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An assessment of run-of-river hydroelectric dams on mountain stream ecosystems using the American dipper as an avian indicator

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ABSTRACT

Rivers provide numerous ecological and cultural services for humans and wildlife that are vulnerable to increasing demands for freshwater and renewable energy production. Run-of-river (RoR) dams are becoming a common energy production alternative on coastal mountain streams throughout the world, but their ecological impacts remain poorly understood. A well-described indicator of water quality sharing steep mountain stream habitat with RoR developments, the American dipper (*Cinclus mexicanus*) river bird is an ideal species for studying potential eco-hydrological impacts of RoR dams. We monitored American dipper populations over two years at stream sites with and without RoR dams across three watersheds in coastal British Columbia, Canada. We found that dippers selected regulated streams across seasons, with the headpond and diversion reach frequently used for foraging. Regulated streams also had higher dipper densities in the slow-flowing habitats, a higher occupancy rate of banded dippers, a higher rate of confirmed year-round residents, and a greater proportion of adults; however, fewer hatch-year dippers were recorded on regulated streams, which may indicate lower reproductive potential or juvenile survival. RoR reaches modified by flow abstraction may offer an opportunity for altitudinal migrant dippers to exploit a consistent food resource closer to their high elevation breeding territory, enabling them to take on a "resident strategy" that is more typical of low elevation river habitats. However, the long-term consequences of year-round occupancy and foraging in headponds requires further investigation, as it could have positive or negative impacts on dippers and their associated foodweb. Collectively, our data suggest that high elevation, RoR-regulated streams provide stable year-round habitat for the American dipper and that presence and density of this species can be used to accurately track changes in stream flow and condition following dam installation.

1. Introduction

With nearly two-thirds of the world's large rivers already fragmented by dams (World Commission on Dams, 2000; Nilsson et al., 2005), run-of-river (RoR) dams on smaller streams are emerging as an alternative approach to harnessing hydroelectric energy where regional geography allows. Also known as river diversions or non-storage hydropower, RoR dams differ from conventional dams in two main ways: 1) they operate on smaller rivers with smaller barriers or intake structures and have a reduced impact area; and 2) impounded water is usually stored for less than 48 h without an extensive reservoir (Community Energy Association, 2008; Anderson et al., 2015), compared to a residence time of several days to years for stored water in larger impoundments (Baxter, 1977). RoR projects function by diverting a portion of a stream's flow from the dam through underground pipes (known as the penstock) before returning it downstream; therefore, they rely on a steep elevation-gradient, and consequently, minimal storage. Further, because altered magnitude and timing of stream flow are limited to the diversion reach (portion of the stream with abstracted flow), RoR projects are suggested to have fewer upstream and downstream effects than conventional storage hydropower projects (Lewis et al., 2012).

There is evidence to suggest, however, that small dams can have negative ecological impacts on stream biota through disruption of the natural flow regime (Poff et al., 1997; Poff and Zimmerman, 2010; Robson et al., 2011; Anderson et al., 2015) and reduced flow (Rolls et al., 2012). Reduced abundance and diversity of benthic algal (Wu et al., 2009) and invertebrate communities (González et al., 2013; Fanny et al., 2013), and reduced macroinvertebrate density (McIntosh et al., 2002) have been observed below small dams. In resident fish,

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effects downstream of small dams are highly variable. Reported observations include: no change in species assemblage (Santos et al., 2006), reduced density of some species but overall increases in species richness (Lessard and Hayes, 2003), and 50% declines in local populations (Almodovar and Nicola, 1999). To date, research on ecological responses to RoR impoundments in British Columbia has focused on resident and migratory salmonids (Connors et al., 2014; Gibeau et al., 2016); many RoR projects in western North America, however, are located on steep, high elevation stream reaches normally impassable by fish. With limited data and variable responses observed across projects, the results are difficult to interpret (Connors et al., 2014), leaving many research gaps (Gibeau et al., 2016). The American dipper, a river resident on mountain streams, may offer further insight into the ecological and toxicological consequences of dams (Tonra et al., 2016; Silverthorn et al., 2017), serving as a sensitive indicator of both upstream and downstream changes to the in-channel and riparian ecosystem.

American dippers, the only truly aquatic songbird in North America, share the specificity for high-elevation, fast-flowing mountain stream habitat that is targeted for RoR projects (Silverthorn et al., 2017). Dippers are found year-round on mountain streams and do not undertake extensive latitudinal migration; however, altitudinal migration to higher elevation stream reaches during the breeding season (late March to August) is common in many Pacific Northwest populations (Price and Bock, 1983; Morrissey, 2004; Morrissey et al., 2004a,b; Walton and Wright, 2008; Green et al., 2015). Their diet is confined to the stream channel where they breed and overwinter, feeding on benthic macroinvertebrates, small fish, and fish eggs by diving and swimming underwater with their wings, or running along the stream bottom (Willson and Kingery, 2011; D'Amico, 2011). Dippers have been used successfully as sentinels of stream health, because of their sensitivity to contaminants (Ormerod and Tyler, 1994; Henny et al., 2005; Morrissey et al., 2005) and variation in river flow regime (D'Amico and Hemery, 2007; D'Amico, 2011; Royan et al., 2014). Therefore, we hypothesized that dipper occupancy, density and demographics would respond to changes in the stream foodweb and habitat related to flow diversion by RoR dams. Flow regulation by RoR dams may alter dipper fitness through changes to the hydrological flow regime that affect prey availability, stream physicochemistry, contaminant levels, and in-channel or riparian habitat.

We compared dipper individual and population responses across regulated and unregulated streams in coastal British Columbia, Canada. Under a regulated flow regime, changes in water flow are not associated with seasonal environmental cues (rainfall or drought) and dippers may be forced to alter their foraging strategies with possible consequences for their survival (D'Amico, 2011). In contrast, habitats modified by the stabilized flow regime may serve as a refuge for dippers as the climate continues to change and catastrophic flood events become more common (Royan et al., 2014), or simply by reducing the energetic demands of foraging in fast-flowing waters (D'Amico et al., 2000). Further, headponds above dams may provide a novel stable habitat with benefits of improved dipper foraging due to changes in the algal, invertebrate and fish communities compared to habitats experiencing high and more variable flows, while also providing year-round ice-free habitat, which is known to attract high densities of wintering dippers (Price and Bock, 1983; Walton and Wright, 2008). While we were unable to predict whether RoR dams would positively or negatively influence local American dipper populations, we hypothesized that dipper population responses would vary in relation to inherent stream site characteristics and flow regulation practices.

2. Methods

2.1. Study area

The 14 mountain streams (seven RoR-regulated and seven unregulated) surveyed during the present study occur within three adjacent watersheds in the Coast Mountain range of British Columbia's Fraser River basin: the Squamish (49854′4.22″N 123817′21.09″W), Lillooet (50818′14.38″N 122842′11.75″W), and Harrison River (49844′32.45″N 1228 8′2.81″W) watersheds (see Silverthorn et al., 2017 for detailed stream information). The majority of creeks and rivers surveyed are steep, third-order streams within the Coastal Western Hemlock, Mountain Hemlock, and Engelmann Spruce Subalpine Fir biogeoclimatic zones. These creeks and rivers experience peak runoff during the winter (November–January) in response to heavy rainfall and a secondary peak runoff event, known as the "spring freshet" (usually late April or May), in response to snowmelt. Minimum flows occur in the summer or often in the early fall, in response to low precipitation and higher ambient temperatures. At streams regulated by RoR dams, the hydrograph is stabilized (because of flow diversion) and the magnitude of peak flooding events is reduced downstream of the impoundment. Anthropogenic flow fluctuations, however, may occur downstream of run-of-river dams, resulting from changes in the proportion of streamflow diverted, emergency shutdowns, operational malfunctions (Gibeau et al., 2016), or recreational releases.

Study streams were initially screened for inclusion of surveys based on suitable dipper habitat and accessibility for wading or walking in or along the stream channel and setting mist-nets across a sufficient portion of the stream to capture birds. Regulated streams in the present study varied in their management, stream morphology, and operational date (Silverthorn et al., 2017), but all were densely forested mountain streams providing potential year-round habitat for dippers. Unregulated streams were selected based on the same criteria in addition to a third criterion of proximity to neighboring regulated streams and assumed similar stream geomorphology, based on proximity. Anadromous salmon (*Oncorhynchus spp.*) were absent upstream of the powerhouse on regulated streams, but five of the lower-elevation unregulated reference streams may have supported at least one species of anadromous salmon, as indicated by the British Columbia Fisheries Inventories Data Queries website (FIDQ, 2018). Resident rainbow trout (*Oncorhynchus mykiss*) inhabited all streams, with the exception of the highest-elevation regulated stream, Fitzsimmons Creek (Silverthorn et al., 2017).

2.2. Trapping and density surveys

All banding and re-sight methods were approved by the University of Saskatchewan Animal Research Ethics Board (Animal Use Protocol # 20120012) and Environment and Climate Change Canada (banding permit # 10268 M). From September to November of 2014 and 2015, 99 adult dippers (n = 48 in 2014 and n = 51 in 2015, plus 3 recaptures from 2014) were banded at 13 (7 regulated, 6 unregulated) of the 14 study streams. Despite numerous attempts and a few dipper sightings during the fall and spring, we were unable to capture dippers at one of the unregulated streams, Roger Creek. Dippers were captured using 6, 9 or 12 m mist-nets set across shallow reaches of each stream and banded with a unique combination of a USGS numbered metal band and three plastic colour bands. Mist-nets were typically set below the dam or within the 1 km survey transect at each stream. All trapping occurred during autumn, when dippers are less territorial and found at higher densities (Price and Bock, 1983; Morrissey, 2004; Whitehorne, 2010) and stream levels are low enough to set mist nests across the channel.

For each individual dipper, tarsus and bill length were measured with dial calipers to the nearest 0.1 mm, maximum wing chord and tail length were recorded with wing rules to the nearest 0.5 mm, and mass was recorded to the nearest gram. In 2015, we were able to reliably age individuals based on eye colour and condition of primary coverts (Pyle, 1997). Size was used to sex the majority of AHY birds in 2015; however, overlap in size among 4% of AHY birds captured prevented absolute categorization during the non-breeding season (Green et al., 2009).

We captured and banded adult dippers for 2–3 consecutive days at 6