



Reduced reproductive success of hatchery fish from a supplementation program for naturalized steelhead in a Minnesota tributary to Lake Superior



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ABSTRACT

Reduced reproductive success of hatchery fish spawning in the natural environment will reduce the ability of stocking programs to enhance wild populations. We used DNA-based parentage assignment to compare the reproductive success of wild fish and first-generation hatchery fish from a smolt stocking program that used broodstock from within the naturalized steelhead *Oncorhynchus mykiss* population in a Minnesota tributary to Lake Superior. The reproductive success of hatchery females was significantly lower than that of wild females (approximately 60%) in all three study years; however, the reproductive success of hatchery males was only significantly lower in one year. Higher reproductive success of wild fish was attributed to greater probability of success (i.e., having at least one offspring) and not differences in numbers of offspring among successful parents. Generalized linear models indicated that run timing was associated with probability of success although this did not explain differences between hatchery and wild fish. Despite runs that extended 7–9 weeks, most successful adults arrived in the first three weeks of the run (85–98% of all successful females, 98–100% of successful males). The early part of the run corresponded to periods of high flow, which likely increased access to quality spawning and rearing habitat higher upstream in the system. Relationships between fish length and reproductive success were inconsistent. Managers may minimize potential environmental and genetic contributors to reduced performance by hatchery fish, but continued reliance on hatchery supplementation may hinder achievement of the long-term goal of a fishery supported largely by naturally reproducing populations.

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Introduction

Multiple studies have reported lower reproductive success for hatchery salmonids than their wild counterparts (e.g., Araki et al., 2008; Bernston et al., 2011; Thériault et al., 2011), but there are several exceptions (e.g., Berejikian et al., 2009; Hess et al., 2012). The source of broodstock, generations of hatchery experience, length of rearing time, and other conditions in the rearing environment all may play a role in the reproductive performance of hatchery fish in the wild. Kitada et al. (2011) applied a bias correction to the data of Araki et al. (2007a,b, 2009) that supported the finding of reduced average reproductive success for hatchery fish and their descendants, but they could not confirm statistically lower reproductive success in a meta-analysis of the

multiple studies of Araki and colleagues. They called for continued evaluations to lead to a general conclusion on the reproductive success of hatchery fish and their descendants when spawning in the wild.

Comparing reproductive success of hatchery and wild fish also provides the opportunity to evaluate other factors associated with reproductive success (e.g., Bernston et al., 2011; Williamson et al., 2010) which may help explain why the groups perform differently or guide management and conservation of wild populations (e.g., size limits or harvest restrictions to protect most valuable spawners). Run timing and size are often associated with reproductive success in salmonids, but not always in a consistent manner. Early run timing usually leads to higher reproductive success, but this may vary by sex (Anderson et al., 2013; Dickerson et al., 2005) and running too early can reduce success (Anderson et al., 2013; Bernston et al., 2011; Dickerson et al., 2005). Larger size is often expected to enhance reproductive success in salmonids, which some studies have confirmed (Bernston et al., 2011; Williamson et al., 2010) while others have not (Garant et al., 2001; Seamons et al., 2004a). Run timing, level of competition for mates, and ability to sneak fertilizations all may complicate the relationship between fish size and reproductive success.

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In the Knife River, a Minnesota tributary to Lake Superior, a declining steelhead *Oncorhynchus mykiss* population led the Minnesota Department of Natural Resources (MNDNR) to begin a supplemental stocking program. The history of the steelhead population and stocking program is described in Caroffino et al. (2008) and Ward et al. (2013). Briefly, steelhead were first stocked in Minnesota waters of Lake Superior in 1895 (Hassinger et al., 1974) and have since established genetically distinct populations spawning within the various tributaries along the shore (Kreuger et al., 1994). Nearly half of the entire spawning and nursery habitat accessible to steelhead in Minnesota waters is found in the Knife River and its tributaries (Schreiner, 1992). Declining populations since the 1970s led to a period of stocking both local and non-local steelhead fry; however, anglers desired greater numbers of adult steelhead returning to the Knife River. After construction of a trap in 1996 that allows monitoring of migrating juveniles and adults (Dexter and Schliep, 2007), a new hatchery program was initiated to stock age-1 juveniles produced from wild Knife River steelhead adults. The long-term MNDNR goal for steelhead in Lake Superior is to rehabilitate stocks to achieve a level that will allow limited angler harvest, largely supported by naturally reproducing populations (Schreiner et al., 2006).

A previous study of fry stocking in the Knife River showed that hatchery females produced more smolts than females spawning in the wild because of the high survival of eggs in the hatchery; however, in the wild, offspring from wild adults had higher fry-to-smolt survival rates than offspring from hatchery adults (Caroffino et al., 2008). Our current study evaluates the reproductive success of spawning steelhead derived from age-1 juveniles stocked in the Knife River. Our main objective was to compare the reproductive success of the returning hatchery-derived adult steelhead to wild steelhead, when both spawned under natural conditions. We also evaluated additional characteristics of spawners (length, run timing) to determine if they relate to reproductive success in the wild. We accomplished these objectives using microsatellite DNA markers to assign parentage of outmigrating smolts to hatchery and wild adults.

Methods

Study site and fish sampling

The MNDNR Knife River trap facility is located 0.8 km upstream from the mouth of the Knife River and has been in operation since 1996 (Fig. 1). The facility contains an incline screen trap that samples fish migrating downstream (hereafter referred to as the smolt trap) and a separate trap that samples fish migrating upstream (hereafter referred to as the adult trap) (Dexter and Schliep, 2007).

In 1996, 1998, 2000, and 2002–2006, gametes collected from a subsample of wild steelhead adults captured in the Knife River adult trap were used to produce age-1 steelhead. Wild refers to all unclipped adults returning to the river to spawn, recognizing that this could have included some fish derived from fry stocking programs. Fish selected for broodstock at the trap were transported to the MNDNR French River Coldwater Hatchery (Fig. 1), where they were held until ready to spawn. Fertilized eggs were hatched in June, and fish were reared for 10–11 months. Age-1 steelhead with a maxillary clip were stocked in the Knife River in April and May in 1997, 1999, 2001, and 2003–2007. The hatchery target size for age-1 stocked steelhead was 178 mm total length and 62 g, or “smolt size” (Negus, 2003).

Adult returns from the hatchery smolts and wild adults were the focus of this study. Prior to 2007, returning clipped hatchery adults had not been passed above the trap. Throughout April and May of 2007–2009, a roughly 50:50 ratio of wild and hatchery adults were passed upstream of the trap to spawn naturally. The number passed for both wild and hatchery adults included slightly fewer males than females (39–49% males). The origin (hatchery or wild), sex, date of capture, and length were recorded for each individual. Approximately 5–8 scales were removed from each adult, air dried, and stored for genetic

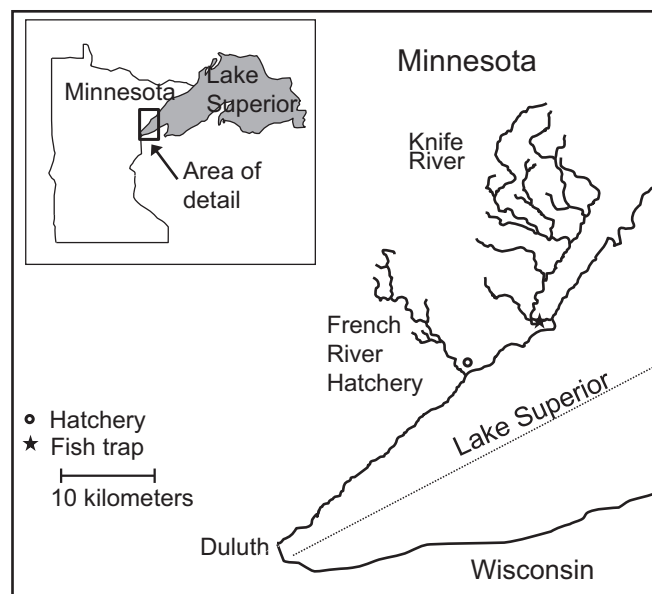


Fig. 1. The western tip of Lake Superior near the city of Duluth, Minnesota. The steelhead population of the Knife River was supplemented using smolts reared in the nearby French River hatchery. A trap facility 0.8 km upstream from the mouth of the Knife River allowed sampling of adults migrating upstream and juveniles migrating downstream.

analysis. From April through June 2009–2011, 8–10 scales were removed from a subsample of age-2 smolts captured annually in the smolt trap for genetic analysis. Fish emigrating at age-2 are of most interest to managers as roughly 80% of adults that return to spawn migrated to Lake Superior as age-2 juveniles (Negus et al., 2012). Sampled smolts were distributed throughout the emigration time period and represented 15–24% of the estimated age-2 emigrants each year.

Adult sampling efficiency

As a result of high discharge rates, typically during the early portions of the spawning period, some adults were able to bypass the adult trap while migrating upstream to spawn and subsequently able to bypass the smolt trap, which can capture many of the adults migrating downstream post-spawn. An estimate of the proportion of the adult population sampled for genetic analysis was needed for parentage assignment. First, population sizes were estimated by sex for both hatchery and wild adults using mark-recapture techniques, as described in Ward et al. (2013) for estimation of the adult trap capture efficiency. Adults were sampled for genetic material whether captured in the adult or smolt trap, so the total adult sampling efficiency was calculated as the total number of unique fish sampled in either trap divided by the estimated population size.

Genotype analysis

Genotype data were obtained for 11 microsatellite DNA loci (*Ogo3*, *Ogo4*, Olsen et al., 1998; *One108*, Olsen et al., 2000; *Omy1001*, *Omy1011*, RT191, Spies et al., 2005; *One2*, Scribner et al., 1996, *Ots4*, Banks et al., 1999; *OtsB5*, Naish and Park, 2002; *Oke4*, GenBank AF330221; *Oki23*, GenBank AF272822) using protocols described in Caroffino et al. (2008) with the exception that alleles were scored using the software GENEMAPPER (Applied Biosystems, Foster City, California). Each sample group, hatchery and wild adults from spawning years 2007–2009 and their age 2 offspring in 2009–2011, was evaluated for conformance with Hardy Weinberg (HW) expectations, null allele frequency, allele frequency differences, and exclusion probabilities using the programs FSTAT version 2.9.3.2 (Goudet, 2001) and CERVUS version 3.0 (Marshall et al., 1998).

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