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ABSTRACT In the early 2000's, declines in the brown trout (*Salmo trutta*) fishery in Rapid Creek, South Dakota, caused concern for anglers and fisheries managers. We conducted a radio telemetry study in 2010 and 2011 to identify predation mortality associated with mink, using hatchery-reared (2010) or wild (2011) brown trout. Estimated predation rates by mink (*Mustela vison*) on radio-tagged brown trout were 30% for hatchery fish and 32% for wild fish. Size frequency analysis revealed that the size distribution of brown trout lost to predation was similar to that of other, radio-tagged brown trout. In both years, a higher proportion of predation mortality (83–92%) occurred during spring, consistent with seasonal fish consumption by mink. Predation by mink appeared to be a significant source of brown trout mortality in our study.

KEY WORDS brown trout, mink, natural mortality, predation, *Salmo trutta*, stream

Beginning in the early 2000s, declines in brown trout (*Salmo trutta*) abundance in Rapid Creek, South Dakota concerned fisheries managers. Annual population surveys indicated that abundance of adult brown trout (> 200 mm total length) had declined by approximately 70% (Carreiro and Wilhite 2007). During this period, the region was experiencing a protracted drought (2002–2005) resulting in below average annual discharge in Rapid Creek (James et al. 2010), potentially reducing carrying capacity for brown trout. Coincident with drought conditions, nuisance blooms of *Didymosphenia geminata* were reported in Rapid Creek below Pactola Reservoir, leading fisheries managers to suspect this may have contributed to the decline of brown trout (James 2011). However, subsequent research indicated that *D. geminata* did not appear to be limiting brown trout recruitment (James 2011, James and Chipps 2010) and while the drought period was associated with low trout biomass, it did not fully explain the population decline of adult brown trout in Rapid Creek (James et al. 2010).

Harvest and predation are two important factors that can contribute to mortality of adult salmonids. Creel surveys have shown that angler harvest in Black Hills trout streams is generally low (Simpson 2007). Moreover, declines in adult brown trout have been reported in Rapid Creek below Pactola Reservoir (James et al. 2010), an area that has long been managed as a catch and release fishery with no allowable harvest. Recent fisheries surveys in Rapid Creek have documented predation on brown trout by American mink (*Mustela vison*) (J. Wilhite, unpubl. data). Mink are effective predators of many small mammals and aquatic organisms (Cuthbert 1979, Nordström et al. 2003, Banks et al. 2004, Ahola et al. 2006), and are particularly efficient at capturing fish (Strachan et al. 1998). Heggenes and Borgstrøm (1988) suggested that mink predation on juvenile fish may be a limiting factor in some salmonid populations. Feral mink have become widely distributed following escapes from fur farms in several European countries including Scotland (Cuthbert 1973), Poland (Jędrzejewska et al. 2001) and Sweden (Erlinge 1969). In many cases, mink have become established causing detrimental effects including competition with native mustelids (Erlinge 1969, Jędrzejewska et al. 2001) and increased mortality of salmonids (Heggenes and Borgstrøm1988).

Winter is often considered a time of increased stress for salmonids and increased mortalities may be associated with factors such as ice conditions, starvation and(or) predation (Simpkins and Hubert 2000, Brown et al. 2011). It has been speculated that salmonids may be more susceptible to predation in winter owing to reduced energy reserves and (or) increased vulnerability to mammalian predators like mink (Gerell 1967). Seasonal diets of mink support this view where studies have shown that fish are a primary diet component in winter and early spring when other prey for mink are generally absent (Marshall 1936, Strachan et al. 1998, Bonesi and Macdonald 2004). Simpkins (1997) speculated that predation by mink contributed to winter loss of rainbow trout (*Oncorhynchus mykiss*) in a regulated river downstream from a large reservoir in Wyoming. Similarly, mink predation was observed on radio-tagged bull trout (*Salvelinus confluentes*) in early winter after ice formation in a Montana stream (Jakober 1995), and on radio-tagged cutthroat trout (*Oncorhyn-*

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chus clarki) and brook trout (*Salvelinus fontinalis*) in the Green River watershed in Wyoming from October through mid-March (Lindstrom and Hubert 2004). In contrast to winter months, summer diets of mink generally contain fewer fish and more terrestrial prey such as small mammals and arthropods (Dunstone and Birks 1987, Strachan et al 1998). Dunstone and Ireland (1989) suggested that in some lotic systems, fish may become less available to aquatic predators during summer months.

As part of a larger study to examine distribution of wild and hatchery-stocked brown trout in Rapid Creek, South Dakota, we quantified mink predation on brown trout during 2010 and 2011. We discuss mink predation as a mortality factor for brown trout and its implications for the trout population in this tailwater fishery.

STUDY AREA

We studied a 4 km section of Rapid Creek below Pactola Dam, approximately 15 km west of Rapid City, South Dakota. Annual discharge below Pactola Dam averages about 1.47 m^3/s (USGS 2008), and the mean stream width within this reach averages 11 m (James et al. 2010). The fish assemblage consists of naturalized brown trout, brook trout, and rainbow trout in this section of Rapid Creek (Bucholz and Wilhite 2010). While the tailwater area of Rapid Creek represents less than 0.5% of the perennial coldwater stream habitat in the Black Hills, it is the largest tailwater trout fishery in the Black Hills and a popular destination for anglers. Additionally, the tailwater reach is managed as a "catch-and-release" trout fishery, and restricted to fishing with artificial lures only.

METHODS

2010 Radio telemetry- hatchery trout

In May 2010, we surgically implanted 20 hatchery-reared brown trout (207 to 294 mm total length, TL) at McNenny State Fish Hatchery in Spearfish, South Dakota, with radio transmitters (Model F1500, Advanced Telemetry Systems, Isanti, MN; mean weight = 1.3 g) using the shielded-needle technique (Ross and Kleiner 1982). We individually anesthetized fish using an un-buffered tricaine methanosulfate solution (MS-222; Argent Chemical Labs, Ferndale, Washington, USA) and held them post-surgery in concrete raceways for 28 days prior to stocking. Fish were stocked into a 2 km reach of Rapid Creek below Pactola Dam and located using a three element folding Yagi antenna (Advance Telemetry Systems, Isanti, Minnesota) and scanning receiver (Challenger R2000, Advanced Telemetry Systems, Isanti, Minnesota). Radio-transmitter locations were determined to within a 2 m radius (Simpkins and Hubert 1998) and recorded using GPS. We located fish three times a week, including twice during daylight hours and once during nighttime hours, from 2 June 2010 to 16 September 2010.

We used criteria reported by Lindstrom and Hubert (2004) to assign tagged fish to one of three outcomes: transmitter failure, apparent mink predation, or unknown fate. Transmitters were considered to have failed if weakened signals or slowed pulse frequencies were observed prior to not being able to locate the fish/transmitter during subsequent surveys. Predation by mink, hereafter referred to as 'apparent predation', was inferred when transmitters were located outside of the stream channel in riparian areas where mink sign (e.g., tracks, scat, latrines or potential den sites) was noted, and when movement had not been detected by the fish for multiple tracking events. We assigned an 'unknown' fate to fish that, after being released in the stream, we were unable to track for the entire study period because they either left the study area or their transmitters were located within the stream.

2011 Radio telemetry-wild trout

Hatchery fish can exhibit reduced survival after stocking into natural environments (Marchetti and Nevitt 2003) and research has shown that wild trout may be better at avoiding predators than hatchery-reared trout (Deverill et al. 1999). Thus, to evaluate mortality of wild brown trout, we collected and tagged fish from the same section of Rapid Creek on 5 April 2011. We captured 37 resident brown trout (195 to 428 mm TL) using a backpack electrofishing unit (Smith Root LR-24, Vancouver, Washington, USA). Fish were anesthetized using carbon dioxide and surgically implanted with radio transmitters (Model F1500, Advanced Telemetry Systems, Isanti, MN; mean weight = 1.3 g) using the same methods employed in 2010 study. Fish were held in recovery cages within the creek for 48 hours post-surgery to assess any short-term mortality (Marking and Meyer 1985, Gilderhus and Marking 1987) and deleterious effects (Taylor and Roberts 1999, Pirohen and Schreck 2003) associated with the surgical procedure. Following the monitoring period, we released fish near their original capture location. Wild brown trout were located in the same manner as in 2010. We located fish from mid-April through August, with the exception of a five week period from 9 May 2011 to 13 June 2011 when stream discharge was elevated and telemetry could not be carried out safely. In cases where we could not locate individual fish, extensive searching was conducted as far as 4 km downstream of the study reach (i.e., total area of 8 km).

Statistical analysis

We compared the size distribution of trout assigned to apparent predation to fish assigned to non-predation events (i.e., transmitter failure and unknown fate) for evidence of size-selective predation. Because length data were not normally distributed (Shapiro-Wilk's test, $P < 0.03$), we used a Kolmogorov-Smirnov two-sample test to compare the length distribution between groups (Neumann and Allen 2007). Because mean size of fish assigned to predation was similar for

2010 (mean=245 mm TL) and 2011 (256 mm TL; Wilcoxon rank test; S = 59, P = 0.87), we pooled length data across years.

To compare the relative risk of predation for hatchery and wild brown trout, we used an odds-ratio test (Cody and Smith 2006). Confidence intervals for odds-ratios were computed using the Mantel-Haenszel method, and for intervals that included a value of 1, we assumed that the relative risk of predation was similar between hatchery and wild fish. Statistical analyses were performed using R v. 2.15.1 (R Development Core Team 2012) where significance was inferred at $\alpha \leq 0.05$.

RESULTS

2010 Radio telemetry-hatchery fish

Of the 20 brown trout we initially tagged, four individuals were successfully tracked until the completion of the study on 16 September 2010. Among the remaining 16 brown trout, 10 were assigned an unknown fate and six were attributed to apparent predation. Of the 10 fish that were lost to unknown causes, three were never detected after stocking, two tags were recovered in the stream bed at the end of the study on September 16, 2010, and five fish were tracked for a period and then lost. Apparent predation was determined on two radio-tagged trout within two weeks of release; with three additional predation events being observed within 32 days post-release. The last predation event on a radio-tagged brown trout occurred 58 days post-release. Most predation (83%) occurred during June (late spring, n = 5) with only one predation event occurring during summer (late July).

2011 Radio telemetry-wild fish

Of the 37 brown trout initially tagged, 13 individuals were tracked until the completion of the study on 1 August 2011. Among the remaining 24 brown trout, two were attributed to transmitter failure, 12 to apparent predation, and 10 were tracked for a period of time and then never detected in the stream (i.e., unknown fates). Apparent predation on six radio-tagged fish occurred within 14 days of tagging. Evidence of three additional predation-related mortality events on radio-tagged fish occurred within 30 days of tagging. The final three predation events were determined on days 69, 73 and 92 respectively. Most predation (92%) occurred during spring (late April-early June) with only one predation event occurring during summer (mid-July).

Selectivity – fish size and origin

Length distribution was similar between brown trout assigned to apparent predation and those that were not, implying that predation was not size-selective (Kolmogorov-Smirnov test; D = 0.205, P = 0.68; Table 1). Cumulative length-frequency distributions revealed that about 80% of fish lost to predation were less than 300 mm; for fish not assigned to predation mortality, 80% were less than 325 mm (Fig. 1).

The incident rate of apparent predation for hatchery fish (6/20 = 0.30) was similar to that for wild brown trout (0.32; χ^2_1 = 0.035, P = 0.85). Moreover, the relative risk of predation for hatchery trout, estimated as an odds-ratio (i.e., 0.30/0.32), revealed that hatchery fish were about 0.94 times (confidence interval 0.41 to 2.1) as likely to be assigned to predation mortality as wild fish; or conversely, wild fish were 1.06 times more likely to be assigned to predation as hatchery fish (confidence interval 0.72 to 1.5).

DISCUSSION

Predation was a notable source of mortality among radio-tagged brown trout in our study. About 30% of tagged brown trout were classified as apparent mink predation – a rate similar to that reported for radio-tagged brook trout (28%) consumed by mink in a Wyoming stream (Lindstrom and Hubert 2004). Although transmitters located in riparian areas/floodplain habitats can be reasonably linked to a terrestrial or avian predation– we had no direct observations of 1) the species of predator involved or 2) if fish died first and

Table 1. Summary of tagging data, predation events, and mean length of hatchery and wild brown trout surveyed using radio-transmitters in Rapid Creek, South Dakota, 2010–2011. Values in parentheses are 1 SE.

			Apparent predation events		Non-predation events	
Year	Brown trout origin	Total number of fish tagged	N	Mean total length (mm)	N	Mean total length (mm)
2010	Hatchery	20	6	245 (15)	14	246 (9)
2011	Wild	37	12	256 (16)	25	279 (16)
Combined	---	57	18	253 (12)	39	267 (11)

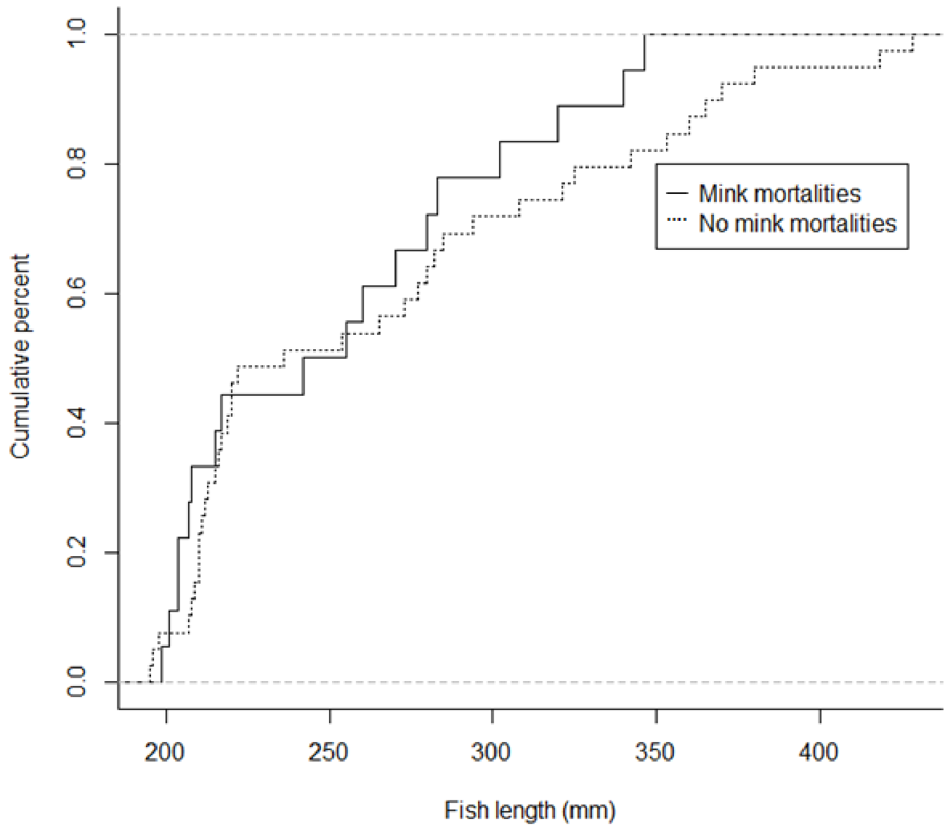

Figure 1. Cumulative-frequency histogram of radio transmitter tagged brown trout in Rapid Creek below Pactola Reservoir, Black Hills, South Dakota, 2010 and 2011.

were then moved to terrestrial areas by a consumer. Nonetheless, the seasonal timing of most predation events (>80%) aligned with the period when mink consumption of fish is greatest (i.e., early spring; Strachan et al. 1998); less than 17% of predation events in our study occurred during summer months (July to September). Moreover, brown trout assigned to unknown fates (55%) could include mink predation events that were not quantified because we were unable to locate the transmitters. Thus, our estimates of apparent mink predation are conservative given the unknown fates of other tagged trout.

Published accounts of size selective predation by mink on salmonids appears to be equivocal. We did not observe evidence of size selective predation mortality on brown trout in our study. Similarly, Willson and Halupka (1995) and Wise et al. (1981) failed to detect evidence of size selectivity on salmonids by mink. However, size selectivity was observed by Erlinge (1969) where trout consumed by mink diets were < 150 mm TL, despite the presence of larger trout in the system. Similarly, Cuthbert (1973) noted that 97% of the salmonids present in mink diets were < 250 mm TL in three rivers in Scotland. Mechanisms that may explain size selectivity in some cases, but not in others are not clear, but Ben-David et al. (1997) suggested the quantity of in-stream cover for fish may play an important role in size selectivity exhibited by mink as the quantity of cover has been shown to affect the predatory success of diving mink (Dunstone and O'Connor 1979*a*).

Several factors may have contributed to the observed level of predation by mink. Susceptibility to predation may have been enhanced as a result of the surgical procedure used to implant the transmitters. While it is difficult to know the true mortality of brown trout (due to mink predation) without comparing tagged individuals to non-tagged individuals, a number of studies have shown that surgical implantation of transmitters in salmonids have only minor effects on mortality, swimming performance and general behavior (Moore et al. 1990, Martinelli et al. 1998, Robertson et al 2003, Aarestrup et al. 2005). Moreover, the body burden created by the transmitters used in our study (maximum of 1.5% of fish weight) was less than the 2% maximum recommended for radio telemetry studies with fish (Winter 1996). In a previous telemetry study of brown trout in Rapid Creek, James et al. (2007) had a mean body burden of 2.1% of weight (maximum of 3.5% of weight) and observed a lower rate of predation

(~11%) by mink on radio-tagged brown trout than what we observed. Similarly, Jakober (1995) had a mean body burden of 2.9% of weight (maximum of 4.9% of weight) during a fall and winter telemetry and observed a lower rate of predation (~13%) by mink on radio-tagged trout. Also, fish in our study were held for 21 days and 2 days post-surgery prior to release in 2010 and 2011, respectively, with no observable deleterious effects (e.g. infections, altered swimming behavior). While the fish tagged in 2011 were held for only two days, there were no observable effects (e.g. loss of equilibrium, bleeding, etc) during this period, and predation was similar to that observed in the fish tagged in 2010, which were held for a longer period. Furthermore, increased susceptibility to predation due to an injury sustained through handling by an angler was considered to be low. Only artificial lures may be used within the study section, which have been shown to have minimal effects (< 5%) on injury and subsequent hooking mortality (Taylor and White 1992). Additionally, we believe the lack of size-selective predation indicates that the presence of the transmitters and associated stressors had little to no effects on tagged fish.

The fish assemblage in the study reach is made up entirely of salmonids, and the apparent lack of alternative prey resources may have contributed to the level of mink predation observed during this study. Mink have been described as a generalist feeder, capable of using as many as five prey groups (mammals, fish, amphibians, crayfish and birds) as their primary or secondary prey (Jędrzejewska et al. 2001). Additionally, fish have been shown to be a secondary or tertiary prey item in the presence of other aquatic prey resources such as crayfish (Burgess and Bider 1980) or terrestrial prey such as lagomorphs (Jenkins and Harper 1980). Similarly, Erlinge (1969) showed that trout populations suffered less mortality in the presence of other fishes that were more susceptible to predation, such as northern pike (*Esox lucius*) and yellow perch (*Perca flavescens*). Conversely, Dunstone and Ireland (1989) showed that in oligotrophic rivers where alternative prey items were uncommon, salmonids were important dietary items. While an established population of northern crayfish (*Orconectes virilis*) exists in Pactola Reservoir, no crayfish have been documented in this section of Rapid Creek below Pactola Dam (SDGFP data). Abundance of terrestrial prey is largely unquantified within the study reach, but previous research within the Black Hills indicated that small mammal densities may be low (Gerads et al. 2001), that might place additional predation pressure (by mink) on stream-dwelling salmonids.

In-stream habitat conditions within the section study area may play an important role in affecting mink predation rates on trout. Cold, hypolimnetic water releases from Pactola Dam may enable mink to successfully capture trout in Rapid Creek below Pactola Reservoir throughout the summer as cold water temperatures may reduce metabolic rates of trout and potentially lower their ability to escape attacks (Gerell 1967, Beamish 1978). Simpson (2009) recorded a maximum summer water temperature within the study reach of 12.7° C, which falls below the optimum temperatures suggested for brown trout metabolism and subsequent growth (Elliot and Hurley 2001). Further, reduced discharge during drought conditions may have increased vulnerability of brown trout to mink predation by reducing in-stream cover available to trout. Reduction of in-stream cover and associated shallow water habitat can increase capture efficiency by terrestrial predators on salmonids (Reinhart and Mattson 1989).

Understanding the role of mink predation on adult brown trout mortality in Rapid Creek is important for effective management, particularly in the tailrace area where the primary management goal is to provide a trophy trout fishery (Erickson et al. 1993). Conditions that exacerbate predation by mink on brown trout are not well known, although several hypotheses have been discussed to explain potential mechanisms (e.g., lack of cover, seasonal availability of prey, and winter habitat conditions). However, many of these hypotheses remain untested, and require additional research to better understand the role of mink predation on population dynamics of salmonids. Information on mink density, distribution, and seasonal diets, when linked to data on radio-tagged brown trout mortality, would provide a more parsimonious view of mink-trout interactions in Rapid Creek. Moreover, research that addresses the role of aquatic habitat complexity and prey availability on mink predation [of trout] would have widespread implications for mink-trout interactions in a variety of systems.

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