Parks Canada - Ecosystem Science Review Reports

Northwest River Atlantic Salmon:

A Discussion of Management Options available to Terra Nova National Park

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ABSTRACT

Anadromous Atlantic salmon (*salmo salar*) returns well below the (Canadian Department of Fisheries and Oceans) calculated conservation requirements have spurred a call for active management programs to recover the Northwest River population. An examination of the available data for Northwest River suggests that: (1) the conservation requirement may be set too high given the river's history; (2) genetic diversity is probably not threatened at current population levels; and (3) The application of the 1 and 5-year rules (Hutchings 1994) to historical data indicate that the current decline may be a result of normal fluctuations. However, it is recommended that precautionary measures be taken because when commercial exploitation is included in the analysis of the 1 and 5-year rules of thumb the observed declines are unusual.

Of the management measures available to restore the Northwest River salmon population, those that foster community involvement, allow for increased enforcement and a better knowledge of the ecology of the system should be pursued. While stocking may appear to be an attractive option, it requires careful implementation so as not to threaten the viability of the population it was designed to save. Further, increased levels of anadromous fish in the upper watershed may negatively impact existing biodiversity (i.e. potentially distinct nonanadromous populations). As a result it is advised that this option only be used as a last resort. In the meantime it is important that baseline information regarding the ecology of Atlantic salmon continue to be gathered for the Northwest River population so that future management actions (including restoration through stocking if warranted) can be more effective.

INTRODUCTION

Throughout its range, Atlantic salmon (*Salmo salar*) are a commercially, recreationally, and culturally valued species. The Northwest River Atlantic salmon have been commercially harvested in salt water and fished recreationally upon their return to natal spawning grounds. In 1992, a commercial moratorium was established around insular Newfoundland in an effort to counter widespread declines in adult returns. This may have proved an effective strategy in the short-term, as adult returns increased island-wide after 1992 (Chaput and Prevost 1998). Available creel census data suggests this moderate growth appears to have been short lived in Northwest River as its population soon began to decline. In 1995, in response to the continual declines determined by creel census, Terra Nova National Park (TNNP) and Department of Fisheries and Oceans (DFO) installed a counting fence as a means to acquire more accurate data on returning adults for monitoring this population. Adult returns below the DFO management requirement, in 1995, necessitated the closure of the river to recreational fishing. This action has yet to stabilize the recent downward trend (Figure 1). This document will examine these trends in light of the river's history, assess if active management is needed to restore the native population of Atlantic salmon, and if so, discuss the options available. These options will be in keeping with the guiding principles of Parks Canada mandate.

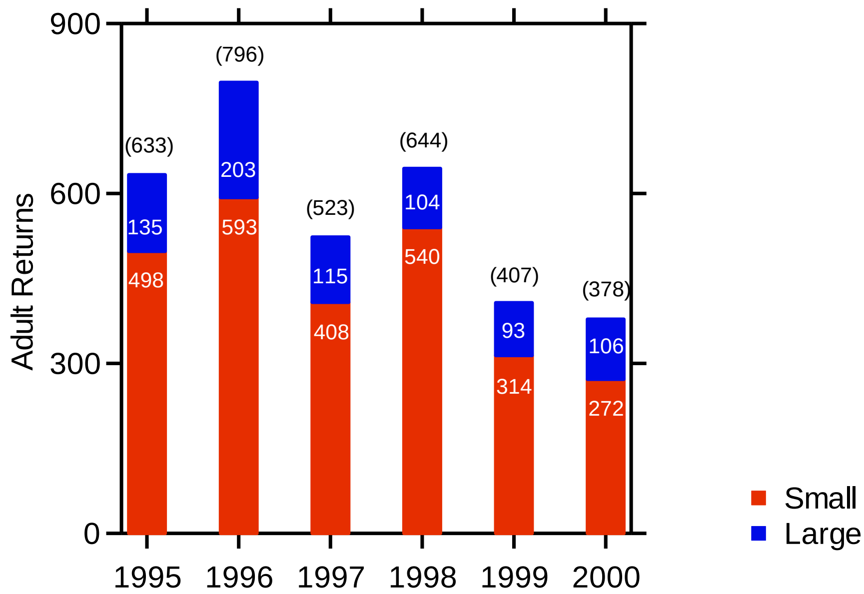

Figure 1: Atlantic salmon returns for Northwest River (1995-2000) for small and large salmon. Total counts are displayed in parentheses.

ECOSYSTEM-BASED MANAGEMENT

National Parks have been "dedicated to people of Canada for their benefit, education, and enjoyment" and are to be protected thus "leaving them unimpaired for the enjoyment of future generations." The guiding principle of Parks Canada's mandate is to manage an area for the maintenance of ecological integrity (EI), based on principles of ecosystem-based management (Parks Canada 1996). This type of management requires that National Park ecosystems be '… managed with minimal interference to natural processes. However, manipulation may be allowed when the structure or function of an ecosystem has been seriously altered and manipulation is the only alternative available to restore ecological integrity' (Parks Canada 1994). Within the context of managing for ecological integrity, it is important for Parks Canada to develop and maintain an integrated database which contains among other things, the information necessary to provide the baseline information on the extent of human-induced changes in the park's ecosystem. Parks Canada (1994) also specifies its policy regarding stocking initiatives as follows: "*Fish stocking will be discontinued except where necessary to restore indigenous fish populations that have been adversely affected by habitat modification*."

In addition to Parks Canada mandates, TNNP is guided by the Canadian Biodiversity Strategy (1995). This strategy, developed by the Government of Canada, provides a framework that promotes the conservation of biodiversity and sustainable use of biological resources. It directs managers to reduce to acceptable levels or eliminate adverse impacts on aquatic diversity from fisheries enhancement programs.

Given these directions, active management on Northwest River should only be pursued as a last resort to restore the native population to a sustainable level and should be carried out in a manner that will preserve the ecological integrity of the watershed.

STATE OF PRESENT KNOWLEDGE

NORTHWEST RIVER WATERSHED

The Northwest River (Figure 2) has an axial length of 60 km and drains an area of 689 km^2. It runs from its headwaters in the Bay du Nord Wilderness Reserve to its outflow in Clode Sound, Bonavista Bay. The upper watershed runs through relatively pristine areas (Forest Districts 2 and 4) until its junction at Northwest Pond. The land-base adjacent to Northwest Pond is partially altered from cabin development, historical sawmilling, and more recent logging operations. The final section running from Northwest Pond to its outflow into Clode Sound is further developed as it contains 7 bridges and splits Terra Nova Golf Course (Jacques Whitford Environment 1995). Approximately 1.9 km of this section rests within the boundaries of Terra Nova National Park. Northwest Falls (Figure 2), located 3.2 km above the river mouth, was the only complete barrier to fish passage. This natural barrier isolated the resident salmon populations in the upper watershed from the sea-run population. In 1948 a fish passage circumventing this barrier was blasted to provide access to upstream spawning habitats for anadromous salmon. Improvements to the fishway were carried out in 1956 and have proven to be effective in allowing fish passage (Porter et al. 1974).

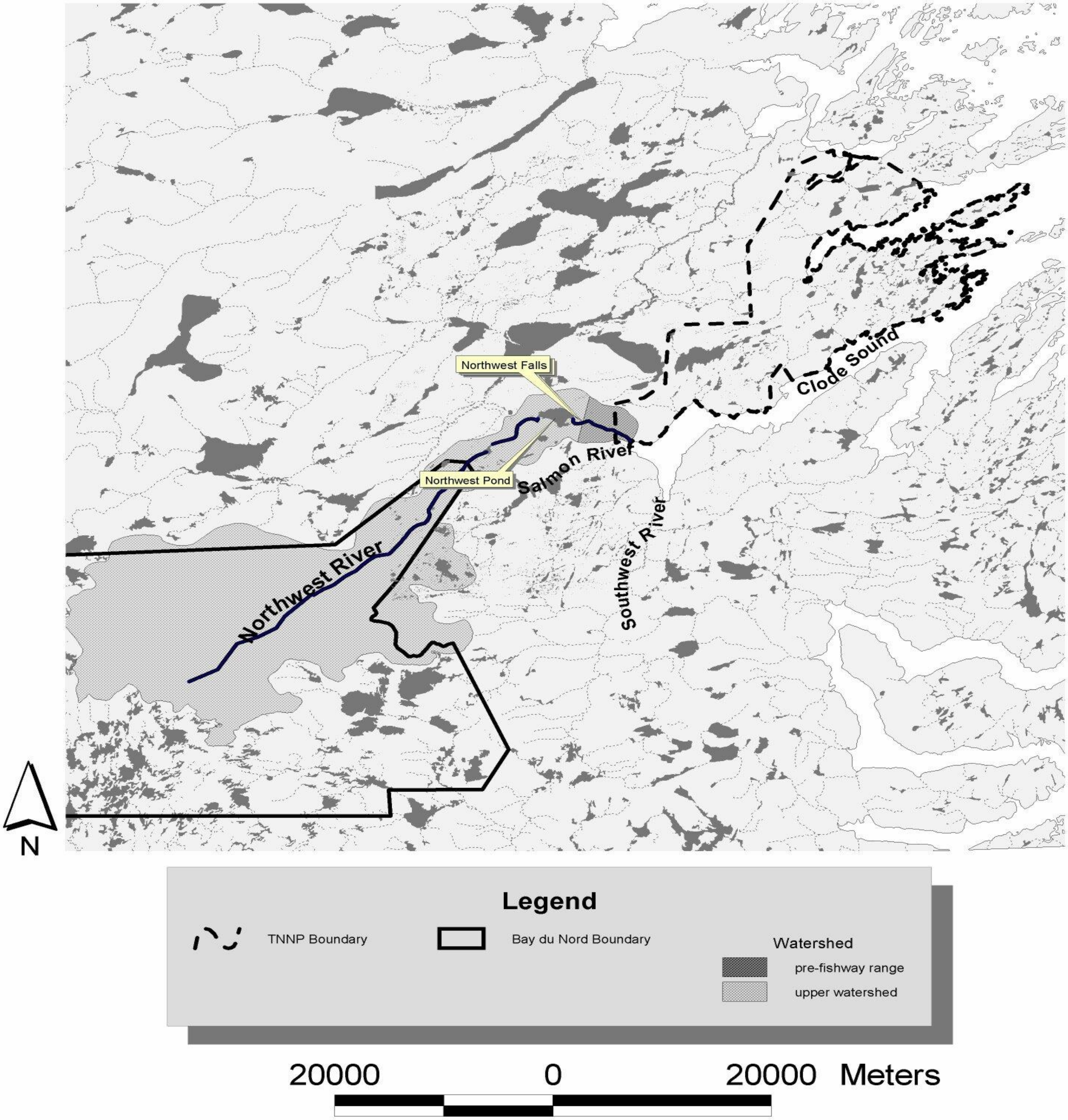

Figure 2: The pre-fishway accessible habitat to anadromous Atlantic salmon in Northwest River.

CONSERVATION REQUIREMENTS

The Department of Fisheries and Oceans (DFO) has established adult return targets for Atlantic salmon for each river as a conservation measure. These conservation requirements do not represent a carrying capacity (maximum sustainable population) for a river but represent the number of adults required to maintain levels (O'Connell et al. 1991; O'Connell and Dempson 1995) of smolt production that is characteristic of Newfoundland rivers, given available habitat.

The calculations for this index are shown in Appendix 1. For Northwest River, the conservation target was calculated to be 1,726 small salmon, based on 8,489 units of lacustrine and 3,944 units of fluvial rearing habitat. According to DFO policy, rivers are closed to recreational fishing when populations decline below 50% of the conservation requirement and are considered for active management (i.e. stocking) when they drop below 30% (R. Porter pers. comm.; DFO). Adult returns in Northwest River have never exceeded the 50% threshold since the fence was installed and have surpassed the 30% threshold in only 2 of 6 years.

Conservation requirements are useful in managing Newfoundland rivers given that management resources are finite. However, application of this technique to Northwest River has several limitations. First, the use of fixed parameters for egg-deposition rates, egg-to-smolt survival, and smolt production must be qualified in that there will be inter annual and inter river variation in these estimates (O'Connell et al. 1991). Hutchings (1994) expressed reluctance to use these fixed parameters because they were not accompanied with associated error values. Second, the value used for lacustrine smolt production (7 smolt/ha.) is based on rivers without nonanadromous salmon. Hutchings (1985) determined a smolt production value of 3.25 smolt/ha on Wings Pond, TNNP where nonanadromous salmon coexist with anadromous salmon. Although the current value may be appropriate for total smolt production (anadromous + nonanadromous), anadromous salmon production may be substantially less (J. Hutchings, pers. comm.; Dalhousie University). Third, the available habitat defined for Northwest River includes the entire upper watershed comprised of an axial length of 56.8 km that has only recently been made accessible (Porter et al. 1974). The pre-fishway population was confined to the 3.2 km of river below Northwest Falls (Figure 2). Although a large percentage of the salmon run ascended the fishway in 1995 (Jacques Whitford Environment 1998) it is uncertain to what extent the upper watershed is utilized for spawning/rearing. Studies on local adaptation have identified that populations with extensive migrations have morphological (Taylor and McPhail 1985a; Riddell and Leggett 1981) and physiological (Taylor and McPhail 1985b) differences from those that spawn in slow moving rivers or close to the sea. Colonization of the upper reaches of Northwest River may be delayed if the resident population's genetics do not predispose them to migrate such distances. Nonetheless, anadromous salmon have been tracked using radio telemetry as far as 38 km from the river mouth (C. Deary pers. comm; University of Waterloo).

Habitat surveys of the portion of Northwest River below the fishway indicate 683 units of moderate spawning/rearing habitat (Jacques Whitford Environment 1995). Using the DFO methodology (see Appendix 1) a pre-fishway conservation target of 70 fish was calculated.

EGG-TO-SMOLT SURVIVAL

In 2000, smolt abundance was estimated with the Petersen mark/recapture technique (outlined in Davis 1963). The results are contingent on the assumption that the fences were put in early enough to the capture the smolt run (spring floods on Northwest River make early fence installation difficult). While it is possible that some smolt may have been missed during the early part of the run, only low levels were measured in the first days of the fence operation.

The smolt run for Northwest River was projected to be 12,115 fish with the lower and upper 95% confidence intervals lying at 4,751 and 19,479 respectively. The majority of smolt (54.6%) in Northwest River leave after 4 years (Linehan and O'Connell 1995), therefore, most of the 2000 smolt class would have been spawned in 1995 and 97.8% would be from the 1994-1996 year classes. To determine egg-to-smolt survival, 1994-1996 adult contributions to the 2000 year-class of smolt were weighted according to the year class proportions listed in Linehan and O'Connell (1995). For example, in 1995 the total run was 633 fish. To obtain that year's contribution to the 2000 smolt run, this figure was multiplied by the proportion of 4+ smolt (0.546) and added to the contributions from 1994 (3+) and 1996 (5+).

By this procedure the number of adult returns contributing to the 2000 smolt run was estimated to be 690. Using previously determined values for mean weight/adult, proportion of females, and eggs per kilogram (from Linehan and O'Connell 1995), an egg deposition value was estimated which in turn allowed an egg-to-smolt survival estimate for Northwest River. Survival values for the 2000 smolt were estimated at 0.74% with 95% confidence intervals being at 0.29% and 1.19%.

These values are lower than the egg-to-smolt survival estimate used for fluvial habitat in Newfoundland rivers (1.25%; O'Connell et al. 1991) and considerably lower than those estimated for lacustrine habitat (1.9%) provided by O'Connell et al. (1991). These values are, however, similar to those found by O'Connell et al. (1992) where egg-to-smolt survival values ranged from 0.28-0.69% in three rivers on the south coast of Newfoundland. As stated by O’Connell et al. (1992) the consequence of an overestimated egg-to-smolt survival would be an underestimate of the target-spawning requirement. For example, if the observed survival values were accurate for the watershed (averaged for lacustrine and fluvial habitats) the existing target spawning requirement would shift from 1,726 small salmon to 4,082. Likewise the pre-fishway target would rise from 70 to 117 small salmon.

HISTORICAL DATA

Unfortunately no data are available that quantify salmon abundance in Northwest River prior to the creation of the fishway in 1948. Creel census was first conducted in 1956 and was conducted every year from 1959 to 1995. In addition, total counts were obtained from 1995-2000 with a counting fence. An examination of these estimates indicates that although much higher adult returns occurred relative to recent years, adult returns have never exceeded the conservation target (Figure 3). However, these estimates do not account for commercial fishing induced mortality. Dempson et al. (1997) estimated a commercial harvest rate of 0.44 for all of Newfoundland and specific exploitation rates of 0.351 and 0.356 for Terra Nova River and Middle Brook. When returns are adjusted to account for a 0.354 harvest rate (mean of Terra Nova and Middle Brook), the population would have exceeded the conservation target of 1,726 fish for 6 of 41 years and was below the 50% threshold in 22 of 41 years (Figure 3). Clearly it may not be justifiable to base any conclusions solely on these data (harvest rates were fixed parameters and creel census data are of questionable reliability); however, it brings two interesting points to the forefront. First, it suggests that the current conservation target may not be realistic for this watershed and second, although the current returns are not unusual relative to historical numbers, it is a concern that they have remained low despite the cessation of commercial and recreational fishing.

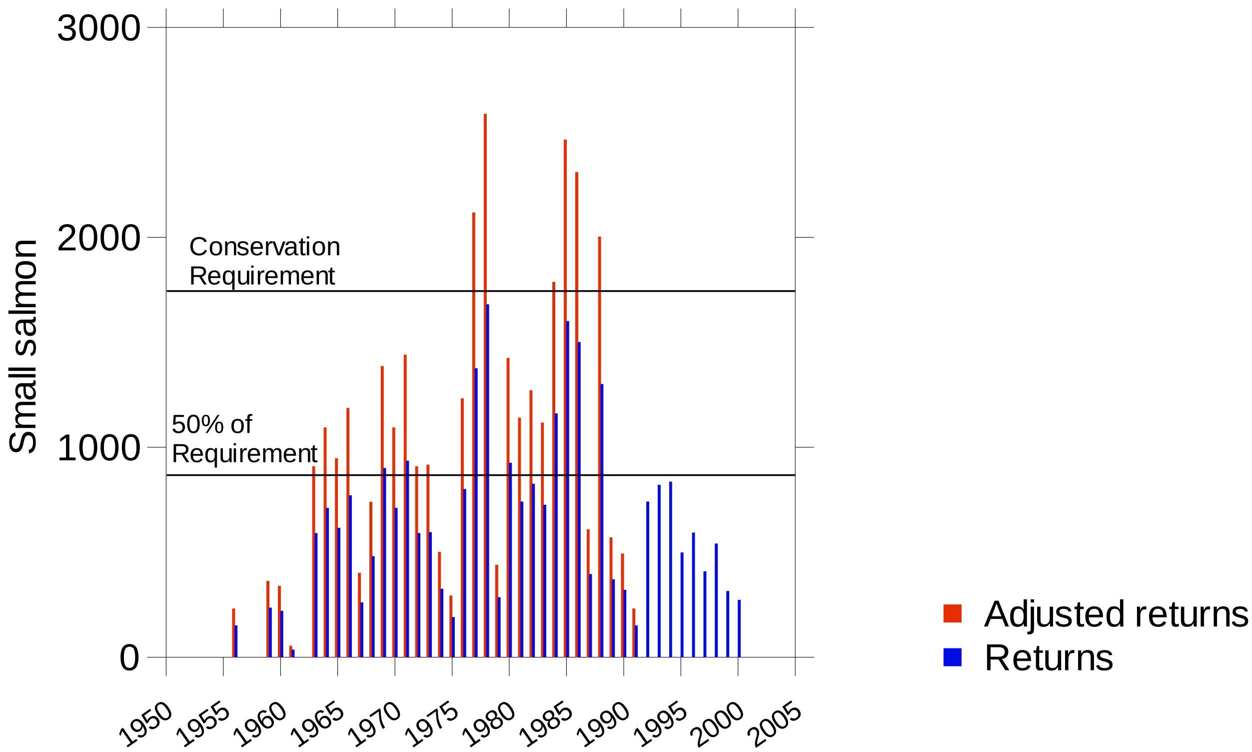

Figure 3: Historical small salmon production, with and without an adjustment for commercial exploitation, on Northwest River. A mean exploitation rate (0.354) from Middle Brook and Terra Nova (Dempson et al. 1997) was used for the adjusted figures. Return estimates from 1956 to 1994 are based on creel census data and a 20% recreational harvest rate assumption. In the years 1995 to present, total counts were obtained from a counting fence.

SOURCES OF DECLINE

The widespread decline of Atlantic salmon over its range hints at broad scale factors such as unfavourable ocean conditions and overfishing (Dempson et al. 1998) and/or habitat degradation (Anderson et al. 2000). Other factors such as interactions with hatchery reared fish (Hutchings 1991), increased predation (Anderson et al 2000) and illegal fishing (Dempson et al. 1998) could also have contributed to salmon declines in eastern North America and elsewhere. Not all the available hypotheses may apply to Northwest River. With little development occurring along the banks of Northwest River (with the exception of Terra Nova Golf Course, some cabin development and some logging around Northwest Pond) and pH being within normal limits (Jacques Whitford Environment 1995; Parks Canada unpubl. data), extensive habitat degradation is not an obvious problem. Genetic deterioration from farmed fish is also improbable since fish farming is constrained to the south coast of Newfoundland. A large-scale factor such as climate change could affect freshwater survival of a population by changing hydrology or elevating temperatures. However, Hawkins (2000) suggested that the smolt production in North American and European rivers has generally been maintained in recent years. Finally, commercial (since 1992) and recreational fishing (since 1996 in Northwest River) have been eliminated or restricted. Of the remaining problems, ocean survival is poorly understood and certainly less easily corrected while illegal fishing is difficult to quantify. However, illegal fishing is one area where improvements could be made. Netting of returning adults occur in both the freshwater and saltwater environments and there are reports of frequent poaching on Northwest River. During the peak salmon run this year (2000), 10-15% of the salmon moving through the trap were recorded as having obvious scarring from encounters with nets (K. Arnold pers. comm.; Parks Canada). Reductions in poaching would result in an immediate increase in escapement and hence future recruitment.

POPULATION VIABILITY

MINIMUM VIABLE POPULATION

Managers who are tasked with preserving the long-term persistence of a population often attempt to identify the Minimum Viable Population (MVP). MVP analysis estimates the probability a population will persist for a given number of years. Unfortunately, "there is no single magic number" for a given population (Soulé 1987). Estimation of MVP requires the determination of three things:

- The impacts of chance events (genetic, environmental, and demographic) on the system;
- Degree of security that is acceptable to society;
- Appropriate time frame for which probability of survival will be estimated.

The impacts of chance events is the only consideration that can be determined scientifically. The latter two, acceptable risk and appropriate time span, will reflect societal values and will vary amongst individuals (Shaffer 1987). Another difficulty with modeling persistence probabilities, particularly in aquatic systems, is acquiring important genetic, demographic and environmental information. Many of these important parameters are not available for the Northwest River. However, even in the absence of specific values it is useful to review the factors that affect the persistence of a population.

EXISTING DANGERS

Populations are threatened with extinction by chance fluctuations in individual survival and fecundity (labeled demographic stochasticity), environmental fluctuations (including natural catastrophes), and genetic problems associated with small population size.

Demographic considerations

Demographic stochasticity occurs as a result of the chance effects related with each individual's survival and fecundity. Small populations are more prone to these chance fluctuations because they do not have the averaging out effect observed in larger populations

(Shaffer 1987; Lande 1993). To illustrate this, consider a situation where an individual's redd has a 50% chance of not drying out from low water levels. Such an example could be related to flipping a coin (as done by Caughley and Gunn 1996); heads representing the drying out of a redd and tails continued immersion. In a population of 4 animals the coin would be flipped 4 times. On average heads should be flipped 50% of the time (since there is an equal chance of obtaining heads or tails on each flip); however, there will be times when there will be a higher or lower proportion as a result of chance. The probability of getting a series of 4 flips with all heads (equivalent to the population going extinct) is (0.5)*(0.5)*(0.5)*(0.5)=0.062 or close to 1/15. Now imagine a series of 100 flips. Again, on average, half of the flips should be heads. However, now the odds of getting a series of flips entirely composed of heads is less than $1x10^{-30}$ (0.5^{100}). Thus, although the variables of chance (in this case the probability of an individual's reproductive success) are the same amongst populations of different sizes, larger populations are less prone to extinction by demographic stochasticity.

Environmental considerations

A second threat is environmental stochasticity. It pertains to the naturally fluctuating environmental conditions that control age specific survival, growth and fecundity. This variable is thought to pose greater risks of extinction than either genetic or demographic stochasticity (Lande 1993; Shaffer 1987) because its effects are felt equally in both small and large populations. An example of this would be unusually high water temperature. Natural catastrophes, really just extreme incidents of environmental stochasticity, have the potential to inflict high levels of mortality regardless of population size. The frequencies at which these phenomena occur play a major role in the long-term sustainability of a population. Expert views on the importance of natural catastrophes vary from extremely important (Shaffer 1987) to uncertain (Lande 1993). Poor ocean survival observed in recent years is likely related to these environmental changes.

Genetic considerations

Levels of genetic variability increase through gene mutation and immigration and decrease from genetic drift and inbreeding. Populations rely on genetic variability to adapt to future environmental conditions. Although the relationship between genetic variability and long-term persistence is not understood (Lande and Barrowclough 1987), population viability increases with genetic heterozygousity in many species (Frankel and Soulé 1981)

Genetic drift is caused by chance fluctuations of genes and should be distinguished from directional shifts in gene frequencies as would be found under natural or artificial selection. Chance fluctuations can eliminate less common (but potentially important) genes. A gene pool with no mutation or immigration would eventually lose all genetic variability as a result of genetic drift. Again, as with demographic stochasticity, the coin flip analogy applies. Smaller populations are more prone to problems associated with genetic drift as chance fluctuations of gene frequencies are greater. Incidents of inbreeding also increase as the population declines and the probability of mating with a close relative increases. Mating amongst individuals with like genotypes reduces heterozygousity, increases exposure to semi-lethal recessive alleles and may ultimately lead to reduced fitness, a further declining population and more inbreeding (Caughley 1994). Such an inbreeding cycle generally has to be held at low levels for several generations (Lande and Barrowclough 1987) for a “substantial” loss of genetic information to occur.

Effective population (N_e) is the population level that would experience similar levels of genetic drift as the actual population (Lande and Barrowclough 1987). However, N_e is reduced by factors such as non-random mating, unequal sex ratios, differences in sex specific fecundity, and variation in number of offspring. Many of these characteristics are likely to occur in the Northwest River salmon population. In the absence of migration, Hutchings (1994) predicted that an Atlantic salmon population comprising of 1500 reproductive females or more would not experience net losses in genetic variability due to genetic drift. Modest amounts of migration can compensate for losses resulting from genetic drift. Basing an analysis on the mean observed straying rates for Atlantic salmon (3%) and assuming a 70% female run, Hutchings (1994) predicted that the number of females necessary to prevent extinction from genetic stochasticity would be approximately 200 females or roughly 300 spawning adults (taking into account observed sex ratios). At the lowest straying rate modeled (1%) approximately 630 spawning adults would be required.

Unfortunately there are no models that integrate all the aforementioned threats to a population's persistence. What is clear, though, is that while a population at high levels of abundance is still vulnerable to natural catastrophes and to a lesser extent environmental stochasticity, a very small population is vulnerable to them all.

POPULATION VIABILITY "RULES OF THUMB" (HUTCHINGS 1994)

In a report prepared for DFO by Hutchings (1994), it was suggested that two simple "rules of thumb" be used for monitoring a population's risk of short-term extinction from environmental and demographic stochasticity. While the 5-year rule examines trends in the mid-range temporal scale (approximately 1 generation for Atlantic salmon), the 1-year rule looks at short-term changes. Although individually they have limited applicability for maintaining a population, together they provide some simple and statistically based methods to assess observed population trends. Both of these "rules of thumb" rely on long-term data regarding a river's adult returns. It is unclear as to whether to apply this analysis on the estimates for escapement or those for production. Using the values for escapement could be justified because it is only those fish that live to spawn that contribute to the next generation and ultimately the long-term persistence of the population. However one might argue that this exercise uses past data to judge vulnerability. Since there has not been a commercial fishery in recent years, it may be wise to estimate the historical salmon returns had there been no commercial fishery (i.e. historical small salmon production from Northwest River). As a result the rules of thumb will be applied with and without the commercial exploitation adjustment. Recreational catches for Northwest River can be used to estimate small salmon returns prior to 1995 using the assumption of a 20% harvest rate (based on derivations for Middle Brook and Terra Nova River). Large salmon were not included in this analysis since there was no recreational catch data for this size-class from 1984-1995 (due to mandatory hook and release policy during this time period).

The 5-year rule

The 5-year rule proposes that there is an equal probability (0.5) of a population increasing or declining from the historical mean from one year to the next. However, the probability of returns being below the historical mean over five consecutive years is $(0.5)^5=0.03$ and therefore (at $\alpha=0.05$) is not likely to occur as a result of chance alone. In actuality the probability of returns being below the historical mean a second year is greater than 0.5 due to auto-correlation and hence this rule of thumb errs on the side of conservation (Hutchings 1994).

In its application to escapement levels on Northwest River, the 5-year rule indicates that there may be no immediate cause of concern as the river was above the long-term mean of 534 returns in 1996 and in 1998. However, when applied to the data adjusted for commercial exploitation, the river has been below the historical mean of 943 adult salmon since 1994. This result suggests that current production has been below average for a longer period than one would expect by chance alone.

The 1-year rule

This rule of thumb relies on historical data to identify short-term declines in abundance that may indicate a reduction in population viability. Three levels of decline were defined in terms of the probability of occurring by chance, very serious, serious, and potentially serious. With these data, yearly differences (of most concern to us being declines) can be examined for their probability of occurring by chance alone (very serious: $p<0.05$ 0-1.96SD; serious: $0.05 \leq p<-0.25$ 0-1.15SD; and potentially serious: $0.25 \leq p<0.50$ 0-0.67SD). A value that falls below the historical average (log transformed for normality) minus the appropriate standard deviation might be cause for concern. In this case, the escapement of 2000 (270, the lowest in recent years) was still above the potentially serious category for a single year abundance given the historical variability. However, production in 2000 was low enough compared to the estimated historical production levels that it fell into the serious classification.

IS THE NORTHWEST RIVER VULNERABLE IN THE SHORT-TERM?

At this time, Northwest River Atlantic salmon returns are well below the DFO calculated conservation requirement, yet they are still at a level which is unlikely to result in the loss of genetic information from genetic stochasticity. In addition, examination of the Northwest River's escapement with the 1 and 5-year rules of thumb have not highlighted the population as particularly vulnerable to extinction in the short term. These conclusions should be qualified however, in light of:

- The 5-year rule indicates recent production to be consistently below historical levels,

- The 1-year rule places 2000 production in the serious classification,
- The reliability of the historical data set that these conclusions are based upon is questionable.

SYNOPSIS

Based on the available data, the salmon population of Northwest River may not be in immediate danger of extinction. Recent declines in spite of the moratorium on commercial and recreational fishing warrant concern and highlight the need to refine available information and fill the gaps of our current knowledge. Furthermore, since only the 1995-2000 data set is reliable, more information is needed to be sure there is significant deviations from historical means, particularly in light of the river's pre-fishway capacity. These proactive measures will ensure that better decisions will be made in the future, particularly in the event that active manipulation is required.

WHAT ACTION CAN BE TAKEN?

There are several options available to reduce the chances of an extinction of salmon in Northwest River.

GATHERING BASELINE INFORMATION

Obtaining baseline data is necessary to make more robust assessments of the population's health. Steps have already been taken in this direction with the implementation of the creel census, 1990-1995, and the establishment of the adult (since 1995) and smolt (2000) counting fences. Further work is required to assess the use of the upper watershed by anadromous spawners, and the levels (and effects) of competition between nonanadromous and anadromous salmon. This information is crucial in determining the appropriateness of the current conservation target. Additionally, in preparation for a stocking scenario, information on the existing levels of genetic variability in wild fish (anadromous and nonanadromous) should be gathered for monitoring purposes in the future.

MANAGE BEYOND NORTHWEST RIVER BASIN

The vulnerability of the Northwest River may result in an increased reliance on other populations (particularly neighbouring rivers such as the Salmon and the Southwest) for long-term persistence. Straying from these rivers can contribute to the genetic variability (Hutchings 1994) needed to adapt to future environmental conditions. Further, in the event of a natural catastrophe, neighbouring rivers will be most likely to recolonize the area. Currently, these rivers are being managed together (all three were closed to recreational fishing based on Northwest River data) and management decisions should continue to consider their impact on one another.

PROTECTION FROM ILLEGAL FISHING

Wild fish should be protected from illegal fishing. Even if 100 were removed by illegal fishing annually it would represent more than 25% of the population at current levels and approximately 235,000 eggs. Understandably, enforcement agencies have limited resources available to them and are unable to stop poaching on all rivers. However, given that the Northwest River is at a level where active manipulation is being considered (i.e. stocking) there is a greater urgency to try to maintain its naturally sustaining population. Some options available to meet this end are:

Increased enforcement: The assignment of a full time DFO River Guardian to the Northwest, Southwest and Salmon rivers may be a measure that will reduce levels of illegal fishing. An additional benefit of this action is that it will not risk the existing genetic integrity of the wild stock. A possible constraint to this solution is that it will require sustained financial and resource commitments (at least until attitudes toward stewardship change) to succeed.

Education: A communication program needs to be employed to encourage a sense of stewardship amongst local residents and other stakeholders. Such a program would emphasize the cultural, economic, recreational and ecological value of a healthy salmon population (i.e. as a symbol of ecosystem health) and outline the damage to the ecosystem and community that is caused by illegal fishing. A constraint of public education programs is that benefits are rarely immediate even though immediate shifts in the attitudes of the community are desirable. However, it is education that will provide the long-term and self-perpetuating changes to community attitudes needed to conserve salmon in the Northwest River, and elsewhere.

Coralling: This strategy would involve blocking the upstream migration of spawners as a means to confine them to an area that is practical to monitor. Just prior to spawning, the fish would be allowed to continue upstream thus limiting their availability to illegal fishers for a shorter period. To work, such a plan would still require security; however, it could be concentrated on a manageable section of river. There are two major flaws with this strategy. First, this approach will only reduce poaching in freshwater whereas the majority is thought to occur in salt water and second, coralling may compromise the timing of migration which could have negative effects on migratory ability and the utilization of the upper watershed by salmon.

Adaptive recreational fishery management: Once agreeable conservation requirements are established, opening a limited recreational fishery may create a sense of stewardship amongst local residents, generate income, and still provide a level of adult returns that is suitable for conservation purposes. Such a strategy would only open the river to angling each year after a particular threshold of escapement is attained and would provide more biological data. The benefit of this approach is that community sanctioned pressure (likely much more effective than regulatory enforcement) would be put on offenders to allow salmon numbers to reach the threshold at which a recreational fishery could be allowed. Managing in such a way may cause a disproportionate amount of mortality on a portion of the run (in this case, those that run late in the year) resulting in artificial selection (Thorpe et al. 1981). However, before this option is pursued, there needs to be discussion amongst management bodies to establish the conditions in which a recreational fishery would be allowed.

EGG INCUBATION

Another strategy that has been used to combat the threat of extinction is stocking a river with juveniles (life-stages stocked vary from eyed eggs to smolt). The benefit of stocking is that it eliminates much of the naturally occurring mortality for those stages raised in the hatchery. Such a technique has been used successfully in Newfoundland to “seed” new habitats (e.g. O’Connell et al. 1983 and Bourgeois 1998) and could also be used to temporarily maintain threatened populations in times of poor environmental conditions. A notable spin-off of these initiatives is that they provide an opportunity for public education and involvement.

Unfortunately there are many accompanying shortcomings to this solution. Although survival is increased in the controlled environment of the hatchery, it is at the cost of an unnatural selection regimen (Waples 1991; Petersson et al. 1996). As a result, hatchery fish are selected on a basis that is different to the environment that they are expected to live and breed in (Cross et al. 1993). Several studies report that fish reared in the hatchery suffer higher mortality after release than wild fish (e.g. Bachman 1984; Jonsson et al. 1991; Reisenbichler and Rubin 1999), are less wary of predators (Berejikian 1995; Johnsson et al. 1996), have more agonistic encounters (Bachman 1984; Swain and Riddell 1990), decreased condition factors (Bachman 1984; Salveit 1998) and are less likely to home (Potter and Russell 1994). The increased genetic contribution from small numbers of broodstock has also been found to cause a reduction in genetic variability (Cross and King 1983; McElligot et al. 1987; Verspoor 1988; Garcia de Leaniz et al. 1989; Moran et al. 1994). This problem can occur after one generation in the hatchery (Verspoor 1988). Thus, although stocking may increase the numbers of fish in a river, it may jeopardize the genetic variability of the entire population (wild+captive) by reducing the effective population size (Ryman et al. 1995). In turn a reduced effective population size (N_e) makes a population more susceptible to genetic drift and inbreeding. Using high numbers of broodstock (e.g. 100 of each sex) can ameliorate the likelihood of genetic drift (Cross et al. 1993); however, the acquisition of gametes comes at a cost to wild egg deposition (Salveit 1998) which is undesirable to populations under threat of extinction.

Another concern is that although the technique of stocking has been in the fishery manager's toolbox for decades (Mills 1989), it has an inconsistent record of success. There are several instances of stocking programs that have failed to boost stock levels or caused them to decline further (Vincent 1987; Garcia de Leaniz et al. 1989; Waples 1991; Hilborn and Winton 1993; Saltveit 1998). When costs are considered, (e.g. Garcia de Leaniz et al. 1989 estimated that the cost of each stocked fish landed was at least $1600), the merit of this type of action may be questionable. Finally, and perhaps the most importantly is, stocking for restoration purposes may be futile unless the sources of the decline are identified and their effects rectified (Cowx 1998).

In the event that adult returns continue to decline in spite of attempts to reduce illegal fishing, it may be necessary to consider stocking in Northwest River. Cowx (1998) has outlined the possible objectives for stocking (Table 1).

Table 1: Objectives for stocking as outlined by Cowx (1998).

Stocking objective	Description/Purpose
Mitigation	• to compensate for stock declines resulting from a dam • continual input because underlying problem has not been removed
Enhancement	• to increase stocks to a level past that which the water body could naturally sustain • permanent in nature
Restoration	• carried out after a limiting factor has been reduced/removed • ultimate goal is a self sustaining population • temporary in nature
Creation of new fisheries	• establishing species to areas that have not previously held that stock • temporary or permanent in nature

It should be reiterated that national parks are to *be 'managed with minimal interference to natural processes. However, active management may be allowed when the structure or function of an ecosystem has been seriously altered and manipulation is the only alternative available to restore ecological integrity.'* With this principle in mind, the only objective of the above list compatible with Parks Canada's direction would be stocking for restoration. Given the risks to the biodiversity of the Northwest River watershed and genetic diversity of the Northwest River salmon population TNNP would only endorse stocking to a minimum viable level after which the population would be required to sustain itself. Restoration initiatives would also have to be conducted in a manner that minimizes the risks of artificial selection, and genetic drift. Further, it is imperative that monitoring be included in such a program so as to assess its success.

Several factors should be considered when initiating a stocking program. Ecological factors (intra and interspecific interactions, genetics, and fish health), socio-economic benefits, along with cultural concerns (intrinsic value of wild salmon vs. cost of having stocked salmon in a river) should be included.

Ecologically there are many issues to consider. Although anadromous salmon currently have access to the upper watershed, losses of local biodiversity could occur if anadromous salmon are stocked at artificially high numbers. Interspecific interactions such as competition and predation may shift vertebrate and invertebrate species' abundance. One concern with stocking in the upper reaches is the potential for increased interbreeding and associated outbreeding depression amongst anadromous and nonanadromous salmon. Vuorinen and Berg (1989) did not detect any hybridization when anadromous salmon fry were stocked in an area with a historically isolated population of nonanadromous salmon. However Hutchings and Myers (1985) showed that anadromous and nonanadromous salmon will interbreed. One way to minimize these problems would be to limit stocking to the pre-fishway range. Unfortunately such a strategy might come at the cost of reduced fry survival due to increased intraspecific competition in these areas. Within-population genetic factors such as increased susceptibility to drift (founder effect), inbreeding depression, and artificial selection must also be recognized. Carefully designed stocking programs, utilizing relatively large numbers of broodstock, have been shown to overcome the losses of genetic variability (from the founder effect) often associated with stocking (Verspoor 1988; Cross et al. 1993). Artificial selection, whether intentional or accidental, can have a negative impact on a fish's fitness in the wild (Ruzzante 1994). Artificial selection occurring in the hatchery can be minimized by reducing the time spent under unnatural conditions.

Most preferable is stocking unfed fry (Kennedy 1988); one of the techniques practiced by DFO in Newfoundland (e.g. O'Connell et al. 1983 and O'Connell and Bourgeois 1987). Incubation of the eggs can occur in a hatchery (as done on the Terra Nova River), in spawning channels (e.g. O'Connell et al. 1983; Bourgeois 1998) or in incubator boxes (e.g. O'Connell et al. 1983; Donaghy and Verspoor 2000). Unfed fry obtain nourishment from their yolk sac and hence are not exposed to unnatural competitive interactions associated with feeding in the hatchery. Unnatural competitive interactions can result in increased aggression and a reluctance to school (Ruzzante 1994). The former may result in an inefficient energy budget in the wild (Bachman 1984) while the latter trait may increase an individuals risk of predation (Ruzzante 1994). Conditions in the hatchery, such as water temperature, water flow and photoperiod, should also reflect those found in the river environment (Cross et al. 1993). Another form of artificial selection occurs when obtaining broodstock. For example, selecting the largest fish of a particular run because they carry the most eggs would generate a bias toward that subset of the population. Even by randomly obtaining fish at a counting fence, a selection is occurring that phases out genetic input from precocious parr. Therefore collection of broodstock should be conducted randomly and account for the natural contributions of various life strategies. In theory, these strategies should greatly reduce the impacts of rearing fish in a hatchery environment. However, to what extent they will be effective in practice is unknown since there has been little evaluation of these techniques.

Suggested Stocking protocol:

Year 1: Test Incubation

The first year of a stocking initiative should be an experimental year. Mortalities due to untested facilities would be catastrophic particularly when broodstock collection comes at a cost to natural reproduction. Therefore only 50 000 eggs (approximately 17 females) would be incubated in the first year. Since it is highly recommended that native broodstock be used where possible (Hindar et al. 1991; Reisenbichler and Rubin 1999), Northwest River broodstock could be obtained by randomly selecting anadromous salmon at the counting fence in Stick Pool. If contributions from precocious parr were thought to be significant in the wild, those gametes would have to be obtained from electro-fishing or perhaps seining. Broodstock could be held in an enclosure in the river; however given the security concerns at Northwest River and its potential for high water, shore-based flow through tanks are recommended. Ideally, eggs would be acquired from female broodstock and fertilized on a 1:1 male:female ratio. Although this ratio may not occur in the wild (due to the skewed sex ratios of the population), effective population size declines as sex ratios become uneven (Ryman 1991). Therefore a 1:1 ratio would maximize the effective population of the offspring. However, since males comprise only 25% of the run in the wild, the removal of 17 males might be costly to the wild population. The inclusion of precocious parr in the broodstock may be an option to reduce the demand on the anadromous males while still maximizing the effective population size.

After stripping, broodstock will be released into the river. Floy tags, attached to the spent adults, will enable monitoring of subsequent mortalities. Fertilized eggs will be incubated in a portable hatchery facility on-site and supplied with Northwest River water. An iodine drip will be added to the water supply for a short time to mark otoliths for future monitoring studies (see below). Although natural water temperatures are desirable, a free flow hatchery system with Northwest River water could be costly. This is because gravity fed flow would be required to prevent freezing of the hatchery water. The alternative is to heat the hatchery facility and maintain the water temperature as close to the river's as possible. As mentioned above, fry will not be fed in the hatchery. Therefore fry will be released a few days prior to their yolk sac being completely consumed. This buffer period will allow the fry to adjust to their new surroundings before active foraging is necessary for survival. Suitable release sites will have to be determined and will be evaluated by characteristics such as substrate, cover, water velocity and depth, and abundance of predators. Concerns of deleterious effects on the nonanadromous populations may require that fry only be stocked below the fishway. Prior to release, water temperatures in the hatchery will be adjusted to match the pre-determined release sites enabling the fry to acclimate. Release of fry will occur at densities that maximize survival (40/unit) as determined by Elson (1975).

Year 2-5: Full restoration

After a successful "test run", the restoration initiative could be expanded to appropriate levels of incubation that would not compromise the effective population size. Ryman (1991) modeled some stocking scenarios and showed that the effective population size can be optimized with careful consideration of the wild population's N_e and the hatchery contribution to the population. For example, if the wild population had an N_e of 200 and was being supported by a broodstock with an N_e of 50, effective population size of the total population would increase if the contribution of the hatchery stock was below 0.2 of that of the wild stock. Hatchery contributions beyond 0.4 would result in declines in the population's N_e. For such an assessment however, N_e would have to be determined for the Northwest River salmon population.

Stocking at this scale should be limited to the time span of one generation. This will reduce the chances of (1) hatchery reared fish being used as broodstock in subsequent hatchery operations (to reduce directional shifts in genetics due to artificial selection) and (2) local dependence on a stocking program for the maintenance of the Northwest River population.

Although stocking may provide a boost to a faltering population, it should be reiterated that it is not the solution to a self-sustaining population. Meffe (1992) indicated that stocking treats the symptom of a declining population (fewer fish) but does nothing to rectify the cause of the decline. Therefore, in the case of Northwest River, stocking can only be justified by using it as a means to provide more time to determine and fix the cause of declines of its salmon population.

Monitoring

Monitoring is a critical component to any restoration initiative. It is important to determine if the restoration project is producing the desired results, so that it can be modified adaptively or terminated. In a scenario that doesn't include a stocking initiative, the primary focus should be to monitor population levels. Given the difficulties of monitoring true levels of illegal fishing, it will be not be possible to distinguish if increases observed at the counting fence are truly the result of a new management plan or a more favourable environment. It will provide information, in the event that counts are lower, that the current measures are not sufficient. If a restricted recreational fishery is allowed, a creel census should be employed to take advantage of the opportunity to acquire life history data and genetic samples. In a scenario where restoration objectives have to be reached through stocking, a more comprehensive monitoring program will need to be initiated. The result of a lack of monitoring in many stocking initiatives has brought about accusations of these programs being nothing more than public relation exercises (Cross et al. 1993) used to reassure user groups that action has been taken on their behalf (Welcomme 1998). A monitoring program is necessary for such programs due to the hazards that the wild stock could be exposed to from stocking. A stocking scenario monitoring program would answer the following questions:

- Are salmon returns at a naturally sustainable level?
- What is the contribution from hatchery reared fish?
- Is the genetic integrity of the stock being maintained?
- Is the biodiversity of the upper watershed threatened?

Once again adult salmon returns would be monitored with the Park counting fence. Contributions of hatchery fish could be assessed if individuals were marked. Unfed fry, the recommended life stage to stock (Kennedy 1988), are too small and too many to mark with fin clips etc. Genetic markers, which rely on breeding individuals that are homozygous for a rare allele, may also be limited in this application. Used in situations where rivers are stocked with broodstock from another population, this method can monitor the contribution of the hatchery by examining an individual's genotype for that rare allele. Obtaining sufficient broodstock with such a rare genotype from the native population would be difficult (often the broodstock is from a different population where that allele is not so rare, e.g. Garcia de Leaniz et al. 1989). Further, selecting broodstock with these characteristics would result in artificial selection.

One alternative would be to mark hatchery fish with an iodine marker in the hatchery. The fry would take up the iodine from the water supply in the hatchery. Upon return as adults, the fish would be identifiable by their iodine-marked otoliths. Sampling of otoliths would require sacrificing adults and therefore would probably depend on a recreational fishery. Another feasible alternative would be to genetically type all broodstock. Scale or adipose fin samples of returning adults would enable paternity analysis and allow an estimate of hatchery contributions (E. Verspoor pers. comm.; FRS Marine Laboratory).

Reductions in heterozygousity, and changes in gene frequencies (from genetic drift), can be tracked in wild populations. The shift of wild gene frequencies toward those found in hatchery fish could indicate the degree of contribution of hatchery reared fish (E. Verspoor pers. comm.; FRS Marine Laboratory). It should be noted that nonanadromous salmon will have to be distinguishable from anadromous ones for such a study to be feasible. Of course effects of stocking have to be compared to pre-stocking times and therefore baseline information (e.g. genetic profiles of the anadromous and nonanadromous populations) would have to be gathered before a stocking program is initiated.

Recommended Course of Action for Northwest River

Given the present circumstances, it is recommended that conservative action be taken. Measures that instill a sense of local stewardship, control illegal fishing and increase knowledge of the ecology of Northwest River should be pursued diligently and immediately using the combined resources of all partners (e.g. TNNP, DFO, Clode Sound Angler's Association, Salmon

Association of Eastern Newfoundland, Atlantic Salmon Federation, and others). Such activities do not risk the integrity of the existing wild stock and at the very least will improve our knowledge of the factors influencing the apparent declines in Northwest River. Stocking for the purposes of restoration should not be ruled out in the future; however, at this point the threats that stocking impose upon the anadromous population (e.g. loss of genetic variability) and ecosystem (e.g. nonanadromous genetic integrity) may not be justifiable when considering its expense and chances of success. In the meantime an opportunity has been presented to build a knowledge base that will enable us to minimize such risks in the event that stocking is necessary for the preservation of the Northwest River Atlantic salmon.

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APPENDIX 1: CONSERVATION REQUIREMENT CALCULATIONS

POST-FISHWAY TARGET

Lacustrine habitat

Total area	8 489 units (1 unit = 1ha)
Smolt production parameter	x 7/unit
Target production	59 423 smolts
Smolt production paramter	7/unit
Egg deposition rate	368/unit
Egg-to-smolt survival rate	1.9%
Egg deposition requirement to meet target smolt production	3 123 952 eggs

Fluvial habitat

Total area	3 944 units (1 unit = 0.01ha)
Smolt production parameter	x 3/unit
Target production	11 832 smolts
Smolt production parameter	3/unit
Egg deposition rate	240/unit
Egg-to-smolt survival	1.25%
Egg deposition requirement to meet target smolt production	946 560

Total deposition requirement 4 070 512 eggs

Conservation Requirement

$$\frac{\text{Tot. egg dep. Req.}}{\text{Mean wt (kg) x \%fem. x fecundity (eggs/kg)}}$$

$$= \frac{4\ 070\ 512}{(1.78)(0.75)(1\ 767)}$$

=**1726 small salmon**

PRE-FISHWAY TARGET

Fluvial habitat

Total area	683 units (1 unit = 0.01ha)
Smolt production parameter	x 3/unit
Target production	2 049 smolts
Smolt production parameter	3/unit
Egg deposition rate	240/unit
Egg-to-smolt survival	1.25%
Egg deposition requirement to meet target smolt production	163 920

Total deposition requirement 163 920 eggs

Conservation Requirement

$$\frac{\text{Tot. egg dep. Req.}}{\text{Mean wt (kg) x \%fem. x fecundity (eggs/kg)}}$$

$$= \frac{163\ 920}{(1.78)(0.75)(1\ 767)}$$

=**70 small salmon**

- Note: if levels of **3.25** smolt/unit for lacustrine habitat are used, as found for Wing's Pond, Terra Nova National Park (Hutchings 1985), the conservation target for the entire Northwest River watershed would be **970** fish.

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