Opinion of Dr. Jeffrey A. Hutchings

Killam Professor of Biology (2012-2017)
Canada Research Chair in Marine Conservation and Biodiversity (2001-2011)
Department of Biology, Dalhousie University
Halifax, Nova Scotia B3H 4R2 Canada

Qualifications

After receiving my doctorate in Evolutionary Ecology from Memorial University of Newfoundland (Canada) in 1991, I undertook postdoctoral research at the University of Edinburgh (Scotland) and at the Department of Fisheries and Oceans, St. John's, Newfoundland. As Killam Professor of Biology at Dalhousie University in Canada and as Adjunct Professor at the University of Oslo in Norway, my research focuses on life history evolution, population ecology, genetics, and conservation biology of fishes. I have published more than 150 research papers in the peer-reviewed, primary scientific literature. Since 1999, I have served on the editorial boards of 6 national and international peer-reviewed scientific journals. From 2006-2010, I chaired Canada's national science advisory body responsible, by federal statute, for assessing the risk of extinction of Canadian species and population (www.cosewic.gc.ca). I am President of the 900-member Canadian Society for Ecology and Evolution (2012-2013). And, since 2009, I have chaired a Royal Society of Canada expert panel studying the effects of climate change, fisheries, and aquaculture on Canadian marine biodiversity, including Atlantic salmon.

Among others, I have had the following experience on scientific issues pertaining to the conservation biology of Atlantic salmon, a species that I started researching thirty years ago, in Newfoundland, in 1982. I was an invited speaker at the inaugural *International Conference on Interactions Between Wild and Cultured Atlantic Salmon* held in Loen, Norway, in April, 1990. Since 1995, I have been regularly invited by the Canadian Department of Fisheries & Oceans (DFO) to serve as a reviewer of stock assessments for Atlantic salmon in the Maritimes and Newfoundland. In 1996, I was a Canadian member of the Canada/U.S. Genetics Subgroup of the *Scientific Working Group on Salmonid Introductions and Transfers*, NASCO (North Atlantic Salmon Conservation Organization). In 1998, I served as a member of two DFO-sponsored, international review panels responsible for assessing the consequences of interactions between wild and cultured Atlantic salmon and striped bass in Atlantic Canada. In 1998 and 2000, I served on 2 separate review panels responsible for evaluating the reasons for the decline of Atlantic salmon returning to North American rivers in the 1990s. Throughout the 2000s, I served on the arms-length-from-government committee (www.cosewic.gc.ca) responsible for assessing the risk of extinction of hundreds of at-risk Canadian species, including Canada's 16 Designatable Units of Atlantic salmon (these are directly analogous to the Distinct Population Segments identified under the U.S. *Endangered Species Act*). Since 2009, I am have co-chaired an international working group at UC Santa Barbara's National Center for Ecological Analysis and

Synthesis on ‘red flags’ of species endangerment (www.nceas.ucsb.edu/projects/12559).

I am being compensated by the Plaintiffs at the rate of US$200 per hour. I have not testified as an expert in any legal matter within the past four years.

1 Introduction

The Gulf of Maine Distinct Population Segment (hereafter, GOM DPS) of Atlantic salmon comprises all sea-run Atlantic salmon whose freshwater range occurs in the watersheds of the Androscoggin River northward along coastal Maine to the Dennys River (including these fish wherever they occur in the estuarine and marine environments, and excluding sections of rivers above impassable falls in some rivers within the DPS) (Fay et al. 2006). The decision by the Biological Review Team to include the Androscoggin and Kennebec Rivers in the DPS (their consideration for inclusion in the DPS in a 2000 final-rule listing decision had been deferred) was based on genetic, life-history, and zoogeographic information (Fay et al. 2006). The GOM DPS is recognized as comprising three Salmon Habitat Recovery Units, or SHRUs. ‘Recovery units’ are deemed necessary to both the survival and recovery of the DPS, according to the National Marine Fisheries Service Interim Recovery Plan Guidance documents. One of these SHRU’s — the Merrymeeting Bay SHRU — comprises salmon in the Androscoggin and Kennebec Rivers.

I have rendered several opinions in this document, which can be summarized as follows. It is my opinion that:

- Restoration of Atlantic salmon populations in both the Androscoggin and Kennebec Rivers of the Merrymeeting Bay SHRU is fundamentally important to the recovery of the GOM DPS of Atlantic salmon;
- Hatchery fish are necessary — but far from sufficient — for the recovery of the Atlantic salmon populations of the Androscoggin and Kennebec Rivers, Merrymeeting Bay SHRU, and, thus, the recovery of the GOM DPS;
- Partitioning of the GOM DPS into three SHRU’s is scientifically reasonable and representative of a responsible management strategy consistent with a precautionary approach to the conservation of biodiversity;
- An Atlantic salmon population that experienced the current levels of smolt-adult survival experienced by hatchery-origin smolts that pass by dams during their downstream migration in the GOM DPS would not increase in abundance and would never recover;
- The mortality experienced by downstream migrating smolts and kelts and by upstream migrating returning adults attributable to dam facilities in the Merrymeeting Bay SHRU will have an adverse impact on the survival and the prospects for recovery of the SHRU and, thus, of the GOM DPS as a whole;
- Given the exceedingly low numbers of returning adults to the SHRU, most notably of fish of wild origin, the loss of a single smolt, or of a single adult, to human-induced causes is significant.

2 Gulf of Maine Distinct Population Segment of Atlantic Salmon

2.1 Importance of the Androscoggin and Kennebec Rivers to the recovery and persistence of the DPS

For recovery purposes, the GOM DPS is partitioned into three Salmon Habitat Recovery Units, or SHRU's. In my opinion, the restoration of Atlantic salmon populations in the Androscoggin and Kennebec Rivers, which comprise the Merrymeeting Bay SHRU, are fundamentally important to the recovery of the Gulf of Maine DPS of Atlantic salmon.

The Androscoggin (266 km long) and Kennebec (373 km) Rivers are among the largest in the GOM DPS. The lengths of these rivers dwarf the lengths of the Downeast Maine rivers (16-107 km long) that are part of the GOM DPS. As a consequence, they are vital to the recovery and persistence of the DPS. It is well-established that large, complex river systems – such as the Androscoggin and Kennebec Rivers – are capable of supporting large salmon populations (Aas et al. 2011). It is also well established that, all else being equal, large populations are less vulnerable than small populations to extinction (*e.g.,* Shaffer 1981; Caughley 1994; Allendorf and Luikart 2007). The greater the number of individuals in a population, the less likely it is that the population will decrease (and the greater the chance that the population will persist) because of: (i) unpredictable environmental changes that similarly affect all individuals (termed 'environmental stochasticity'); (ii) unpredictable environmental changes that affect some but not all individuals (termed 'demographic stochasticity'); and (iii) unpredictable changes in genes and/or gene frequencies, which can lead to inbreeding and the fixation of harmful genes (termed 'genetic stochasticity') (Lande 1988, 1993).

Large populations are also less likely to experience a situation manifested by what is termed an 'Allee effect', which can lead to population decline. It is normally assumed that as populations decrease in abundance, their *rate of population growth* steadily increases (Gotelli 2010). Population growth rate is assumed to increase because as a population declines, conditions favorable to survival, growth, and reproduction should improve; lower population abundance is assumed to translate into reduced competition, meaning that each individual has better access to necessary resources, such as food, at low population abundance than at high population abundance. An Allee effect exists when population growth rate begins to decline, rather than increase, at a certain 'threshold' level of abundance (Courchamp et al. 2008). All else being equal, large populations are less likely than small populations to decline to this threshold level of abundance, at which the Allee effect is expressed.

Large populations are also of fundamental importance to the recovery of the GOM DPS because of the contributions that large populations make to the persistence of small populations, such as those that exist in the northern coastal part of the DPS. This is because of the 'straying' characteristic of salmon populations. (Based on historical documents, such as those written by Atkins and Foster (1867, 1868), it is highly probable that the Androscoggin, Kennebec, and Penobscot Rivers each once supported adult salmon populations comprising at least 100,000 spawning adults.)

That is, when adults return from the ocean to their natal rivers to spawn, errors in migration can occur, and some adults (albeit a small percentage, estimated to be 1% for the GOM DPS; Baum 1997) end up spawning in rivers in which they were not born. This straying can be extremely important to the persistence of small salmon populations (that are at greater risk of decline because of the three forms of stochasticity, or unpredictability, identified above) because of the additional spawners that large populations, produced by large rivers, can provide (Fraser et al. 2007). Put another way, the large salmon populations that can be produced by large rivers, such as the Androscoggin, Kennebec, and Penobscot Rivers of the GOM DPS, can provide a ‘rescue effect’ to small populations, thus increasing the chance that population groups, such as the GOM DPS, will persist through time.

In addition to their potential for producing large populations of salmon, the inclusion of the Androscoggin and Kennebec Rivers in the GOM DPS provides far greater potential for the ability of the DPS to adapt to future environmental change. This is because of the *increased diversity* that recovered salmon populations in the Merrymeeting Bay SHRU would provide to the DPS as a whole.

Diversity is directly related to persistence. The more variable systems are, the more likely they will persist over time. Stock market portfolios typically reflect breadth to reduce the overall risk to one’s investment capital. Farmers typically grow a variety of crops to reduce the chance of failure of any one particular crop. From a biological perspective, high genetic diversity increases the likelihood of having or producing individuals with genes that will allow adaptation to environmental change, including alterations to habitat or biological community brought about by natural variation and human actions.

The greater the genetic variation and the phenotypic differentiation (*i.e.,* variation in observable characteristics such as body size, behavior, and growth) within and among salmon populations, the greater the likelihood that some salmon populations within the DPS will be better able to respond favorably to environmental change than others. Extremely strong evidence of the vital importance of population differentiation and diversity to the persistence of salmon meta-populations, or DPS’s, has recently been provided in a study of sockeye salmon in the Gulf of Alaska (Schindler et al. 2010).

2.2 Importance of hatchery fish to the recovery of the Merrymeeting Bay SHRU

It is my opinion that hatchery fish are necessary — but far from sufficient — for the recovery of the Merrymeeting Bay SHRU of Atlantic salmon and, thus, the recovery of the GOM DPS. Hatchery fish are likely to be of greatest importance to recovery efforts during the initial years of the recovery program, when population numbers are very low, as they are now. At present, as Table 1 below indicates, fewer than 10 adult fish of wild origin have been returning to the SHRU annually in each of the past five years for which data are available (2006-2010). This is an exceedingly low number of returning adults and places the SHRU at heightened risk of extinction because of the SHRU's increased susceptibility to stochastic, unpredictable events — anything from droughts to disease to chemical spills — that increase the chance of extinction. *Any measure that increases the chances of survival to the returning-adult stage will reduce the SHRU's probability of extinction.*

Even though hatchery-origin fish have lower survival rates than wild-origin fish in the GOM DPS (Table 2), they are capable of increasing the number of spawning adults in the short term, providing a potentially important 'kick start' to the recovery process (Waples et al. 2007; Berejikian et al. 2008). The period of time that constitutes the 'short term' depends on many factors and cannot be articulated precisely for any given situation. Nonetheless, it has been noted that fitness losses in salmonids can potentially arise after only 1 or 2 generations of captive-breeding/rearing (Fraser 2008; Christie et al. 2011). And there is considerable evidence, both theoretical and empirical in nature, to suggest that the magnitude of fitness loss increases as the duration of hatchery populations in captivity increases. As concluded by Fraser (2008) in his exhaustive review of the ability of hatchery and captive breeding programs to conserve salmonid biodiversity, "No matter how good the intentions, it would appear that as yet, humans have not generated a group of captive-bred/reared fish that on average will perform equally to wild fish once they are released into the wild".

Notwithstanding their importance in the early stages of the recovery program, the use of hatchery fish does not present a medium- or long-term solution. One reason for this can be attributed to the genetic and phenotypic differences that exist between hatchery-spawned and/or reared fish and those that are spawned and reared in the wild (Fraser 2008; Christie et al. 2011). Such differences can exist even in the offspring of hatchery broodstock obtained directly from the wild because of inherited maladaptive phenotypic characteristics. A second reason, as discussed in greater detail below (section 3.2), is the observation that smolts of hatchery origin (documented for Penobscot River smolts that must pass dams during their downstream migration) within the GOM DPS are estimated to have less than 25% the rate of survival to the adult stage as smolts of wild origin (documented for Narraguagus River smolts that do not pass dams during their downstream migration) (USASAC 2011). It is my opinion that some part of the elevated mortality experienced by hatchery-origin smolts in the Penobscot River is caused by their hatchery origin and some part is caused by their passage by dams. A third reason, also discussed below (Section 3.3), is that an Atlantic salmon population that experiences the smolt-adult survival rates that have been documented for hatchery-origin smolts in the GOM DPS (and that pass by dams in the Penobscot River) will experience negative population growth, meaning that it will decline with time.

In short, while hatchery-bred fish and eggs can provide an essential supplement to wild salmon populations at the brink of extinction, such as those in the Merrymeeting Bay SHRU, they cannot by themselves bring such populations back to sustainable levels. That is, hatchery fish are necessary — but far from sufficient — for the recovery of the Atlantic salmon populations of the Androscoggin and Kennebec Rivers, Merrymeeting Bay SHRU, and, thus, the recovery of the GOM DPS.

2.3 Recovery of Salmon Habitat Recovery Units (SHRU's)

In my opinion, the partitioning of the GOM DPS of Atlantic salmon into three Salmon Habitat Recovery units, or SHRU's, is scientifically sound, theoretically and empirically defensible, and representative of a responsible management strategy consistent with a precautionary approach to resource management and the conservation of biodiversity.

As noted by the 2009 draft of the Gulf of Maine Distinct Population Segment Management Guidance for Recovery (NOAA 2009), "maintaining a population in all three SHRU's is necessary in order to preserve the genetic variability of the DPS, which in turn is necessary in ensuring that the population is capable of adapting to and surviving natural environmental and demographic variation that all populations are subjected to over time".

The responsible authorities have proposed a minimum census abundance of 500 spawners of non-hatchery origin for each SHRU to serve as a "benchmark to evaluate the population as either recovered or one that requires protection under the ESA [Endangered Species Act]" (NOAA 2009). That is, the census abundance of 500 spawners per SHRU is meant to provide a 'starting point' for establishing delisting criteria (NOAA 2009). As noted by NOAA (2009), this benchmark of 500 spawners is consistent with viability criteria established for endangered and threatened salmonid populations elsewhere in the U.S, such as those in the Interior Columbia Basin (Cooney et al. 2007) and in the Central Valley region of California for endangered winter-run Chinook salmon, threatened spring-run Chinook salmon, and threatened steelhead (NMFS 2009). It is worth noting, however, that this benchmark of 500 is less than 1% of the presumed historical spawning population sizes of at least 100,000 for *each* river within the SHRU.

It is also important that the benchmark of 500 spawners be distributed between the Androscoggin and Kennebec Rivers to ensure that the breadth of ecological and environmental conditions that each river's watershed contributes to the process of natural selection in salmon is maintained. It is necessary to maintain this breadth in order to generate the genetic and phenotypic variability within and among salmon populations that is necessary for the Merrymeeting Bay SHRU to contribute positively to the persistence of the GOM DPS.

3 Merrymeeting Bay SHRU

3.1 Current status: numbers of returning adults

Remnant populations of Atlantic salmon exist in the Merrymeeting Bay SHRU. As noted above and elsewhere (*e.g.,* Baum 1997), historical records indicate that several hundred thousand adults returned annually to the largest rivers in the GOM DPS. Atkins and Foster (1867) estimated that between 68,000 and 216,000 adults were harvested in Kennebec River in 1820, and that the average annual yield of salmon in Penobscot River, before the construction of dams in the river, could not have been less than 150,000 adult salmon (Atkins and Foster 1868).

The historical numbers of salmon returning annually to the largest rivers in the GOM DPS were more than ten thousand times greater than the annual counts of adults of wild origin in the Androscoggin and Kennebec Rivers in the past 3 to 4 decades (Table 1; USASAC 2011). Several observations can be drawn from these census count data:

- Since 2006, fewer than 50 adults have returned annually to the Androscoggin River; in 4 of the past 6 years, the numbers of returning adults have numbered 20 or less;
- Since 2006, fewer than 65 adults have returned annually to the Kennebec River; in 4 of the past 6 years, the numbers of returning adults have numbered 21 or less;
- Since 2006, the number of adults returning to the Merrymeeting Bay SHRU has fluctuated considerably, reaching a low of 14 adults in 2010 and a high of 110 adults in 2011;
- Based on the most recent 5 years for which data are available (2006-2010), 77% of adults returning to the Merrymeeting Bay SHRU have been of hatchery origin;
- Based on the most recent 5 years for which data are available (2006-2010), 71% of adults returning to the Merrymeeting Bay SHRU that were spawning for the first time were two-sea-winter (2SW) fish (meaning they spent 2 winters at sea before returning to the river to spawn);
- Based on the most recent 5 years for which data are available (2006-2010), 4% of adults returning to the Merrymeeting Bay SHRU have been 3SW fish or Previous Spawners (PS) (*i.e.*, adults who spawned, returned to the sea, and are back to spawn again).

The proportion of 1SW, 2SW, 3SW, and PS salmon varies considerably among Atlantic salmon populations throughout the species' range. In the GOM DPS, the incidence of 2SW adults is quite high; much higher than the incidence in many rivers in Nova Scotia and New Brunswick and far greater than those in Newfoundland (where most salmon spawn as 1SW adults) (Hutchings and Jones 1998). These differences in sea-age at maturity are adaptive, meaning that, in the GOM DPS, adults that return to spawn as 2SW fish have greater reproductive success (are better ‘adapted’ to local environments) than salmon returning to spawn at other ages. However, it is certainly possible that the recent predominance of 2SW adults represents an adaptive response to recent (*e.g.,* past century) human-induced changes to the environment, meaning that 2SW adults might not have been as dominant historically when 3SW (and possibly 4SW) adults might have been more common. It is also reasonable to hypothesize that PS fish, which migrate downstream to the sea as ‘kelts’, represent genotypes that are well-adapted to current local conditions, given that they survived to potentially spawn more than once – further emphasizing the importance of safe downstream passage for kelts.

3.2 Survival rates

In general, the life cycle of Atlantic salmon can be thought of as comprising three stages: (i) egg-to-smolt stage; (ii) smolt-to-spawning-adult stage; (iii) post-spawning stage. The first stage represents the period from the time at which the eggs are released by the female until the time at which the salmon begin their downstream migration to the ocean as smolts. The second stage represents the period from the beginning of the smolt migration until the time at which the returning adults are spawning. The third stage represents the ‘kelt’ or ‘previous spawner’ stage and extends from the time of initial spawning until the time at which the same individual spawns again.

Table 1. *Atlantic salmon of wild and hatchery origin returning to Androscoggin and Kennebec Rivers (USASAC 2011). Abbreviations: 1SW, 2SW, 3SW refer to salmon that spent 1, 2, and 3 winters at sea, respectively, before returning to a river to spawn for their first time; PS refers to Previously Spawned adult; NA= data not yet available.*

		Hatchery Origin				**Wild Origin**				**Total**
River	**Years(s)**	**1SW**	**2SW**	**3SW**	**PS**	**1SW**	**2SW**	**3SW**	**PS**	
Androscoggin	1983-2000	26	507	6	2	6	83	0	1	631
	2001	1	4	0	0	0	0	0	0	5
	2002	0	2	0	0	0	0	0	0	2
	2003	0	3	0	0	0	0	0	0	3
	2004	3	7	0	0	0	1	0	0	11
	2005	2	8	0	0	0	0	0	0	10
	2006	5	1	0	0	0	0	0	0	6
	2007	6	11	0	0	1	2	0	0	20
	2008	8	5	0	0	2	1	0	0	16
	2009	2	19	0	0	0	3	0	0	24
	2010	2	5	0	0	0	2	0	0	9
	2011									47
Annual average	**2006-2010**	**4.6**	**8.2**	**0**	**0**	**0.6**	**1.6**	**0**	**0**	**15**
Annual average	**2007-2011**	NA	NA	NA	NA	NA	NA	NA	NA	**23.2**
Kennebec	1975-	12	189	5	1	0	9	0	0	216

	2000									
	2006	4	6	0	0	3	2	0	0	15
	2007	2	5	1	0	2	6	0	0	16
	2008	6	15	0	0	0	0	0	0	21
	2009	0	16	0	6	1	10	0	0	33
	2010	0	2	0	0	1	2	0	0	5
	2011									63
Annual average	**2006-2010**	**2.4**	**8.8**	**0.2**	**1.2**	**1.4**	**4.0**	**0**	**0**	**18**
Annual average	**2007-2011**	NA	NA	NA	NA	NA	NA	NA	NA	**27.6**

Estimates of survival between the egg and smolt stages are rare for populations within the GOM DPS, based on the reviews undertaken by Bley and Moring (1988) and by Hutchings and Jones (1998). The only study cited by either review for GOM DPS Atlantic salmon is the work of Meister (1962) who provided an estimate of 1.1% for salmon in Cove Brook, Maine (part of the GOM DPS). Based on egg-smolt survival data compiled for 12 rivers worldwide, Hutchings and Jones (1998) reported a median probability of surviving between the egg and smolt stages of 0.0137 (*i.e.,* 1.37%). Restricting the smolt-adult survival data to those populations (located in New Brunswick and Québec) nearest to the GOM DPS (Big Salmon River: 0.0017; Miramichi: 0.0047; Pollett: 0.0198; Bec-Scie: 0.0156; Saint-Jean: 0.303; and Trinité: 0.0324), the median egg-smolt survival is 0.0177. For the model simulations used here, the value of 0.0177 was used. (Note that this value of almost 1.8% exceeds the value estimated by Meister (1962) for a GOM DPS salmon population.)

Estimates of survival between the smolt and returning-adult stages are not available for the Merrymeeting Bay SHRU populations. However, there are smolt-adult survival estimates available for salmon in two other rivers in the GOM DPS (USASAC 2011). These survival data distinguish Penobscot River smolts of hatchery origin that pass by one or more dams during their downstream migration and Narraguagus River smolts of wild origin for which their downstream passage is unimpeded by dams. Smolt-adult survival data are available from: (i) 1969 to 2009 for hatchery-origin smolts returning as 1SW adults to Penobscot River; (ii) 1969 to 2008 for hatchery-origin smolts returning as 2SW adults to Penobscot River; and (iii) 1997 to 2008 for wild-origin smolts returning as 2SW adults to Narraguagus River (Table 2).

Estimates of survival during the kelt stage in the scientific literature are rare. In a Newfoundland population where all of the fish spawn as 1SW adults, Chadwick et al. (1978) estimated a mean overwinter survival of post-spawning 1SW fish to the kelt stage to be 63%. Given the absence of data for other rivers, that is the estimate used here. (Although there are reports that 20% of kelts migrate downstream before winter in the Merrymeeting Bay SHRU (NextEra 2011), it is assumed here that all kelts spend the winter in the river before returning to the ocean the following spring. This assumption has little effect on the final model results.) During their downstream migration, kelts are assumed to experience a survival rate of 82% as they pass each dam (based on the average of 4 whole-station kelt survival estimates for dams in the Kennebec and Androscoggin Rivers; NextEra 2011). Once kelts have entered the ocean, they are assumed to experience an 80% survival rate prior to their return to the river in the same year to spawn.

3.3. Population growth rate

It is my opinion that an Atlantic salmon population that experienced the current levels of smolt-adult survival realized by hatchery-origin smolts that pass by dams during their downstream migration in the GOM DPS (Table 2) would not increase in abundance and would never recover.

A standard measure of density-independent population growth is provided by r, a parameter often referred to as the intrinsic rate of population growth (*e.g.,* Gotelli 2010). Using life-history data (*i.e.,* information on a survival rates and estimates of the number of eggs a female produces), population growth rate (r) can be estimated from what is commonly known as the Euler-Lotka equation (Roff 2002; Gotelli 2010):

$$1 = l_x\, m_x \exp(-rx)$$

where l_x is the probability of surviving from birth until age x and m_x is the number of eggs produced by an individual breeding at age x (Roff 2002). In estimating r for the Merrymeeting Bay SHRU, the number of eggs per female was assumed to be 8,500 eggs for each adult spawning for the first time and 10,000 eggs for each Previously Spawned adult (or kelt), based on eggs-per-female data provided by USASAC (2011). By estimating population growth rate, one can then determine whether a population is likely to increase or decrease under a range of potential survival conditions. When a population is increasing, the population growth rate (r) is positive and it is greater than zero; when a population is declining, r is negative and it is less than zero.

Table 2. *Estimates of the survival of fish, expressed as a proportion, between the smolt and returning-adult stage over the most recent ten-year period for which data are available (USASAC 2011). If survival is sufficient to result in population growth (meaning that the number of returning adults would increase over time), a positive sign is indicated in parentheses. If survival is not sufficient to produce population growth (meaning that the number of returning adults would decline over time), a negative sign is indicated. 'Year of Smolt Cohort' is the year in which smolts migrated downstream to the ocean. Abbreviations: SW=sea winter; H=hatchery-origin smolts that pass dams in Penobscot River; W=wild-origin smolts that pass no dams in Narraguagus River.*

Year of Smolt Cohort	**2SW (W)**	**2SW (H)**	**1SW (H)**
2009	--------	--------	0.0009 (−)
2008	0.0063 (+)	0.0020 (−)	0.0006 (−)
2007	0.0200 (+)	0.0036 (−)	0.0018 (−)
2006	0.0076 (+)	0.0030 (−)	0.0006 (−)
2005	0.0073 (+)	0.0014 (−)	0.0008 (−)
2004	0.0097 (+)	0.0015 (−)	0.0007 (−)
2003	0.0104 (+)	0.0016 (−)	0.0007 (−)
2002	0.0060 (+)	0.0021 (−)	0.0006 (−)
2001	0.0084 (+)	0.0019 (−)	0.0008 (−)
2000	0.0017 (−)	0.0010 (−)	0.0006 (−)
1999	0.0052 (+)	0.0011 (−)	--------

10-year average	**0.0083 (+)**	**0.0019 (−)**	**0.0008 (−)**

Three important conclusions can be drawn from the data in Table 2, which represent prevailing smolt-adult survival rates for two rivers in the GOM DPS:

- During the past ten years, the survival to the 2SW adult stage has, on average, been *4 times greater* for smolts of wild origin that pass *no* dams during downstream migration (0.83%) than it has been for smolts of hatchery origin that *do* pass dams during downstream migration (0.19%);
- An Atlantic salmon population that experienced the smolt-adult survival rates reported for wild-origin 2SW adults that do not migrate past dams would increase with time ($r > 0$ in 9 of the past 10 years);
- An Atlantic salmon population that experienced the smolt-adult survival rates reported for hatchery-origin 2SW adults that must migrate past dams would decrease with time ($r < 0$ every year in the past 10 years).

Another, and perhaps more intuitive, way to think of the survival data in Table 2 is to determine the number of smolts required to produce a single returning adult. (This is simply 1 divided by the survival proportions given in Table 2.) These estimates are given in Table 3. They show that, on average, and over the past ten years:

- In the absence of dams, 120 wild-origin smolts are required to produce a single returning 2SW adult;
- In the presence of dams, 526 hatchery-origin smolts are required to produce a single returning 2SW adult;
- In the presence of dams,1250 hatchery-origin smolts are required to produce a single returning 1SW adult.

Table 3. *Smolt-to-adult survival data from Table 2 expressed as the number of smolts required to produce a single returning adult. For example, if smolt-adult survival was 0.001, the number of smolts required to produce 1 returning adult is 1/0.001 = 1,000. Abbreviations are the same as those in the caption for Table 2.*

Year of Smolt Cohort	**2SW (W)**	**2SW (H)**	**1SW (H)**
2009	--------	--------	1111
2008	159	500	1667
2007	50	278	556
2006	132	333	1667
2005	137	714	1250
2004	103	667	1429
2003	96	625	1429
2002	167	476	1667
2001	119	526	1250
2000	588	1000	1667
1999	192	909	--------
10-year average	**120**	**526**	**1250**

4 Effect of Dams on the Merrymeeting Bay SHRU

4.1 Effect of dams on survival

For the Merrymeeting Bay SHRU of Atlantic salmon, there are potentially several periods of life during which survival is negatively affected by the presence of dams. One occurs during the smolt migration; a second occurs during the upstream migration of returning adults to the spawning grounds. Additional periods would include the downstream and subsequent upstream migrations of post-spawning kelts. And the prevention of upstream migration by spawning adults to suitable spawning habitat would represent another example of how the presence of dams can affect population viability and persistence.

There are estimates of smolt survival as they pass by dam facilities. Based on the four estimates of whole-station smolt survival available for the Kennebec and Androscoggin Rivers (NextEra 2011), the average whole-station survival rate per dam, using the initial injury rate model estimates (the most defensible estimates among those available), is 87%. (These 'initial' injuries include scale loss, gill damage, severed body/backbone, and bruised head or body (NextEra 2011), all of which can be expected to result in significantly increased likelihood of death. However, the injury-rate mortality estimates do not account for delayed mortality, *i.e*., the mortality that occurs after a smolt has passed a dam but that can be attributed to dam passage.) Although estimates of the survival probabilities for upstream migrating adults could be estimated from available data (potentially between 67 and 76%; Bailey 2011), these estimates will not be considered further in this opinion for the purpose of predicting recovery times and population growth rate. In other words, the assumption here is that *all* returning adults survive the upstream migration to the spawning grounds. This assumption will have the effect of *under*-estimating recovery times and *over*-estimating population growth in the forecasts presented below. The forecasts presented here are thus conservative estimates that understate the effects that dams have on Atlantic salmon mortality. Put another way, the forecasts demonstrate that even if existing dams were modified to provide 100% effective upstream passage, the downstream impacts alone will have significant effects.

As mentioned previously, survival data are not available for salmon in the Merrymeeting Bay SHRU, necessitating the use of survival data for the only two rivers in the GOM DPS for which such data are available: the Penobscot and Narraguagus Rivers. Given that there are dams on the Penobscot River, it is not unreasonable to consider the prevailing smolt-adult survival rates experienced by hatchery-origin smolts, recorded from the Penobscot River (Table 2), to be representative of prevailing smolt-adult survival in the presence of dams for salmon in the Androscoggin and Kennebec Rivers. Similarly, it is not unreasonable to consider the prevailing smolt-adult survival rates experienced by wild-origin smolts, recorded from the Narraguagus River (Table 2), to be representative of prevailing smolt-adult survival in the absence of dams for salmon in the Androscoggin and Kennebec Rivers.

The smolt-adult survival data in Table 2 allow for two different analyses to be undertaken to explore the effects of dams on salmon population growth rate and recovery. The first method involves *removing* the effects of dam-related mortality on kelt survival and from the smolt-adult survival rates reported for hatchery-origin smolts in the Penobscot River. The second method involves *including* the effects of dam-related mortality on kelt survival and on the smolt-adult survival rates reported for wild-origin smolts in the Narraguagus River. The use of *both* approaches should yield an empirically defensible range of estimates of the consequences of dams to the population growth rate and recovery of the Merrymeeting Bay SHRU.

To *remove* the influence that each dam has on smolt-adult survival (using the Penobscot River data), one simply needs to *divide* the prevailing survival rate (*i.e.*, those for *hatchery*-origin smolts presented in Table 2, which factor in mortality related to passing multiple dams) by 0.87^n, where n represents the number of dams through which smolts must pass during their downstream migration and for which one is now assuming 100% safe downstream passage. To *include* the influence that each dam has on smolt-adult survival (using the Narraguagus River data), one *multiplies* the prevailing survival rate (*i.e.*, those for *wild*-origin smolts that do not pass dams; Table 2) by 0.87^x, where x represents the number of dams through which smolts must pass during their downstream migration.

Based on hatchery-origin smolt survival rate data from the Penobscot River, even if smolt and kelt survival were to be improved when passing 3 dams now presumed 100% safe or 4 dams now presumed 100% safe, the population growth rate (r) would be negative (Table 4).

Based on wild-origin smolt survival rate data from the Narraguagus River (in which dams do not affect salmon passage), if smolt and kelt survival declined when passing 3 or 4 dams, the population growth rate (r) would be negative for 6 of the past 10 years in the presence of 3 dams and negative for 7 of the past 10 years in the presence of 4 dams (Table 4).

4.2 Effects of dams on recovery time

The population growth rate (r) can be used to predict the times required for the Merrymeeting Bay SHRU to reach 500 returning adults of wild origin. The estimates provided here represent scenarios for which there is no future input of hatchery-origin fish into the SHRU, *i.e.*, all of the production will be assumed to originate from fish spawning in the wild. Of course, additional inputs of hatchery-origin fish into the Kennebec River are anticipated. What this means for the forecasts presented here is that the predicted recovery times may be over-estimated. However, the *qualitative* differences in recovery times under different survival-rate scenarios will not be affected. For example, if the time to achieve 500 adults is estimated to be 60 years if smolts and kelts experience 100% survival through each of 3 dams, as opposed to 120 years under survival rates of smolt and kelt involving passage through dams, the 60- and 120-year time frames might represent over-estimates, but the predicted *doubling* of recovery time is a robust estimate of the effects of dams on recovery time.

Table 4. *Estimates of the survival of fish, expressed as a proportion, between the smolt and returning-adult stage over the most recent ten-year period for which data are available (a) if the smolt survival consequences of migrating past 3 and 4 dams are included in the smolt-adult survival rates of 2SW wild-origin smolts (see* '2SW (W)' *in the table) or (b) if the smolt survival consequences of migrating past 3 and 4 dams are excluded from the smolt-adult survival rates of 2SW and 1SW hatchery-origin smolts (see* '2SW (H) and 1SW (H)' *in the table.*

Year of Smolt Cohort	**2SW (W)**		**2SW (H)**		**1SW (H)**	
	3 dams' impacts included	4 dams' impacts included	3 dams' impacts removed	4 dams' impacts removed	3 dams' impacts removed	4 dams' impacts removed
2009	--------	--------	--------	--------	0.0014 (−)	0.0016 (−)
2008	0.0042 (−)	0.0036 (−)	0.0030 (−)	0.0035 (−)	0.0009 (−)	0.0010 (−)
2007	0.0132 (+)	0.0115 (+)	0.0055 (−)	0.0063 (+)	0.0027 (−)	0.0031 (−)
2006	0.0050 (−)	0.0044 (−)	0.0046 (−)	0.0052 (−)	0.0009 (−)	0.0010 (−)
2005	0.0048 (−)	0.0042 (−)	0.0021 (−)	0.0024 (−)	0.0012 (−)	0.0014 (−)
2004	0.0064 (+)	0.0056 (+)	0.0023 (−)	0.0026 (−)	0.0011 (−)	0.0012 (−)
2003	0.0068 (+)	0.0060 (+)	0.0024 (−)	0.0028 (−)	0.0011 (−)	0.0012 (−)
2002	0.0040 (−)	0.0034 (−)	0.0032 (−)	0.0037 (−)	0.0009 (−)	0.0010 (−)
2001	0.0055 (+)	0.0048 (−)	0.0029 (−)	0.0033 (−)	0.0012 (−)	0.0014 (−)
2000	0.0011 (−)	0.0010 (−)	0.0015 (−)	0.0017 (−)	0.0009 (−)	0.0010 (−)
1999	0.0034 (−)	0.0030 (−)	0.0017 (−)	0.0019 (−)	--------	--------
10-year average	**0.0054 (+)**	**0.0047** (−)	**0.0029 (−)**	**0.0034 (−)**	**0.0012 (−)**	**0.0014 (−)**

To estimate recovery times for the Merrymeeting Bay SHRU under different smolt-adult survival scenarios, one can use the following equation (Gotelli 2010) to estimate how the abundance of returning adults (N) will change with generation time (t) for different rates of population growth (r) for any particular starting population size (N_0):

$$N_t = N_0 (\exp(rt)) \quad .$$

For the present purposes, the starting population size (N_0) was set to two numbers. The first (N_0 = 50) represents the average number of adults returning to the Merrymeeting Bay SHRU in the past 5 years (2007-2011; Table 1). The second (N_0 = 110) represents the maximum number of adults returning to the SHRU in the past 5 years (in 2011; Table 1). The time required to achieve 500 2SW adults is equal to the number of generations (t) multiplied by 5 years (Table 5).

The results of this analysis indicate that the presence of dams very significantly increases the time required to achieve the benchmark of 500 wild spawners in the Merrymeeting Bay SHRU.

The first analysis uses the smolt-adult survival data for wild-origin 2SW

Narraguagus River salmon as the baseline and incorporates the survival consequences of dam passage for smolts and kelts. The results indicate that the presence of 3 dams, when compared to the no-dam scenario, reduces population growth rate to such a large extent (*r* declines from 0.130 to 0.015) that the recovery time is increased by a factor almost ten. The same analysis indicates that population growth rate (*r*) would be negative (−0.02) in the presence of 4 dams, meaning that the population would never recover.

The risk of such greatly extended recovery times — and the reason one would want to reduce recovery time — is that the longer a population exists near the brink of extinction, the more likely it is that one or more stochastic, unpredictable events will occur which might significantly increase the chance of extinction of the SHRU.

The second analysis uses the smolt-adult survival data for hatchery-origin 2SW and 1SW Penobscot River salmon as the baseline and removes the survival consequences of dam passage for smolts and kelts. The results suggest that 100% safe passage by both smolts and kelts by either 3 or 4 dams would not be sufficient to result in positive population growth, meaning that the population would never recover.

Table 5. *Estimated effects of dams on smolt-adult survival, population growth rate (r), and the estimated time, in years, for a population size of 500 adults to be attained, under two different starting population sizes (N_0 = 50 and 110). For 2SW wild-origin smolts* ('2SW (W)')*, the current conditions reflect survival in the absence of dams; by including the effects of dams on survival, the smolt-adult survival rates are reduced. For 2SW and 1SW hatchery-origin smolts* ('2SW (H)' *and* '1SW (H)')*, the current conditions reflect survival in the presence of dams; by excluding the effects of dams on survival, the smolt-adult survival rates are increased.*

	2SW (W)			**2SW (H)**			**1SW (H)**		
	Current smolt survival	Lowered smolt and kelt survival through 3 dams	Lowered smolt and kelt survival through 4 dams	Current smolt survival	100% smolt and kelt survival through 3 dams	100% smolt and kelt survival through 4 dams	Current smolt survival	100% smolt and kelt survival through 3 dams	100% smolt and kelt survival through 4 dams
10-year average smolt-adult survival	0.0083	0.0054	0.0047	0.0019	0.0029	0.0034	0.0008	0.0012	0.0014
Population growth rate (*r*)	0.130	0.015	-0.02	−0.16	−0.07	−0.04	−0.39	−0.28	−0.25
Time (yr) to achieve 500 2SW adults when N_0=50	90	770	never	never	never	never	never	never	never

Time (yr) to achieve 500 2SW adults when N_0=110	60	505	never	never	never	never	never	never	never

5 Summary

Atlantic salmon in the Merrymeeting Bay SHRU are at historically low levels of abundance. The very low abundance of returning adults (Table 1) renders the SHRU extremely vulnerable to *any* anthropogenic or natural factor that threatens the survival of Atlantic salmon, particularly those of wild origin. The total number of adult salmon of wild origin returning annually to Androscoggin and Kennebec Rivers in the past 5 years (2006-2010) for which the smolt origin (wild vs hatchery) is known has been less than 10. The 2011 count of all fish returning to the Merrymeeting Bay SHRU, irrespective of smolt origin, was 110. By comparison, most salmon populations in Canada number in the hundreds, thousands, and tens of thousands of spawning Atlantic salmon (COSEWIC 2011).

Measured against the number of returning adults of wild origin, the Merrymeeting Bay SHRU is on the brink of extinction. As a consequence of this fragility, it is my opinion that the mortality experienced by downstream migrating smolts and kelts, and by upstream migrating returning adults, attributable to dam facilities in the SHRU will have an adverse impact on the survival and the prospects for recovery of the Merrymeeting Bay SHRU and, thus, of the GOM DPS as a whole. Given the exceedingly low numbers of returning adults, most notably of fish of wild origin, the loss of a single smolt, or of a single adult, is significant.

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Jeffrey A. Hutchings

Date