Rationale for Including the Giant Salmonfly (*Pteronarcys californica*) as a Species of Greatest Conservation Need in the State of Utah

Prepared For:
Utah Division of Wildlife Resources

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Contents:

Species Description:

<u>Classification</u>:

Kingdom – Animals (Animalia)
  Phylum – Spiders, Insects, and Crustaceans (Arthropoda)
    Class – Insects (Insecta)
      Order – Stoneflies (Plecoptera)
        Family – Giant Stoneflies (Pteronarcyidae)
          Genus – Salmonflies (*Pteronarcys*)
            Species – Giant Salmonfly (*Pteronarcys californica*)

Pteronarcys californica (Newport, 1848), commonly known as the giant salmonfly or California giant stonefly, is a species of giant stonefly (Pteronarcyidae) found in mountain streams and rivers of Western North America. Aquatic nymphs and terrestrial adults may be dark-orange to black-colored. However, nymphs may have subtle patterns on the abdomen, and adults often have bright orange coloration at the joints of their body segments. Adults have two pairs of large, many-veined wings that fold back over the body when at rest. Female salmonflies carry clusters of orange eggs resembling salmon roe, which they deposit in the river after mating. For a full description of diagnostic characters of *P. californica* and their North American conspecifics, see Merritt et al. (2008) and Myers & Kondratieff (2017).

<u>Life History</u>:

P. californica are among the largest of all stoneflies. Mature individuals can often measure > 5 cm in length and weigh > 1.5 g, with females typically being much larger than males (Townsend

& Prichard, 1998). It takes individuals four to five years to complete development, including a 9-11-month egg diapause and three to four years as nymphs (DeWalt & Stewart, 1995; Townsend & Prichard, 1998, 2000). Such a long life history likely makes *P. californica* more sensitive to environmental disturbances than other, short-lived species (Fore et al., 1996).

Phenology**:**
Adults tend to emerge between May and July, with individuals emerging sooner in rivers or microclimates with warmer winter and spring temperatures (Gregory et al., 2000; Rockwell & Newell 2009; Anderson et al., 2019). Emergences of adults tend to be large and synchronous, stimulating aggressive feeding behavior by trout and migratory bird species. (Townsend & Prichard, 1998; Stagliano, 2010). *P. californica* emergences are also highly anticipated by anglers (Stagliano, 2010).

Diet and Feeding Behavior:
P. californica are shredders, predominately feeding on coarse particulate matter, such as leaves and woody debris (Merritt et al., 2008). Despite being important detritivores, members of the genus *Pteronarcys* are only 10% efficient at converting consumed leaves into animal biomass because they lack key enzymes for digesting plant debris (Martin et al. 1981; McDiffet, 1970; Perry et al., 1987). Like many detritivores, the majority of their detritus-borne nutrition comes from consuming decomposing microbes (i.e., biofilms) on the leaf material and woody debris they consume (Martin et al., 1981). However, *P. californica* diet is variable in both space and time, and a significant proportion of nymphs' diets also include amorphous detritus, moss, filamentous algae, diatoms, and other invertebrates (Richardson & Gaufin, 1971; Fuller & Stewart, 1979; Plague et al., 1998; Albertson et al. 2022).

Species Range:
Global Range:
P. californica is native to western North America and found along the Coast, Cascade, Rocky, and Sierra Nevada Mountains from Alaska and the Yukon south to Mexico and throughout most of the Basin and Range of the western United States (Stewart & Oswood, 2006). Occurrence records indicate *P. californica* occurs in Alaska, British Columbia, Alberta, Washington, Idaho, Montana, Oregon, Nevada, Utah, Wyoming, Colorado, California, and New Mexico (National Aquatic Monitoring Center (NAMC), 2024; iNaturalist, 2024).

Utah Distribution and Population Sizes:
There are no specific population estimates for *P. californica* in Utah, and no programs currently exist for providing reliable statewide population data. However, surveys of individual populations within specific watersheds have been conducted from time to time (NAMC, 2024), along with independent observations made by community scientists (iNaturalist, 2024). Together, these efforts show that *P. californica* are broadly distributed in streams and rivers near many of the State's mountain ranges (Fig. 1). Due to the lack of systematic, statewide surveys, however, the actual extent of their distribution is unknown and may be significantly larger.

Despite their broad distribution, *P. californica* have declined substantially since the mid-20th century in Utah, and in other western states, including Montana, Colorado, and likely, Wyoming (Colborn, 1985; Vincent, 2008; Stagliano, 2010; Nehring, 2011; Birrell et al., 2019; Anderson et al., 2019; Kowalski & Richer, 2020; Birrell & Frakes, 2024a; Birrell & Kowalski, unpublished data). In Utah, *P. californica* have been extirpated from the entire Logan River and the majority of the Provo River – two Blue Ribbon trout streams where they were once prolific (Vinson, 2008; Birrell et al., 2019). They have also disappeared from the lower Blacksmith Fork (Birrell & Kowalski, unpublished data), and have likely declined on the Ogden and Spanish Fork Rivers (Williamson, 2021; Birrell & Kowalski, unpublished data). Whether the species has also been extirpated from other watersheds is unknown due to a lack of targeted surveys. However, other extirpations are likely, considering the strong, negative statewide trends in population density, reported below.

Fig. 1

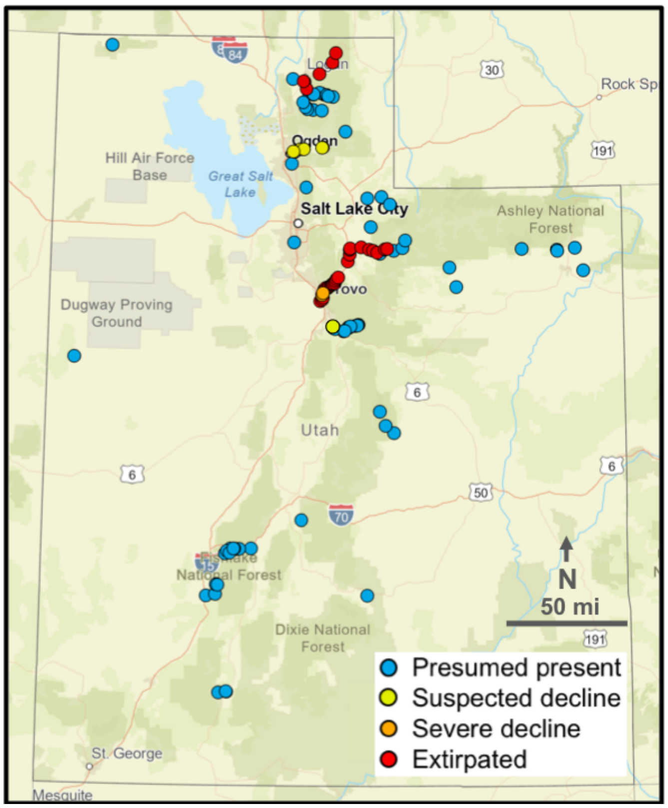

Fig. 1: Map of known, present occurrences of *Pteronarcys californica* (blue), along with locations of suspected declines (yellow), severe declines (orange), extirpations (red). Presence locations retrieved from the National Aquatic Monitoring Center and iNaturalist databases. Decline and extirpation locations retrieved from Vinson (2008), Birrell et al. (2019), and Birrell & Kowalski (unpublished data). For each location with a historical record of occurrence, *P. californica* were presumed present unless specific data suggested otherwise. The map was produced in ArcGIS, version 10.8.2.

Current Conservation Status:

<u>Conservation Rankings</u>

P. californica has a NatureServe global ranking of 'secure', G5, and an updated Utah state ranking of 'vulnerable', S2, due to strong statewide declines and its importance as a bioindicator of water quality and keystone species for benthic food webs (Utah Division of Wildlife Resources, 2023; NatureServe, 2024). *P. californica* is listed as 'secure', S5, in Idaho and 'apparently secure', S4, in British Columbia, Canada; however, *P. californica* has not yet been assessed for state rank in other states or Canadian provinces (NatureServe 2024). As of May 2024, *P. californica* has not been assessed for inclusion in the International Union for Conservation of Nature's Red List of Threatened Species, nor have any other species in the order Plecoptera (IUCN Red List, version 3, May 2017). Additionally, *P. californica* has not been designated as a 'Sensitive Species' by the Bureau of Land Management or the U.S. Forest Service, nor evaluated for listing as 'Threatened' or 'Endangered' under the Endangered Species Act by the U.S. Fish and Wildlife Service.

Population Trends in Utah:
Populations of *P. californica* in Utah have undergone strong declines over the last century (Birrell et al., 2019). *P. californica* have been extirpated from the Logan River and the majority of the Provo River, with a small resident population remaining near the mouth of Provo Canyon (Vinson, 2008; Birrell et al., 2019). *P. californica* have also declined throughout the lower Blacksmith Fork River (Birrell & Kowalski, unpublished data) and are likely in decline on the Ogden and Spanish Fork Rivers as well (Williamson, 2021; Birrell & Kowalski, unpublished data).

Fig. 2

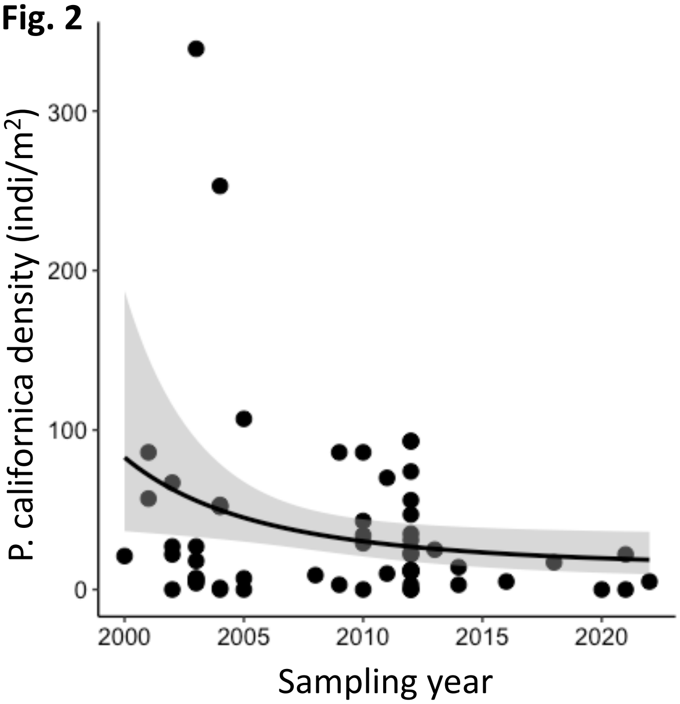

Fig. 2: Scatterplot of *Pteronarcys californica* densities (individuals/m^2) in Utah from 2000-2022 from the National Aquatic Monitoring Center (NAMC). Densities decreased significantly over time (P = 0.006), falling by approximately 84% since 2000. Regression line and confidence intervals derived with function geom_smooth (package: ggplot2; https://cran.r-project.org/web/packages/ggplot2/index.html) based on the coefficients of the zero-inflated generalized linear mixed effects model described in the text.

To quantify *P. californica* trends, density data was compiled from NAMC (NAMC, 2024) and changes in density were analyzed from 2000 to 2022 using a zero-inflated generalized linear mixed effects model with R (package: ZINNB; function: glmm.zinb; Zhang & Yi, 2020). Data were filtered to only include sites where *P. californica* has been found at least once, resulting in 58 density records. A zero-inflated generalized linear mixed effects model was chosen to account for repeated sampling at some sites, with site location included as a random effect, and because of the over-dispersed, zero-inflated nature of the data. The model shows that statewide *P. californica* densities significantly declined by 84% (P = 0.006) since 2000, with mean densities falling from around 80.4 individuals per m^2 in 2000 to 12.5 individuals per m^2 in 2022 (Fig. 2). Interpretations of this model should be made with some caution, however, as the analysis assumes that the quality of selected sampling sites have remained the same over time. Future efforts should instead analyze statewide trends for repeatedly sampled sites, which was not possible in this study due to insufficient sites with repeated samples in the dataset (i.e., 10). This data gap demonstrates the need for additional systematic surveys of *P. californica*, especially at historically sampled sites (discussed further below).

Despite an important model assumption, significant negative population trends in Utah are corroborated by known extirpations and declines on specific rivers (i.e., Logan, Provo, Blacksmith Fork, Diamond Fork, and Ogden Rivers; outlined above), and by a separate analysis of the trends in the full range of *P. californica*. This range-wide analysis was performed using the same methods as above and was based on 931 occurrences within the NAMC database. This model showed that *P. californica* range-wide densities near-significantly declined ($P = 0.087$) by 32% from 1987-2022, with mean densities falling from 11.9 individuals per m^2 in 1987 to 8.0 individuals per m^2 in 2022. With such a robust sample size, this result indicates that strong declines in at least some states are likely (i.e., Utah) and that reassessing the global conservation status of *P. californica* (listed as 'secure', G5; last reviewed in 2011; NatureServe, 2024) is warranted. Furthermore, this analysis demonstrates the need for reassessing conservation status in other Western states and Canadian provinces, especially in states where no state rank has been assigned.

Habitat Description:

P. californica typically inhabit third- to seventh-order mountain streams with cool temperatures and large, unconsolidated cobbles. *P. californica* have been found in streams ranging from near sea level to 2500 m (Knight & Gaufin, 1966; Birrell et al., 2019; NAMC, 2024). Nymph densities are positively associated with substrate size, with individuals typically occupying sites with median particle diameters of at least 8 cm and substrates composed of less than 10% fine sediment (Brusven & Prather, 1974, Huff, 2006; Relyea, 2007; Kowalski & Richer, 2020).

Though *P. californica* are not cold-water stenotherms, they tend to be rare in rivers with mean August temperatures > 19 °C (Huff, 2006; Anderson et al., 2019; Birrell & Frakes, 2024b) and mean maximum monthly summer temperatures > 23 °C (Birrell et al., 2023). They have never been recorded in streams with instantaneous temperatures > 25°C (Richards et al., 2013).

Susceptibility of *P. californica* to high temperature can be exacerbated by other stressors including hypoxia, low flows, and heavy metals (Frakes et al., 2021; 2022). They are strongly sensitive to heavy metals such as copper and cadmium, but are fairly tolerant to lead (Colborn, 1985; Frakes et al., 2022). Due to their general sensitivity to environmental degradation, *P. californica* are widely used as bioindicators of water quality and are listed as 'very sensitive' on multiple regional bioassessment indices (Colborn, 1985; Barbour et al. 1990; Fore et al. 1996;; Merritt et al. 2008). The susceptibility of *P. californica* to other factors, such as pH and salinity, is unknown.

Habitat Trends:

Rivers and streams are under rising pressure in Utah due to rapid human growth, with increasing levels of land-use change, habitat degradation, and dewatering to support human development (Khatri et al., 2018; Harris, 2020 Khatri & Strong, 2020). Cumulatively, these pressures, along with reduced flows and rising temperatures from climate change (Isaak et al., 2012; Dettinger et al., 2013), sedimentation (Henley et al., 2000), and more pervasive algal blooms and hypoxia from nutrient pollution (Chapra et al. 2017), will likely lead to further extirpations and population declines. Trends of other environmental factors, such as heavy metals, pH, salinity, and neonicotinoid insecticides are generally unknown but should be expected to increase in localized areas where mining, road-use, agriculture, and other disturbances become more prevalent.

Ecological Role:

P. californica as a Keystone Species

Large leaf-shredders, like *P. californica,* are critical for maintaining the structure and function of lotic food webs, and their presence can lead to emergent ecosystem properties (Lecerf & Richardson, 2011). Indeed, *P. californica* can be considered a keystone species because they increase food and nutrient availability for other species across multiple trophic levels (Stout, 1999; Lecerf & Richardson, 2011; Walters et al., 2018). For collector- and filterer-gatherers, *P. californica* are key producers of readily available food (Merritt et al., 2008). *Pteronarcys* nymphs typically break down 30-60% of their weight in detritus daily, > 80% of which is expelled as non-digested feces and fed on by other collectors (Poole, 1981, Perry et al. 1987). Over a nymph's lifetime, this equates to the production 800-2000 kCal of energy for low-level consumers (Poole, 1981) and has been experimentally shown to significantly increase in-stream nutrient cycling (Short & Maslin, 1977).

P. californica are also critical food sources for fish (Muttkowski, 1925). Indeed, in some rivers*, P. californica* can make up the > 60% of the annual diet of rainbow trout (Nehring, 2011). They are also consumed by numerous terrestrial animals, including spiders, snakes, frogs, birds, ground squirrels, and even, humans (e.g., indigenous peoples of Northeastern California, including the Pit River & Modoc tribes), during their large summer emergences (Muttkowski, 1925; Sutton, 1985; Rockwell et al., 2009). In rivers with large populations, emergences of adult *P. californica* can transfer more carbon into terrestrial ecosystems than the combined annual emergences of all other insects at a given site, suggesting that this species is key to supporting the total energy and nutrient budgets of riparian ecosystems (Walters et al., 2018). With so many species relying on *P. californica* in both terrestrial and aquatic systems, population declines and extirpations of the species are expected to have far-reaching ecological implications, emphasizing the urgent need for their conservation.

Relevant Threats and Drivers of Declines:

Aquatic insects are faced with numerous threats stemming from increased human development, land-use change, and climate change, including warming temperatures, dewatering, hypoxia, sedimentation, habitat fragmentation and degradation, invasive species, and water pollution (DeWalt et al. 2005; Dudgeon et al., 2006; Strayer, 2006; Collen et al., 2012; Birrell et al., 2020; Costante et al., 2022). While all of these challenges are likely to affect *P. californica* populations, few studies have rigorously investigated the impacts of stressors on natural populations (but see Anderson et al., 2019; Kowalski & Richer, 2020). Indeed, additional, large-scale surveys and distribution models will be necessary to accurately assess and identify the importance of potential threats and to direct conservation priorities at range-wide to local scales. At present, however, current limited data must be relied upon to assess potential threats, and these are outlined and discussed below.

Case studies of *P. californica* declines in different regions point to various drivers of local extirpations and declines. In Utah, severe, periodic dewatering to support local agriculture and municipal uses have extirpated populations on the lower Blacksmith Fork and lower Spanish Fork Rivers (Birrell & Kowalski, unpublished data). Restoring these populations is an important and feasible conservation priority, as both rivers have intact populations immediately upstream of the dewatered reaches, which would likely reestablish the lower reaches once water availability is improved (Birrell & Kowalski, unpublished data). Drivers of local declines on the Provo River are unconfirmed, but are hypothesized to be driven by hydrological shifts and dewatering from two large, hypolimnetic-release dams, local water withdrawals systems, and trans-basin water diversions, along with nutrient pollution and hypoxia from urban and agricultural runoff (Birrell et al., 2019). In a 2022 survey, water temperatures and sediment levels on the Provo appeared to be conducive to *P. californica* survival, and problems with these factors are unlikely to be primary drivers of the decline (Birrell & Kowalski, unpublished data).

The local extinction of *P. californica* from the Logan River is more mysterious, as temperature, flow, oxygen, and sediment conditions appear to be within healthy levels (Vinson, 2008; Birrell & Kowalski, unpublished data). Indeed, the majority of the River is free-flowing and surrounded by National Forest lands, protecting it from excessive water withdrawals and stressors arising from human development. Some have speculated, however, that that populations have been extirpated due to excessive road-salting or applications of herbicides, though these hypotheses have not been tested (Vinson, 2008). In other states, declines of *P. californica* have been attributed to other stressors, including hydrological shifts and sedimentation (e.g., Gunnison and Colorado Rivers, Colorado; Kowalski & Richer, 2020), heavy metal pollution (e.g., Clark Fork River, Montana and Arkansas River, Colorado; Stagliano, 2010) and warming temperatures from river impoundments and climate change (Madison River, Montana; Anderson et al., 2019). Limiting these stressors, along with other potentially harmful and currently unmeasured factors, like insecticides, across rivers in Utah will be necessary to prevent further population declines.

Concern for Long-Term Persistence in Utah:

There is sufficient scientific information available to determine that the long-term persistence of *P. californica* in Utah is a substantial conservation concern. Given preliminary rates of statewide declines exceeding 4% per year, reported above, wide-spread extirpations may be expected within the next two decades. Performing additional surveys to improve data on the current range of *P. californica*, estimates of population declines, and potential drivers of local to regional trends will be key to taking conservation steps towards their long-term persistence in Utah.

Rationale for SGCN Designation:

According to the best-available data, *P. californica* has undergone an 84% decline in statewide population densities since 2000. Local extirpations have occurred on at least three watersheds:

the Logan, Provo, and lower Blacksmith Fork Rivers (Vinson, 2008, Birrell et al., 2019; Birrell & Kowalski, unpublished data), with additional declines likely in the Spanish Fork and Ogden Rivers (Williamson 2021; Birrell & Kowalski, unpublished data). Extirpations in other systems are probable, but are unconfirmed due to the lack of systematic surveys of the species. Unless otherwise prevented, declines are expected to continue, and possibly intensify, due to the cumulative effects of increased dewatering, pollution, environmental degradation, and thermal stress associated with Utah's rapid human growth, development, and warming climate (Khatri et al., 2018; Harris, 2020 Khatri & Strong, 2020). Such reductions are expected to have far-reaching ecological implications, as *P. californica* are large-bodied, keystone species that increase food availability for numerous species across trophic levels (Short & Maslin, 1977; Poole, 1981; Lecerf & Richardson, 2011; Nehring, 2011; Walters et al., 2018).

Recommended Conservation and Monitoring Actions:
Improving monitoring of *P. californica* populations and associated environmental conditions will be key to refining estimated rates of population trends, assessing and identifying threats and solutions, and ultimately, securing effective conservation efforts for the species in Utah. In the statewide *P. californica* dataset, described above, densities had been recorded at 58 locations, yet only 10 locations had been repeatedly sampled. Returning to historical occurrence locations to resurvey the species (using the same methods), will be a feasible and cost-effective way to improve data on population declines. Surveying the additional 128 sites where unspecified species of the *Pteronarcys* genus have been found – which have a significantly larger known range extent than *P. californica* (NAMC, 2024) – will be an additional way to improve data on the range of the species and to identify new sites where reoccurring monitoring can occur.

To track population trends into the future, a subset of historically sampled sites should be selected for reoccurring monitoring, with sites selected strategically in different regions to detect areas of greatest conservation concern and that may be associated with different stressors linked to *P. californica* declines (e.g., high temperatures, dewatering, sedimentation, etc.). Monitoring may occur annually at all sites or at a subset of sites on a rotating two- to five-year basis, as is performed in other large-scale monitoring programs (e.g., PacFish/InFish; US Forest Service, 2024). Incorporating these monitoring efforts into existing rapid bioassessment and biodiversity surveys and monitoring efforts should be feasible for *P. californica* as sampling techniques are easy to learn and teach (e.g., Birrell & Frakes, 2024b). In addition, *P. californica* nymphs are always present in streams due to their three- to four-year lifespan, providing some flexibility to when monitoring may occur, though adjustments to the data may be necessary to account for seasonal density differences. Nymphal densities may also be estimated by collecting exuvia (nymphal skins) of newly emerged adults (Heinhold et al., 2020). Whenever possible, surveying methods should rely on quantitative methods that reduce sample variance (e.g., Surber or Hess samplers) to facilitate optimal power for detecting changes in species densities over time (Birrell & Frakes 2024b). Doing so will be especially important for *P. californica* because of the patchy nature of their population structures, which frequently leads to over-dispersed data (Elder & Gaufin 1973; Townsend, 1989).

In addition to collecting data on species densities, future surveys should sample important environmental conditions commonly associated with *P. californica* densities and declines. These include temperature, sedimentation, and dewatering, nutrient, and hypoxia levels (e.g., Anderson, et al., 2019; Birrell et al., 2019; Kowalski & Richer, 2020; Frakes et al., 2021), as well as other factors like heavy metals and pesticide levels in areas where impacts from these factors appear likely (Frakes et al., 2022). By mapping and establishing trends in environmental conditions associated with *P. californica* densities and declines, these efforts will help refine information on the species' tolerance thresholds, potential drivers of populations trends, and region-specific conservation solutions. Species distribution models may also be used to find new waterways where *P. californica* are likely to exist, as well as refugium that may shield them from future disturbances, and which should be actively managed and protected to conserve local populations. Spatial models that estimate current and future environmental conditions of interest, including water temperature and flow discharges, will be particularly useful for establishing distribution models and identifying at-risk and refuge waterways, especially when measuring conditions in the field is not feasible (e.g., NorWest, Streamflow Metrics; Wegner et al. 2010; Isaak et al., 2017).

Although additional data are needed to guide *P. californica* conservation in Utah, sufficient information exists for providing basic conservation recommendations. In waterways with existing *P. californica* populations, including rivers with high densities (e.g., upper Blacksmith Fork and Diamond Fork Rivers; Birrell & Kowalski, unpublished data), efforts should be made to maintain ecologically relevant flow regimes. Flow not only provides basic habitat for *P. californica* and other macroinvertebrates, but also reduces rates of warming and facilitates oxygen delivery to respiratory surfaces (Frakes et al., 2021). Sufficient flows should also be restored and maintained in reaches where *P. californica* have likely been extirpated due to dewatering, including the lower Spanish Fork and lower Blacksmith Fork Rivers, so populations may reestablish (Birrell & Kowalski, unpublished data). Managing rivers so they maintain non-harmful nutrient, heavy metal, and pesticide levels and promoting responsible agricultural and construction techniques to reduce sedimentation will also be key for maintaining *P. californica* populations (e.g., Kowalski & Richer, 2020; Frakes et al. 2021; 2022).

Acknowledgements and Data Availability:

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References:

Albertson, L. K., Briggs, M. A., Maguire, Z., Swart, S., Cross, W. F., Twining, C. W., … Walters, D. M. (2022). Dietary composition and fatty acid content of giant salmonflies (Pteronarcys californica) in two Rocky Mountain rivers . *Ecosphere*, *13*(1), 1–10.

Anderson, H. E., Albertson, L. K., & Walters, D. M. (2019). Water temperature drives variability in salmonfly abundance, emergence timing, and body size. *River Research and Applications*, *35*(7), 1013–1022.

Barbour, M. T., Faulkner, C., & Gerritsen, J. (1990). Rapid Bioassessment Protocols For Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates, and Fish Second Edition. By: Project Officer. *George Gibson (Ed). Biological Criteria: Research and Regulation, Proceedings of a Symposium (December 1213, 1990: Arlington, Virginia),* 1-174.

Birrell, J. H., Meek, J. B., & Nelson, C. R. (2019). Decline of the Giant Salmonfly Pteronarcys Californica Newport , 1848 (Plecoptera : Pteronarcyidae) in the Provo River, Utah, USA. *Illiesia*, *15*(5), 83–97.

Birrell, J. H., Shah, A. A., Hotaling, S., Giersch, J. J., Williamson, C. E., Jacobsen, D., & Woods, H. A. (2020). Insects in high-elevation streams: Life in extreme environments imperiled by climate change. *Global Change Biology*, *26*(12), 6667–6684.

Birrell, J. H., Frakes, J. (2024a). Monitoring Aquatic Insect Densities and Environmental Factors on the Upper Snake River, Wyoming – 2023 Report. *The Salmonfly Project*, 2, 1-23.

Birrell, J. H. & Frakes, J. (2024b). Monitoring Aquatic Insect Densities and Environmental Factors on the Bitterroot River, Wyoming – 2023 Report. *The Salmonfly Project*, 3, 1-23.

Birrell, J. H. & Kowalski, D. (unpublished data). Drivers of Pteronarcys californica declines in Utah and Colorado. Manuscript in preparation.

Brusven, M. A. & Prather, K. V. (1974). Influence of stream sediments on distribution of macrobenthos. Journal of the Entomological Society of British Columbia. 71, 25 32.

Chapra, S. C., Boehlert, B., Fant, C., Bierman Jr, V. J., Henderson, J., Mills, D., ... & Paerl, H. W. (2017). Climate change impacts on harmful algal blooms in US freshwaters: a screening-level assessment. *Environmental Science & Technology*, *51*(16), 8933-8943.

Colborn, T. E. (1985). *The use of the stonefly, Pteronarcys californica Newport, as a measure of biologically available cadmium in a high-altitude river system, Gunnison County, Colorado*.

Collen, B., J. Baillie, M. Böhm, and R. Kemp. 2012. Spineless: status and trends of the world's invertebrates. Zoological Society of London.

Costante, D. M., A. M. Haines, and M. Leu. 2022. Threats to neglected biodiversity: Conservation success requires more than charisma. Frontiers in Conservation Science 2:11

Dettinger, M., Udall, B., & Georgakakos, A. (2015). Western water and climate change. *Ecological Applications*, *25*(8), 2069-2093.

DeWalt, R. E., & Stewart, K. W. (1995). Life histories of stoneflies (plecoptera) in the rio conejos of southern colorado. *Great Basin Naturalist*, *55*(1), 1–18.

DeWalt, R. E., Favret, C., & Webb, D. W. (2005). Just How Imperiled Are Aquatic Insects? A Case Study of Stoneflies (Plecoptera) in Illinois. *Annals of the Entomological Society of America*, *98*(6), 941–950.

Dudgeon, D., Arthington, A. H., Gessner, M. O., Kawabata, Z. I., Knowler, D. J., Lévêque, C., … Sullivan, C. A. (2006). Freshwater biodiversity: Importance, threats, status and conservation challenges. *Biological Reviews of the Cambridge Philosophical Society*, *81*(2), 163–182.

Elder, J. A., & Gaufin, A. R. (1973). Notes on the occurrence and distribution of *Pteronarcys california* Newport (Plecoptera) within streams. *Great Basin Naturalist*, *33*(4), 218–220.

Fore, L. S., Karr, J. R., & Wisseman, R. W. (1996). Assessing invertebrate responses to human activities: Evaluating alternative approaches. Journal of the North American Benthological Society,15: 212-231.

Frakes, J. I., Birrell, J. H., Shah, A. A., & Woods, H. A. (2021). Flow increases tolerance of heat and hypoxia of an aquatic insect. *Biology Letters*, *17*(5).

Frakes, J. I., Malison, R. L., Sydor, M. J., & Arthur Woods, H. (2022). Exposure to copper increases hypoxia sensitivity and decreases upper thermal tolerance of giant salmonfly nymphs (Pteronarcys californica). *Journal of Insect Physiology*, *143*(November), 104455.

Fuller, R. L., & Stewart, K. W. (1979). Stonefly (Plecoptera) Food Habits and Prey Preference in the Dolores River , Colorado. *The American Midland Naturalist*, *101*(1), 170–181.

Gregory, J. S., Beesley, S. S., & Van Kirk, R. W. (2000). Effect of springtime water temperature on the time of emergence and size of Pteronarcys californica in the Henry's Fork catchment, Idaho, U.S.A. *Freshwater Biology*, *45*(1), 75–83.

Harris, E. (2020). State and County Population Estimates for Utah: 2020. *Research Brief. Kem C. Gardner Policy Institute, University of Utah, Salt Lake City*.

Heinold, B. D., Kowalski, D. A., & Barry Nehring, R. (2020). Estimating densities of larval Salmonflies (Pteronarcys californica) through multiple pass removal of post-emergent exuvia in Colorado rivers. *PLoS ONE*, *15*(4), 1–10.

Henley, W. F., Patterson, M. A., Neves, R. J., & Lemly, A. D. (2000). Effects of sedimentation and turbidity on lotic food webs: a concise review for natural resource managers. *Reviews in Fisheries Science*, *8*(2), 125-139.

Huff, D. D., Hubler, S. L., Pan, Y. D., & Drake, D. L. (2006). Detecting shifts in macroinvertebrate assemblage requirements: Implicating causes of impairment in streams. Oregon Department of Environmental Quality Watershed Assessment Report, Portland, OR, 38.

iNaturalist community (2024). Observations of Pteronarcys californica from Utah, USA. iNaturalist, San Rafael, Californica, USA. Available at: https://www.inaturalist.org/observations (Accessed: Jan 1, 2024).

Isaak, D. J., Wollrab, S., Horan, D., & Chandler, G. (2012). Climate change effects on stream and river temperatures across the northwest US from 1980–2009 and implications for salmonid fishes. *Climatic change*, *113*, 499-524.

Isaak, D. J., Wenger, S. J., Peterson, E. E., Ver Hoef, J. M., Nagel, D. E., Luce, C. H., … Parkes-Payne, S. (2017). The NorWeST Summer Stream Temperature Model and Scenarios for the Western U.S.: A Crowd-Sourced Database and New Geospatial Tools Foster a User Community and Predict Broad Climate Warming of Rivers and Streams. *Water Resources Research*, *53*(11), 9181–9205.

Khatri, K. B., Strong, C., Kochanski, A. K., Burian, S., Miller, C., & Hasenyager, C. (2018). Water resources criticality due to future climate change and population growth: Case of river basins in Utah, USA. *Journal of Water Resources Planning and Management*, *144*(8), 04018041.

Khatri, K. B., & Strong, C. (2020). Climate change, water resources, and potential adaptation strategies in Utah. *Salt Lake City, UT: Division of Water Resources, Utah Department of Natural*.

Knight, A. W., & Gaufin, A. R. (1966). Altitudinal Distribution of Stoneflies (Plecoptera) in a Rocky Mountain Drainage System. *Journal of the Kansas Entomological Society*, *39*(4), 668–675.

Kowalski, D. A., & Richer, E. E. (2020). Quantifying the habitat preferences of the stonefly Pteronarcys californica in Colorado. *River Research and Applications*, *36*(10), 2043–2050.

Lecerf, A., & Richardson, J. S. (2011). Assessing the functional importance of large-bodied invertebrates in experimental headwater streams. *Oikos*, *120*(6), 950–960.

Martin, M. M., Martin, J. S., Kukor, J. J., & Merritt, R. W. (1981). The digestive enzymes of detritus-feeding stonefly nymphs (Plecoptera; Pteronarcyidae). *Canadian Journal of Zoology*, *59*(10), 1947–1951.

McDiffett, W. F. (1970). The Transformation of Energy by a Stream Detritivore, Pteronarcys Scotti (Plecoptera). *Ecology*, *51*(6), 975–988.

Merritt, R. W., Cummins, K. W., & Berg, M. B. (2008). *An introduction to the aquatic insects of North America. Kendall Hunt, 1996.* Kendall.

Muttkowski, R. A. 1925. The food of trout in Yellowstone National Park. Roosevelt Wild Life Bulletin 2:470–497.

Myers, L. W., & Kondratieff, B. C. (2017). Larvae of North American species of Pteronarcys (Plecoptera: Pteronarcyidae). *Illiesia*, *13*(16), 192-224.

National Aquatic Monitoring Center. (2024). Aquatic Invertebrates Database. National Aquatic Monitoring Center, Utah State University, Logan, Utah. Available at: https://namc-usu.org/data/ (Accessed: Jan 1, 2024).

NatureServe. (2024). NatureServe Network Biodiversity Location Data accessed through NatureServe Explorer. NatureServe, Arlington, Virginia. Available at: https://explorer.natureserve.org/Taxon/ELEMENT_GLOBAL.2.112052/Pteronarcys_californica. (Accessed: May 20, 2024).

Nehring, R. B., Heinold, B., & Pomeranz, J. (2011). Colorado River Aquatic Resources Investigations Federal Aid Project F-237R-18. *Colorado Division of Wildlife*.

Perry, W. B., Benfield, E. F., Perry, S. A., & Webster, J. R. (1987). Energetics, Growth, and Production of a Leaf-Shredding Stonefly in an Appalachian Mountain Stream. *Journal of the North American Benthological Society*, *6*(1), 12–25.

Plague, G. R., Wallace, J. B., & Grubaugh, J. W. (1998). Linkages between trophic variability and distribution of Pteronarcys spp. (Plecoptera: Pteronarcyidae) along a stream continuum. *American Midland Naturalist*, *139*(2), 224–234.

Poole, W. C. (1981). Ecological Bioenergetics of *Pteronarcys californica* (Newport). *Idaho State University*, 125.

Relyea, C. D. (2007). Fine Inorganic Sediment Effects on Stream Macroinvertebrates. *Idaho State University*, (December), 1–24.

Richards, D. C., Bilger, M., & Lester, G. (2013). Development of Idaho Macroinvertebrate Temperature Occurrence Models. *EcoAnalysts, Inc.*, 1–71.

Richardson, J. W., & Gaufin, A. R. (1971). Food Habits of Some Western Stonefly Nymphs. *Transactions of the American Entomological Society*, *97*(1), 91–121.

Ripley, B., Venables, B., Bates, D. M., Hornik, K., Gebhardt, A., Firth, D., & Ripley, M. B. (2013). Package 'MASS'. *Cran r*, *538*, 113-120.

Rockwell, I. P., & Newell, R. L. (2009). Note on mortality of the emerging stonefly Pteronarcys californica on the Jocko River, Montana, USA. *Western North American Naturalist*, *69*(2), 264-266.

Short, R. A., & Maslin, P. E. (1977). Processing of Leaf Litter by a Stream Detritivore: Effect on Nutrient Availability to Collectors. *Ecology*, *58*(4), 935–938.

Stagliano, D. (2010). Evaluation of salmonflies in Montana's rivers : are statewide populations really declining? *Montana Natural Heritage Program*, 1–29.

Stewart, K.W. and M.W. Oswood. 2006. The Stoneflies (Plecoptera) of Alaska and Western Canada. The Caddis Press: Columbus, Ohio. 325 pp.

Strayer, D. L. (2006). Challenges for freshwater invertebrate conservation. *Journal of the North American Benthological Society*, *25*(2), 271–287.

Sutton, M. Q. 1985. The California salmon fly as a food source in Northeastern California. Journal of California and Great Basin Anthropology 7:176–182.

Townsend, C. R. (1989). The Patch Dynamics Concept of Stream Community Ecology. *North American Benthological Society*, *8*(1), 36–50.

Townsend, G. D., & Pritchard, G. (1998). Larval growth and development of the stonefly Pteronarcys californica (Insecta: Plecoptera) in the Crowsnest River, Alberta. *Canadian Journal of Zoology*, *76*(12), 2274–2280.

Townsend, G. D., & Pritchard, G. (2000). Egg Development in the Stonefly Pteronarcys californica Newport (Plecoptera: Pteronarcyidae). *Aquatic Insects*, *22*(1), 19–26.

United Stats Forest Service. (2024). PacFish/InFish *Overview. United States Department of Agriculture, United States Forest Service*, Washington D.C. Available at: https://www.fs.usda.gov/detail/r4/landmanagement/resourcemanagement/?cid=stelprd3845865

Utah Division of Wildlife Resources. (2023). Utah Species Field Guide. Utah Division of Wildlife Resources, Salt Lake City, Utah. Available at: https://fieldguide.wildlife.utah.gov/?species=pteronarcys%20californica (Accessed: May 20, 2024).

Vinson, B. M. (2008). A short history of Pteronarcys californica and Pteronarcella badia in the Logan River, Cache County, Utah. *Utah State University*,1–10.

Wenger, S. J., Luce, C. H., Hamlet, A. F., Isaak, D. J., & Neville, H. M. (2010). Macroscale hydrologic modeling of ecologically relevant flow metrics. *Water Resources Research*, *46*(9).

Walters, D. M., Wesner, J. S., Zuellig, R. E., Kowalski, D. A., & Kondratieff, M. C. (2018). Holy flux. *Ecology*, *99*(1), 238-240.

Williamson, R. (2021). What happened to Utah's salmonfly? KSL.com, Salt Lake City, Utah. Available at: https://www.ksl.com/article/50193001/what-happened-to-utahs-salmonfly (Accessed: May 1, 2024)

Zhang, X., & Yi, N. 2020. NBZIMM: negative binomial and zero-inflated mixed models, with application to microbiome/metagenomics data analysis. BMC Bioinformatics, 21:1–19.