ABSTRACT
STORM INDUCED CHANGES IN TURBIDITY, CHLOROPHYLL, AND BRACHIONUS POPULATION DYNAMICS IN ACTON LAKE

by Samanthia Jean Noble

This study analyzed effects of storm intensity on turbidity, chlorophyll, abundance and population parameters of three Brachionus in a reservoir. I predicted chlorophyll and Brachionus abundance, growth rate, and birth rate would be negatively correlated with storm intensity. I expected positive correlations between storm intensity and non-volatile suspended sediments (NVSS) as well as Brachionus death rates. I used linear regression to relate NVSS and chlorophyll concentrations and changes in each parameter during and after storms to storm intensity. A significant positive correlation between NVSS and storm intensity was observed. Influence of storm events on Brachionus parameters was variable and species specific. During storms, significant positive correlations were observed between changes in B.calyciflorus abundance as well as in B.angularis growth rate with storm intensity. Significant negative correlations were observed between changes in B.angularis growth rate as well as in B.caudatus resting egg production with storm intensity during the post-storm period.
STORM INDUCED CHANGES IN TURBIDITY, CHLOROPHYLL, AND BRACHIONUS POPULATION DYNAMICS IN ACTON LAKE

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Dedication

This thesis is dedicated to my wonderful mother, Jeanne Douglas, who has always given me support, strength, and love and to my son, Isaiah Briones, who continually inspires me.
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INTRODUCTION

Disturbances traditionally have been viewed as uncommon, irregular events that cause abrupt structural changes in natural communities, thus moving them away from static, near-equilibrium conditions (Sousa, 1984). Alternatively, disturbance can be defined as any relatively discrete event that disrupts ecosystem, community, or population structure, and that changes resources, availability of substratum, or the physical environment (Pickett and White, 1985). Disturbances may be anthropogenic changes in pollution (Solomon et al., 1996; Thruman et al., 1991) or land use (McEachern et al., 2002), or they may be natural disturbances such as fires (McEachern et al., 2002) and floods (Dirnberger and Threlkeld, 1986; Godlewska et al., 2003).

Storms are natural disturbances that can alter several processes in lakes by increasing turbidity (Ludlam, 1967; Boström et al., 1982), changing the water temperature (Carmack et al., 1979), increasing nutrient fluxes (Vanni et al., 2001), and introducing toxins (Isensee et al., 1990; Thruman et al., 1991). However, the magnitude of the disturbance caused by storms in reservoirs may be unnaturally large due to the impact of the land use within the watershed. In lakes, storm events can cause decreases of chlorophyll $a$ concentrations (Godlewska et al., 2003) and phytoplankton biomass (Jacobsen and Simonsen, 1993). Complex interactions of parameters influenced by storms may cause both positive and negative changes to rotifers communities (Fig. 1). Reduction in zooplankton biomass and changes in zooplankton community composition have been associated with flood events in reservoirs (Godlewska et al., 2003; Dirnberger and Threlkeld 1986). However, the overall effect of storm events on reservoirs may depend on the frequency and intensity of the storm events. The main objective of this study is to analyze the effect of storm intensity on the turbidity and phytoplankton (as chlorophyll) of the lake and abundance patterns and population parameters of three rotifer species in a reservoir.

Storm events may be of particular importance in reservoirs compared to natural lakes. In general, inflow of natural lakes is usually restricted to overland flow and small streams and the impact of inflows is usually confined to the littoral zone and surface waters (Ford, 1990). In contrast, major river or stream inflows enter the upper end of reservoirs. In some reservoirs, runoff from individual storm events dominates the water budget and during elevated flow events, water may pass through a reservoir in a few days, even though the theoretical hydraulic residence time is much longer (Ford, 1990).
Reservoirs have drainage basins that are relatively larger than those of natural lakes (Ryder, 1978). Since there is a relation between size of drainage area and flow, larger drainage basins associated with reservoirs may result in greater annual flows than in natural lakes (Thornton, 1990). In turn, the absolute quantity of sediment and its adsorbed constituents delivered to a body of water increase with increased drainage area (Thornton, 1990). Therefore, storm events may impact reservoirs more heavily by delivering more sediment and associated organic matter, nutrients, and toxicants to reservoirs than natural lakes. Furthermore, in reservoirs with a high percentage of the drainage area devoted to agricultural activities, there may be considerable sediment loading due to pulses associated with storm runoff. Suspended sediment load concentrations greater than 1.0 g/L\(^{-1}\) are not uncommon (Marzolf, 1990).

Storm events can cause increases in reservoir turbidity due to increased watershed inputs (Ludlam, 1967; Thornton, 1990) or due to hypolimnetic inputs caused by vertical mixing during the storm (Boström et al., 1982). In either case, the turbidity can be caused by inorganic sediments and by organic materials including detritus and algae. Increased turbidity can cause decreased light penetration (Chandler, 1942; Lammens, 1997), which can in turn reduce phytoplankton growth (Krause-Jensen and Sand-Jensen, 1998). The turbidity in agricultural reservoirs is often sufficient to limit the photosynthetic activity of planktonic algae (Marzolf and Osborne, 1971). Decreases in phytoplankton abundances due to increased inorganic turbidity may then affect zooplankton growth (Dumont, 1977). However, this effect may vary among different taxonomic groups. It has been suggested that turbid conditions favor dominance of small zooplankton such as rotifers (Kirk and Gilbert, 1990; Koenings et al., 1990; Kirk, 1991). McCabe and O’Brien (1983) found that both filtering and assimilation rates of *Daphnia pulex* were severely depressed even at low concentrations of suspended silt and clay and population growth was also significantly reduced. Kirk (1991) suggested that this shift may be due to the selective nature of rotifer feeding, whereas cladocerans are less selective filter feeders. Rotifers are highly selective in favor of phytoplankton when grown in cultures containing both radioactively labeled phytoplankton and clay particles (Kirk, 1991). Therefore, the presence of sediment may not directly affect feeding rates and therefore the population growth rates of rotifers. Furthermore, in lab experiments, increased levels of both course and fine clay did not affect the population growth rate of four different rotifer species including *Brachionus calyciflorus* (Kirk and Gilbert, 1990). Therefore, one might expect that since storms increase
turbidity, they would shift the balance of competition toward rotifers and copepods which are selective feeders.

During intense storms, the entire epilimnion of a reservoir can be replaced and a high percentage of the phytoplankton biomass can be removed (Barbiero et al., 1999). High flushing rates can also cause downstream “washout” or removal of zooplankton from the lake or reservoir (Armitage and Capper, 1976; Campbell, 2002).

Storm events can also have positive effects on planktonic communities. Nutrient pulses to lakes occur during storm events by either watershed inputs (Vanni et al., 2001) or by hypolimnetic inputs caused by vertical mixing (Boström et al., 1982). Phytoplankton can become limited by the availability of nutrients even when light and temperature are adequate (Hecky and Kilham, 1988). Therefore, this nutrient flux can lead to an increase in phytoplankton. Webber et al. (1992) found that after flooding of the Hellshire Coast in Jamaica, phytoplankton abundances increased, followed by a subsequent increase in zooplankton.

Sources of organic turbidity such as algae and detritus resuspended in the water column during a storm can also serve as a food source for the zooplankton (Pennak, 1946; Lammens et al., 1997). Therefore, storm events, which cause increased organic turbidity or nutrients, might benefit zooplankton.

High concentrations of suspended sediments provide refuge from visual predators (Miner and Stein, 1993) such as fish, and therefore may reduce predation pressure. Gizzard shad can reach very high abundance in midwestern reservoirs (Stein et al., 1995). Previous studies have shown that larval gizzard shad can be an important visual predator of crustaceans and rotifers (De Vries and Stein, 1992). However, rotifers can also be regulated by invertebrate predators, such as the predatory rotifer Asplanchna and copepods (Starkweather, 1987, Williamson, 1991). Since these invertebrate predators are not visual predators, storms would not provide a visual refuge from these predators. In addition, the increased turbidity may provide a refuge for larval gizzard shad from piscivorous fish and therefore could lead to increased predator levels.

Storm events may trigger changes in the reproductive pattern of rotifers that may have consequences for their population dynamics. Rotifers have a cyclic reproductive pattern in which parthenogenesis (amictic phase) takes place in the absence of males. Rotifer abundance increases very rapidly during asexual reproduction. Periodically rotifers may be induced to produce males and reproduce sexually, by changing environmental conditions such as decreases
in food availability due to crowding (Gilbert, 1974). Sexual reproduction results in resting eggs, and therefore is associated with less rapid increases in rotifer abundance. Therefore, a shift from asexual to sexual reproduction can cause decreases in population growth. The timing of a shift in reproduction patterns may be affected by storms events. If storm events decrease phytoplankton abundance, then food limitation could cause resting egg production. If, however, nutrients increase due to agricultural runoff, then phytoplankton abundance may increase and subsequently the rotifer abundance could increase to crowding levels which could also induce resting egg production.

Immigration from resting eggs is a potential source of individuals in the lake. Nipkow (1952) stated that resting egg emergence was dependent upon the removal of the resting eggs from the sediments into an environment with warmer temperatures, higher oxygen, and lower concentrations of carbon dioxide. If removal of resting eggs from the sediments by water currents does in fact cause hatching, then storms may induce resting egg emergence if the turbulence is strong enough to disturb the sediments of the reservoir. Therefore, sudden increases in abundance that are not associated with birthrates may be related to resting egg emergence.

This study characterizes the changes in the inorganic turbidity, as measured by non volatile suspended solids (NVSS), phytoplankton biomass (chlorophyll), as well as in the abundance and population parameters of three *Brachionus* species (*Brachionus calyciflorus*, *Brachionus angularis*, and *Brachionus caudatus*) caused by storms of varying intensity in Acton Lake, a reservoir located in southwestern Ohio. These species were chosen because in general they are very abundant in reservoirs (Betsill and van den Avyle, 1994 and Pollard, 1998). A positive relationship between NVSS level and storm intensity was expected. A negative correlation between chlorophyll and storm intensity was also expected. I predicted that the duration of changes in NVSS and chlorophyll would be positively correlated with storm intensity, with the largest storms causing changes that would be observed even after discharge had returned to pre-storm levels.

Changes in rotifer abundance, growth rates and birth rates were expected to be negatively correlated with storm intensity, while death rates would be positively correlated with storm intensity. I predicted that these changes would persist for a longer post-storm periods as storm
intensity increases. I also expected a positive correlation between the proportion of resting eggs produced and storm intensity both during and after storm events.

**STUDY SITE**

Acton Lake is a 253 ha eutrophic reservoir located in Hueston Woods State Park in Southwestern Ohio. Agricultural land (primarily corn and soybeans) comprises more than 90% of Acton Lake’s watershed, with conventional and conservation tillage as common practices (Vanni et al., 2001). It has typical reservoir characteristics, including pronounced physical and chemical gradients from the riverine to the lacustrine end (Kimmel, 1990; Knoll et al., 2003). During periods of high stream flow, such as those experienced after storm events, nutrients and suspended solids from agricultural sources increase dramatically (Vanni et al., 2001).

**METHODS:**

Sampling was carried out in spring and summer during 2001-2003 (late April to mid-July). Discharge was measured using three permanent gauging stations located near the confluence of the three streams that supply the majority of the water to the lake (Vanni et al., 2001). Storm periods were defined as the period from the date of initial increase in discharge until the discharge returned to base flow. Storm intensity was determined by the total discharge to the reservoir during the elevated flow (m³ / storm). The period before the storm was considered to be three days before the increase in discharge and the period after the storm was considered to be the three days after discharge returned to base flow whenever possible. Due to storms occurring unexpectedly sometimes it was not possible to have a complete set of days before the storm period. It was not always possible to have a complete set of days during and after the storm period due to flooding and wind conditions. Six storms were chosen based on the completeness of the data before, during, and after the storm periods. Although these storms were the most complete, the storms observed in May 2002 and May 2003 are missing data on reservoir parameters from the day of peak discharge due to unsafe flooding and wind conditions. Therefore, average abundances for these two storms may be either over or underestimated. An additional storm, in July 2003, was used in estimates of the NVSS and chlorophyll levels during storm events; however, this storm was not used in the percent change calculations due to incomplete data of reservoir parameters during the pre-storm and post-storm periods.

Temperature readings and samples of NVSS, chlorophyll, and zooplankton were taken at least three times per week at a permanent location near the inflow of the lake, as the impact of
storms is most likely most pronounced at the inflow. Two replicates of water were taken for NVSS and chlorophyll samples. Non-volatile suspended solids (NVSS) are a representation of the inorganic turbidity of the lake. Chlorophyll samples are representative of the amount of algae in the lake, and therefore, the food supply available to the zooplankton. Daily samples were taken at least one day before and several days after storm events whenever possible.

NVSS samples were processed by filtering a known volume of water through a pre-weighed, pre-ashed 47mm glass fiber filter. The samples were dried at 60°C for at least 24 hours and then weighed again using a microbalance. They were then transferred to a 475°C muffle furnace and ashed for four hours. The samples were then weighed a final time using a microbalance. The NVSS in mg/L was obtained using the following formula:

(1) NVSS = (weightsample*(weightfilter-0.437))/(volumesample)

where

weightsample = the weight of the muffled sample (mg)
weightfilter = initial weight of filter (mg)
volumesample = volume filtered (L)

Chlorophyll concentrations were determined using a method adapted from EPA method 445.0. A known volume of water was filtered through a 47-mm glass fiber filter. The samples were then frozen until further processed. Twenty-five milliliters of 90% acetone was then added to each sample. The samples were refrigerated at 5°C for at least two hours, but no more than 24 hours to allow the chlorophyll extraction. Samples were allowed to reach room temperature. A fluorometer was used to determine chlorophyll concentrations. Six milliliters of the well mixed extracted sample was transferred to a clean cuvette and the concentration of chlorophyll in the cuvette before acidification (Fb) was determined. An 180µl aliquot of 0.1-N HCL was added to the sample and another fluorometer reading was taken to determine the concentration of chlorophyll after acidification (Fa). The concentration of chlorophyll within the lake was determined using the following equation:

(2) µg chl/L in cuvette = (r/r-1)(Fb-Fa)

where,

r = (Fb/Fa) of a pure chlorophyll sample

(3) µg chl/L in lake = (µg chl/L in cuvette* volumeextraction)/filtered volumesample
Zooplankton was sampled using plankton net with 63 µm mesh. One tow was taken each day during the 2001 and 2002 sampling seasons and two tows were taken and averaged during the 2003 season. The zooplankton were immediately transferred to collection cups, anesthetized using Alka-Seltzer (CO₂), and preserved with a 10% buffered sucrose formalin solution before being brought back to the lab for analysis. Two sub-samples from each sample were taken using a 1ml Hensen-Stempel pipette. Individuals of each Brachionus species were enumerated using a Sedgwick-Rafter counting cell and a compound microscope. Amictic and mictic (resting) eggs were enumerated for each species.

Species abundance was expressed as the number of individuals of each species per liter of lake water. The population parameters, birth rate, growth rate, and death rate, of each Brachionus species were calculated using the equations described by Edmundson (1977). The equation for growth rates were modified by adding a one to all abundances since zero values were detected.

\[
(4) \quad r = \frac{\ln(N_t+1) - \ln(N_0+1)}{T}
\]

where:
- \( r \) = growth rate
- \( N_0 \) = abundance at time zero
- \( N_t \) = abundance at time \( t \)
- \( T \) = time (days)

\[
(5) \quad b = \frac{\ln(E+1)}{D}
\]

where:
- \( b \) = birth rate
- \( E \) = egg ratio (number of amictic eggs per individual)
- \( D \) = time required for eggs to develop (from the time an egg is laid to the time it is released as a free swimming individual)

Birth rates were calculated without the inclusion of resting eggs, since resting eggs most likely do not contribute to the current population.

Development times for rotifers were calculated as described in Hergiz (1983):

\[
(6) \quad D = a (t-b)^c
\]

Where \( t \) = temperature in °C and \( a, b, \) and \( c \) are constants found by fitting a regression line through the development time in days versus the temperature.
B. calyciflorus: a=4, b=9.44, c=0.86
B. angularis: a=11, 8.8, c=1.001
B. caudatus: a=11, 8.8, c=1.001

(7) proportion resting eggs= \( \frac{r_e}{t_e} \).

where:
\( r_e \) =the number of resting eggs per liter of lake water
\( t_e \) =the total number of eggs per liter of lake water

(8) \( d = b-r \)

where
\( d \) =death rate

It is important to note that calculating death rates in this way assumes immigration and emigration rates of zero. Physical removal of individuals from the reservoir is likely a factor when dealing with storms events and therefore, death rates may be overestimated when emigration is high and underestimated when immigration is high, since these parameters are factored in with death.

Percent changes in NVSS and chlorophyll as well as the abundance of the three rotifers species from before to during the storm (during-before) and from before to after the storm (after-before) were calculated as follows:

(9) percent change\(_{(during\text{-}before)}\) = \( \frac{(y-x)}{x} \times 100 \)

(10) percent change\(_{(after\text{-}before)}\) = \( \frac{(z-x)}{x} \times 100 \)

where  
\( y \) =Parameter value during storm period
\( x \) = Parameter value during period before storm
\( z \) = Parameter value during period after storm

When calculating the percent change of abundance zero values were replaced with 0.1 individual per liter, which was lower than the lowest observed density. These changes may have caused the percent change to be underestimated resulting in a conservative estimate.

Actual changes in the birth rates, growth rates, death rates, and proportion of resting eggs produced from before to during the storm (during-before) and from before to after the storm (after-before) were calculated as follows:

(11) change\(_{(during\text{-}before)}\) = \( y-x \)

(12) change\(_{(after\text{-}before)}\) = \( z-x \)
where \( y \) = Parameter value during storm period
\( x \) = Parameter value during period before storm
\( z \) = Parameter value during period after storm

Linear regression was used to relate the percent change of the NVSS, chlorophyll and abundance and the actual change of the birth rates, growth rates, death rates, and proportion of resting eggs with storm intensity as well as the relationship between NVSS and chlorophyll values (SAS – Institute, 2000). Storm intensity values were log transformed for regression analysis. Since only five to seven storms were analyzed, the alpha value was set at 0.1.

There are several possible relationships between changes in the parameters examined in this study and storm intensity (Fig. 3a-f). In the first case scenario, the given parameter decreases during all storm intensities and there is a negative correlation between the parameter and storm intensity (Fig 1a). This would indicate that storms have a negative impact on that parameter and that the degree to which the parameter is affected is related to storm intensity (larger storms cause larger decreases). In the second scenario, storms of all intensities cause increases in the parameter and there is a positive correlation between the parameter and storm intensity (Fig 1b). This would indicate that storms of all intensities have a positive effect on the parameter and that the degree to which the parameter is affected is related to storm intensity (larger storms cause larger increases). The next two scenarios are reversals of the first two. In scenario three, as in the first, storms of all intensities cause decreases in the parameter, however a positive correlation between changes in the parameter and storm intensity is observed (Fig 1c). This would suggest that although all storm intensities cause decreases in the parameter, storms of the lowest intensity cause the greatest changes. In the fourth scenario, all storm intensities cause increases in the parameter, however a negative correlation is observed, suggesting that although the parameter is increased during all storm intensities, that the lowest intensity storms would have the largest changes (Fig 1d). The final two scenarios are combinations of the first four (Figs 1e-f). For both scenarios, storms cause both increases and decreases in the parameter. However, there is a negative correlation between changes in the parameter and storm intensity in the fifth and a positive correlation in the sixth. In both scenarios, the magnitude of the changes could be equal for the highest and lowest intensity storms; however, the direction of the change is different. In the fifth scenario, the lowest intensity storm caused the largest increases and the highest intensity storm caused the largest decreases. In the sixth the opposite is true.
When analyzing the effect of storm intensity on the post-storm period it is important to note the direction of the changes as well as the magnitude of the changes as in the previous figures. It was predicted that the largest intensity storms would have the longest lasting effect on the changes, therefore if an increase was observed, then an increase in the parameter for the highest intensity storms during the post-storm period would be expected; however the lower intensity storms should have a change closer to zero when compared to the change observed during the storm period.

RESULTS

Discharge, turbidity and chlorophyll

Seasonal patterns

Intensity of storms varied from 494,420 m$^3$/storm to 23,015,086 m$^3$/storm (Fig. 3a-c). Temporal differences in the timing, frequency and intensity of storms was observed. In 2001, peak discharge was always less than 50 m$^3$/sec and storms occurred from mid May to mid July (Fig. 3a). In 2002, discharge peaked to 75 m$^3$/sec only in one storm in mid May. Storm frequency was greater early in the year (mid April to mid May) in 2002 compared to 2001 and 2003. However, no storms occurred after early June (Fig. 3b). In 2003, peak discharge was higher than 50 m$^3$/sec in two storms. Similar to 2001, storms occurred from mid May to mid July (Fig. 3c).

Overall, NVSS concentrations were lower in 2001 than in 2002 and 2003. Increases in turbidity (NVSS) typically occurred during or soon after elevated discharge (Fig. 3d-f). During May 2002, the NVSS reached its highest peak before the peak discharge of the largest storm, perhaps corresponding to the storm peaking May 7$^{th}$. The highest level of NVSS recorded for this study was observed during the June 2003 storm (Fig. 3f).

Chlorophyll concentrations tended to be higher in 2002 than in 2001 and 2003 with the largest peaks in chlorophyll observed during 2002 (Fig. 3g-i). A general trend of higher chlorophyll concentrations in June than earlier in the season was observed. In 2003, the highest chlorophyll concentrations were observed earlier, from mid May to mid June. Higher overall chlorophyll levels tended to correspond to relatively low NVSS (early June - early July 2001, late May - late June 2002 and mid May - early June 2003).
Storm intensity patterns

Turbidity

As predicted, there was a positive correlation between the average NVSS and storm intensity during the storm period (p=0.005; Fig. 4). No correlation between NVSS percent change (during-before) and storm intensity was detected; however, a positive trend was observed (Fig. 5a). The NVSS levels increased during the storm period in three of the six storms and decreased in three of the six storms (Fig. 5a). There was no correlation between percent change (after-before) and storm intensity (p=0.97). However, the post-storm NVSS levels were higher than pre-storm levels in four of the six storms indicating that the NVSS level remain elevated after the storms (Fig. 5b).

Chlorophyll

Contrary to the prediction, no significant linear correlation between average chlorophyll during the storm period and storm intensity was detected (p=0.53; Fig. 6a). This trend was caused by high average chlorophyll concentrations during the two highest intensity storms. When examined using a polynomial trend line, a relationship can be seen, however, it is not a strong correlation. Looking at the first five storms a negative relationship can be seen between storm intensity and the level of chlorophyll in the lake during the storm period. On the other hand, during the two highest intensity storms, the chlorophyll levels were similar to the lower two lowest intensity storms. There was also no significant correlation between average chlorophyll and NVSS during the storm period (p=0.91; Fig. 7a). However, a polynomial trend line offers a stronger correlation (Fig 7b). Once again, the two highest intensity storms, which exhibited the highest levels of NVSS, had chlorophyll levels that were higher than observed during storms with intermediate levels of NVSS. This difference in the degree of correlation, using a curved as opposed to a linear trend line, may be due to the seasonality of the storms. The highest intensity storms occur late in the season (June and July) (Fig.3i).

The chlorophyll percent change (during-before) was not correlated with either storm intensity (p=0.34; Fig. 8a) or the percent change in NVSS (p=0.87; Fig. 9a). Similarly, the percent change (after-before) in chlorophyll was not correlated with storm intensity (p=0.67; Fig. 8b) or percent change in NVSS (p=0.22; Fig. 9b).
Rotifer abundance

Seasonal patterns

All species achieved their highest peak abundances during 2001 and experienced their lowest peak abundances during 2003 (Fig. 10a-i). A drastic increase in *B. calyciflorus* abundance during the storm in May 2001 (325 ind/L) followed by a sharp decline to pre-storm levels (Fig 10a) was observed. *B. calyciflorus* abundance increased on June 6, 2001 and June 9, 2001, however these abundance changes do not seem to be related to storm activity. Abundance of this rotifer was lower than 5 ind/L during the remaining of the sampling season. During 2002, *B. calyciflorus* abundance remained low during the period of intense storm activity (April 14-May 15). However, *B. calyciflorus* abundance peaked before the early June storm reaching 250 ind/L before quickly declining (Fig. 10b). A second peak was observed a few days later, reaching its highest peak of approximately 300 ind/L, returning to an abundance of less than 50 ind/L by mid-June. Abundances remained lower than 50 ind/L until early July when abundance increase again to 250 ind/L, with no detectable changes in discharge. During 2003 *B. calyciflorus* abundance remained lower than 60 ind/L during the sampling period (Fig. 10c).

*Brachionus angularis* abundance reached the highest abundance of the three species in 2001 (Fig 10d). In contrast, *B. angularis* showed the lowest abundance of the three species in 2002 and 2003 (Figs. 10e-f). Similar to *B. calyciflorus*, *B. angularis* abundance drastically increased during the storm in late May (1616 ind/L). A second peak in *B. angularis* abundance in early July (657 ind/L), which was not related to storm activity was observed. *B. angularis* abundance remained lower than 50 ind/L throughout most of the sampling period of in 2002 and 2003, reaching abundances near 100 ind/L in early and late July in 2002 and in late July in 2003 (Figs. 10e-f).

*B. caudatus* abundance also showed its highest abundance in 2001 compared with 2002 and 2003 (Fig. 10g-i). In 2001, similar to the other *Brachionus* species, I observed a rapid abundance increase during the storm in late May, followed by a drastic decline. *Brachionus caudatus* abundance remained lower than 100 ind/L, until early July when it reached its peak abundance during a period of low discharge. After a few days, *B. caudatus* abundance declined but remained higher than 100 ind/L until late July. In 2002, an initial increase in *B. caudatus* abundance in early June associated with a low intensity storm, followed by a decline to very low abundance in late June was observed. A second peak abundance occurred later in early July
similar to 2001. In 2003, *B. caudatus* abundance was lower than in previous years, and this species showed its highest abundance later in the year (late July).

**Storm intensity patterns**

In the analysis of the *Brachionus* spp. population parameters, the highest intensity storm (July 2003) was not considered due to incomplete rotifer data. Furthermore, the storm occurring in late-May 2001 was excluded because the large increase exhibited by all species may be a response to low predation pressure. Larval gizzard shad are present in Acton Lake from early May to mid-July. In 2001 the lowest larval gizzard shad abundance (2.58 ind/m\(^3\)) recorded since 1997 (4.21 - 6.96 ind/L) was observed.

**Abundance**

All three species exhibit a positive trend between percent change (during-before) in abundance and storm intensity. However, this trend is significant only for *B. calyciflorus* (p=0.009; Fig. 11a). *B. calyciflorus* abundance increased during all except the two lowest intensity storms. It is important to note that although the percent change for the three highest intensity storms was high, the actual population densities were low, with fewer than 50 individuals per liter. *B. angularis* increased in the storms with the lowest and highest discharge and decreased during the three intermediate storms (Fig 11b). *B. caudatus* abundance increased during three of the five storms (Fig. 11c). There was no correlation between percent change (after-before) and storm intensity for any of the three species (p ≥ 0.46; Figs. 11d-f).

**Growth Rate**

There was not a significant correlation between change (during-before) in growth rate of *B. calyciflorus* and storm intensity (p=0.41; Fig. 12a), however, I observed an increase in growth during the highest intensity storm and decreases in all other storms (Fig. 12a). No significant correlation between the change (after-before) in growth rate (p=0.53) and storm intensity was observed (Fig. 12d). There was however, a positive trend with similar changes observed during the post-storm period as in the period during the storm.

For *B. angularis*, a significant positive correlation between the change (during-before) in growth rate and storm intensity was observed (p=0.01; Fig. 12b). Furthermore, changes in growth rates for all storm intensities were negative suggesting that the average growth rate before the storm was higher than the average growth rate during the storm period. A marginally significant negative correlation with the change (after-before) (p=0.11) and storm intensity was
observed (Fig. 12e). The negative values of the change_{after-before} suggest declines in growth rate values during the post-storm period. The changes_{after-before} were smaller for the lowest intensity storms than the change_{during-before} (Figs. 12b, e) suggesting that growth rates may increase during the post-storm period however they never reached the pre-storm values.

Similar to *B. calyciflorus*, there was no correlation between the change_{during-before} in growth rate of *B. caudatus* (p=0.20) and the change_{after-before} (p=0.24) with storm intensity (Figs. 12c, 12f). In addition, growth rate decreased during three of the five storms (negative values of the percent change_{during-before}; Fig. 12c), and in three of the five storms during the post-storm period (Fig. 12f).

**Birth Rate**

No significant correlation between the change_{during-before} in birth rate was observed for any of the *Brachionus* species with storm intensity (p ≥ 0.30; Fig. 13a-c). Declines in birth rate were observed in two of five storms for and *B. calyciflorus*, four of the five storms for *B. angularis* and three of the five storms for *B. caudatus*. A negative trend was observed between change_{during-before} in birth rate and storm intensity for *B. angularis*, which was driven primarily by a large decrease in birth following the highest intensity storm.

For all three rotifer species, no correlation between the percent change_{after-before} in birth rate and storm intensity was detected (p ≥ 0.30; Fig. 13d-f). There was no change in birth rate from before to the post-storm period in three of the five storm for *B. calyciflorus* and two decreases. All storms, except one, produced lower birth rates in the post-storm period than before in *B. angularis*. For *B. caudatus* three storms exhibited no change in birth rate from before the storm to the post-storm period and two exhibited decreases.

**Resting Egg Production**

The change_{during-before} in the proportion of resting eggs produced by *B. calyciflorus* was not significantly correlated to storm intensity (p=0.37 Figs. 14a). However, a stronger trend between change_{after-before} and storm intensity was observed (p=0.17; Fig. 14d).

For *B. angularis*, a positive correlation between the change_{during-before} in the proportion of resting eggs and storm intensity was observed, however, it was not significant (p=0.24; Fig. 14b) However, there was no trend observed between the change_{after-before} in the proportion of resting eggs and storm intensity was observed (p=0.54; Fig. 14e).
For *B. caudatus*, no correlation between the change during-storm (during-before) in the proportion of resting eggs and storm intensity was detected (p=0.55; Fig. 14c). However, for this rotifer species a significant negative correlation between the change after-storm (after-before) in the production of resting and storm intensity was observed (p=0.05; Fig. 14f).

**Death Rate**

No correlation between *B. calyciflorus* change during-storm (p=0.41) or change after-storm (p=0.50) in death rate and storm intensity was detected; however, negative trends were observed (Figs. 15a, d).

In *B. angularis*, a negative trend between the change during-storm in the death rate and storm intensity was observed; however, it was not significant (p=0.16; Fig. 15b). No correlation was observed between the change after-storm in death rate for *B. angularis* with storm intensity (p=0.54; Fig. 15e).

For *B. caudatus*, a negative trend between change during-storm (p=0.15), as well as between the change after-storm in death rate (p=0.17) and storm intensity was detected (Figs. 15c, f); however, these trends were not significant.

**DISCUSSION**

**Turbidity and Chlorophyll**

As predicted, actual NVSS levels within the lake during the storms were positively correlated with storm intensity (Table 1). There was also a positive trend observed between change during-storm in NVSS and storm intensity, although it was not significant. Barbiero et al. (1999) found decreased water transparency in Eau Galle Reservoir during storm events, which they attributed to sediment loads. However in this study, three of the six storms (May 2003, June 2002, and July 2001) yielded NVSS concentrations that were lower during the storm than during the pre-storm period. This could be due to low sediment loads reaching the lake during the storm. Two of the negative changes were observed during the two lowest intensity storms, which occurred later in the season (June 2002 and July 2001) when sediment loading may be reduced due to crop cover and leafing out of trees.

After four of the storms, NVSS levels were elevated during the post-storm period compared to pre-storm levels (Table 1). However, the lack of correlation between percentage changes during the post-storm period in NVSS with storm intensity may suggest that other factors in addition to intensity of the storm are important during the recovery period. Except for
the lowest intensity storm, a positive trend was observed between changes in all of the storms and storm intensity suggesting that NVSS levels remain elevated for longer periods of time following storms of higher intensity. The lowest intensity storm occurred in July after a prolonged period of low discharge. This may have caused lake levels to be low during the time of the storm. If wind remained strong following the storm, it may have induced turbulence in the lake causing sediments to be suspended in the water column.

Chlorophyll levels were similar in 2001 and 2003, with the largest peaks in chlorophyll observed during 2002. Although, chlorophyll concentrations were not as closely related to individual storm events as NVSS, overall, chlorophyll concentrations appeared to be highest during periods of lower NVSS. During 2002, the last storm observed during the sampling period occurred on June 6th, therefore, the large peak in chlorophyll, observed June 21st, 2002, may be explained by decreased levels of discharge and associated NVSS.

These results suggest that the relationship between chlorophyll and storm intensity is not linear (Table 1). Chlorophyll concentrations were higher in the low and two high intensity storms than during the other storms. This pattern may be related to seasonal variation. Two of the highest intensity storms were observed in mid-June 2003 (18,540,845 m³/storm) and mid-July 2003 (23,015,086 m³/storm), while a third high intensity storm occurred in May 2002 (12,982,710 m³/storm). Phytoplankton growth can be negatively affected by high sediment loading during storms (Cuker, 1987). However, high nutrient inputs during storms may positively affect phytoplankton growth (Cuker, 1987; Hecky and Kilham, 1988). Therefore, these results suggest that during low intensity storms, high chlorophyll concentrations may be related to low sediments loads, while during the high intensity storms high chlorophyll concentrations may be related to high nutrient inputs. Therefore, nutrient inputs might mitigate the effect of high sediments loads during storms. Vanni et al. (2001) found that nutrient levels in the streams flowing into Acton Lake increase during storm events. Also, during this study, the average total phosphorus concentrations in the lake during the storm period for the two highest intensity storms were higher than the other storms. During the June 2003 storm, the average total phosphorus concentration was over 400 µg/L whereas all other storms had total phosphorus concentrations of less than 300 µg/L. Although not correlated with storm intensity, there was an observed decrease in chlorophyll concentrations in four of the six storms during the storm event and in three of the six post-storm periods. A decrease in chlorophyll concentrations is consistent
with other studies, which have found that phytoplankton biomass (Jacobsen and Simonsen, 1993) and chlorophyll $a$ concentrations (Godlewksa et al., 2003) are negatively impacted by storm events. However, the relationship between chlorophyll concentration and storms may be more complex than a mere function of storm intensity. Furthermore, Hambright and Zohary (2000) found that the resilience of phytoplankton communities was negatively correlated with disturbance intensity. Although the highest intensity storm did not result in a decrease in chlorophyll concentrations during the storm period, in the period following the storm the chlorophyll levels declined, yielding the largest decrease in chlorophyll observed during the post-storm period.

**Rotifer Abundance and Population Parameters**

The prediction that changes in species abundance during the storm period would be negatively correlated with storm intensity was not supported. In *B. calyciflorus* and *B. caudatus*, a positive trend was observed, suggesting that storms of larger intensity may positively affect these species during storm events (Table 1). Only in the case of *B. calyciflorus*, however, was this correlation significant. No trend was observed for *B. angularis*; however, this increase in abundance observed during the largest intensity storm refutes the prediction. Kizito and Nauwerck (1995) found that rotifer peaks were correlated with rainy periods. However, these periods also corresponded to increased water clarity, whereas turbidity increased during several of the storms in this study.

Changes in growth rates were not negatively correlated with storm intensity as hypothesized (Table 1). In fact, the correlation between changes in the growth rates of all three species during the storm period exhibited a positive trend, with a significant correlation detected for *B. angularis*. Some studies suggest that rainfall events may be beneficial to rotifers. Webber et al. (1992) found that after flooding of the Hellshire Coast in Jamaica, phytoplankton abundances increased, followed by a subsequent increase in zooplankton. However, the increases observed in this study were immediate, not following an increase in food resources. Nevertheless, during some storms, food resources were high as in the highest intensity storm which may have enhanced the positive affects of the storms. It is also possible that the rotifers were not relying on algae alone as a food source. *B. calyciflorus* growth rates have been shown to increase when their diet of algal prey was supplemented with ciliates and flagellates (Mohr and Adrian, 2002). Therefore, it is possible that even when chlorophyll levels decrease due to
storms, that B. calyciflorus can utilize other food sources. Also, B. calyciflorus growth rates have been shown to be unaffected by increased turbidity even at very low food concentrations (Kirk and Gilbert, 1990), so perhaps the increases in turbidity were not harmful to this species.

A significant positive correlation between the change in growth rate of B. angularis and storm intensity was detected. However, all changes were negative, suggesting that although higher intensity storms negatively impacted the growth of B. angularis, lower intensity storms had a larger negative impact on growth.

There was no correlation observed between changes in B. caudatus growth during the storm period and storm intensity; however, a positive trend was detected. The lowest intensity storms caused decreases in growth rates, while the intermediate storms caused increases.

It was predicted that birth rate would be negatively correlated with storm intensity; however, no correlation between changes in birth rate from before to during the storm period and storm intensity for any of the three species examined was detected (Table 1). Interestingly, the largest increase in birth rate for both B. calyciflorus and B. caudatus, occurred during the storm (May 2002) with the lowest chlorophyll level observed during a storm period. Once again, this increase in birth rate may be caused by the availability of an alternative food source not quantified in this study such as ciliates.

There was no correlation between changes in B. calyciflorus birth rate storm intensity during the storm period. In most cases, the changes detected in birth rates cannot explain the changes detected in the abundances and growth rates. For example, during the highest intensity storm (16.9) an increase in abundance and growth rate was observed with no change in birth rate. The changes observed during the storm in which birth cannot explain the change in abundance and growth may be due to emigration, such as in the lowest intensity storm, and immigration such as in the case of the highest intensity storm.

In most cases, storms seemed to have very little impact on B. caudatus birth rate, even when chlorophyll level decreased. B. caudatus has reduced female fecundity when starved (Kirk, 1997). In Acton Lake the average chlorophyll levels never reached below 5 µg per liter and usually stayed above 20 µg per liter, therefore it is possible that food limitation was not an important factor during storm periods. If individual storms are analyzed, the changes in abundance and growth rate cannot be explained by changes in birth rate; therefore, these increases in abundance and growth may be related to some sort of immigration such as
individuals being moved from other parts of the lake. Increases in abundance and growth may also be explained by the emergence of resting eggs during the storms.

A negative trend was observed between changes in *B. angularis* birth rate and storm intensity, therefore, the correlation between changes in growth and storm intensity cannot be explained by changes in birth. The differences in the slopes of the trend lines of these two population parameters (negative for birth rate and positive for growth rate) with storm intensity suggests that factors other than birth may also affect rotifer growth rates. Baker (1979) found that resource limitation can affect birth rate in certain rotifers however; he found no correlation between birth rate of *B. angularis* and food concentration. Since birth rate in *B. angularis* was reduced even during the storms with the highest concentration of chlorophyll during the storm (early-June 2002 and mid-June 2003) and when concentrations of chlorophyll increased during the storm period, the decreases in birth rate can not be attributed to resource limitation.

The hypothesis that changes in death rates during storm events would be positively correlated with storm intensity was not supported for the three species in this study. For all species, the negative trend observed in the changes in death rate during the storms seems to explain the changes in growth rate (Table 1). The increased death rates observed during the lowest intensity storm may be due increased predation pressure from *Asplanchna* spp. which has been shown to be a predator of Brachionid rotifers (Kumar and Rao, 2001) and attained a population density of over 150 ind/L during that time period. The lower death rates observed in all species during the higher intensity storms coupled with the high level of discharge during these storms may suggest that death rates are being underestimated in these cases. Most likely loss of individuals from the inflow of the lake either to the outflow area or over the dam would be higher during these high intensity storms. However, in all cases death rates (which include emigration) are lower or unchanged during the highest intensity storm. This may suggest that resting egg emergence or individuals from other parts of the lake are mitigating the loss of individuals caused by washout.

A positive correlation between the proportion of resting eggs produced and storm intensity during storm events was expected. This prediction was not supported by any of the species during the storm period (Table 1), however, positive trends were observed for all *Brachionus* species.
A correlation between changes during the storms and storm intensity in resting egg production of *B. calyciflorus* was not observed. Two storms produced increases in the proportion of resting eggs produced during the storm. In the June 2002 storm (log (discharge)=15.04); this species achieved a large population density immediately before the storm occurred. Resting egg production in *B. calyciflorus* can be induced by crowding (Gilbert, 2003). Therefore, the increase in resting egg production may have been due to crowding before the storm, and therefore may be unrelated to storm activity. The other increase was observed during the storm with the lowest average chlorophyll level (5 µg/L, mid-May 2002, log (discharge)=16.38) was detected. Perhaps the low food availability caused a shift from sexual to asexual reproduction during this storm.

For *B. angularis* the highest intensity storm showed an increase in the proportion of resting eggs produced, whereas some of the smaller storms showed slight decreases in resting egg production during the storm. The increased production of resting eggs during the highest storm intensity was most likely not cause by food limitation since the levels of chlorophyll were very high (51 µg/L).

For *B. caudatus* all storms cause an increase in the proportion of resting eggs produced. Similar to *B. calyciflorus*, this rotifer showed the largest increase in resting egg production during the storm period in which the lowest average chlorophyll level (5 µg/L, mid-May 2002, log (discharge)=16.38) was detected. *B. caudatus* abundance also increases during this storm period, although, growth rate declines. Therefore, as with *B. calyciflorus*, the increase in resting egg production of this species during this storm may have been caused by low chlorophyll levels coupled with an increase in abundance.

It was predicted that the changes observed in the various population parameters would persist for a longer period after the storms as storm intensity increases. This prediction was only supported in a few cases. The prediction was supported for changes in *B. angularis* growth and death rates. The changes observed during the highest intensity storm persisted into the post-storm period; however, the changes were smaller during the post-storm period of the lowest intensity storms compared with the changes observed during the storm period. This suggests that storm intensity may affect the recovery of this species during the post-storm period, with lower intensity storms having a shorter recovery period.
In contrast, the changes in growth and death rates seem to be very similar for the period during the storm as well as during the post-storm period for *B. calyciflorus* and *B. caudatus*. This suggests that storms may have long term effects on *B. calyciflorus* and *B. caudatus* regardless of storm intensity. Also, a stronger positive correlation between resting egg production and storm intensity is also observed during the post-storm periods for *B. calyciflorus* and a significant negative correlation is observed for *B. caudatus*.

Although the prediction that changes would be more persistent following the highest intensity storms was not supported for most of the population parameters, some changes observed during the post-storm period are important to note. In all three species, the changes in abundance observed during the highest intensity storm were positive, however, during the post-storm period, none of the species exhibited an increase in abundance. This suggests that the highest intensity storms produce only short-term positive effects on abundance.

Changes in growth exhibited a positive trend for *B. angularis* and storm intensity during the storm period, however, the opposite trend was observed during the post-storm period for this specie with a significant negative correlation observed. Also, a decrease in growth rate for both of *B. angularis* and *B. calyciflorus* was observed during the post-storm period of the highest intensity storms even though *B. calyciflorus* growth increased during this storm and *B. angularis* growth, although negatively affected, exhibited the lowest decrease during this storm. This suggests that high intensity storms may negatively impact these two species in the longer term.

The decreases observed in *B. calyciflorus* birth rate during the intermediate intensity storms intensify during the post-storm period, whereas during the remaining three storms, no change is observed during the post-storm period from the pre-storm period. Although the changes in birth rate observed during the storm period do not seem to support the changes seen in growth rate, birth rates during the post-storm period in this species may explain the changes in growth rate.

All species achieved their highest peak abundances during 2001 and experienced their lowest peak abundances during 2003. The lowest intensity and frequency storms during the spring and early summer occurred during 2001. This may suggest that overall rotifer populations are negatively influenced by storms of high intensity and frequency. *B. angularis* abundance was highest during 2001, having the highest peak abundance of the three species observed for that year. During the years with high intensity and frequency (2002) and high intensity (2003) *B.*
angularis experienced lower abundances than the other two species. This may suggest that this species is more susceptible to storm events than B. caudatus and B. calyciflorus. Differences in the effect of turbidity on several rotifer species have been documented. Kirk and Gilbert, (1990) found that increases in clay concentration under laboratory conditions decrease Keratella crassa growth rate, but the growth rate of Brachionus calyciflorus, Keratella cochlearis, Polyarthra vulgaris, and Synchaeta pectinata were not affected. Therefore, changes in turbidity in the lake due to storm events may have species-specific effects on rotifer population growth. Although B. caudatus population parameters were not significantly affected by storm intensity and growth rates were negatively impacted by storms of all intensity, B. caudatus does not seem to be affected by differences in the frequency and intensity of storms among years. B. calyciflorus seemed to thrive during the year of the most frequent high intensity storms (2002). It is also interesting to note that other than May 2001, B. calyciflorus seems to peak between peaks in B. angularis and B. caudatus. Disturbances are thought to allow species that would otherwise be competitively excluded to persist and may even change the competitive outcome. Kumar and Rao (2001) found that in the absence of predators, B. angularis out competed B. calyciflorus. However, in the presence of Asplanchna intermedia and low densities of Mesocyclops thermocyclopoides, B. calyciflorus was able to persist longer than B. angularis. They suggested that this shift in competitive advantage may allow the two species to coexist. If B. angularis is more susceptible to storms than B. calyciflorus, then storms may allow B. calyciflorus to coexist with B. angularis as well. If B. calyciflorus is able to increase its abundance, even temporarily, storms may allow it to compete with B. angularis and B. caudatus which are more negatively impacted by storm events.

These results suggest a complex potential effect of storms on the population dynamics of these rotifer species. Other factors such as frequency of storm events as well as seasonal and inter-annual variability may be considered in future analyses.
Figure 1. Conceptual model of the potential effects of storms events on rotifer populations.

Figure 2. Potential trends for correlation between percent change of a given parameter and storm intensity.

Figure 3. Discharge to Acton Lake from April 1st to July 30th. Storms are numbered by intensity with the numerical value for (a-c) total discharge in m³/storm located above the storm, (d-f) NVSS (mg/L), and (g-i) chlorophyll a (µg/L) during the sampling period of 2001-2003. NVSS and chlorophyll concentrations are represented by the heavy line, while discharge is represented by the fine line. Vertical lines designate the storm period.

Figure 4. Correlation between average NVSS (mg/L) during the storm period and log storm intensity as measured by total discharge (m³/storm) during the period of elevated discharge.

Figure 5. Correlation between (a) NVSS percent change(duing-before) and (b) NVSS percent change(after-before) with log storm intensity.

Figure 6. Correlation between average chlorophyll (µg/L) during the storm period and log storm intensity (a) using linear regression and (b) using a polynomial trend line.

Figure 7. Correlation between average chlorophyll (µg/L) during the storm period and average NVSS (mg/L) during the storm period (a) using linear regression and (b) a polynomial trend line.

Figure 8. Correlation between (a) chlorophyll percent change(duing-before) and (b) chlorophyll percent change(after-before) with log storm intensity.

Figure 9. Correlation between (a) chlorophyll percent change(duing-before) with NVSS percent change(duing-before) and (b) chlorophyll percent change(duing-after) with NVSS percent change(duing-after).

Figure 10. Abundances of (a-c) Brachionus angularis, (d-f)Brachionus caudatus, and (g-i) Brachionus calyciflorus and discharge from April 1st to July 30th during the sampling period of 2001-2003. Abundances are represented by the heavy line, while discharge is represented by the fine line. Vertical lines designate the storm period.

Figure 11. Correlation between abundance percent change(duing-before) for (a) B. angularis, (b) B. caudatus, and (c) B. calyciflorus and abundance percent change(duing-before) for (d) B. angularis, (e) B. caudatus, and (f) B. calyciflorus with log storm intensity.

Figure 12. Correlation between growth rate percent change(duing-before) for (a) B. angularis, (b) B. caudatus, and (c) B. calyciflorus and growth rate percent change(duing-before) for (d) B. angularis, (e) B. caudatus, and (f) B. calyciflorus with log storm intensity.

Figure 13. Correlation between birth rate percent change(duing-before) for (a) B. angularis, (b) B. caudatus, and (c) B. calyciflorus and birth rate percent change(duing-before) for (d) B. angularis, (e) B. caudatus, and (f) B. calyciflorus with log storm intensity.
Figure 14. Correlation between proportion resting egg percent change (during-before) for (a) *B. angularis*, (b) *B. caudatus*, and (c) *B. calyciflorus* and proportion resting egg percent change (during-before) for (d) *B. angularis*, (e) *B. caudatus*, and (f) *B. calyciflorus* with log storm intensity.

Figure 15. Correlation between death rate percent change (during-before) for (a) *B. angularis*, (b) *B. caudatus*, and (c) *B. calyciflorus* and death rate percent change (during-before) for (d) *B. angularis*, (e) *B. caudatus*, and (f) *B. calyciflorus* with log storm intensity.

Table 1. Summary of observed trends in all parameters during storm and post-storm periods. Positive trends are indicated by a plus symbol (+), negative trends are indicated by a negative symbol (-), and no trend is indicated by NT. Significant correlations are delineated by and asterisk (*).
Log Storm Intensity

Average NVSS (mg/L) during storm period

\[ y = 27.876x - 400.9 \]

\[ R^2 = 0.8154 \]
Average chlorophyll (µg/L) during storm period

Average NVSS (mg/L) during storm period

\[ y = -0.0407x + 36.35 \]
\[ R^2 = 0.0028 \]

\[ y = 0.0175x^2 - 1.7899x + 66.21 \]
\[ R^2 = 0.4179 \]
\[ y = 124.35x - 1884.7 \]
\[ R^2 = 0.4338 \]

\[ y = 2.0838x + 7.704 \]
\[ R^2 = 0.0004 \]
\[ y = -18.98x + 279.3 \]
\[ R^2 = 0.2256 \]

\[ y = -12.183x + 176.47 \]
\[ R^2 = 0.0508 \]
Average chlorophyll (µg/L) during storm period

Log Storm Intensity

\[ y = -6.94x + 145.2 \]
\[ R^2 = 0.0853 \]

\[ y = 12.794x^2 - 413.36x + 3362.9 \]
\[ R^2 = 0.2445 \]
Abundance

B. calyciflorus

Percent change (during-before)

Percent change (after-before)

Log Storm Intensity

B. angularis

y = 133.41x - 2038.7

R² = 0.923

B. caudatus

y = 35.903x - 574.0

R² = 0.1893

B. calyciflorus

y = 17.886x - 300.6

R² = 0.0848

B. angularis

y = 89.625x - 1258.2

R² = 0.3375

B. caudatus

y = 19.821x - 217.5

R² = 0.0066

y = -1.2121x - 9.57

R² = 0.0013
**Birth Rate**

**B.calyciflorus**

\[ y = 0.0033x - 0.0979 \]

\[ R^2 = 0.0488 \]

**B.angularis**

\[ y = 0.0557x + 0.820 \]

\[ R^2 = 0.3192 \]

**B.caudatus**

\[ y = 0.0278x - 0.4119 \]

\[ R^2 = 0.0303 \]

**Log Storm Intensity**

**Change (during-before)**

- **B.calyciflorus**
- **B.angularis**
- **B.caudatus**
Proportion Resting Eggs

B. calyciflorus

Log Storm Intensity

Change (during-before)

Change (after-before)

a

y = 0.106x - 3.129
R² = 0.2645

b

y = 0.138x - 2.135
R² = 0.4287

c

y = 0.152x - 2.089
R² = 0.1232

d

y = 0.185x - 3.129
R² = 0.2645

e

y = 0.3156x - 5.262
R² = 0.5153

f

y = 0.0381x - 0.563
R² = 0.1451

B. angularis

B. caudatus
Death Rate

$B.\text{calyciflorus}$

$y = -0.5439x + 9.058$

$R^2 = 0.2387$

$B.\text{angularis}$

$y = -0.4569x + 7.3$

$R^2 = 0.5458$

$B.\text{caudatus}$

$y = -0.7289x + 11.96$

$R^2 = 0.5201$

$y = -0.4368x + 7.294$

$R^2 = 0.1668$

Death Rate

Log Storm Intensity

$B.\text{calyciflorus}$

$B.\text{angularis}$

$B.\text{caudatus}$

Change (during-before)

Change (after-before)
### NVSS and chlorophyll

<table>
<thead>
<tr>
<th>Parameter</th>
<th>NVSS</th>
<th>Δ in NVSS</th>
<th>chlorophyll</th>
<th>Δ in chlorophyll</th>
<th>chlorophyll vs NVSS</th>
<th>Δ in chlorophyll vs Δ in NVSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>during</td>
<td>+*</td>
<td>+*</td>
<td>curve</td>
<td>NT</td>
<td>curve</td>
<td>NT</td>
</tr>
<tr>
<td>post-storm</td>
<td>NT</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td>+</td>
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</tbody>
</table>

### Changes\((\text{during-before})\) in rotifer population parameters

<table>
<thead>
<tr>
<th>Species</th>
<th>Δ in abundance</th>
<th>Δ in growth rate</th>
<th>Δ in birth rate</th>
<th>Δ in death rate</th>
<th>Δ in proportion resting eggs</th>
</tr>
</thead>
<tbody>
<tr>
<td>B. calyciflorus</td>
<td>+*</td>
<td>+</td>
<td>NT</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>B. angularis</td>
<td>+</td>
<td>+*</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>B. caudatus</td>
<td>+</td>
<td>+</td>
<td>NT</td>
<td>-</td>
<td>+</td>
</tr>
</tbody>
</table>

### Changes\((\text{after-before})\) in rotifer population parameters

<table>
<thead>
<tr>
<th>Species</th>
<th>Δ in abundance</th>
<th>Δ in growth rate</th>
<th>Δ in birth rate</th>
<th>Δ in death rate</th>
<th>Δ in proportion resting eggs</th>
</tr>
</thead>
<tbody>
<tr>
<td>B. calyciflorus</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>B. angularis</td>
<td>NT</td>
<td>-*</td>
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<td>-</td>
<td>NT</td>
</tr>
<tr>
<td>B. caudatus</td>
<td>NT</td>
<td>+</td>
<td>NT</td>
<td>-</td>
<td>-*</td>
</tr>
</tbody>
</table>
LITERATURE CITED:


