Resource and Energy Economics 36 (2014) 417–435

Contents lists available at ScienceDirect

Resource and Energy Economics

journal homepage: www.elsevier.com/locate/ree

# Wild salmon fishing: Harvesting the old or young?

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ARTICLE INFO

*Article history:*
Received 1 February 2013
Received in revised form 29 January 2014
Accepted 31 January 2014
Available online 11 February 2014

*JEL classification:*
Q22
Q57
C61

*Keywords:*
Salmon fishery
Age classes
Maximum economic yield

ABSTRACT

This paper develops an optimal harvesting model for the wild Atlantic salmon (*Salmo salar*), where various age classes of the population are included. It is shown that the marginal value–fecundity relationship of the spawning population, comprising young and old fish, is crucial for the optimal fishing composition. If the value–fecundity ratio is higher for the old spawning population, this age-class should be harvested more aggressively than the young spawning population, and vice versa. It is also shown that changes in prices and interest rate have similar as well as different effects than in the standard fishing biomass model. Small changes in the relative price for the harvestable age classes could either increase or reduce the optimal harvest intensity, or have no effect. While a higher interest rate tends to increase fishing, there also exist intervals of the interest rate in which the optimal harvest program is not affected by changes in the interest rate.



## 1. Introduction

For many years, the North Atlantic salmon (*Salmo salar*) has been one of the most important fish species in Norway because of its social, cultural, and economic importance. It was traditionally harvested for food, but today is most important to recreational anglers. Norwegian rivers are the most important spawning rivers for the Atlantic stock, and about 30% of the remaining stocks spawn there.

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http://dx.doi.org/10.1016/j.reseneeco.2014.01.006

The wild salmon is harvested by commercial and recreational fisheries. The marine harvest is commercial and semi commercial, whereas the harvest in the spawning rivers is recreational (NOU, 1999). The amount harvested in marine and river fisheries has been more or less similar over the last few years, but the value of river fishery is much higher because of the higher willingness to pay for sport fishing (NOU, 1999; Olaussen and Skonhoft, 2008).

However, the abundance of wild salmon stocks has been declining during the last few decades. Stock development has been especially disappointing since the 1990s because of a combination of various factors, such as sea temperature, diseases, and human activity, both in the spawning streams and through the strong growth of salmon sea farming (NASCO, 2004). As the wild stock began to decrease during the 1980s, the Norwegian government imposed gear restrictions to limit the marine harvest. Drift net fishing was banned in 1989, and the fishing season of bend net fishing, taking place in the fjords and close to the spawning rivers, has been restricted several times. At the same time, the sport fishing season in the spawning rivers has been subject to various restrictions (NOU, 1999). However, despite all these measures taken to secure and rebuild the stock, the abundance of wild salmon seems to be at only half the level experienced in the 1960s and 1970s. It is believed that the rapid expansion of the farmed salmon industry has played the most important role in this decline and today, farmed salmon is regarded as the main threat to the viability of the wild salmon population because of the spread of diseases, escapees, and environment pollution (Hindar et al., 2006). In Liu et al. (2013) possible biological as well as economic effects of farmed salmon escapees are analyzed and numerically illustrated.

Wild salmon fishing has been studied in many papers from an economic perspective. Routledge (2001) studied a mixed stock versus single stock fishery related to Pacific salmon while Laukkanen (2001) analyzed the northern Baltic salmon fishery in a sequential fishing biomass model. Olaussen and Skonhoft (2008) also analyzed a sequential harvesting biomass model, but with recreational fishery in the rivers as its focus. The economics of the Baltic salmon fishery is studied in an age structured dynamic model in Kulmala et al. (2008), comprising migration and seasonal harvest and competing harvesting by commercial and recreational fishermen. Uncertainty is also included, and the model is parameterized and solved numerically for a Finnish river stock. In what follows, an age-structured wild salmon model is analyzed as well, but within a much simpler framework than that of Kulmala et al. The goal is, from a theoretical point of view, to study how the harvesting of different age classes influences recruitment and stock abundance, and the main focus is to find the harvest composition that maximizes the economic yield (*MEY*) under various economic conditions. We will think of the fishing related to a river recreational fishery such that the harvesting value is made up of the angler willingness to pay for the catch minus the cost of organizing the fishery and no stock dependent costs are included.

Age-structured models are far more complex than biomass models. On the one hand, it is relatively straightforward to formulate a reasonably good age-structured model and numerically simulate the effects of variations in fishing mortality between age classes and over time. On the other hand, it is notoriously difficult to understand the various biological and economic forces at work in such models. Tahvonen (2009) has analyzed some of these issues in which he finds some results in a dynamic setting, but under quite restrictive assumptions (i.e., only one agent, or one fleet, causing fishing mortality). Early contributions analyzing age-structured models include Reed (1980), who studied the maximum sustainable yield problem. He found that optimal harvesting comprises, at most, two age classes. Further, if two age classes are harvested, the elder is harvested completely. This model is extended in various directions in Skonhoft et al. (2012). Getz and Haight (1988) reviewed various age-structured models, and formulated the solution for the maximum sustainable yield problem as well as the maximum yield problem over a finite planning horizon. The following analysis has similarities with Reed (1980) and Skonhoft et al. (2012), but we study a different biological system in which all the spawning fish, i.e., salmon, die after spawning. This contrasts with the above mentioned works, where the spawning fish (e.g., cod) survive and enter an older age class after spawning. As will be seen, this difference has important implications for the optimal harvesting policy. In addition, just as in Tahvonen (2009), and also the age structured models in Quaas et al. (2013) and Diekert et al. (2010), our analysis is framed in a dynamic setting. While our analysis is directly related to Atlantic salmon, we will find that it fits various Pacific