A Dynamic Model of the Atlantic Salmon Fisheries Under Distant and Home Water Harvesting

Lars Olson
Cornell University

ABSTRACT

This paper uses a dynamic model to study the effect of distant and home water fishing on the Atlantic salmon fisheries. Under open access, capacity in each fishery oscillates due to overfishing and adjustment lags in capital investment. It is shown that development of a feeding ground fishery imposes significant costs on home water fisheries. In a regulated environment, joint operation of the two fisheries can result in higher total catches and profits than when a moratorium is placed on feeding ground fishing.

INTRODUCTION

The discovery of the distant water feeding grounds of the Atlantic salmon (Salmo salar) off the coasts of Greenland and the Faroe Islands during the 1960's and 1970's has had far reaching implications for the Atlantic salmon fisheries. Tagging studies have shown that the Greenland fishery captures fish originating from both North America and Europe (May, 1973; Paloheimo and Elson, 1974a; Paloheimo and Elson, 1974b; Kreiberg, 1983), while the Faroe Islands fishery affects the home-water stocks of a number of European nations (Brewster, 1982; anonymous, 1983a; Meister, 1983). These studies have linked the expansion of the distant water feeding ground fisheries to significant reductions in home water catches of Atlantic salmon. As a result, complicated management questions have arisen and pressure has mounted for the development of a coherent management strategy encompassing the fishing interests of all affected nations. In the past, the extremely complex nature of the salmon fishery made development of domestic management policies difficult enough, but the fishing of distant water feeding grounds has made international cooperation an additional part of the management task.

The primary goal of this paper will be to learn more about the control and management of the Atlantic salmon fishery under distant and home water exploitation. A simulation model will be used to study the long run dynamics produced by the interaction of the fisheries under a competitive economic environment. Commonly used management strategies such as catch limits, gear restrictions, and limitations on capacity will be tested for their effect on fishery performance as measured by stock levels, harvests, and employment.

Beverton and Holt (1957), and Ricker (1958) laid the foundations for modern fisheries management with their classic works on the dynamics of exploited fish populations. They give extensive treatment to the biological relationships associated with fish populations and the impact of harvesting on such relationships. Little or no consideration is given to the economic factors underlying the harvesting decision. As a result, early fisheries management was directed toward attaining maximum sustainable yield. Since, it has been recognized that managing a fishery for maximum long-term harvests will sometimes not be optimal when economic considerations are taken into account. Clark (1976) presents a synthesis of theoretical models developed to account for both the biological and economic aspects of a fishery. Several of these models separately examine issues associated with the salmon fisheries. These include an analysis of multi-cohort fisheries and a model of an inshore-offshore fishery. However, there are several shortcomings which render these models of limited practical use for application to the Atlantic salmon problem. The life cycle of the salmon is too complex to be captured by simple multi-cohort models. In addition, the complexity of a multi-cohort model makes analysis difficult when other characteristics of the fishery (such as inshore-offshore fishing) are added.

In general, management of the Atlantic salmon fishery is complicated by the complex feedback dynamics which characterize the fishery. The complex biological life cycle of the Atlantic salmon, its exposure to different fisheries at various stages of its migrations, the mingling of several home-stocks in the ocean, and the attractiveness of salmon as a sport fish make accurate description a difficult problem. Larsson (1984) used a simulation model to study the impact of a reduction in the offshore fishery on home water catches of Atlantic salmon in the Baltic; however, the dynamic aspects of the model were limited since the simulations were done using various levels of distant water fishing effort and assumed constant home water exploitation rates and landing prices.

In this paper's model, investment in both the distant and home water fishing fleets adjusts to changes in the net return to fishing. In addition, prices fluctuate with catch levels. As a result of including economic feedback dynamics, this model can be used to examine long term policy questions, as well as the short term issues considered in other studies. The paper is divided into three main sections: (1) a description of the life cycle of the Atlantic salmon, (2) a description of the distant and home water fisheries, and (3) a discussion of the model simulations and policy implications.

THE LIFE CYCLE OF THE ATLANTIC SALMON

The life of an Atlantic salmon begins when spawning females deposit eggs in the gravel of a river bottom. Salmon fry hatch after a period of three to four weeks and begin feeding in the river. The model assumes that a spawning female deposits 1320 eggs for each kilogram of her weight (Netboy, 1980; Menzies, 1949). The survival rate of the salmon from egg to sea life is taken to be 0.2 percent (calculated from data in Netboy, 1980). Salmon from each year's hatching spend varying lengths of time in the river and ocean stages of their existence. Atlantic salmon generally remain in the river for two to four years and spend from one to four years at sea. The majority of salmon spend two or three years feeding in the ocean and undergo their main period of growth at this time. Healthier salmon tend to migrate to the ocean sooner and gain weight faster than less healthy members of the species (Griswold and Hume, 1930). Figure 1 gives the assumptions made on the life cycle and weight characteristics for each year class.

Figure 1

Life Cycle and Weight Characteristics[1]

Year class[2]	Percent of Hatch[3]	Sea Weight(kg)	Mature Weight(kg)[4]
31	12	-	1.8
42	18	3.3	4.2
53	27	6.0	8.5
64	3	8.1	10.9
41	8	1.8	2.0
52	26	4.2	5.0
63	6	7.0	9.0

[1] Adapted from Larsson (1980), and Griswold and Hume (1930).

[2] Year classes are categorized according to age and time spent at sea. A fish in year class 53 is a potential five year old fish, with three of those years spent at sea.

[3] Percent of hatch represents the percentage of each year's hatch which enters a given year class.

[4] Weights are greater for the home water salmon as a result of increased time at sea (the time spent returning from the feeding grounds).

Very little is known about the ocean stage of a salmon's life, but mortality rates are high, particularly during the first few months spent at sea (Griswold and Hume, 1930; Netboy, 1968). The model assumes that mortality from natural or predatory causes rises as the salmon population approaches some limiting threshold. Such a threshold will arise naturally as a result of competition for limited food supplies and increased vulnerability to predators.

The final stage in the life of a salmon occurs when it leaves the ocean to spawn and returns to the river in which it was hatched. The salmon stops feeding as it approaches freshwater (although it will still strike a fisherman's lure), and once it reaches the headwater of the stream in which it was born it pairs with another salmon to fertilize or lay eggs in the river bottom. The salmon's ability to find its way back to the stream in which it was born is well documented; salmon are known to overcome great barriers in their struggle to reach their spawning grounds, leaping waterfalls of up to 12 feet in height (Mills, 1971), but the ordeal of spawning proves to be too much for most salmon. Seventy to ninety percent die shortly after laying or fertilizing eggs (Mills, 1971). In the model, this figure is set at 85 percent.

THE ATLANTIC SALMON FISHERIES

The development of the commercial feeding ground fisheries is a fairly recent occurrence. Only in the early 1960's was a distant water fishery developed near Greenland. Soon afterwards, another feeding ground fishery was developed in waters off the Norwegian coast (MacKenzie, 1976). In contrast, Atlantic salmon have been fished commercially in home waters since as early as the thirteenth century (Netboy, 1980).

The distant water fisheries have gained attention in recent years because of their detrimental impacts on home water stocks; however, the majority of salmon fisheries are still concentrated along the coasts and estuaries of various countries and catch the fish as they return to their parent rivers to spawn (Mills, 1971). Since the home water fisheries attack the salmon at a point in time when they are highly congregated, they have a much greater impact on salmon stocks than the feeding ground ones which catch the fish when they are much more dispersed. Indeed, extremely high levels of fishing effort by a home water fishery could conceivably result in the complete elimination of salmon from a given river.

The model assumes that the commercial home water and distant water fisheries are run as a business so that the entry and exit of commercial fishermen will depend on the average profit earned in the fishery in preceding years. Here, profit is defined as the net return to capital, or revenues less variable costs as a percent of investment. Variable costs include those dependent on the number and length of fishing trips taken by each boat as well as the share of catch value granted to the ship's crew. Costs are estimated from available data (Charron, 1972; Meister, 1983). The crew's share of the catch value is assumed to be forty percent for the distant water fishery, while the crew share for the home water fishery is slightly higher. Given a normal rate of return, it is assumed that small profits are likely to induce entry into a fishery, while relatively greater losses are needed for capital to be retired. Movement of fisheries capital appears to have followed this pattern in the past, largely due to the durability of vessels and gear and the opportunities available for investment financing and tax credits.

The model assumes that the price of Atlantic salmon is derived from a fixed demand curve. Bell (1978) gives empirical estimates of the price elasticity for salmon. Due to the long run nature of the model, slightly more elastic estimates are used in representing the demand for salmon.

The model posits that the number of salmon caught by each fishery depends both on the size of the fishery and the number of salmon available. A catch coefficient is included in the model in order to prevent the home water fishery from completely wiping out the population of salmon. This coefficient limits the home water catch to a specified percent of the number of salmon beginning their spawning run. Therefore, it has essentially the same effect as restrictions on allowable gear. Such restrictions have been established by many governments in order to maintain salmon runs on as many rivers as possible. The coefficient can be adjusted up or down according to the allowable strength of the home water fishing effort. A similar "gear restriction" is included as a policy option for management of the distant water fishery. Catch and capacity limits for both fisheries are also included in the model for use as a possible policy tool.

MODEL BEHAVIOR AND POLICY ANALYSIS

Behavior of the salmon fisheries model is examined, first, under conditions of open access in both commercial fisheries, and then, under a variety of management schemes. A brief description of the dynamics under open access is given to improve understanding of fishery behavior in the absence of government regulation. Management policies tested include: catch limits, or limitations on fishing efficiency, and limits on fishing capacity. The success of the various management policies will be judged according to their effectiveness in providing sustained total harvests and revenues.

Under open access, both commercial fisheries are assumed to be operating in an unregulated, competitive economic environment. As a result, the level of demand is the primary determinant of the equilibrium salmon stock. At low levels of demand, equilibrium stocks are relatively high; however, as demand rises, it becomes economic to deplete the salmon population to levels which greatly reduce the efficiency of harvesting. This depletion is largely a result of harvests in the shore fishery and is the primary reason gear restrictions have been imposed in the home waters of most salmon producing nations.

When the ability to catch fish is impaired by low salmon stocks, oscillations occur in investment in fisheries capital. The cyclical behavior arises from the linkage between the capital adjustment process and the impact of harvests today on the availability of salmon for harvest in the future. Capital investment in each fishery adjusts to changes in return on investment. When salmon are plentiful, profitability is high and capital moves into the fishery. At some point, harvests from the expanding fishery begin to drive down the salmon population. Eventually, the population is no longer capable of maintaining the increased catch levels and harvests per boat fall. Returns on investment begin dropping and this causes capital to leave the fishery. As capacity adjusts downward, pressure on the reproductive potential of the salmon is reduced and stocks begin to recover. Fisheries capital and total catches continue to fall, while at the same time salmon prices rise. This pattern continues until declining capacity, increasing salmon prices, and a recovering salmon stock combine to bring about an increase in profits. Then, fishing capacity begins to expand again and the cycle repeats itself. Over a very long period of time, the goal seeking nature of the capital adjustment process acts to dampen the cycles and eventually the model approaches a stable equilibrium. Cycles such as this are a well known phenomenon in marine fisheries (Adam, 1972).

With the behavior of the combined distant and home water fishery as background, we now turn our attention to an examination of the impact of distant water fishing on the home water fishery. As mentioned earlier, previous studies have cited the development of the feeding ground fisheries as the cause of recent reductions in home water catches of Atlantic salmon. To study this further, the model is used to examine home water fishing behavior in the presence and absence of feeding ground exploitation. In analyzing the results, emphasis should be placed on the qualitative nature of the change rather than the precise quantities involved. It should be noted that the distant water fishery is allowed to develop as an open access fishery. This is probably a reasonable approximation of initial events in the history of the Atlantic salmon fisheries. However, with the fall-off in Canadian and European catches, restrictions were imposed on both the Greenland and Faroe Islands fisheries. No attempt is made here to capture the effect of these restrictions.

Simulations were conducted in two modes. First, allowing no feeding ground fishing, and then, with both fisheries in operation. As expected, the addition of the distant water fishery results in substantially reduced home water catches and a marked decline in capacity in the home water fishery. This is due to the obvious fact that fishing at the feeding grounds leaves fewer salmon to migrate home. The home water fishing industry must suffer unless the number of salmon returning to spawn is in excess of the number needed to support the maximum potential harvest by the existing home water fishing fleet. This will not be the case under open access. In such circumstances, the development of the feeding ground fishery causes a 23 percent reduction in home water harvests and home water fishing capacity declines by 38 percent. Detrimental effects also occur if the home water fishery is limited to harvesting a certain percentage of migrating salmon each year. Under a 25 percent home water harvesting efficiency, distant water fishing causes a 26 percent decline in home water harvests, while under a 15 percent harvesting efficiency, catches fall 20 percent over the long run. Similar reductions occur for other harvesting efficiencies.

The main problems caused by the opening of the feeding ground fisheries stems from the fact that they began operating at a point in time when most home water stocks of Atlantic salmon were severely depleted. The strain placed on depressed local fisheries has been a major problem for most Atlantic salmon producing nations. From the standpoint of Greenland and the Faroe Islands, however, feeding ground catches represent a "grazing fee," justified by the fact that Atlantic salmon spend considerable time feeding within their territorial waters. This paper makes no attempt to determine the proper grazing fee, if one ought to exist, and we have already discussed some of the costs distant water harvests impose on a home water fishery. Now we shall concentrate on examining the effect of various policies on a jointly operated distant and home water fishery. The results indicate that allowing some degree of harvesting in both fisheries will yield higher total catches than placing a moratorium on feeding ground fishing.

Three types of policies are tested for their ability to bring about increased harvests and revenues. They are: catch limits, capacity limits, and limits on harvesting efficiency. By the last it is meant that each fishery is limited to catching a fixed percentage of the salmon available for exploitation in any given year. This last policy is meant to capture the effect of a gear restriction policy, but is not precisely the same thing. For one thing, gear restrictions are likely to involve changes in the cost of fishing. These cost effects were not incorporated into the model because they are highly dependent on the form of restriction which is imposed and may vary widely across the range of feasible restrictions.

In examining the effects of the different policies it quickly becomes clear that any of the three policies is equally effective in achieving a target harvest level. In fact, for harvests less than the maximum sustained yield, many different policies may exist which yield the same catch level. In the tests conducted, total yields and profits were highest if each fishery was allowed to catch approximately 25 percent of the fish available for exploitation. Under such regulations, the total commercial catch was five times as great as the catch under open access. This level of catch could be achieved either by limiting the efficiency of harvesting, or through the appropriate catch or capacity limits.

It is interesting that such a policy would imply the existence of a fairly large distant water fishery. Once the distant water fishery is allowed to reap significant harvests, the appropriate grazing fee becomes a crucial issue. The ratio of distant to home water harvesting which yields the largest total catch may not result in a desirable distribution on revenues, particularly from the standpoint of salmon producing nations. Achieving the appropriate distribution would require either require an international transfer payment or regulations aimed at providing the optimal income distribution rather than the optimal overall harvest level.

Reaching the high catch levels described above poses significant management problems. For such large harvests to be sustainable, it would be necessary to allow the Atlantic salmon stock to recover to much higher levels than exist presently. Simulations indicate that stocks would need to be at least 5 times as large as those under open access; probably more, depending on demand conditions. Achieving stocks of this magnitude would require painful short term sacrifices. Determining the best way to retire the excess capital which prevents fish stocks from recovering is a common problem facing over-exploited fisheries.

In conclusion, we have seen that under simulated conditions, the distant water Atlantic salmon fishery imposes significant costs on home water fisheries. However, if Atlantic salmon stocks can be increased in the future, operation of a distant water fishery in conjunction with the home water fisheries will yield sustained total harvests and revenues larger than the home water fisheries are capable of producing in isolation.

ACKNOWLEDGEMENTS

The author wishes to thank Nathan Forrester for his helpful comments and suggestions. Thanks are also due the National Science Foundation for their support of my graduate education.

REFERENCES

Adam, P. 1972. "Practical Problems of Policy Formulation in Fisheries," in Economic Aspects of Fish Production, Paris: OECD. pp. 40-49.

Anonymous. 1983. "Iceland Salmon and Faroese Fishermen," The Atlantic Salmon Journal, Summer, p. 11.

Bell, Frederick. 1978. Food From the Sea: The Economics and Politics of Ocean Fisheries. Boulder: Westview Press.

Beverton, R.J.H. and S.J. Holt. 1957. On the Dynamics of Exploited Fish Populations. London: Ministry of Agriculture, Fisheries and Food. Fisheries Investigations. Series 2:19.

Brewster, William S. 1982. "Are the Faroese Ruining Salmon Fishing?," *The Atlantic Salmon Journal*, September, 8-11.

Charron, J.P. 1972. *Costs and Earnings of Selected Fishing Enterprises: Atlantic Provinces, 1969*. Ottawa: Environment Canada. Primary Industry Studies, 19:1.

Clark, Colin. 1976. *Mathematical Bioeconomics*. New York: Wiley.

Griswold, F.G. and R.D. Hume. 1930. *The Life-History of the Atlantic and Pacific Salmon of Canada*. New York: Dutton's Inc.

Kreiberg, H. 1980. *Report on the Greenland Expedition, 1980*. New York: International Atlantic Salmon Foundation. Special Publication Series, 9.

Larsson, P.O. 1984. "Effects of Reduced Fishing for Feeding Salmon (Salmo salar L.) in the Baltic on Home Water Fisheries According to Simulations with the Carlin-Larsson Population Model," *Fisheries Management*, 15:3, 97-105.

MacKenzie, Hugh. 1976. "Some Notes on International Measures for the Control of Fishing for Salmon in the North Atlantic Outside national Fishery Limits, ie. on the 'High Seas'," *Fisheries Management*, 7:2, 38-41.

May, A.W. 1973. "Distribution and Migrations of Salmon in the North Atlantic," p. 373-382, in M.W. Smith and W.M Carter (eds.), *International Atlantic Salmon Symposium 1972*. New York: International Atlantic Salmon Foundation. Special Publication Series, 4:1.

Meister, Alfred L. 1983. *The Faroese Salmon Fishing Industry and its Management*. New York: The Atlantic Salmon Federation. Special Publication Series, 11.

Menzies, W.J.M. 1949. *The Stock of Salmon*. London: Edward Arnold and Co.

Mills, Derek. 1971. *Salmon and Trout: A Resource, its Ecology, Conservation and Management*. New York: St. Martin's Press.

Netboy, Anthony. 1968. *The Atlantic Salmon: A Vanishing Species*. London: Faber and Faber, Ltd.

Netboy, Anthony. 1980. *Salmon: The World's Most Harassed Fish*. Tulsa: Winchester Press.

Paloheimo, J.E., and P.F. Elson. 1974a. *Effects of the Greenland Fishery for Atlantic Salmon on Canadian Stocks*. New York: International Atlantic Salmon Foundation. Special Publication Series, 5:1.

Paloheimo, J.E. and P.F. Elson. 1974b. "Reduction of Atlantic Salmon (Salmo salar) Catches in Canada Attributed to the Greenland Fishery," _J. Fisheries Research Board of Canada_. 31: 1467-1480.

Ricker, W.E. 1958. "Handbook of Computations for Biological Statistics of Fish Populations," _Bulletin of the Fisheries Research Board of Canada_, 119.