**RATIONALE FOR POPULATION VIABILITY RECOVERY CRITERIA**

**FOR THE GULF OF MAINE DPS OF ATLANTIC SALMON**

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### The 50/500 Rule

A minimum viable population (MVP) is defined by Shaffer (1981) as the smallest isolated population that has a 99 percent probability of remaining extant for 1000 years despite natural demographic, environmental, and genetic stochasticity and natural catastrophes. The number of organisms present within a population does not necessarily denote the actual number of viable organisms within that population. Therefore, when determining viability, it is important to acknowledge the potential for variations between the actual (census) population size (N) and the viable (effective) component of that population. As a result, we not only recognize the importance of the MVP but also the importance of defining criteria for effective population size (Ne) for setting robust recovery criteria. Franklin (1980) described an Ne size of 500 as necessary to retain sufficient genetic variation for long-term population persistence. Soulé (1980) identified an Ne of 50 or greater needed to assure that a population, over the short term, would have an inbreeding rate of less than 1 percent. Higher rates of inbreeding that can occur in populations of fewer than 50 can fix deleterious genes too rapidly for natural selection to eliminate them. Soulé (1980) states that even at a 1 percent rate of inbreeding, the loss of genetic variation after a few generations will be appreciable even in the presence of natural selection. Soulé (1980) also states that after 20 to 30 generations, a population held at 50 can expect to lose about one fourth of its genetic variation along with much of its capacity to adapt to changing conditions. Franklin (1980) also states that in random populations, when considering the consequences of inbreeding, the number of individuals should not fall below 50 and that, in the long term, genetic variability will be maintained only if population sizes are an order of magnitude higher than 50.

Allendorf et al. (1997) applied the 50/500 rules described by Franklin (1980) and Soulé (1980) to describe risk of extinction to Pacific salmon populations, where populations with an Ne below 500 per generation would be at high risk of losing potentially important genetic variability and populations with an Ne below 50 per generation would be at very high risk. Wainwright and Waples (1998) responded to Allendorf et al. (1997), stating that the inclusion of demographic and environmental stochasticities as well as depensatory effects would be significant and likely to vary with life history and habitat types. They concluded that applying a single abundance criterion may not be appropriate for all Pacific salmon stocks.

An example of the 500 rule being applied to salmon is the Draft Viability Criteria for Application to Interior Columbia Basin Salmonid ESUs (Cooney et al. 2007). (ESU is the acronym for “evolutionarily significant units,” a construct adopted by NOAA Fisheries that is analogous to distinct population segments.) Cooney et al. (2007) developed ESU-level viability criteria needed to maintain the Lower Columbia/Willamette ESU in the face of long-term ecological and evolutionary processes. They proposed a minimum abundance threshold of 500 spawners (census population) for some salmonid populations within the ESU based on the reasoning that populations with fewer than 500 individuals are at higher risk for inbreeding depression and a variety of other genetic concerns. They maintained that a minimum abundance of 500 spawners appears to be adequate for compensatory processes and to maintain within-population spatial structure for smaller Interior Columbia Basin salmon populations.

Using similar reasoning, we have chosen to use a census population of 500 adult spawners (assuming a 1:1 sex ratio) in each SHRU to represent the effective population size for recovery. We used the census number rather than an effective population size for four reasons: (1) The adult census through redd counts or trap catches has been used as the principle indicator of population health in the GOM DPS since Charles Atkins first started estimating returns in the mid- to late-1800s. (2) A census population of 500 spawners per SHRU is only one of several considerations related to reduced extinction risk. (3) Atlantic salmon have tremendously complex life histories, allowing great opportunity for extensive cross-generational breeding. This is so because of the salmon’s iteroparity and because precocious parr, one-sea winter fish, and multi-sea winter fish can all participate in spawning activity. Having multi-generational participation in spawning activity significantly reduces the effective population to census population ratio, but it also makes determining the actual Ne /N ratios extremely difficult and highly debatable for the natural population. (4) Although there has been much debate in the literature about assigning a general number to represent when specific populations are sufficiently large enough to maintain genetic variation (Reiman and Allendorf 2001, Allendorf and Luikart 2007, Waples andYokota 2007), the 500 rule introduced by Franklin (1980) has not been superseded by any other rule and continues to serve as a useful indicator of when a population may be at risk of losing genetic variability (Allendorf and Luikart 2007).

### Demographic Modeling

The current low numbers of adult Atlantic salmon are a result of a regime shift in productivity of Atlantic salmon in the northwest Atlantic from 1991 to 2006 (Chaput et al. 2005). Applying estimates of spawner escapement from this period to a simplified PVA, NOAA (2009) projected that 2,000 wild spawners in each SHRU would support a population that is not likely to fall below 500 adult spawners 15 years into the future.

The input data used in the PVA were based on an adult return redd count linear regression model (described in USASAC 2013) for the watersheds included in the GOM DPS as delineated in 2000 (65 FR 69469). The 2000 DPS data are thought to be most appropriate because of the relative consistency in management practices among those watersheds (see NOAA 2009). The Penobscot River was excluded from the input data to the PVA, because the river has been dominated by smolt stocking, and the large variations in stocking practices there could bias the estimation of population growth rates.

The PVA used the mean population growth rate and standard deviation from the 2000 GOM DPS to simulate the number of spawners 15 years into the future. Populations were simulated with initial population sizes starting at 500, and 10,000 iterations of the model were run to determine the probability of falling below 500 spawners in 15 years. Additional simulations were conducted in which the initial population size was increased until an initial population was found that had a less than 50 percent probability of falling below 500 spawners in 15 years. This initial population equaled 2,000 spawners per year and is considered the minimum population necessary to withstand a downturn in marine survival similar to that seen starting in 1991 and stay above the threshold of 500 spawners (NOAA 2009).

### Genetic Considerations

Effective population size (N*e*) is defined as the size of an ideal population (N) that will result in the same amount of genetic drift as the actual population being considered. Many factors can influence N*e*, such as sex ratios, generation time (Ryman et al. 1981), overlapping generations (Waples 2002), reproductive variance (Ryman and Laikre 1991), and gene flow (Waples 1998). Applied to conservation planning, the concept of N*e* has been used to identify minimal targets necessary to maintain adequate genetic variance for adaptive evolution in quantitative traits (Franklin 1980), or as the lower limit for a wildlife population to be genetically viable (Soulé 1987). Estimation of N*e* in Atlantic salmon is complicated by a complex life history that includes overlapping generations, precocious male parr, and repeat spawning (Palstra et al. 2009). Effective population size is measured on a per generation basis, so counting the number of adults spawning annually is only a portion of the total N*e* for a population. In Atlantic salmon, Palstra et al. (2009) identified a range of N*e* to N ratios from 0.03 to 0.71, depending on life history and demographic characteristics of populations. Assuming an *Ne* to N ratio of 0.2 for recovery planning, the N*e* for a GOM DPS of Atlantic salmon population should be approximately equal to the average annual spawner escapement, assuming a generation length of 5 years. Although precocious male parr can reproduce and therefore be included in estimates of the number of adult spawners, Palstra et al. (2009) determined that reproduction by male Atlantic salmon parr makes a limited contribution to the overall N*e* for the population.

Although NOAA (2009) attempted to minimize bias in estimating the mean population growth rate used in the PVA by excluding the Penobscot River due to stocking of hatchery fish, it is likely that some bias remains. The numbers of returns used in the estimation of population growth rate are still the product of natural spawning and fry stocking. If returning adults resulting from stocked hatchery fry are reproducing and contributing to the next generation, then true population trends may be masked (McClure et al. 2003), and the true population growth rate may be lower than that estimated by NOAA (2009). In this case, the minimum population required to have a less than 50 percent chance of falling below 500 spawners under another period of low marine survival is 2,000 spawners per year in each SHRU. Estimates of population growth rate can be corrected for the input of hatchery fish, but this requires differentiating between returns of wild origin and fry-stocked salmon; this in turn requires genetic determination of parentage, but the ability to adequately sample returning adults on all rivers is limited. The estimate of 2,000 spawners thus serves as a starting point for evaluating population status, but this benchmark and the methods by which it is calculated should be re-evaluated in the future as more data and better methods for partitioning returning adults become available. The threshold of 2,000 wild spawners per SHRU, totaling 6,000 annual wild spawners for the GOM DPS is similar to other estimates of the population size needed for long-term persistence (Thomas 1990, Traill et al. 2009).

As an intermediate target, naturally reared adult spawners (i.e., returning adults originating from egg and fry stocking) can be included in assessments of recovery progress; however, full recovery should include only adult spawners of wild origin. Hatchery-origin adult spawners (i.e., returns from parr and smolt stocking) will not be included when assessing recovery progress, because targets could be artificially met by simply increasing hatchery production of smolts. Further, naturally reared adult spawners are likely to be more fit than hatchery-origin adult spawners, as their fitness is less due to hatchery influence and the majority of their lifetime is spent under the influence of natural selection processes in the wild. In addition, carrying capacities in the freshwater environment elicit a density-dependent effect on survivorship above which additional fry stocking would not produce greater numbers of fish at later life stages (McMenemy 1995, Armstrong et al. 2003). Finally, a population reliant upon hatchery fish for sustainability is indicative of a population that continues to be at risk.

Adult spawner populations will be assessed through a combination of trap counts of returning adult salmon and estimates of adult spawners from redd surveys; a statistical model is used to estimate the number of adult spawners using annual redd count survey data. Trap counts and redd-based return estimates will be totaled to determine the number of returning adults per SHRU.

Recovery progress will also be assessed on the basis of each SHRU demonstrating a sustained population growth rate indicative of an increasing population. The mean life span of Atlantic salmon is 5 years; therefore, consistent population growth must be observed for at least two generations (10 years) to show sustained improvement. If the geometric mean population growth rate of the most recent 10-year period is greater than 1.0, this provides assurance that recent population increases are not random population fluctuations but more likely are a reflection of true positive population growth. The geometric mean population growth rate is calculated as:

$$GM\_{\overbar{R}}=\sqrt[10]{R\_{t}∙R\_{t-1}∙R\_{t-2}∙…R\_{t-9}}$$

where $GM\_{\overbar{R}}$ is the geometric mean population growth rate of the most recent 10-year period and $R\_{t}$ is the 5-year replacement rate in year *t*. The 5-year replacement rate in year *t* is calculated as:

$$R\_{t}={N\_{t}}/{N\_{t-5}}$$

where *Nt* is the number of adult spawners in year *t* and *Nt*-5 is the number of adult spawners 5 years prior. Naturally reared adult spawners can count in this calculation of population growth rate in assessing progress toward achieving reclassification objectives, while only wild adult spawners can be used in assessing progress toward achieving delisting objectives. As described in the 2009 Critical Habitat rule, a recovered GOM DPS must represent the natural population where the adult returns must originate from natural reproduction that has occurred in the wild.

If and when the GOM DPS is considered to be no longer at risk of extinction and eligible for reclassification to threatened status, a hatchery management plan will be needed to detail how hatchery supplementation should be phased out to reach recovered status; this plan should include population benchmarks that trigger decreasing hatchery input. The benchmarks should be based upon improved PVA models that incorporate contemporary demographic rates and simulate various stocking scenarios to assess the probability of achieving long-term demographic viability.