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May stocking programs effect the predator stocks and decrease the survival of the wild Atlantic salmon juveniles?

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Abstract
Stocking of Atlantic salmon juveniles is carried out in many rivers to increase the production of smolts. In many cases, the number of stocked juveniles exceeds the assumed carrying capacity of the river, and represents a conciderable and instantaneously increase of the fish biomass. Normally, the stocked juveniles suffer from high predation mortality, presumably higher than for native fish. Therefore, the introduction of stocked naive prey may influence the number and size of predators. When the stocked juveniles has been depleted, the predation upon their wild conspecifics might increase. In this paper we will discuss possible relationship between the survival of the wild juveniles and the introduced biomass, the time of stocking and its influence on the stock of predators.

Introduction
Stocking of juvenile stages of Atlantic salmon in rivers has been performed throughout this century and in a high number of rivers to enhance stocks of Atlantic salmon. Initially, alevins at the yolk sac stage was the most frequently used for stocking. Following improved culture techniques and investments in local hatcheries, there has been a clear trend towards stocking with older juveniles and occasionally smolts ready to migrate to the sea.

Stocking of Atlantic salmon in Norway is performed to maintain fisheries in regulated rivers and where the original stock is lost or heavily reduced due to acidification (Hesthagen & Hansen 1991) or due to infestations of the parasite fluke *Gyrodactylus salaris* (Johnsen & Jensen 1991). The stocking in regulated rivers is usually carried out to enhance fisheries under the assumption that the natural production has been lowered.

A release of hatcery-reared young salmon into the river environment and the effect on vertebrate predators may in some sense be compared to a rapid build up of short-lived, cyclical prey populations in terrestrial environments. Examples of such terrestrial prey-predator relationships are: snoeshoe-hare-fox, moose-wolf, ptarmigan-fox, small rodents-birds of prey among many others. The common features of these prey populations are rapid growth, very high reproductive rate, short livfespan, and highly fluctuating population densities. The predators are longer lived and their response to a temporary increase in prey availability is an increase in number and survival of their offspring leading to an enlarged predatory stock. When the temporary prey is depleted or reduced due to other density-dependent factors, the increased number of predators are forced to switch their feeding to other prey which experience an increased predation pressure.

We have chosen an approach based on the examples from West Norwegian watercourses hosting populations of anadromous Atlantic salmon and brown trout. In the part of the river inhabited by anadromous fish, Atlantic salmon and brown trout are the dominating fish species, in addition European eel may be found. In lakes situated at the parts accessable for anadromous fish, brown trout and Arctic charr are normally the dominating original fish species, followed by European eel and occassionally populations of three spined stickleback. In contrast to the almost obligate anadromous Atlantic salmon, the populatons of brown trout consist of both anadromous and resident individuals (Jonsson 1985,1989), but there are little or no genetic difference between sympatric populations of anadromous and resident trout (Skaala 1992, Hindar et. al. 1991). Young fish in the rivers are predated upon by conspecifics, however to an unknown extent. Other predators are mink, otters, heron and mergansers, but river resident brown trout is regarded as the most important predator in larger rivers.

The present study deals with stocking of young Atlantic salmon of the year during August and November in rivers where natural recruitment of Atlantic salmon takes place, i.e. supportative breeding. At the time of release, the high number of predator naive fish increases the total number of young fish considerably and one should expect increased level of aggression, territorial conflicts and probably some state of territorial chaos between stocked and wild conspecifics. Also, there might be an increased mortality through cannibalization of wild specimen (Evans and Willox 1991) and indirect effect through the build up of predatory species in response to large scale releases (Wood 1986, Beamish et. al 1992).

In this paper we will describe possible effects ecological of stockings. The knowledge on interactions between the stocked fish and structural changes in the predatory stocks is however limited. This discussion will therefore be based upon, and discuss the following assumptions that may be fulfilled in some rivers:

1) The carrying capasity in the river is reached during late winter.
2) The production of wild fish is at, or close to, carrying capasity.
3) The mortality of stocked juveniles is considerable higher than that of the wild.
4) The biomass of juvenile salmon change seasonally with a maximum during late autumn.
5) The introduced biomass of stocked fish is high in relation to the wild biomass.
6) Because of their sizes, the stocked juveniles are available as prey for the trout.
7) The biomass of the stocked juveniles is sufficient to increase the number and/or size of predatory trout.
8) While the majority of the stocked juveniles are depleted, the enlarged stock of piscivore trout represent a long-term increase in the predation pressure upon survivors and the wild juveniles.

1) The carrying capasity in the river is reached during late winter.
It may be anticipated that the carrying capacity of the river is basically determined by bottlenecks during winter. The mortality of young salmon and trout might be high during winter due to habitat compression and resticted overwintering area (Hvidsten 1993, Fjellheim et al. 1995, Gibson 1993). Winter mortality of larger fish, i.e. those that spend their last winter in the river before migrating to the sea as smolts has been estimated to 30% during the last winter in freshwater (Gibson 1993). However, in the regulated river Orkla, the production of Atlantic salmon smolts increased after regulation. This was ascribed as an effect of higher and less variable discharge during winter and increased area of suitable habitats (Hvidsten 1993, Hvidsten and Johnsen 1995). It is not known whether the reduced natural mortality was caused by reduced competition or reduced predation.

2) The production of wild fish is at, or close to, carrying capasity.
We assume that the abundance will reach carrying capacity during winter irrespectively of the abundance in late autumn. Suggestively, some of the stocked fish will survive at the expence of wild conspecifics if the number of wild juveniles was high enough to reach winter capacity levels. The production of smolts varies a lot between rivers and there is a general trend that smaller second-order rivers are more productive than larger rivers with higher discharge (Gibson 1993). Within a river, the production of smolts varies less between years than the total density including all yearclasses of juvenile fish, which means that the pattern of mortality varies considerably between years depending on number of recruits (age-0) and the carrying capacity of fish of the size of smolts (Lacroix 1989, Gibson 1993, Saltveit 1993, Baglenière et al. 1994, Hvidsten & Johnsen 1995, Jensen et al. 1995, Saksgård et al. 1995).

3) The mortality of stocked juveniles is considerable higher than that of the wild.
There are very few studies on the survival of stocked juvenile Atlantic salmon compared to the wild ones and interactions between the effects of stocking and the survival of wild. Survival of stocked brown trout have been estimated in the regulated River Teigdalselva in Western Norway (Fjellheim et. al 1995). A number of 70.000 brown trout parr (age-0) with average length of 6.4 cm were stocked in late June in 1992. The total density of juvenile trout increased more than ten-fold after stocking with maximum densisty of 684 individuals per 100m^2. Until 10 October 1992 the density of stocked fish was still very high at and near the stocking sites. During this period the stocked fish spread to a certain extent, and predominantly upstream, but they did not cross the river, showing that dispersal after stocking lasts for a long period. The next spring, in April

1993, the total density of brown trout juveniles was at the same level as in April 1992, prior to the stocking. The mortality from stocking until April 1993 was estimated to 99% for stocked fish and 79% for wild brown trout, all juvenile age-classes included. It is not known if survival of wild fish was affected negatively by the stocking, but stocked brown trout cannibalizated smaller young conspecifics (Fjellheim et. al 1995). The result from this study clearly indicates that irrespecticve of density in autumn, there is density dependent mortality over the winter reducing the density to the level of the carrying capacity and also that the mortality was highest for the stocked fish for a long period after stocking.

In a neighbouring, regulated river, the density of brown trout increased 10 times in the area upstream a weir during the years following the weir construction, presumbaly due to enlarged winter areas increasing survival (Raddum et. al 1989). Although these examples refer to brown trout, the main results might well apply for Atlantic salmon.

4) The biomass of juvenile salmon change seasonally with a maximum during late autumn
The density and biomass varies conciderably within a river and between seasons. The biomass is lowest in spring and early summer after the smolts have left the river and is probably highest just in the end of the growing season, i.e. end of October. Due to winter mortality and low growth under low temperatures one should assume that there is a gradual reduction of fish biomass during winter, and then an abrupt decrease when the smolts leave the river during April and May The seasonal variation in biomass is higher in rivers with 2-year old smolts compared to rivers where the smolt age is higher due to more year-classes present throughout the year.

5) The introduced biomass of stocked fish is high in relation to the wild biomass
In rivers where the average smolt age is 3 years or more, the smolt production is at a level of 2 to 5 smolts/100m^2, while in rivers where the largest portion of the fish smoltify after two years, the production is conciderably higher, 5-15 smolts/100m^2 (Gibson 1993, Hvidsten & Johnsen 1995, own unpublished results). These figures refer to northern rivers.

Stocking of juveniles takes place mainly in August and September, during the second half of the growth season. Normally, the stocked fish are first fed or raised in culture throughout the summer. Size when stocked depends on hatching time and temperatures. Where eggs and young are kept at elevated temperatures, the stocked fish might reach a lenght of 8-10 cm during the first summer weighing app. 10 g in August (as for instance in River Suldalslågen). Where temperatures and growth opportunities are lower, the size is between 4-8 cm, weighing 1-3 g when stocked in August, for instance in River Vosso.

In River Vosso, the stocking density is 5 fish per 100m^2 (average fish weight of 2 g) if distributed evenly on the total river area, however, the stocking is carried out through releases of a high number of fish in restricted areas, where the initial density exceeds 100 fish per 100 m^2. In River Suldalslågen, the average stocking density was 4 per 100m^2 (average weight 9 g) in 1995 (Svein Jacob Saltveit, pers. med.) and as in Vosso the density of stocked fish exceeded 100 fish per 100 m^2 at and near the stocking sites.

At the stocking sites, the biomass of salmon parr may increase twice to four times the original biomass of wild parr. Over time, the fish will spread from the stocking site and occupy adjacent areas, this process might however last for a considerable time, up to several months (Fjellheim et al. 1995).

6) Because of their sizes, the stocked juveniles are available as prey for the trout.
The released cultured juveniles are predated upon if their sizes are suitable for predatory trout. The facultative piscivorous wild brown trout selects prey with lengths approximately 25% of its own length (L'Abée-Lund et al. 1992). Tank experiments with predatory brown trout fed living Arctic charr as prey revealed a similar selection for prey sizes as the studies of wild trout (Damsgård 1993). There are few records of piscivorous small brown trout in rivers. However, they do excist and juvenile trout of 12 and 17 cm length have been found with Atlantic salmon juvenils in their stomachs with lengths between 29% and 41% of the predators length (own unpublished results).

Damsgård (1993) found that the piscivorous trout ate 0.4 prey each day on average and daily food consumption was 7 mg fresh weight of prey per g fresh weight of predator per day. The specific growth rate was 0.2% per day, daily consumption were up to 25 mg fw*g fw^{-1} , with a growth efficiency of 15%.

In field experiments studying stocking of 30 cm long brown trout predating on Arctic charr in lakes, daily and yearly food consumption of the trout was calculated by tracing of radioisotopes of cecium originating from the Tjernobyl accident (Sandlund and Forseth 1995). The obligate piscivorous brown trout ingested a daily ration of 2.54 mg dry weight of Arctic charr prey per g wet weight of the predator. This estimate of 2.54 mg is of the same magnitude as 1.75 mg, which is obtained from the tank experiment of Damsgård (1993) if the wet to dry weight conversion factor of 25 % (Lien 1978) is applied. Results from the field experiments suggested that each brown trout consumed 3,49 kg of Arctic charr prey each year on average, and with a mean prey weight of 10 grams, the total number eaten per trout was 349 from 10 May until 20 October, i.e. approximately 2 preys per fish per day.

7) The biomass of the stocked juveniles is sufficient to increase the number and/or size of predatory trout
Brown trout is a facultative piscivore and it is at present not known how the environment and genetic bakcground influence the individual decision to become a piscivore or not. Enhancement programmes using parents of the same stock that were piscivore or not did not influence the feeding strategy of the offspring, thereby indicating that the decision is under environmental control or happens at random. However, availabilty of naive prey could influence the decision. One may suggest that the dominant and most aggressive individuals (and/or the largest) has the highest chance of becoming a piscivore. Piscivory implies a different foraging tactic that is benefitable in terms of growth as fish prey are larger, but also less easily captured. Therefore, if the change to a piscivore lifestyle is followed by an enlarged body size of the predator it may be difficult to switch to other prey when the resource is depleted to cover the energetic demands.

The smallest that become piscivores might be fish with size smaller than smolts if the stocked fish is small, i.e. a very high number of potential predators. If the stocked fish is larger, the number of potential piscovores is lower. In addition, a high number of sea trout return to the rivers from the sea from July to September and if offered easy prey they may feed in the river. Sea run trout that returned to lakes in late summer was shown to predate on Arctic charr (Jonsson 1985).

The following stocking densities and sizes of fish stocked are actual examples from rivers in Western Norway that may be used to produce rough estimates of the increase in piscivore trout. One might assume that 50% of the stocked fish are eaten by brown trout and the conversion factor is 15% (Damsgård 1993) to calculate the increase in biomass of piscivorous brown trout after stocking. If the size of the stocked parr is 2 grams and the number stocked is 50.00, the biomass eaten is 50 kg and the increase in trout biomass is 7,5 kg. If the stocked fish is 10 g and the number stocked is 150.000, then he biomass eaten is 750 kg, representing an increase of 112,5 kg in trout biomass. If the average weight of predators is 0,5 kg, the increased biomass represents 15 and 225 piscivores, respectively. If we assume that each of these eat 1 fish prey of the size of presmolts each third day from January through April, i.e. 120 days, they will then eat 600 and 9600 presmolts, respectively. These figures indicate that a high stocking density of relatively large fish will have a much higher potential effect on the predator stock than stocking of smaller fish. However, when the stocked fish is small there is a much higher number of potential predators, i.e. presmolt of trout. For these the extra input of prey might influence the choice of staying in freshwater or migrate to the sea. The choice between these alternatives depends presumably on the trade off between increased growth potential and reduced chance of survival in the sea. When extra prey is added in the freshwater habitat both growth potential and survival will increase, presumably favouring residence. Additionally, if the stocking resulted in a switch in feeding strategy of resident brown trout, the increase in number of piscivore trout is larger than these estimates because they may already be large enough to change feeding mode.

In addition, mergansers might predate heavily on Atlantic salmon parr and these birds immigrate to rivers in western Norway during winter, presumably to feed on salmonids in habitats free of ice. The high mobility and scanning abilities of these birds imply that they can locate rivers with high densities of fish. Sites where fish has been stocked may thereby attract birds and this may contribute to a heavier predation on both stocked and wild fish.

8) While the majority of the stocked juveniles are depleted, the enlarged stock of piscivore trout represent a long-term increase in the predation pressure upon survivors and the wild juveniles.

Atlantic salmon and brown trout parr feed during winter, but the growth in length is normally low. The habitat use and diurnal activity is different in winter compared to the summer with a switch to predominantly nocturnal feeding when temperatures are low (Heggenes et. al. 1993). The ability to feed and digest food under low temperatures increases with fish size, piscivorous brown trout may therefore search for prey also during winter. Prolonged predation and low salmon ongrowth will result in biomass reduction during winter. In general, brown trout is able to feed and digest food under lower temperatures than Atlantic salmon. According to Jensen (1990) the lower temperature limit is 4 and 7°C for small brown trout and Atlantic salmon, respectively.

Small fish have lower energetic reserves than large fish and depend on continuous feeding to survive. Large Atlantic salmon and brown trout can survive for a long time without feeding due to large reserves of fats and proteins. For instance, an adult female salmon that return to the river in June one year might stay in the river for 12 months without feeding and during this time approximately 20% of original biomass is lost during growth of gonads, and there is also a considerable loss of energy related to the work when digging redds during spawning.

Piscivorous trout might store large fat reserves after having fed on stocked juvenile Atlantic salmon during the autumn and early winter. This reserves will enhance survival during winter without extra feeding and may maintain the stock of predatory trout at an extended over time. During the smolt run next spring it might well predate on the migrating smolts which are very vulnerable at that time. Due to the ability to survive for long periods without food when temperatures are low, there might well over years be an accumulating effect of stocked biomass that is transformed into piscivorous brown trout biomass, especially when the stocking is repeated over years. If so, it must be anticipated that the predation upon the wild juvenioles is increased as a consequence of the stocking.

Overall conclusions

Immediately after stocking there is presumably a hierarchical chaos at the stocking sites. In this situation with a high number of naive fish interferring with the established territorial patterns, one could assume an increased level of aggression among territory holders. When brown trout experience the award of fish prey one should assume that this feeding mode is carried on. An increase in the number of piscivores might in turn lead to heavy predation on stocked fish.

The initial increase in fish biomass following stocking might be reduced to carrying capacity during winter due to habitat compression, restricted winter areas, natural mortality and converted into piscivore trout, bird or mammal biomass. When the density of young salmon is reduced to carrying capacity there may still be a higher biomass of piscivores present. An increase in the stock of piscivore brown trout following a single stocking one year might have negative effects on the population of Atlantic salmon parr over several years due to the longivity of brown trout that also might use other habitats like lakes or the sea for feeding in parts of the year. Although not verified, this scenario is not unlikely and should probably be considered when stocking is recommended.

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