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DECLINE OF THE GIANT SALMONFLY *PTERONARCYS CALIFORNICA* NEWPORT, 1848 (PLECOPTERA: PTERONARCYIDAE) IN THE PROVO RIVER, UTAH, USA

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ABSTRACT

Anthropogenic disturbances are causing many aquatic insect species, including those in Plecoptera, to lose geographic range, and, in some cases, succumb to extinction. One species, *Pteronarcys californica* Newport, 1848, has declined in several rivers in the western United States during the past century. It has been extirpated from the Arkansas River of Colorado and the Logan River of northern Utah and is now in decline in the Provo River of central Utah. We sampled the Provo River for two years (2016–2017) to determine the abundance and distribution of *P. californica* and other stonefly species. In over 300 samples, we found only 17 *P. californica* individuals. Our study demonstrates that their abundance and distribution have declined dramatically when compared to baseline values obtained from museum records, unpublished data and publications from the past century. Total stonefly species abundance and richness may also be lower compared to historical data. Because Plecoptera are bioindicators of water quality, this decline indicates that the health of the Provo River is deteriorating, especially in the lower reaches where few stoneflies were found. These findings suggest that active steps should be taken to protect the Provo River and its aquatic biodiversity.

Keywords: stonefly, bioindicators, dams, conservation

INTRODUCTION

Plecoptera (stoneflies) are important components of aquatic ecosystems worldwide (Fochetti & Tierno de Figueroa 2008). They feed in diverse ways and perform various ecosystem services (Merritt et al. 2008) by providing food resources for both aquatic and terrestrial carnivores (Cummins 1973, Baxter et al. 2005), acting as ecosystem engineers (Zanetell & Peckarsky 1996) and contributing to energy and nutrient cycling (McDiffett 1970, Anderson & Sedell 1979, Walters et al. 2018). Large stoneflies, such as the giant salmonfly, *Pteronarcys californica* Newport, 1848 (Pteronarcyidae), can be particularly important for a variety of ecosystem functions (Lecerf & Richardson 2011). Individuals of *P. californica* are among the largest of all stoneflies (Kauwe et al. 2004), with body lengths > 5 cm (McClelland & Brusven 1980) and weights > 1 g (Elder & Gaufin 1973). They also can occur in high densities and thus can be a major component of in-stream biomass (Needham & Christenson, 1927, Gaufin 1951, Erickson 1983, Nehring et al. 2011). *Pteronarcys californica* are shredders (Merritt et al. 2008) and therefore increase nutrient availability in downstream areas (McDiffett 1970, Short & Maslin 1977). They support aquatic (Nehring 1987) and terrestrial fauna during their large emergence pulses (Muttkowski 1925, Rockwell & Newell 2009, Walters et al. 2014). Like other stoneflies, giant salmonflies are sensitive to pollution and are used as indicators of river health (Barbour et al. 1999). Fishermen also appreciate these charismatic insects. Despite their importance to ecology, conservation and culture, Plecoptera, including *P. californica*, are in decline (Master et al. 2000, DeWalt et al. 2005, Fochetti & Tierno de Figueroa 2008).

Anthropogenic disturbances, including pollution, dams, urbanization and climate change, lead to lower water quality and decreased aquatic biodiversity (Malmqvist & Rundle 2002). However, impacts may be especially severe within Plecoptera. They are one of the most imperiled groups of insects (Master et al. 2000, Fochetti & Figueroa 2004, 2006, Tierno de Figueroa et al. 2010) due to their low dispersal ability (Griffith et al. 1998, Petersen et al. 1999), high level of endemism (Fochetti & Tierno de Figueroa 2006) and their need for high dissolved oxygen concentrations and cool water temperatures (Barbour et al. 1999). Some species have suffered extinction in recent years, including *Alloperla roberti* Surdick, 1980 and *Isoperla conspicua* Frison, 1931 of Illinois (DeWalt et al. 2005) and *Taeniopteryx araneoides* Klapálek, 1902 and *Oemopteryx loewi* Albarda, 1899 of central Europe (Zwick 1992). Many others are regionally declining (Fochetti & Figueroa 2006). Five of the 100 species native to the Czech Republic have become regionally extinct (Bojková et al. 2012) and 22 of 77 species have been lost from Illinois, USA (DeWalt et al. 2005).

Pteronarcys californica appears to be disappearing from local stream reaches across the western United States. They have been lost from >550 km river miles in Montana (Stagliano 2010), the Arkansas River (Kowalski 2015) and several Colorado (Nehring et al. 2011) and Gunnison River reaches (Knight 1965, Colborn 1987) in Colorado. Giant salmonflies have also been extirpated from the Logan River of northern Utah and, despite reintroduction efforts, have not been collected there since 1966 (Vinson 2008). They are also thought to be in decline in the Provo River of central Utah.

Historically, *P. californica* was prevalent in the Provo River. In 1951, Gaufin found them in 40% of his samples and at eight adjacent sites across the Lower and Middle Provo, with an average abundance of 153 and 10 individuals per site, respectively. *Pteronarcys californica* specimens were most abundant in the Lower Provo and absent from the Upper Provo (Fig. 1, 2) (Gaufin 1951). Twenty years later, however, Richardson and Gaufin (1971) refer to their abundance in the Upper Provo, but do not provide quantitative data. Other studies only qualitatively refer to the presence or abundance of *P. californica* on the Lower Provo. However, some of these indicate very high historic populations, where 50 could be collected under a single boulder (Needham & Christenson 1927) and thousands could be collected in a year (Elder & Gaufin, 1973). Collection records from the Brigham Young University (BYU) Monte L. Bean Museum (31 records), anecdotal occurrence notes (9 records) and unpublished raw data (5 records) also indicate their distribution in the Lower (40 records) and Middle Provo (5 records). These records as well as Gaufin's (1951) data make up a total of 19 exact historic collection locations for *P. californica* on the Provo River (Fig. 3A).

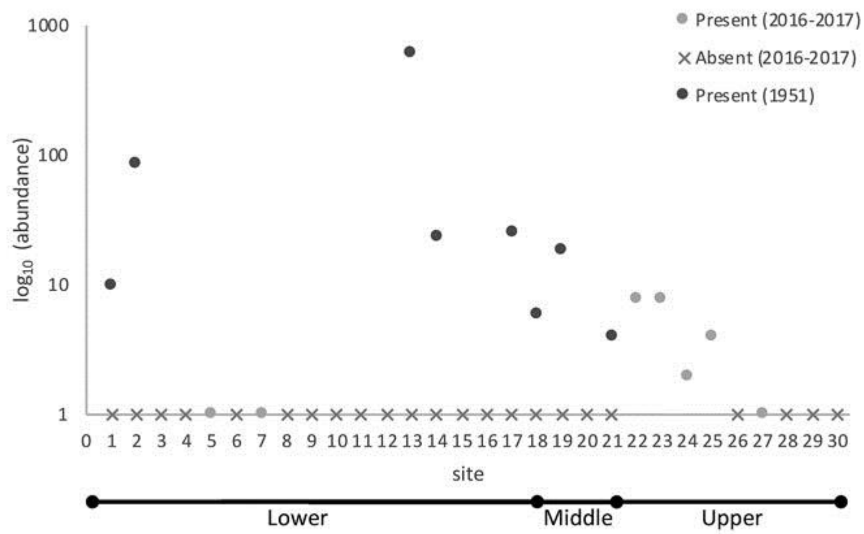

Fig. 1. Additive abundance of *P. californica* from the 8 boulder samples at each site for 2016–2017, compared with Gaufin (1951). We cannot directly compare abundances from sites 13 and 14. We could not sample at these locations because they have been deepened and channelized since 1951. Furthermore, although Gaufin (1951) collected at 5 locations in the Upper Provo and found no giant salmonflies, we could not determine his exact collection locations. These points are thus excluded from this figure.

Despite being historically abundant, data cited in gray literature, informal reports and occurrence notes suggest that *P. californica* is currently less common and widespread in the Provo River (C.R. Nelson, personal communication, R.W. Baumann, personal communication, Shiozawa & Weibell 2002, 2006). We are therefore concerned that they are being extirpated and that these changes in abundance and distribution are indications that the water quality, physical attributes and ecology of the stream are changing. With this in mind, we quantified *P. californica* abundance and distribution in the Provo River. We also documented the abundance and richness of all other stonefly species found in the stream in order to provide a biodiversity baseline for future studies.

MATERIALS AND METHODS

The Provo River is a fourth-order cold-water mountain stream in central Utah, USA. It begins in the Uinta Mountains at Wall Lake (elevation: 3,091 meters). From there, it flows 110 kilometers southwest, cutting through Provo Canyon in the Wasatch Mountains before emptying into Utah Lake (elevation: 1,367 meters) near Provo, Utah. The Provo River is partitioned by dams and reservoirs into three sections, the Lower, Middle and Upper Provo, each with differing levels of human induced stress (see Discussion). We refer to each section of river (Lower, Middle and Upper) as segments, geolocations where sampling occurred as sites and individual boulders as unique samples.

We created a baseline for the abundance and distribution of *P. californica* with which to compare our findings by compiling data from published literature. We also used collections from the Monte L. Bean Museum, personal records of BYU professors (C.R. Nelson, personal communication, R.W. Baumann, personal communication) and unpublished raw data (Shiozawa & Weibell 2002, 2006) (see Introduction).

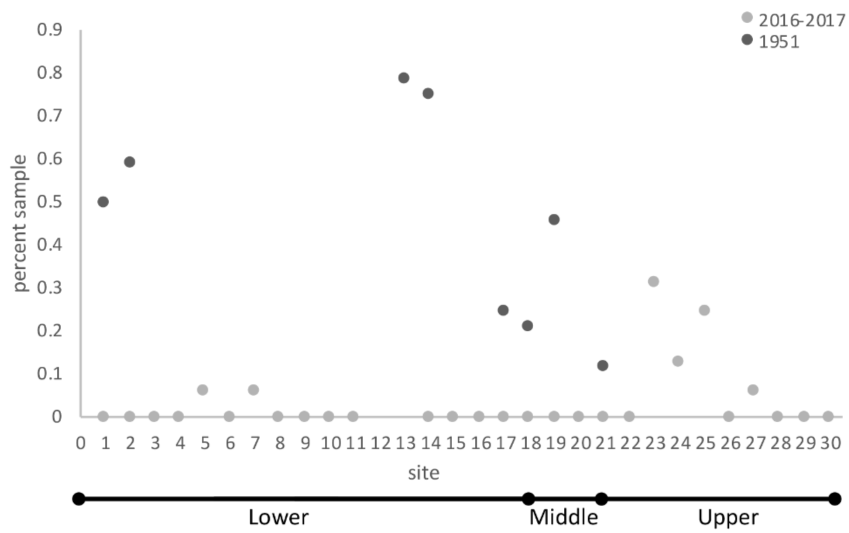

Fig. 2. Percent of samples taken in 2016–2017 where *P. californica* were collected, compared with Gaufin (1951). Identical data restrictions as indicated in the caption of Fig. 1.

In order to determine the current range and distribution of *P. californica,* we sampled in each segment of the Provo River in areas that met either of two requirements: sites where giant salmonflies had previously been encountered or locations which met their general ecological requirements. *Pteronarcys californica* require well-oxygenated water and live under large boulders in riffles (Elder & Gaufin, 1973). We therefore collected in areas that contained at least eight boulders (>30 cm in diameter) on a riffle. Although we identified 19 sites where *P. californica* were previously collected (see Introduction), due to access issues and proximity (<0.5 km) to some historical collection sites, we reduced this to 14 exact historic collection locations that we could sample (11 in Lower, 3 in Middle, 0 in Upper).

We sampled stonefly nymphs in 2016 and 2017 (Fig. 3B) from eight boulders at each site (one boulder = one sample). To do so, the first collector lifted the boulder, scrubbed the underside by hand and kicked the sediment beneath. The second collector held a kick screen with 1 mm mesh immediately downstream and collected all insects that were dislodged. We placed the contents in a sorting tray and used forceps to field-sort all stoneflies. The remaining invertebrates and sample debris were returned to the stream.

In 2016, from April 20 to May 26, we sampled at 30 total sites: 17 in the Lower Provo, 4 in the Middle Provo and 9 in the Upper Provo. In 2017, we sampled from June 15 to July 15 because high-water levels made spring sampling impossible. Due to the late start of our study and personal time constraints, we simplified our sampling regime and randomly sampled only 6, 2 and 4 sites from the Lower, Middle and Upper Provo, respectively, for a total of 12 sites. We followed the same sampling methodology used the previous year.

Although many stoneflies have a synchronized one-year life cycle, (Stewart & Stark 1988) *P. californica* has a four-year life cycle (DeWalt & Stewart 1995, Townsend & Pritchard 1998). Therefore, some size classes of *P. californica* nymphs are always present in the streams where they occur. This enabled us to sample over the course of several weeks each year, without compromising presence/absence data. Such was

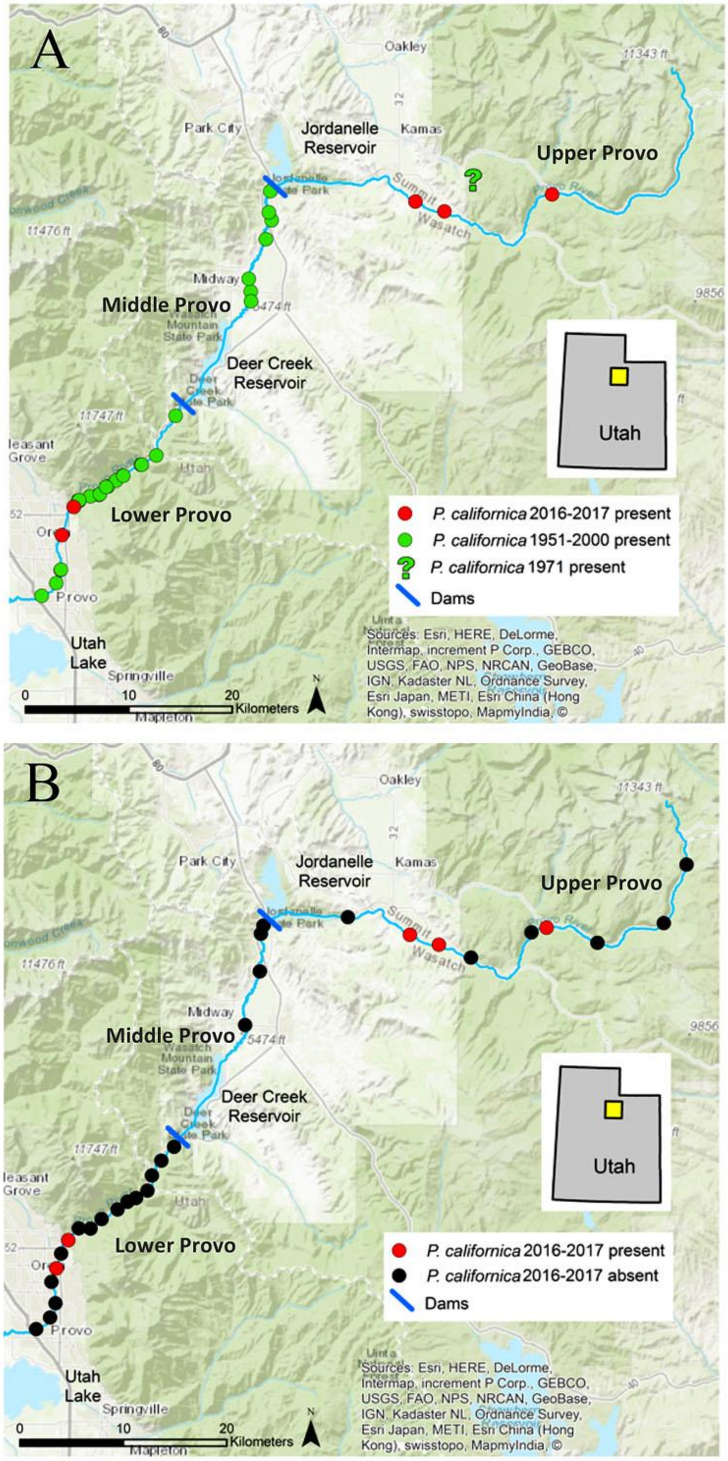

Fig. 3. (A) Shift in distribution of *P. californica* on the Provo River since 1951. Points indicate presence at least once during the interval. (B) Presence versus absence of *P. californica* from 2016–2017 sampling efforts.

not the case with many of the other stoneflies we collected. For this reason, non-*Pteronarcys* are excluded from our 2017 sampling data because many of them had already emerged from the stream by the time we sampled.

In the laboratory, we identified all stoneflies to genus or species, using dichotomous keys in Merritt et al. (2008) and Baumann et al. (1977). Each unique stonefly genus or species was counted as a different taxon. Specimens that were damaged or too young to identify to genus were excluded from our study.

RESULTS

We collected 18 stonefly taxa in the Provo River (Table 1). The greatest taxa richness and abundance occurred in the Upper Provo, where all 18 taxa were present. The Middle (5 taxa) and Lower (6 taxa) segments demonstrated approximately one-third of the taxa richness of the Upper Provo (Fig. 4). Stonefly abundance showed a similar pattern compared to taxa richness (Fig. 5). The Lower Provo had a mean stonefly abundance per boulder of 3, while the Middle had 2 and Upper had 14.

We found *P. californica* at 6 of 30 collection sites and at only 1 of the 14 historic collection locations that we could sample (Fig. 3A, B). They occurred at 2 sites in the Lower Provo, 0 sites in the Middle and 4 sites in the Upper. Giant salmonflies were most abundant in the Upper Provo. In total, we collected 17 individuals, including 2 from the Lower Provo, 0 in the Middle and 15 in the Upper (Fig. 1). Giant salmonflies were present in 1.1% of our total boulder samples in the Lower Provo, 0% in the Middle and 11.5% in the Upper. At sites 5 and 7 of the Lower Provo, we found them in 6.3% of our boulder samples. At sites 23, 24, 25 and 27 in the Upper Provo, we collected *P. californica* in 31.3, 12.5, 25.0 and 6.3 percent of our boulder samples, respectively. All other sites contained no giant salmonflies (Fig. 2).

We found *P. californica* less frequently and at lower abundances than did Gaufin in 1951. He collected giant salmonflies at 8/9 (88.9%) of his sites and in 40% of his samples along the Lower and Middle Provo, whereas we only found them at 2/21 (9.5%) of our sites and 1.2% of our samples along these stream segments. The sites of most obvious decline are Sites 2, 17, and 19, where we collected zero giant salmonflies, and where Gaufin found them in 59%, 79% and 75% of his samples and abundances of 86, 26, and 19, respectively. At Sites 13 and 14, Gaufin reported finding 642 total individuals in 1951; unfortunately, we could not resample at these exact locations due to river channelization and deepening. While it is possible that a population of *P. californica* is present at these locations, it is unlikely due to severe structural manipulations of the river and because we found zero individuals at the sites immediately above and below Sites 13 and 14.

DISCUSSION

Pteronarcys californica has undergone a severe decline in abundance and distribution in the Provo River over the past century. Despite taking 320 samples across 30 different sites, we found only 17 individuals, with no more than four specimens being collected from a single boulder. This is far less than the abundant status described historically, where 50 individuals could be collected from a single boulder (Needham & Christenson 1927) or thousands collected in a year (Elder & Gaufin 1973). Indeed, in comparison with Gaufin (1951), we show that *P. californica* abundance has declined by a magnitude of 2 (base-10 log scale) (Fig. 1). Although our sampling methods differed, it is striking that the species appeared in only 1.2% of our samples compared to 40% of Gaufin's (Fig. 2). Giant salmonflies are also less evenly distributed in the Lower Provo and may be extirpated altogether from the Middle Provo (Fig. 3A). We found that *P. californica* are currently most common in the Upper Provo, but even these populations are small. The total stonefly diversity of the stream may also be in decline, as we found less than half of the total stonefly species richness described historically (Winger et al. 1972) (Table 1).

As mentioned above, Plecoptera are sensitive to declines in water quality and are commonly used

Table 1: Stonefly taxa collected in 2016–2017 in each segment of the Provo River, compared with those found by Winger et al. (1972).

Species	Lower (sites 1–17)	Middle (sites 18–21)	Upper (sites 22–30)	Provo River Winger et al. 1972
Capniidae				
Capnia sp.			x	
Capnia confusa Claassen, 1936				x
Capnia gracilaria Claassen, 1924				x
Capnia nana wasatchae Nebeker & Gaufin, 1967				x
Capnia uintahi Gaufin, 1964				x
Eucapnopsis brevicauda (Claassen, 1924)				x
Isocapania crinita (Needham and Claassen, 1925)				x
Isocapania grandis (Banks, 1907)				x
Utacapnia columbiana (Claassen, 1924)				x
Utacapnia lemoniana (Nebeker & Gaufin, 1965)				x
Utacapnia logana (Nebeker & Gaufin, 1965)				x
Chloroperlidae				
Alloperla sp.			x	
Alloperla severa (Hagen, 1861)				x
Paraperla frontalis (Banks, 1902)				x
Plumiperla diversa (Frison, 1935)			x	
Suwallia pallidula (Banks, 1904)				x
Sweltsa sp.	x		x	
Sweltsa borealis (Banks, 1895)				x
Sweltsa coloradensis (Banks, 1898)				x
Sweltsa lamba (Needham & Claassen, 1925)				x
Triznaka sp.			x	
Triznaka pintada (Ricker, 1952)				x
Triznaka signata (Banks, 1895)				x
Utaperla sopladora Ricker, 1952				x
Leuctridae				
Paraleuctra occidentalis (Banks, 1907)			x	x
Nemouridae				
Malenka californica (Claassen, 1923)				x
Prostoia besametsa (Ricker, 1952)			x	x
Zapada cinctipes (Banks, 1897)			x	x

Zapada columbiana (Claassen, 1923)				x
Zapada haysi (Ricker, 1952)				x
Zapada oregonensis (Claassen, 1923)			x	x
Perlidae				
Claassenia sabulosa (Banks, 1900)		x	x	x
Hesperoperla pacifica (Banks, 1900)	x	x	x	x
Perlodidae				
Cultus aestivalis (Needham & Claassen, 1925)				x
Diura knowltoni (Frison, 1937)				x
Isoperla fulva Claassen, 1937	x	x	x	x
Isoperla mormona Banks, 1920		x	x	x
Isoperla pinta Frison, 1937				x
Isoperla quinquepunctata (Banks, 1902)				x
Isoperla sobria (Hagen, 1874)				x
Kogotus modestus (Banks, 1908)				x
Megarcys signata (Hagen, 1874)			x	x
Skwala americana (Klapálek, 1912)	x		x	x
Pteronarcyidae				
Pteronarcella badia (Hagen, 1874)	x	x	x	x
Pteronarcys californica Newport, 1848	x		x	x
Taeniopterygidae				
Taenionema sp.			x	
Taenionema pacificum (Banks, 1900)				x
Taenionema pallidum (Banks, 1902)				x
Total	**6**	**5**	**18**	**42**

as bioindicators of river health (Barbour et al. 1999). *Pteronarcys californica* is thought to be even less resilient than many other stoneflies because of their large size and time needed to complete their life cycle (Fore et al. 1996). We hypothesize that the decline of *P. californica* on the Provo River is a result of anthropogenic disturbances and indicates a decline in water quality.

Over the last 80 years, the Lower and Middle segments of the stream have been heavily modified by dams and channelization (Olsen & Holden 2006). The negative impacts of such physical alterations are well-studied worldwide (Ward & Stanford 1995, Bunn & Arthington 2002, Nilsson et al. 2005, Graf 2006, Palmer, Menninger & Bernhardt 2010, Sabater et al. 2018) and may contribute to the extirpation of stonefly species through sedimentation and armoring (Waters 1995), thermal modification (Ward & Stanford 1982), habitat loss (Walker et al. 1992) and other impacts of altered flow regimes (Bunn & Arthington 2002). *P. californica* may be particularly sensitive because large dams rob streams of coarse organic matter that giant salmonflies feed upon (Ward & Stanford 1983) and disrupt the natural annual temperature regimes that are needed to

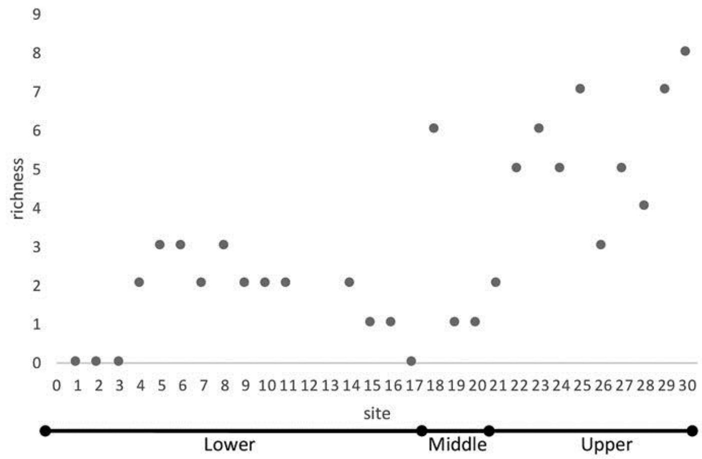

Fig. 4. Total species richness per site for 2016–2017. Urban sites: 1–4. Physically modified sites (channelized, flooded, or rerouted): 9, 12, 13, 17, 21, and 25. Sites adjacent to agriculture: 18, 19, 23, 24, and 25. Sites directly downstream of large dams: 17 and 21.

break egg diapause and advance development (Townsend & Pritchard 2000). These impacts may be influential in the Provo River. Despite recent restoration efforts to remedy the effects of channelization and armoring on the Middle Provo (URMCC 1997), aquatic communities have not returned to previous measures of health and abundance (Belk 2016, J.B. Meek unpub. data).

The water quality and health of aquatic communities in the Provo River may also be threatened by pollution. The Upper Provo (Wall Lake to Jordanelle Reservoir) runs through the Uinta-Wasatch-Cache National Forest and low-population agricultural communities (total population: 1,787) and is the least disturbed; the Middle Provo (Jordanelle Dam to Deer Creek Reservoir) flows through higher density agricultural communities and several larger towns (total population: 21,363); the Lower Provo (Deer Creek Dam to Utah Lake) passes through the heavily traveled Provo Canyon and the rapidly-growing urban cities of Provo and Orem (total population: 215,174), where agricultural land has largely been converted to housing developments and shopping centers (Evans et al. 1988). Urban runoff has driven out sensitive taxa such as stoneflies in the Lower Provo because of metal contamination and decreased oxygen (Gray 2004). Nutrient inputs from groundwater, agriculture, and urbanization, which is increasing along the Middle Provo (Goodsell et al. 2017), may also have had an impact on stonefly populations (Lemly 1982).

The combined effects of river modification, dam construction and pollution have significantly altered the natural geochemistry of the Provo River (Carling et al. 2015). Our study provides some evidence of these influences, based on the relatively low total stonefly abundance and richness observed below dams and in channelized, urban or agricultural areas (Fig. 4, Fig. 5). However, further research is needed to quantify the combined effects of these causes and whether they are responsible for the decline of the giant salmonfly.

Finally, climate change may also be negatively impacting stonefly abundance. Warmer temperatures are thought to be responsible for the upslope migration of insects and other taxa as they seek cooler, more suitable conditions (Sheldon

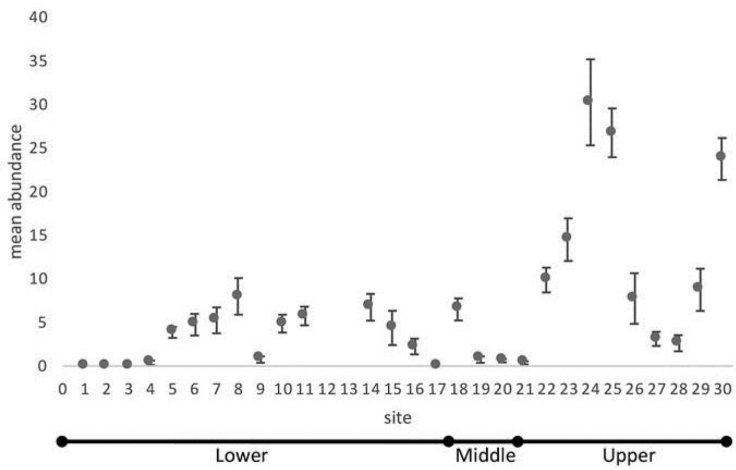

Fig. 5. Mean stonefly abundance (per boulder) at each site for 2016–2017. Identical site characteristics as described in the caption of Fig. 4.

2012, Wiens 2016). This may be the case for *P. californica*. In 1951, Gaufin found no giant salmonflies in his five sites on the Upper Provo (Gaufin 1951). Their presence in 1971 (Richardson 1971), 2016 and 2017 (this study) may indicate that warmer temperatures are pushing them to higher elevations. This could be problematic for Upper Provo populations because they may be nearing their upper elevation tolerance (Knight & Gaufin 1966, 1967).

The current status of *P. californica* in the Provo River is troubling. This species often occurs at high densities (Erickson 1983, Needham & Christenson, 1927, Nehring et al. 2011). Therefore, finding only a few individuals could mean that their populations may be so low that they are already functionally extirpated in this locale. Low abundance may not only denote a decline in water quality but may also have broader ecological implications. Because *P. californica* are an important food resource for fish species, the trout populations of this Blue Ribbon fishery may suffer (Erickson 1983). Stream invertebrates that use fine organic matter have historically relied on shredders such as *P. californica* to increase access to fine particulate matter (Short & Maslin 1977, Vannote et al. 1980, Lecerf & Richardson 2011). In some rivers, the emergence of giant salmonflies can represent up to 250% of the entire flux in carbon from aquatic to terrestrial ecosystems per year (Walters 2018). Losing this resource could therefore impact whole ecosystem function by altering fluxes in energy and nutrients from aquatic to terrestrial environments. Furthermore, because stoneflies act as ecosystem engineers, the decline of stonefly diversity and abundance in downstream segments may decrease micro-habitat heterogeneity and therefore also have broad ecological impacts across other aquatic species (Zanetell & Peckarsky 1999).

The decline of *P. californica* is not unique to the Provo River. They have become regionally extinct in stream reaches across Montana (Stagliano 2010), Colorado (Knight 1965, Colburn 1987, Nehring et al. 2011) and other areas of Utah (Vinson 2008). We strongly recommend that further studies be initiated to quantify the decline of giant salmonflies in other areas of the Western United States and identify healthy populations that can be protected. We also suggest the following conservation efforts: prevent further hypolimnetic-release dams from being built, reduce riparian grazing and improve the treatment of domestic wastewater. Additionally, we encourage state Fish and Wildlife Departments to consider adding *Pteronarcys californica* to the Species of Greatest Conservation Need (SGCN, USGS 2017) in their State Wildlife Action Plans. We hope that these measures, along with help from state and local governments to educate the public about native stoneflies, will increase awareness of the decline of this valuable species and create funds to expand further research into its health and rehabilitation.

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