Why aren't there more Atlantic salmon (*Salmo salar*)?

Donna L. Parrish, Robert J. Behnke, Stephen R. Gephard, Stephen D. McCormick, and Gordon H. Reeves

Abstract: Numbers of wild anadromous Atlantic salmon (*Salmo salar*) have declined demonstrably throughout their native range. The current status of runs on rivers historically supporting salmon indicate widespread declines and extirpations in Europe and North America primarily in southern portions of the range. Many of these declines or extirpations can be attributed to the construction of mainstem dams, pollution (including acid rain), and total dewatering of streams. Purported effects on declines during the 1960s through the 1990s include overfishing, and more recently, changing ocean conditions, and intensive aquaculture. Most factors affecting salmon numbers do not act singly, but rather in concert, which masks the relative contribution of each factor. Salmon researchers and managers should not look for a single culprit in declining numbers of salmon, but rather, seek solutions through rigorous data gathering and testing of multiple effects integrated across space and time.

Résumé : Les effectifs de saumon de l'Atlantique (*Salmo salar*) sauvage anadrome ont diminué notablement dans toute l'aire de répartition naturelle de l'espèce. On a observé des baisses étendues et même la disparition des remontes dans les rivières à saumon en Europe et en Amérique du Nord, surtout dans les parties méridionales de l'aire de répartition de l'espèce. Bon nombre de ces déclins ou de ces disparitions sont attribuables à la construction de barrages sur les cours principaux des rivières, à la pollution (notamment aux pluies acides) et à l'assèchement complet de certains cours d'eau. On pense aussi que les déclins qui se sont produits depuis les années 1960 jusque dans les années 1980 pourraient aussi être dus à la surpêche et, plus récemment, à l'altération des conditions océaniques et à l'aquaculture intensive. La plupart des facteurs influant sur les effectifs du saumon n'agissent pas seuls mais de concert avec d'autres facteurs, ce qui masque la contribution relative de chacun de ces facteurs. Les chercheurs et les gestionnaires qui s'intéressent au saumon ne devraient pas chercher une cause unique qui serait responsable du déclin des effectifs de saumon, mais plutôt rechercher des solutions en recueillant des données de façon rigoureuse et en examinant des effets multiples considérés dans le temps et dans l'espace.

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Introduction

We want to know why aren't there more Atlantic salmon (*Salmo salar*)? The irony of this question is that Atlantic salmon are now more abundant than at any time previously. Virtually all (~98% of the biomass) of the present abundance is because of the artificial culture of salmon as a food fish, whereas wild Atlantic salmon numbers have been in a general decline. In this paper, we examine the geographic distribution of extirpations and declines in anadromous populations of Atlantic salmon (omitting aquaculture and nonanadromous populations) and establish the reasons for these changes.

We cannot determine exactly how many salmon existed 400 years ago, or even presently, because our estimates of abundance are based mostly on catch data for which fishing effort is often inaccurate (Shearer 1992). The total North Atlantic commercial salmon catch from 1960 through 1987 indicates a high abundance cycle from the mid-1960s to the mid-1970s, with catch maxima of about 12 000 t in 1967 and 1973 (Mills 1989). Numbers of salmon returning to home rivers declined precipitously during this time frame

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and now most fisheries are closed. Although current abundance estimates must come from variable data sources (e.g., adult escapement, smolt production), there is no question that in general salmon numbers are further declining during the time of fishery closures, indicating more than overfishing is responsible for continued declines.

Current status of Atlantic salmon

We reviewed available information to develop maps showing the current status of wild anadromous Atlantic salmon in the world. Status categories for these maps are based solely on current numbers of adults returning to rivers. Categories were: Extirpated (E) — no returns for at least 10 years, Extirpated with restoration (E/R) — no returns for many years followed by the initiation of a program to reintroduce salmon, Declining (D) — long-term decrease (>10 years) in numbers of adults returning, or Stable (S) — no consistent decline in numbers of adults returning during the last 10 years. We determined categories with substantial input of participants from Europe and North America at the March 1997 workshop as well as other biologists polled after the meeting. This approach does not allow for determining the status of salmon in every river historically supporting salmon; nonetheless, employing our approach allows us to portray patterns of salmon status across broad geographical areas, which was our ultimate goal.

Distributions of salmon populations in Europe (Fig. 1 and Table 1) and North America (Fig. 2 and Table 2) indicate many rivers historically supporting Atlantic salmon populations on these continents have experienced extirpation or great declines. (Note: Fig. 1 does not show the entire range of Atlantic salmon, which extends to the Pechora River, Russia, northeast of the White Sea. Rivers not shown on the European map are considered stable.)

Globally, most watersheds in the southern portions of the salmon range are extirpated (Figs. 1 and 2). It is not coincidental that these areas have the highest human population densities and have experienced the greatest environmental damage resulting from human activity. In Europe, three distinct tiers emerge; in the north, populations are stable; at intermediate latitudes, populations are declining; and in the south, populations are largely extirpated. Restoration efforts in Europe are few and scattered across the tiers.

North American populations follow a pattern similar to that of Europe in that northern populations (Canadian) are stable and southern populations are extirpated (Fig. 2). A major difference between distributions in North America and Europe is that proportionally more restoration efforts are in place in North America (e.g., most U.S. populations were extirpated and most large watersheds are targeted for restoration). A few small U.S. drainages near the Canadian border retain native, albeit, declining runs. Generally, Canadian rivers range from stable populations in the north, to declining populations in the midsection, to extirpated runs (including those under restoration) in the southern reaches. A deviation from the European pattern in North America is the area along the St. Lawrence in middle latitudes, where rivers are extirpated with restoration. The St. John in New Brunswick and many southeast Nova Scotia rivers are examples of rivers that are declining, which follows the pattern shown at middle latitudes of the salmon distribution in Europe.

What causes declines in Atlantic salmon abundance?

It is unmistakably evident from the European and North American maps that the current status of many salmon rivers is declining or extirpated. What factors are responsible for the declines and extirpations of Atlantic salmon globally? Armstrong et al. (1998: fig. 1) provide a useful depiction of hierarchical effects on Atlantic salmon populations, based on spatial and temporal scales. Clearly, many causal factors act in concert often masking the contribution of individual components and thereby complicating our ability to discern individual mechanisms (Armstrong et al. 1998). In cases of extirpation, it is possible to identify some of the single factors, but in currently declining populations multiple factors are more likely responsible. Below we provide descriptions of some of the causes implicated as contributing to the demise of Atlantic salmon populations as related to the status of salmon in Europe and North America (Figs. 1 and 2). Factors such as competition (Fausch 1998), introductions (Youngson and Verspoor 1998), pathogens and diseases (Bakke and Harris 1998), predation (Hansen and Quinn 1998; Mather 1998), prey (Poff and Huryn 1998; Hansen and Quinn 1998), and ocean conditions, especially related to thermal distributional patterns (Friedland 1998) are likely to contribute to declines, but not necessarily extirpations of Atlantic salmon populations. There are questionable effects of global warming and intensive aquaculture that could alter the long-term sustainability of salmon populations (Wilzbach et al. 1998), but the effects are too subtle or undetermined to attribute to the patterns of extirpation and declines of Atlantic salmon populations.

The construction of dams without fish passage has extirpated entire salmon runs in many rivers and is listed as the single major cause of salmon extirpations (MacCrimmon and Gots 1979). In the U.S., dams caused the local extinction of Atlantic salmon on the Connecticut and Merrimack rivers and had negative consequences in several Maine rivers (Moffitt et al. 1982). Extirpations because of dams have occurred throughout Canada (Dunfield 1985), Spain (Garcia de Leaniz and Martinez 1986), Czechoslovakia, Denmark, Finland, France, Germany, and Sweden (MacCrimmon and Gots 1979). Lower mainstem dams on major rivers occur in areas that correspond to red (extirpated) or red-striped (extirpated with restoration) sections on the maps of Europe and North America (Figs. 1 and 2). The density of dams generally corresponds to human population density.

Sewage, which included human waste, was one of the major pollutants that reduced numbers of salmon in the River Thames in England (MacCrimmon and Gots 1979). Industrial pollution in the rios Miera and Besaya in Spain (Garcia de Leaniz and Martinez 1986) and pesticides in several New Brunswick (Canada) rivers (Elson 1967) were to blame for elimination of salmon. High levels of pollution occurred in all of the European countries listed above where dams were constructed.

Fig. 1. Map of Atlantic salmon population status for major watersheds throughout original range in Europe. Numbering of watersheds is in Table 1. Note: Distance to Iceland is not to scale and range in Russia is truncated.

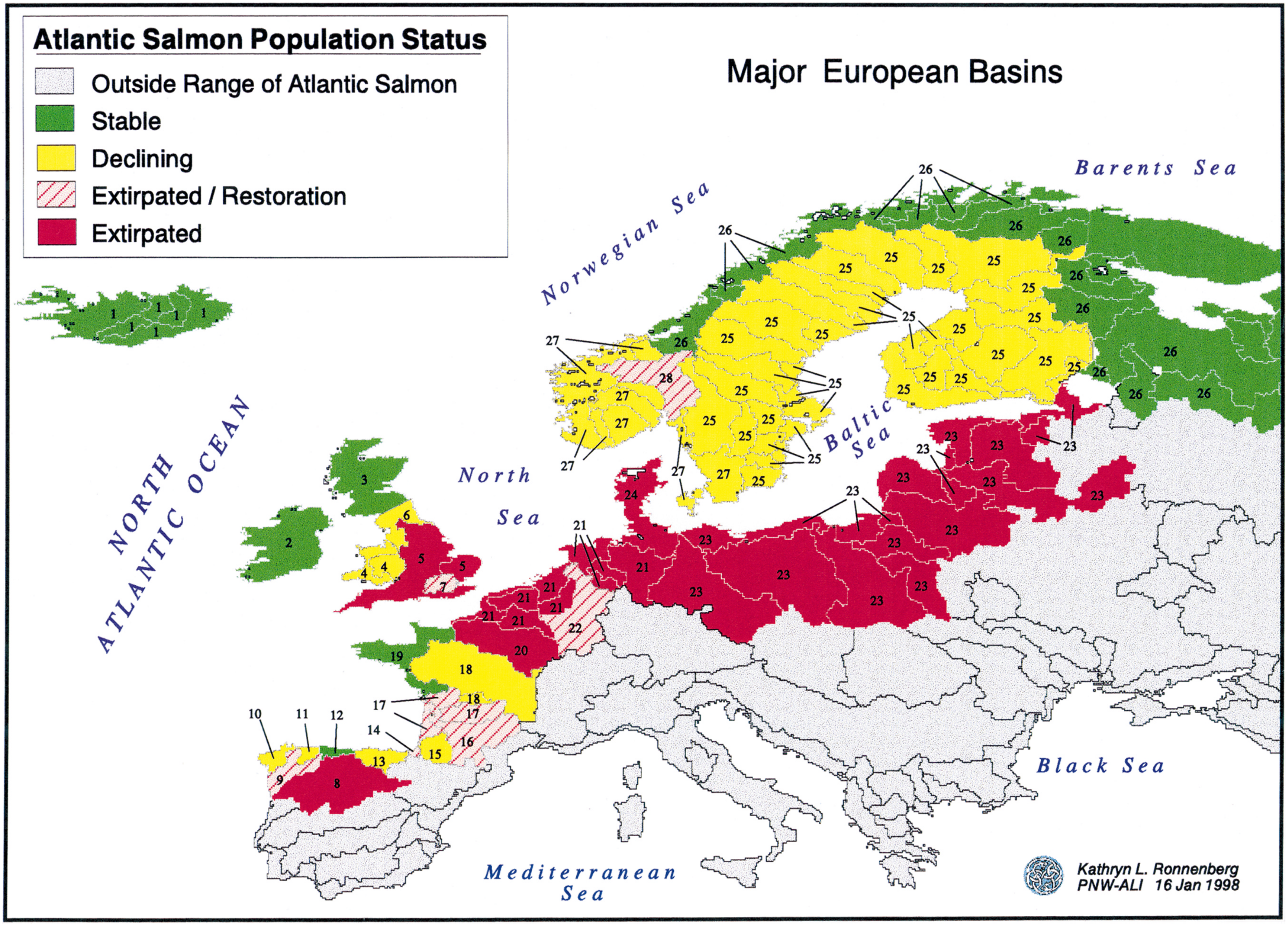

Table 1. Current status of Atlantic salmon populations in the major river basins of Europe and Iceland.

Number	River basin or region (country)	Status
1	Iceland	S
2	Ireland (Shannon, Erne, and Lee rivers: D)	S
3	Scotland	S
4	Wales	D
5	Southern and Central England	E
6	Northern England	D
7	Thames River (England)	E/R
8	Duoro River (Portugal and Spain)	E
9	Mino River (Portugal and Spain)	E/R
10	Galicia (Spain)	D
11	Austurias (Spain)	D
12	Cantabria (Spain)	D
13	Cantabria/Vasco (Spain)	E
14	Rio Bidasoa (Spain)	E/R
15	Adour River (France)	D
16	Garronne River (France)	E/R
17	Dodogne River (France)	E/R
18	Loire River (France)	D
19	Britanny and Normandy (France) (Orne, Vire, and Rance rivers: E)	S
20	Seine River (France)	E
21	Coastal N. France, Belgium, Netherlands, and Germany	E
22	Rhine River (Germany and Switzerland (not shown))	E/R
23	Southern Baltic (Germany, Poland, Lithuania, Latvia, Estonia, Russia)	E
24	Denmark	E
25	Northern Baltic (Sweden and Finland)	D
26	Northern Norway, Finnmark, Russia	S
27	Southern Norway	D
28	Glama River (Norway)	E/R

Acid pollution affects salmon in northern Europe and North America and presents a more complex spatial pattern. In Norway, salmon populations in 25 rivers were driven to extinction because of lethal pH levels (Hesthagen and Hansen 1991) and salmon rivers have been negatively affected in Nova Scotia, Canada (Lacroix and Townsend 1987). Acid rain is substantially different from dams or pollution in that acid rain is the result of industrial emissions often far from the point of deposition. In Europe, countries on the southern side of the Baltic Sea are responsible for creating acid rain in Sweden and Norway and in North America, industrial activity in midwestern U.S. and Canada creates most of the problems for Canadian rivers. Consequently, the large-scale effects of acid rain are more difficult to prove than the river-level effects of dams or direct-input pollution because of dispersion, prevailing weather patterns, and watershed geology. Therefore, acid rain, because of inconstant factors, may be a major component responsible for the more variable patterns of salmon status at the mid-latitudes than those in the north and south (Figs. 1 and 2).

With the exception of dams and water pollution, examples of habitat degradation or improvements that have affected adult Atlantic salmon populations are, to our knowledge, nonexistent. Potentially one of the most severe alterations of fish habitat is flow depletion from withdrawals for industrial, domestic, and agricultural use. When a river is completely dewatered the obvious result is no fish. The Nepaug River, Connecticut, U.S.A., a former salmon river, has no flow at its mouth because all water is diverted to supply drinking water to the City of Hartford (Stephen R. Gephard, personal observation). However, most water withdrawals divert only a portion of the total stream flow and assessing the impacts on salmon in relation to magnitude and timing of the altered hydrograph is not a simple matter. The nature of the problem has been well described and potential impacts have been speculated upon for streams in Scotland (Mills 1980), England (Dill et al. 1975; Harris 1980), Ireland (Piggins 1980), and the Rio Ascon in Spain (Garcia de Leaniz, Servicio de Montes, personal communication), all areas of significant urbanization.

The effects of commercial fishing are also variable and often unpredictable. Reasons for this include: (*i*) home-water vs. distant-water (intercepter) fisheries, (*ii*) interplay of changing ocean currents and catch, (*iii*) inaccurate catch and effort data, and (*iv*) compensatory mortality mechanisms of salmon. However, some examples showing the effects of fisheries follow: numbers of grilse returning to 20 Newfoundland rivers have generally increased following the closures of Newfoundland fisheries in 1992 and 1993 (O'Connell 1997) and adult returns increased in the Highland's River where returning fish were monitored the years after the 1992 fishing moratorium (Gibson et al. 1996). Regardless, given that the moratorium in major fisheries (Can-

Fig. 2. Map of Atlantic salmon population status for major watersheds throughout original range in North America and Greenland. Numbering of watersheds is in Table 2. Note: Distance from Greenland to North America not to scale.

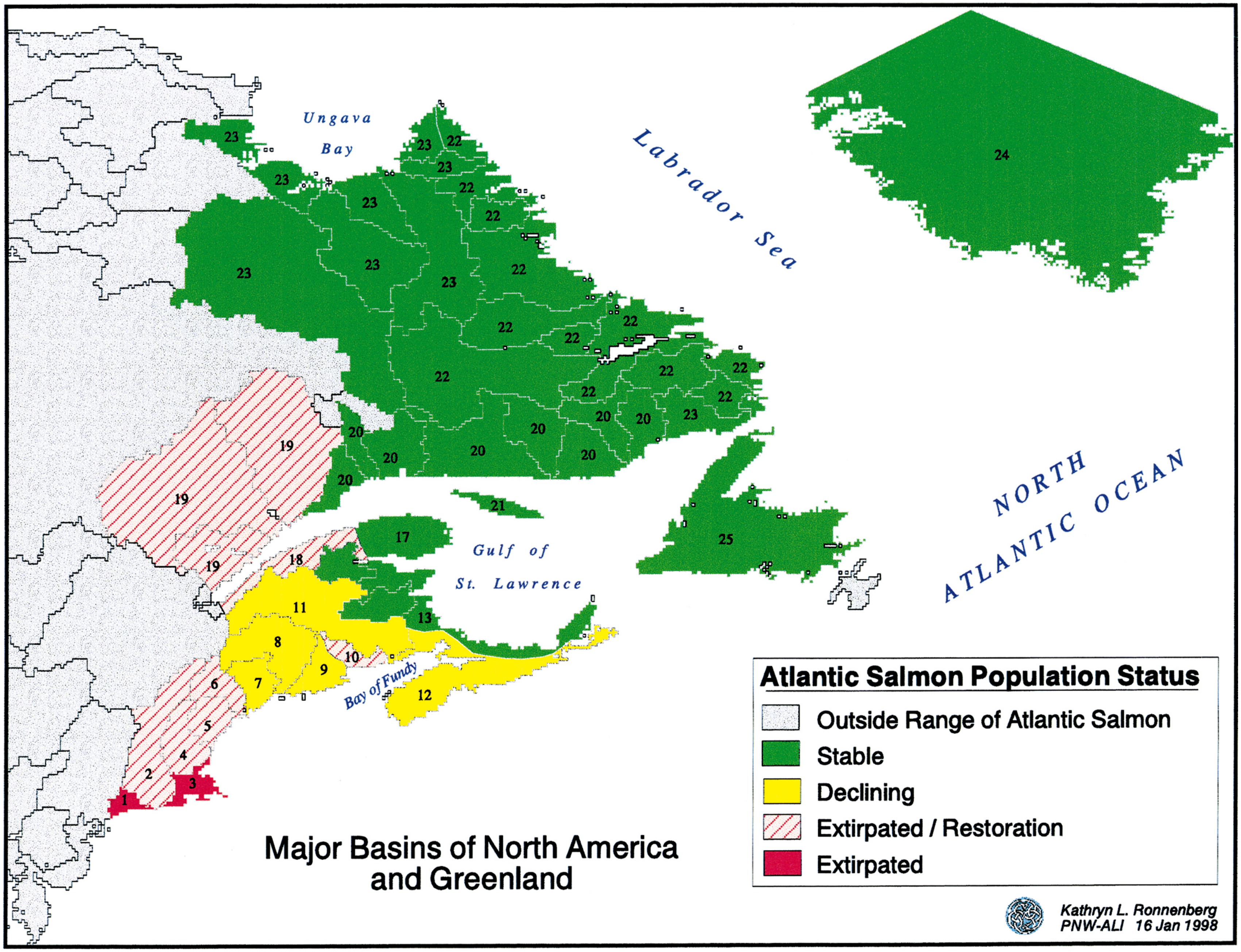

Table 2. Current status of Atlantic salmon populations in the major river basins of North America (U.S.A. and Canada) and Greenland.

Number	River basin or region (state or province, country)	Status
1	Housatonic River and coastal drainages (CT, U.S.A.)	E
2	Connecticut River (U.S.A.)	E/R
3	Coastal drainages (CT, RI, and MA, U.S.A.) (Pawcatuck River, RI: E/R)	E
4	Merrimack River (MA and NH, U.S.A.)	E/R
5	Saco River and coastal drainages (NH and ME, U.S.A.)	E/R
6	Androscoggin River (ME, U.S.A.)	E/R
7	Kennebec, Sheepscot, Ducktrap rivers (ME, U.S.A.)	D
8	Penobscot River (ME, U.S.A.)	D
9	Downeast Rivers (Dennys, Machias, Narraguagus, Pleasant, E. Machias) (ME, U.S.A.)	D
10	St. Croix River (ME, U.S.A., and NB, Canada) (Western NB coastal drainage: D)	E/R
11	St. John River (NB, Canada)	D
12	Bay of Fundy (NB, Canada) and Southeast and Atlantic Nova Scotia (Canada)	D
13	Gulf of St. Lawrence (NB and NS, Canada)	S
14	Miramichi River (NB, Canada)	S
15	Nepisiguit River and coastal drainage (NB, Canada)	S
16	Restigouche River (NB, Canada)	S
17	Gaspé Peninsula drainage (PQ, Canada)	S
18	South Shore St. Lawrence (PQ, Canada)	E/R
19	N. Shore St. Lawrence River (PQ, Canada)	E/R
20	N. Shore St. Lawrence (PQ, Canada)	S
21	Anticosti Island (PQ, Canada)	S
22	Labrador (NF, Canada)	S
23	Ungava River drainage (PQ, Canada)	S
24	Greenland	S
25	Newfoundland (Canada)	S

Note: States in the U.S.A. are as follows: CT = Connecticut, MA = Massachusetts, ME = Maine, NH = New Hampshire, RI = Rhode Island. Provinces in Canada are as follows: NB = New Brunswick, NF = Newfoundland, NS = Nova Scotia, PQ = Quebec.

ada, West Greenland, and the Faroes Islands) is less than 10 years old, we cannot address the effects of fisheries on salmon abundances on a global scale (Figs. 1 and 2).

Concluding remarks

Efforts in the past have attempted to summarize the status of Atlantic salmon populations regionally (e.g., Atkins 1874; Kendall 1935; Garcia de Leaniz and Martinez 1986) and globally (Netboy 1968; MacCrimmon and Gots 1979). In this paper, we specifically provided information regarding the declines and extirpation of salmon on a global scale, but a more comprehensive treatment is warranted. The information presented shows that Atlantic salmon stocks continue to decline despite the efforts of many nations to study, protect, and restore runs.

Our charge was to address the spatial pattern and reasons for declines in populations of wild Atlantic salmon. We were able to do that in some cases where single factors could be identified (i.e., dams, pollution, and dewatering) for specific sites. The available evidence allows us to speculate that more dams result in fewer salmon and that greater densities of humans near salmon rivers also result in fewer salmon. However, we can not link cause and effect for most declines because they are the result of multiple factors and we do not have the data that discriminate factors on scales of space or time. Consequently, we can not allocate the proportional impacts of multiple factors contributing to the demise of salmon populations and without this information we can only guess at specific causes.

To determine the specific contributions of multiple factors, we need to establish sampling programs that provide definitive results. If data were collected rigorously and comparably throughout the Atlantic salmon range, we could, for example, perform meta-analyses, conduct experimental procedures to address specific questions, and expand the use of models to predict changes in salmon sustainability (Wilzbach et al. 1998). The onus is on researchers and managers to use newer rigorous methodologies, including developing effective sampling designs and incorporating adaptive management (Wilzbach et al. 1998), to determine why salmon have declined and continue to do so. By applying science to management at appropriate temporal and spatial scales (Armstrong et al.1998), and through concerted conservation efforts (Dodson et al. 1998; Wilzbach et al. 1998), we hope the status of many Atlantic salmon rivers reported here as declining or extirpated with restoration will be changed in years ahead to a new category of increasing abundances.

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