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Ecological and economic costs of supportive breeding: Atlantic salmon (*Salmo salar*) as a case study

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ABSTRACT

Supportive breeding is a common management action carried out to enhance Atlantic salmon populations in the region of Asturias (northern Spain), but its real success is yet unknown despite the high effort expended in the last decades (since 1992). Identification of returning adult salmon as hatchery descendants was carried out with microsatellite loci and pedigree tests in two rivers of the region (Sella and Cares). High levels of straying between rivers and rates of return between 6% and 11% of Atlantic salmon hatchery descendants in sport fishing catches were found. The estimated cost of each salmon caught was higher than €4000.

1. Introduction

Stocking is a common management action used with the intention of enhancing depleted populations of diverse fish species (e.g., Borrell et al., 2011; Wasko et al., 2004; Wedekind et al., 2001), among which are anadromous species such as salmonids (van Zyll de Jong et al., 2004). The main stocking impact on natural populations is the introgression of hatchery genes (Launey et al., 2006; Levin et al., 2001); even the complete replacement of wild fishes with hatchery-reared fishes has been reported (Englbrecht et al., 2002). In salmonids, some studies have not found evidence of introgression of hatchery fish despite high levels of releases, whereas in other cases different levels of this type of introgression have been reported (see a review in Fleming and Petersson, 2001).

Hatchery-reared salmonids exhibit behavioral modifications. Cultured salmon usually grows faster than wild salmon, and larger individuals dominate over smaller ones. For individuals of the same size, it is not clear if wild individuals will dominate over hatchery ones or vice versa. The effect of domestication on aggressiveness has been intensively debated. Earlier experiments suggest that agonistic behavior either can increase (Mesa, 1991; Moyle, 1969; Swain and Riddell, 1990), decrease (Hedenskog et al., 2002; Robinson and Doyle, 1990; Ruzzante and Doyle, 1991) or be stable (Ruzzante and Doyle, 1993) with domestication. Game theory predicts that at high densities (such as those found in hatcheries) there should be strong selection pressure for less aggressive individuals because the number of interactions with conspecifics will make it almost impossible to maintain territories (Doyle and Talbot, 1986; Ruzzante, 1994). It seems that the direction and intensity of the relationship between agonistic behavior and growth in fish may be dependent on the environmental conditions under which the competition for food take place; in fact, wild individuals can be similarly or more aggressive than hatchery ones (Petersson and Järvi, 2000, 2003). Anti-predator behavior also differs between wild and domesticated fish; the domesticated most likely exhibit a behavioral repertoire that is inferior in the wild (Petersson and Järvi, 2006). In general, behavior changes associated with domestication make hatchery fish poorly adaptable: lifetime reproductive success of cultured fish has been estimated to be 17% of that of wild fish (Jonsson and Jonsson, 2006). Finally, other behaviors of hatchery fish can significantly alter wild population structuring when released in the rivers. For example, straying rate is higher in domesticated than in wild salmonids (Jonsson and Jonsson, 2006), hence contributing to the dilution of spatial population structuring.

Atlantic salmon is an anadromous species, in which northern Spanish populations have been declining for the last two decades (Horreo et al., 2011a). This decline is a consequence of a combination of fishing pressure, habitat pollution, and destruction or inaccessibility of spawning areas (Garcia de Leaniz et al., 1992), estimated to be reduced by more than 80% in the region due to construction of dams (García de Leaniz, 2008). To increase population sizes, managers have carried out supportive breeding in Asturias (northern Spain) since 1992. Supportive breeding employs autochthonous individuals as broodstock and therefore

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avoids problems associated with foreign stocking, which was ineffective in the region for increasing population sizes (Ciborowski et al., 2007; Garcia-Vazquez et al., 1991) and threatened local adaptation (Moran et al., 2005) by introgression of foreign genes (Ayllon et al., 2006; Martinez et al., 2001).

Asturian hatcheries have produced approximately 10 million Atlantic salmon juveniles of autochthonous origin between 1992 and 2008 (Horreo et al., 2011b). This enormous number of fish released in small rivers may impact on natural populations in different ways. Losses of genetic variability have been reported in Asturian hatchery stocks (Machado-Schiaffino et al., 2007) likely due to early-stage competition of juveniles in the hatchery (Horreo et al., 2008). Hatchery releases may thus disturb genetic variability of the natural populations if genetic resources are not managed well. Reduced variability can endanger the viability of the populations by decreasing their capacity for local adaptation (Frankel and Soulé, 1981). In addition, survival of large numbers of hatchery-reared juveniles may overcome the carrying capacity of the river habitats and induce stressful processes of competition between wild and released individuals (Jonsson and Jonsson, 2006). On the other hand, if supportive releases were not successful, detraction of many breeders from the wild populations for producing the supportive hatchery stocks would have served nothing except high economic expenses and environmental costs. The European Commission has recently suggested phasing out of the release of salmon in rivers that have man-made obstacles and without potential for the re-establishment of self-sustaining wild salmon populations in order to protect the genetic diversity of the wild stocks (see http://europa.eu/rapid/pressReleasesAction.do?reference=IP/11/961&format=HTML&aged=0&language=EN&guiLanguage=en).

Despite the high investment made by the stakeholders, biological and economic costs of Atlantic salmon supportive breeding have not been assessed in Asturias yet. The aim of this study was therefore to evaluate the success of Atlantic salmon supportive breeding management in Asturias (northern Spain), quantifying its contribution to recreational fisheries and assessing the cost of hatchery-reared returning salmon. Pedigree tests were carried out based on hypervariable microsatellite loci for identifying returning adults of hatchery origin amongst the sport catches in two rivers of the region (Sella and Cares).

2. Material and methods

2.1. Supportive breeding management

Two of the most important salmonid rivers in Spain (the southern limit of this species' natural distribution) were analyzed: the rivers Sella and Cares (Fig. 1). These rivers have very similar length (56 and 54 km for the Sella and Cares rivers, respectively) and characteristics (habitat, climate, water flow, etc.). Their river mouths are separated by 50 km. After the removal of one obstacle in the Sella River 10 years ago, the two rivers are now totally accessible for Atlantic salmon (previously, Atlantic salmon only was present in the downstream area of the river). They are managed by the Regional Government of Asturias with hatcheries (two in the Sella River and one in the Cares River) close to the rivers. Each population is managed separately; Sella River hatcheries contain only Sella River salmon, while salmon from the Cares River is reared only in the Cares River hatchery. Supportive breeding produces about 300,000 salmon juveniles per hatchery. These juveniles are descendants of Atlantic salmon returning to the river, which spawn artificially in the hatcheries. Each cross is done pooling together the sperm of at least two males to combine with the ova of one female and is kept separately. After some weeks, progeny of different crosses are pooled together in batches. Two/three months after that, the alevins from these batches are pooled again in big tanks. Six to eight-month-old juveniles are released in different points along the original river.

The annual costs of supportive breeding in these rivers (salaries as well as maintenance of broodstocks and amortization of facilities) were obtained from the Asturian Regional Government (Dirección General de Recursos Naturales del Principado de Asturias). A hatchery of medium size in this region produces an average 300,000 juveniles/year and employs two persons full time. Staff salaries, costs of stock maintenance (fish feed and electricity), veterinarian care, expenditures necessary for releasing the juveniles (transport and staff per diem) and amortization of the facilities – including equipments – were considered.

2.2. Sample collection

All the breeders employed for producing the supportive stocks released in the Sella and Cares rivers in 2005 were sampled (adipose fin clips) for genetic analyses. The details were described in previous articles (Horreo et al., 2008; Machado-Schiaffino et al., 2007). The Sella River stock was created with 99 breeders of different age classes, and the Cares River stock with 44 breeders. Those adult mature breeders were caught (electrofished) or trapped from the respective rivers in December 2004 and artificially crossed in the hatcheries as explained above. The broodstocks were not genetically different from the respective river stocks (Machado-Schiaffino et al., 2007). The Sella River breeders were split in the two different hatcheries located in the drainage (66 and 33 in each one). The Cares River breeders and their offspring were kept in the Cares River hatchery.

It is possible that breeders chosen as broodstock could be hatchery descendants of past supportive releases or hybrids between hatchery and wild individuals. However, since the breeders are caught from returns each year, it would not influence on results. The progeny of these broodstocks were genetically analyzed in previous studies commented above (Horreo et al., 2008; Machado-Schiaffino et al., 2007) and small effective size (Ne) was detected for the Sella River alevins

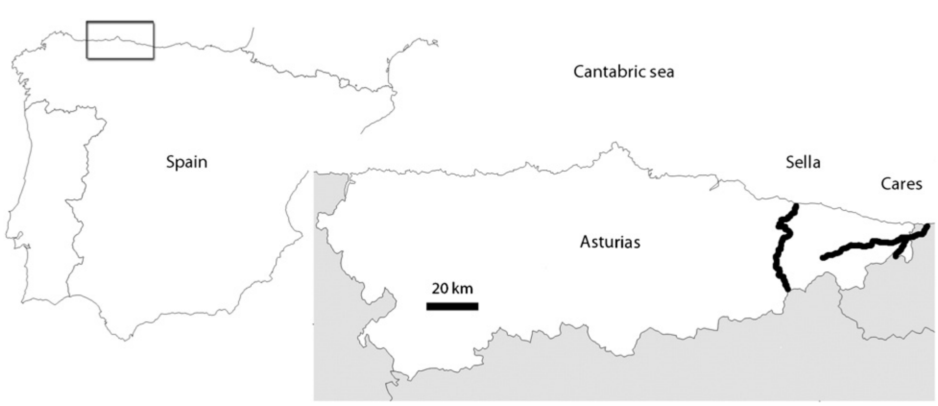

Fig. 1. Geographic location of the Sella and Cares rivers in Asturias (North of Spain).