EXAMINING THE HABITATS OF RUSTY CRAYFISH (*ORCONECTES RUSTICUS*) AND AMERICAN EELS (*ANGUILLA ROSTRATA*) IN 12 STREAMS IN EASTERN NEW YORK

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Abstract. Species invasions are a major concern in conservation today. One example of this is the invasive rusty crayfish (*Orconectes rusticus*), a species native to the Midwest that has been introduced to many areas throughout the United States, and has caused problems due to its ability to proliferate and outcompete native predators. One of these declining native predators along the eastern seaboard of the United States is the American eel (*Anguilla rostrata*). Rusty crayfish appear not to coexist with American eels. We hypothesized that this may be due to some relationship between biotic and abiotic variables and the habitat requirements for the two species. To explore the habitat requirements of these two species, we measured biotic and abiotic aspects of 12 streams that contained eels, crayfish or neither. We measured the macroinvertebrate community and measured abiotic variables (Ca2+ concentration, average water velocity, depth, and conductivity). We found that variation within a stream category (e.g. eels, crayfish or neither) was greater than variation among stream categories. We found no relationship between abiotic or biotic variability among sites that explain the presence of eels and crayfish and concluded that the variables measure do not explain the distribution patterns of these species.

INTRODUCTION

Species invasions are a major concern in conservation. Non-native species cause declines in native species because of their greater competitive abilities and a lack of predators (Olden et al. 2006). Often they occur in much larger numbers than they would in their native habitat, and this way swamp out the native species through competition (Olden et al. 2006). One of the more voracious of these invasive species that is causing a problem in the freshwater systems of the United States is the rusty crayfish (*Orconectes rusticus)* (Olden et al. 2006). The rusty crayfish is a species native to streams of the Ohio River drainage basin (Olden et al. 2006). Through human introductions (e.g. bait buckets), rusty crayfish have invaded other basins throughout the northeastern United States and have been shown to spread to other streams (Lodge et al. 1994; Kershner and Lodge 1995; Charlebois and Lamberti 1996; Olden et al. 2006). Rusty crayfish are now found within the Hudson River watershed (Mount 2009).

American eels (*Anguilla rostrata*) inhabit freshwater streams, rivers, lakes, and estuaries from their juvenile stages to their adult stages, when they migrate to the Sargasso Sea to spawn (Hammers 1996; Velez-Espino and Koops 2010). These eels are native to the entire eastern seaboard of North America, including streams in the Hudson River watershed (Mount 2009, Velez-Espino and Koops 2010). The American eel population is currently declining due to several reasons, including human activities such as dams, overharvest, and pollution (Velez-Espino and Koops, 2010). The American eel is the target of current conservation efforts, as it is an important predator and game fish in American freshwater streams (Hammers 1996; Machut 2006).

The possibility of a link between the invasion of rusty crayfish and American eel population declines have been suggested (Mount 2009). Both rusty crayfish and American eels eat macroinvertebrates, are nocturnally active, and use similar substrate types (cobble-boulders) for hiding and feeding (Lodge et al.

1994; Kershner and Lodge 1995; Hammers 1996). However, in a recent survey, rusty crayfish were not observed in the same sites as American eels (Mount 2009). In addition, native crayfish generally do not exist in high densities when American eels are present (personal observation, Mount 2009). American eels prey on native crayfish and may outcompete them for shelter, which may result in low densities of crayfish in eel-dominated streams. (Machut 2006; Mount 2009). This relationship is less clear between rusty crayfish and eels, as competition for shelter between the two species appeared to depend on their body size (Mount 2009). Also, it is not known whether eels can prey upon rusty crayfish; however, rusty crayfish have been observed to prey on glass (juvenile) eels in a laboratory setting (Turrin 2009).

Given the lack of strong evidence for competition or predation between these species, we hypothesized that the lack of overlap among eels and rusty crayfish may be a result of abiotic and biotic variables at a site. The purpose of this study is to examine possible biotic and abiotic factors that may be distinct between streams that contain rusty crayfish versus American eels resulting in the distribution patterns of these species. We hypothesized that abiotic stream characteristics (i.e., water chemistry), biotic stream characteristics (i.e., the macroinvertebrate community), or both contribute to this distribution. For example, rusty crayfish require a minimum calcium ion concentration of 2.5mg/L (Capelli and Magnuson 1983; Olden et al. 2006). Also, Wilson et al. (2004) demonstrated that rusty crayfish caused a decline in fish populations that fed on the same prey taxa as the crayfish. One question we attempted to answer was if the biotic community of macroinvertebrates differed between different classes of streams (those with eels, those with rusty crayfish, and those with neither). We explored the abiotic and biotic characteristics of sites which contain eels, crayfish or neither to attempt to identify which, if any, of these variables relate to the distribution patterns observed.

MATERIALS AND METHODS

Study Sites

We sampled 12 streams throughout southeastern New York during the summer of 2010. We chose streams based on the presence of either rusty crayfish, American eels, or neither (Table 1). Four streams had moderate to high densities of American eels, four streams had high densities of rusty crayfish, and the last four contained neither. Sites with neither served as reference conditions.

Field Sampling

At each site we measured stream width at the bottom, middle, and top of a 20m reach. We collected a water sample for each site in a clean polyethylene bottle for later chemical analysis of calcium concentration and conductivity. Water samples were analyzed for conductivity using a Fisher-Accumet AR20 pH/conductivity meter and were analyzed for calcium ion concentration using a Leeman Labs Inductively Coupled Plasma Spectrometer (Teledyne Technologies, Los Angeles, CA). We took 5 measurements of stream velocity and depth using a Marsh-McBirney 201 electromagnetic current meter across the 20m reach. These measurements were taken haphazardly along the reach; however, an effort was made to include areas of varying depths and velocities in order to better characterize the stream.

To sample the macroinvertebrates, we used a $0.1m^2$ mesh size Surber sampler. We haphazardly selected 3 locations in each stream and disturbed the substrate to a depth of approximately 15cm, and scrubbed all the rocks. The sample was then placed in a jar, returned to the lab, and preserved in 70% ethanol.

We conducted crayfish surveys in each reach. We turned over rocks and substrate for ten minutes actively searching for crayfish. In streams with rusty crayfish, this was to positively identify the crayfish in the stream as *Orconectes rusticus*. In streams without rusty crayfish, this was done to ensure no rusty crayfish had invaded, as well as document what native crayfish inhabited the streams. All crayfish collected were identified and recorded.

Surber samples were sorted by two different methods. Samples with smaller amounts of substrate (muck, gravel, sand, silt, rocks, and organic matter) that did not entirely cover the whole surface of a 2mm mesh sieve were picked and all hexapods, decapods, and gastropods were subsequently identified to family. Samples with large amounts of substrate were first washed through a 2mm mesh sieve to remove larger inorganic particles. All large invertebrates remaining in the sieve were identified to family and then set aside. We subsampled the remaining material by identifying a quarter of the invertebrates to family. If fewer than forty invertebrates were identified this way, another quarter was taken and identified. We used these subsamples plus the larger invertebrates previously identified to estimate the total number of individuals in the entire sample.

Statistical Analyses

In order to explore differences in the macroinvertebrate communities among each stream type, we performed a Canonical Correspondence Analysis using the PC-ORD version 4 (MjM Software Design, Gleneden Beach, Oregon, USA) on the raw numbers of each macroinvertebrate family (see Appendix 1) in each stream (Figure 1). We set up the ordination twice, first calculating graph scores using abiotic variables, and secondly, biotic variables (Figure 1). We also included abiotic variables (Appendix 2) in the analysis superimposed on the ordination graph as vectors to each axis (Figure 1). Due to the large number of rare taxa (occurring in small numbers overall), we chose to down-weight the rare taxa during the CCA ordination procedure. This helps give interpretable results. The resulting graph produced by the CCA has 2 axes with no specific units. Axis 1 and 2 together explain the most variation within the data set defined as each stream community. These axes do not directly relate to one individual variable, but can explain variation in specific variables themselves. The amount to which each axis explains a variable is shown by a vector going through the graph for each variable (Figure 1). A vector of 45° for Variable A would signify that the variation in each stream for Variable A is explained equally by both Axis 1 and 2. Conversely, a vector of 90° would signify that the variation in each stream for Variable A would be explained entirely by Axis 2. So if Variable A was conductivity and the vector was 90° to Axis 1, conductivity would increase up the Y axis. PC-ORD also calculates an r value for each variable on each axis, which states the percentage of that variable explained by that axis as an r^2 value. In sum, variation found between stream categories (the data points on the graph) can be correlated to each variable within each site (both biotic families present and abiotic) as a function of its vector to each axis. Therefore, similar streams will have similar variables, and therefore similar positions along the X- Y axes. If there is large variation among stream categories compared to within stream categories in all the variables present, then we expect eel streams to cluster together on the graph separately from rusty crayfish streams, which will cluster out separately from streams with neither.

RESULTS

Stream characteristics varied among streams, including depth, stream flow, and macroinvertebrates present (both in raw numbers and diversity). Although the same number of samples were taken per stream, some streams had many macroinvertebrates (Swamp River, 766 individuals) while others had few (Croton, 60 individuals).

Streams did not cluster by category (Figure 1). The rusty crayfish streams appear similar to one another, but an MRPP test was not significant for either the biotic variables (MRPP T=0.39, p=0.59) or the abiotic variables (MRPP T= -0.79, p=0.19). The total variance between all streams explained by Axis 1 and Axis 2 is 29.6% (Figure 1). To see which variables may be described by Axes 1 and 2, we overlaid the abiotic variables Average Depth of the stream (AVGD), Average Velocity (AVGV), Conductivity (COND), and Calcium Ion concentration (Ca^{2+}) as vectors on the graph (Figure 1). The vector for Calcium Ion concentration is nearly horizontal. Therefore, variation in Calcium Ion concentration between stream sites is best described by Axis 1. The opposite is true for Average Velocity, best described by Axis 2. Conductivity and Average Depth are described somewhat by Axis 2 but mostly by Axis 1. However, due to the fact that Axis 1 and 2 together explain only 29.6% of the total variation between stream scores, and because the stream scores did not significantly cluster on the graphs, we conclude that biotic and abiotic stream characteristics that we measured did not influence distribution patterns of eels and crayfish in the stream.

As shown in Figure 1 there was much variation between streams within the same category as well as between categories. The four crayfish streams appeared closer to each other than either of the other two categories' streams. However, because less than a third of the total overall variation could be explained by the two axes, and the source of the variation denoted by both axes is not clear, we believe that this provides us with no useful information. We had hypothesized that there may be both abiotic and biotic variables defining an "eel" stream versus a "rusty crayfish" stream. This may still be the case, but we were unable to determine if there is a clear definition between "eel" streams, "rusty crayfish" streams, and streams with "neither," and we were unable to elucidate which variables may be responsible for this. Based on the macroinvertebrate communities of streams with American eels and those with rusty crayfish, it also remains unclear if the identity of the predator in the stream has an effect on the families present in the stream.

DISCUSSION

Patterns of rusty crayfish and American eel densities in the 12 streams sampled were not explained by any of the abiotic or biotic variables measured. This was likely due to a large amount of variation among stream sites unaccounted for by this study.

We believe that one factor contributing to the large amount of variation in this study was time. Due to the design of the study, we sampled the twelve streams over the course of two months (June to July). Because different macroinvertebrates emerge from the stream at different times, the dominant family in each stream will change as the season progresses (McElravy et al. 1989). Also, it may be that macroinvertebrate community structure in these streams was not dictated by the predator present. McElravy et al. (1989) demonstrated that macroinvertebrate community composition can change from year to year through abiotic factors. Short-term changes, such as drought or high water flow from a storm, can temporarily alter macroinvertebrate communities as well (McElravy et al. 1989). To better assess community composition, we would have to sample during the same time of year for several years in order to account for variation caused by abiotic factors (McElravy et al. 1989).

Abiotic characteristics were not related to differences in distribution patterns of eels and crayfish; however, abiotic habitat characteristics that we did not measure may be influencing distribution patterns. For example, stream substrate may play a role in regulating rusty crayfish and American eel distributions (Mount 2009). Larger rocks and cobble are preferred for sheltering both species (Mount 2009). Predator-prey or competitive interactions between the two species may be more important than habitat characteristic that we measured, but more research is needed (Turrin 2009).

Examining the relationship between rusty crayfish and American eel is important, especially if American eels have the ability to exclude rusty crayfish from habitats (Mount 2009). Also, because American eels are declining throughout the eastern United States, it is important to know if rusty crayfish play a part in this decline (Velez-Espino and Koops 2010). It may prove more worthwhile to consider direct interactions between rusty crayfish and American eels that influence distribution of these species, especially a predator-prey relationship (Turrin 2009).

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APPENDIX

Biotic Variables

The number of each macroinvertebrate family collected in each stream. This data was used to generate the CCA ordination results graphed in Figure 1.

	Hydropsychidae	Lepidostomatidae	Chironomidae	Brachycentridae	Hydroptilidae
Saw Kill Down	116	0	109	0	2
S. Lattintown	78	0	145	0	56
Landsman's Kill Down	61	1	55	0	0
Crum Elbow Down	10	2	142	1	1
Webatuck	133	0	21	0	0
Swamp River	120	5	28	0	0
Croton River	4	0	18	0	0
Lattintown	2	0	11	0	0
Little Wappinger	52	0	45	12	3
Saw Kill Up	174	0	106	4	6
Landsman's Kill Up	29	0	108	0	0
Crum Elbow Up	19	0	37	13	23

	Tipulidae	Heptageniidae	Ancylidae	Gyrinidae	Psephenidae
Saw Kill Down	52	5	2	0	15
S. Lattintown	82	0	0	0	4
Landsman's Kill Down	1	3	0	0	10
Crum Elbow Down	0	2	3	0	6
Webatuck	10	92	0	0	23
Swamp River	8	2	8	0	23
Croton River	0	7	0	1	1
Lattintown	0	2	1	0	10
Little Wappinger	7	3	8	11	4
Saw Kill Up	16	0	0	0	19
Landsman's Kill Up	1	39	0	5	25
Crum Elbow Up	26	1	13	0	6

	Perlolidae	Polycentropodidae	Oligoneuriidae	Haliplidae	Siphlonuridae
Saw Kill Down	18	0	4	0	6
S. Lattintown	0	0	0	0	47
Landsman's Kill Down	5	5	2	0	66
Crum Elbow Down	0	4	0	0	0
Webatuck	4	0	22	0	1
Swamp River	13	4	75	0	0
Croton River	0	5	0	0	0
Lattintown	0	1	0	0	0
Little Wappinger	8	0	2	2	1
Saw Kill Up	12	62	9	0	8
Landsman's Kill Up	65	2	13	0	4
Crum Elbow Up	1	20	1	0	0

	Ephemeridae	Caenidae	Corydalidae	Leptoceridae	Limniphilidae
Saw Kill Down	0	0	6	0	0
S. Lattintown	0	0	0	7	0
Landsman’s Kill Down	0	0	0	0	0
Crum Elbow Down	0	2	0	8	0
Webatuck	0	14	3	0	0
Swamp River	0	16	0	0	0
Croton River	0	0	0	0	0
Lattintown	0	1	1	0	0
Little Wappinger	4	3	1	7	2
Saw Kill Up	0	0	3	2	0
Landsman’s Kill Up	0	0	8	25	0
Crum Elbow Up	0	0	6	1	0

	Sphaeridae	Tricorythidae	Odontoceridae	Uenoidae	Glossosomatidae
Saw Kill Down	0	2	0	0	0
S. Lattintown	0	0	0	0	27
Landsman’s Kill Down	0	0	0	0	0
Crum Elbow Down	0	0	0	0	0
Webatuck	0	0	0	0	1
Swamp River	0	0	0	0	1
Croton River	0	0	0	0	0
Lattintown	4	0	0	0	0
Little Wappinger	27	13	1	1	0
Saw Kill Up	0	1	0	0	0
Landsman’s Kill Up	0	0	0	0	0
Crum Elbow Up	0	0	0	1	0

	Veliidae	Philopotamidae	Polymitarcyidae	Psychomyiidae	Libellulidae
Saw Kill Down	1	29	0	1	1
S. Lattintown	2	0	0	0	0
Landsman’s Kill Down	6	0	0	0	0
Crum Elbow Down	0	0	0	0	0
Webatuck	1	1	1	13	0
Swamp River	2	10	0	0	0
Croton River	0	0	0	0	0
Lattintown	3	0	0	0	0
Little Wappinger	0	0	0	0	0
Saw Kill Up	0	0	0	4	0
Landsman’s Kill Up	0	0	0	0	0
Crum Elbow Up	2	0	0	2	0

	Stratiomyidae	Heliopsychidae	Aeshnidae	Gammaridae	Asellidae
Saw Kill Down	1	2	3	1	1
S. Lattintown	0	0	2	0	2
Landsman's Kill Down	0	0	1	27	56
Crum Elbow Down	0	0	0	83	12
Webatuck	0	0	0	0	0
Swamp River	0	0	0	0	0
Croton River	0	0	0	7	3
Lattintown	0	0	1	5	10
Little Wappinger	0	0	0	0	0
Saw Kill Up	0	0	0	0	0
Landsman's Kill Up	0	0	0	0	0
Crum Elbow Up	0	0	0	1	0

	Planorbidae	Ryacophilidae	Coenagrionidae	Tanyderidae	Gerridae
Saw Kill Down	2	0	0	0	0
S. Lattintown	1	0	0	0	0
Landsman's Kill Down	0	0	1	0	0
Crum Elbow Down	0	0	0	0	0
Webatuck	0	0	0	1	1
Swamp River	0	0	0	0	0
Croton River	0	0	0	0	0
Lattintown	0	0	0	0	0
Little Wappinger	0	0	0	0	0
Saw Kill Up	2	9	3	0	0
Landsman's Kill Up	0	0	0	0	0
Crum Elbow Up	0	3	0	0	0

	Corixidae	Petaluridae	Physidae	Dytiscidae	Curculionidae
Saw Kill Down	0	0	0	0	0
S. Lattintown	0	0	0	0	0
Landsman's Kill Down	0	1	0	0	0
Crum Elbow Down	0	0	0	0	0
Webatuck	0	0	0	0	0
Swamp River	0	0	0	0	1
Croton River	0	0	0	0	0
Lattintown	0	0	0	0	0
Little Wappinger	0	0	0	0	0
Saw Kill Up	1	5	3	1	0
Landsman's Kill Up	0	14	0	0	0
Crum Elbow Up	0	0	10	0	0

	Simulidae	Potomanthidae	Athericidae	Dolichopodidae	Gomphidae
Saw Kill Down	0	0	0	0	0
S. Lattintown	4	0	0	0	0
Landsman's Kill Down	0	0	0	0	0
Crum Elbow Down	0	0	1	0	0
Webatuck	0	0	0	0	0
Swamp River	0	5	0	0	0
Croton River	0	0	0	0	0
Lattintown	0	0	0	0	0
Little Wappinger	0	0	0	0	0
Saw Kill Up	0	0	0	0	0
Landsman's Kill Up	1	1	0	0	0
Crum Elbow Up	0	0	0	1	10

	ALL TAXA
Saw Kill Down	474
S. Lattintown	819
Landsman's Kill Down	675
Crum Elbow Down	321
Webatuck	771
Swamp River	766
Croton River	60
Lattintown	114
Little Wappinger	287
Saw Kill Up	625
Landsman's Kill Up	744
Crum Elbow Up	274

Abiotic stream variables

Abiotic stream variables were used to generate graph scores in Figure 1 and were overlayed as vectors to Axis 1 and 2 on Figure 1.

	Average Velocity (m/s)	Average Depth (cm)	Conductivity (µS/cm)	Calcium ion (mg/L)
Saw Kill Down	35.4	18.8	421	56
S. Lattintown	23.6	15.6	494	53.3
Landsman's Kill Down	13.6	8.8	447	55
Crum Elbow Down	7	18.4	579	56.4
Webatuck	13	4.17	424	47.4
Swamp River	20.2	13.6	396	43.4
Croton River	2.8	15.6	405	38.7
Lattintown	2.2	12	267	37.2
Little Wappinger	12	11.8	335	35.8
Saw Kill Up	27.6	14	427	56.8
Landsman's Kill Up	14	9.6	376	50.9
Crum Elbow Up	4.2	23.8	510	54.3

TABLE 1. Stream abbreviations and names. EE1-4 are streams with American eels, CF1-4 are streams with rusty crayfish, and NT1-4 are streams with neither.

Abbreviation	**Stream Name**
EE1	Saw Kill Down
EE2	S. Lattintown
EE3	Landsman's Kill Down
EE4	Crum Elbow Down
CF1	Webatuck
CF2	Swamp River
CF3	Croton River
CF4	Lattintown
NT1	Little Wappinger
NT2	Saw Kill Up
NT3	Landsman's Kill Up
NT4	Crum Elbow Up

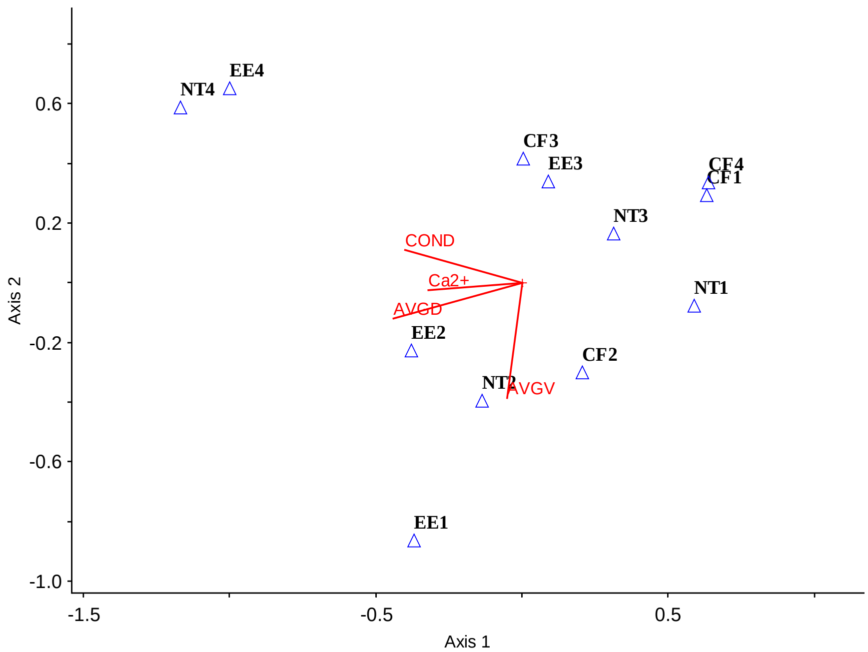

FIGURE 1. CCA ordination results generating stream scores from abiotic stream variables. Stream abbreviations correspond to Table 1. Abiotic stream variables (Appendix 2) are overlayed on the graph. The vector of each abiotic variable to each axis shows how much of the variation between streams is explained by each axis.