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Impact of flooding on the densities of selected aquatic insects

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Abstract

Data from a four-year study of five aquatic insect species, *Hydropsyche betteni, H. morosa, H. bronta, Isonychia bicolor*, and *Ephoron leucon*, were utilized to evaluate the impact of a 60-year flood and a few lesser floods. The survey began in August, 1984 and was terminated in October, 1987 with the 60-year flood occurring in November, 1985. Four sampling sites were established on the South River and six quantitative samples were taken each month from each site. Gauging stations on the South River provided accurate discharge data for the sampling sites and useful historical data. Densities for the five species were utilized in the evaluation of the floods. The importance of timing is pointed out, that is, floods that occur very close together or near the end of the life cycle of an insect make it difficult to evaluate floods as disturbances. The importance of life history traits, such as behavior and egg diapause, are discussed in respect to floods. Densities were reduced to less than 50% of their average values immediately after the 60-year flood for the three *Hydropsyche* spp. and at three sites for *I. bicolor. Ephoron leucon* showed no response to the 60-year flood. Densities of the four impacted species returned to previous levels in the following generation. The 60-year flood was considered a disturbance in the near term but not for more than one generation.

Introduction

In aquatic systems, one of the primary potential agents of disturbance is flooding. Resh *et al.* (1988) are quite insistent that floods impact structural and functional components of stream biotas and that floods may play a role in the evolution of these organisms. It seems quite logical to stress, as some researchers do, that floods are disturbances (Resh *et al.*, 1988; Poff & Ward, 1989), even without biological evidence. However, Connell & Sousa (1983) argue that if a 'disturbing force does not cause a significant change in the characteristic of interest, there is no perturbation; the assemblage has resisted the force'. Further, they state 'The time scale of a perturbation is also important. Concepts of stability or persistence refer to responses to discrete, punctuated disturbances that perturb abundances but do not cause long-term changes (*i.e.*, longer than the turnover time of the assemblage) in the abiotic environment'. Hoopes (1974), Siegfried & Knight (1977), Bane & Linn (1978), and Sagar (1986) present biological evidence indicating that floods behaved as disturbances in the systems they studied.

The above studies do not indicate the importance of life cycles and the timing of floods when studying the impacts of floods. Insect species with two or more generations per year may quickly overcome the effects of a flood through their ability to produce large numbers of offspring. The impact of a flood that occurs late in a life cycle may be misinterpreted if samples are taken from the subsequent generations. If a flood occurs in the middle of a bivoltine life cycle, an adequate number of samples may not be collected through time to properly evaluate the flood's impact. When studying a variable such as density, it is doubtful that samples from one or two months would adequately describe a flood's effect. Phenomenological accounts (Townsend, 1989) or correlative surveys (Power *et al.*, 1988) such as this one require four or five replicate data sets in order for the researcher to suggest confidently a cause-and-effect relationship between a flood and reduced densities. This can best be achieved when the flood occurs early in the life cycle of a species.

In early November, 1985, massive flooding occurred in all of the river basins in Virginia. In many localities, flooding was severe enough to be classified as 100-year floods or greater. A second flood occurred in April, 1987, on the South River. A quantitative population study in the South River was initiated in August, 1984, and terminated in October, 1987, for the purpose of evaluating the impact of mercury on selected insect species. The purpose of this report is to determine if the floods were disturbances, to describe the impact of flooding on five insect species, and to suggest a mechanistic role for disturbances in the altering of genotype frequencies.

Table 1. Basin characteristics of the South River. Flow data for Waynesboro (1953-1987) and Dooms (1975-1987) comes from U.S.G.S. gauging stations. Discharge is the mean annual discharge.

	Waynesboro	Dooms
Discharge ($m^3\ s^{-1}$)	1.487	2.456
Drainage Area (km^2)	328.9	385.9
Elevation (m)	395.1	380.1
Channel Slope ($m\ km^{-1}$)	3.50	1.47
Predictability (P)	0.439*(0.38**)	0.441*
Constancy (C)	0.212*(0.216**)	0.250*
Contingency (M)	0.227*(0.164**)	0.191*
M/P	0.517*(0.432**)	0.433*
Location		
Latitude	38.03.27	38.05.19
Longitude	78.54.30	78.52.38
Gauge Number	01626000	01626850

* = 13 year period. ** = 35 year period.

Site description

Four sampling sites were established in riffles of the South River, a fourth order tributary of the South Fork of the Shenandoah River. The following variables were measured in the South River: (1) Flow (cm s^{-1}) range 67 to 81, (2) Depth (cm) 18 to 26, (3) pH 7.4 to 8.1 and (4) hardness (mg l^{-1} $CaCO_3$) 144 to 185. United States Geological Survey (USGS) gauging stations were located approximately 2 km downstream of Sites 1 and 2 at Waynesboro, Virginia and 3 km upstream of Sites 3 and 4 at Dooms, Virginia. Data pertinent to the two gauging stations are given in Table 1.

Immediately following flooding in November, 1985, Sites 1 and 2 were disrupted by earth moving equipment used to construct levies to protect against future flooding. The areas were not widened and remained the same except for two channels parallel to the river banks at Site 1 and disturbance of the substrates at both sites.

Materials and methods

Grids of 1 m^2 were established at each site and numbers were randomly drawn for each site each month to determine the location of six sampling points per site. The lengths of the grids at each site were always 10 meters long while the width of each grid depended upon the width of the stream. The widths of the stream varied from seven to 10 meters. The samples were taken with a modified Hess sampler (0.1 m^2 area and 250 micron mesh net). The samples were preserved in the field with formalin and returned to the laboratory for sorting and identification. The following five species were chosen for identification and counting each month: *Hydropsyche betteni, H. morosa, H. bronta, Isonychia bicalor*, and *Ephoron leucon*. The organisms were sorted to size classes through head capsule measurements. This allowed us to establish the voltinism for each species.

Benthic samples were taken each month along with flow (General Oceanics Model 2030), depth, and substrate size (length × width × height). After converting discharges into liters per second as suggested by Resh *et al.* (1988) and utilizing flows from 1953–1987, predictability, constancy, and contingency were determined according to Colwell (1974). We used the conservative 2-year return flow (>49.5 $m^3\ s^{-1}$ daily average) to estimate bankfull discharge (Poff & Ward, 1989). However, we also consider the possibility that threshold discharge may occur every 1.4 years (>33.5 $m^3\ s^{-1}$ daily average) as suggested by Richards (1982). Measurements that would have allowed us to determine shear stress (McElravy, 1989) were not made.

Graphical analysis of proportional densities were utilized to demonstrate the severe reductions (greater than 50%) that occurred in densities after the flooding.

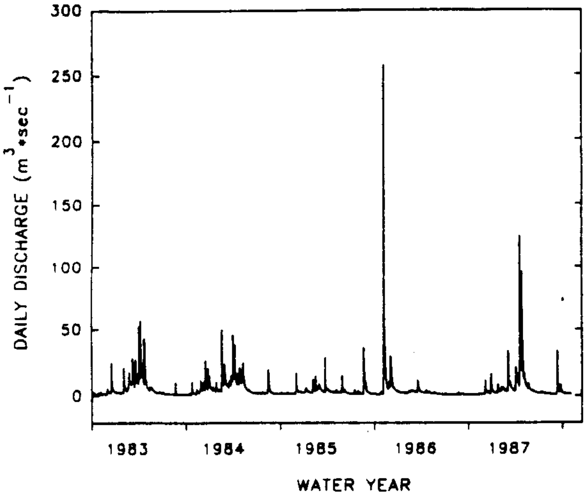

Fig. 1. Daily discharge in $m^3 sec^{-1}$ from the USGS guaging station at Waynesboro, Virginia.

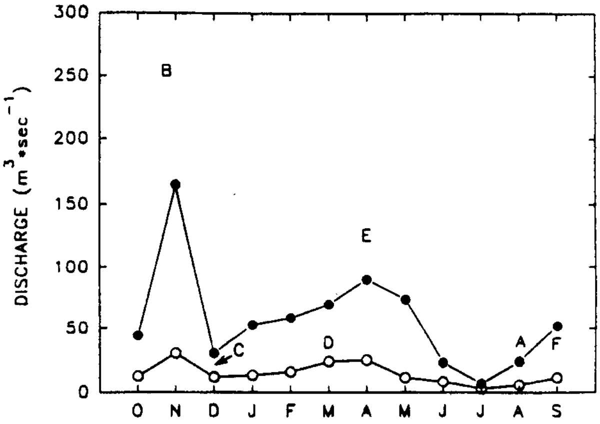

Fig. 2. Mean maxiumum monthly discharge plus two standard diviations at Waynesboro, Virginia. The location of the letters give the month and magnitude of the floods.

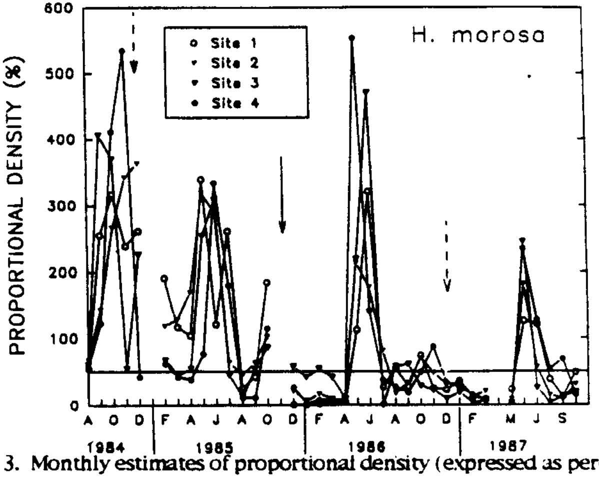

Fig. 3. Monthly estimates of proportional density (expressed as percent of overall average density for the entire period of the study) for populations of *H. morosa* at four sites in the South River, Virginia. Solid arrow indicates the date of the flood, and dashed arrows represent the same time of the year for the yearsprior and following the flood.

Results

Floods

Mean daily discharge in $m^3\ s^{-1}$ is shown in Fig. 1. Flow data from water years 1983 and 1984 are given because those years and 1987 show the normal flow patterns observed in East Coast streams, *i.e.*, high flows in winter and spring and low flows in summer and fall. This pattern was not observed in 1985 and 1986. 1985 was a dry water year (1264 $m^{3s}\ s^{-1}$; average for the five water years = 1962 $m^3\ s^{-1}$), and 1986 (1917 $m^3\ s^{-1}$) was also dry except for the massive flooding that occurred in November 1985 (1986 water year). The mean maximum monthly discharges from 1953 to 1987 are given in Fig. 2. Included in Fig. 2 is a second line showing two standard deviations above the mean maximum discharges. The letters in Fig. 2 correspond to the following flows A = 36 $m^3\ s^{-1}$, B = 257 $m^3\ s^{-1}$, C = 29 $m^3\ s^{-1}$, D = 33 $m^3\ s^{-1}$, E = 125 $m^3\ s^{-1}$, and F = 33 $m^3\ s^{-1}$. These discharges were near or above the threshold level (Richards, 1982) for the South River. The flow at Waynesboro is given since it was a much larger data base.

Responses of species

All species, except *E. Leucon*, were bivoltine. Egg laying by winter and summer adults occurred in May and September, respectively. Thus, the summer generations occupied approximately 4 months and winter generations approximately 8. It was quite common for generations to overlap during May and September. *Ephoron leucon* was univoltine, with adults laying eggs in August and eggs hatching in May (Snyder *et al.*, 1991).

Figures 3 through 7 were generated by dividing the monthly density values by the average for all months (36 months) and multiplying by 100. The monthly values were the means of the six samples collected each month. Thus, the 100% level represents the average density for all months for each site. Samples were not taken in January, 1985, November, 1985 and April, 1987.

Hydropsyche morosa densities were severely reduced (50% reduction or greater) at Sites 1, 2, and 4 but showed no reduction at Site 3 during winter months of 1985–86, *i.e.*, immediately following the November, 1985 flood, (Fig. 3) when compared to the

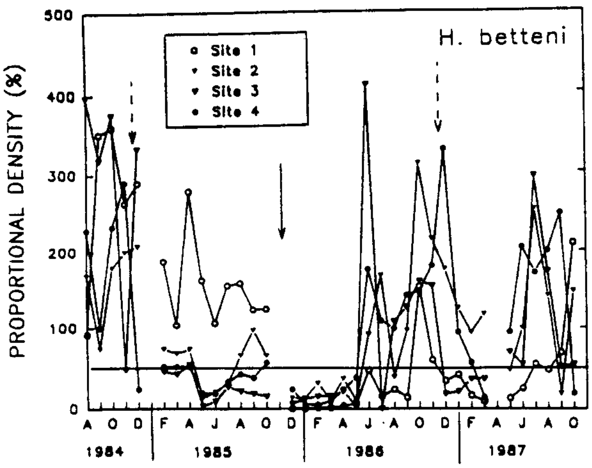

Fig. 4. *H. betteni* in the South River, Virginia (see Fig. 3 legend for explanation)

winter months of 1984–85. All sites exhibited severe reductions in densities during the 1986–87 winter when compared to 1984–85. The summer generation after the flood of 1985 exhibited no real decreases in densities in comparison to the 1985 summer densities. The summer densities for 1987 were reduced in comparison to the 1986 summer densities. This reduction in densities and the low numbers of individuals in May, 1987, indicated an impact from the April, 1987, flood.

Hydropsyche betteni populations at all sites were severely reduced in the 1985–86 winter compared to the winter of 1984–85. All sites except Site 1 showed recovery in winter 1986–87. Densities in the 1986 summer were greater at all sites except Site 1 in comparison with summer 1985 densities. Summer 1987 densities did not exhibit any negative responses to the April, 1987, flood.

Hydropsyche bronta densities were severely reduced at Site 1 during the 1985–86 winter months (Fig. 5) in comparison with the 1984–85 densities. Summer densities for 1986 and 1987 were greater than those for 1985. Extremely low numbers, often zero, of *H. bronta* were taken at Sites 3 and 4 throughout the study period; therefore, we decided not to utilize those data.

Isonychia bicolor (Fig. 6) demonstrated a slight increase in density at Site 1 in winter months after the flood with a concomitant decrease in density at Sites 2, 3, and 4. Summer 1986 densities at Sites 1 and 2 were reduced in comparison to summer densities of 1985. Summer densities of 1987 were generally higher than the previous summers.

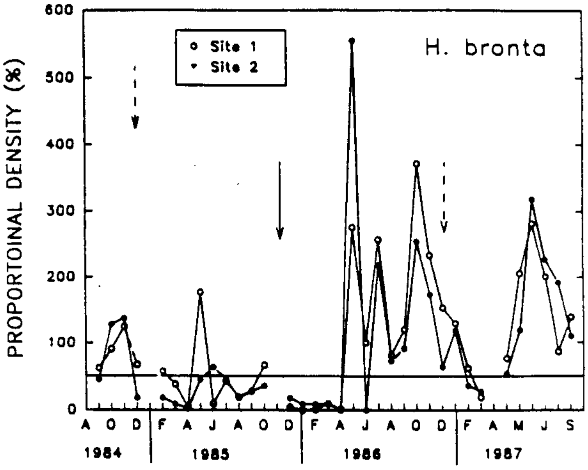

Fig. 5. *H. bronta* in the South River, Virginia (see Fig. 3 legend for explanation)

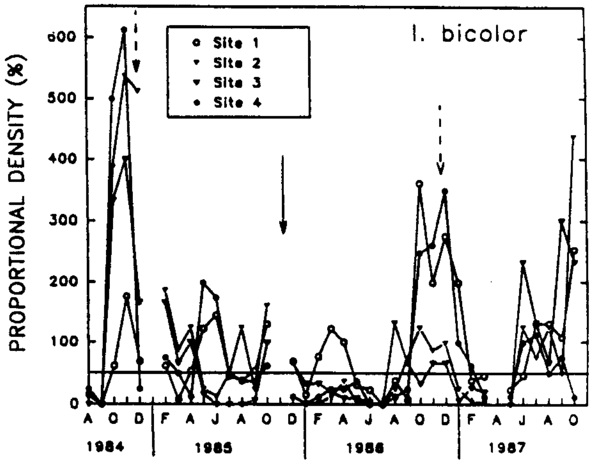

Fig. 6. *I. bicolor* in the South River, Virginia (see Fig. 3 legend for explanation)

Ephoron leucon (Fig. 7) densities at Site 3 were diminished after the 1985 flood in summers of 1986 and 1987. At Sites 1 and 4, there were no differences in summer after the flood but increases in density occurred in 1987. Site 2 exhibited no clear responses to the November flood. The April, 1987, flood did not severely reduce densities at any of the sites.

Discussion

Floods

During the study period (August, 1984 to October, 1987), the South River was visited by at least two massive floods. The November, 1985, flood was three

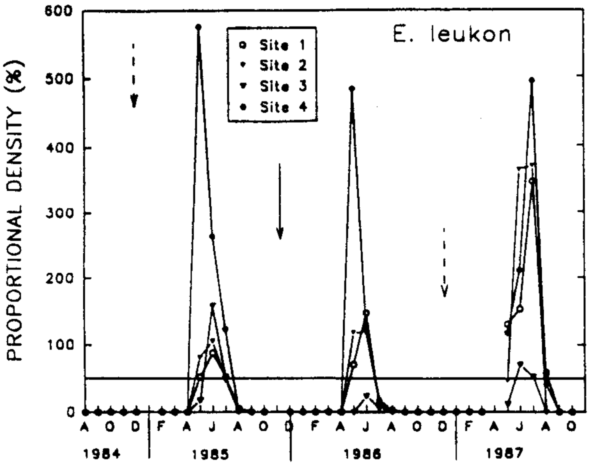

Fig. 7. *E. leucon* in the South River, Virginia (see Fig. 3 legend for explanation)

standard deviations (Resh *et al.*, 1988) greater than the maximum mean monthly flow for November and had a return time of approximately 60 years (Fig. 2, letter B). It occurred at the beginning of the wet season which peaks in April. This is not to imply, however, that flooding does not occur during this time of the year, since 10 floods with returns greater than once every 2 years has occurred in the late fall during the last 59 years. Also, the low predictability values generated for the South River (Table 1) suggest that flooding can be expected throughout the year. The second most intensive flood occurred in April, 1987. It had a return period of approximately 7 years, and was 2.6 standard deviations greater than the maximum mean monthly discharge (Fig. 2, letter E). Four lesser floods, probably less than bank full but near to our estimation of threshold discharge (*i.e.*, >33.5 m^3 s^{-1}) were experienced. They are shown as letters A, C, D, and F in Fig. 2.

It would appear that all of these floods had the potential to disturb the stream's substrate, and three of them (letters A, B, and E, Fig. 2) would be classified as disturbances (Resh *et al.*, 1988) since they fell outside the two standard deviation limit.

Responses of species

Data from this study suggest that the November flood did have an immediate impact at all sites on *H. betteni* (severe reduction at all sites), *H. morosa* (severe reduction at three sites), and *H. bronta* (severe reduction at one site). Other studies have shown Hydropsychid larvae to be sensitive to floods (Hoopes, 1974; Siegfried & Knight, 1977; Scullion & Sinton, 1983; Sagar, 1986). The retreat building behavior of Hydropsychid, along with their relatively large bodies and poor mobility, apparently makes the larvae susceptible to flooding and the concomitant scouring of the substrate.

The sensitivity of mayflies to flooding appears to be uncertain at this time. One study (Siegfried & Knight, 1977) found little or no impact of flooding on mayflies while others (Hoopes, 1974; Scullion & Sinton, 1983) have shown a mixed response by mayflies. It appears that the faster, stronger swimming mayflies, such as *I. bicolor* and *Baetis* spp. (Hoopes, 1974), are able to withstand the ravages of flooding and scouring. Our data show that *I. bicolor* densities were reduced severely at three of the sites studied. However, the fact that *I. bicolor* density at Site 1 in winter 1985–86 was greater than its density in winter 1984–85 contribute to the uncertainty of its response. Also, all sites showed greater numbers in the 1987 summer, immediately after the April, 1987 flood than previous summers. These data indicate that *I. bicolor* can exhibit long term resistance (> one generation) to flooding, but, under certain conditions, their numbers may be severely reduced in the short term (< one generation).

Ephoron leucon densities could not be determined immediately after the November flood because only eggs were present in the substrate. The densities we observed in summer following the flood indicated no detrimental impact to *E. leucon* at three sites. Our data appear to be the only set that allows evaluation of the impact of flooding on the egg stage of an aquatic insect. The life history of *E. leucon* is not sufficiently understood to suggest a mechanism that protected the organisms from the flood and scouring. The eggs of the congeneric, *E. album*, are oviposited in packets on the surface of the water, the material cementing the eggs together dissolves and the eggs settle to the bottom (Edmunds *et al.*, 1956). Threads from the polar caps uncoil and attach the eggs to any surface they touch. A similar phenomenon occurs in *E. leucon* (personal observations), apparently this close association with the substrate adequately protected the eggs during flooding.

The flood of April 17, 1987, appeared to cause harm to *H. morosa*. Apparently, the flood reduced the 1986–87 winter generation densities of *H. morosa* to the point that enough offspring could not be produced to generate densities similar to the two previous summers. It did not appear that summer generations of the other species were impacted by the April flood.

The four lesser floods did not have an impact on the five species. There was no consistent decrease in numbers for more than a month. However, the timing of the floods must be considered in attempting to evaluate their impacts. The floods that occurred in August, March, and September came at the end of a generation or during a transition month. The December flood came immediately after the massive one of November; therefore its impact could not be separated from the larger flood. Due to the ambiguity of the data for the four lesser floods and the April, 1987, flood, we consider only the November, 1985 flood in the remainder of this discussion.

Phenotypic stability

Connell & Sousa's (1983) arguments for intensity, time, and spatial scales in the description of disturbances impose criteria that should be used in the evaluation of floods. That is, if the disturbance is not sufficiently intense to cause a significant change in population density, if the response is not long term, or if the disturbance did not occur on a sufficiently large scale, then the population can be classified as stable and exhibiting resistance (no response). The November, 1985 flood was quite extensive in that entire river basins were impacted. The intensity of the flood severely reduced the population densities of four of the species that were studied at a number of sites. The responses of the species were not long term in that the population densities did not remain reduced for longer than the turnover time of the populations. The time scale is particularly important because it addresses the importance of fecundity for insects in recolonizing an area. Even though the number of individuals were severely reduced, the populations were resistant to the flood since densities were not reduced for more than one generation.

If only the response to the intensity of the flood is considered, *i.e.*, a short term response (< one generation) then two types of stability patterns were exhibited. *Hydropsyche betteni* and *H. morosa* showed resiliency in that they could return to density levels similar to preflood levels. This has been shown by others working with benthic insects (Hoopes, 1974; Reice, 1985) and fish (Matthews, 1986). *Hydropsyche bronta* responded positively to the flood, indicating competitive release from *H. betteni* and perhaps *H. morosa*. *Isonychia bicolor* exhibited both resistance (Site 1) and resiliency (Sites 2, 3, and 4) to the flood. *Ephoron leucon* exhibited resistance to the flood.

The intensity and time scales are critical in judging the response of species to a flood. Quite obviously, organisms, such as insects, that can produce large numbers of offspring within one-egg laying period can recover completely in one turnover time of the population. However, in order to evaluate intensity and time scales accurately, long-term studies with properly placed floods are required. All aquatic field studies to date have been designed only to investigate the intensity of floods and to assign resistance or resilience on that criteria. This is understandable since floods are random by nature and many studies, such as this one, were designed to answer questions completely unrelated to floods.

Genotypic stability

The phenotypic resistance exhibited by *H. morosa* (see summer densities, Fig. 3) appeared to be short lived since the 1987 winter generation densities were more similar to the 1986 than the 1985 winter generation densities (Fig. 3). We suggest that an explanation for this lies in the gene pools of summer generations. It appears that densities of summer generations reflect relatively consistent carrying capacities (K). For example, at Site 1, the K was approximately 60 org 0.1 m^{-2} for the three summers. For Sites 2 and 4, the K values were approximately 35 and 100 org 0.1 m^{-2}. Site 3 was more difficult to assign a K value due to the increase in numbers in 1986. In order to explain how the summer generations could obtain the same average size over the three years, we assume that a greater percentage of offspring from the 1985–86 and 1986–87 winter generations lived than did those from the 1984–85 winter generation. For example, at Site 1, one organism of the 1984–85 winter generation produced one organism in the following generation. In the 1985–86 winter generation, one organism produced 30 organisms in the summer generation, and, in the next two generations, one organism produced five. We suggest that this was due to reduced intraspecific competition (see Wallace, 1981, for a discussion of frequency-dependent and density-dependent selection) during the latter two summer generations. We further suggest that the 1986 summer generation was not as genetically stable as was the 1985 summer generation due to the survival of a large number of weaker genotypes (Wallace, 1981). The 1986–87 winter population numbers were severely reduced because of the lack of selection pressures on the phenotypes of the 1986 summer generation. Of importance here is the fact that mortality rates were strikingly high in the 1986–87 winter generation (almost as high as in the 1985–86 winter generation) between the October and December samples. This was a period of extreme changes, *i.e.*, temperatures decreased, the wet season began (thus higher flows), and these organisms switched from a filtering to a grazing mode (Rhame & Stewart, 1975; Fuller & Mackay, 1980).

Consequently, we suggest that a large number of genetically inferior organisms succumbed to these harsher conditions. Again the stabilities of the population numbers were demonstrated in the 1987 summer generations, but we suggest that the populations were not genetically stable by the end of the study period. We further suggest that this same phenomenon was occurring at a lesser degree with *H. betteni* (Fig. 4).

Acknowledgments

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Summary

1. Densities from a four-year study of *Hydropsyche betteni*, *H. bronta*, *H. morosa*, *Isonychia bicolor* and *Ephoron leucon* were utilized to evaluate the impact of a 60-year flood and a few lesser floods on these insect populations.

2. *H. betteni*, *H. morosa* and *I. bicolor* populations were resistant to the 60-year flood in the long term, *i.e.*, greater than one generation. In the short term (less than one generation) they exhibited resilience and in one instance resistance was exhibited.

3. *H. bronta* responded positively to the 60-year flood, in the long term, suggesting competitive release.

4. *E. leucon* exhibited no response to the flood.

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