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Sampling Dragonflies for Mercury Analysis in Grand Canyon National Park, 2018–2024

A Contribution of the Dragonfly Mercury Project

Grand Canyon Youth participants on a Colorado River trip to conduct science and sample dragonflies for mercury in Grand Canyon National Park, Arizona.

NPS / USGS

Sampling dragonflies for mercury analysis in Grand Canyon National Park, 2018–2024: A contribution of the Dragonfly Mercury Project

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Contents

Figures

Tables

Appendices

Abstract

The Dragonfly Mercury Project is a collaborative initiative that utilizes dragonfly larvae as biosentinels to monitor mercury concentrations across 180 national parks and other protected lands, including Grand Canyon National Park (GRCA). These indicators serve as surrogates for environmental risk and can indicate where fish consumption could pose health risks through exposure to mercury. From 2018 to 2024, citizen scientists and staff from the National Park Service and U.S. Geological Survey helped collect close to 400 larvae from 25 GRCA sites across nearly 300 river miles, revealing mercury concentrations ranged from 3.0 to 1,337 ng/g (parts per billion) dry weight. Results were available for 20 tributary sites. Upon comparing mercury concentrations to an impairment index, 90% of the sites (N = 18) were classified as low or no risk for ecological impairment, though 10% (2 sites) exceeded moderate or severe risk benchmarks (Pete's Pocket and Buck Farm Canyon, respectively). The data from GRCA tributaries suggests that mercury (Hg) risk is relatively low compared to the nationwide dataset. A catch-per-unit-effort metric was used to assess sampling difficulty at 10 sites, revealing that Nankoweap Creek would take the longest to sample, while the mainstem site at Colorado River RM204 would take the shortest. Sources of mercury to GRCA likely stem from a combination of atmospheric deposition, upstream discharge from Lake Powell, and other watershed contributions. In addition, food web dynamics, underlying water chemistry, and environmental disturbances (e.g., floods) contribute to mercury mobilization, production, and bioaccumulation. Report findings provide a baseline for connecting ongoing science in the Colorado River watershed, informing management actions, and enhancing public engagement through citizen science.

Acknowledgments

Support for this work was provided by the National Park Service (NPS), U.S. Geological Survey (USGS–NPS Water Quality Partnership, and the Environmental Health Mission Program within the Ecosystems Mission Area), and the National Park Foundation. Further, the U.S. Geological Survey Grand Canyon Monitoring Research Center (USGS–GCMRC) provided the logistical and in-kind support and coordination necessary to undertake these science missions. We value the highly regarded oversight provided by USGS–GCMRC, particularly from Ted Kennedy and Morgan Ford. Ted Kennedy and David VanderMeulen (NPS Great Lakes Inventory & Monitoring Network) provided peer reviews of this report, while Kristi Morris and Anthony Prenni of NPS Air Resources Division served as peer review manager and internal reviewer, respectively. Starting in 2021, Grand Canyon Youth and the Ancestral Lands Conservation Corps provided all-Indigenous conservation crew members to assist with dragonfly sample collection through the Partners in Science Colorado River expeditions. We are particularly indebted to Lonnie Pilkington and other dedicated NPS staff, as well as the hundreds of citizen scientists who volunteered their time and energy to collect dragonfly larvae in Grand Canyon National Park. Finally, the skilled boatmen who navigate the Colorado River make this work possible. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government. This is contribution #18 of the Dragonfly Mercury Project.

Dragonfly Mercury Project logo
NPS / AIR RESOURCES DIVISION

Introduction

The Dragonfly Mercury Project (DMP) is a research, monitoring, and education initiative that aims to understand mercury contamination across national parks and protected places using dragonfly larvae as biosentinels. Dragonfly larvae are effective biomonitoring tools due to their ubiquity across ecosystems, ease of collection, cost-effectiveness, and their ability to provide high-quality data reflecting mercury exposure in fish and wildlife. Measuring mercury in these aquatic insects reveals the extent of environmental mercury contamination, which poses risks to both human and wildlife health (Eagles-Smith et al. 2020, Driscoll et al. 2013).

Mercury, a potent neurotoxin, often reaches remote national parks through atmospheric deposition (Eagles-Smith et al. 2014, Landers et al. 2010). Its most toxic form, methylmercury, is highly bioavailable, readily accumulating in living organisms and magnifying through the food chain (Driscoll et al. 2013). Specific environmental conditions are required for methylmercury production, and human-made water systems, such as reservoirs and dam-regulated waters, can increase its bioavailability in aquatic food webs by altering mercury distribution and production (Willacker et al. 2016a).

At Grand Canyon National Park (GRCA) in Arizona, aquatic animals in the Colorado River have been shown to accumulate mercury at levels posing risks to wildlife and humans (Eagles-Smith 2016, Walters et al. 2015, Eagles-Smith et al. 2014). Long-range transport from upstream sources, such as Lake Powell, a reservoir formed by Glen Canyon Dam, can play a significant role in delivering mercury downstream (Naftz et al. 2019). In addition, food web structure, species traits and interactions, and disturbances such as floods have been shown to influence mercury transport and food web integration of mercury in the Colorado River (Walters et al. 2020).

Building on that previous research, this study uses dragonfly larvae to estimate mercury exposure risk to wildlife and human health at sites throughout the Colorado River and tributaries within GRCA. Field aims include establishing dragonfly larvae collection sites along the mainstem of the Colorado River to connect mercury data in mainstem food webs, expand the spatial extent of mercury data to tributary sites, and build on the temporal data record at long-term sites.

The main objectives are to:

1. Report mercury concentrations in dragonfly larvae for 20 GRCA tributary sampling locations from 2018 to 2023,
2. Provide site characteristics for 25 GRCA tributary and mainstem sampling locations established from 2018 to 2024,
3. Calculate and report dragonfly mercury impairment thresholds associated with risks to human and wildlife health, and
4. Define next steps in DMP research and sampling strategy in GRCA.

Methods

Sample Sites

Information for these sites was amassed from the Dragonfly Mercury Project (DMP) database, field data sheets, and field notes from past participants to determine site coordinates, river mile (according to the National Geographic Trails Illustrated map), DMP site ID, dragonfly family ID, and site description (Figure 1, Appendix A). When establishing new sites, the site selection process was random, with most GRCA sites being chosen opportunistically based on available resources and time during scheduled sampling trips. Resampling was conducted at select sites because these locations were established areas of productivity, consistently accessible, and relatively easy to sample (see Future Considerations).

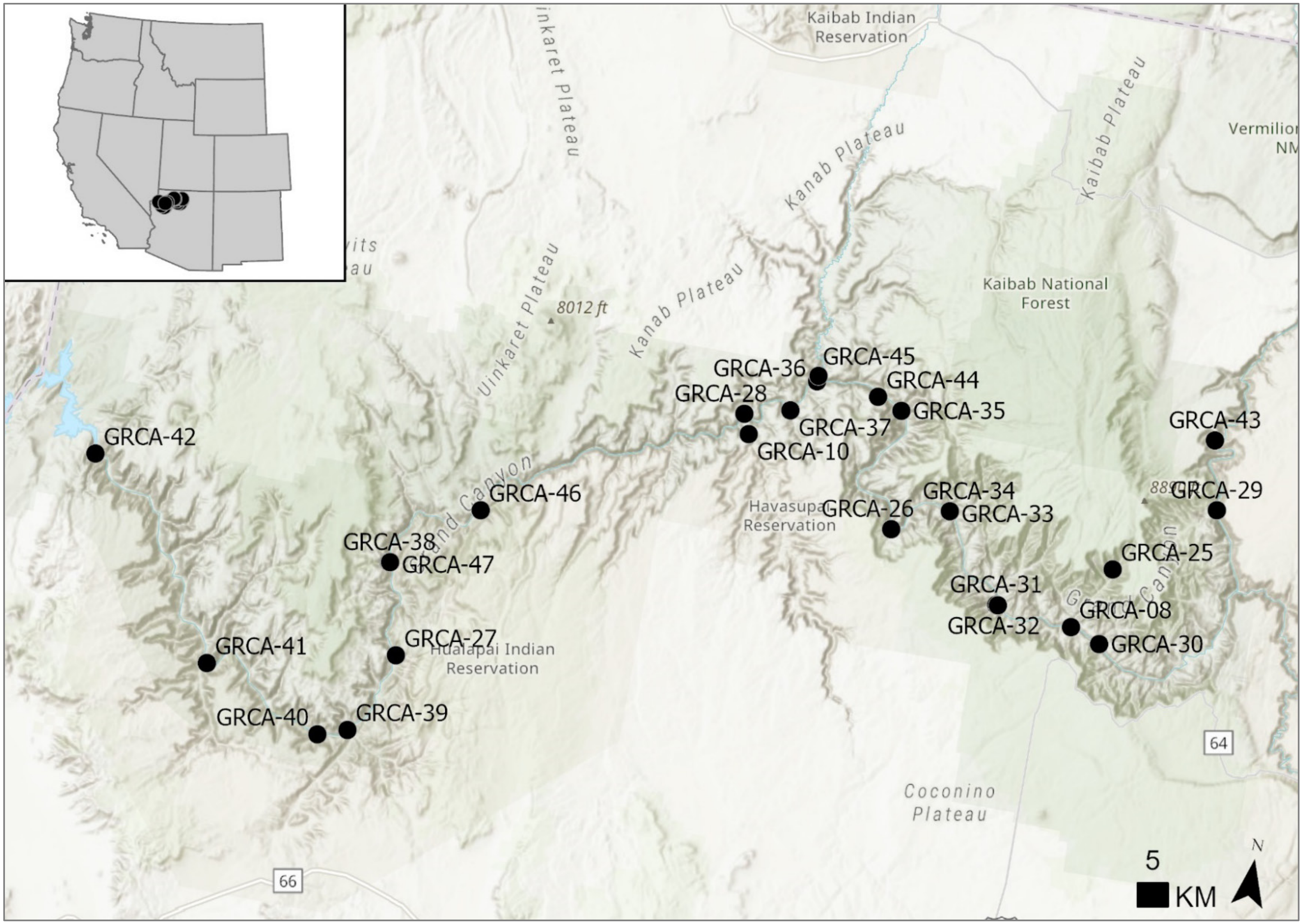

Figure 1. Site map of dragonfly mercury study sites in and along the Colorado River and tributaries through Grand Canyon National Park, Arizona, 2018–2024. Site IDs defined in Table 1. Source: ESRI.

USGS / B. JOHNSON

Table 1. Site list of dragonfly mercury study sites in and along the Colorado River and tributaries through Grand Canyon National Park, Arizona, 2018–2024. Sites ordered by river mile (RM); RM calculated according to National Geographic *Trails Illustrated* (Lees Ferry, AZ = RM 0).

#	Site ID	Site Name	River Mile	Latitude	Longitude	Collection Year
1	GRCA-43	Buck Farm Canyon	41	36.40619	−111.88701	2023
2	GRCA-29	Nankoweap Creek	52	36.30508	−111.86217	2021, 2024
3	GRCA-30	Clear Creek_AZ	84	36.08269	−112.03553	2021
4	GRCA-08	Bright Angel Creek	88	36.10031	−112.09200	2021
5	GRCA-25	Roaring Springs	88	36.19386	−112.03422	2018
6	GRCA-31	Boucher Creek-1	97	36.11392	−112.23494	2021, 2024
7	GRCA-32	Boucher Creek-2	97	36.11385	−112.23248	2021
8	GRCA-34	Shinumo Creek	108	36.23760	−112.34908	2021
9	GRCA-33	Shinumo temporary wetland	109	36.23722	−112.34894	2021
10	GRCA-26	Royal Arch Creek	117	36.19721	−112.45070	2019, 2022–24
11	GRCA-35	Tapeats Creek	134	36.37108	−112.46967	2021
12	GRCA-44	Deer Creek Falls	136	36.38503	−112.51585	2024
13	GRCA-36	Kanab Creek-1	144	36.39233	−112.63283	2021
14	GRCA-45	Kanab Creek-2	144	36.40031	−112.63179	2024
15	GRCA-37	Matkatamiba Canyon	148	36.34320	−112.67180	2021
16	GRCA-28	Pete's Pocket	155	36.32625	−112.75526	2019, 2022–23
17	GRCA-10	Havasu Creek	157	36.29800	−112.74023	2021
18	GRCA-46	Colorado River RM190	190	36.11808	−113.20288	2024
19	GRCA-47	Colorado River RM204	204	36.01853	−113.35000	2024
20	GRCA-38	Spring Canyon	205	36.01869	−113.35147	2021
21	GRCA-27	Three Springs	215	35.88565	−113.30814	2019, 2021–22
22	GRCA-39	Diamond Creek	226	35.76522	−113.37133	2021
23	GRCA-40	Travertine Falls Creek	229	35.75078	−113.42431	2021
24	GRCA-41	Spencer Creek	246	35.82367	−113.64792	2021
25	GRCA-42	Columbine Falls	274	36.09561	−113.92114	2021

Sample Collection and Level of Effort

Detailed dragonfly larvae sampling methods, including field collection, identification to family, and shipping protocols can be found in Eagles-Smith et al. 2020 and Flanagan Pritz et al. 2022. The DMP sampling guide is available internally via the Dragonfly Mercury Project SharePoint site. In brief, larvae were collected at designated sites using standardized handling and documentation methods to prepare each sample for mercury analysis. Citizen scientists assisted with the sampling and used field datasheets to record key data, including collection site details, dragonfly identification, time to sample, and number of people collecting. Appendix B describes sample preservation considerations for extended trips in desert environments, such as GRCA.

To estimate the sampling effort relative to dragonfly sample collection, a catch-per-unit-effort metric, or CPUE, was calculated as the number of larvae collected per person, per hour of sampling (larvae/person/hour, or LPH). This calculation used the number of larvae submitted for analysis (i.e., it only included dragonfly samples that were large enough for mercury analysis), participant numbers as recorded in the field, and duration of time spent sampling at each site. For sites with multiple years of sampling the CPUE was calculated for each sampling event with all necessary data, and the average CPUE was then calculated across all events at the site. The distribution of CPUE data was then categorized into terciles or three "degrees of difficulty" to obtain the requisite sample size at each site: Difficult (0.043–0.71 LPH), Moderate (0.72–3.3 LPH), and Easy (3.4–11.3 LPH). This measure does not account for approach time to the site.

Because multiple mission objectives necessitate efficient sampling, the amount of time it takes to sample sites was determined. Estimated sampling time was calculated as the time (minutes [min] or hours [h]) it would take the average number of participants (8.6 people) to collect 15 larvae based on the average CPUE at each site. The mean number of participants was calculated across all GRCA sites and events.

The CPUE calculation approach relies on several assumptions that may limit the accuracy of the estimates, including: (1) no additional dragonfly larvae were captured and released during sampling, (2) all participants recorded on the field datasheets were actively sampling dragonfly larvae, (3) all participants were equally proficient at sampling dragonfly larvae, (4) the entirety of the time at the site was spent actively sampling dragonfly larvae, and (5) the participation and time at site data recorded are accurate. Several of these assumptions are routinely violated, so CPUE data and the resultant "degree of difficulty" should be viewed as rough approximations. CPUE was not estimated for any events that had incomplete participation or time at site data recorded; thereby, degree of difficulty not available (N/A).

Mercury Data Analysis

Dragonfly larvae were sent to the USGS Contaminant Ecology Laboratory in Corvallis, where field identifications were cross-verified, and samples were analyzed for total Hg (Flanagan Pritz et al. 2022, Eagles-Smith et al. 2020). At the time of report writing, GRCA dragonfly Hg data were available through 2023 from the USGS online database (Eagles-Smith et al. 2018).

Total mercury (THg) concentrations in each dragonfly larva not in the Aeshnid family were converted to Aeshnid-equivalent (AE) THg concentrations to normalize for differences in THg concentrations observed among dragonfly families (Eagles-Smith et al. 2020). The AE equations were developed by correlating paired geometric mean THg concentrations of different dragonfly families collected concurrently at the same site. For each family pair, linear regression equations for predicting THg concentrations in one family, based on those in another, were developed. These linear regression equations were used to adjust THg from various families (e.g., Gomphidae, Libellulidae, Corduliidae) to an AE concentration for all samples, enabling consistent comparisons across sites, while minimizing the influence of differences in dragonfly taxonomy.

To account for the log-normal distribution (i.e., a right-skewed distribution with a long "tail" extending towards higher THg values) of AE THg data in dragonfly larvae, geometric means (± standard error) were calculated for each site-year of data. Site geometric means were also used to assign an impairment category for each site, in accordance with the Integrated Impairment Index reported in Eagles-Smith et al. 2020.

Nearly all (80%) mercury measured in dragonfly larvae is in the form of methylmercury (Eagles-Smith et al. 2020). References to "mercury" or "total mercury" specifically indicate methylmercury, the form that poses significant risks to both human and wildlife health (Driscoll et al. 2013).

Results and Discussion

From 2018 to 2024, more than 194 citizen scientists contributed to the collection of 383 dragonfly larvae from 25 individual sites at Grand Canyon National Park (Figure 1, Table 1). The greatest number of sites sampled in one year was N = 17 in 2021 during a USGS science mission, and the least number of sites sampled in one year was N = 1 in 2018 during a pilot effort from the rim. Zero sites were established in 2020 due to COVID precautions. Twenty sites were sampled only one year, and 5 sites were sampled multiple years. Two mainstem sites were established in 2024 while the remaining 23 sites are tributary sites. Dragonfly sampling occurred during Partners in Science youth science trips in 2019, 2022, 2023, and 2024. An annotated site list is provided in Appendix A.

Sample Collection and Level of Effort

The CPUE, i.e., degree of difficulty, was calculated for 10 of 25 sites, where data to assess this metric were available (Table 2). Among the sites where CPUE could be calculated, Roaring Springs/GRCA-25, Deer Creek Falls/GRCA-44, and Colorado River RM204/GRCA-47 were determined to be the easiest sites for 8.6 participants to collect dragonfly larvae (N = 15), with an estimated sampling time (min) of 17, 17, and 9.2, respectively. Nankoweap Creek/GRCA-29 and Colorado River RM190/GRCA-46 were determined to be the most difficult sites for 8.6 participants to collect dragonfly larvae (N = 15), with an estimated sampling time (h) of 43.6 and 17.4, respectively.

Table 2. Degree of difficulty to obtain requisite sample size at dragonfly mercury study sites in and along the Colorado River and tributaries through Grand Canyon National Park, Arizona, 2018–2024, where sufficient data are available. CPUE = catch-per-unit-effort, LPH = the number of larvae per person per hour of sampling. CPUE data categorized into terciles or three "degrees of difficulty" and defined as: Difficult (0.043–0.71 LPH), Moderate (0.72–3.3 LPH), and Easy (3.4–11.3 LPH). This measure does not account for approach time to the site.

#	Site ID	Site Name	River Mile	Typical Time at Site (hours)	Mean Participants per Event	Mean Number of Larvae Collected	CPUE (LPH)	Estimated Sampling Time [A]	Degree of Difficulty
2	GRCA-29	Nankoweap Creek	52	2.00	12.5	5.0	0.04	43.6 h	Difficult
5	GRCA-25	Roaring Springs	88	2.50	1.0	15.0	6	17 min	Easy
6	GRCA-31	Boucher Creek-1	97	1.00	12.0	14.5	0.73	2.4 h	Moderate
10	GRCA-26	Royal Arch Creek	117	1.50	20.5	12.8	2.63	40 min	Moderate
12	GRCA-44	Deer Creek Falls	136	0.75	4.0	18.0	6	17 min	Easy
14	GRCA-45	Kanab Creek-2	144	0.75	7.0	18.0	3.43	31 min	Easy
16	GRCA-28	Pete's Pocket	155	0.74	15.7	14.0	1.41	1.2 h	Moderate
18	GRCA-46	Colorado River RM190	190	4.00	5.0	2.0	0.1	17.4 h	Difficult
19	GRCA-47	Colorado River RM204	204	0.75	2.0	17.0	11.33	9.2 min	Easy
21	GRCA-27	Three Springs	215	0.75	20.0	10.7	0.44	4.0 h	Difficult

[A] Estimated sampling time is the time (minutes [min] or hours [h]) it would take the average number of participants (8.6 people) to collect 15 larvae based on the average CPUE at each site.

Family Identifications

Identification to family occurred in the field as time allowed. All field IDs were verified, and if necessary, corrected by taxonomy experts in the USGS lab prior to THg analysis (Table 3). Libellulidae was the most identified family, while Cordulegastridae was least identified. Libellulid nymphs prefer still, shallower, warmer water, although some live near streams or rivers. Libellulidae and Corduliidae were combined as a single-family group because their distinction can be uncertain without the identification of the genus (Eagles-Smith et al. 2020).

Table 3. Dragonfly family identification for sampling sites in Grand Canyon National Park, 2018–2024. Site number 8 excluded (data not recorded). An "X" indicates presence of family at site.

#	Site ID	Site Name	Aeshnidae	Cordulegastridae	Corduliidae	Gomphidae	Libellulidae
1	GRCA-43	Buck Farm Canyon	X	–	–	–	–
2	GRCA-29	Nankoweap Creek	–	–	–	X	X
3	GRCA-30	Clear Creek_AZ	–	–	–	–	X
4	GRCA-08	Bright Angel Creek	–	–	–	–	X
5	GRCA-25	Roaring Springs	X	X	–	–	–
6	GRCA-31	Boucher Creek-1	X	–	–	–	X
7	GRCA-32	Boucher Creek-2	–	–	X	–	X
9	GRCA-33	Shinumo temporary wetland	–	–	–	–	X
10	GRCA-26	Royal Arch Creek	X	–	–	X	X
11	GRCA-35	Tapeats Creek	X	–	–	–	–
12	GRCA-44	Deer Creek Falls	X	–	–	–	X
13	GRCA-36	Kanab Creek-1	–	–	–	X	X
14	GRCA-45	Kanab Creek-2	–	–	–	–	X
15	GRCA-37	Matkatamiba Canyon	–	–	–	–	X
16	GRCA-28	Pete's Pocket	X	–	–	–	X
17	GRCA-10	Havasu Creek	–	–	–	–	X
18	GRCA-46	Colorado River RM190	–	–	–	X	–
19	GRCA-47	Colorado River RM204	–	–	X	–	X
20	GRCA-38	Spring Canyon	–	–	–	–	X
21	GRCA-27	Three Springs	X	–	X	–	X
22	GRCA-39	Diamond Creek	–	–	X	X	X
23	GRCA-40	Travertine Falls Creek	–	–	–	X	X
24	GRCA-41	Spencer Creek	–	–	–	X	X
25	GRCA-42	Columbine Falls	–	–	X	–	X

Mercury Levels and Impairment

The AE geometric mean (± geometric standard error) THg concentration [ng/g dry weight (dw)] of individual dragonfly larvae collected from 2018–2023 across 20 sites was 47.8 ± 3.1. The site at GRCA with the highest geometric mean THg concentrations (ng/g dw) was Buck Farm Canyon (GRCA-43, 1074 ± 54.8), whereas those with the lowest THg concentrations were found in Columbine Falls (GRCA-42, 9.6 ± 1.1), Boucher Creek-2 (GRCA-32, 12.6 ± 0.4), Spencer Creek (GRCA-41, 13.4 ± 1.2), and Spring Canyon (GRCA-38, 17.2 ± 0.3) (Figure 2, Table 4). Individual dragonfly larvae THg concentrations ranged 446-fold, from 3.0 to 1337 ng/g dw across all sites, while the site-specific geometric mean THg concentrations ranged 112-fold (9.6−1074 ng/g dw).

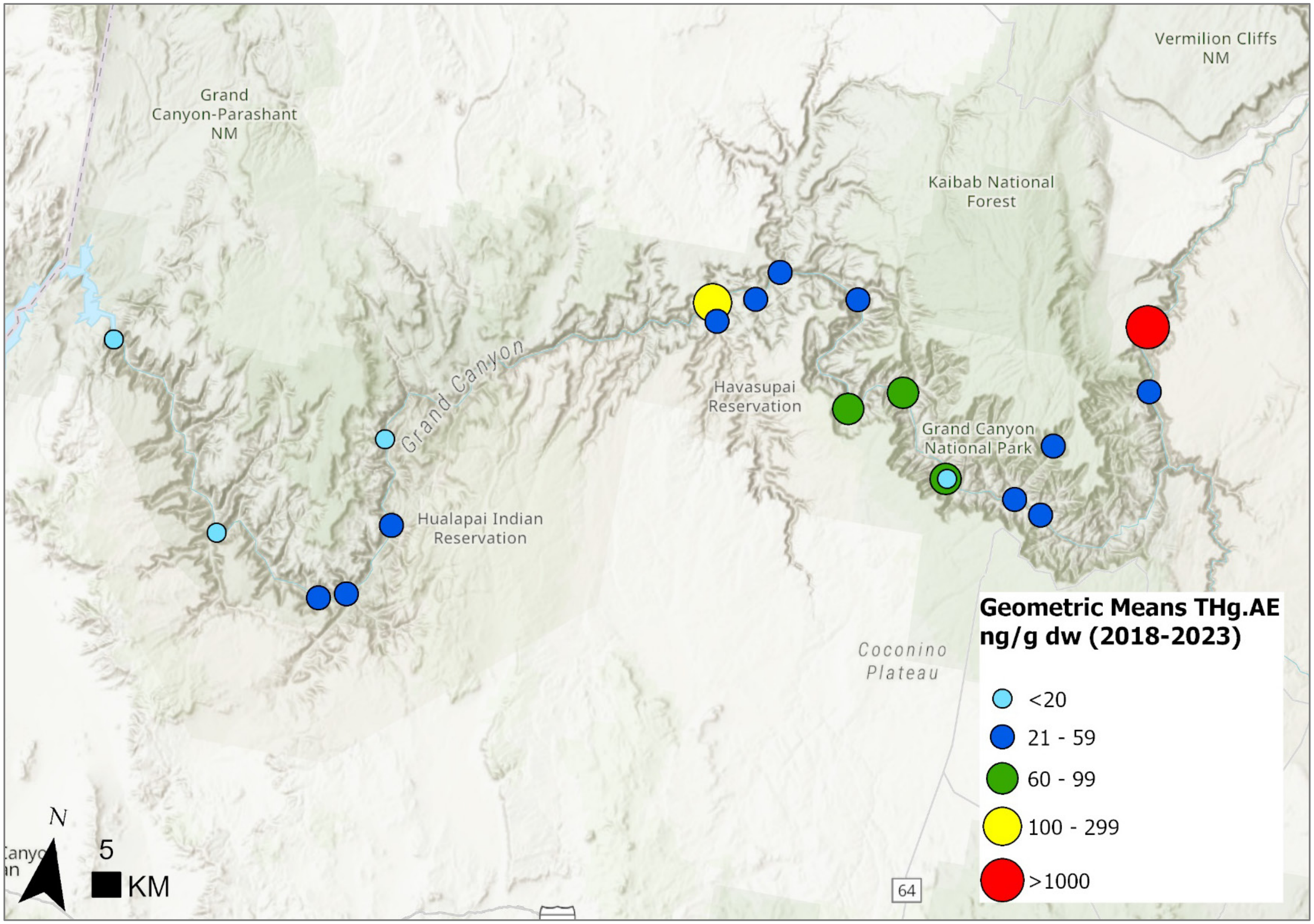

Figure 2. Geometric means of total mercury (THg) in dragonfly larvae (ng/g dry weight, dw) across study sites in Grand Canyon National Park, Arizona, 2018–2023. THg concentrations presented in Aeshnid-equivalent (THg.AE) to allow for comparisons across sites where multiple families were sampled. Colors correspond to the Integrated Impairment Indices (ng/g dw; Figure 3): Blue (<60) = little to no known effects, Green (60–99) = low risk, Yellow (100–299) = moderate risk, Red (>700) = severe risk. Source: ESRI.

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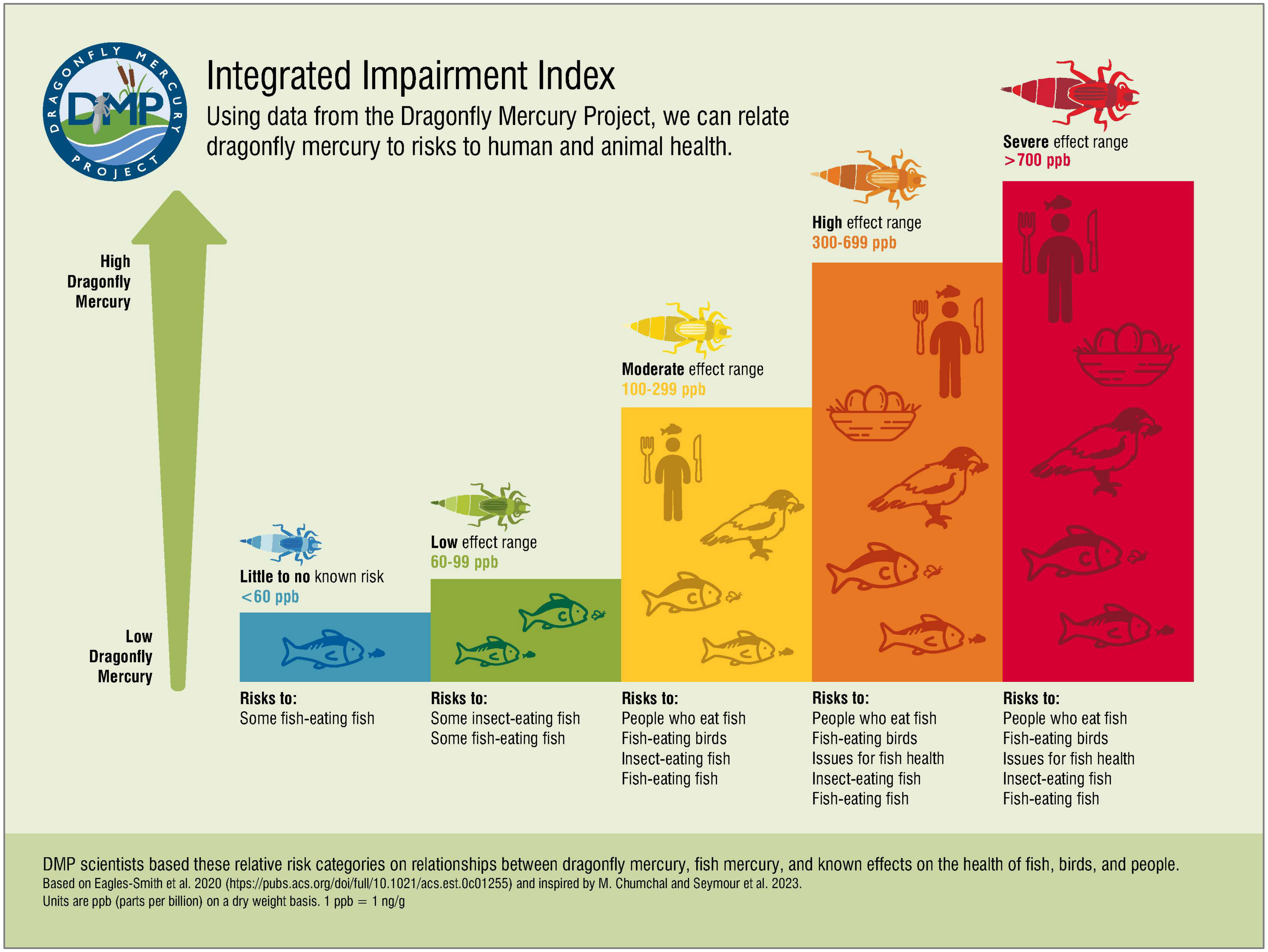

Figure 3. Integrated impairment risk categories utilized to translate mercury in dragonfly data to human and wildlife health risks. Note that ppb = ng/g dry weight.

INFOGRAPHIC PRODUCED IN COLLABORATION WITH APPALACHIAN MOUNTAIN CLUB / S. NELSON

Table 4. Aeshnid-equivalent total mercury geometric mean (ng/g dw), standard error (ng/g dw), and impairment categories for dragonfly mercury study sites in and along the Colorado River and tributaries through Grand Canyon National Park, Arizona, 2018–2023. For impairment categories (ng/g dw), <60 = little to no known effects (i.e., Sub-), 60–99 = low risk, 100–299 = moderate risk, 300–699 = high risk, and >700 = severe risk. dw = dry weight. Site numbers 8, 12, 14, 18, and 19 excluded (data not available).

#	Site ID	Site Name	River Mile	THg Geometric Mean (ng/g dw)	THg Standard Error (ng/g dw)	Impairment Category
1	GRCA-43	Buck Farm Canyon	41	1074 (N=12)	54.8	Severe
2	GRCA-29	Nankoweap Creek	52	41.9 (N=6)	7.4	Sub-
3	GRCA-30	Clear Creek_AZ	84	24.9 (N=12)	1.8	Sub-
4	GRCA-08	Bright Angel Creek	88	30.7 (N=3)	2	Sub-
5	GRCA-25	Roaring Springs	88	57.3 (N=15)	6.5	Sub-
6	GRCA-31	Boucher Creek-1	97	74.5 (N=6)	5.5	Low
7	GRCA-32	Boucher Creek-2	97	12.6 (N=12)	0.4	Sub-
9	GRCA-33	Shinumo temporary wetland	109	75.2 (N=8)	2.9	Low
10	GRCA-26	Royal Arch Creek	117	68.1 (N=30)	5.7	Low
11	GRCA-35	Tapeats Creek	134	32.2 (N=8)	4.3	Sub-
13	GRCA-36	Kanab Creek-1	144	36.4 (N=10)	1.1	Sub-
15	GRCA-37	Matkatamiba Canyon	148	52.2 (N=14)	2	Sub-
16	GRCA-28	Pete’s Pocket	155	99.9 (N=42)	9.4	Moderate
17	GRCA-10	Havasu Creek	157	36.2 (N=9)	5.2	Sub-
20	GRCA-38	Spring Canyon	205	17.2 (N=3)	0.3	Sub-
21	GRCA-27	Three Springs	215	27.6 (N=32)	3.3	Sub-
22	GRCA-39	Diamond Creek	226	25.3 (N=11)	2.1	Sub-
23	GRCA-40	Travertine Falls Creek	229	46.5 (N=10)	2.8	Sub-
24	GRCA-41	Spencer Creek	246	13.4 (N=10)	1.2	Sub-
25	GRCA-42	Columbine Falls	274	9.6 (N=9)	1.1	Sub-

All sites with available mercury data (2018–2023) are tributaries. Data from the two mainstem sites (GRCA-46 and GRCA-47) were collected only in 2024 and not yet analyzed at the time of report writing. Additionally, tributary sites GRCA-44 and GRCA-45 were also established in 2024 and thereby data were likewise not yet available. Further, data for GRCA-34 were not available because vials containing samples from the site were destroyed during transit.

In accordance with the Integrated Impairment Index reported in Eagles-Smith et al. 2020 (Figure 3), 75% of the 20 sites (15 sites) with data (2018–2023) had geometric mean Aeshnid-equivalent THg concentrations that were below any of the deleterious effect benchmarks, and 15% (3 sites) were associated with low risk of impairment (Table 4). In contrast, 5% (1 site, Pete’s Pocket/GRCA-28) were categorized as moderate risk of impairment, and 5% (1 site, Buck Farm Canyon/GRCA-43) as severe risk of impairment. An index of moderate impairment or higher suggests some fish may exceed the US EPA benchmark for protection of human health (Figure 3). The two sites categorized as moderate impairment or higher are not known to support fish populations (T. Kennedy pers comm), although potential risks to other wildlife, such as amphibians and songbirds, are unknown.

In contrast, when accounting for approximately 600 individual waterbodies sampled across U.S. NPS units through 2023 (Johnson et al. 2021), 74% of the site-year data fell in the moderate risk category, 9% in low risk, and 2% in the sub-impairment category. An additional 15% of the site-year data fell in the high-risk category and no data fell in the severe impairment category. With data from 90% (18 sites) of the GRCA tributary sites sampled falling below the moderate risk category in either the low risk or sub-impairment categories, except for two sites, this sampling exercise suggests that Hg risk in the GRCA tributaries is relatively low upon comparison to the nationwide dataset.

Future Considerations

For existing sites, resampling could be prioritized based on degree of difficulty, length of data record, and risk assessment. Given their low difficulty and established data records, Royal Arch Creek (#10) and Pete's Pocket (#16) might be prioritized for resampling. While the degree of difficulty was not calculated at Buck Farm Canyon (#1), the associated risk determination (severe) alone warrants resampling to ascertain impairment trends. Likewise, the associated risk determination (moderate) at Pete's Pocket (#16) warrants resampling. While site data were not yet available, Deer Creek Falls (#12) is another sampling site that resides low on the difficulty gradient, with relative ease of accessibility, that could be considered as a third-tier site to prioritize for resampling.

Establishing locations along the mainstem of the Colorado River to link to previous mercury sampling efforts (Walters et al. 2020), particularly downstream of RM 180, may be advisable. Other potential mainstem settings for establishment of new sites may include the candidate cobble bar on island, RM 200 (36.07590, −113.32688); RM 172 (36.23177, −112.97752); and RM 186.5 (36.15832, −113.18691). Other locations like the RM 275 marsh might be ideal habitat, though the site may be logistically challenging due to the necessity for bushwhacking and waders.

When establishing new tributary sites to compare to existing tributary Hg risk data, many side canyons in GRCA may offer suitable habitat for dragonfly larvae, particularly in lower-gradient areas with pools and emergent vegetation. Accessible sites like Travertine Falls, RM 231.5, provide some potential habitat to consider. However, due to the dynamic nature of flash floods, there may, or may not, be vegetation along the creek beds and riparian edges, thereby impacting dragonfly habitat. The boatmen are generally knowledgeable of what canyons have water or springs in them, if they have suitable habitat for dragonflies, and if they have recently flooded, which reduces habitat and populations of dragonflies.

The citizen science initiative has been instrumental in creating a robust and valuable baseline dataset of dragonfly mercury concentrations for GRCA. However, there are logistical challenges unique to this approach, such as the group's composition (e.g., youth participants), equipment limitations (e.g., maneuverability of 38-foot motor rigs vs. jet boats), and a general inability to select targeted or focused sampling sites because of opposing trip missions (Appendix C). Future sampling of new mainstem or tributary locations, based on identified needs and objectives by GRCA and NPS staff, may be conducted as part of a USGS-led scientific mission.

Future work may include assessing factors influencing mercury sources and integration into freshwater food webs in and along the Colorado River and tributaries within GRCA, determining Hg source contributions via stable Hg isotope analysis (Janssen et al. 2024), and quantifying the extent of the threat that Hg poses to fish, wildlife, and humans in GRCA. Data collected can contribute to a national-scale predictive Hg risk model, allowing inference to unsampled park waters, and locations within and outside of park boundaries, offering partnering opportunities with other entities (i.e., Tribes) to address potential Hg exposure risk. Modeled estimates of Hg risk can direct targeted monitoring (Willacker et al. 2016b), inform resource condition assessments and potential mitigation strategies (Kotalik et al. 2025), address Tribal communities disproportionately burdened by Hg (Harris et al. 2007), and improve outreach to park visitors and partners about the threats to human health posed by Hg (Eagles-Smith et al. 2016).

Paired dragonfly-water chemistry data will help identify the most important drivers influencing Hg risk within a park using a sensitivity analysis, as recently demonstrated on a national scale by Kotalik et al. 2025. This park-specific information can inform mitigation actions (e.g., erosion control, water management, wetland restoration, and prescribed fire), and assist parks in working with landowners and managers to address drivers of Hg risk that exist outside park boundaries (e.g., dam control, uranium mining, nutrient loading, and grazing). Future work will also allow scenario testing to predict how changes to drivers of Hg cycling will influence Hg risks within parks, providing insight as to how climate change, for example, may impact Hg bioaccumulation.

The above proposed work could help address key questions guiding future Hg monitoring at GRCA, such as:

- Do dragonfly Hg concentrations correlate with those in other aquatic animals (e.g., fish) in the Colorado River food web?
- Are there localized drivers of Hg production associated with dragonfly Hg concentrations?
- How much variation is there in dragonfly Hg concentrations among sites and why?
- Where do the sources of Hg in dragonflies differ among GRCA sites?

Conclusion

The spatial and temporal record established by the dragonfly mercury sampling in GRCA and other national parks and protected places will help measure the success of domestic and international policies established to reduce Hg emissions and exposure, and help policy makers and resource managers make informed decisions to protect human and wildlife health. Uniquely suitable for large-scale projects with hundreds of volunteers, dragonflies are also charismatic insects that ignite public passion and enthusiasm. Therefore, by way of this work, we hope to increase awareness in the study, underscore the importance of continued participation, and learn about the cultural significance of dragonflies from the Tribal participants. Information gathered from this study will help to determine the viability of dragonfly larvae sample collection in the mainstem and tributaries to the Colorado River, and it contributes to ongoing science in the Grand Canyon, improving our understanding of mercury dynamics and risk in the Colorado River. Study results have the potential to help inform mitigation or management actions that could be implemented to reduce the threat of mercury across the park landscape.

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Appendix A

Site List: 2018–2024

Sites ordered according to river mile. Four sites are recommended for repeat sampling due to relative ease of sampling, increased Hg risk, and/or to maintain long-term record: Buck Farm Canyon, Royal Arch Creek, Deer Creek Falls, and Pete's Pocket. Table 3 provides dragonfly family identifications. Site coordinates are provided as NAD83. N/A = data not available. All reported discharge estimates are summarized from USGS National Water Information System, queried from 2021–2024 (USGS 2016).

Note: Site descriptions are inconsistent and largely based on field notes, with some including visual estimates of width and discharge while others lack these details. The vague access descriptions may also make it difficult for future participants to accurately relocate sampling sites. Further, site characteristics described here reflect conditions at the time of report writing and may vary significantly on an annual or even daily basis due to the dynamic nature of the Grand Canyon.

1. Buck Farm Canyon (recommended for repeat sampling)

- **Site Coordinates:** 36.40619, −111.88701
- **River Mile:** 41
- **Site ID:** GRCA-43
- **Degree of Difficulty:** N/A
- **Site Description:** N/A
- **Sampling Location:** N/A
- **Access:** N/A

2. Nankoweap Creek

- **Site Coordinates:** 36.305083, −111.862167
- **River Mile:** 52
- **Site ID:** GRCA-29
- **Degree of Difficulty:** Difficult
- **Site Description:** Small stream 0.5–1 m wide. Baseflow 0.02–1.1 ft^3/sec. Embedded channel. Pools with sediment in cut banks in the debris flow.
- **Sampling Location:** Near Colorado River confluence
- **Access:** This is a very popular camping spot for commercial trips. Trek across to creek and move upstream.

Sampling location at Nankoweap Creek.
NPS

3. Clear Creek

- **Site Coordinates:** 36.082694, −112.035528
- **River Mile:** 84
- **Site ID:** GRCA-30
- **Degree of Difficulty:** N/A
- **Site Description:** Small stream ~1m wide. Baseflow 1–2 ft^3/sec. Mostly bedrock.
- **Sampling Location:** Colorado River confluence
- **Access:** N/A

4. Bright Angel Creek

- **Site Coordinates:** 36.100306, −112.092
- **River Mile:** 87.5
- **Site ID:** GRCA-08
- **Degree of Difficulty:** N/A
- **Site Description:** Larger stream, about 3−4m wide. Baseflow 13–20 ft^3/sec. High gradient cobble/boulder. Depositional areas covered with invasive plant. Very tough to sample for dragonflies.
- **Sampling Location:** Consider sampling closer to the confluence. As one moves upstream the habitat is too fast moving. You'll likely find a higher gradient, classic cobble-bottom stream that is conducive to impacts from flash flooding, and not necessarily dragonflies.
- **Access:** Easy 0.25-mile hike from the beach to the creek near the bathrooms. Convenient to sample while others explore Phantom Ranch.

Bright Angel Creek as it enters the Colorado River, Arizona.
NPS

5. Roaring Springs

- **Site Coordinates:** 36.19386, −112.03422
- **River Mile:** 87.5
- **Site ID:** GRCA-25
- **Degree of Difficulty:** Easy
- **Site Description:** Roaring Spring emerges from Muav Limestone. No discharge/water above spring (~800ft from sampling location).
- **Sampling Location:** Samples collected along reach of creek from Roaring Springs and confluence with Bright Angel Creek. Samples came mainly from two large pools from emergent & submerged plants & within thick roots & algae along bankside.
- **Access:** Best accessed on foot from the North Rim. This site is a 4.7-mile hike to heliport on North Kaibab Trail. From river it is a 10.3-mile hike up North Kaibab Trail through Bright Angel Canyon.

6. Boucher Creek-1

- **Site Coordinates:** 36.113919, −112.234939
- **River Mile:** 96.5
- **Site ID:** GRCA-31
- **Degree of Difficulty:** Moderate
- **Site Description:** Spring seep next to Boucher Creek. Baseflow ~ 0.5 ft^3/sec. This spring was perched on top of floodplain above Boucher creek. 3m wide, soft bottom with macrophytes.
- **Sampling Location:** N/A
- **Access:** N/A

Sampling location at Boucher Creek-1.
NPS

7. Boucher Creek-2

- **Site Coordinates:** 36.113849, −112.232475
- **River Mile:** 96.5
- **Site ID:** GRCA-32
- **Degree of Difficulty:** N/A
- **Site Description:** Downstream of spring seep (GRCA-31). Baseflow ~0.5 ft^3/sec. Loose cobble substrate with some fines.
- **Sampling Location:** N/A
- **Access:** N/A

8. Shinumo Creek

- **Site Coordinates:** 36.237596, −112.349083
- **River Mile:** 108
- **Site ID:** GRCA-34
- **Degree of Difficulty:** N/A
- **Site Description:** Midsize stream. Cobble substrate leading up to steep bedrock. Baseflow 6–15 ft^3/sec. Dumped into fine floodplain at mouth.
- **Sampling Location:** Colorado River confluence
- **Access:** A 1-to-1.5-mile hike to the lower creek or 1.5-to-2-mile hike to the upper creek depending on which beach you park at. The hike can be very hot.

9. Shinumo temporary wetland

- **Site Coordinates:** 36.237219, −112.348943
- **River Mile:** 109
- **Site ID:** GRCA-33
- **Degree of Difficulty:** N/A
- **Site Description:** Floodplain wetland/sandbar near mouth of Shinumo Creek. Likely connected by subsurface flow. Soft substrate with macrophytes.
- **Sampling Location:** Best sited close to confluence at gravel bar. As you move upstream there is very limited marginal wetland habitat with little water to sample. A deep pool exists; we observed flannel mouth suckerfish and an invasive killifish.
- **Access:** N/A

10. Royal Arch Creek (recommended for repeat sampling)

- **Site Coordinates:** 36.197208, −112.450696
- **River Mile:** 116.5
- **Site ID:** GRCA-26
- **Degree of Difficulty:** Moderate
- **Site Description:** Shallow pool with riparian vegetation and algae.
- **Sampling Location:** There are two small ponds at the bottom of the creek where larvae are located. Baseflow ~0.15–0.3 ft^3/sec. There's also a small pool right below the large swimming area with some algae where more larvae can be found. Other pools also exist.
- **Access:** Elves Chasm is a popular stop for commercial trips. It was a rocky 0.25-mile hike from the shore to the sampling site; an even shorter hike from the main pull off. Most parties stop for the upper swimming hole, so the sampling pools would be accessible either way.

Sampling location at Royal Arch Creek.
NPS

11. Tapeats Creek

- **Site Coordinates:** 36.371083, −112.469667
- **River Mile:** 134
- **Site ID:** GRCA-35
- **Degree of Difficulty:** N/A
- **Site Description:** Small to midsize stream. Baseflow ~50–75 ft^3/sec. Cold-water. Generally high gradient with cobble & boulder bed.
- **Sampling Location:** Colorado River confluence. Here, both wetland habitat and lots of life exist alongside microhabitats in the sand and gravel bars near mainstem.
- **Access:** Possible to sample from the campsites. Also possible to access from Racetrack camp, though the hike includes a traverse over exposed schist.

Scouting for dragonflies at the mouth of Tapeats Creek.
NPS

12. Deer Creek Falls (recommended for repeat sampling)

- **Site Coordinates:** 36.38503, −112.51585
- **River Mile:** 136
- **Site ID:** GRCA-44
- **Degree of Difficulty:** Easy
- **Site Description:** Shallow pool with vegetation on margins. Baseflow ~4–7 ft^3/sec
- **Sampling Location:** Puddle located downstream from the falls.
- **Access:** This is a popular stop as the falls are quite stunning and the approach is easy.
- **Another area nearby to consider:** Above Deer Falls (36.39409, −112.50571) and above the slot canyon, there appears to be lots of riparian vegetation and good habitat alongside creek. It is about a 0.7 mi hike one way.

Deer Creek Falls (left) and downstream dragonfly sampling location (right).
NPS

13. Kanab Creek-1

- **Site Coordinates:** 36.392333, −112.632833
- **River Mile:** 144
- **Site ID:** GRCA-36
- **Degree of Difficulty:** N/A
- **Site Description:** Small to midsize stream. Baseflow ~3.5–4.8 ft^3/sec. Mix of gravel, fine sediment & bedrock pools.
- **Sampling Location:** Colorado River confluence
- **Access:** N/A

14. Kanab Creek-2

- **Site Coordinates:** 36.40031, −112.63179
- **River Mile:** 144
- **Site ID:** GRCA-45
- **Degree of Difficulty:** Easy
- **Site Description:** Site upstream from established location at sandbar. Baseflow ~3.5–4.8 ft^3/sec.
- **Sampling Location:** Small pools with both vegetation on the edges and algae within.
- **Access:** This was a long open canyon that was easy to access. It may take a little walking upstream to locate the pools.

15. Matkatamiba Canyon

- **Site Coordinates:** 36.343197, −112.671798
- **River Mile:** 148
- **Site ID:** GRCA-37
- **Degree of Difficulty:** N/A
- **Site Description:** Small stream. Baseflow ~0.1 ft^3/sec. Slot canyon with bedrock pools & falls. Gravel and fine sediment at mouth.
- **Sampling Location:** Small pools with slow running water.
- **Access:** Can be difficult for boats to park here. It's about a 0.25-to-0.5-mile scramble to the Patio where the creek opens, but past that there are a lot of small pools and slow running water where larvae are likely to occur.

16. Pete's Pocket (recommended for repeat sampling)

- **Site Coordinates:** 36.326253, −112.755264
- **River Mile:** 155
- **Site ID:** GRCA-28
- **Degree of Difficulty:** Moderate
- **Site Description:** Perched spring above the mainstem.
- **Sampling Location:** One large pool and lots of riparian vegetation to poke around in. The creek from main pool might also harbor more larvae.
- **Access:** Requires parking the boat just upriver right and then hiking up a slope on a lightly used trail for about 0.25 mile. Some participants consider this to be steep and hot hike up the canyon, though the site is reliable.

Sampling location at Pete's Pocket.
NPS

17. Havasu Creek

- **Site Coordinates:** 36.298, −112.74023
- **River Mile:** 157
- **Site ID:** GRCA-10
- **Degree of Difficulty:** N/A
- **Site Description:** Mid to large stream. Baseflow 65–70 ft^3/sec. High conductivity dominated by travertine and marl substrate. Large plunge pools.
- **Sampling Location:** N/A
- **Access:** Upstream from photo depicted below.

Mouth of Havasu Creek.
NPS

18. Colorado River, RM 190

- **Site Coordinates:** 36.11808, −113.20288
- **River Mile:** 190
- **Site ID:** GRCA-46
- **Degree of Difficulty:** Difficult
- **Site Description:** Sand beach. Lack of vegetation. Use of seine highly recommended.
- **Sampling Location:** Colorado River
- **Access:** Easy

Sampling location at Colorado RM 190.
NPS

19. Colorado River, RM 204

- **Site Coordinates:** 36.01853, −113.35000
- **River Mile:** 204
- **Site ID:** GRCA-47
- **Degree of Difficulty:** Easy
- **Site Description:** Cobble bars along margins of mainstem. Success sampling right next to vegetation and slower moving pools behind larger cobble.
- **Sampling Location:** Colorado River downstream from mouth of Spring Canyon.
- **Access:** Park boat downstream of from mouth of canyon on river right. Walk margins of mainstem through vegetation.

Sampling location at Colorado RM 204.
NPS

20. Spring Canyon

- **Site Coordinates:** 36.018694, −113.351472
- **River Mile:** 205
- **Site ID:** GRCA-38
- **Degree of Difficulty:** N/A
- **Site Description:** Small stream, baseflow ~0.1–0.35 ft^3/sec, generally <1m wide. Very thick vegetation. Fine substrate.
- **Sampling Location:** Colorado River confluence.
- **Access:** Best to park boat upriver from mouth of canyon and the hike over ridge into drainage.

  Great habitat for dragonflies, but very dense vegetation and lots of bushwhacking. The terrain is also technical. Would need to work through jungle to get samples and should only take capable hikers.

21. Three Springs

- **Site Coordinates:** 35.885646, −113.308143
- **River Mile:** 215
- **Site ID:** GRCA-27
- **Degree of Difficulty:** Difficult
- **Site Description:** Three Springs Creek. Small stream 1−2m wide. Plunge pools with aquatic vegetation and soft sediments.
- **Sampling Location:** Three approximately 1m × 2m pools where larvae are located. This site should be top notch, but it hasn't flooded in a long time and is completely overgrown with vegetation. It could use a little restoration to open some water.
- **Access:** It's a rocky 0.25-mile scramble from the shore to the site. Many boats park here to jump off the rocks, but not many access the creek. Easier approach than Pete's Pocket.

Sampling location at Three Springs.
NPS

22. Diamond Creek

- **Site Coordinates:** 35.765222, −113.371333
- **River Mile:** 226
- **Site ID:** GRCA-39
- **Degree of Difficulty:** N/A
- **Site Description:** Small stream ~1−2m wide. Low gradient at mouth with fine gravel & sand substrate.
- **Sampling Location:** Colorado River confluence
- **Access:** Could be the ideal activity for some participants to engage in if established as take-out and while boats derig, presuming sufficient Tribal permitting is provided (Hualapai Indian Reservation).

23. Travertine Falls Creek

- **Site Coordinates:** 35.750778, −113.424306
- **River Mile:** 229
- **Site ID:** GRCA-40
- **Degree of Difficulty:** N/A
- **Site Description:** Smaller stream 1−2m wide originating at base of Travertine Falls ca. <100m from mouth. Heavy travertine influence.
- **Sampling Location:** Near confluence with Colorado River
- **Access:** N/A

24. Spencer Creek

- **Site Coordinates:** 35.823667, −113.647917
- **River Mile:** 246
- **Site ID:** GRCA-41
- **Degree of Difficulty:** N/A
- **Site Description:** Spencer Creek, Baseflow ~ 5 ft^3/sec. Small stream with lots of filamentous algae in pools near mouth where we sampled.
- **Sampling Location:** Near confluence with Colorado River
- **Access:** N/A

25. Columbine Falls

- **Site Coordinates:** 36.095611, −113.921139
- **River Mile:** 274
- **Site ID:** GRCA-42
- **Degree of Difficulty:** N/A
- **Site Description:** Columbine Falls stream is small (0.5−1m width). Mix of cobbles & pools. Fairly low gradient. Starting at base of falls. 400m from mainstem.
- **Sampling Location:** Near confluence with Colorado River
- **Access:** N/A
- **Another area nearby to consider:** Above the falls, there is significant habitat with dragonflies flying all over the place. Very technical hike for citizen scientists to take to get above the falls though and there is serious potential of kicking rocks down into waterfall and onto anyone below.

Appendix B

Sample Preservation and Liquid Nitrogen in Desert Environments

Liquid nitrogen (LN) is a necessary means of sample preservation given the length of sampling trips and that samples cannot remain properly frozen on dry ice for the entirety of a 10-day trip in a desert canyon. Using LN on field sampling trips requires careful planning, use of safety equipment (i.e., PPE; gloves, apron, eye protection), and adaptation to ensure the preservation of samples while navigating logistical challenges. Up to two dewars of LN may be brought on any single sampling expedition to store dragonfly larvae samples over the course of the trip. In addition to the usual plastic bags provided by the standard DMP sampling kit, the USGS Contaminant Ecology Research Lab supplies 15ml vials for storage of 2–4 individually bagged and barcoded dragonfly larvae per vial. Adequate dewar size is important to ensure sufficient chamber space for the sample vials.

To prevent mishaps, the cage should be lowered slowly into the dewar to allow the vials to freeze and sink securely. If the cage is lowered too quickly, the vials may float out of the cage and later sink to the bottom of the dewar, making sample retrieval difficult. Caps on the vials should be tightened thoroughly, as the extreme cold can cause them to loosen. Aluminum foil can be "balled up" and placed on top of each cage to prevent samples from floating out, but the size of the aluminum foil ball must be slightly larger than the LN cage diameter to account for shrinkage.

Extracting frozen dragonfly samples from liquid nitrogen dewar upon de-rigging boats in Flagstaff, Arizona.

USGS / C. KOTALIK

Appendix C

Youth Science Trips

Embarking on a youth science trip in the Grand Canyon, such as the dragonfly larvae sampling journey with Grand Canyon Youth and the Ancestral Lands Conservation Corps, offers a unique blend of scientific exploration, educational outreach, and physical endurance. These experiences highlight the challenges and rewards of conducting fieldwork in one of the most remote and iconic landscapes in the U.S.

Balancing Dual Objectives

Guides and scientists on these trips often navigate the tension between two distinct goals. On one hand, guides prioritize the safety and logistical success of transporting participants through the rugged terrain and swift waters of the Colorado River. On the other hand, scientists must focus on collecting data aligned with their research permits. Aligning these objectives requires clear communication and adaptability from all parties.

Challenges of Sampling in Harsh Environments

Sampling dragonfly larvae in the Grand Canyon is not for the faint of heart. The intense heat, often surpassing 110°F in the summer, can turn hiking tributaries into grueling treks. The Colorado River itself presents additional challenges, with fast-flowing waters and limited mainstem habitats suitable for sampling until well downstream. Patience and resilience are essential, as dragonfly populations can be sparse and environmental conditions unpredictable.

Preparing for the Journey

Participants must prepare for days of extreme heat, physical exertion, and occasional frustration. These conditions test endurance and adaptability, offering lessons in coordination, flexibility, and dealing with natural disruptions like flash floods. Yet, these challenges also cultivate camaraderie and resilience among participants.

Engaging Youth in Science and Conservation

Beyond the scientific mission, these trips create meaningful opportunities for youth to engage with both natural and cultural history and explore science careers. The cultural significance of the Grand Canyon for many Tribal youth is unparalleled and should be honored as sacred. While interactions with scientists allow young participants to ask questions, share personal stories, and connect their cultural heritage to the fieldwork, the dialogues should be two-way. These conversations enrich the experience, fostering a deeper appreciation for conservation, Indigenous Knowledge, and federal land management.

The Importance of Advance Communication

Successful coordination begins weeks before the trip, with thorough communication between guides and scientists. Aligning priorities and expectations ensures that both the scientific and logistical objectives are met, creating a smooth and fulfilling experience for everyone involved.

In summary, youth science trips in the Grand Canyon are both physically demanding and profoundly rewarding. They provide participants with a firsthand understanding of environmental science, resilience in the face of challenges, and inspiration to pursue careers in science and conservation.

Grand Canyon Youth participants on a river trip to sample dragonflies in Grand Canyon National Park.
NPS / C. FLANAGAN PRITZ

Additional Information

Ancestral Lands Conservation Corps joins USGS for Grand Canyon Research Expedition | U.S. Geological Survey

Grand Canyon National Park and Ancestral Lands Conservation Corps receive National Park Foundation grant for Native Conservation Corps - Grand Canyon National Park (U.S. National Park Service) (nps.gov)

Dragonfly Mercury Project - Citizen Science (U.S. National Park Service)

The Dragonfly Mercury Project | U.S. Geological Survey

The Dragonfly Mercury Project Data Dashboard

Partners in Science | U.S. Geological Survey

National Park Service
U.S. Department of the Interior

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