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**IMPACTS OF HYDROELECTRIC DAMS ON AQUATIC
MACROINVERTEBRATE OVIPOSITION STRATEGIES: THE
ROLE OF DESICCATION**

by

Jesse R. Fleri

**Capstone submitted in partial fulfillment of
the requirements for graduation with**

UNIVERSITY HONORS

with a major in

**Conservation & Restoration Ecology
in the Department of Wildland Resources**

Approved:

**UTAH STATE UNIVERSITY
Logan, UT**

[Spring 2018]

1 Abstract:

2 Previous studies quantifying the density, distribution and diversity of aquatic insects
3 overwhelmingly focus on larval life stages. However, many aquatic insects exhibit selective
4 oviposition behaviors, with a preference for emergent substrates along a river's edge. The
5 practice of hydropeaking creates an artificial intertidal zone that is absent from natural rivers and
6 to which freshwater organisms are not adapted. We hypothesized that this novel disturbance
7 could reduce the availability and temporal persistence of oviposition habitats resulting in egg
8 mortality. To test this hypothesis, we quantified the oviposition behavior of four aquatic insects
9 using a hierarchical field survey of habitat availability and utilization. We found that three out of
10 four genera exhibited preferences for larger, emergent substrates located along the river edge,
11 thus increasing the likelihood of desiccation during stage height fluctuations. When subject to
12 experimental drying, we observed up to 93% egg mortality during desiccation lasting two hours
13 or less, and 100% mortality when desiccation exceeded four hours. These paired field and
14 experimental results suggest that hydropeaking could impart a population bottleneck on aquatic
15 insects. This project is on-going and these writing do not reflect the final views of the authors.

Title: Oviposition habitat selectivity and egg mass desiccation tolerances of select aquatic insects in a tailwater ecosystem: implications for population dynamics in large regulated rivers

Authors: Matt Schroer, Jesse Fleri, Ted Kennedy, Scott Miller

Introduction

It is widely recognized that large rivers are among the most anthropogenically impacted ecosystems on Earth (Allan and Flecker 1993, Dynesius and Nilsson 1994, Carpenter et al. 2011). Rivers have long been valued by human societies as sources of drinking water, aquaculture, waste disposal, transportation, recreation, and energy production (World Commission on Dams 2000, Kennedy et al. 2016). The construction and management of large dams may be among the most ubiquitous impacts, with an estimated 800,000 dams worldwide (Richter and Thomas 2007), and a mere 2% of the United States' rivers maintain unaltered hydrologic regimes (Graf 1993). Dam construction and management can negatively impact downstream ecosystems, known as *tailwaters*, by altering hydrologic, sediment, and thermal regimes, as well as by imposing significant migration barriers to aquatic organisms (Poff et al. 2007, Schmidt and Wilcock 2008, Olden and Naiman 2010, Dugan et al. 2010).

Power generation is a core function of dams worldwide, with an estimated 20% of global power supplied by hydroelectricity (World Commission on Dams 2000, Zarfl et al. 2015). Hydropeaking and load following flows are common water release strategies used to meet daily peak power needs and to maximize the market value of produced power (García et al. 2011, Førsund 2015, Kennedy et al. 2016). Under these scenarios, the magnitude of daily discharge fluctuates to coincide with peak energy demand, with either a single long-duration peak or two

short-duration peak discharge events occurring daily (i.e., *double-peaking*). In either scenario, hydropeaking operations can substantially increase daily hydrologic variability (Cushman 1985, Gore et al. 1994), which can alter downstream algal, macroinvertebrate, and fish assemblages (Moog 1993, Blinn et al. 1995, Young et al. 2011, Miller and Judson 2014). For example, Blinn et al. (1995) found that hydropeaking led to significant reductions in both green algae and macroinvertebrate biomass within hydrologically variable shoreline habitats of the Colorado River below Glen Canyon Dam compared to the permanently wet main channel. Despite extensive study of ecological impacts to downstream organisms, the specific mechanisms by which hydropower production alters tailwater community composition are uncertain.

The novel environmental conditions resulting from dam construction and management can be particularly deleterious to disturbance adapted populations having evolved life history strategies optimized to survive and even exploit natural disturbances (reviewed in Lytle and Poff 2004). This is particularly true for aquatic insects having complex life cycles that typically require both aquatic (larvae, pupae, eggs) and terrestrial (adult) life stages. The dependence of aquatic insects on both aquatic and terrestrial habitats means they can be subjected to novel conditions created by altered flows as both aquatic larvae and terrestrial adults returning to complete their life cycle. Previous studies have disproportionately focused on aquatic larvae (Downes and Reich 2008, *citations*), but recent evidence suggests that environmental alterations impacting other life stages such as adult or egg could be equally important for population dynamics (Kennedy et al. 2016). For example, studies have demonstrated that additions and reductions of preferred adult egg-laying, or oviposition, habitat from small stream reaches correlate to significant increases and decreases, respectively, in the abundance of both egg masses (Encalada and Peckarsky 2012, MacQueen and Downes 2015) and larvae (Encalada and

Peckarsky 2012, Lancaster and Downes 2014). Furthermore, certain caddisfly egg mass morphologies have been shown to reduce deleterious effects of high flows and predation, potentially increasing survivorship of new larvae (Bovill et al. 2013, Bovill et al. 2014). However, these studies have largely addressed life history responses to natural disturbance regimes in small streams and not novel environmental conditions such as those resulting from hydropower production in large, tailwater environments.

The potential for altered flows to influence non-larval insect life stages remains vastly underexplored. Only recently have researchers proposed that insect population viability could be limited by recruitment (the number of juveniles added to a population) constraints imposed by hydropеaking operations on large rivers (Encalada and Peckarsky 2012, Bovill et al. 2013, Kennedy et al. 2016). Hydropеaking operations can create artificial intertidal zones along shorelines, known as varial zones, which are rare in naturally flowing rivers (Benenati et al. 1998, Blinn et al. 1995, Kennedy et al. 2016). If flow fluctuations due to hydropеaking are frequent and severe, the varial zone can alternate between wet and dry phases on a daily basis, becoming a harsh environment for tailwater organisms that use shoreline habitats during one or more life stages. Since most adult tailwater insects are believed to preferentially oviposit on emergent substrates located within the varial zone (Kennedy et al. 2016), intra- and inter-daily water level fluctuations from hydropеaking could influence recruitment by altering the spatial and temporal availability of optimum oviposition habitats or by desiccating eggs cemented to benthic substrates. Specifically, rising water levels can act to submerge suitable emergent substrates along the shoreline, while receding waters can essentially remove these substrates from the confines of the wetted channel. Additionally, cemented egg masses laid at artificially high stage heights can become stranded when water levels retreat, increasing the risk of

desiccation-induced mortality. If hydropeaking flows create unfavorable environmental conditions that reduce or prohibit successful oviposition, egg hatching, or both, population bottlenecks could occur, potentially changing assemblage composition and ecosystem function.

The goal of this study was to examine hydropeaking-induced mechanisms that affect processes at non-larval insect life stages, specifically adult oviposition habitat selectivity and egg mass desiccation. We used a combination of benthic particle surveys and artificial substrate deployments to determine preferred oviposition habitats, and hypothesized that adult tailwater insects would differentially oviposit on emergent mineral substrates located in the varial zone. With oviposition habitat preferences identified, we then asked if daily water level fluctuations from hydropeaking alter the availability of preferred habitats, and whether egg masses in these habitats were at greater risk of desiccation-induced mortality due to chronic atmospheric exposure. To investigate the role of desiccation, we subjected egg masses of three insect taxa to various durations of atmospheric exposure in the lab and monitored the subsequent hatching success of individual egg masses. We predicted that hatching success rates would vary as a function of exposure time and egg mass morphology, with gelatinous egg masses possessing the greatest desiccation tolerance. Information obtained through this study will inform the adaptive management of hydropower operations to better balance societal power demands with the integrity of aquatic insect population dynamics and community composition in large tailwater ecosystems.

Methods

Study area

This study was conducted within a 27 km section of the Green River below Flaming Gorge Dam (FGD), near Dutch John, Utah, USA (Fig. 1). The Green River originates in the Wind River Mountains in Wyoming, USA, and flows south through Wyoming, Colorado and Utah. The Green River is the largest tributary of the Colorado River, and is historically characterized by a snowmelt hydrologic regime with maximum flows occurring in the spring, and relatively stable base flows dominating the remainder of the year. The completion of FGD in 1963 (4.67×10^9 cubic meter storage capacity relative to mean annual flow of $52 \text{ m}^3 \text{ sec}^{-1}$) significantly altered the hydrology of the river by reducing the mean annual peak flow, altering the seasonal timing of high and low flow events, increasing base flows and increasing intra-daily variation due to hydropeaking for electrical power generation (Vinson 2001, Miller et al. 2013). The direct and indirect effects of hydrologic alteration resulted in the extirpation of over twenty macroinvertebrate species, with the present day tailwater supporting a depauperate invertebrate fauna dominated by *Hyallela azteca*, Chironomidae spp., *Simulium* sp., *Gammarus lacustris*, Oligochaeta, and *Baetis* spp. (Vinson, 2001).

Study organisms

We characterized the oviposition habitat selectivity of four Green River tailwater insect taxa: *Baetis* spp. (Ephemeroptera), *Hydropsyche occidentalis* (Trichoptera), *Brachycentrus occidentalis* (Trichoptera), and Chironomidae (Diptera). For all taxa but Chironomidae, we also quantified egg mass desiccation tolerance. These taxa were selected because they are thought to exhibit differential oviposition strategies (e.g., edge versus deep-water specialists, landing on versus swimming to oviposition substrates), possess differing egg mass morphologies (e.g.,

gelatinous versus non-gelatinous, flat versus spherical; see descriptions below), and they are common in large, western U.S. rivers.

Baetis spp. mayflies (hereafter, *Baetis*) are ubiquitous aquatic insects with extensively studied oviposition behaviors (Eaton 1888, Morgan 1911, Elliot 1972, Peckarsky et al. 2000, Peckarsky et al. 2001, Peckarsky et al. 2002). Populations in the Green River are bivoltine, with an overwintering larval generation that emerges and reproduces as adults throughout April and May, and a summer generation that emerges and reproduces between September and October. Previous studies in other systems have observed that *Baetis* spp. exhibit highly specialized oviposition behaviors where adult females will land on large, emergent rocks and then crawl on the downstream side to oviposit a single egg mass under water on the rock's ventral surface (Eaton 1888, Peckarsky et al. 2000, Encalada and Peckarsky 2006). Each *Baetis* egg mass contains hundreds to thousands of eggs laid in rows to form a single, flat layer that resembles the shape of a tombstone and is only protected by a thin chorion (Fig. 2).

Hydropsyche occidentalis is a free-living, filter-feeding caddisfly common in rivers and streams of the western U.S. Green River populations are univoltine, with prolonged adult emergence occurring during summer and fall months (June – October). As observed in other caddisflies (Lancaster et al. 2010b), adult female Hydropsychids swim through the water column to oviposit on the undersides of submerged substrates, sometimes exceeding four meters in depth (Deutsch 1984). *H. occidentalis* egg masses are similar to those of *Baetis* in that they are arranged in a single, non-gelatinous layer of several hundred eggs cemented to a substrate's ventral surface (Fig. 2). However, egg masses of *H. occidentalis* are more irregular in shape, and individual eggs are larger.

Brachycentrus occidentalis is a case-building, filter-feeding caddisfly that occurs throughout running waters of western North America. Previous studies indicate that populations of *B. occidentalis* are univoltine with adult emergence occurring mostly in spring and early summer (Wiggins 1996, Gallepp 1974). While it is unclear how adult females reach oviposition sites, we observed egg masses of this species cemented below the water line on the lateral and near-ventral edges of emergent particles. Egg masses of *B. occidentalis* are unique compared to those of *Baetis* or *H. occidentalis* in that masses are spherical, and individual eggs are embedded within a gelatinous matrix (Fig. 2), which was absent from all other egg mass types in this study.

Non-biting midges in the family Chironomidae are worldwide in distribution and often contribute significantly to the energetics of aquatic ecosystems and surrounding landscapes due to short life cycles and high biomass (Merritt et al. 2008). Chironomids emerge year-round on the Green River, though the majority of adults are found in spring and summer months (M. Schroer, personal observation). During our study, adult females were observed to land on emergent rocks and crawl to the water, where they would lay egg masses (often en-masse) primarily along the downstream edge at the water surface elevation. Sampled egg masses, known as ropes, consisted of hundreds to thousands of rod shaped eggs arranged in spiraled strings (Fig. 2). We were unable to distinguish among egg masses of different midge species, but examination of pupal exuviae collected during surveys and larval taxonomic records indicate that four genera accounted for most egg masses in this study: *Diamesa*, *Eukiefferiella*, *Tvetenia* and the *Cricotopus/Orthocladius* complex.

Oviposition habitat surveys

To quantify oviposition habitat availability and selectivity, we conducted substrate surveys in 2015 and 2016. We used personal observations and communication with local fishing guides to identify periods of peak insect emergence and subsequent oviposition. We focused on three sites below FGD: Tailrace (1 kbd), Grasshopper Island (14 kbd), and Indian Crossing (26 kbd), hereafter referred to as S1, S2, and S3, respectively. These sites were selected to represent geomorphic and hydrologic gradients below FGD, particularly the interaction of width:depth ratios and the magnitude of intra-daily stage height fluctuations resulting from hydropeaking. For example, S1 is located in a deep bedrock canyon where bankfull widths range from 40 – 150 m and base flow water depth from 1 – 10 m. Bed material in riffles consists of coarse gravel, cobbles and boulders. In this river section, the canyon bound morphology results in the greatest stage height fluctuations during periods of hydropeaking. In contrast, S3 is located in alluvial plains of Brown's Park where bankfull widths increase to 200 m, base flow water depths decrease to an average of 0.5 – 2 m and bed material grades from gravel and cobble to seasonal deposits of sand and silt exported from Red Creek located upstream (Vinson, 2001).

We employed a hierarchical sample design to characterize oviposition habitat availability and use. Using aerial photography, a single 1.5 km river segment was chosen to be representative of the geomorphic diversity within each of the three sites. Two fast-water (i.e., riffles) and two slow-water (i.e., runs) reaches (maximum length = 75 m) were randomly selected for sampling for a total of four reaches per 1.5 km segment. The three river segments (12 reaches total) were sampled on multiple occasions during summer of 2015 and spring of 2016. To control for changing daily water levels due to hydropeaking, surveys across all sites and reaches were conducted at the lowest day time discharge, which were 51.0 and 22.7 m³ s⁻¹ for summer 2015 and spring 2016, respectively.

Observations from past studies (Peckarsky et al. 2000, Hoffmann and Resh 2003, Lancaster et al. 2010a and 2010b), as well as a pilot study below FGD, indicate that egg masses, in general, are disproportionately found on emergent rocks or woody substrates in moderate water velocities, often near river margins. As these habitats are not present in equal proportions from reach to reach or segment to segment, a simple random sample would result in under-sampling some habitats (e.g., emergent rocks or vegetation) and oversampling others (e.g., submerged rocks). Therefore, to characterize both available and selected oviposition habitats (also interchangeably referred to as substrates and particles), we followed Reich and Downes (2003) and utilized a two-stage sample design. In the first stage, referred to as random surveys, reaches were sampled using a random-systematic approach to characterize substrate availability, as well as the physical characteristics of substrates. Specifically, 10 points were sampled along each of five transects for a total of 50 points per reach. Transects were located using a random starting point within each reach and then systematically spaced at regular intervals. Transects were oriented perpendicular to the channel and extended to mid-channel or a depth of 1 m for safety reasons. Lastly, the 10 points per transect were not equally spaced, with the first five particles spaced at 0.5 m intervals to measure more rapid physical changes along channel margins. The remaining five particles were spaced at regular intervals to mid-channel or a depth of 1 m, whichever came first.

The second sampling stage, referred to as *stratified surveys*, involved the stratification of sample reaches by substrate type for a total of five possible strata: 1) submerged rocks, 2) emergent rocks, 3) submerged wood, 4) emergent wood and 5) emergent vegetation. To achieve minimum sample sizes among strata ($n = 15$), up to 15 additional random points were sampled per strata per reach (note that the 50 random points used to quantify substrate availability in stage

one counted towards the substrate counts in the respective strata). In total, we sampled between 75 – 110 points per reach for a total of 300 – 440 points per 1.5 km segment, depending on the number of strata present per reach.

At each of the 75 – 110 points per reach, the following parameters were measured: reach type, distance from bankfull, particle type, particle size, particle depth, emergent area, water velocity, embeddedness and the type and abundance of egg masses (Table 1). The aggregated morphology of Chironomidae egg masses precluded direct enumeration, so we developed an ordinal scale based on aerial extent of the substrate covered by egg masses. If midge egg masses were present, the area of substrate covered by all masses was estimated to be less than the area of either a standard US postal stamp (2.2 x 2.5 cm), credit card (5.4 x 8.5 cm), standard envelope (10.5 x 24.0 cm) or an 8.5 x 11 inch sheet of paper (21.5 x 27.9 cm) (Table 1). For all other taxa, egg abundances were categorized as: 1 – 10, 11 – 50, 51 – 100 and > 100 egg masses per rock.

Artificial oviposition substrates

To validate our observational study of oviposition habitat preferences, we experimentally manipulated particle depth (i.e., emergent versus submerged) and distance from bankfull in two separate trials. We focused on these two environmental factors because they form the basis for hypotheses related to hydropeaking and egg viability, they were among the top predictors in habitat selectivity models and they were easily manipulated. Specifically, we used 20 x 20 x 20 cm cinderblocks as artificial substrates for oviposition. Blocks were arranged in five transects, with four replicates per transect. The five transects were oriented parallel to the river bank and located approximately 3.0, 4.5, 7.5, 10.5 and 13.5 m from the bank.

The first trial was run with all emergent blocks and the second all submerged. Combined, these two experimental trials allowed us to test for differential use of emergent versus submerged particles and whether use depended on distance from bankfull. For the submerged treatment, we also included an emergent control to ensure oviposition was actively occurring. Trials were run consecutively in March and April of 2016, and each trial lasted for 7 – 17 days to allow sufficient time for adults to oviposit on blocks. At the beginning and end of each trial, we recorded distance from bankfull (m) and particle depth (cm) for each of the 20 artificial substrates. At the end of each trial, substrates were retrieved and checked for egg masses of *Baetis* and Chironomidae. *H. occidentalis* and *B. occidentalis* egg masses were not found on artificial substrates in sufficient numbers for analysis.

Hydropeaking effects on optimal oviposition habitats

We used differences in baseflow discharge between years (2016: $51.0 \text{ m}^3 \text{ s}^{-1}$ and 2015: $22.7 \text{ m}^3 \text{ s}^{-1}$) to understand how emergent substrate availability varies with stage height fluctuations; the difference in discharge between years was equivalent to the stage height fluctuations associated with hydropeaking for 2015. Specifically, for each of the three segments, we calculated the average number of emergent rocks and compared the values between years. We chose to examine emergent rocks, as these proved to be highly preferred substrates for *Baetis*, *B. occidentalis* and Chironomidae.

Desiccation tolerances of egg masses

To determine desiccation tolerances of insect eggs, we exposed egg masses to a single drying event of varying duration and measured the hatching success of each mass. Egg masses

249 were collected from the Green River using both natural and artificial substrates (slate tiles
250 attached to cinder blocks). Egg masses and/or slate tiles were removed from substrates, placed in
251 Whirlpak® bags filled with river water, stored on ice and transferred to the lab. Within 24 hours
252 (h) of collection, we placed egg masses into individual petri dishes filled with chlorine-free water
253 and assigned egg masses to one of six desiccation treatments: 0, 0.5, 1.0, 2.0, 4.0 or 8.0 h in a
254 completely randomized factorial design. Treatment levels greater than 2.0 h represent common
255 durations for varial zone exposure below hydropeaking dams, while treatment durations less than
256 2.0 h were added to understand general insect desiccation tolerances. The number of replicates
257 per treatment depended on egg mass availability and ranged from 14-16 (total n = 84, 96 and 90
258 for *Baetis* spp., *H. occidentalis* and *B. occidentalis*, respectively). Results from Chironomidae
259 desiccation trials are only anecdotally presented in the discussion due to difficulties in
260 enumerating the total number of eggs per mass.

261 After each treatment, egg masses were rehydrated, photographed under a dissecting
262 microscope and reared at approximately 23°C under an artificial light regime of 12 h light:dark.
263 The total number of eggs per mass was estimated using Image J© software, or counted directly
264 in the case of *H. occidentalis*. Water was renewed in each petri dish every 24 – 48 h in an effort
265 to maintain dissolved oxygen levels and to reduce potential for fungal or bacterial growth. We
266 checked egg masses every 2 – 3 days for hatched larvae, which were counted and removed. An
267 individual was considered “hatched” if it showed evidence of physical development beyond the
268 embryo stage (e.g., formation of sclerotized plates or uncurling of abdomen). Experiments ran
269 for a total of 4 – 7 weeks and were terminated when the cumulative number of hatched
270 individuals counted across all treatments on a given day fell below 1.0% of the total number of
271 hatched individuals for the experiment to date. For all experiments, desiccation tolerance was

interpreted from hatching success, defined as the ratio of hatched individuals to the total number of eggs per mass.

Statistical analyses

We used Random Forest (hereafter, RF) models fit in R (package ‘randomForest’, version 3.4.1, R Development Core Team 2017) to quantify the relationship between egg mass abundance and environmental variables at segment, reach and substrate particle scales. Year was not a significant factor in any models and thus data from 2015 and 2016 was combined into a single model per species with egg abundance as the response variable. RF is a tree-based approach that fits thousands of classification or regression trees to a dataset where individual trees are developed for a bootstrapped sample of the data using a random subset of predictors at each split to find the most homogenous groups (Breiman 2001, Liaw and Wiener 2002). Model performance was assessed using percent variance explained, which is an internal cross validated metric defined as $1 - (\text{mean squared error})/(\text{variance}(\text{response}))$, and is analogous to r-squared (Pang et al. 2006). Variable importance was assessed using percent increase in mean square error (MSE) following the permutation of individual predictor variables, with higher MSE values indicating a greater decrease in model accuracy (Pang et al. 2006). Partial dependence plots were constructed to assess the relationship of individual predictors to the response variable by holding the effects of all other predictors in the model constant (Cutler et al. 2007).

For artificial substrates we tested for differences in egg mass abundance as a function of distance from bankfull (five levels: 3.0, 4.5, 7.5, 10.5 and 13.5 m) using a generalized linear model (GLM) in R (‘glm’ function in the package ‘stats’, version 3.4.1). Models were built using a poisson distribution and log link function and run separately for each of *Baetis* spp. and

Chironomidae. *H. occidentalis* and *B. occidentalis* were not found in sufficient numbers for analysis and no formal models were run for tests of egg abundance differences between emergent and submerged particles, as only one of 20 submerged particles contained eggs.

GLM models were also used to test for differential hatching success among desiccation treatments. Specifically, models were built using a quasibinomial distribution and logit link, where a quasibinomial distribution was used to mitigate the effects of over-dispersion. Significant overall model results were followed by Tukey post-hoc test to determine the exact duration of desiccation that resulted in a significant decline in hatching success. This analysis allowed us to determine critical desiccation threshold ranges and emphasize the importance of different egg morphologies.

Results

Egg mass abundance and distribution patterns

We enumerated 5527 egg masses among the three study segments with *Baetis* having the greatest number (2606) followed by *B. occidentalis* (2152), Chironomidae (492) and *H. occidentalis* (277). *H. occidentalis* and *B. occidentalis* egg masses were only found during late June and July sampling events, while *Baetis* and Chironomidae were found throughout spring and summer months, with higher abundances in spring than summer. Egg mass abundances generally differed among segments; *H. occidentalis* egg mass abundances increased with distance downstream and *Baetis* and Chironomidae abundances decreased (Fig. 3). Egg mass abundances were consistently higher in fast water reaches compared to slow water, with downstream abundances of *Baetis* being the one exception.

Oviposition habitat selectivity

Preferred oviposition habitats of all four taxa were not randomly distributed, but rather differentially located within reaches and across substrate types. RF model precision was 68% for Chironomidae, 52% for *B. occidentalis*, 43% for *Baetis* and 20.8% for *H. occidentalis*. The relative importance of the nine predictor variables was similar among models, with measures of particle size, type and emergent area, distance from bankfull, particle depth and segment among the top predictors (Fig. 4). In general, all four taxa preferred large and/or emergent particles (Fig. 5). *Baetis*, *B. occidentalis* and Chironomidae appear to be edge specialists, preferring large emergent particles located close to the bank or in otherwise shallow waters, while *H. occidentalis* utilized mostly large particles located in deeper water (Fig. 6). Notable differences among models included the strong influence of water velocity for *Baetis* and *B. occidentalis* and to a lesser extent, differences among segments for *Baetis*, *H. occidentalis*, and Chironomidae.

Artificial oviposition substrates

We observed similar particle preferences for *Baetis* and Chironomidae during experimental manipulations of particle depth and distance from bankfull. Oviposition almost exclusively occurred on emergent particles, with only one of 20 submerged particles containing eleven *Baetis* egg masses. Chironomidae adults laid eggs on emergent cinder blocks only – no egg masses were found on submerged blocks. Given the paucity of egg masses on submerged particles, we compared egg abundances as a function of distance from bankfull for only emergent particles. *Baetis* egg mass abundances significantly differed among transects ($\chi^2 = 40.6$, $df=3$, $p < 0.001$), with the two closest transects having the highest abundances and significantly lower abundances for transects located 7.5 and 10.5 m from bankfull. In contrast,

we observed no differences in Chironomidae egg mass abundance with distance from bankfull
($\chi^2 = 0.62$, $df=3$, $p = 0.891$).

Hydropeaking effects on optimal oviposition habitats

We observed reductions of 37, 88 and 100% in the average number of emergent rocks per
segment found during random surveys conducted at 50.97 and 22.65 m³ s⁻¹ among S1, S2 and
S3, respectively (Fig. 7). Reductions in the number of emergent rocks increased with distance
downstream as mean particle size decreased; the mean particle size of emergent rocks found
during random surveys decreased from 524 mm at S1 to 302 mm at S3.

Desiccation tolerances of egg masses

All three taxa exhibited reductions in hatching success in response to desiccation,
although the duration of desiccation corresponding to the greatest declines differed among taxa
(Fig. 8). *Baetis* exhibited the lowest desiccation tolerance, followed by *H. occidentalis* and then
B. occidentalis. The hatching success of *Baetis* significantly differed among treatments ($\chi^2 =$
3013.9, $df=3$, $p < 0.001$), with significant declines starting after one hour of desiccation ($\beta = -$
4.32, $z = -3.37$, $p = 0.003$). On average, eggs masses desiccated for 0.0 h were 37% more likely
to hatch than eggs desiccated for 1.0 h. *Baetis* treatments lasting longer than 2.0 h resulted in
100% egg mortality (Fig. 8).

We observed 100% egg mortality in both the 4.0 and 8.0 h treatments for *H. occidentalis*,
while a single individual hatched across all 2.0 h replicates. In contrast, there was no evidence of
differences in hatching success among the control, 0.5 and 1.0 h treatments ($\chi^2 = 7.6$, $df=2$, $p =$
0.839).

Egg masses of *B. occidentalis* were the most tolerant to desiccation. We observed significantly different hatching success among treatments ($\chi^2 = 355.8$, $df=5$, $p < 0.026$), but no significant differences were observed for pair-wise comparisons to the control.

Discussion

Aquatic insect assemblages have been shown to be depauperate below hydroelectric dams in comparison to unaltered systems; however, the exact mechanisms for population declines has eluded researchers. We provide evidence for a novel hypothesis related to egg recruitment limitations resulting from hydroelectric dam operations. Specifically, we found that adult tailwater insects generally prefer to oviposit on large, emergent particles located along river's edge, and that fewer of these preferred substrates are present within segments at higher flows commonly associated with hydropeaking. Additionally, we observed high mortality rates to short duration desiccation events highlighting the susceptibility of egg masses subject to fluctuating flows and subsequent atmospheric exposure. Below we discuss these results and highlight two mechanisms by which hydroelectric dam operations have the potential to limit insect population recruitment.

Oviposition habitat selectivity

Researchers have long suggested that organisms select habitats using a hierarchical process, whereby decisions are made at several nested spatial scales (Hildén 1965, Orians and Wittenberger 1991, Wildermuth 1994). Hoffmann and Resh (2003) provided early evidence of hierarchical oviposition habitat selection for aquatic insects in small streams, showing that females of two caddisfly species use cues at three different spatial scales, from the stream reach

down to the scale of individual substratum, to determine an oviposition site. We found similar support for hierarchical habitat selection by ovipositing insects in a large western US tailwater. Results from our surveys suggest that most female adults use cues at segment, reach and substratum scales (see methods) to determine optimal oviposition habitats. Specifically, adults largely prefer to oviposit on emergent particles located along a river's margin in fast-water reaches.

At the segment scale, adults appear to specifically target faster flows, as the vast majority of all egg masses surveyed were found in fast-water reaches (Fig. 3). Adults likely use polarized light from faster moving water to cue in to these areas (Schwind 1991, Kriska et al. 1998), and hypotheses as to why these flows are targeted include better dispersal capabilities for hatched larvae, more reliable oxygen delivery to egg masses and mitigation against fine sediment build-up (Hoffmann and Resh 2003, Lancaster et al. 2010b). Faster waters may also provide some protection against receding water levels, as faster moving water is more likely to induce splashing, which could act to distribute small amounts of water to additional areas and maintain a moist environment for egg masses left exposed above water line after flows recede.

Once a reach has been chosen, insects in this study overwhelmingly oviposited on substrates located in the varial zone near water's edge. *Baetis*, *B. occidentalis*, and Chironomidae all exhibited strong edge-specialist oviposition behaviors (Fig. 6 Panels XYZ). Only *H. occidentalis* showed some preference for substrates located more mid-channel (Fig. 6 Panel X). Egg masses of edge-specialists were found aggregated in high numbers on substrates located within 5 m of bankfull, while substrates located outside the varial zone contained significantly fewer egg masses. Though a causal basis for preferring substrates located nearer to shore has yet to be demonstrated, it is thought that this behavior may reduce predation risk for adult females

(Lancaster et al. 2010b). Adult tailwater insects are often found in riparian vegetation or flying in mating swarms along a river's edge, so ovipositing on substrates closer to these environments reduces the distance an adult female must travel, in turn reducing costs to fitness and the chances of predation. Additionally, substrates found in mid-channel are often located in deeper water, requiring an adult female with cementing oviposition behavior to swim or crawl a further distance to reach the optimal area of a substrate, increasing chances to be predated upon or swept downstream in the current. Perhaps the simplest explanation for this result in large rivers, however, is that the largest proportion of favored habitat (i.e., emergent particles, see below) is naturally located in shallower water near shore. Additional research is warranted to further explore this selective behavior.

At the scale of individual particles, several substrate characteristics were consistently ranked as top predictor variables across all study taxa – most notably particle size, particle type and emergent area (Fig. 4). All study taxa showed preferences for larger particles (Fig. 5). Evolutionarily, this makes sense given that larger particles are less prone to disturbance by catastrophic flows, which could damage egg masses (Encalada and Peckarsky 2006). It is also thought that laying eggs on larger substrates may provide flow refugia for neonate larvae (Hoffmann and Resh 2003). In addition to particle size, all study taxa exhibited preferences for certain particle types. Edge-specialists all strongly preferred emergent particles, while *H. occidentalis* targeted submerged particles (Fig. 6). Overall, emergent particles accounted for only X% of all substrates sampled during random surveys, but accounted for Y% of substrates found with egg masses present. This provides evidence that *Baetis*, *B. occidentalis*, and Chironomidae are specifically targeting emergent particles for oviposition. Additionally, when egg masses were found on emergent particles, ones with larger emergent areas were favored (Fig. 5). Larger

emergent areas may break up polarized light, helping females cue in to ideal substrates. They may also serve as “landing pads” for adults to alight upon before crawling underwater to oviposit. These results confirm our hypothesis that most adult tailwater insects are disproportionately targeting preferred habitats in the varial zone for oviposition, despite their relative short supply compared to other potential oviposition sites.

In contrast to edge-specialists that land and aggregate egg masses on emergent particles within 5 m of shore, *H. occidentalis* females appear to swim through the water column to oviposit on the undersides of submerged particles, including some located beyond 10 m. Previous studies have documented this swimming behavior in other members of the Hydropsychidae family (Fremling 1960, Rhame and Stewart 1976, Deutsch 1984). In this study, *H. occidentalis* egg masses were found in low numbers - typically only 1 or 2 individual egg masses - on submerged particles located in shallow water within 10 m from bankfull. Accumulations of multiple egg masses were found on particles located in deeper water beyond 10 m, suggesting that these non-varial zone substrates were more preferred by females than substrates located closer. It is important to note that we did not sample particles deeper than 1 m for safety reasons, so it is quite possible that adults oviposited on particles located even further away from shore than our results show, especially considering Deutsch (1984) observed *Cheumatopsyche speciose* and *Hydropsyche phalerata* regularly swim 2-3 m to oviposit on the riverbed of the Susquehanna River. This swimming behavior may help release *H. occidentalis* from recruitment pressures amplified by hydropeaking operations (see below).

We believe results from our particle surveys are the first to empirically demonstrate that tailwater insects strongly prefer to oviposit on particles found in varial zone environments. Kennedy et al. (2016) concluded similar oviposition behaviors using trait databases for all

aquatic insects (Statzner and Beche 2010), but a formal test of these preferences was not conducted. The oviposition preference results in our study are in line with previous studies from smaller systems that have shown most adult insects to oviposit on large, emergent particles near stream margins. While some adults lay their eggs directly into the water column (Encalada and Peckarsky 2007) or within plants (Siva-Jothy et al. 1995), roughly 80% of aquatic insects with known oviposition behaviors cement their eggs onto specific substrates (Statzner and Beche 2010, Kennedy et al. 2016). These substrates include wood (Hoffmann and Resh 2003, MacQueen and Downes 2015), terrestrial and trailing vegetation (Hoffmann and Resh 2003) and submerged and emergent rocks (Deutsch 1984, Peckarsky et al. 2000). Emergent rocks appear to be especially important to several species of aquatic insects. Additionally, Lancaster et al. (2010b) and Hoffmann and Resh (2003) also found evidence that certain species of caddisfly (*Polycentropus flavomaculatus*, *Hydropsyche siltalai*, and *Hydatophylax* sp.) prefer to lay eggs along stream margins.

Artificial oviposition substrates

Artificial substrate trials strongly corroborated results of our particle surveys that certain tailwater insects overwhelmingly target emergent particles for oviposition. *Baetis* and Chironomidae oviposition occurred almost exclusively on emergent blocks in experimental trials. When given the exact same substrate at varying distances from shore, adult *Baetis* oviposited on the two near shore transects. In nature, *Baetis* females may lay eggs on substrates further out from shore if other attributes of that substrate are appealing (size, flow, emergent area, etc.), but when conditions are equal, habitats closer to shore are preferred. Although *Baetis* females showed analogous patterns of oviposition in relation to distance from bankfull for both natural

and artificial substrates, midges oviposited equally across all transects in the artificial substrate trials, showing no apparent preference for blocks closer to shore. This is somewhat in contrast to results from particle surveys (Fig. 6) that showed a strong tendency for midges to lay egg masses on substrates located within 5 m from bankfull. However, it should be noted that bank distance was not as strong of a predictor variable for Chironomidae as compared to all other study taxa (Fig. 4). One possible explanation for this is that midges in this study were observed to lay eggs at the water surface elevation along emergent particles. In contrast, *Baetis* (as well as *H. occidentalis* and *B. occidentalis*) cement their egg masses well below water line. This behavior requires adult *Baetis* females to fully submerge themselves, which can increase the risk of predation by fish, as well as increase the risk of drowning or being swept downstream. Adults with submerging behaviors may decrease these risks by ovipositing on particles located in shallow waters near shore where velocities and shear stress are typically less severe. Our modeling results provide some additional support for this hypothesis, with water velocity being a more important predictor for *Baetis* (4th out of nine predictors) than for midges (7th out of nine predictors). Another explanation for midges using all transects includes the possibility that adult midge densities during the experimental trials and in the areas they were conducted were much higher than for our particle surveys. Higher oviposition densities could lead to over-saturation and use of sub-optimal habitats during the experimental trials. Nonetheless, results from artificial trials for both *Baetis* and Chironomidae reinforce the concept that many tailwater insects lay a large proportion of their egg masses on emergent particles in near shore environments.

Hydropeaking effects on optimal oviposition habitats

Stage-height fluctuations associated with hydropeaking have the potential to significantly reduce the availability of optimal oviposition habitat on the Green River. We observed declines in the average number of emergent rocks per segment between high and low water levels, and the magnitude of these declines grew stronger moving downstream. The stark declines at S2 and S3 make sense given changes in channel geomorphology and particle size. The Green River at these sites is much wider and shallower as compared to S1, and average particle size declines downstream (see methods and results). These smaller average substrates will be more easily submerged by higher flows as compared to larger average particles found upstream.

Egg mass desiccation tolerance

Few studies have sought to quantify, compare or understand the importance of aquatic insect egg morphologies, let alone test the potential effects of differing morphologies on recruitment success and population dynamics. Recent studies involving desiccation have focused on multivariate trait-based approaches to explain how macroinvertebrates can persist in arid regions (Poff et al. 2006; Strachan et al. 2015) yet fail to demonstrate how variation in drying time may influence their results. Our results suggest that egg morphology, specifically spumaline, is a more significant factor for withstanding desiccating events than previously thought. We consistently observed the greatest resistance to desiccation by taxa with the largest volume of spumaline. For taxa with little to no spumaline, *Baetis* and *Hydropsyche*, 99% of eggs were unable to hatch after a single 2 hour desiccating event. In contrast, *Brachycentrus* eggs exhibited no significant change in hatching success after 8 hours of drying. Previous studies have suggested that collateral coatings such as spumaline may protect eggs against predation, parasitism, and desiccation (Hinton 1981, Hilker et al. 2008). Although few studies have

examined the chemical constituents of spumaline which may become increasingly important for understanding the mechanisms driving tailwater community dynamics. Macroinvertebrates with spumaline coated eggs may be better suited for survival in stochastic environments such as tailwater fisheries, but spumaline producing glands are absent from Ephemeroptera, Plecoptera, and most Coleoptera (Matsuda 1976). Ephemeroptera and Plecoptera are among the most popular taxa used as indicators of biologic health in freshwater ecosystems and are being extirpated from tailwaters at an alarming rate (Vaikasas et al. 2013, Holt et al. 2015, Kennedy et al. 2016).

Hydropeaking as a novel environmental filter and driver of insect community structure

Flowing waters are among the most complex and dynamic ecosystems on Earth, and they harbor diverse communities of organisms that have evolved myriad morphological, behavioral and life-history adaptations in response to natural flow conditions (Naiman et al. 1993, Dynesius and Nilsson 1994). When natural flows are altered, organisms may not have the required traits or behaviors needed to persist under the alternative hydrologic regime. Species with complex life cycles requiring specific sets of conditions at multiple life stages will be especially susceptible to detrimental effects (Smith et al. 2009, Alp et al. 2013). Loss of insects and other groups from tailwaters after dam construction is well documented (Ward and Stanford 1979, Power et al. 1996, Vinson 2001, Arthington et al. 2006). Our results, in combination with those of other researchers, demonstrate that successful insect recruitment in tailwaters could be heavily dependent upon flow conditions, and limitations to recruitment caused by hydropeaking could be one explanation as to why some insect taxa are extirpated from tailwaters while others persist. We present two novel mechanisms by which insect recruitment and, subsequently, community

structure may be altered by novel flow fluctuations: reductions in oviposition habitat availability and increased risk of egg mortality due to desiccation.

Reductions in the total number of oviposition sites due to hydropeaking could have severe consequences for populations of larval aquatic insects. Lancaster and Downes (2014) found that numbers of early instar *Baetis rhodani* and *Rhyacophila dorsalis* were positively correlated with the number of oviposition sites, in this case emergent rocks. Adults of both of these species cement their egg masses to emergent rocks. Interestingly, numbers of *Simulium* spp. larvae, whose adults lay eggs on trailing riparian vegetation, did not correlate to the number of emergent rocks present, suggesting that differences in *B. rhodani* and *R. dorsalis* larval numbers between reaches were due specifically to changes in the abundance of preferred oviposition sites. More compellingly, Encalada and Peckarsky (2012) demonstrated that direct manipulations to the abundance of emergent rocks across several stream reaches altered both egg mass densities and larval abundances of *Baetis bicaudatus*. In reaches where all emergent rocks were removed, egg densities dropped to zero and average larval densities declined by a factor of almost 2.5 one year after the manipulations. In combination, these studies provide strong evidence that availability of preferred oviposition habitats is more important to recruitment and population sizes of aquatic insect larvae than previously thought.

Management of dam releases such as hydropeaking can essentially manipulate the abundance of preferred oviposition sites, just as in Encalada and Peckarsky's experiment, only on timescales that range from hours to days. Under commonly used double-peaking regimes, river discharge increases in the hours around both dusk and dawn to generate electricity at peak consumption hours, in turn raising stage height and altering the availability of oviposition sites. Since dusk and dawn hours are believed to be the peak times for aquatic insect mating and

569 oviposition to occur (citations: Kriska et al 1998, others??), double-peaking flows have the
570 potential to negatively affect oviposition site availability and subsequent recruitment for insects
571 with edge-specialist, cementing behaviors. In addition to releasing water for generating power,
572 hydropeaking dams often conduct sustained high flow events (HFEs) for either reservoir water
573 storage or to mimic natural flooding. These high flow events can last anywhere from a few days
574 to several months, as was the case below FGD in 2017, when flows remained at or above 198 m^3
575 s^{-1} (more than 8x the minimum flow of $22.7 \text{ m}^3 \text{ s}^{-1}$) for three months. If HFEs act to submerge
576 most or all oviposition sites during times of peak oviposition, insect recruitment could be
577 severely depressed. Regulated flows of any type essentially present ovipositing insects with a
578 “moving target” in terms of where and when optimal oviposition sites will be available. Over
579 time, repeated exposure to this novel pressure may act to extirpate taxa with rigid oviposition
580 behaviors that cannot adapt.

581 Researchers have suggested that these two recruitment limitations imposed by
582 hydropeaking operations could influence community structure by leading to the extirpation of
583 select insect taxa, specifically those considered as edge-specialists that utilize varial zone
584 habitats for oviposition (Kennedy et al. 2016). Both hydropeaking high and low flows have the
585 potential to reduce population recruitment, but by different mechanisms – loss of habitat and
586 desiccation, respectively. These mechanisms could very well explain the virtual dearth of
587 sensitive taxa from the orders Ephemeroptera, Plecoptera, and Trichoptera (EPT) in the Colorado
588 River tailwater below Glen Canyon Dam, as well as the depleted assemblages in other desert
589 tailwaters such as that below Hoover Dam. Hydropeaking regimes in these tailwaters are more
590 intense compared to the FGD tailwater (see Kennedy et al. 2016), with large disparities between
591 low and high flows on a regular, daily basis. Additionally, the canyon-bound geography of these

particular tailwaters means changes in discharge will translate to significant stage height fluctuations in varial zone habitats, both submerging (negative for ovipositing adults) and exposing (negative for egg masses) emergent particles more easily. This, in combination with highly arid atmospheric conditions in the surrounding terrestrial landscape, creates a highly stressful environment for both adults and egg masses of aquatic insects with edge-specialist, cementing oviposition behaviors. In these specific systems, hydropeaking may artificially select against these taxa, producing a depauperate insect community.

However, other tailwaters with hydropeaking regimes, such as that below FGD, contain a relatively healthy assemblage of EPT taxa, which begs the question as to the relative strength of these hydropeaking-induced recruitment constraints in shaping insect community structure. If the regional species pool is comprised of taxa with relative plasticity in oviposition behaviors, these communities may not be as affected by detrimental effects of fluctuating water levels on habitat availability. For example, while all previous research found *Baetis spp.* oviposition to occur almost entirely on emergent rocks (Eaton 1888, Peckarsky et al. 2000, Encalada and Peckarsky 2006, Encalada and Peckarsky 2012), we found *Baetis* egg masses on a variety of substrates, including *Typha* reeds, pine cones and bark and willow branches. The ability for *Baetis* in this study to oviposit on a variety of substrates may help ensure recruitment for this taxon at times when flows significantly reduce the abundance of preferred substrates. Similarly, if the regional pool consists of taxa with oviposition behaviors that are not as susceptible to negative effects of altered flows, such as the swimming behaviors of *H. occidentalis*, extirpations may not be as widespread.

Suggestions for large river management

River managers and dam operators are increasingly interested in balancing societal power needs with the ecological integrity of tailwaters and the flora and fauna that inhabit these ecosystems. Given the potential for hydropeaking flows to alter the spatial and temporal existence of optimal oviposition habitats, as well as to increase the risk of mortality for unhatched eggs, it is important to consider how management practices could be used to mitigate the negative effects of altered flows on processes occurring during non-larval insect life stages. The most straightforward method to diminish the effects of hydropeaking on adult oviposition and egg mass hatching is to reduce hydropeaking flows during periods of intense oviposition. Most uni- and multi-voltine aquatic insects oviposit during spring and summer months (citations), so reducing the disparity between high and low daily flows during these periods of the year would undoubtedly help to alleviate the potential detrimental effects of hydropeaking mentioned thus far. Similarly, running lower flows during daily peak oviposition hours would increase the chances of egg masses being laid at low stage heights, thus remaining submerged during higher flows. It is thought that most aquatic insects oviposit near dawn and dusk hours (citations). Unfortunately, morning and evening hours are precisely the times of day when electricity demand is often highest and hydropeaking flows are implemented. Therefore, this method seems unlikely. Instead, more stable, lower flow regimes implemented for short periods during peak oviposition, such as the low weekend flow regime suggested by Kennedy et al. (2016), may be more economically and sociably feasible. Regardless, solutions to recruitment constraints imposed by hydropeaking flows will require robust data sets on regional and local insect phenologies and cooperation between land managers, scientists, and the public.

638 **Acknowledgements**

639 This work was supported in part by the Western Area Power Administration, Bureau of Land
640 Management, U.S. Geological Survey, Utah State University's Honors College and Office of
641 Research and Graduate Studies. Co-author Jesse Fleri would like to specifically recognize his
642 committee members Scott Miller and Matt Schroer for all of their assistance over the past three
643 years.

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FIGURES

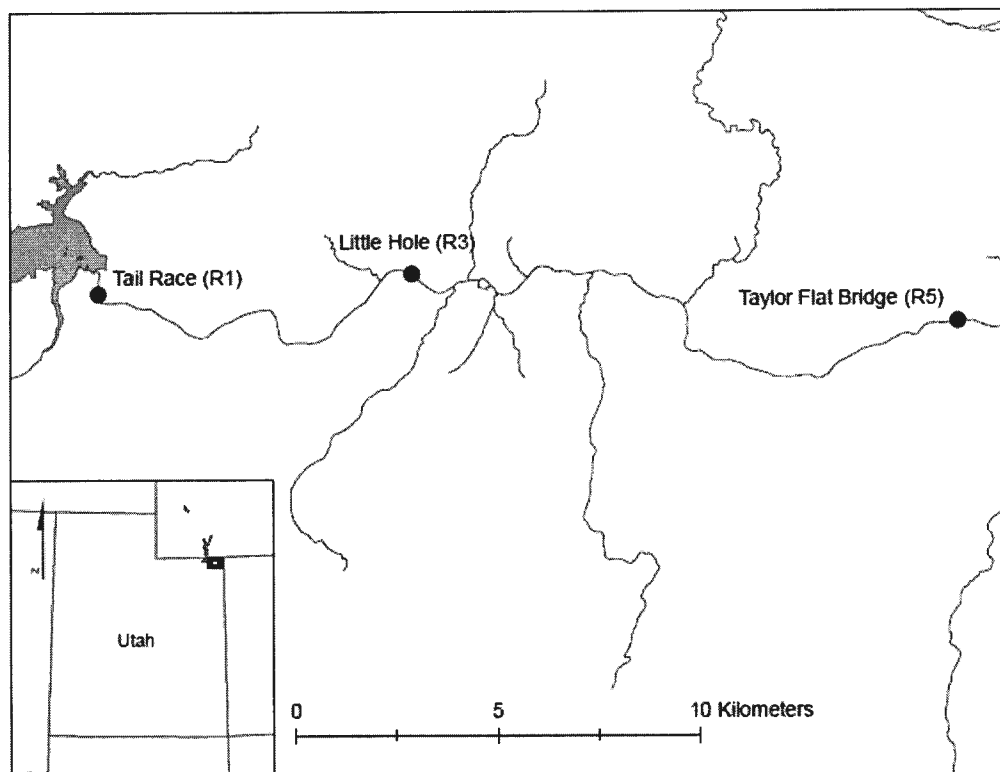


Figure 1. Location of the Green River within Wyoming, Utah and Colorado. Shown are the three study segments located below Flaming Gorge Dam: Tail Race, Little Hole and Taylor Flat Bridge.



Figure 2. Larval and egg mass photos of *Brachycentrus occidentalis* (Trichoptera), *Hydropsyche occidentalis* (Trichoptera), Chironomidae (Diptera) and *Baetis* spp. (Ephemeroptera).

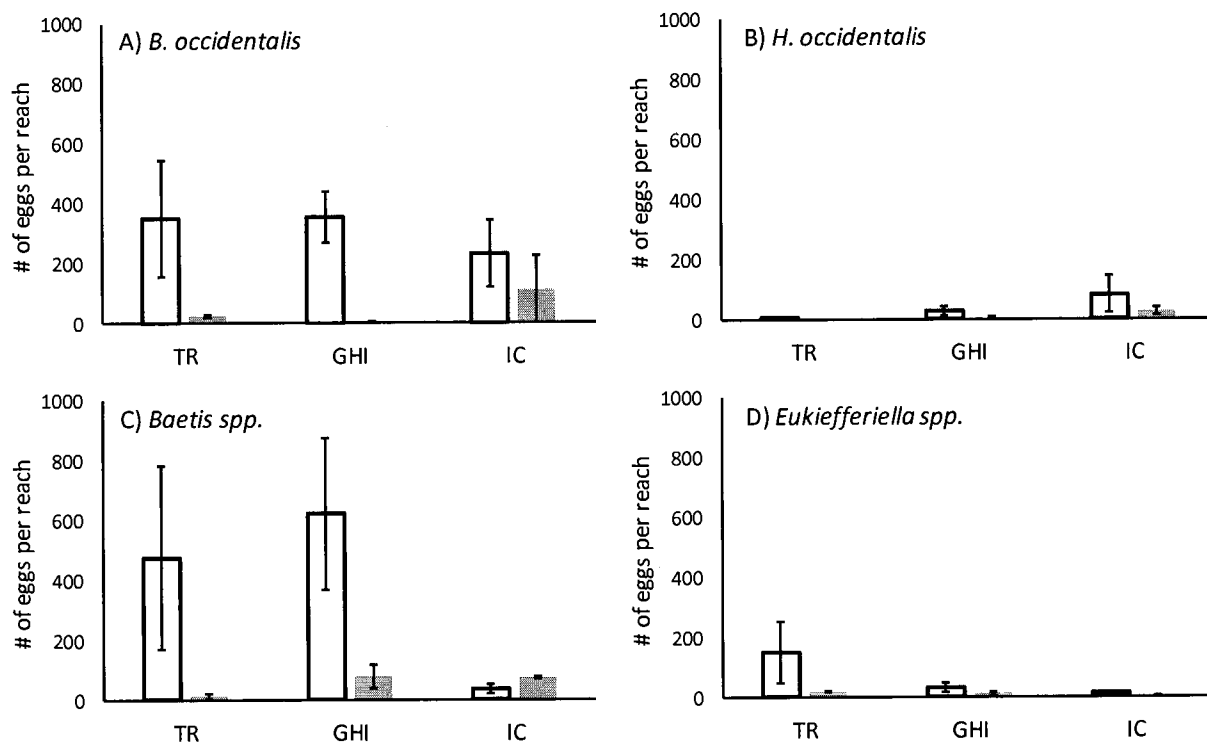


Figure 3. Average number of egg masses (\pm SE) per fast- (open bars) and slow-water (closed bars) reach compared among each of the three study segments for A) *B. occidentalis*, B) *H. occidentalis*, C) *Baetis* spp. and D) Chironomidae.

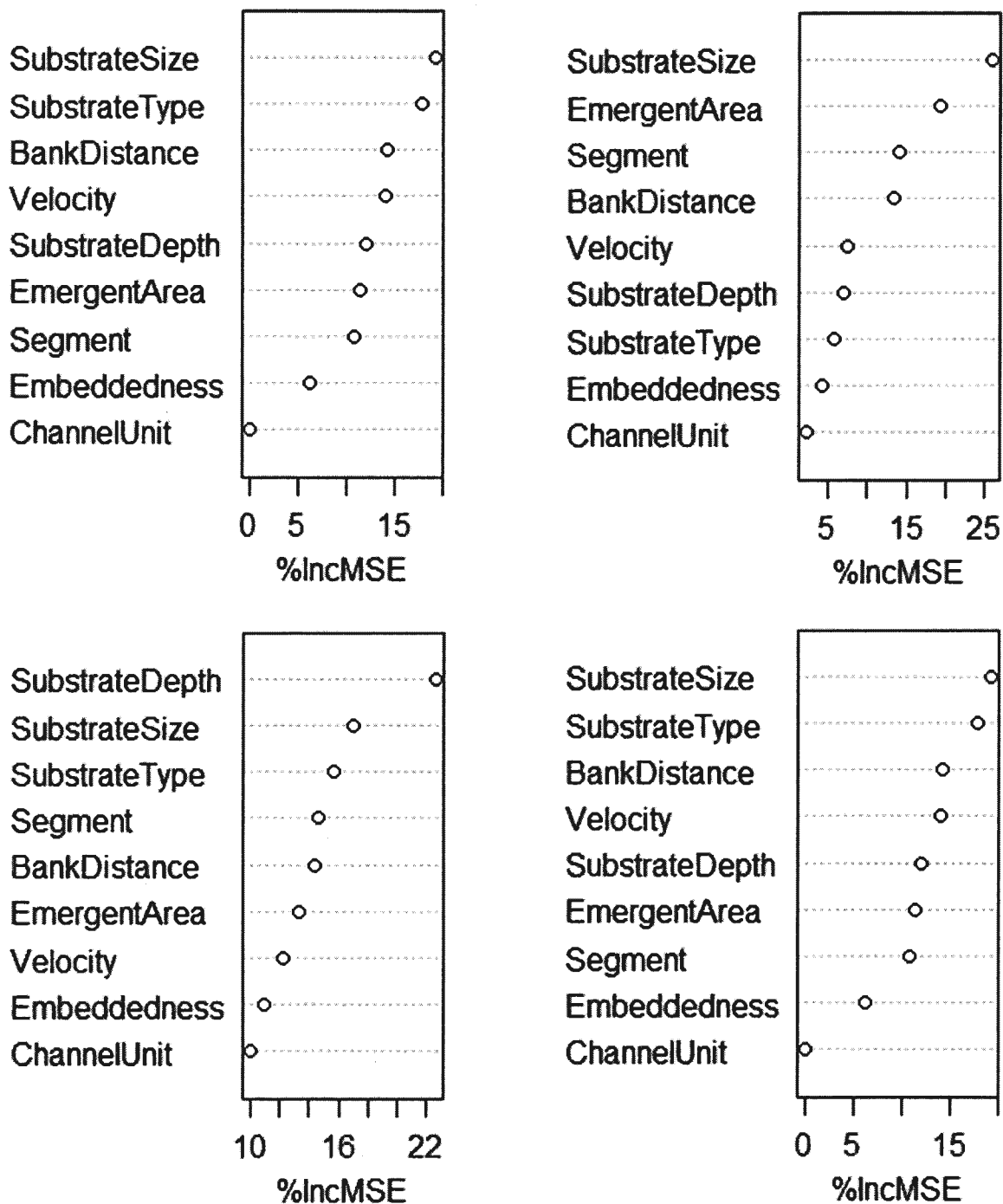
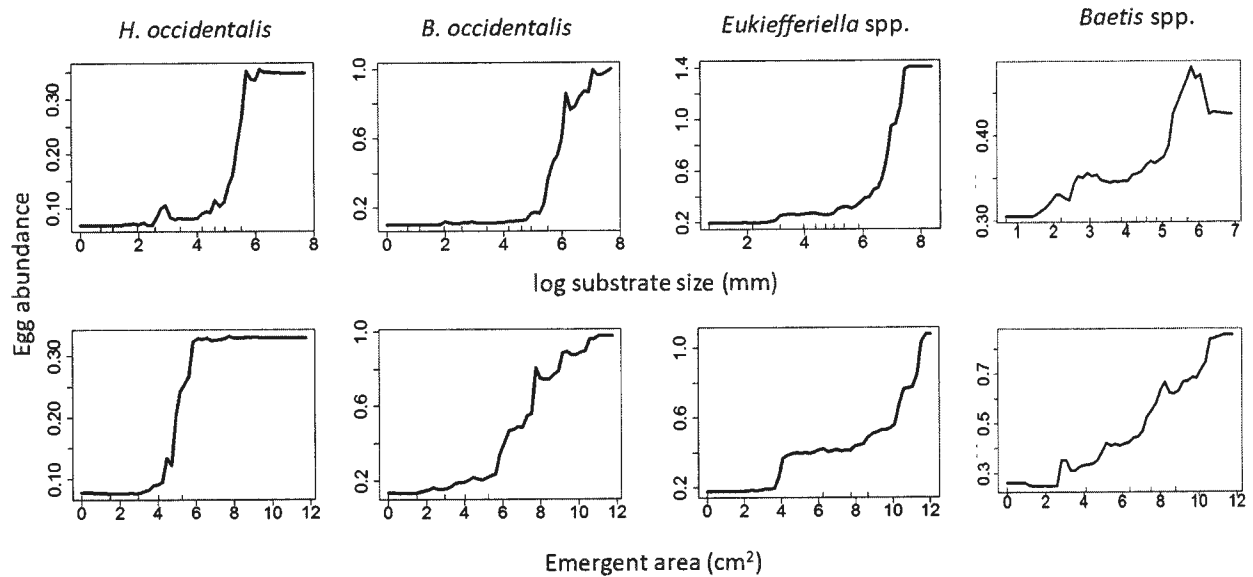
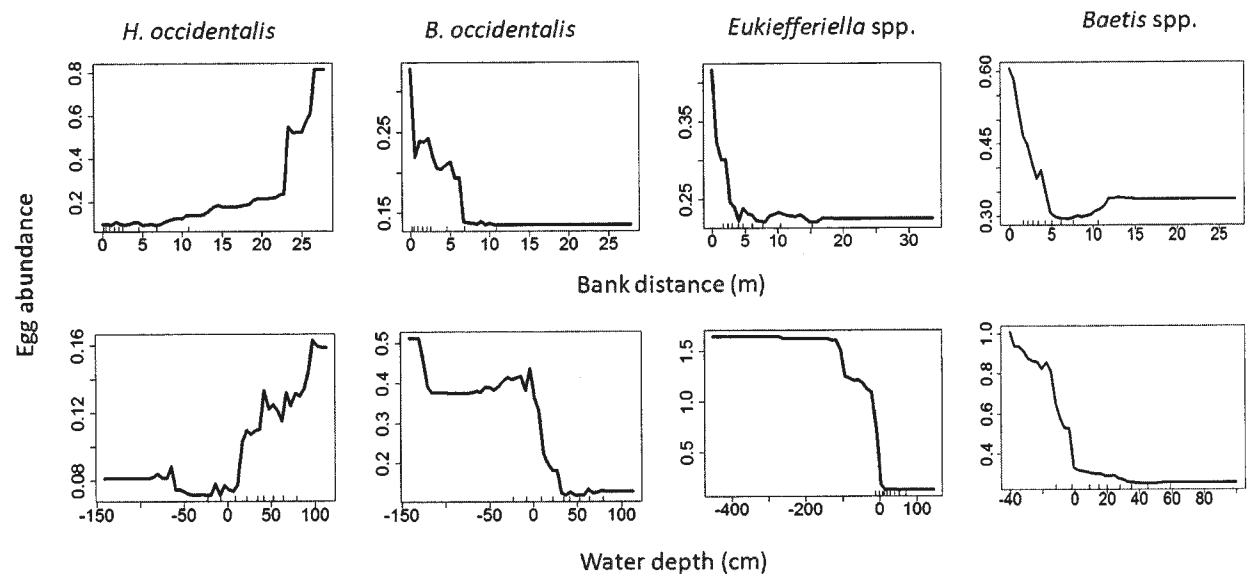


Figure 4. Variable importance plots for the random forest models developed to understand relationships between oviposition egg density and environmental conditions for *B. occidentalis* (top left), *H. occidentalis* (top right), Chironomidae (bottom left) and *Baetis* spp. (bottom right). The sensitivity of egg density to individual predictors was assessed by quantifying the percent increase in mean square error (%IncMSE) when the validation data for an individual predictor was permuted.

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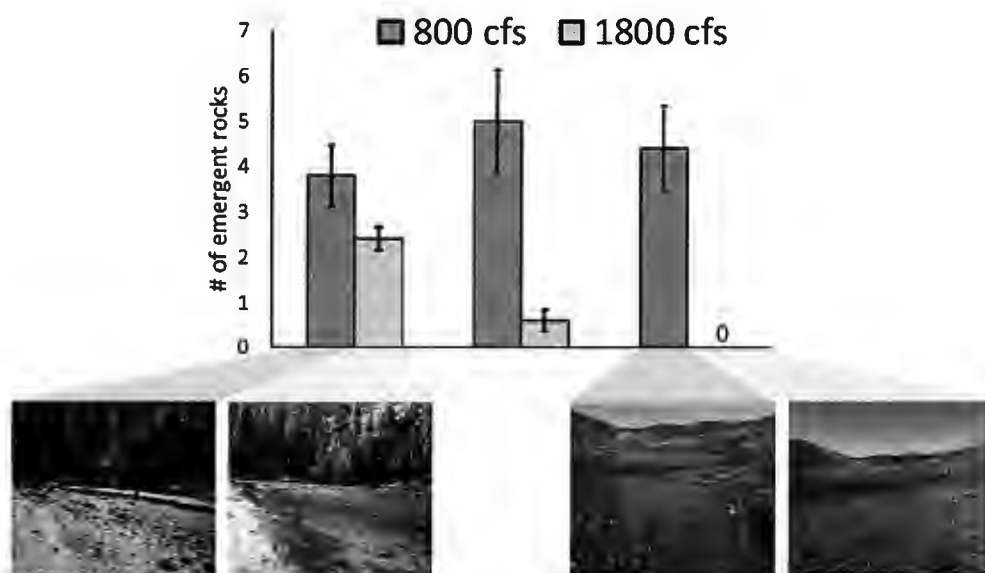


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831 Figure 5 Partial dependency plots of *H. occidentalis*, *B. occidentalis*, Chironomidae and *Baetis*
832 spp. egg densities exhibiting similar relationships with substrate size and emergent area from
833 each of the four independent Random Forest models. All four taxa show preferences for large,
834 emergent substrates.



835
836 Figure 6. Partial dependency plots of *H. occidentalis*, *B. occidentalis*, Chironomidae and *Baetis*
837 spp. egg densities exhibiting differential relationships with bank distance and water depth from
838 each of the four independent Random Forest models. *B. occidentalis*, Orthocladiinae and *Baetis*
839 spp. exhibited similar relationships, while *H. occidentalis* differed. Negative values for water
840 depth represent egg mass that were above water during the surveys (i.e., surveys were conducted
841 at daily low flows and these egg masses were likely laid at daily high flows).
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Figure 7. Average number of emergent rocks found during random surveys compared between 800 and 1800 cfs for Tailrace, Grasshopper Island and Indian Crossing study segments.

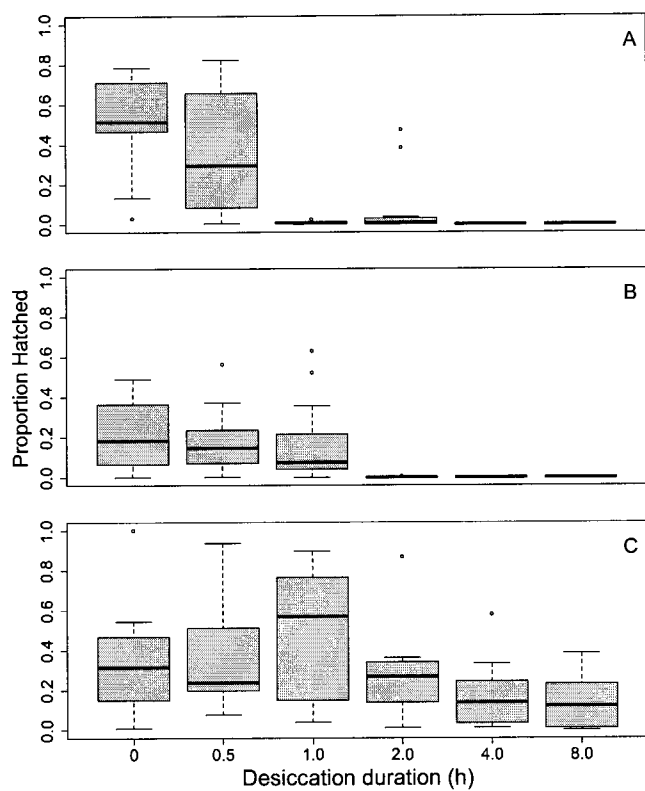


Figure 8. Proportional hatching success compared among a control and five levels of desiccation for (A) *Baetis* spp., (B) *Hydropsyche occidentalis* and (C) *Brachycentrus occidentalis* egg masses.

Table 1. Measured physical habitat variables used to characterize both habitat availability and habitat utilization by ovipositing invertebrates in the tailwater of the Green River, Utah, USA.

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1. Segment scale - location of oviposition substrate within study segment
 - 1.1 Reach type (fast or slow)
 2. Reach scale - location of substrate within study reach
 - 2.1 Distance from bankfull (m)
 3. Substrate scale - characteristics of substrate
 - 3.1 Type (emergent rock, submerged rock, emergent wood, submerged wood, or emergent vegetation)
 - 3.2 Size (mm; b-axis or max. diameter for mineral or organic substrates, respectively)
 - 3.3 Particle depth (cm)*
 - 3.4 Emergent area (cm²)
 - 3.5 Water velocity at 60% water depth and immediately upstream of substrate; measured in bins: <0.06; 0.06 - 0.25; 0.26 - 0.50, 0.51 - 1.00; and >1.00 m³ sec⁻¹
 - 3.6 Embeddedness: <10, 10 - 40, 41 - 75, and >75%
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* Measured as distance from water surface to top of particle; negative value indicates height of emergent particle above water

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864 Reflection:

865 Conducting research as an undergraduate can be a challenging experience, where some students
866 have a natural talent for forming questions and carrying out experiments. While other
867 undergraduates might have to learn how to think analytically, being mindful of their influence on
868 a project's outcome. To some extent, I believe I have traits and qualities from both of these
869 groups.

870 I was fortunate enough to have found a job at the National Aquatic Monitoring Center (NAMC)
871 early in my freshman year at Utah State University. I was a laboratory technician, working with
872 aquatic macroinvertebrates (insects). At the time, I did not have much interest in entomology but
873 felt the experience was too good to pass up and that I would start looking for a different position
874 after six months. I stayed at the lab for all four years of my undergraduate career. My research
875 experience with NAMC began at the start of my 2nd year when I approached the lab director, Dr.
876 Scott Miller, about being a summer field technician. Quickly, he gaged my interest and sat me
877 down with an inch-thick stack of scientific papers which outlined the project in great detail. I
878 was to join a small team of researchers with the proposed goal of re-examining how society
879 views a renewable resource, hydroelectric power. Over the past three years, I have found that
880 hydropower is sustainable in the context of producing electricity but not ecologically.

881 My first major struggle was trying to "catch up" with my colleagues who had been on this
882 project and in the field for years prior to my start. It seemed like I would never reach their level
883 of understanding. It still doesn't, but I know now that individuals apart of a team do not need to
884 know everything. Rather, everyone has an individual area of expertise that can contribute to the
885 greater project goal. In time my expertise would revolve around insect eggs, everything from

886 their physiology and anatomy to their ecology and conservation. Its an odd niche to fill but it is
887 rewarding to have peers seek you out for assistance.

888 The project itself entail week long trips to the Green River where I would collect larval insects as
889 well as their eggs for experiments. Floating rivers is a phenomenal way to spend a summer, but it
890 was coupled with week long periods, setting and observing egg development under various
891 environmental conditions. Most researchers talk about how great the field aspect of their jobs can
892 be but fail to mention how much time is spent inside a hot lab space during summer days. It was
893 during those long lab days that I realized how fully immersed I was with this project and with the
894 research process as a whole. I was enamored by the physically exhausting days and mentally
895 exhausting nights, I felt like a workaholic and I loved it because I was trying to make a
896 difference. I wanted to contribute to the well-being and sustainable management of environments
897 at a large scale and that is exactly what I was doing.

898 I came to college with little to no understanding of what I really wanted from my next four years,
899 I will be leaving Utah knowing exactly where I want to end up. Getting involved with both
900 undergraduate research and clubs as a freshman allowed me to flourish as a student. It challenged
901 me to explore different fields, work with new people, and push myself to succeed. While at USU,
902 I successfully completed four research projects that were independent of each other and partially
903 worked on two others. I discovered what I was passionate about by trying to do anything and
904 everything that came my way. Water chemistry, geomorphology, climate physics, and aquatic
905 ecology are just a few of the bigger themes that were covered by these projects. I knew very little
906 about any of those topics prior to working with them but nothing can beat 1st hand experience.
907 My biggest piece of advice to 1st year's is to push yourself outside your comfort zone because
908 that is where you will learn something new about yourself or the world around you.

909 **Biography**

910 Jesse Fleri is a fourth-year student pursuing a B.S. in Conservation and Restoration Ecology with
911 double minors in fisheries science and soil science. He will graduate with honors in the spring of
912 2018 having completed four research projects on a variety of natural resources topics. He has
913 conducted research with physicists in a radiocarbon dating lab, environmental engineers
914 assessing wastewater treatment standards, aquatic entomologists investigating life history
915 bottlenecks in macroinvertebrate communities and geomorphologist modelling salt marsh
916 morphodynamics in restored Chesapeake Bay islands. Jesse has been fortunate in his research
917 pursuits, having participated in the NSF funded EPSCoR iUtah fellows programs as well as the
918 NSF funded Maryland Sea Grant Research Experience for Undergrads (REU) fellows program.
919 Jesse has presented oral and poster presentations at several conferences and recently had work he
920 co-authored accepted for presentation at the European Geoscience Union. He is currently in the
921 process of preparing two manuscripts for publication in peer-reviewed journals. Jesse will be
922 pursuing a M.Sc. in Forestry at the University of British Columbia in conservation planning,
923 community ecology, and spatial ecology of invasive species. He was awarded the college wide and
924 university wide awards for Undergraduate Researcher of the Year in 2018.

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