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AQUATIC BEETLE ASSEMBLAGES RESPONSE TO DROUGHT IN SMALL WOODLAND STREAMS

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Abstract

The effect of an unstable hydrological regime on aquatic beetle (Coleoptera) assemblages in intermittent streams (with periodic summer droughts in some segments) was investigated in two successive years with differing climatic conditions. Samples were taken after complete flow resumption in October in each of four unnamed streams flowing into and out of Lake Łękuk Wielki (northeastern Poland). Nine taxa representing five families of aquatic beetles were identified. Seasonal changes in the density and biomass of aquatic beetles were similar in both years of the study. Maximum values of those parameters were noted in the fall followed by strong, distinct decreases in January. The null hypothesis that there was no difference between dry and wet years for taxon richness, mean biomass, and mean density was tested. No significant differences for these attributes were noted, except biomass at one station. Significant differences (ANOSIM, $p < 0.05$) were determined in beetle assemblages between wet and dry years.

Introduction

Flow-generated disturbances that periodically disrupt stable conditions in streams vary greatly in duration, spatial extent, and predictability (LAKE 2000). Perturbations in the ecosystems of flowing waters can destroy habitat patches and create new ones that are then colonized and inhabited by biota with the return of stable flow conditions. Global climate change scenarios predict more frequent, extended droughts of flowing waters (BOULTON and LAKE 2008). During droughts, macroinvertebrate communities often shift toward populations more capable of withstanding harsh conditions associated with drought, including decreased water quality and higher water temperatures (BECHE et al. 2006). In beetle communities there is a reconstruction of the species composition, in which the

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species are beginning to have the greatest quantitative significance (Pakulnicka et al. 2015, Westveer et al. 2018). Taxonomic diversity over time can be enhanced in temporary streams as compared with perennial systems because of fluctuations in community composition between lotic, lentic, and terrestrial phases (Bogan and Lytle 2007).

Perennial streams are common in Central Europe and the drying up of this stream type is unpredictable and can occur in extremely dry years (Řezníčková et al. 2007). Streams that maintain any year-round flow are common in the postglacial area of northern Poland. Most streams in this region are perennial, and they account for 44% of the drainage network length (Mazurek 2010), although streams with intermittent or ephemeral flows also exist. The Lake Łękuk Wielki watershed is located in the Puszcza Borecka and is one of the seven Base Stations of Integrated Monitoring of the Environment in Poland that was created to monitor the conditions of and changes in natural ecosystems in Poland (Kostrzewski et al. 1995) where human impact is not intense.

Coleoptera fauna in perennial streams was studied by Zaťovičová et al. (2004), and in intermittent streams by Pavićević and Pešić (2012), while other researchers focused on comparisons between these two stream classes (Řezníčková et al. 2013) or between perennial and temporary streams (Stubbington et al. 2009). This study included observations of assemblages of aquatic beetles inhabiting a few perennial streams located in the same catchment area in two years in which the hydrological regimes differed.

The aim of this study was to determine the species composition of aquatic Coleoptera occurred in perennial streams, to compare beetle assemblages among all the sampling sites, and to estimate biomass. Another purpose of the study was to identify possible differences between coleopterans from wet and dry years distinguished mainly using precipitation parameters. Therefore, the null hypothesis that there was no difference between dry and wet years for taxon richness, mean biomass, and mean density was tested.

Material and Method

Research subject

The study was performed in the catchment area of Lake Łękuk Wielki in the Borecka Primeval Forest located in the Great Mazurian Lakeland of northeastern Poland (22°02'E, 54°08'N). The western part of the catchment area is formed by a vast dead-ice depression in which Lake Łękuk

Wielki (23.7 ha) is located. Four small, unnamed streams (0.3–4.2 km long) flow directly into the lake and drain a catchment area of 13.5 km^2 (Figure 1). Land uses in the Łękuk Wielki catchment include 66% forest (mainly spruce, *Picea abies*, beech, *Fagus silvatica*, oak, *Quercus robur*, and alder, *Alnus* sp.), 25% pastures, and 6% wetlands (mainly peats and swamps) with very little human impact.

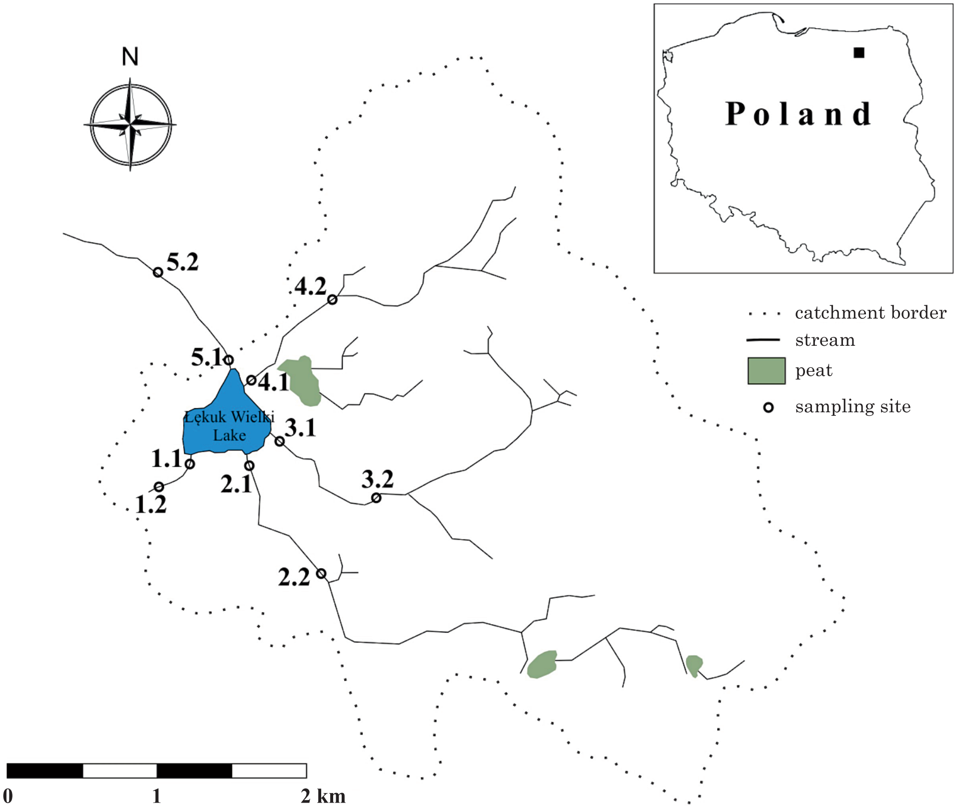

Fig. 1. Study area and location of 10 sampling sites

The lake tributaries run through a forest covering the catchment, and originate from a broken drain-pipe (stream 1) or have no well-defined sources and originate from several permanent springs situated between the moraine hills at an altitude of 180 m (streams 2, 3, and 4). The upper and middle courses of the streams (except for stream 1) are in flat areas, and their gradients do not exceed 1%. Along most of its length, stream 1 is fed from a partly damaged drainage system located nearby. At the boundary between the morainic upland and the dead-ice depression the streams flow in ravines and their gradients reach about 3%. The final segments of the streams are in a flat area formed of alluvial deposits, and their gradients are again low (SMOLEŃSKI and SIEKLUCKI 1997). The outflow from the lake (stream 5) has regulated banks at a distance of about 1 km, while the remaining parts are of a natural character. *Ulothrix zonata* (Chlorophyta) occurs in the streambed from late winter to mid spring at a distance up to 20 m below the lake. Periphyton (represented almost exclusively by diatoms) was very weakly developed in the inflows (DUMNICKA and KOSZAŁKA 2005).

In the streams studied, the discharge varied from high in spring to very low or completely absent in summer. Very low precipitation over several weeks resulted in the stream beds drying up (SMOLEŃSKI and SIEKLUCKi 1997). Drying proceeded along the stream courses from evaporation and infiltration through the sandy sediment to the hyporheic zone. The outflow from the lake could also dry up. The inflows were typical woodland streams, where leaf breakdown was a very important component of the allochthonous organic matter. Marginal vegetation was limited to the relatively short final segments of the streams (DUMNICKA and KOSZAŁKA 2005).

The hydrochemical properties of the water in all the streams studied were similar, but seasonal changes at the same stations were high and were correlated with discharge values. During the study period, stream waters had an alkaline pH range of 7.5–8.2, medium values of conductivity (322–600 μS cm^{-1}), and a low to medium nutrient content ($P–PO_4$ 1–131 μg dm^{-3}; $N\text{-}NO_3$ 0.1–6 mg dm^{-3}) (ŚNIEŻEK et al. 2000).

Methodology

The streams were studied over a 24-month period, from October 1997 to September 1999. All the streams dried up nearly completely from July to mid October, before the sampling period. The first samples were collected four weeks after the streams filled with water, and the last samples were collected from the dried stream beds. Surface water disappeared in the lower segments of streams 1, 2, and 3 and the outlet. Only stream 4 was considerably diminished, but its bed in the lowest segment remained moist. Two stations were selected at each stream - on the alluvial deposits near the lake (site codes – stream number and n. 1) and at the sector flowing through the forested slopes (sites codes – stream number and n. 2). A pair of stations was also located in the outlet of the lake (Figure 1).

Aquatic Coleoptera were sampled with a core sampler (a steel tube with an area of 29.2 cm^2), and each sample comprised ten sub-samples, for a total of 221 samples and 2210 total sub-samples. The sub-samples were taken across the stream from each station at each sampling, and they were distributed proportionally to the area occupied by the habitats (silt and clay, sand, gravel and pebbles, cobbles, woody debris, and algae). Live coleopterans were picked from the sediments under a stereoscopic microscope after washing them through a sieve (mesh size 0.25 mm) and were preserved in formalin (4%).

Coleoptera larvae were identified to the genus or species, and adults were identified to the species mainly according to GALEWSKI and TRANDA (1978), ROZKOŠNY (1980), GALEWSKI (1990) and KLAUSNITZER (2009). All specimens identified were weighed to determine wet mass to the nearest 0.1 mg on an analytical scale.

Statistical analysis

To characterize the structure of the beetle assemblages found in the streams, we used species/genus composition, biomass, and density data collected at each sampling site. Analysis of similarity (UPGMA, Bray-Curtis distance metric) was used to compare differences in the coleopteran communities among sites. Cluster analysis dendrogram classification was produced with the MultiVariate Statistical Package 3.13 (KOVACH 2007).

To verify pattern occurrence in the aquatic beetle communities, Non-metric Multidimensional Scaling (NMDS) analysis was performed using aquatic beetle density, with each point as a sampling unit and the year (dry or rainy) as the group variable. The metaMDS function from the vegan package was used (OKSANEN et al. 2020) with the Bray-Curtis distance measure. The ordination stress statistic was used as a measure of goodness of fit. To compare beetle community structures in wet versus dry years, while pooling across seasons, one-way analysis of similarity (ANOSIM; CLARKE and WARWICK 1994) was conducted using the Bray Curtis similarity matrix. Non-metric multidimensional scaling (nMDS; 100 restarts) plots were used to create graphic representations of the ANOSIM results. The analyses were performed in the R statistical environment (*R Core Team* 2021).

The Wilcoxon rank-sum test was used to detect whether there were significant differences ($p < 0.05$) in taxon richness, mean biomass, and mean density for each month sampled between dry and wet years. The analysis was performed with the TIBCO Software Inc. statistical package (2017).

Results

Nine taxa of aquatic beetle were confirmed in the material collected. Among the larvae collected, two were identified to the species and four to the genus, and they belonged to five families. One Coleoptera in the imago stage was identified as *Scarodytes halensis*. Within the genus *Elodes* two forms were designated with numbers. Additionally, larvae that were not classified to the genus were also observed. Overall, 186 individuals were caught. Representatives of the order Coleoptera were collected at all of the sampling sites. The greatest taxon richness was confirmed at site 4.1, where six taxa were observed. The highest mean density and biomass of beetles was confirmed at site 4.2 at 122 ind. m^{-2} and 1.37 g m^{-2}. The highest share in the number (49%) and biomass (57%) of the order Coleoptera was of larvae from the genus *Elodes*, which were distinguished with the number 1. Larvae of the genus *Agabus* were the only aquatic beetles that inhabited all of the streams studied, and they were noted at all eight sampling sites. The list of all the taxa recorded, including data on their density (%) share of the samples, is presented in Table 1.

Table 1

Percentage share of aquatic Coleoptera taxa at sampling sites

Specification	1.1	1.2	2.1	2.2	3.1	3.2	4.1	4.2	5.1	5.2
Dytyscidae										
Agabus sp.	67	40	–	67	50	60	54	2	–	2
Platambus maculatus (Linné)	–	–	–	–	–	–	17	–	–	2
Scarodytes halensis (Fabricius) – imago	–	–	–	–	–	–	8	–	–	4
Hydraenidae	–	–	–	–	–	–	–	–	–	–
Hydraena sp.	–	–	50	–	–	–	4	–	–	–
Hydrophilidae										
Helophorus sp.	–	–	50	–	50	–	4	–	–	–
Elmidae										
Oulimnius tuberculatus (Müller)	8	–	–	–	–	–	–	–	100	87
Scirtidae										
Elodes sp. 1	17	50	–	–	–	40	13	95	–	4
Elodes sp. 2	8	10	–	–	–	–	–	2	–	–
Coleoptera n.d.	–	–	–	33	–	–	–	–	–	–
Average density [ind. m^{-2}]	20	16	3	5	3	8	36	122	2	70

The density of Coleoptera changed significantly during the study period. The highest density values were recorded at the beginning of the study (in the first wet season) just after the dry period and in October and in December in the second year of the study (Figure 2).

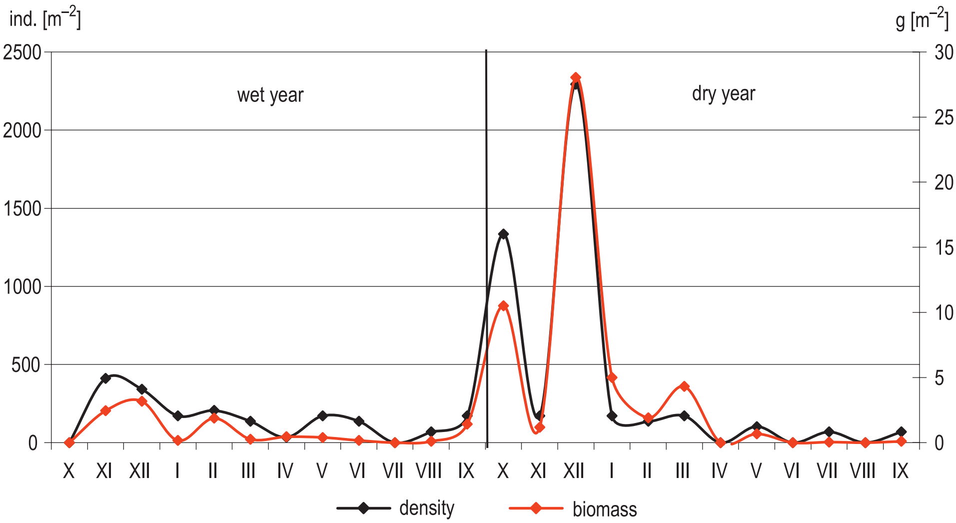

Fig. 2. Seasonal variation in the density (ind. m^{-2}) and biomass (g m^{-2}) of all aquatic beetle taxa (larvae and adults) at sampling sites

Based on the taxonomic structure of the individual assemblages, cluster analysis distinguished several groups of sites (Figure 3). The beetle assemblages at both sites in stream 1 and at site 3.2 were similar.

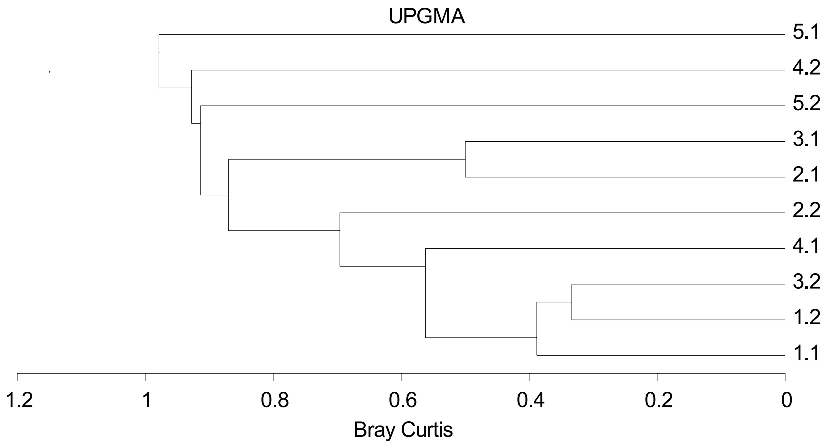

Fig. 3. Dendrogram of cluster analysis based on the aquatic beetles assemblages

The assemblages inhabiting the remaining sites did not exhibit much similarity, and the most differentiated assemblages occurred at both of the sites at the outflow and at site 4.2.

The nMDS plot using the Bray-Curtis index showed clear separation among sampling sites located in the inflowing streams and the outflow with 0.8 stress. The distribution of the sites by season was apparent at sites 2.1 and 3.1 (wet) and also at sites 1.1 and 3.2 (dry) – Figure 4. On the graph, the distribution scheme in stream 4 was in agreement with the sites independently of season.

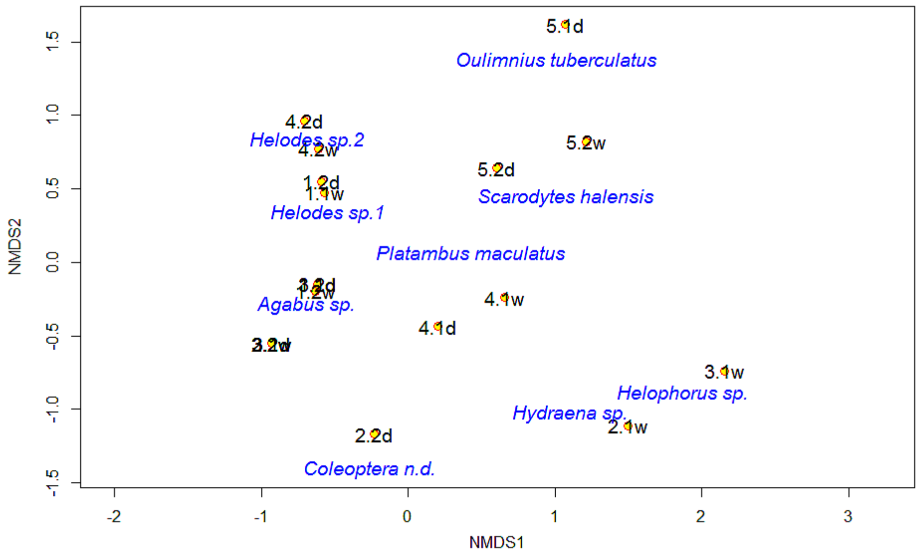

Fig. 4. Graphical representation of the non-metric dimensional scaling (NMDS) with Bray-Curtis similarity and ANOSIM. nMDS plots comparing beetle community structure between wet and dry year (site number.w and site number.d, respectively)

In the first year of the study, seven taxa were confirmed in the streams, which was exactly the same number as was confirmed in the following year. Among the Coleoptera collected, only larvae of the species *Platambus maculatus* occurred for the first time in the streams studied in the second season of the study. The occurrence of larvae of the genus *Helophorus* and *Scarodytes halensis* imagines was not noted in the second year of the study. Higher density values of Coleoptera were confirmed in the second, dry year of the study, and only at sites 1.1 and 2.1 was the opposite noted. At site 3.1 mean density values were the same in each of the two years compared. The comparison of the mean beetle biomass differed; at sites 1.1 and 2.1 higher values were noted in the first, wet study year, while at the other sites higher biomass was noted in the second year. Taxa richness was higher at sites 1.1 and 2.1 in the first year of the study, while at sites 3.1 and both of the sites in stream 4 it was the same. At the remaining sampling sites taxonomic differentiation varied, but it was higher in the second year of the study.

Significant differences were noted in beetle assemblages between wet and dry years (ANOSIM Global $R = 0.285$, $p = 0.022$). While, there was no significant difference in aquatic beetle density between the wet and dry years at the stations studied, there was significant variation in biomass between the wet and dry years at station 4.1 (The Wilcoxon rank-sum test, $p < 0.05$) – Table 2, but these differences were not statistically significant at the other stations.

Table 2

Density, biomass and taxa richness of the beetles collected at the sampling sites

Sites	Density				Biomass				Richness	
	wet	dry	z	*p* value	wet	dry	z	*p* value	wet	dry
1.1	25.7	8.6	1.527	0.127	0.298	0.159	0.676	0.499	3	2
1.2	5.7	22.8	1.930	0.054	0.098	0.289	1.521	0.128	2	3
2.1	5.7	0.0	1.414	0.157	0.003	0.000	1.342	0.180	2	0
2.2	2.9	5.7	0.577	0.564	0.035	0.194	1.069	0.285	1	2
3.1	2.9	2.9	0.000	1.000	0.002	0.051	0.447	0.655	1	1
3.2	5.7	8.6	0.577	0.564	0.013	0.084	0.730	0.465	1	2
4.1	22.8	45.6	1.156	0.248	0.144	0.881	2.366	0.018*	4	4
4.2	22.8	211.0	0.738	0.461	0.138	2.493	1.363	0.173	3	3
5.1	0.0	2.9	1.000	0.317	0.000	0.002	1.000	0.317	0	1
5.2	59.9	68.4	1.539	0.124	0.138	0.158	1.491	0.136	3	4

Comparison of density and biomass was carried out using the non-parametric Wilcoxon matched--pairs test (exact *p* values)

* Orders with significant differences ($p < 0.05$)

Discussion

Aquatic beetles quickly recolonized dried-up streams, and they were observed in all of them as soon as the first month of the study. The highest taxa richness was recorded at site 4.1, where six of the nine beetle taxa occurring in the streams studied were confirmed. This could have stemmed from the conditions in stream 4 that were the most stable in terms of water flow. This stream was also the least likely to dry up during dry periods (SMOLEŃSKI and SIEKLUCKI 1997), and when the surface flow stopped, the bottom sediments were kept moist by the water table that was at a depth of 20–50 cm beneath the stream bed (SOSZKA et al. 1992). The beetles inhabiting stream 4 had the most advantageous conditions for waiting out dry periods in the interstitial waters, wet sediments, and fallen leaves on the bottom and banks of the stream. This is how beetles of the genus *Elodes* were able to recolonize this stream from the hyporheic zone (Durkota et al. 2019). Representatives of this widely distributed genus (Klausnitzer 2009) had the greatest effect on the seasonal fluctuations observed in Coleoptera assemblage density. These beetles inhabit areas adjacent to typical water bodies such as rivers (Szawaryn et al. 2021), oxbows (Pakulnicka et al. 2016) and streams (Ruta et al. 2003) and also ones with more extreme hydrological conditions such as streams that dry up (Moth Iversen et al. 1978) and even tree holes (Baltzley et al. 1999), and they appear to be well adapted to life in perennial streams in which drought conditions occur sporadically. Their numerous density in fall was correlated with the availability of leaves that fall into the water from trees growing near the stream.

Beetles can also recolonize streams by aerial routes, which is limited, according to Williams and Hynes (1976), in the temperate climate from spring to fall. Adult Coleoptera either inhabit or lay eggs in steams. The occurrence of only *Scarodytes* imagines noted during the first year of the study in the runoff and at stream 4 sampling station at the outflow could suggest that they originated from the lake. This species is one of the first beetles to colonize newly-formed water bodies (Kehl and Dettner 2003, Pakulnicka 2008).

Although the streams studied were similar in type and physical, chemical, and geological conditions, the water beetle assemblages differed at the sampling sites. Only three of the sites exhibited any distinct taxonomic similarity, and these were characterized by the occurrence nearly exclusively and in very similar proportions of larvae of the genera *Agabus* and *Elodes*.

Studies conducted simultaneously on permanent and intermittent (the one that regularly dries up in the summer) streams showed that the former was inhabited by six taxa of aquatic beetle and the latter by just two (Řezníčková et al. 2013). In their studies of streams in southern England, both Casey and Ladle (1976) and Furse (1977) reported significant differences in invertebrate assemblages between periodically dry and permanent sites. The results of the current study were different in that there was a lack of differences in the density of taxa between the seasons with different hydrological conditions. This was consistent with Bottorff and Knight (1988), who investigated two first order streams in California, one of which was a periodic stream while the other had year-round flow, and they confirmed that the macrozoobenthos assemblages were similar with regard to the number of taxa in the main benthic taxonomic groups.

Changes in Coleoptera density and biomass in the streams studied can also be confirmed by WARD's (1992) hypothesis that nearly all species of aquatic beetle occurring in the temperate zone produce one generation annually. Seasonal changes in beetle density and biomass were similar in both seasons of the study. Maximum values were observed in fall followed by distinct, sharp declines in January. Despite the notable higher overall beetle density observed in the second, dry year of the study, differences between the seasons were statistically insignificant at each of the sites sampled.

Conclusions

Precipitation deficits led to abnormally low streamflow and drought. Such extreme conditions led the aquatic beetles to recolonize, and the number of taxa did not differ in the streams studied in the following season when water flowed continuously. Seasonal changes in beetle density and biomass were similar regardless of hydrological regime, except significant variation in biomass between the wet and dry years at station 4.1 ($p < 0.05$). The results of the study indicated that the taxa best adapted to variable conditions in the streams were the beetles of the genus *Elodes*.

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