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Traveling across the toe: Riverbank features and their impact on emergence distance of *Gomphus vastus* and *Stylurus spiniceps*

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Abstract

The distance that an emergent dragonfly nymph travels from the water's edge influences its chance of successful eclosure. In many riverine systems, heavy riverbank erosion has led to a variety of bank stabilization methods being applied. In the Turners Falls Reservoir (Massachusetts), bank stabilization methods have included the placement of rocks along the toe of the slope. Dragonflies that travel across these rocks are often exposed to boat wakes, water level changes, and predation. This study investigated how riverbank features (such as rock size, width of riprap zone, slope, and sediment) affected the distance traveled by two species of riverine dragonfly (*Gomphus vastus* and *Stylurus spiniceps*).

Introduction

Riverbanks represent the final hurdle that must be crossed for the nymphs of many riverine dragonfly species. These habitats are composed of a combination of both aquatic and terrestrial characteristics and are frequently influenced by human activities. Riverbank ecotones are typically highly complex areas with a variety of emergent and established vegetation, alluvial deposits, and woody debris, and provide refuge for many species of insects (van Looy et al., 2005). The interface zone between two landscape types, termed an edge, has long been the focus of researchers (Samways & Steytler, 1996; Urbine-Cardona et al., 2006). Edges provide unique habitats that often are not found in either of the adjacent areas. While the importance of terrestrial edges has been well documented, little focus has been placed on the unique edge that exists between aquatic and terrestrial landscapes (Homan et al., 2004; Gamble et al., 2006).

Adjacent forest cover and land use determine the geomorphic evolution of the riverbank, and can create the potential for erosion (Weins, 2002). Aquatic characteristics also impact the riverbank ecotone. For example, seasonal flooding and altered hydroperiods (e.g., due to dams and reservoir releases), affect sediment deposition and transport, can lead to increased erosion of riverbanks, and ultimately may modify habitats for benthic macroinvertebrates (McClelland & Brusven, 1980; Naiman & Dēcamps, 1997; Magilligan & Nislow, 2001). Recreational boat activity and subsequent generation of boat wakes add stress to the riverbank ecotone (Schorr, 2000).

Within many river systems in New England, riprap is commonly used to control bank erosion. Typically riprap slope stabilization is applied at the lowest section of the bank, and extends into the water line. While riprap does control the rate of erosion, it creates highly variable, potentially hazardous ecotones for dragonflies. Characteristics of this ecotone include an extensive interstitial space (which may provide refugia for the nymphs), relative substrate stability, and permanent exposure to wave action.

The exposed rock toe may also create a thermal barrier to eclosing nymphs. Although research has been conducted on the colonization of these areas by plants and invertebrates (Tockner, 1991), little attention has been centered on the important role this biotope plays for species that must traverse it. Presence of riprap can alter morphologic evolution of the river through natural changes in energy flow (organic nutrients), physical characteristics, and plant succession (Fischenich, 2003), and the size of the riprap alters habitat for many fish species (Lister et al., 1995; Beamer & Henderson, 1998). Riprap can also affect the hydrologic balance causing changes in river slope or profile, barriers between surface, subsurface, and benthic waters, or alteration of flow (Fischenich, 2003).

The distance traveled by emergent dragonfly nymphs is highly variable. The minimum height traveled for any species is at the water surface, or within 20 cm above the water surface (Corbet, 1993). Fincke et al. (2009) reported finding *Hagenius brevistylus* nymphs a meter away from the water, and *Didymops transversa* nymphs 9 m away from the water. Gomphids generally travel between 25–50 cm from the water's edge (Kurata, 1971; Inoue, 1979).

Methods

Research was conducted within the Turners Falls Reservoir (Gill, Massachusetts: Franklin Co.) section of the Connecticut River. The Connecticut River is the main hydrological feature of the Turners Falls Reservoir, but since the con-

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struction of the Turners Falls dam (1904), Vernon, Vermont (1910) and the Northfield Mountain Pump Storage Project (1972), the reservoir can be considered as a managed system. A variety of streambank restoration methods (from concrete blocks to large boulders) were implemented soon after the hydroelectric facility began operation.

At the Turners Falls Reservoir, the Northfield Mountain Pump Storage intake/outflow facility was designated the center of my study area. The Route 10 Bridge served as the northernmost boundary, and Barton Cove was the southernmost boundary. Fifty quadrats (25 control sites [eroded], and 25 riprap sites) were located upriver and fifty transects (25 control sites [eroded], and 25 riprap sites) were located downriver of this location. A random numbers table was used to establish the location of the furthest upriver and downriver transect (relative to the intake/outflow facility). All sampling locations were situated within the reservoir. Each quadrat covered 1.5 m of shoreline; the upper extent of the quadrat was determined by establishing a point 12.19 m vertically up the slope of the bank from the two shoreline points. Each location was visited 1–2 times per week beginning on 10 June 2008 and ending on 14 August 2008.

Slope was determined from the waterside edge of the riprap toe to 12.19 m up the bank. Three river-bed sediment samples (one from the upriver edge of the quadrat, one from the midpoint, and one from the downriver edge of the quadrat) were taken 0.61 m beyond the edge of the bank; these samples were combined and percent composition of sand, silt, and clay was determined. The width of the riprap toe (stabilization using rocks) was recorded, and individual riprap circumference (mm) was ascertained by measuring 100 random samples with a Wildco (95 Botsford Place, Buffalo, NY) gravelometer (Potyondy & Hardy, 1993; Bunte & Abt, 2001). Water temperature was recorded at the beginning of each sampling session using a digital thermometer. The temperature of the air (above the water/land interface), and substrate temperature (at the interface zone) were also recorded using a digital thermometer. Water level was recorded using a staff gauge (USGS), which was placed vertically in the water 1.22 m from the shoreline. Water level was recorded at ten-minute intervals throughout the monitoring period. Water velocity was recorded 1.22 m from the shoreline using a Wildco flowmeter. The distance traveled from the edge of the water to the eclosure site for *Gomphus vastus* and *Stylurus spiniceps* was determined through either (1) direct observation of eclosing nymphs, or (2) presence of attached exuviae.

Analysis of the effect of location on *G. vastus* and *S. spiniceps* emergence distance was conducted using Mann-Whitney U. Pearson correlation was used to highlight connections between location, abiotic features and emergence distance. In order to more clearly encompass the complexities of the Turners Falls Reservoir, backwards elimination multiple regression (BEMR) was conducted on the relationships between location, abiotic factors, and emergence distance of *G. vastus* and *S. spiniceps*. The purpose of BEMR is to find a model that best predicts the dependent variable (travel distance of *G. vastus* and *S. spiniceps*) as a linear function of the independent variables (location and abiotic factors). BEMR analysis begins with a multiple regression that includes all of the independent variables; additional multiple regressions are conducted, with each independent variable removed one at a time. The process proceeds until any additional removal of an independent variable would cause a significant decrease in R^2.

Results

Mann-Whitney U analysis highlighted significant ($p < 0.05$) differences between several abiotic features at upriver versus downriver locations. Air temperature (°F) was an average of 6.62 degrees warmer (mean = 74.74, sd = 4.76) at the downriver locations as compared to the upriver sites (mean = 68.12, sd = 6.22, $p < 0.05$). Substrate temperature (°F) was also warmer at downriver sites (mean = 73.24, sd = 4.46) than at the upriver quadrats (mean = 71.39, sd = 4.17, ($p < 0.05$). Water velocity (m/sec) was slightly slower at the upriver locations (mean = 1.59, sd = 0.50) as compared to the downriver locations (mean = 1.63, sd = 0.37, $p < 0.05$). The riprap zone was significantly wider ($p < 0.05$) at the downriver locations (mean = 1.20, sd = 1.62) than the upriver sites (mean = 1.48, sd = 1.48). Circumference of the rocks within the riprap zone varied considerably at both the upriver and downriver locations with downriver sites having slightly larger rocks. The composition of sediment located in the near riverbank zone differed between upriver and downriver locations ($p < 0.05$). The percentage of sand found within the zone was 6.17% higher at the downriver locations, while both percentage of silt and percentage of clay were higher at the upriver locations. There was no significant difference in water temperature, water level change, or slope between the upriver and downriver locations.

The distance traveled to eclosure site, in areas where there were no obvious limitations to travel, reflected species-specific preferences. Both *S. spiniceps* and *G. vastus* displayed differences in distance traveled at the upriver locations versus the downriver locations. In my study, recorded travel distances for both *S. spiniceps* and *G. vastus* far exceeded the distances recorded by Kurata (1971) and Inoue (1979). The maximum distance traveled by *S. spiniceps* at any location was 0.88 m. *G. vastus* traveled an impressive 3.94 m at upriver locations and 2.72 m at downriver locations.

On average, *S. spiniceps* traveled 0.33 m (n = 83, sd = 0.55 $p > 0.05$) from the water at the upriver sites, and 0.19 m (n =

126, sd = 0.09, p > 0.05) from the water at downriver site. *G. vastus* also traveled further from the water at upriver sites than downriver sites (3.94 m, n = 299, sd = 1.49, and 2.72 m, n = 216, sd = 1.17 respectively; p < 0.05).

Table 1. Pearson correlation on the influences of selected abiotic factors at upriver versus downriver locations for distance traveled by *S. spiniceps* and *G. vastus* (p < 0.05) represents no significant correlation).

Abiotic factors	**Species**	**Upriver**	**Downriver**
Air temperature	*S. spiniceps* *G. vastus*	0.35 0.18	0.43 -0.18
Water temperature	*S. spiniceps* *G. vastus*	0.40 0.24	0.43 -0.19
Substrate temperature	*S. spiniceps* *G. vastus*	0.28 0.10	0.49 -0.27
Water level change	*S. spiniceps* *G. vastus*	0.22 -0.61	– 0.10
Width of riprap (m)	*S. spiniceps* *G. vastus*	– 0.22	-0.46 -0.15
Circumference of riprap (mm)	*S. spiniceps* *G. vastus*	– –	0.36 -0.18
Water velocity (m/sec)	*G. vastus*	0.40	0.17
Slope	*G. vastus*	-0.30	0.51
% sand	*S. spiniceps* *G. vastus*	– -0.16	0.21 0.59
% silt	*S. spiniceps* *G. vastus*	-0.23 0.19	– -0.49
% clay	*G. vastus*	0.19	-0.35

A total of eight abiotic factors (Table 1) was included in the BEMR model for how far *S. spiniceps* traveled from the water. All eleven abiotic factors significantly affected the distance *G. vastus* traveled from the water.

BEMR analysis of the distance traveled by *S. spiniceps* resulted in two different models. The downriver model contained more significant (p < 0.05) factors than the upriver model. Overall, the upriver model accounts for 88% of the variance shown within the distance traveled by *S. spiniceps*, while the downriver model accounts for 54% of the variance (Table 2).

Air temperature was significant in both models. For every 10° F increase in air temperature at the upriver sites, *S. spiniceps* traveled an additional 2.15 m. At the downriver sites a 10° F increase in air temperature was correlated with a 0.59 m reduction in the distance traveled by *S. spiniceps*.

A 10° F increase in water temperature at the downriver sites resulted in a 1.76 m increase in distance traveled by *S. spiniceps*, but the variable was not included in the upriver BEMR model. Substrate temperature was only included in the downriver model; for every 10° F increase substrate temperature, *S. spiniceps* reduced its travel distance by 0.81 m.

Water velocity was included in both models. A 1 m/sec increase in water velocity was correlated with a subsequent increase in distance traveled (0.58 m upriver, 0.37 m downriver). A 1 cm/hour change in water level was correlated with increases in *S. spiniceps* travel distance at both upriver and downriver locations (2.05 m, 0.38 m respectively). Increasing the width of the riprap zone by 1 m was correlated with an increase (2.40 m) in travel distance at the upriver locations, and a decrease (1.06 m) in travel distance of *S. spiniceps* at the downriver locations. The affect of rock circumference within the riprap zone also varied between upriver and downriver locations. A 1 mm increase in rock size at the upriver sites was correlated with a 1.93 m reduction in travel distance, while the same rock size increase at downriver sites was correlated with a 0.54 m increase in travel distance. Sediment composition (%

Table 2. Significant models of the effects of multiple abiotic factors on distance traveled by *S. spiniceps* and *G. vastus* as generated by BEMR analysis. All abiotic factors are significant (p < 0.05).

	Upriver		**Downriver**	
	Features	**Standardized B**	**Features**	**Standardized B**
S. spiniceps	Air temperature	2.15	Air temperature	-0.59
	Water velocity	0.58	Water temperature	1.76
	Water level change (cm)	2.05	Water level change (cm)	0.38
	Width of riprap (m)	2.40	Width or riprap (m)	-1.06
	Circumference of riprap (mm)	-1.93	Circumference of riprap (mm)	0.54
	% silt in sediment	0.69	Water velocity (m/sec)	0.37
			Substrate temperature	-0.81
	R^2	**0.88**	**R^2**	**0.54**
G. vastus	Water temperature	0.67	Air temperature	-0.50
	Substrate temperature	-0.48	Substrate temperature	0.35
	Water velocity	-0.09	Water velocity	-0.23
	Water level change	-0.61	Water level change	0.16
	Width of riprap	0.42	Width of riprap	-0.45
	Circumference of riprap	-0.73	Circumference of riprap	-0.19
	% sand in sediment	0.59	% slope	0.31
	% silt in sediment	0.47	% silt in sediment	-0.24
	% clay in sediment	0.30		
	R^2	**0.77**	**R^2**	**0.67**

silt) was only included in the upriver model. A 1% increase in silt was correlated with a 0.69 m increase in distance traveled by *S. spiniceps*.

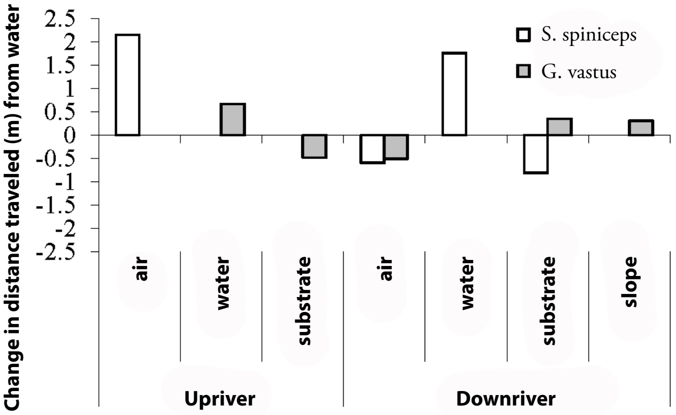

Figure 1. Effects of increasing air temperature, water temperature, substrate temperature and slope on distance traveled by *S. spiniceps* (avg$_{\text{upriver}}$ = 0.33 m, avg$_{\text{downriver}}$ = 0.19 m) and *G. vastus* (avg$_{\text{upriver}}$ = 3.94 m, avg$_{\text{downriver}}$ = 2.72 m).

BEMR analysis of the distance traveled by *G. vastus* resulted in two significant models. The upriver model accounts for 77% of the variance shown within the distance traveled by *G. vastus*, while the downriver model accounts for 67% of the variance (Table 2). Air temperature was included only in the downriver models. For each 10° F increase in air temperature, *G. vastus* travel distance was reduced by 0.50 m.

Substrate temperature was significant in both models. For every 10° F increase in substrate temperature at the upriver sites, *G. vastus* decreased its travel distance by 0.48 m, while at the downriver sites, distance traveled increased by 0.35 m. A 1 m/sec increase in water velocity was correlated with a decrease in travel distance of 0.09 m at the upriver sites, and a reduction in travel distance of 0.23 m at the downriver sites. Water level change was negatively correlated with *G. vastus* travel distance at downriver sites, but positively correlated with the distance traveled at upriver sites. A 1 cm/hour change in water level resulted in an increasing travel distance by 0.16 m downriver, and decrease of 0.61 m upriver.

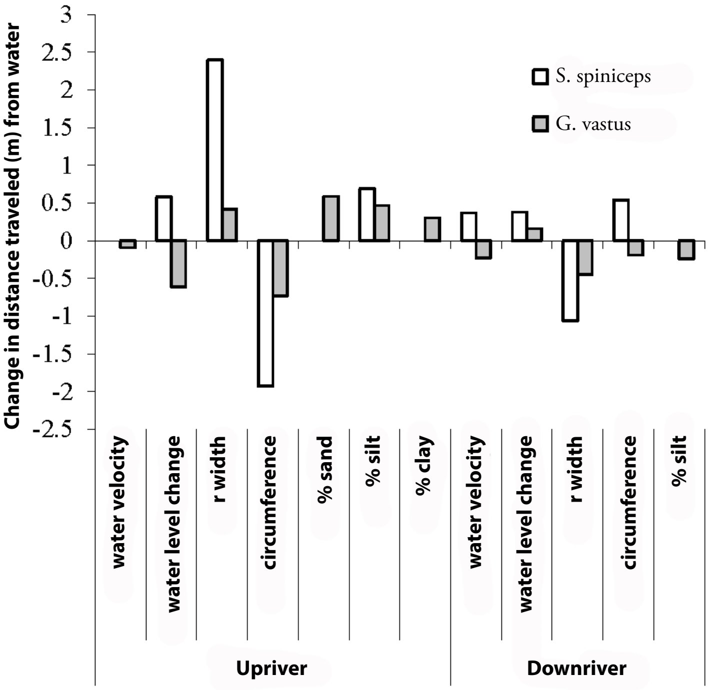

Figure 2: Effects of water velocity, water level change, width of riprap zone (r width), circumference of rocks within the riprap zone (circumference), and composition of sediment (% sand, % silt, % clay) on distance traveled by *S. spiniceps* (avg$_{\text{upriver}}$ = 0.33 m, avg$_{\text{downriver}}$ = 0.19 m) and *G. vastus* (avg$_{\text{upriver}}$ = 3.94 m, avg$_{\text{downriver}}$ = 2.72 m).

Riprap characteristics (width and size of rocks within the zone) were significant factors in both models. Increasing the width of the riprap zone by 1 m resulted in a reduction in travel distance downriver (0.45 m), while the same increase in riprap width upriver resulted in *G. vastus* increasing its travel distance by 0.42 m. Increasing the circumference of the riprap by 1 cm resulted in a decrease in travel distance in both upriver and downriver locations (0.73 m upriver, 0.19 m downriver).

The percentage of silt within the sediment was a significant factor in determining the distance traveled by *G. vastus* at both locations. Increasing silt composition by 1% decreased the distance *G. vastus* traveled by 0.24 m at downriver sites, but increased the distance traveled by 0.47 m at upriver sites. The percentage of sand within the sediment was a significant factor at upriver locations, a 1% increase led to an additional 0.59 m being traveled by *G. vastus*. Slope was a significant component of the downriver model. A 1% increase in slope, increased the distance traveled by 0.31 m.

While the reasons *G. vastus* traveled significantly greater distances at the upriver sites are currently unknown, the results of both the Pearson analysis and BEMR suggest some interesting trends. Significant associations were found between all three temperatures (substrate, air, and water) and the distance traveled by *S. spiniceps* and *G. vastus*. Interestingly, the effects of air, water, and substrate temperature on distance traveled varied both with the species, and with location. In general, increasing temperature had a negative effect on *G. vastus* travel distance, specifically at downriver locations, but had a positive effect on *S. spiniceps* (Fig. 1). The differences in effect due to location present several intriguing questions as to the effect of site-specific topography, vegetational features, and the impact of the intake/outtake facility. When correlated with other abiotic features, the three temperature variables remained significant, but their inclusion in the BEMR models was dependent on the location. The effect of location suggests that *G. vastus* and *S. spiniceps* are responding to site-specific features and processes. The variability at the ecotone seems to be a vital factor in whether or not these two species increase or decrease their emergence distances.

Interestingly, both *S. spiniceps* and *G. vastus* decreased their travel distances in areas with riprap. Increasing the circumference of the rocks within the zone decreased the distance traveled by both the species. The association between the width of the riprap zone and how far the species traveled was less clear, but once again, location appeared to be an influential factor. At upriver locations, increase in riprap zone width was linked with increased travel in both *S. spiniceps* and *G. vastus*, while at downriver locations, both species had decreased travel distances. Both *S. spiniceps* and *G. vastus* displayed different responses to changes in water velocity and water level. *S. spiniceps* emergence distance was not significantly correlated with changes in water velocity at either the upriver or downriver locations, while *G. vastus* travel distance was positively correlated with water velocity (Fig. 2). The influence of water velocity on *G. vastus* travel distance was also correlated with location. There was no uniformity in the effects of water level change on either *S. spiniceps* or *G. vastus*. While a 1 cm/hr change in water level at upriver locations resulted in an increase in distance traveled by *S. spiniceps* it resulted in a decrease in distance traveled by *G. vastus*. *G. vastus* at downriver sites traveled further when faced with the same water level change. These results suggest that there might be additional site-specific features that influence the behavior of these two species.

The difference between models for *G. vastus* travel distance was not as distinctive as was the case for *S. spiniceps*, but there are still several interesting differences. The upriver model for *G. vastus* accounted for 77% of the impact on travel distance, while the downriver model accounted for only 67%. Only six abiotic factors (substrate temperature, water velocity, water level change, width of riprap zone, circumference of rocks within the riprap zone, and the percentage of silt in the sediment) were included in both models, yet the individual effect of these features varied widely between the models.

Discussion

The results of this study suggest that the presence of riprap reduces the distance *G. vastus* and *S. spiniceps* traveled to their eclosure location. By eclosing closer to the water, both species are at increased risk of being drowned by rising water or boat wakes.

While the individual correlations between the selected abiotic features and travel distance of *S. spiniceps* and *G. vastus* suggests species-specific responses to environmental features, it is in consideration of multiple abiotic features that a clearer picture emerges. The resultant four models produced through BEMR analysis illustrate the impact that location had on both *S. spiniceps* and *G. vastus*. If location was not an influential feature, then the upriver and downriver models should be identical, and this was not the result. The upriver model for *S. spiniceps* travel distance included only six abiotic features (air temperature, water velocity, water level change, width of riprap zone, size of rocks within the riprap zone, and the percentage of silt in the sediment), yet it accounted for 88% of the impact on travel distance. The downriver model included seven features, yet only accounted for 54% of the impact on travel distance. In addition to the different assessment of abiotic impacts, individual abiotic features that were included in both models, did not have the same impact at upriver sites as they had at downriver sites. Since there were few universal impacts (occurring at both upriver and downriver locations) among the sediment features, the effect of microenvironment (i.e. location of riverbank) appears to have a very influential role in determining how far *G. vastus* and *S. spiniceps* will travel.

In addition to the variation shown in the BEMR models, the Mann-Whitney U analysis of the eleven abiotic factors included in this study showed significant differences between upriver and downriver locations for eight of the abiotic variables. Only percent slope, water level change, and water temperature were similar between upriver and downriver locations. Interestingly, these three variables were not uniformly present in the BEMR models. Water level change was the only one of these variables that appeared as a significant variable in both upriver and downriver models for *G. vastus*. This occurrence is interesting, as an increase in water level resulted in a decrease in *G. vastus* travel distance at downriver locations, and an increase in travel distance at upriver locations.

Unfortunately, a number of factors may have influenced the results of this study. The survey quadrats in most of the locations were heavily vegetated, and nymphal abundances might be higher than reported. Since sites were not visited every day, it is difficult to draw definitive connections between temperature at the time of surveying, and the actual temperature at the time of emergence. The number of potential habitat variables at the survey locations is extensive, and it was time and cost prohibitive to include all habitat variables in the study. Based on the results of the study, there appear to be several important variations between the locations, and further research, either field or lab based, is needed to better understand how these habitat variables may impact emergence distance.

Conclusion

The difficulties of quantifying relationships between abiotic variables and organismal behavior are very evident in the results of this study. Ecosystems are highly complex units which include multiple layers of interactions. Location appears to be a defining feature of how far *G. vastus* and *S. spiniceps* travel from the edge of the water. Even within a relatively stable system, like the Turners Falls Reservoir, there are both micro and macroscale differences in habitat.

The results of this study suggest the powerful impact that microenvironments have on the emergence of *G. vastus* and *S. spiniceps*. The issue of a unique feature, in the case of my study the presence of a hydroelectric intake/outflow facility, may potentially offset the ability of ecologists to predict any one species response to restoration changes. Many of the current biological assessment models of riverine habitats are focused on either a reach scale or even a landscape scale. Since results of my study support the conclusion that the distance specific dragonfly species travel during emergence is intricately tied to ecological variations at the microscale level, it is imperative that more holistic models recognize the importance of these smaller scales and incorporate them into their framework. Overall, there were only a few abiotic features that resulted in similar emergence distances at both upriver and downriver locations. Based on extensive observations of these two species, it is apparent that even the most finite of connections is extremely influential on how far these species travel from the water's edge, and ultimately on their likelihood of survival.

Future studies in this area may need to retreat to the relatively less complex realm of the laboratory in order to better understand the connections between abiotic variables and dragonfly behavior. The results of my study underscore the need for additional research into this area.

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The Dragonfly Society Of The Americas

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Journals Published By The Society

Argia, the quarterly news journal of the DSA, is devoted to non-technical papers and news items relating to nearly every aspect of the study of Odonata and the people who are interested in them. The editor especially welcomes reports of studies in progress, news of forthcoming meetings, commentaries on species, habitat conservation, noteworthy occurrences, personal news items, accounts of meetings and collecting trips, and reviews of technical and non-technical publications. Membership in DSA includes a digital subscription to Argia.

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Mission of the Dragonfly Society of the Americas

The Dragonfly Society of the Americas advances the discovery, conservation and knowledge of Odonata through observation, collection, research, publication, and education.