



## Barrier pitfall traps increase captures of ground beetles (Coleoptera: Carabidae) on exposed riverine sediments

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**Abstract.** Exposed riverine sediments are unique riparian environments that exhibit high biodiversity and harbor many specialist species. Ground beetles are the most well studied inhabitants within these environments where they are often sampled using pitfall traps. In order to develop conservation measures for species occupying these habitats a logical first step is to refine sampling methods so that proper biodiversity assessments can be carried out. To that end, the effectiveness of two pitfall trap designs (standard trap vs. barrier trap) was evaluated. Over three sampling periods we collected 5,186 individuals represented by 43 species. Barrier traps proved to be superior, yielding significantly greater numbers of individuals ( $n = 3,456$  vs.  $1,730$ ) than standard traps. Additionally, we collected more ground beetle species (37 vs. 30) in barrier traps than in standard pitfall traps. This study supports the rationale for deployment of more than one trap design to avoid deficiencies exhibited by a single type.

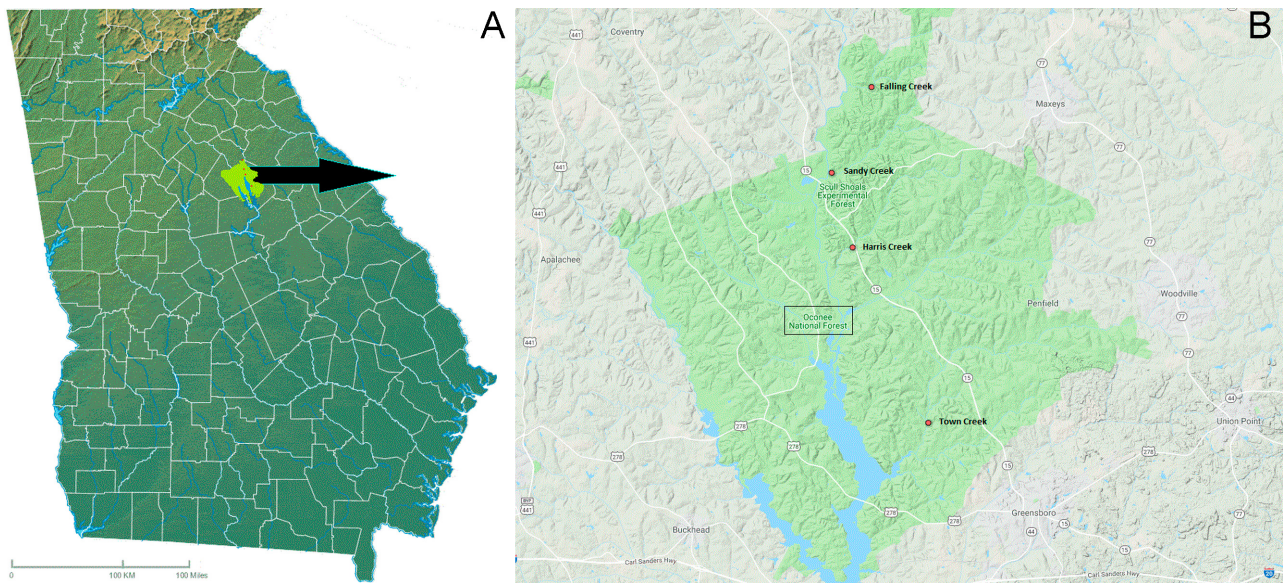
### INTRODUCTION

Exposed riverine sediments (ERS) are sparsely vegetated areas consisting of gravel, sand, or silt that occur between the stream bank and the water's edge. This ecotone generally has a high level of habitat heterogeneity associated with high beetle diversity (Bates et al., 2007a). The lack of vegetation, extreme temperatures, and frequent inundation lead to a dynamic system replete with rare species of arthropods (Bates et al., 2009 and sources therein), many of which are specialists adapted to the physical or climatic extremes within this unique environment (Eyre et al., 2001; Sadler et al., 2004; Lambeets et al., 2009). As a result of this specialization, many of these invertebrates are vulnerable to anthropogenic alterations of rivers and streams and thus serve as model organisms to study impacts of human-induced change (O'Callaghan et al., 2013; Langhans & Tockner, 2014; Sinnadura et al., 2016).

Many of the beetles residing on ERS exploit aquatic food sources (Hering & Plachter, 1997; Paetzold et al., 2005) whereas others predominantly known to occur in forested habitats have been caught on ERS suggesting that they are opportunistically taking advantage of resources stranded near the water's edge (Horn & Ulyshen, 2009). Due to the importance of these unique environments to the surrounding riparian system, as well as the sensitivity and vulnerability of these habitats, appeals have been directed at the restoration and conservation of ERS in North America (Ulyshen & Horn, 2010) and Europe (Bates et al., 2009). This research has focused on the ecological consequences of

major threats like channelization, damage from livestock, gravel and sand extraction, and dams (Knisley & Fenster, 2005; Sadler et al., 2006; Bates et al., 2007b; Paetzold et al., 2008). In order to maximize monitoring programs aimed at pinpointing causal agents of ERS degradation and subsequent acts of restoration, it is imperative to develop sampling methods that are both easy to deploy and highly effective for targeted organisms.

Many invertebrate groups reside on ERS but none are as prominent and well-studied as ground beetles (Carabidae). Carabids are often considered a model taxon when it comes to evaluating human impacts to natural ecosystems (i.e. "bioindicator") because they (1) are easy to identify and collect, (2) have wide distributions, (3) are present in large numbers, (4) are often specialized in their habitat preferences, and (5) can reflect changes to defined habitats (Rainio & Niemelä, 2003; Pearce & Venier, 2006; Koivu-la, 2011; Cajiaba et al., 2018). Studies have successfully monitored ground beetle species and/or communities to assess the effects of various forest management prescriptions such as fire (Beaudry et al., 1997; Hanula & Wade, 2003), clearcutting (Duchesne et al., 1999; Pearce et al., 2003) and gap harvesting (Klimaszewski et al., 2005; Ulyshen et al., 2005a) demonstrating their usefulness at detecting change. Likewise, they have proven effective as potential indicators to environmental pollution through bioaccumulation (Conti, 2017). Regardless of the habitat or disturbance type sampled, a large majority of carabid studies use pitfall traps.



**Fig. 1.** (A) Map showing regional location of study within the state of Georgia, USA and (B) individual stream locations within the National Forest and Oconee River watershed.

Although many methods are routinely used to sample ground-dwelling arthropods, pitfall traps remain the most utilized and effective method for measuring ground beetle populations for ecological studies, although some limitations do exist. For example, they tend to be biased towards larger species (Spence & Niemelä, 1994; Hancock & Legg, 2012) and have the potential to reduce local populations (Digweed et al., 1995; Slezák et al., 2010). Moreover, it has been pointed out that pitfalls reflect ‘activity density’ of terrestrial arthropods rather than true abundance (Lövei & Sunderland, 1996; Kotze et al., 2011; Brown & Matthews, 2016), therefore data interpretation should be treated accordingly, but still no other method is as cost-effective, easy to deploy, and repeatable under various environmental conditions.

Despite widespread use of pitfall traps there have been calls for a standard design (Hancock & Legg, 2012; Brown & Matthews, 2016) so that studies from around the world can be reported and interpreted in a comparable fashion. This can be partly attributed to the vast amount of work that has been conducted on variations in trap design, ranging from the influence of color (Buchholz et al., 2010), preservatives (Knapp & Růžička, 2012; Skvarla et al., 2014), presence of covers (Buchholz & Hannig, 2009; Csaszar et al., 2018), use of funnels (Radawiec & Aleksandrowicz, 2013; Csazar et al., 2018), diameter of the opening size (Koivula et al., 2003; Lange et al., 2011), and barriers (Durkis & Reeves, 1982; Mommertz et al., 1996; Holland & Smith, 1999; Winder et al., 2001; Brennan et al., 2005; Hansen & New, 2005; Boetzel et al., 2018).

Determining efficiency of different pitfall trap designs under various environmental conditions seems to be a simple, yet plausible undertaking. Much effort has been directed at comparing the various designs. However, consideration should also be directed on how each of these designs perform in different habitats, because vegetative structure and microclimate may differentially affect trap

catch according to pitfall trap design (Phillips & Cobb, 2005; Taboada et al., 2006; Thomas et al., 2006). To date, most studies conducted using pitfall traps on ERS have used a single cup method without a barrier (Eyre et al., 2001; Eyre & Luff, 2002; Sadler et al., 2004; Bates et al., 2005, 2007a; Horn & Ulyshen, 2009). The objective of this study was to sample ERS ground beetle communities along four streams and determine if pitfall trap design made a difference in assessing their populations in those areas.

## MATERIALS AND METHODS

### Site description

This study was conducted along four secondary streams (Town Creek: 33°36'49.0608"N, 83°14'19.5072"W, Harris Creek: 33°42'28.9764"N, 83°17'30.1236"W, Falling Creek: 33°47'3.6852"N, 83°14'31.3116"W, and Sandy Creek: 33°43'28.6572"N, 83°17'20.976"W; Google Maps, 2018) (Fig. 1) within the Oconee National Forest in Oglethorpe and Greene County, GA, USA. All streams were within the Oconee River Basin which is located within the Piedmont Physiographic Region, an area that was reforested starting in the 1940's after extensive degradation due to cotton farming. The lasting impacts to these waterways from the devastating erosion that occurred are large volumes of sediment within the streams bordered by steep banks and gullies (Edwards et al., 2013). Current forests are now dominated by over-story species such as willow oak (*Quercus phellos* L.), water oak (*Quercus nigra* L.), sycamore (*Platanus occidentalis* L.), sweetgum (*Liquidambar styraciflua* L.), black walnut (*Juglans nigra* L.), and loblolly pine (*Pinus taeda* L.). Common mid/understory species include spicebush (*Lindera benzoin* (L.) Blume), Georgia buckeye (*Aesculus sylvatica* W. Bartram), Carolina silverbell (*Halesia carolina* L.), ironwood (*Carpinus caroliniana* Walter), and Chinese privet (*Ligustrum sinense* Lour.).

The four streams were all located within 17 km of one another and very similar in nature (i.e. flow rates, sediment loads, sediment size, surrounding canopy cover, etc.). Individual sandbars (Fig. 2) were composed of fine sand with low amounts of deposited leaf litter and some coarse woody debris. Sandbars averaged about 20 m in length and 5 m in width. In spring and early





**Fig. 2.** Typical view of sand-dominated exposed riverine sediments which occur along secondary streams in the study area.

summer sandbars had little to no vegetation occurring on them, however by late summer to fall there was a limited amount of herbaceous plant growth.

### Beetle trapping

For each of the four streams we selected four sandbars upon which to place a pair of traps for comparison. Traps were placed approximately 8–10 m apart depending on sandbar size, as well as spaced halfway between the bank and water's edge. At each stream the four sandbar samples were collected and combined by "trap type" (8 total samples each collection period). The standard trap consists of a 480 ml plastic cup fitted with an 8.4 cm diameter funnel designed to direct beetles into a 120 ml specimen cup (i.e. Horn & Ulyshen, 2009) (Fig. 3A). Second, the same cup dimensions were used as described above except that each was positioned at the intersection of four 0.5 m long metal barriers (forming an "X") (i.e. Ulyshen et al., 2005a, b) (Fig. 3B). The preservative used in the collection cups was a 2% formaldehyde and saturated NaCl solution with a few drops of dish detergent added to reduce surface tension.

Upon collection, samples were transferred to 70% ethanol for storage until they could be identified using a local reference collection (USDA Forest Service, Forestry Sciences Laboratory Collection) and regional ground beetle key (Ciegler, 2000). While not in operation, a square ceramic tile (10.5 cm × 10.5 cm) was placed over all cup openings to prevent the accidental capture of other organisms. Pitfall traps were operated for three 5-day intervals in 2008 and the collection dates were as follows: 25 April, 30 May, and 11 July. The reported annual rainfall amount for the area in 2008 was 92.38 cm which is lower than average and the amounts for the trapping periods were: 7.62 cm (April), 5.66 cm (May), and 10.03 cm (July). Mean temperatures for the trapping periods were 16.2°C for April, 20.6°C for May, and 26.8°C for July.



**Fig. 3.** (A) Standard pitfall trap and (B) Barrier pitfall trap used for collection of ground beetles on exposed riverine sediments in this study.

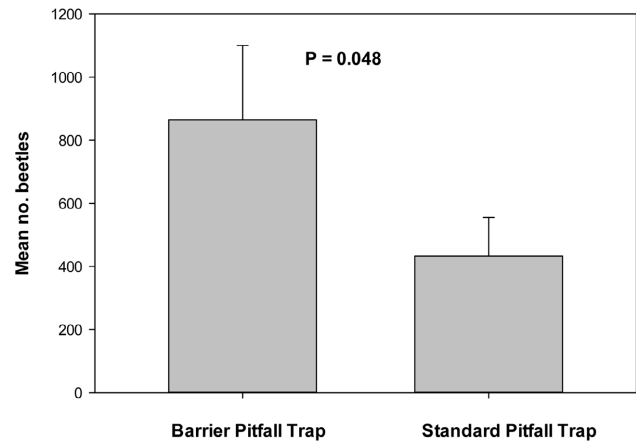
### Statistical analyses

Individual sandbar collections (4 sandbars) were combined at each stream location (4 streams) by trap type (2 trap designs) for a total of 8 samples each trapping period. The data was normally distributed according to a Shapiro-Wilk normality test, ( $P = 0.282$ ). To avoid a lack of independence, the sampling periods were pooled and a paired t-test (SYSTAT 8.0) was used to determine if trap design resulted in differences of mean abundance for ground beetles active on ERS in our area. In addition, a one-way PERMANOVA using PC-ORD (McCune & Mefford, 2011) was performed to determine if community composition differed between the two trap designs. Different sampling periods were pooled for this analysis and only the 19 species captured in at least 3 of the 8 samples each month were included. The same

**Table 1.** Total number of ground beetle specimens for each species captured on sandbars from two pitfall trap designs. Numbers reflect total abundance for the four streams sampled and across all sampling periods combined.

| Ground beetle taxon                             | Total number     |                 |
|---|------------------|-----------------|
|   | Standard pitfall | Barrier pitfall |
| <i>Agonum extensicolle</i> (Say, 1823)          | 127              | 337             |
| <i>Agonum ferreum</i> Haldeman, 1843            | 23               | 41              |
| <i>Agonum</i> spp. Bonelli, 1810                | 0                | 1               |
| <i>Amara</i> spp. Bonelli, 1810                 | 2                | 5               |
| <i>Anisodactylus melanopus</i> (Haldeman, 1843) | 0                | 1               |
| <i>Anisodactylus verticalis</i> (LeConte, 1848) | 3                | 0               |
| <i>Badister flavipes</i> LeConte, 1853          | 0                | 1               |
| <i>Badister notatus</i> Haldeman, 1843          | 0                | 2               |
| <i>Bembidion aenulum</i> Hayward, 1901          | 86               | 316             |
| <i>Bembidion inaequale</i> Say, 1823            | 30               | 26              |
| <i>Bembidion versicolor</i> (LeConte, 1848)     | 6                | 3               |
| <i>Brachinus alternans</i> Dejean, 1825         | 17               | 10              |
| <i>Brachinus americanus</i> (LeConte, 1844)     | 3                | 0               |
| <i>Brachinus janthinipennis</i> (Dejean, 1831)  | 537              | 1015            |
| <i>Carabus vinctus</i> (Weber, 1801)            | 0                | 1               |
| <i>Chlaenius aestivus</i> Say, 1823             | 69               | 191             |
| <i>Chlaenius impunctifrons</i> Say, 1823        | 0                | 1               |
| <i>Chlaenius nemoralis</i> Say, 1823            | 1                | 1               |
| <i>Chlaenius prasinus</i> Dejean, 1826          | 1                | 1               |
| <i>Cicindela repanda</i> Dejean, 1825           | 62               | 51              |
| <i>Cicindela sexguttata</i> Fabricius, 1775     | 30               | 23              |
| <i>Clivina bipustulata</i> (Fabricius, 1801)    | 3                | 4               |
| <i>Clivina dentipes</i> Dejean, 1825            | 3                | 8               |
| <i>Clivina ferrea</i> LeConte, 1857             | 2                | 0               |
| <i>Dicaelus dilatatus</i> Say, 1823             | 0                | 1               |
| <i>Dicaelus elongates</i> Bonelli, 1813         | 2                | 3               |
| <i>Dyschirius</i> spp. Bonelli, 1810            | 1                | 1               |
| <i>Elaphrus ruscarius</i> Say, 1830             | 0                | 5               |
| <i>Galerita bicolor</i> (Drury, 1773)           | 1                | 0               |
| <i>Harpalus pennsylvanicus</i> (DeGeer, 1774)   | 0                | 1               |
| <i>Loxandrus</i> spp. LeConte, 1852             | 0                | 1               |
| <i>Omophron americanum</i> Dejean, 1831         | 546              | 1041            |
| <i>Oodes brevis</i> Lindroth, 1957              | 2                | 8               |
| <i>Panagaeus fasciatus</i> Say, 1823            | 0                | 1               |
| <i>Paratachys</i> spp. Casey, 1918              | 2                | 33              |
| <i>Patrobus longicornus</i> (Say, 1823)         | 2                | 6               |
| <i>Platynus dicentis</i> (Say, 1823)            | 0                | 1               |
| <i>Poecilus lucublandus</i> (Say, 1823)         | 1                | 0               |
| <i>Scarites quadriceps</i> Chaudoir, 1843       | 1                | 0               |
| <i>Scarites subterraneus</i> Fabricius, 1775    | 1                | 1               |
| <i>Schizogenius ferrugineus</i> Putzeys, 1846   | 121              | 253             |
| <i>Semiardistomis viridis</i> (Say, 1823)       | 45               | 60              |
| <i>Stenolophus ochropezus</i> (Say, 1823)       | 0                | 1               |

\*All nomenclature follows that used by Larochelle & Larivière (2003) and Ciegler (2000).



**Fig. 4.** Mean number ( $\bar{x} + SE$ ) of ground beetles captured in each pitfall trap design. Significance based on a paired t-test after sampling periods were pooled ( $P < 0.05$ ).

dataset was used to perform an indicator species analysis using PC-ORD following the approach of Dufrene & Legendre (1997) to determine if certain species seemed to be associated with trap type.

### RESULTS AND DISCUSSION

This study yielded a total of 5,186 specimens between the two trap designs, represented by 43 species (Table 1). The barrier traps caught almost twice as many individual ground beetles as the standard traps ( $n = 3,456$  vs. 1,730) where they accounted for 66% of the total. A paired t-test revealed significant differences in the mean number of ground beetles collected from barrier pitfall traps ( $M = 864$ ,  $SD = 473.33$ ) and standard traps ( $M = 432.5$ ,  $SD = 245.49$ );  $t(3) = 3.23$ ,  $P = 0.048$ . (Fig. 4). There is evidence in other habitats that support the finding that barriers increase arthropod catch. For example, Durkis & Reeves (1982) sampled a mixed hardwood forest in New Hampshire and found that not only did a barrier increase their catch of ground beetles, but captures went up with length of the fence design as well. Similarly, Hansen & New (2005) found that the use of a trap barrier consistently caught more individuals and morphospecies than a conventional trap in an open, grassy woodland of Australia. Moreover, a study conducted in Germany in a semi-natural meadow revealed that pitfall traps with barriers were up to five times more effective than conventional traps and were more reflective in their species assemblage approximations (Boetzel et al., 2018). These studies, as well as the results reported here from ERS show that barrier pitfall traps are useful for increasing ground beetle catches no matter the habitat sampled.

Although barriers increased the numbers of ground beetles captured, an indicator species analysis revealed no species were indicative of trap type. Likewise, a PERMANOVA showed that the community composition did not differ significantly between the trap designs ( $F = 0.60$ ;  $df = 1, 6$ ;  $P = 0.6846$ ). In contrast, Boetzel et al. (2018) caught twice as many species in barrier traps and their species accumulation curves indicate that one of these traps is equal to

deployment of four or five simple pitfall traps. They conclude that conventional traps might be necessary for comparisons with existing literature, but barrier traps are far superior for studies concerned with biodiversity inventories. Information from the present study seems to support this conclusion because thirteen of the recorded species were captured only in barrier traps while 6 were found only in standard pitfalls, often represented by a single specimen. This underscores the importance of deploying multiple trap types, especially when trying to assess the presence of as many taxa as possible. For example, Mommertz et al. (1996) evaluated trap construction within an agroecosystem and concluded that unfenced traps overestimate the percentage of ground beetles present and that the use of multiple designs are advisable to overcome shortcomings exhibited by just one type of trap.

Table 1 includes all carabid species encountered during sampling as well as the number caught by each trap design. The most commonly collected species were *Omophron americanum*, *Brachinus janthinipennis*, *Agonum extensicollis*, *Bembidion aenulum*, *Schizogenius ferrugineus*, *Chlaenius aestivus*, and *Cicindela repanda*. Each of these species were captured in higher numbers from barrier pitfall traps with the exception of the bronzed tiger beetle, *C. repanda*. The only other tiger beetle captured, *C. sexguttata* was also caught more often in standard traps without a barrier. Most tiger beetles are diurnal and exhibit a stop and look hunting style (Pearson et al., 2006). This behavior likely reduces the chance of them being “directed” into a trap by a barrier fence. Physical characteristics such as body size have also been proposed as a possible factor influencing capture rates. Winder et al. (2001) found some evidence that smaller species of ground beetles might be more prone to collection with traps using barrier fences but the results were inconsistent. Findings here were similar when ground beetles were classified as either being small (< 10 mm body length) or large (> 10 mm body length). Barrier traps accounted for 67% of small-bodied and 61% of large-bodied ground beetles collected suggesting that smaller beetles might be more susceptible to capture if directed by a fence.

As is often the case when invertebrates are sampled, distributions are highly skewed, with many rare species present and only a few common ones that make up the bulk of the community (Verberk, 2011). That was the case in this study as well where 24 of the 43 species were represented by five or less individuals. The ground beetle captured most frequently was the hunch-backed beetle, *O. americanum* which accounted for 31% of the total catch while *B. janthinipennis* made up 30%. These two beetles accounted for the majority of captures in a previous study conducted on one of the four streams utilized here (Horn & Ulyshen, 2009), thus it was not a surprise that they were common on nearby streams with similar characteristics. *O. americanum* is a burrowing, mostly nocturnal species that is restricted to the vicinity of water on sparsely vegetated sandy substrates (Lindroth, 1961; Larochelle & Larivière, 2003). Lakeshores, riverbanks, and moist sandy soils are

listed as typical habitat for *B. janthinipennis* where it is reported to be an ectoparasite of gyridid (*Dineutes* spp.) and hydrophilid (*Tropisternus* spp.) pupae (Larochelle & Larivière, 2003).

Carabid seasonality can be influenced by many factors such as their abundance, breeding or dormancy periods, and larval development but many of the species that occur in disturbed habitats (i.e. dynamic stream systems) can exhibit various levels of plasticity (Rainio, 2013). Results presented here are consistent with earlier work in the same habitats (Horn & Ulyshen, 2009) and reveal that the earliest trapping session in April yielded the most abundance and diversity ( $n = 3,010$  and 35 species) from which it declined the following two sampling periods in May ( $n = 1,545$  and 29 species) and July ( $n = 631$  and 15 species). This is in line with seasonality records for the most commonly collected species, as well as breeding records for *O. americanum* that have reported it to be a spring breeder (Larochelle & Larivière, 2003).

There are several reasons why this community might be tilted towards larger populations early in the season. First, it could be a result of beetle communities within this dynamic system being strongly tied to early season resource availability that occur from late winter/early spring flooding. Evidence exists that some taxa, e.g. tiger beetles are strongly influenced by the availability of food (Pearson & Knisley, 1985), thus it stands to reason that their seasonality would be closely linked to times when it is most readily available. Secondly, traps could have shown reduced catches because beetle activity was restricted due to increases in vegetation density (i.e. Honěk, 1988; Thomas et al., 2006) on the sandbars as the season progressed. Lastly, a “trap-out” effect could explain part of the declines given that the two most commonly collected species seem to be restricted to these relatively small sandbars adjacent to the water’s edge thus rendering populations vulnerable to reduction over time.

Recent studies (Hallmann et al., 2017; Sánchez-Bayo & Wyckhuys, 2019) have sounded the alarm on global insect declines and ushered in a discussion about the negative effects to the planet due to the loss of ecosystem services they provide. In order to develop conservation strategies for insects as a whole, it is vital to identify which groups are most at risk and then employ efficient monitoring protocols to determine if management actions are needed. My objective in this study was to determine if trap design would make a difference on the diversity and abundance of ground beetle catches on exposed riverine sediments, especially given how prominent this unique habitat is on secondary streams in our area. This study showed that the community did not differ between traps on the four streams sampled, however it does indicate that barrier traps are more effective based on the collection of greater numbers of individuals and species from that design. This study aligns with previous work that has recommended incorporating multiple trap types into studies to alleviate the biases associated with a particular style. In addition, because exposed riverine sediments serve as habitat to many stenotopic species, barrier



traps might be the best option for biodiversity assessments. Future studies are needed to determine how these traps perform in different regions, over longer periods of time, and under different environmental conditions.

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