.        33.
      8                99.8                      0.        11.        41.
      9               100.0                     14.        25.        66.
     10               100.0                     14.        24.        63.
     11                99.8                      0.        13.        53.
```

Table 19. Section of SalmonPVA output from base case run with 10,000 simulations. The median and range of the average number of spawners in a user defined period are output for the natural, hatchery, and total populations. The hatchery and total population matrices are not shown here due to space constraints. The percent of simulations which had the average number of spawners in the user defined period greater than or equal to a range of values provided by the user are next provided for each river, only the first two rivers are shown here.

```
average number of natural spawners for years  2082 to  2102
stock/groupID  NatMin      NatMed      NatMax
      1           0.0        14.5       260.9
      2           0.0        19.0       345.0
      3           0.0        32.9       846.6
      4           0.0         2.7       161.6
      5           0.0        34.0       749.8
      6           0.0         0.5        35.8
      7           0.0         2.1        95.6
      8           0.0        16.7       313.6
      9           0.0       135.1      2696.7
     10           0.0       111.3      2356.0
     11           0.0        21.7       434.6
```

(hatchery and total matrices here)

```
Percent of Simulations where Average Spawners Exceeded These Values

Spawner Exceedence Table for river/group   1
Spawners       Natural     Hatchery        Total
    0.0          94.3          0.0          94.3
   10.0          58.3          0.0          58.3
   50.0          18.3          0.0          18.3
  100.0           4.3          0.0           4.3
  200.0           0.1          0.0           0.1

Spawner Exceedence Table for river/group   2
Spawners       Natural     Hatchery        Total
    0.0          96.5          0.0          96.5
   10.0          65.2          0.0          65.2
   50.0          23.8          0.0          23.8
  100.0           8.3          0.0           8.3
  200.0           0.7          0.0           0.7
```

Table 20. Section of SalmonPVA output from base case run with 10,000 simulations. The median replacement rates for each river and river group are provided, followed by a table of the frequency and cumulative probability for replacement rates less than or equal to the values in the first column. Only the Dennys river table is shown.

```
Median Replacment Rates by Stock/GroupID
     1                0.502
     2                0.571
     3                0.639
     4                0.000
     5                0.636
     6                0.000
     7                0.000
     8                0.544
     9                0.734
    10                0.726
    11                0.583

Replacement Rate Frequencies and Cummulative Probabilities

River            1  = DE
Replacement Rate   Frequency     Cummulative Probability
     0.0           2637.            0.2637
     0.1            217.            0.2854
     0.2            299.            0.3153
     0.3            430.            0.3583
     0.4            587.            0.4170
     0.5            825.            0.4995
     0.6            909.            0.5904
     0.7           1028.            0.6932
     0.8            946.            0.7878
     0.9            761.            0.8639
     1.0            599.            0.9238
     1.1            303.            0.9541
     1.2            208.            0.9749
     1.3            130.            0.9879
     1.4             63.            0.9942
     1.5             31.            0.9973
     1.6             12.            0.9985
     1.7              8.            0.9993
     1.8              6.            0.9999
     1.9              1.            1.0000
     2.0              0.            1.0000
```

Table 21. Sensitivity analyses results for probability of extinction, median of average spawners in years 2082 to 2102, and replacement rate. The sensitivity analyses increased the juvenile survival rates (Sens1 = egg to fry, Sens2 = fry to parr0+, Sens3 = parr0+ to parr1+, Sens4 = parr1+ to smolt) or average marine survival (Sens5) by 20%.

	Probability of Extinction					
	Base	Sens1	Sens2	Sens3	Sens4	Sens5
DE	18.9	1.6	1.9	0.9	1.5	0.0
EM	14.4	1.0	1.1	0.6	0.7	0.0
MC	9.4	0.4	0.5	0.2	0.2	0.0
PL	47.2	8.3	8.6	5.1	6.7	0.3
NG	8.9	0.3	0.4	0.2	0.2	0.0
CB	68.4	25.0	25.6	18.6	21.6	2.5
DT	50.6	10.3	10.4	6.3	8.5	0.5
SHP	16.6	1.2	1.5	0.7	1.0	0.0
DPS	2.7	0.1	0.1	0.0	0.0	0.0
Downeast	3.1	0.1	0.1	0.0	0.0	0.0
Southwest	14.9	0.9	1.1	0.5	0.7	0.0
	Median of Average Spawners 2082 to 2102					
	Base	Sens1	Sens2	Sens3	Sens4	Sens5
DE	14.5	75.1	71.9	84.6	78.5	192.4
EM	19.0	98.3	93.6	112.1	103.0	246.0
MC	32.9	190.5	183.5	216.4	198.3	485.3
PL	2.7	32.6	31.1	37.9	35.2	95.9
NG	34.0	187.3	180.0	212.4	195.5	475.4
CB	0.5	8.0	7.6	9.3	8.5	22.0
DT	2.1	24.4	23.1	28.1	25.7	68.5
SHP	16.7	88.6	84.0	101.7	93.0	226.0
DPS	135.1	703.3	671.9	807.4	739.8	1816.4
Downeast	111.3	584.7	559.0	666.4	611.1	1499.6
Southwest	21.7	121.1	115.0	139.4	127.3	316.1
	Replacement Rate					
	Base	Sens1	Sens2	Sens3	Sens4	Sens5
DE	0.502	0.850	0.833	0.879	0.859	0.976
EM	0.571	0.866	0.858	0.901	0.875	0.980
MC	0.639	0.884	0.870	0.909	0.885	0.982
PL	0.000	0.801	0.781	0.847	0.818	0.982
NG	0.636	0.885	0.867	0.907	0.883	0.981
CB	0.000	0.657	0.622	0.729	0.679	0.957
DT	0.000	0.773	0.752	0.825	0.789	0.968
SHP	0.544	0.860	0.849	0.895	0.866	0.978
DPS	0.734	0.918	0.908	0.939	0.917	0.998
Downeast	0.726	0.917	0.904	0.937	0.915	0.996
Southwest	0.583	0.884	0.873	0.913	0.888	0.991

Table 22. Probabilities of extinction and habitat limitation along with medians of the average number of spawners in years 2082 to 2102 (denoted Spawners) and median replacement rate (denoted Rep Rate) from multiple rivers under base case inputs with and without stocking. Downeast rivers are DE, EM, MC, PL, and NG. Southwest rivers are CB, DT, SHP.

Base Case With Stocking				
	Percent Chance of			
	Extinction	Habitat Lim	Spawners	Rep Rate
DE	18.9	100.0	14.5	0.502
EM	14.4	100.0	19.0	0.571
MC	9.4	98.7	32.9	0.639
PL	47.2	47.5	2.7	0.000
NG	8.9	99.8	34.0	0.636
CB	68.4	83.5	0.5	0.000
DT	50.6	63.1	2.1	0.000
SHP	16.6	99.8	16.7	0.544
DPS	2.7	100.0	135.1	0.734
Downeast	3.1	100.0	111.3	0.726
Southwest	14.9	99.8	21.7	0.583

No Stocking				
	Percent Chance of			
	Extinction	Habitat Lim	Spawners	Rep Rate
DE	74.3	15.3	0.0	0.000
EM	68.9	14.2	0.0	0.000
MC	60.9	9.3	0.2	0.000
PL	83.9	22.6	0.0	0.000
NG	64.3	8.8	0.0	0.000
CB	96.8	24.7	0.0	0.000
DT	81.6	38.0	0.0	0.000
SHP	76.7	8.0	0.0	0.000
DPS	39.0	54.1	6.6	0.071
Downeast	41.9	34.1	5.2	0.000
Southwest	68.6	47.4	0.0	0.000

Table 23. Probability of extinction and habitat limitation, average number of spawners in years 2082 to 2102, and replacement rate for three levels of straying among rivers (natural, hatchery).

Base Case (1%, 2% stray rates)				
	Percent Chance of			
	Extinction	Habitat Lim	Spawners	Rep Rate
DE	18.9	100.0	14.5	0.502
EM	14.4	100.0	19.0	0.571
MC	9.4	98.7	32.9	0.639
PL	47.2	47.5	2.7	0.000
NG	8.9	99.8	34.0	0.636
CB	68.4	83.5	0.5	0.000
DT	50.6	63.1	2.1	0.000
SHP	16.6	99.8	16.7	0.544
DPS	2.7	100.0	135.1	0.734
Downeast	3.1	100.0	111.3	0.726
Southwest	14.9	99.8	21.7	0.583
No Straying				
	Percent Chance of			
	Extinction	Habitat Lim	Spawners	Rep Rate
DE	18.8	100.0	14.8	0.499
EM	15.7	100.0	18.0	0.534
MC	9.2	98.7	36.3	0.645
PL	86.2	21.6	0.0	0.000
NG	8.0	99.8	36.4	0.655
CB	98.5	18.2	0.0	0.000
DT	83.5	36.5	0.0	0.000
SHP	17.6	99.8	16.0	0.513
DPS	2.5	100.0	133.8	0.741
Downeast	2.8	100.0	114.9	0.735
Southwest	17.1	99.9	16.9	0.520
Increased Straying (5%, 10%)				
	Percent Chance of			
	Extinction	Habitat Lim	Spawners	Rep Rate
DE	19.5	100.0	13.2	0.544
EM	12.6	100.0	20.7	0.631
MC	10.9	98.1	25.9	0.622
PL	20.8	88.5	10.9	0.551
NG	11.0	99.7	25.7	0.625
CB	31.7	99.8	5.1	0.465
DT	23.3	94.1	9.2	0.530
SHP	14.7	99.8	17.6	0.600
DPS	3.2	100.0	135.5	0.728
Downeast	4.0	100.0	102.2	0.714
Southwest	10.7	100.0	32.9	0.679

Table 24. Probability of extinction and habitat limitation, average number of spawners in years 2082 to 2102, and replacement rate for three levels habitat limitation at the parr1+ stage.

	Percent Chance of			
	Extinction	Habitat Lim	Spawners	Rep Rate
Base Case (7 parr/unit)				
DE	18.9	100.0	14.5	0.502
EM	14.4	100.0	19.0	0.571
MC	9.4	98.7	32.9	0.639
PL	47.2	47.5	2.7	0.000
NG	8.9	99.8	34.0	0.636
CB	68.4	83.5	0.5	0.000
DT	50.6	63.1	2.1	0.000
SHP	16.6	99.8	16.7	0.544
DPS	2.7	100.0	135.1	0.734
Downeast	3.1	100.0	111.3	0.726
Southwest	14.9	99.8	21.7	0.583
Decreased Productivity (3 parr/unit)				
	Percent Chance of			
	Extinction	Habitat Lim	Spawners	Rep Rate
DE	37.4	100.0	4.9	0.052
EM	29.9	100.0	7.3	0.309
MC	19.1	100.0	14.6	0.500
PL	68.5	69.9	0.2	0.000
NG	19.2	100.0	14.5	0.500
CB	93.0	89.5	0.0	0.000
DT	73.2	84.4	0.2	0.000
SHP	32.9	100.0	6.2	0.225
DPS	7.3	100.0	55.9	0.673
Downeast	8.0	100.0	47.1	0.660
Southwest	30.9	100.0	7.5	0.314
Increased Productivity (11 parr/unit)				
	Percent Chance of			
	Extinction	Habitat Lim	Spawners	Rep Rate
DE	12.8	100.0	22.5	0.585
EM	10.2	99.5	28.0	0.631
MC	6.9	90.6	45.5	0.674
PL	38.2	36.4	5.1	0.228
NG	6.6	96.6	49.2	0.675
CB	56.1	76.3	1.5	0.000
DT	42.6	49.6	3.8	0.083
SHP	13.1	97.5	24.3	0.605
DPS	1.7	100.0	195.8	0.752
Downeast	2.0	100.0	161.1	0.745
Southwest	11.5	98.1	32.8	0.643

Table 25. Probability of extinction and habitat limitation, average number of spawners in years 2082 to 2102, and replacement rate for three levels of linkages in juvenile survival among rivers.

Base Case (Linked 0.05 noise)	Percent Chance of			
	Extinction	Habitat Lim	Spawners	Rep Rate
DE	18.9	100.0	14.5	0.502
EM	14.4	100.0	19.0	0.571
MC	9.4	98.7	32.9	0.639
PL	47.2	47.5	2.7	0.000
NG	8.9	99.8	34.0	0.636
CB	68.4	83.5	0.5	0.000
DT	50.6	63.1	2.1	0.000
SHP	16.6	99.8	16.7	0.544
DPS	2.7	100.0	135.1	0.734
Downeast	3.1	100.0	111.3	0.726
Southwest	14.9	99.8	21.7	0.583
Juvenile S Independent Among Rivers (All Noise)				
	Percent Chance of			
	Extinction	Habitat Lim	Spawners	Rep Rate
DE	32.0	100.0	7.1	0.236
EM	23.7	100.0	10.5	0.394
MC	17.7	99.2	17.1	0.464
PL	57.1	48.3	1.2	0.000
NG	17.3	99.9	18.0	0.464
CB	80.7	84.1	0.2	0.000
DT	62.9	62.5	0.8	0.000
SHP	26.7	100.0	9.0	0.347
DPS	1.0	100.0	113.2	0.756
Downeast	1.7	100.0	90.2	0.730
Southwest	19.5	100.0	14.2	0.500
Same Juvenile S for All Rivers (No Noise)				
	Percent Chance of			
	Extinction	Habitat Lim	Spawners	Rep Rate
DE	41.2	100.0	4.7	0.000
EM	35.5	99.9	6.5	0.150
MC	27.6	98.0	12.0	0.340
PL	69.5	45.5	0.2	0.000
NG	27.3	99.5	12.4	0.349
CB	85.6	77.2	0.1	0.000
DT	72.7	59.7	0.1	0.000
SHP	39.5	99.7	5.5	0.051
DPS	14.3	100.0	48.5	0.525
Downeast	15.3	100.0	40.2	0.516
Southwest	37.7	99.7	6.7	0.150

Table 26. Probability of extinction and habitat limitation, average number of spawners in years 2082 to 2102, and replacement rate for two levels of initial abundance in rivers.

Base Case (Observed/Estimated Returns)				
	Percent Chance of			
	Extinction	Habitat Lim	Spawners	Rep Rate
DE	18.9	100.0	14.5	0.502
EM	14.4	100.0	19.0	0.571
MC	9.4	98.7	32.9	0.639
PL	47.2	47.5	2.7	0.000
NG	8.9	99.8	34.0	0.636
CB	68.4	83.5	0.5	0.000
DT	50.6	63.1	2.1	0.000
SHP	16.6	99.8	16.7	0.544
DPS	2.7	100.0	135.1	0.734
Downeast	3.1	100.0	111.3	0.726
Southwest	14.9	99.8	21.7	0.583
Initial Populations Doubled				
	Percent Chance of			
	Extinction	Habitat Lim	Spawners	Rep Rate
DE	18.5	100.0	13.7	0.500
EM	14.4	100.0	18.3	0.564
MC	9.0	99.2	32.5	0.638
PL	46.1	63.3	3.0	0.000
NG	8.4	99.9	33.5	0.640
CB	67.5	88.1	0.5	0.000
DT	49.0	79.6	2.3	0.000
SHP	16.9	99.9	16.1	0.536
DPS	2.5	100.0	133.4	0.733
Downeast	2.9	100.0	110.6	0.725
Southwest	14.7	100.0	21.2	0.583

Table 27. River specific juvenile habitat and Conservation Spawning Escapement (CSE), the number of two sea winter adults returning to each river required to fully seed the available juvenile habitat in each river. These calculations assume full seeding of habitat occurs at 240 eggs/unit, each 2SW female produces 7,200 eggs, and half the returns of 2SW salmon are females.

River	Habitat	CSE
DE	2414	161
EM	3006	200
MC	6156	410
PL	1220	81
NG	6014	401
DT	845	56
SHP	2797	186
CB	235	16

Table 28. River specific replacement rates when CSE levels are used for initial population abundances, no stocking occurs, and base case parameters or survival rates increased to achieve a median replacement rate for the DPS of one.

River	Base Case	JuvenileS*1.35	MarineS*1.21
DE	0.130	0.959	0.978
EM	0.364	0.976	0.986
MC	0.521	0.980	0.985
PL	0.000	0.949	0.976
NG	0.512	0.977	0.985
CB	0.000	0.898	0.963
DT	0.000	0.940	0.969
SHP	0.300	0.971	0.983
DPS	0.675	1.001	1.001
Downeast	0.667	0.997	0.997
Southwest	0.425	0.986	0.996

Table 29. Probability of extinction, average spawners for years 2082 to 2102, and replacement rate for two scenarios of increased survival, marine and parr1+ to smolt (juvenile), and five multiples of Conservation Spawning Escapement levels as initial population abundances.

	Marine Survival Increased 21%					**Juvenile Survival Increased 35%**				
	Probability of Extinction					Probability of Extinction				
River	10%CSE	20%CSE	30%CSE	40%CSE	50%CSE	10%CSE	20%CSE	30%CSE	40%CSE	50%CSE
DE	3.1	0.9	0.4	0.2	0.1	5.7	1.7	0.9	0.5	0.5
EM	1.7	0.5	0.2	0.1	0.1	3.0	0.9	0.4	0.3	0.2
MC	0.7	0.1	0.0	0.0	0.0	1.3	0.3	0.1	0.1	0.1
PL	7.0	1.9	1.1	0.5	0.3	10.4	3.4	2.1	1.1	1.2
NG	0.7	0.2	0.1	0.1	0.0	1.5	0.3	0.1	0.1	0.1
CB	34.3	17.0	8.1	5.7	4.1	43.4	25.6	16.4	12.7	11.4
DT	11.1	3.6	1.6	1.0	0.7	15.0	6.0	3.5	2.5	2.3
SHP	2.2	0.6	0.3	0.2	0.0	3.5	1.2	0.6	0.4	0.3
DPS	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0
Down	0.1	0.0	0.0	0.0	0.0	0.2	0.1	0.0	0.0	0.0
South	1.5	0.3	0.1	0.1	0.0	2.4	0.8	0.4	0.3	0.1
	Average Spawners					Average Spawners				
River	10%CSE	20%CSE	30%CSE	40%CSE	50%CSE	10%CSE	20%CSE	30%CSE	40%CSE	50%CSE
DE	152.4	176.7	187.0	188.9	191.5	100.0	116.9	124.5	127.3	126.3
EM	204.2	228.8	240.2	243.3	246.8	134.5	152.9	160.7	164.9	162.9
MC	398.6	453.2	476.2	483.8	488.7	268.3	304.6	319.1	327.0	324.0
PL	80.2	94.6	99.0	100.7	102.1	51.8	61.3	65.2	67.3	66.1
NG	388.5	441.5	463.7	471.7	477.8	261.1	297.7	311.4	320.2	314.1
CB	17.3	20.4	21.6	21.8	22.2	9.8	12.2	13.2	13.7	13.8
DT	56.1	65.3	68.7	70.5	71.4	35.2	42.2	44.9	46.5	46.0
SHP	183.4	210.2	220.0	222.7	226.0	122.6	139.3	147.2	151.2	149.1
DPS	1464.3	1681.7	1769.7	1797.5	1824.6	973.7	1122.2	1177.7	1210.0	1198.2
Down	1215.3	1389.8	1459.7	1487.0	1507.4	807.3	930.6	974.4	1000.0	990.3
South	255.3	294.7	310.5	313.8	318.9	167.5	193.6	204.3	209.9	208.0
	Replacement Rate					Replacement Rate				
River	10%CSE	20%CSE	30%CSE	40%CSE	50%CSE	10%CSE	20%CSE	30%CSE	40%CSE	50%CSE
DE	0.970	0.977	0.978	0.980	0.978	0.931	0.951	0.953	0.961	0.955
EM	0.987	0.987	0.988	0.987	0.984	0.961	0.974	0.964	0.972	0.965
MC	0.992	0.991	0.987	0.989	0.987	0.974	0.981	0.979	0.977	0.975
PL	0.968	0.974	0.974	0.974	0.977	0.910	0.940	0.947	0.949	0.943
NG	0.994	0.987	0.986	0.984	0.987	0.972	0.974	0.975	0.979	0.975
CB	0.929	0.953	0.958	0.961	0.962	0.798	0.869	0.875	0.889	0.888
DT	0.952	0.961	0.971	0.971	0.973	0.894	0.919	0.929	0.931	0.933
SHP	0.983	0.983	0.983	0.983	0.984	0.951	0.964	0.963	0.966	0.967
DPS	1.019	1.010	1.004	1.006	1.001	1.011	1.006	1.000	1.002	0.998
Down	1.015	1.007	1.002	1.003	1.001	1.008	1.005	1.000	0.999	0.995
South	1.000	0.998	0.999	0.998	0.995	0.978	0.986	0.982	0.984	0.982

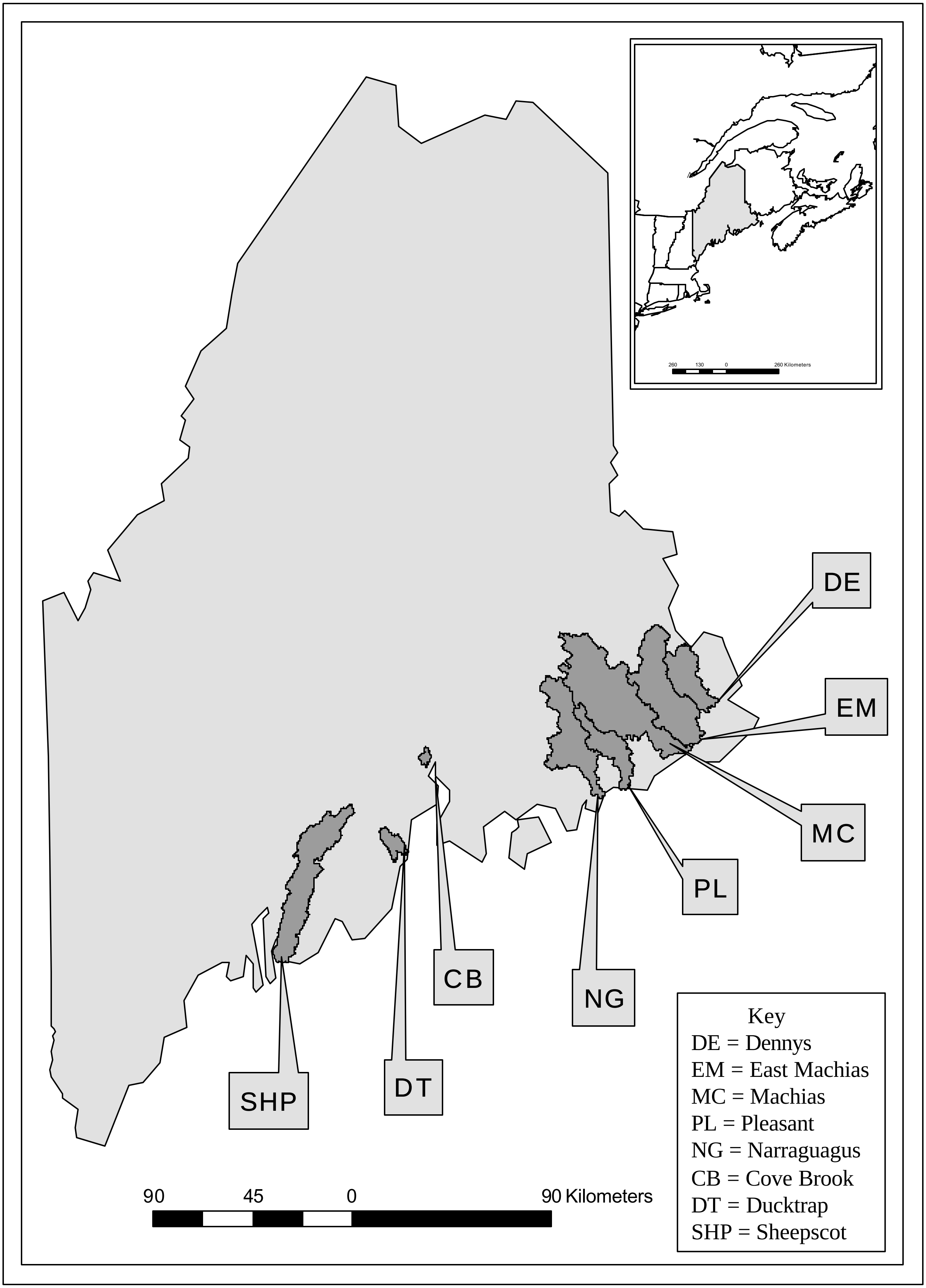


Figure 1: Watersheds of the eight rivers within the Maine DPS with extant Atlantic salmon.

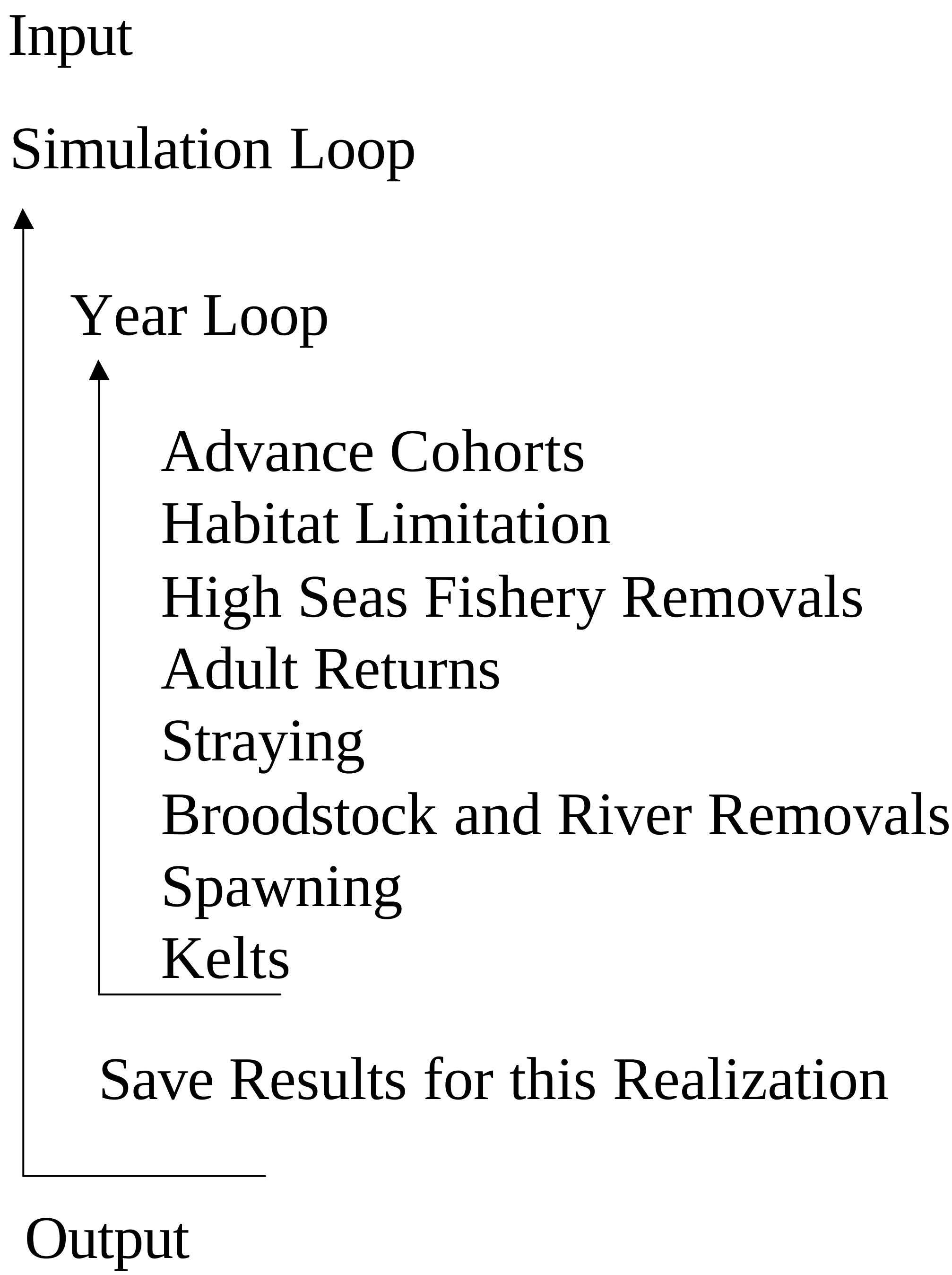


Figure 2: Flowchart of SalmonPVA showing modular program construction.

Number of Fish in Each Life Stage by Year					
Year	Eggs	Fry	Parr0+	Parr1+	Smolt
1	**15000**	5367	4162	521	117
2	22634	**4417**	**2156**	773	149
3	31679	5641	2237	**704**	363
4	16239	7151	2880	547	**320**

Survival by Life Stage and Year					
Year	Eggs	Fry	Parr0+	Parr1+	
1	**0.30**	0.57	0.19	0.28	
2	0.25	**0.49**	**0.33**	0.46	
3	0.23	0.51	0.24	**0.45**	

Figure 3. Example of state-space calculations for salmon PVA model. Bold values denote a single cohort progressing through juvenile life stages. The binomial distribution is used to randomly determine the number of survivors from the cohort's previous life stage given the survival value randomly chosen from an input distribution.

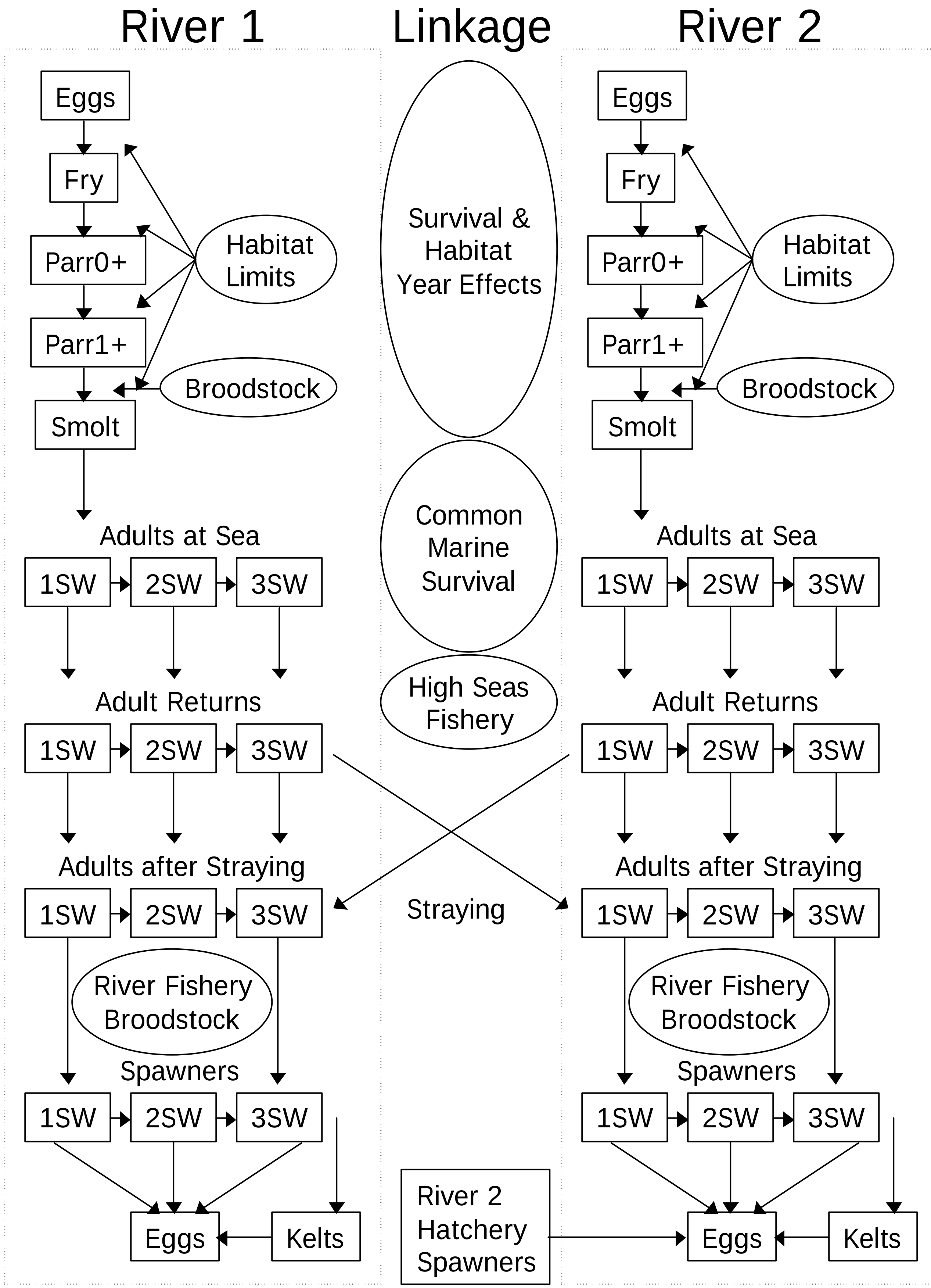


Figure 4. Flowchart of salmon PVA model showing potential linkages between rivers.

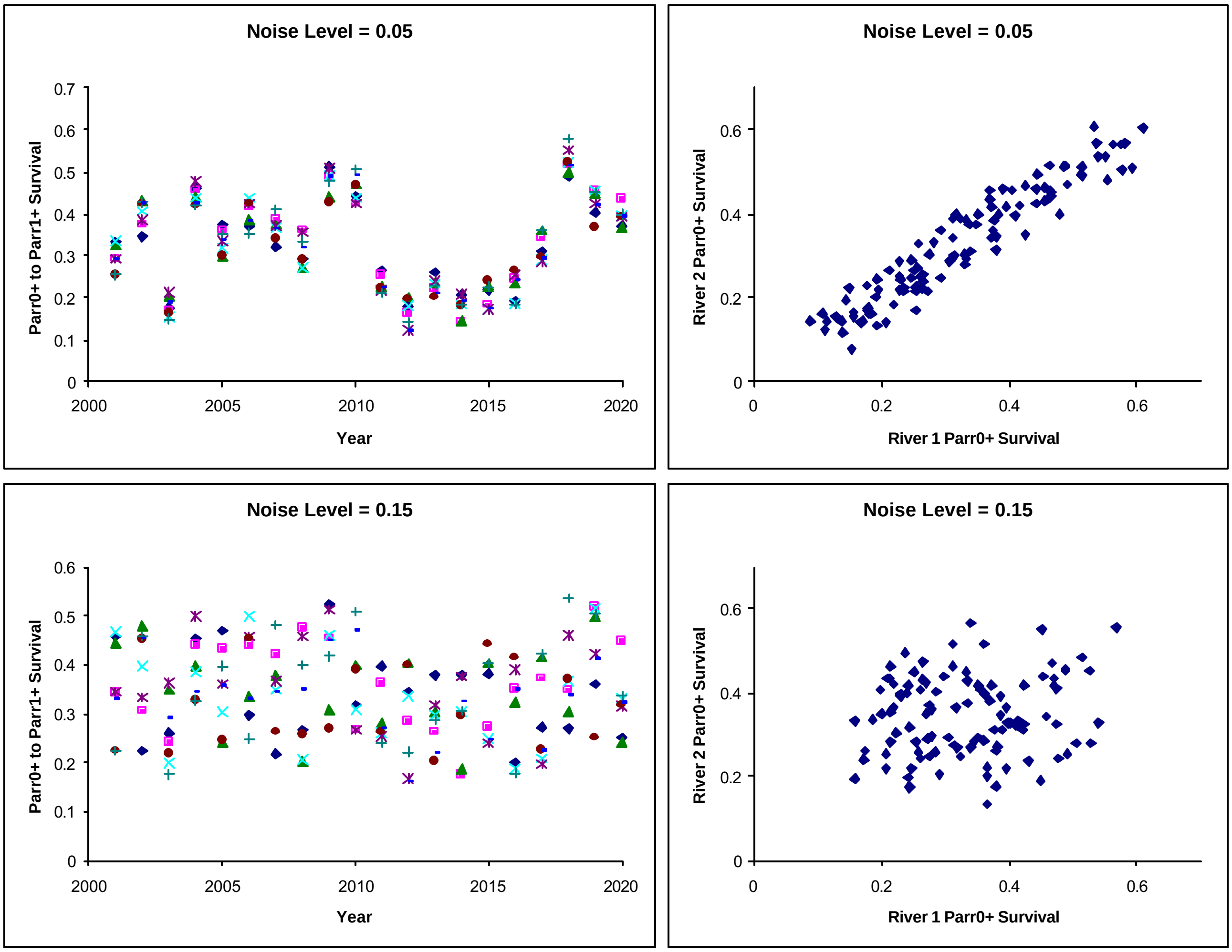


Figure 5. Comparison of tight coupling among rivers (top panels) and near independence among rivers (lower panels) for survival rates of parr 0+. In the left panels each symbol denotes a separate river while the right panels are show the relationship for two of the rivers.

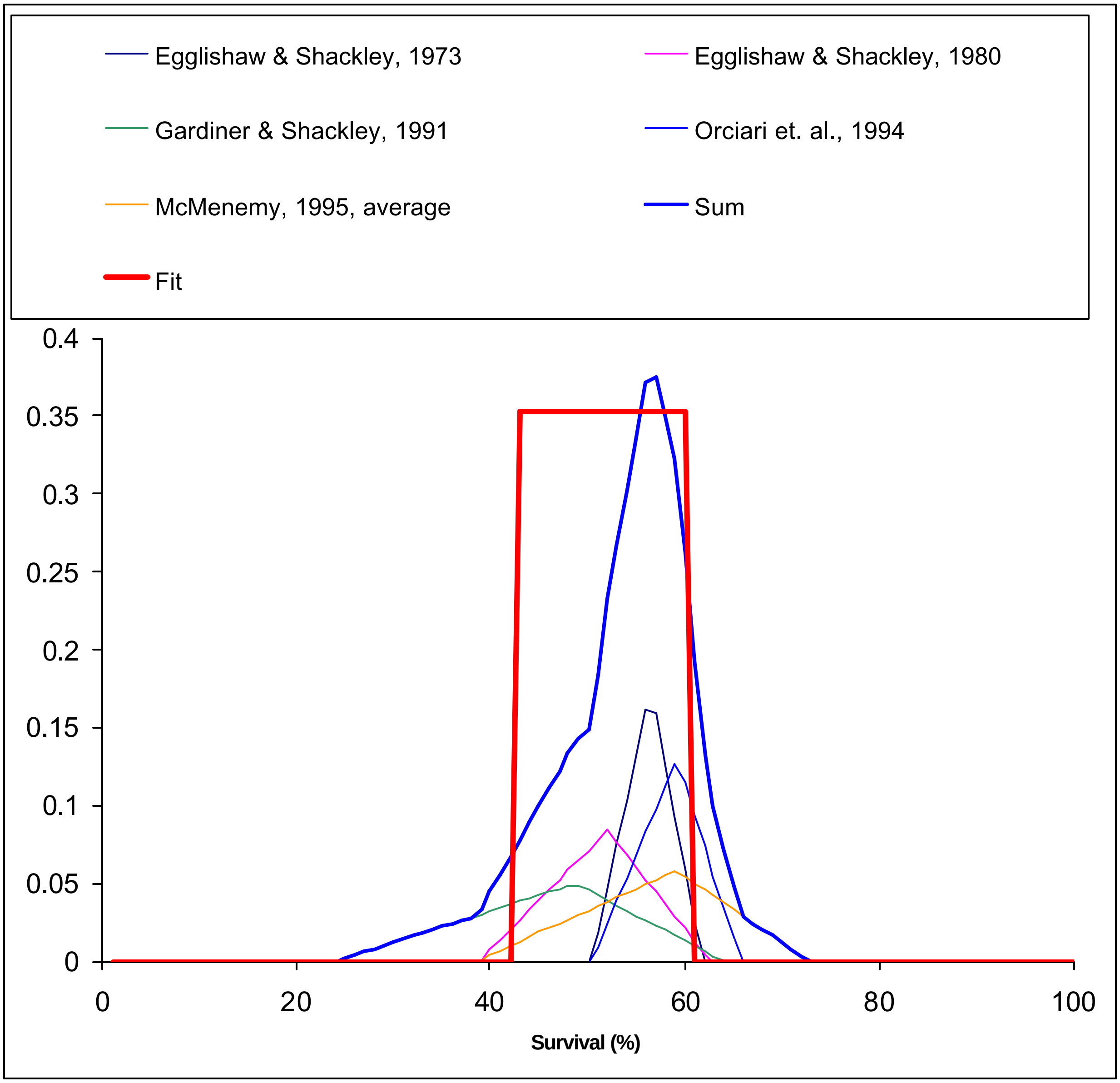


Figure 6. Fry to Parr0+ survival estimates from five studies, the calculated sum of these values, and the assumed uniform distribution that results (denoted Fit).

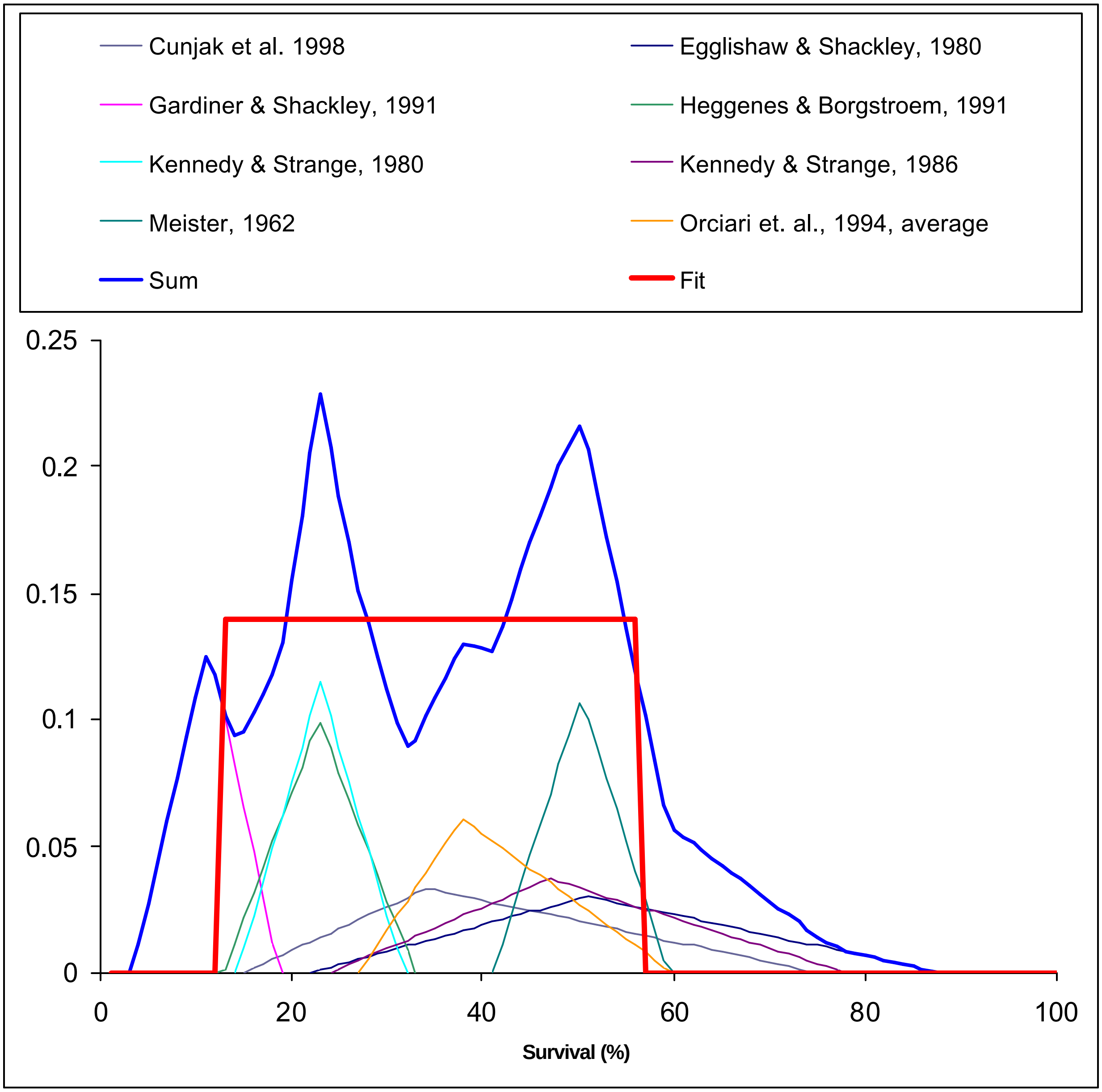


Figure 7. Parr0+ to Parr1+ survival estimates from eight studies, the calculated sum of these values, and the assumed uniform distribution that results (denoted Fit).

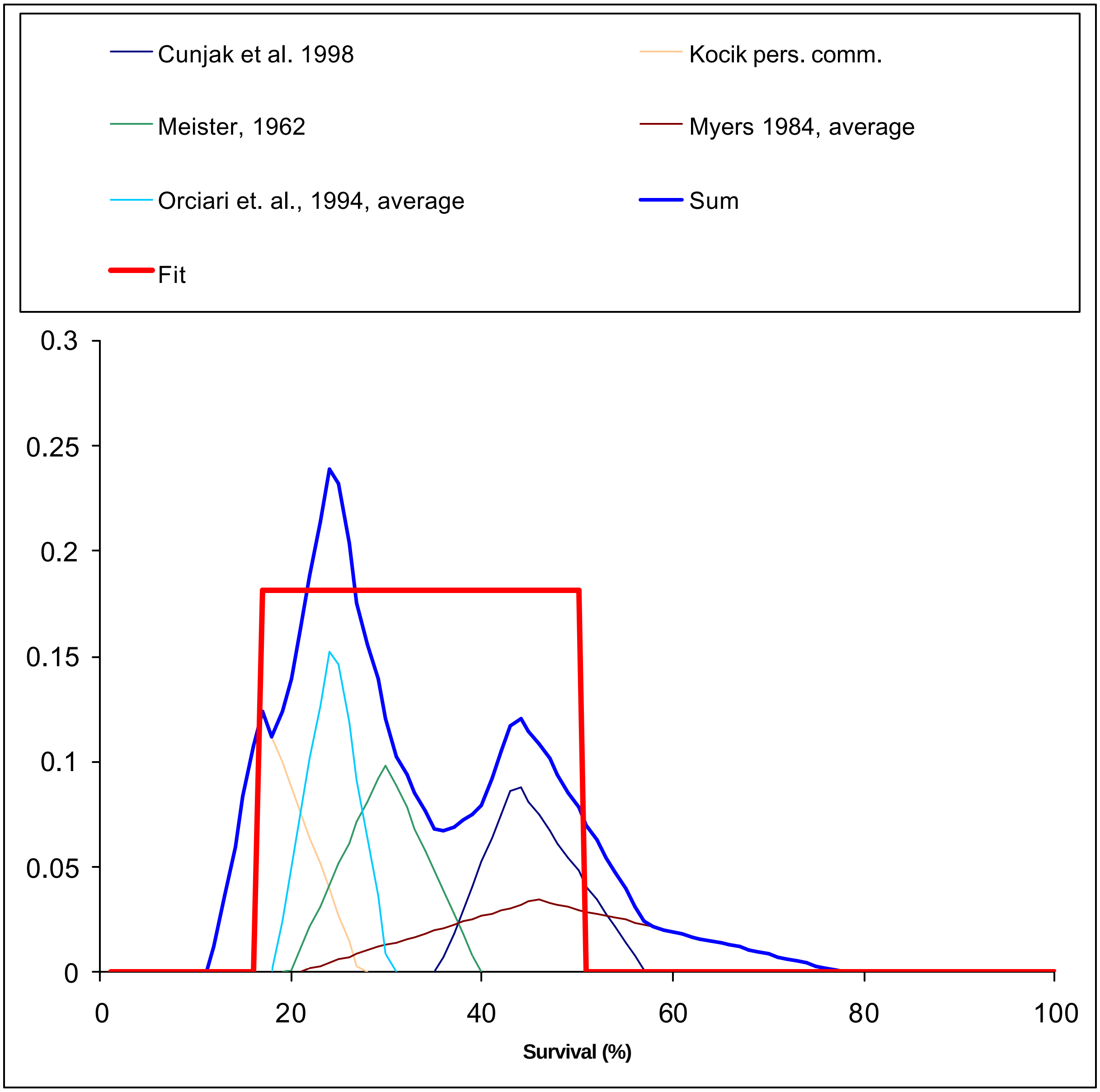


Figure 8. Parr1+ to smolt survival estimates from four studies, the calculated sum of these values, and the assumed uniform distribution that results (denoted Fit).

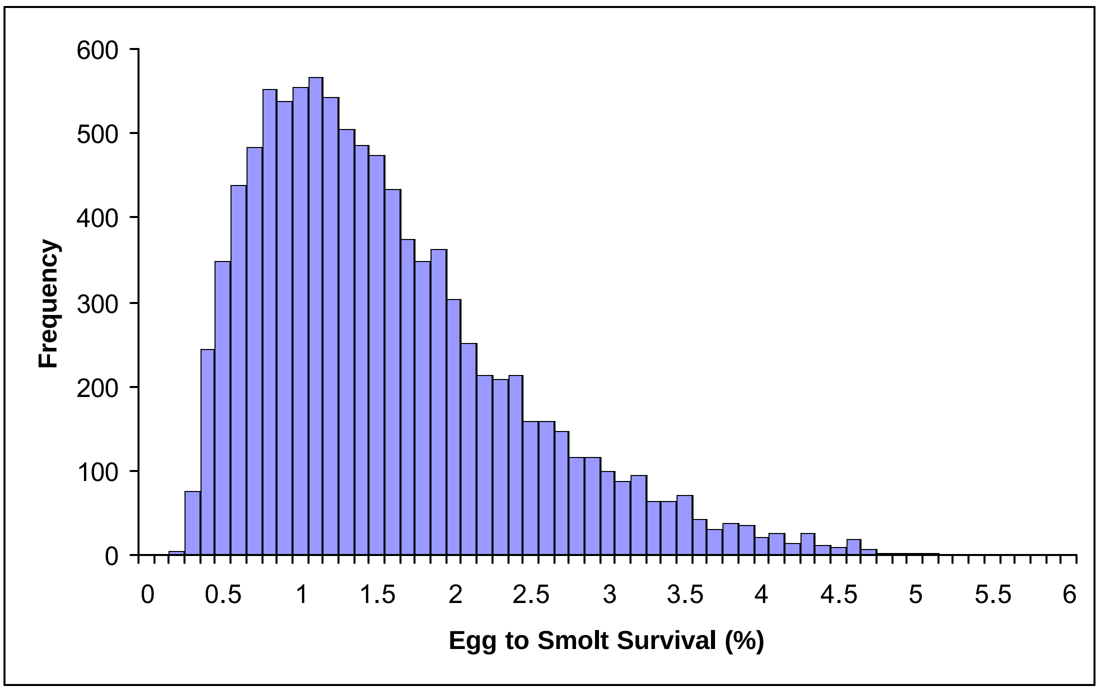


Figure 9. Histogram of 1,000 egg to smolt survival rates calculated by randomly selecting a survival value from each of the uniform distributions associated with the four juvenile life stage transitions.

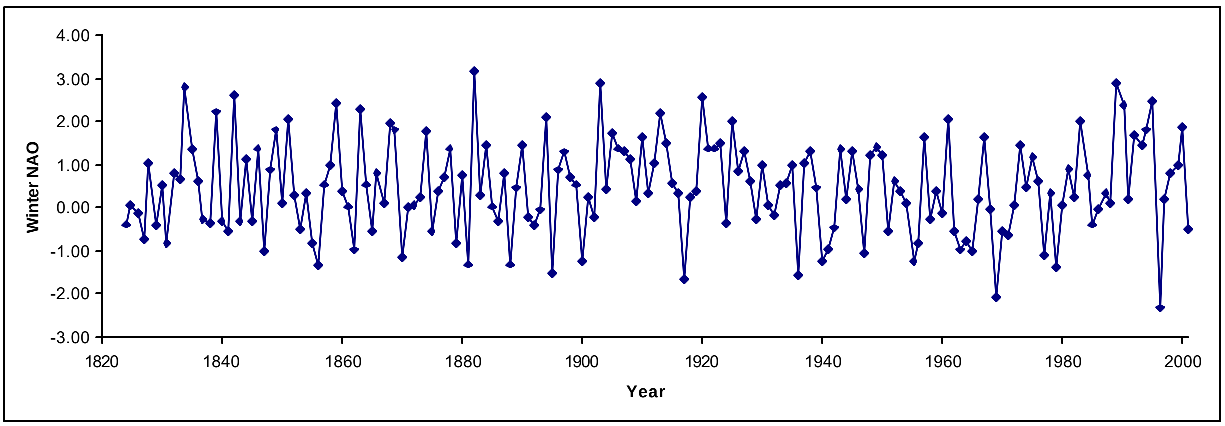


Figure 10. Winter North Atlantic Oscillation (NAO) values from 1824 to 2001.

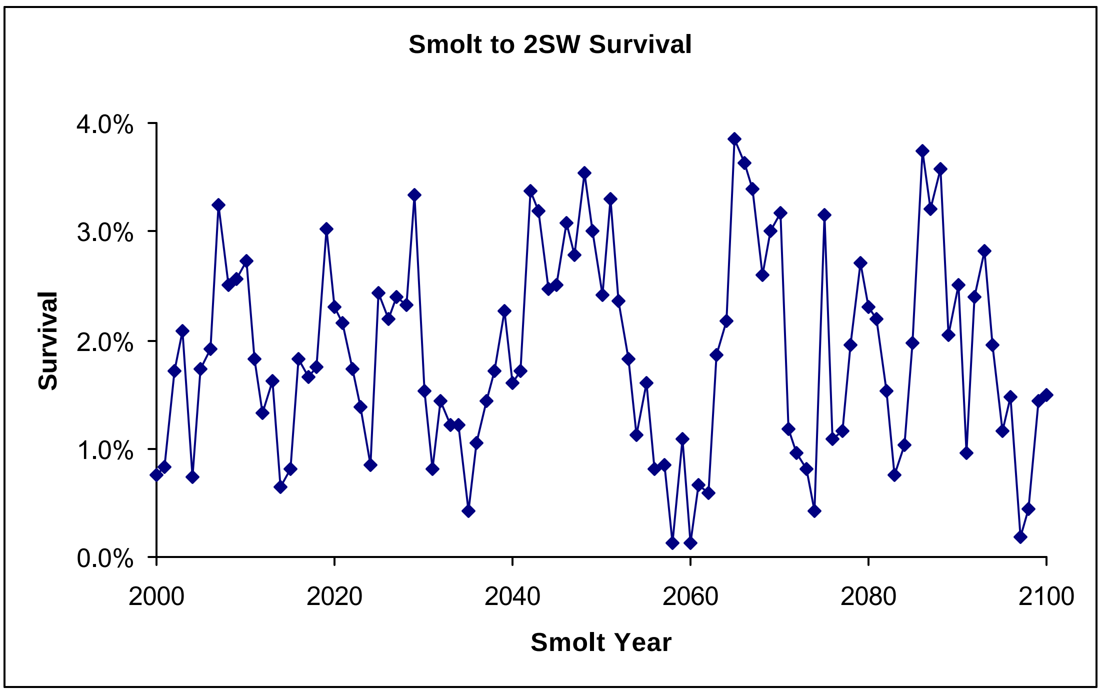


Figure 11. Example random realization of smolt to 2 sea winter adult survival.

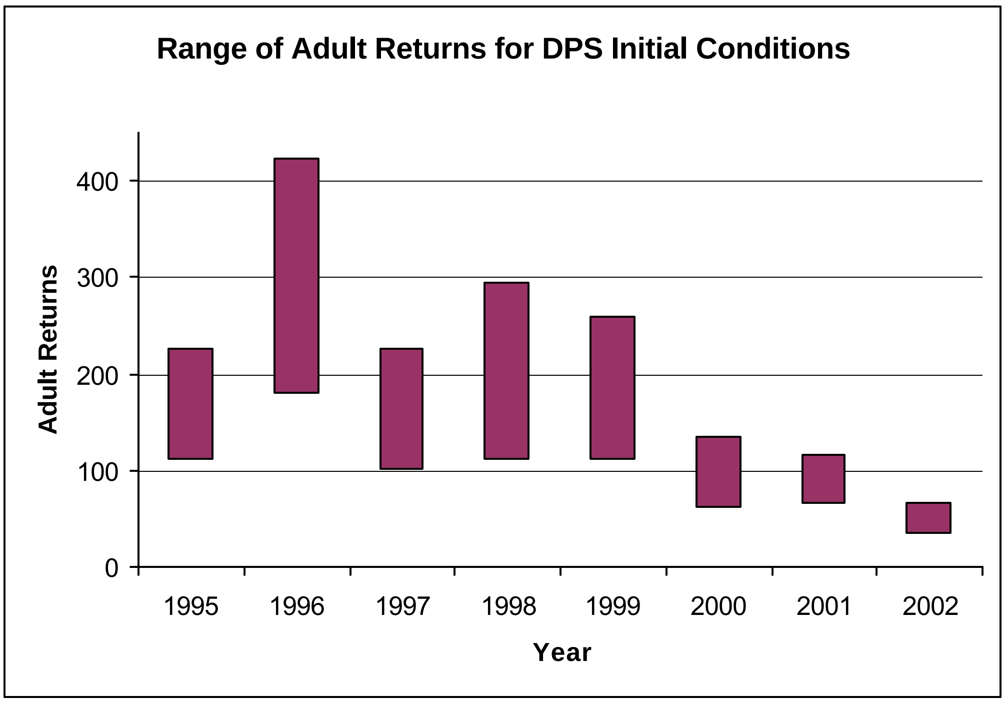


Figure 12. Range of adult returns summed over the eight DPS rivers during the years used for SalmonPVA initialization.

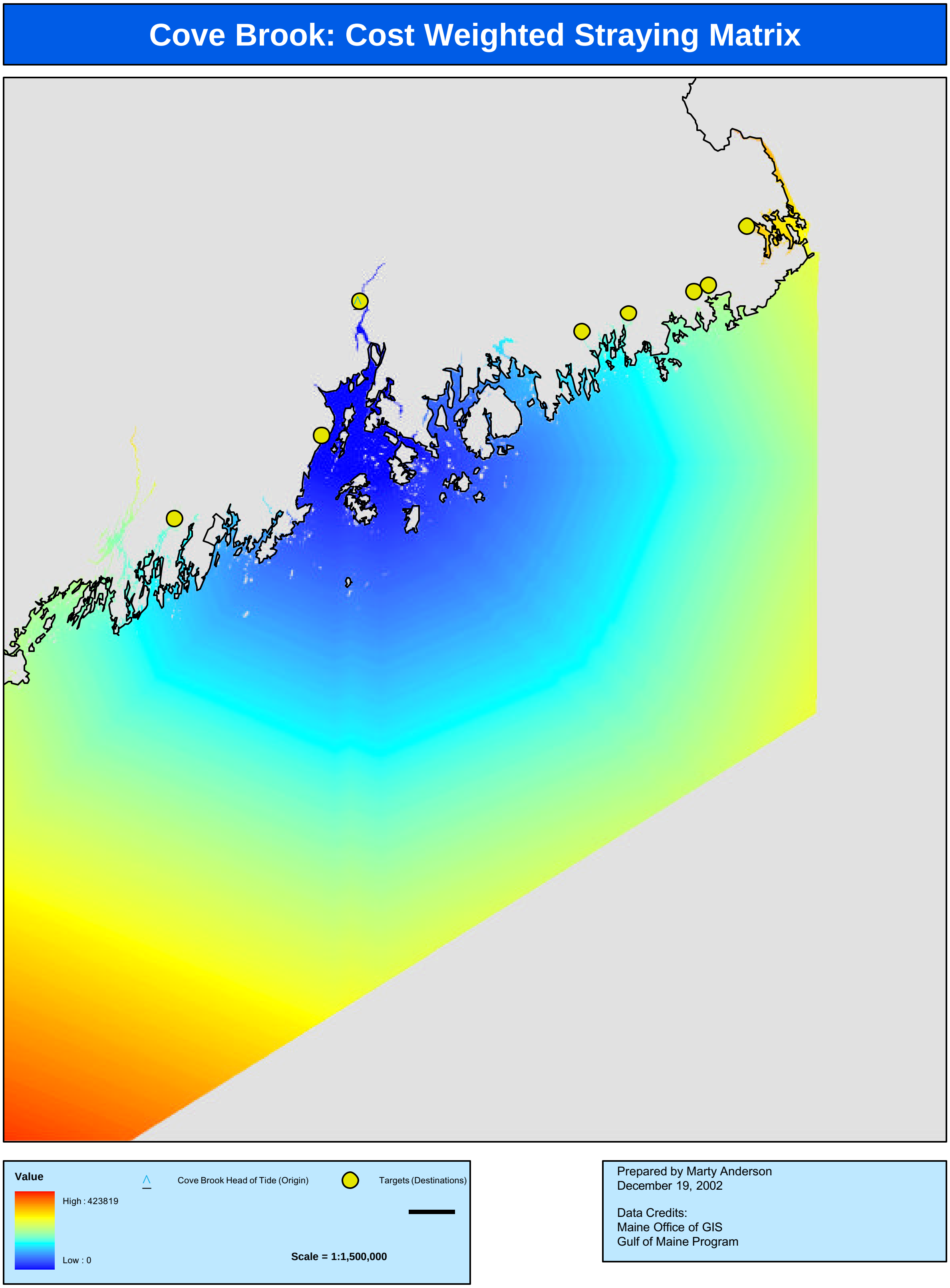


Figure 13. Example of cost weighted straying values for Cove Brook.

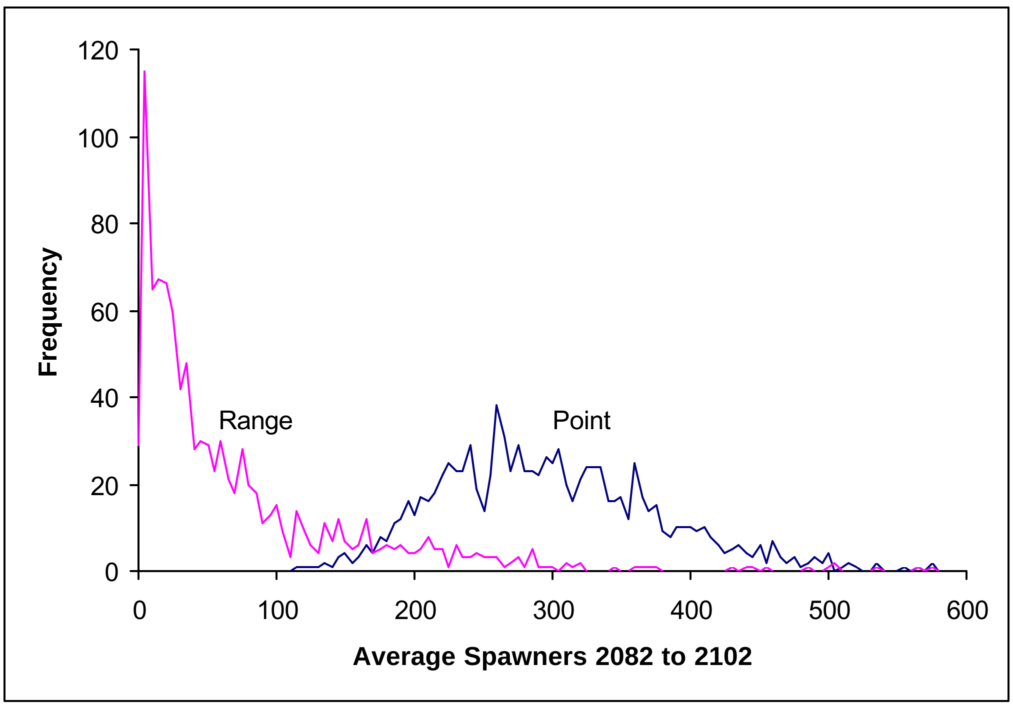
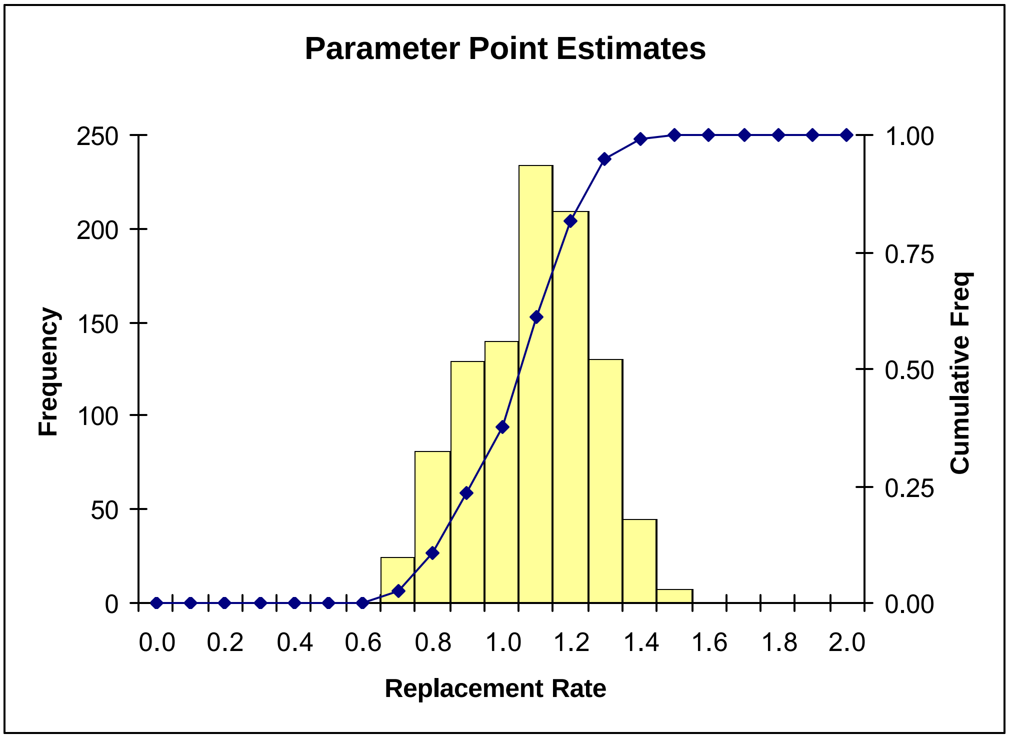


Figure 14. Comparison of frequency distributions for average spawners in years 2082 to 2102 between point and range tests for parameter variability.



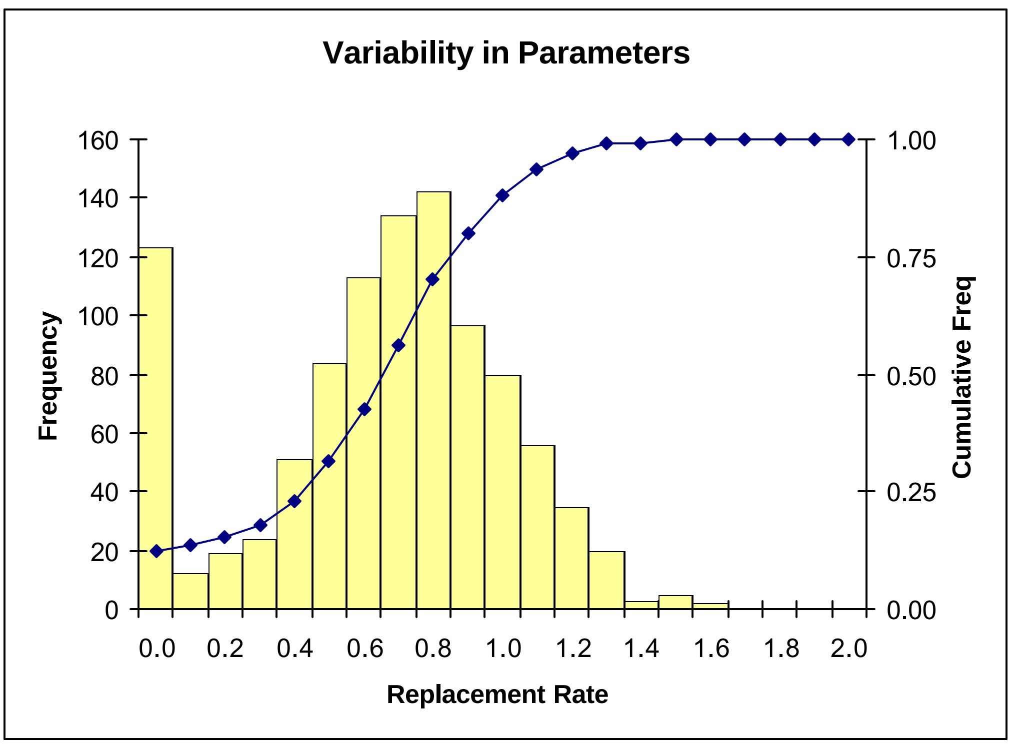


Figure 15. Comparison of replacement rate distributins between point and range tests for parameter variability.

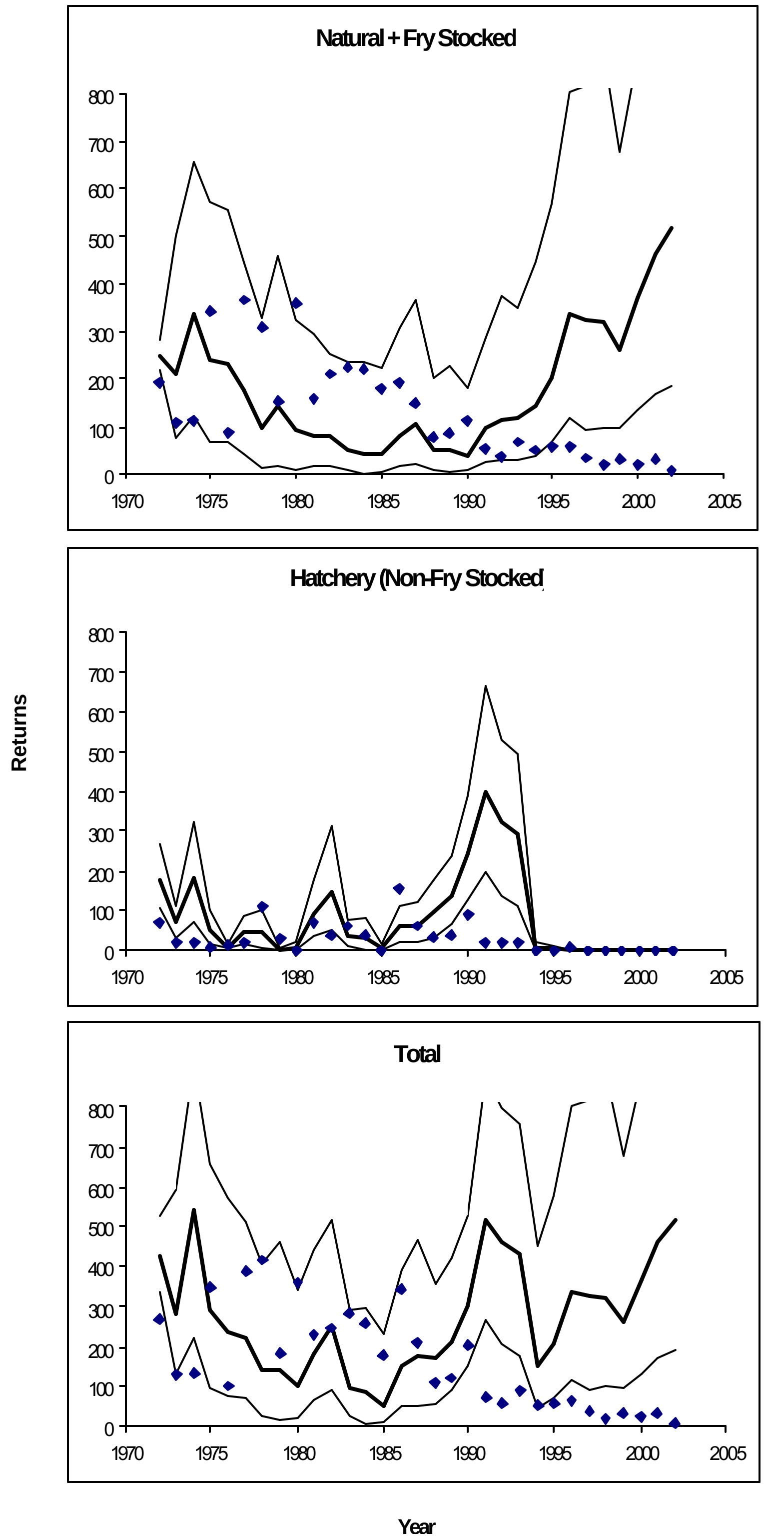


Figure 16. Observerd returns (diamonds) with simulated medians (heavy line) and 80% confidence intervals (thin lines) for base Narraguagus verification test.

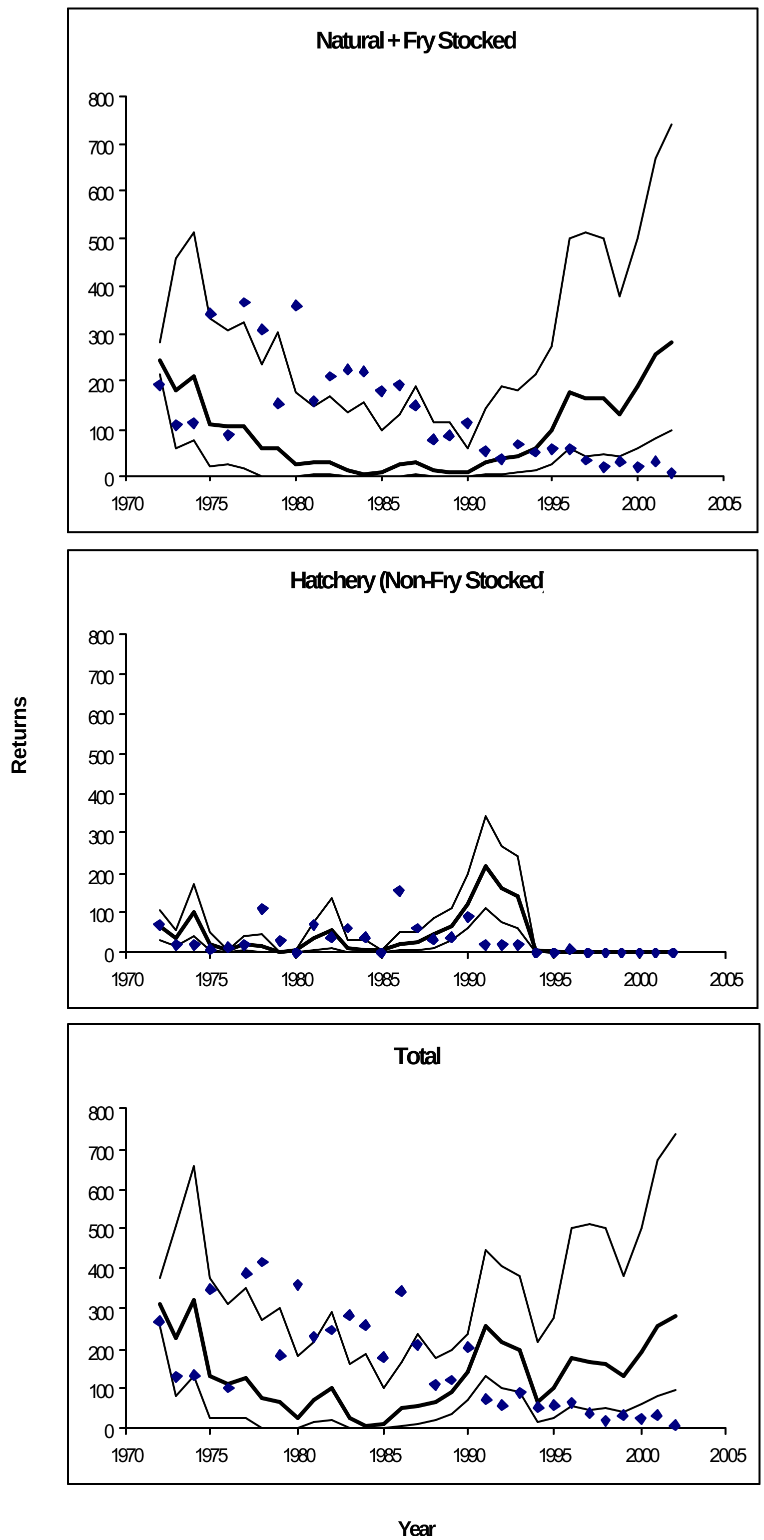


Figure 17. Narraguagus verification test when numbers of fish stocked are reduced by 50%. Symbols and lines as in Figure 15.

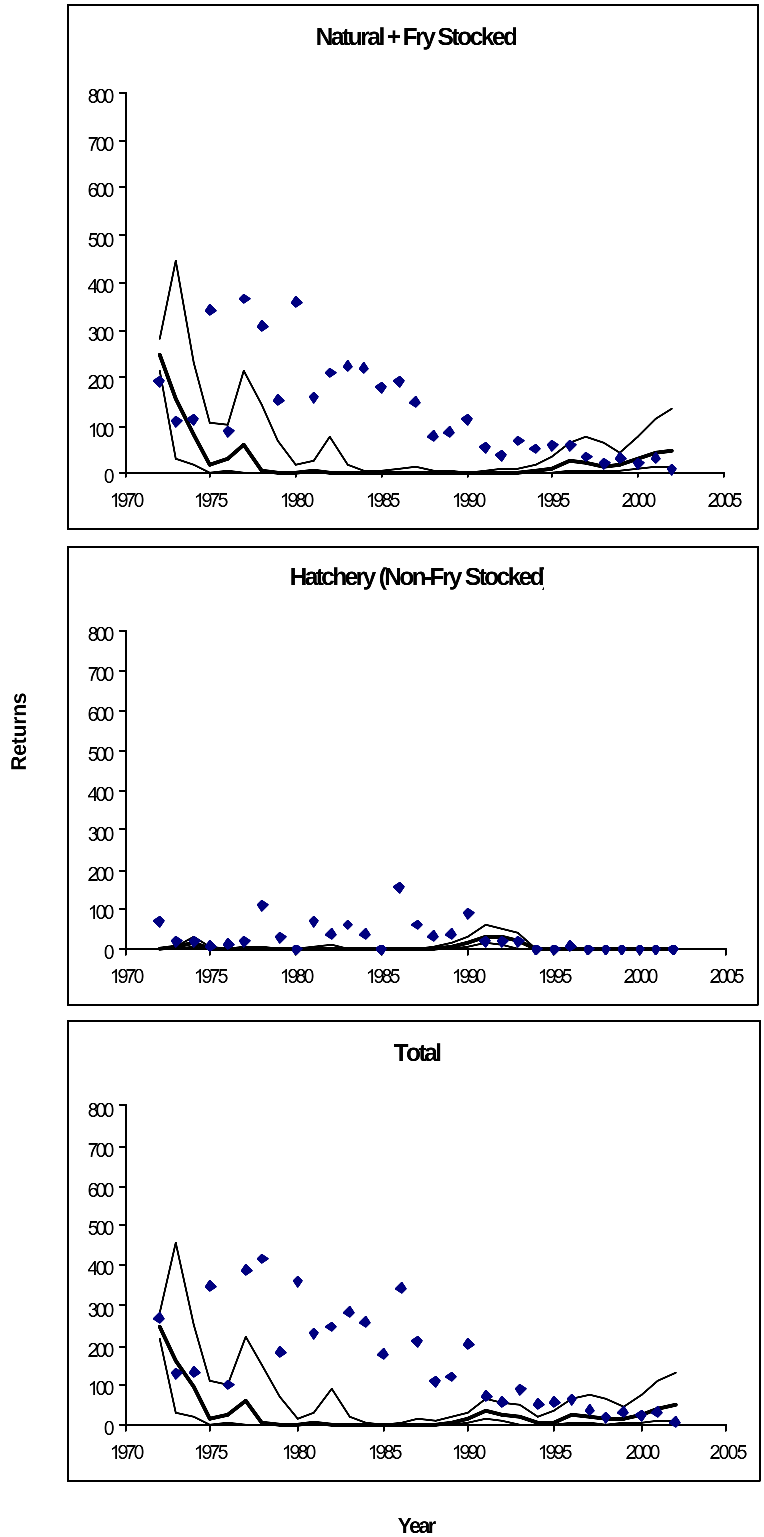


Figure 18. Narraguagus verification test when numbers of fish stocked are reduced by 90%. Symbols and lines as in Figure 15.

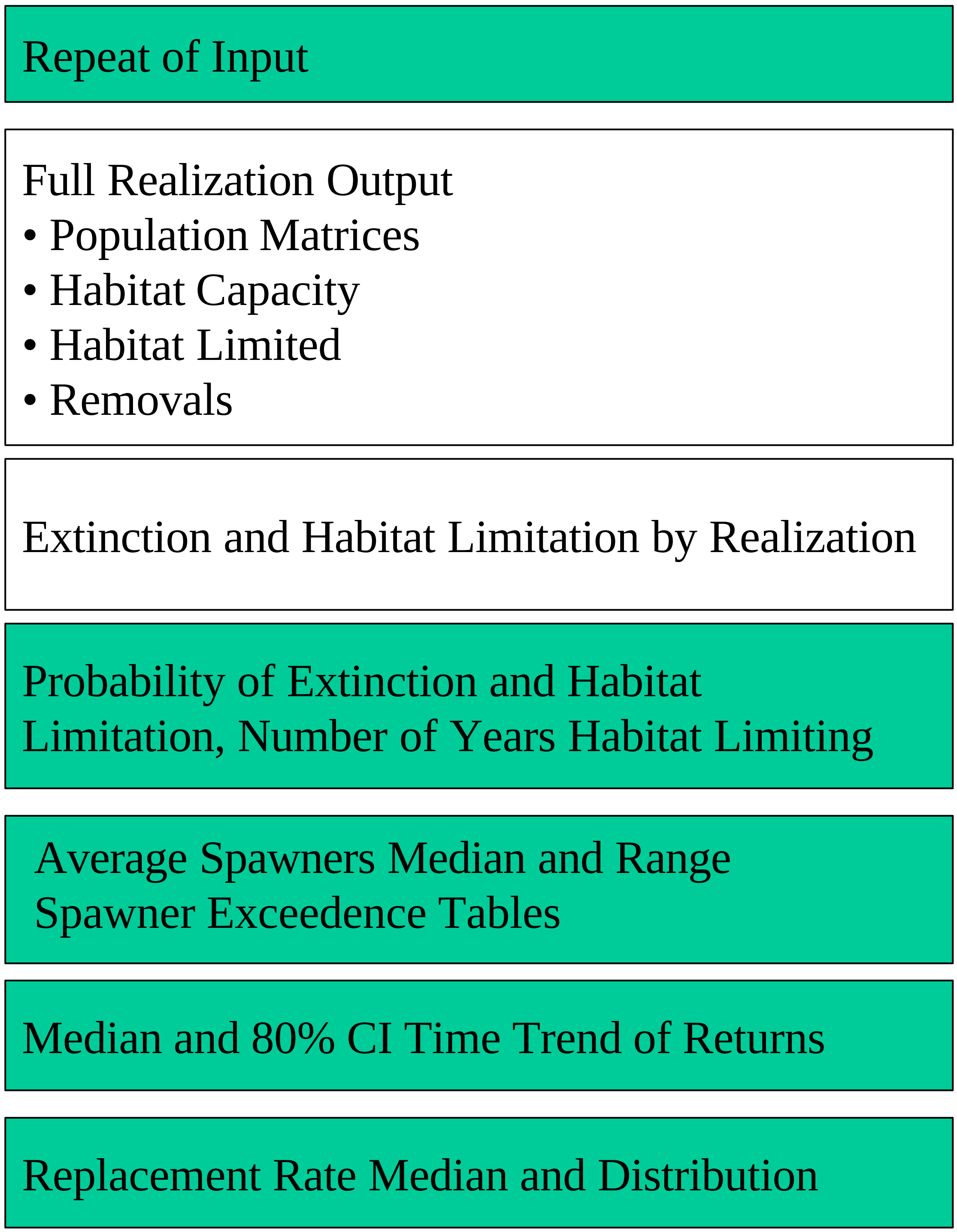


Figure 19. Layout of output file. Shaded boxes are always present, clear boxes are optional.

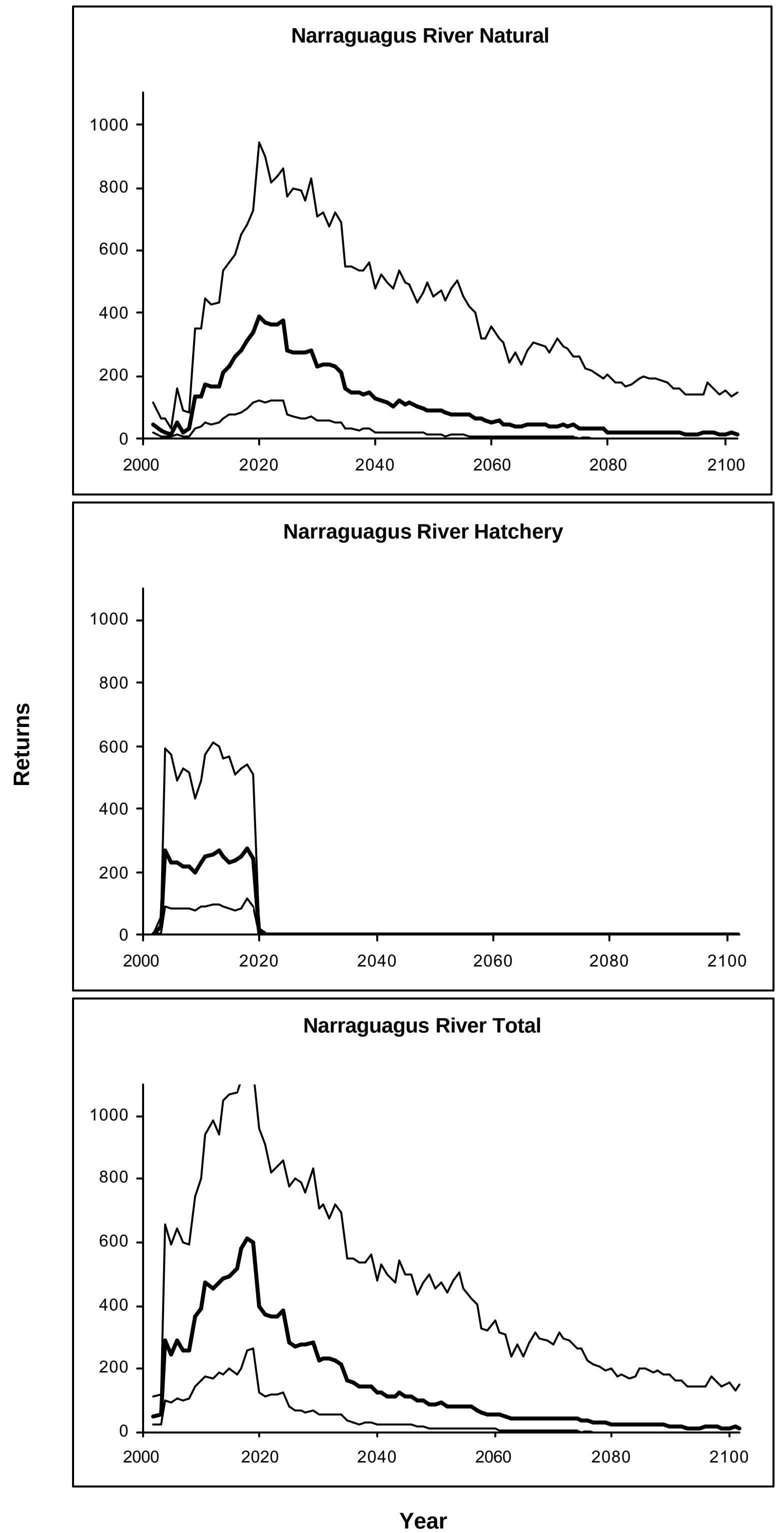


Figure 20. Annual medians (bold line) and 80% confidence intervals (light lines) of natural, hatchery, and total returns from 1,000 simulations of the base case for the Narraguagus river.

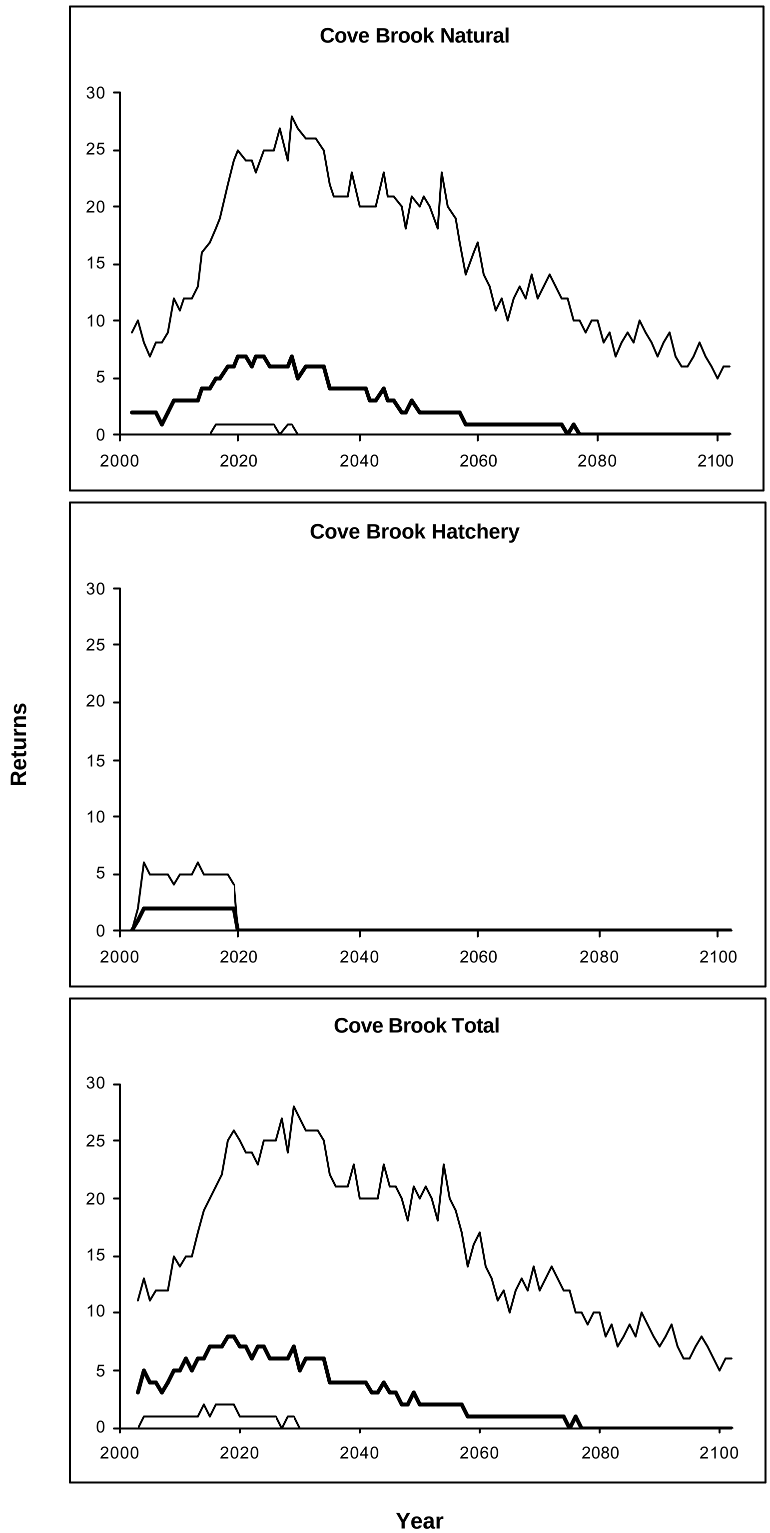


Figure 21. Annual medians (bold line) and 80% confidence intervals (light lines) of natural, hatchery, and total returns from 1,000 simulations of the base case for Cove Brook.

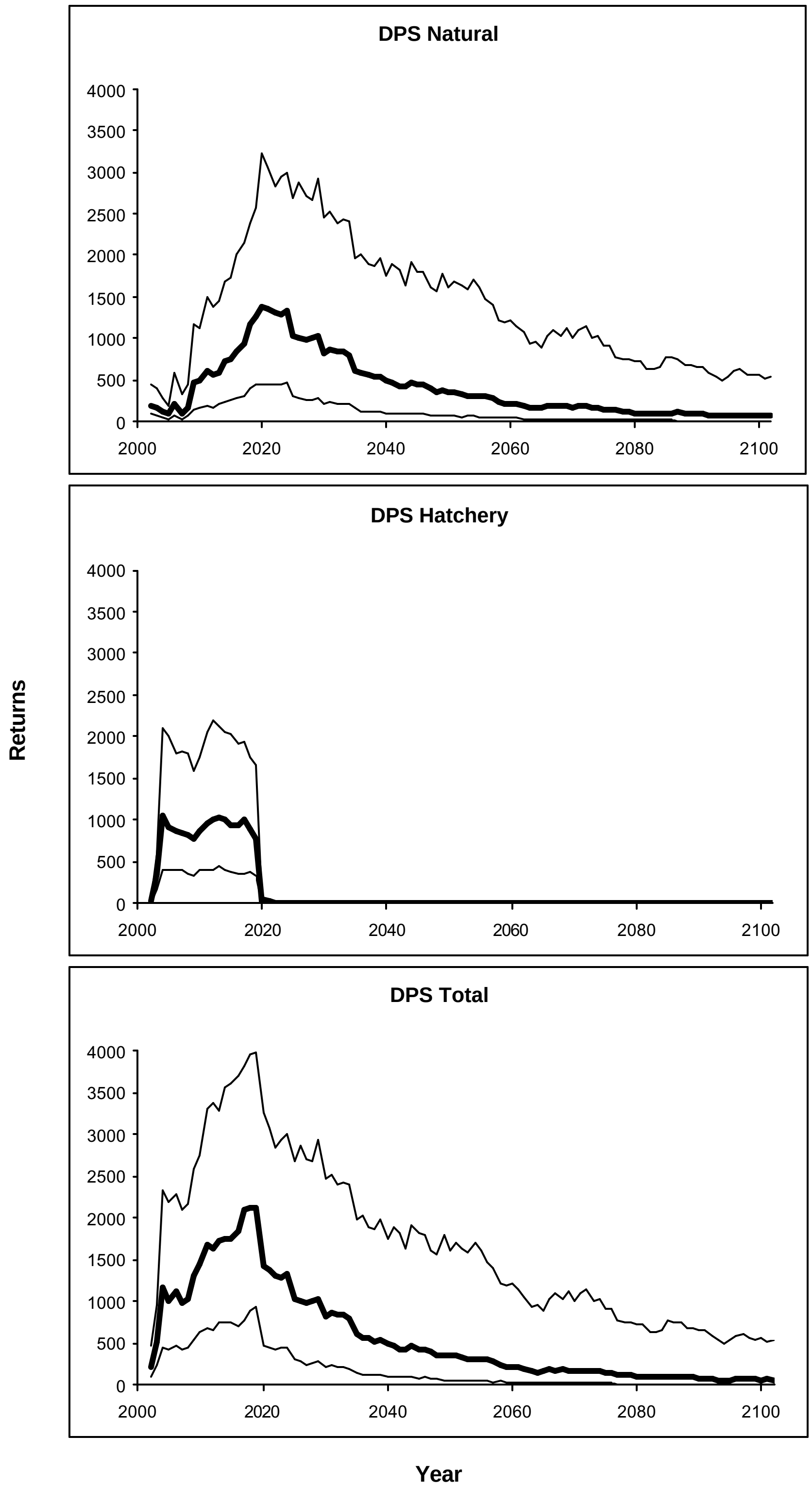


Figure 22. Annual medians (bold line) and 80% confidence intervals (light lines) of natural, hatchery, and total returns from 1,000 simulations of the base case for all 8 DPS rivers.

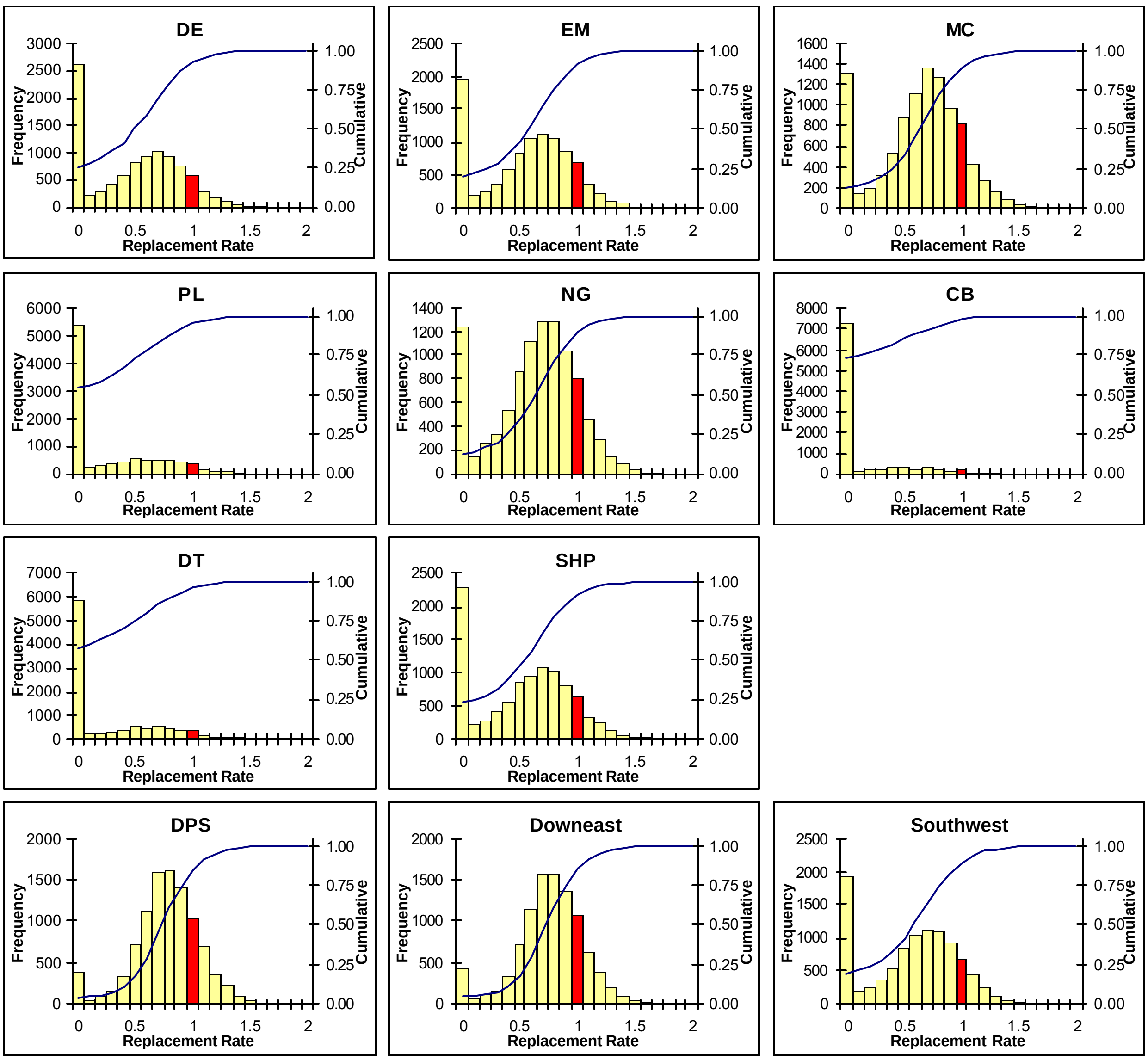


Figure 23. Replacement rate distributions for all rivers and river groups using base case inputs and 10,000 simulations. The red bars denote the bin containing 1.0 as its upper bound.

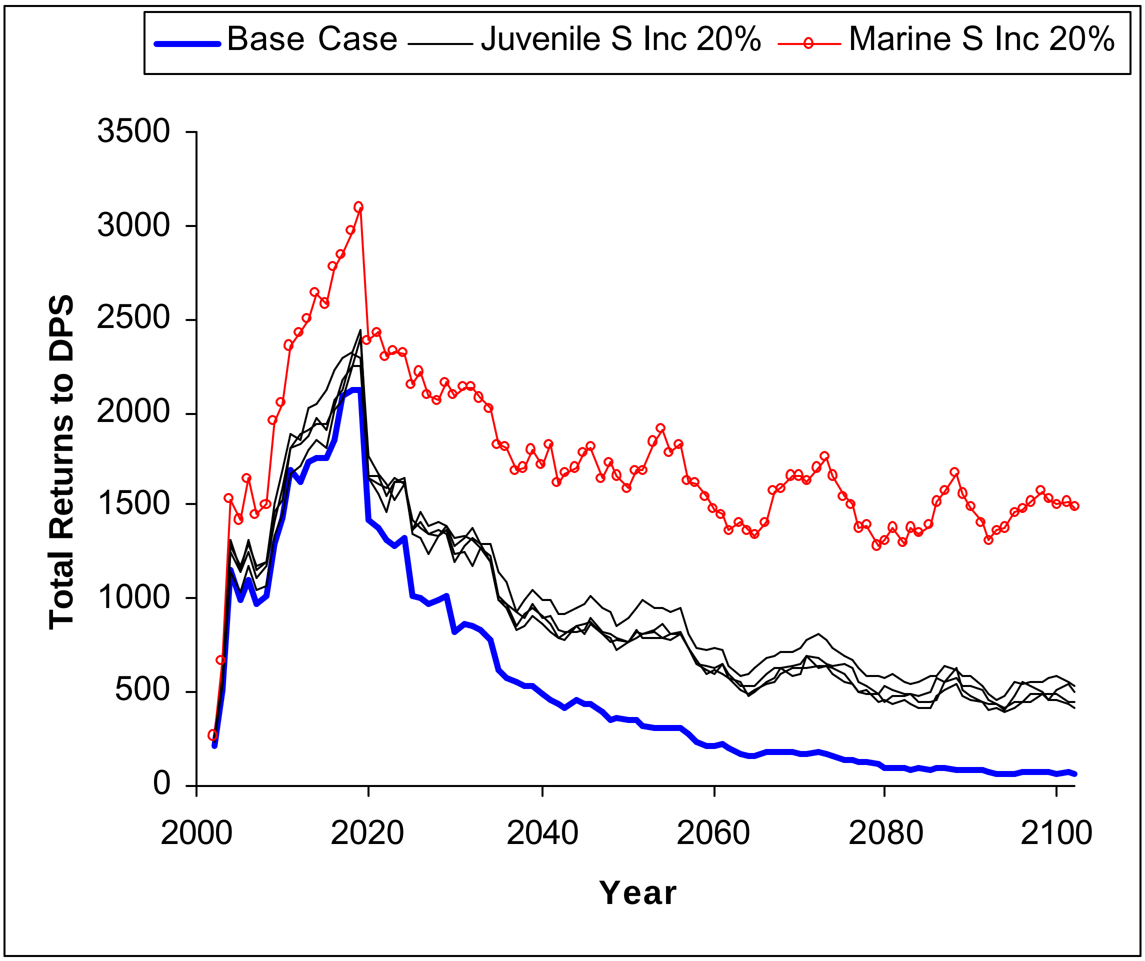


Figure 24. Medians of total returns to the DPS when juvenile survival (four thin lines) or average marine survival (line with circles) are increased 20% compared to the base case (thick line).

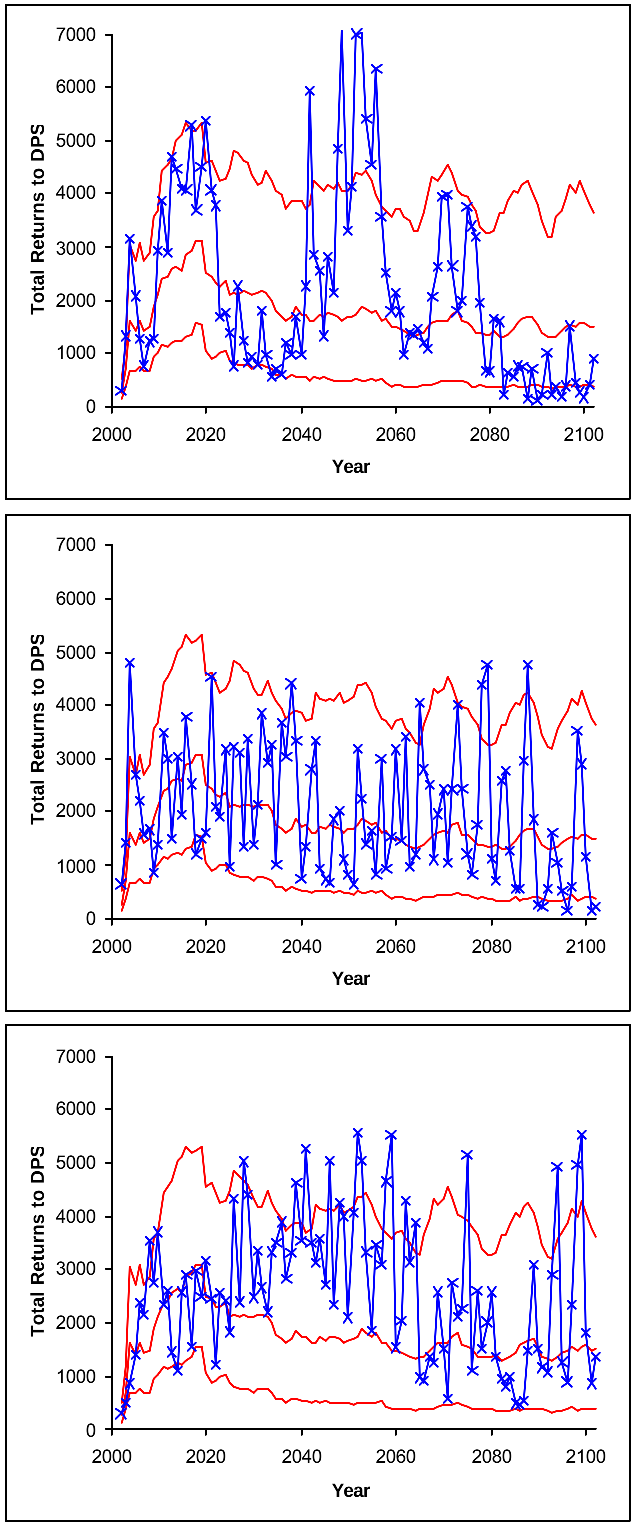


Figure 25. Three separate trajectories of total returns to the DPS (thin lines with symbols) shown relative to the median and 80% confidence interval (thick lines) from the sensitivity analysis when average marine survival was increased 20%.

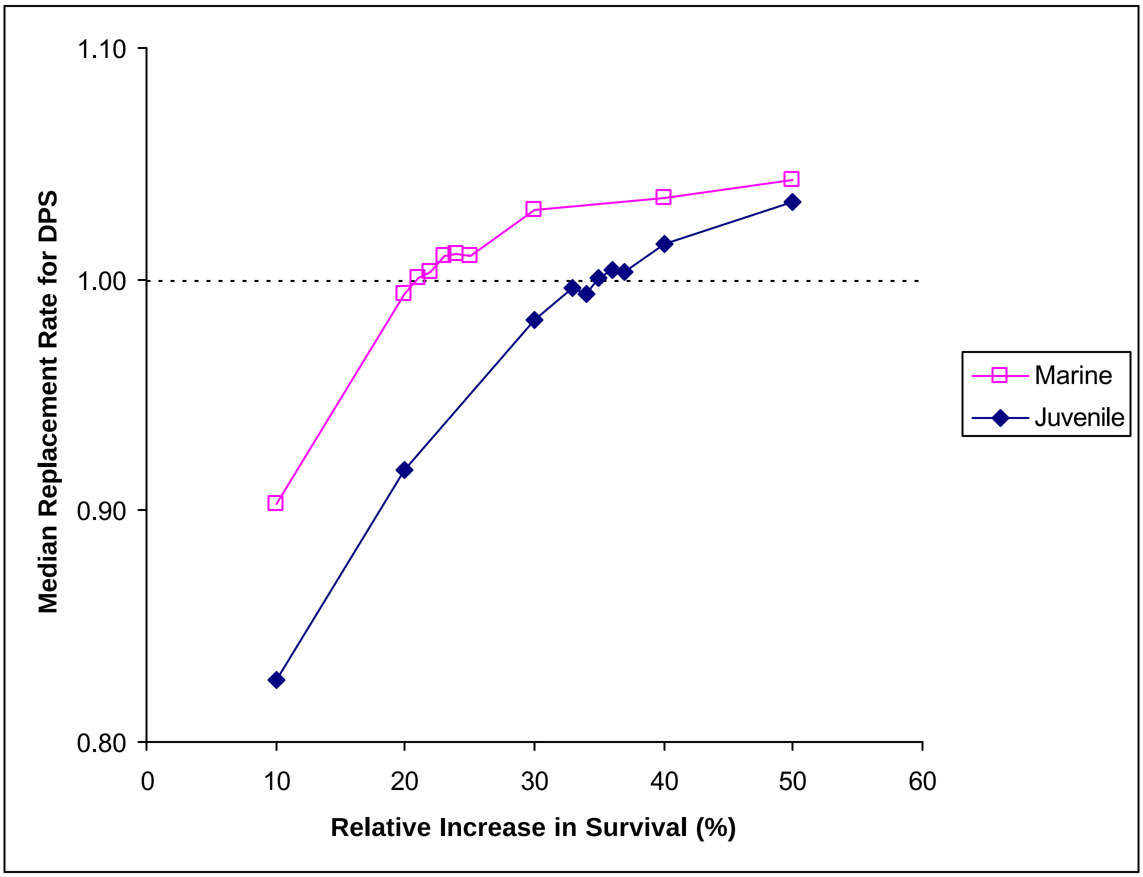


Figure 26. Median replacment rate of the DPS as a function of changes in either the average marine survival rate or the parr1+ to smolt (juvenile) survival rate.

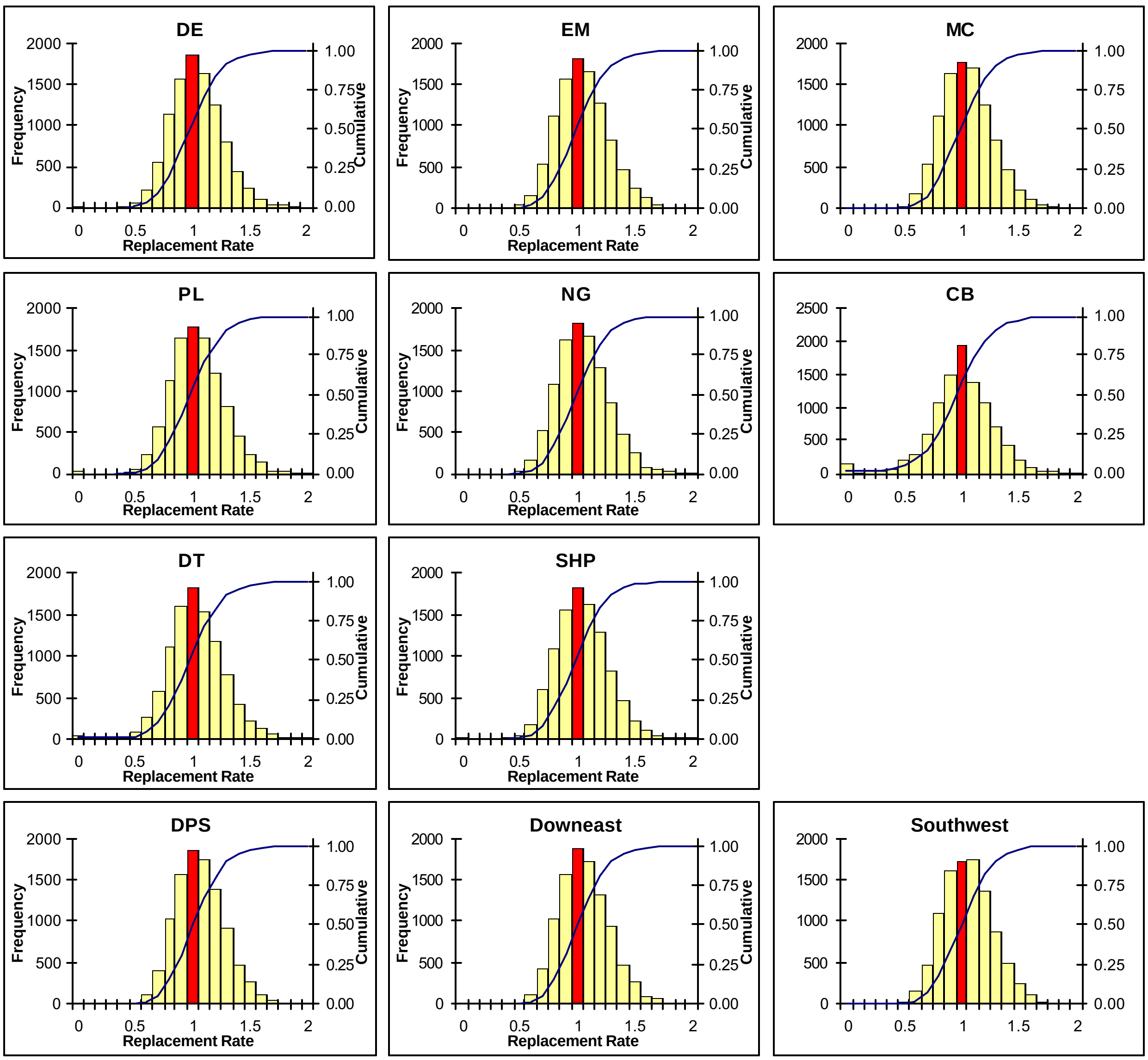


Figure 27. Replacement rate distributions for all rivers and river groups using CSE levels for population abundance, increasing average marine survival 35%, and 10,000 simulations. The red bars denote the bin containing 1.0 as its upper bound.

Appendix

List of Working Group Participants and Affiliations

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Colligan, Mary	NMFS
Cooney, Tom	NMFS
Hawkes, Jim	NMFS
Hecht, Anne	FWS
ICES WGNAS	various
Kimball, Dan	FWS
Kinnison, Mike	UMaine
Kocik, John	NMFS
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Lindley, Steve	NMFS
Mackey, Greg	AFS
Marancik, Jerry	FWS
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Minton, Mark	NMFS
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Parkin, Mary	FWS
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Sheehan, Tim	NMFS
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Wainwright, Tom	NMFS
Waples, Robin	NMFS

ASC = Maine Atlantic Salmon Commission
FWS = US Fish and Wildlife Service
NMFS = National Marine Fisheries Service
UMaine = University of Maine
WGNAS = Working Group on North Atlantic Salmon

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