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Recovery of aquatic insect communities after a catastrophic flood in a Korean stream

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In August 2002, a heavy rainfall (445 mm in total for 5 consecutive days) resulted in a catastrophic flood, and it completely washed away the benthic fauna from the mainstream channel of the Gapyeong stream, a typical mid-sized stream in the central Korean peninsula. This study was to investigate the recovery patterns of aquatic insect communities that were damaged by the flood. Aquatic insects were sampled quantitatively using a Surber sampler (50 × 50 cm, 1 riffle and 1 pool/run habitats per site) from three sites (4th-6th order) of the Gapyeong stream prior to 2000 and seasonally after the flood event from 2003 to 2006. Before the flood in the reference year (2000), a total of 77 species of aquatic insects were collected, whereas after the flood 47 species (2003), 51 species (2004), 64 species (2005) and 55 species (2006) were collected from the whole sampling sites. The aquatic insect density decreased to 26.85% (2003), 90.25% (2004), 52.53% (2005) and 54.95% (2006) of that recorded in the reference year. Although approximately 70% of the aquatic insect fauna has recovered since the flood event, the species composition in the most recent year differed substantially (similarity ca. 50%). On the other hand, the compositions of functional groups have not significantly changed. Aquatic insect communities at the riffle sites were affected more profoundly than those at the pool/run sites. The aquatic insect communities at the upstream site recovered more rapidly than those at the downstream sites.

Keywords: benthic macroinvertebrates; community recovery; disturbance ecology; flood impact; Gapyeong stream; monsoon climate

Introduction

Floods are one of the most frequent natural disasters in most areas of the world, and they cause major natural disturbances in streams and rivers (Ward 1992). Floods play an important role in controlling the distribution and richness of aquatic organisms within the lotic ecosystem (Resh et al. 1988; Lake 2000). A sudden increase in discharge may induce not only the rearrangement of stream substrates, but may also effect a reduction in the diversity and density of benthic macroinvertebrates, including aquatic insects, in diverse stream systems (Badri et al. 1987; Scrimgeour et al. 1988; Hendricks et al. 1995; Lytle 2000; Imbert et al. 2005).

In general, benthic macroinvertebrate communities are highly resilient and usually recover rapidly after disturbances (Townsend et al. 1987; Brooks and Boulton 1991; Boulton et al. 1992). The recovery of benthic macroinvertebrate communities from floods in disturbed streams has been attributed to the use of refuges (Gray and Fisher 1981; Sagar 1986; Angradi 1997; Laura et al. 1999), drift (Williams and Hynes 1976; Gray and Ward 1982; Sagar 1983), aerial dispersals (Gray and Fisher 1981), and a variety of other life history characteristics in order to minimize the impact of floods (Gray 1981; Reice 1985).

A number of studies have been conducted regarding the influence of floods on benthic macroinvertebrate communities and their recovery processes (Wallace 1990; Brooks and Boulton 1991; Laura et al. 1999; Imbert et al. 2005; Snyder and Johnson 2006). In normal conditions, the recovery periods for density and community structure of benthic macroinvertebrates are generally shorter than the life spans of the species, and it normally requires a few weeks or months in streams located in temperate climatic regions (Badri et al. 1987; Fisher et al. 1982; Hendricks et al. 1995; Mackay 1992; Matthaei et al. 1997). In Northeast Asia, where more than 70% of the annual precipitation falls in the rainy season as the result of the monsoon climate, however, the impacts of floods on benthic macroinvertebrate communities are frequently more profound, and the recovery patterns may be different from those observed in other climatic regions (Magnuson et al. 1979; Vannote and Sweeney 1980). Few studies have been conducted in streams in the Asian monsoon climate region in terms of the damage to and recovery of benthic macroinvertebrate communities under severe flood conditions.

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In August 2002, a catastrophic flood caused by a localized torrential rainfall, struck the Gapyeong stream area of Gyeonggi-do, which is located in the central Korean peninsula. At that time, 445 mm of precipitation (consecutive maximum precipitation for 5 days) was measured at the measurement station (Hwaak) in that area. The stream substrate was totally disrupted and the riparian zone was wiped out. The debris flows caused by the flood completely altered the habitats of the stream. Immediately after the flood, no benthic communities including aquatic insects were observed throughout the main stream channel. After 2002, the stream has been affected by periodic floods, which are typical of the normal precipitation patterns of the country.

The principal objective of this study was to assess the damage to and recovery of aquatic insect communities after a catastrophic flood in a Korean stream in a monsoon climatic area. This study focused on the changes in aquatic insect communities in terms of (1) fauna, (2) community (taxa richness, abundance, and diversity), (3) functional groups (e.g. functional feeding groups or FFGs and habitat orientation groups or HOGs), and (4) recovery rate changes.

Materials and methods

Study area and sites

The Gapyeong stream is a typical mountain stream in Korea, and is located approximately 60 km northeast of Seoul. The stream originates from a preserved Myeongjisan (Mt.) area (highest peak 1267 m above sea level) in Gyeonggi-do (Province), runs through farmlands, villages and a town, and flows into the Bukhan River. The total length of the stream is approximately 42 km. The area consists of brown forest soil and rocks with intruded schist and granite. The climate is a temperate monsoon climate, and between 2000 and 2005 the average annual temperature of the area was 11.3°C (January temperature −4.0 °C; August temperature 24.5 °C); the average annual precipitation was 1265 mm, and this occurred primarily in the summer months. The riparian forest is characterized principally by the Sasamorpha-oak trees, which are common in the deciduous forest area of temperate Northeast Asia. In addition, the Gapyeong stream is typical of granitic geology, and features habitat structures of turbulent riffles, small cascades, runs and pools. The stream bed of the tributaries of mountain streams is composed largely of bedrock and boulders. The upstream channel is steep and narrow, whereas the downstream channel is relatively flat and wide. Although the stream runs through agricultural areas and small villages, it is relatively well preserved because the upper reaches of the stream, which belong to a natural preserve, are protected by the local government.

Three study sites were selected in the middle and downstream sections (stream order 4–6), which contain the typical habitats of the stream (Figure 1).

Precipitation

The precipitation and water level data of the stream were acquired from the flood control office, the Han River Flood Control Center. Consecutive maximum precipitation during the catastrophic flood in 2002 was 445 mm for five days, from August 3 to 7. The maximum daily precipitation was 236 mm (August 6), whereas the maximum daily water level at the mouth of the Gapyeong stream was 4.0 m (August 6) (Figure 2). This event represented an unprecedented localized torrential rain. Although annual precipitation levels were even higher in 2001 (1316 mm) and 2003 (1828 mm), as compared to the year 2002 (1269 mm), the distribution of the yearly precipitation was relatively normal in terms of intensity and frequency in those and in other remaining years.

Field survey and sampling

For this study, seasonal investigations were conducted at three study sites from 2002 to 2006 (August 2002, April 2003, August 2003, October 2003, February 2004, October 2004, April 2005, August 2005, December 2005, May 2006). The winter investigations sometimes proved impossible due to freezing. The reference data for 2000 (April 2000), prior to the flood, were taken at the same study sites. Descriptions of microhabitats and sampling methods with quantitative sampling data in the Gapyeong stream are given in Bae et al. (2003).

Aquatic insects were sampled quantitatively using a Surber sampler (50 × 50 cm, mesh 0.2 mm, each 1 riffle and 1 pool/run sample per site, two samples in total per site). The samples were preserved with Kahle's solution and transported to the laboratory for sorting and identification. Aquatic insects were identified to the species level using the available references (Yoon 1995; Merrit and Cummins 1996; Kawai and Tanida 2005). Other methods for the sampling and habitat investigation were conducted in accordance with the general protocols (Ward 1992; Williams and Feltmate 1992; Allan 1995; Merrit and Cummins 1996).

Data analysis

A two-way ANOVA test (SAS Institute 1996) and Bray-Curtis similarity measure (Bray and Curtis 1957)

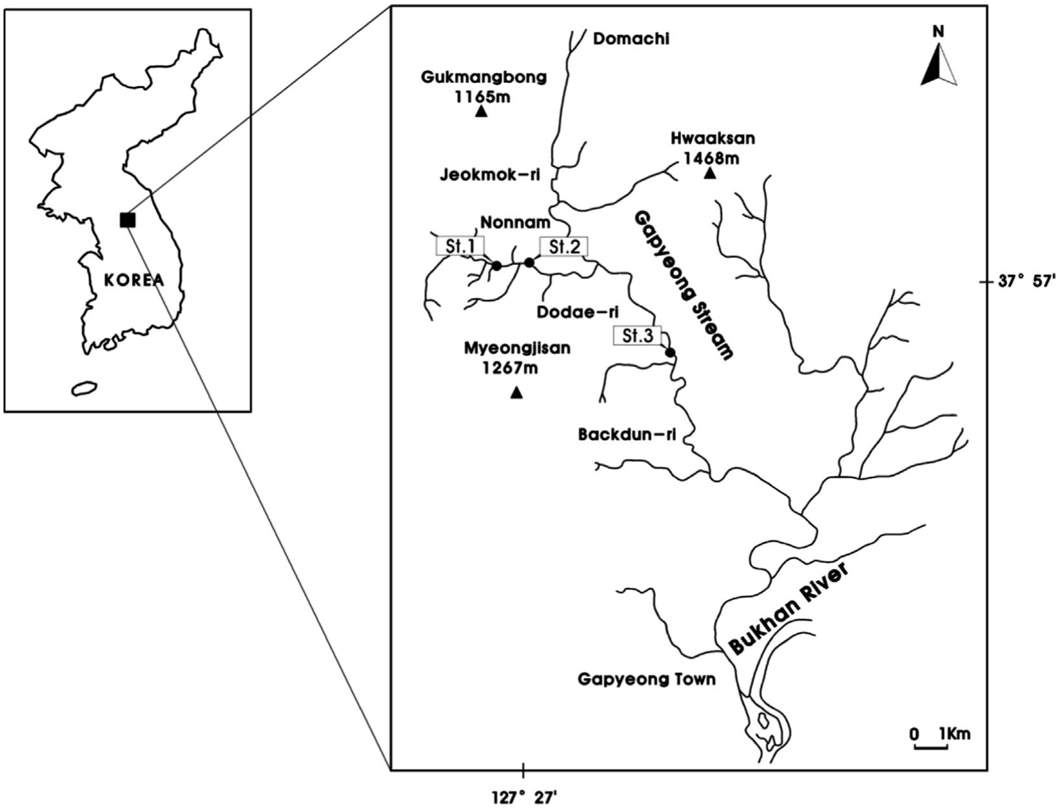

Figure 1. Location of study sites in the Gapyeong stream, Korea.

were utilized to test the chronological changes of aquatic insect communities in terms of the taxa richness, density, and Shannon diversity indices. FFGs and HOGs were classified principally in accordance with the methods of Merrit and Cummins (1996). The recovery rate was expressed as the relative percentage of the seasonal richness after the flood, to the reference year (SPR-2000).

Results

Faunal and community changes

Before the flood in the reference year (2000), a total of 77 species in 52 genera of aquatic insects were collected from the whole sampling sites, whereas, after the flood, a total of 47 species in 38 genera (2003), 51 species in 41 genera (2004), 64 species in 50 genera (2005), and 55

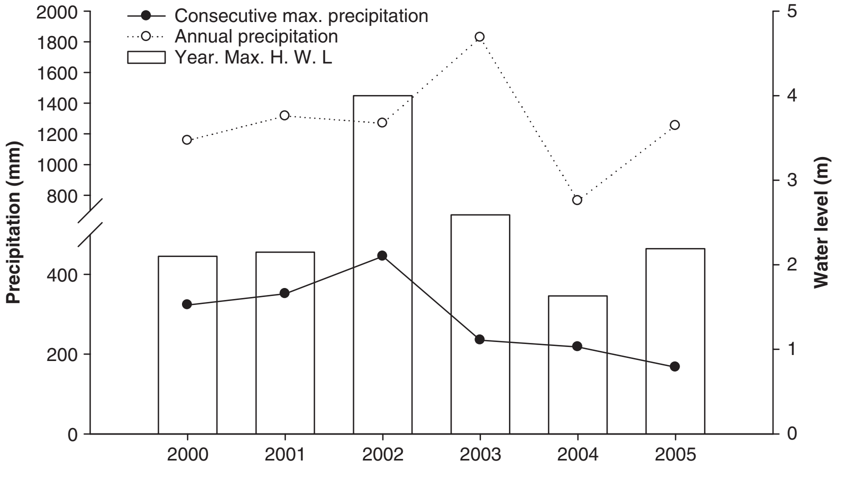

Figure 2. Precipitation and water level in the Gapyeong stream.

species in 44 genera (2006) were collected from the sites. The individual abundance of aquatic insects decreased to 26.85% (2003), 90.25% (2004), 52.53% (2005), and 54.95% (2006) of that recorded in the reference year.

Taxa richness and density differed significantly ($p < 0.05$), whereas Shannon diversity did not differ significantly between the sampling trials (Table 1). In the spring of 2003, after the flood, the taxa richness and density decreased altogether, as compared to those of reference year 2000. Differences of biotic variables of riffles were generally greater than those of pools.

Taxa richness was assessed in accordance with the riffle and pool habitats (Figure 3A). A larger number of species was detected in the riffles (32 ± 2) than in the pools (27 ± 1) prior to the flood event (SPR-2000), but it was higher in the pools in the spring and summer of 2003, one year after the flood event. After the spring of 2004, however, the species number was again higher in the riffles. In the summer of 2002, immediately after the flood, no single aquatic insect individual was detected throughout the main stream channel, including the study sites. The density of aquatic insects was relatively similar between the riffles (326 ± 7) and pools (342 ± 4) prior to the flood, but was higher in the pools in the spring and summer of 2003, one year after the flood event (Figure 3B). The taxa richness and density of aquatic insects have gradually increased to a certain level since the flood event.

However, the composition of functional groups of aquatic insect communities such as FFGs and HOGs has not changed since the 2002 flood. Throughout the study period, gatherers accounted for a higher ratio in both the riffles and pools with regard to taxa richness and density (Figure 4A, B). FFGs after the flood, in both the riffles and pools, were determined to be similar in composition between the sampling trials. Clingers were most abundant both in the riffles and pools with regard to taxa richness and density, a pattern similar to that observed prior to the flood (Figure 5A, B). In summary, the disturbance caused by the flood brought changes in the species composition and density of the aquatic insect communities, but the composition of FFGs and HOGs were similar to the pre-flood year.

On the basis of our analysis of the Bray-Curtis community similarity index (Table 2), aquatic insect communities proved to be relatively more similar between the springs of 2004, 2005, and 2006, but they were relatively dissimilar for summer 2003 and other sampling trials. In general, the similarities between sampling trials evidenced a tendency toward increase, but the levels remained around 50% similar to the community recorded in the reference year, 2000.

Community recovery

Recovery rate was separately assessed according to riffles and pools (Figure 6). Immediately after the catastrophic flood, the recovery rate was found to be higher in the pools than in the riffles. The recovery rate achieved a level of approximately 70%, and a certain stable level was maintained after approximately 4 years from the flood event. In general, the recovery rate was higher in the pools (74.34%) than in the riffles (64.01%).

In terms of both the riffle and pool data, the similarities were the closest between years 2005 and 2006, as was also evidenced by the Bray-Curtis similarity (Table 2). The distances between the sample units were determined to be less in the upstream sites than in the downstream sites, which means that recovery occurred more rapidly in the upstream sites.

Table 1. Mean values (± SE) of biotic variables in seasons at the sampling sites (2 replicates per site and 6 replicates in total) of the Gapyeong stream. The different letters mean statistically significant difference ($p < 0.05$) and ^{ab} and ^{abc} mean no significant difference (Tukey-Kramer's procedure).

	Biotic variables					
	Taxa richness		Density		Shannon diversity	
	Riffle (mean ± SE)	Pool (mean ± SE)	Riffle (mean ± SE)	Pool (mean ± SE)	Riffle (mean ± SE)	Pool (mean ± SE)
SPR-00	32 ± 1^{a}	27 ± 1^{a}	470 ± 144^{a}	342 ± 4^{abc}	2.54 ± 0.10	2.47 ± 0.08
SPR-03	17 ± 2^{bc}	23 ± 2^{ab}	110 ± 6^{ab}	156 ± 13^{abc}	2.22 ± 0.23	2.24 ± 0.10
SUM-03	11 ± 1^{c}	12 ± 2^{b}	36 ± 10^{b}	61 ± 15^{c}	2.00 ± 0.09	1.76 ± 0.50
AUT-03	24 ± 3^{ab}	24 ± 2^{ab}	272 ± 95^{ab}	224 ± 67^{abc}	2.38 ± 0.10	2.38 ± 0.38
SPR-04	29 ± 4^{ab}	23 ± 3^{ab}	343 ± 103^{ab}	402 ± 102^{ab}	2.55 ± 0.19	2.09 ± 0.12
AUT-04	31 ± 4^{a}	25 ± 4^{ab}	385 ± 56^{ab}	241 ± 58^{abc}	2.56 ± 0.10	2.47 ± 0.16
SPR-05	29 ± 3^{ab}	22 ± 2^{ab}	253 ± 26^{ab}	255 ± 48^{abc}	2.73 ± 0.12	2.38 ± 0.08
SUM-05	25 ± 1^{ab}	13 ± 0^{b}	286 ± 78^{ab}	110 ± 52^{bc}	2.60 ± 0.16	2.03 ± 0.18
AUT-05	34 ± 0^{a}	30 ± 1^{a}	446 ± 93^{a}	425 ± 82^{a}	3.04 ± 0.03	2.71 ± 0.16
SPR-06	27 ± 1^{ab}	22 ± 2^{ab}	331 ± 21^{ab}	200 ± 26^{abc}	2.65 ± 0.08	2.43 ± 0.15

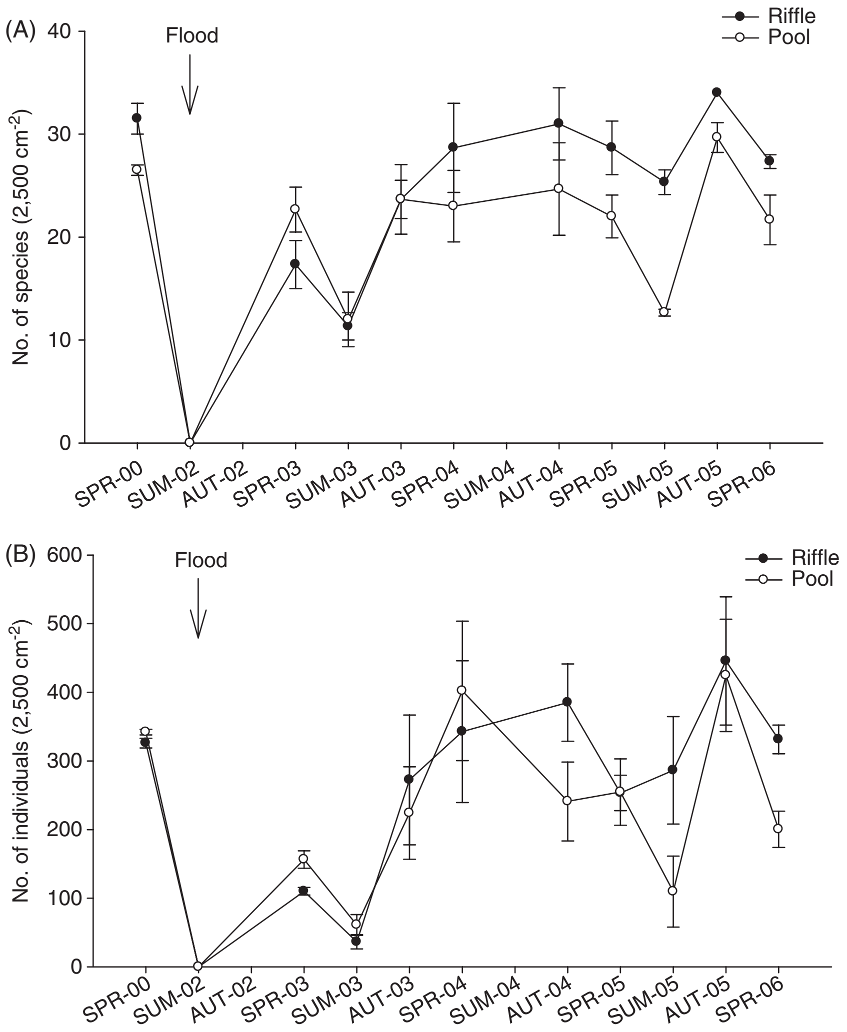

Figure 3. Mean values (±SE) of taxa richness (A) and density (B) of aquatic insects in seasons at three sites in the Gapyeong stream.

Table 2. Bray-Curtis[a] index in seasons for 2000, 2003-2006.

	SPR-03	SUM-03	AUT-03	SPR-04	AUT-04	SPR-05	SUM-05	AUT-05	SPR-06
SPR-00	32.22	19.11	44.49	41.08	54.08	43.39	37.05	54.67	49.77
SPR-03	–	33.73	31.99	37.13	37.88	48.13	53.55	36.31	52.88
SUM-03	–	–	27.40	16.94	21.57	27.31	32.70	16.26	27.98
AUT-03	–	–	–	42.33	49.42	45.87	26.30	47.71	44.03
SPR-04	–	–	–	–	53.16	55.03	32.55	47.80	55.31
AUT-04	–	–	–	–	–	53.09	39.33	61.53	50.45
SPR-05	–	–	–	–	–	–	39.60	45.27	68.55
SUM-05	–	–	–	–	–	–	–	42.59	49.01
AUT-05	–	–	–	–	–	–	–	–	53.83

[a] Bray and Curtis (1957).

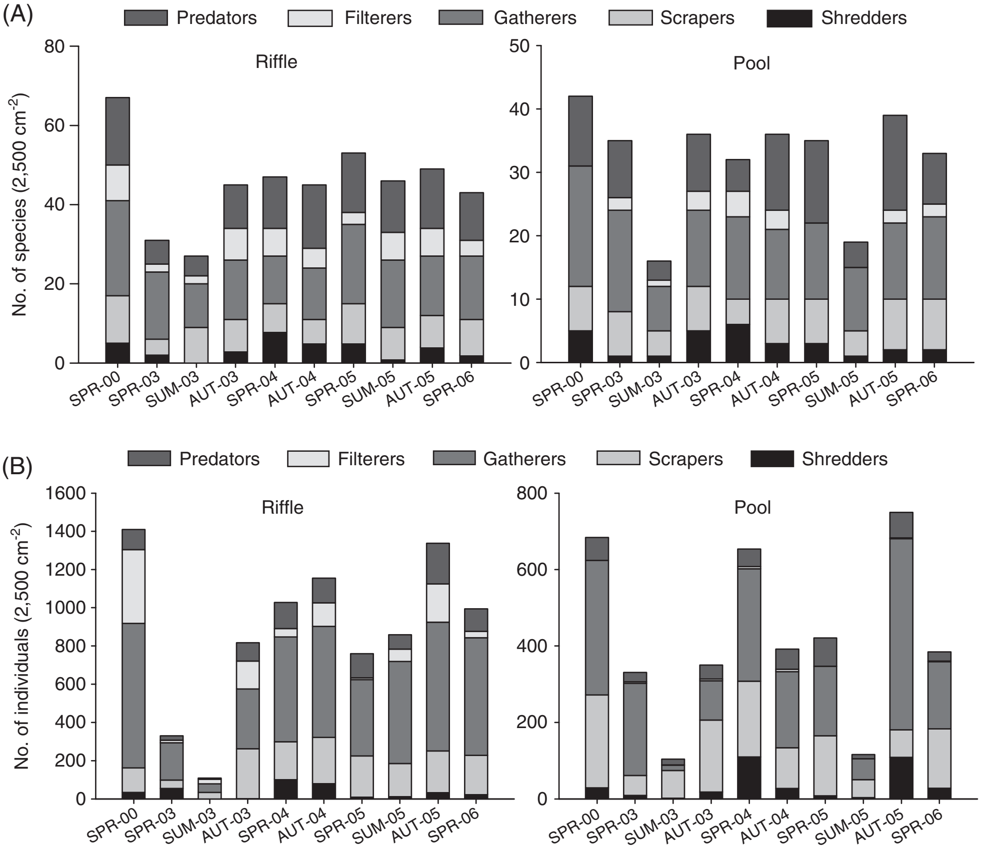

Figure 4. Taxa richness (A) and density (B) of functional feeding groups (FFGs) between the samples.

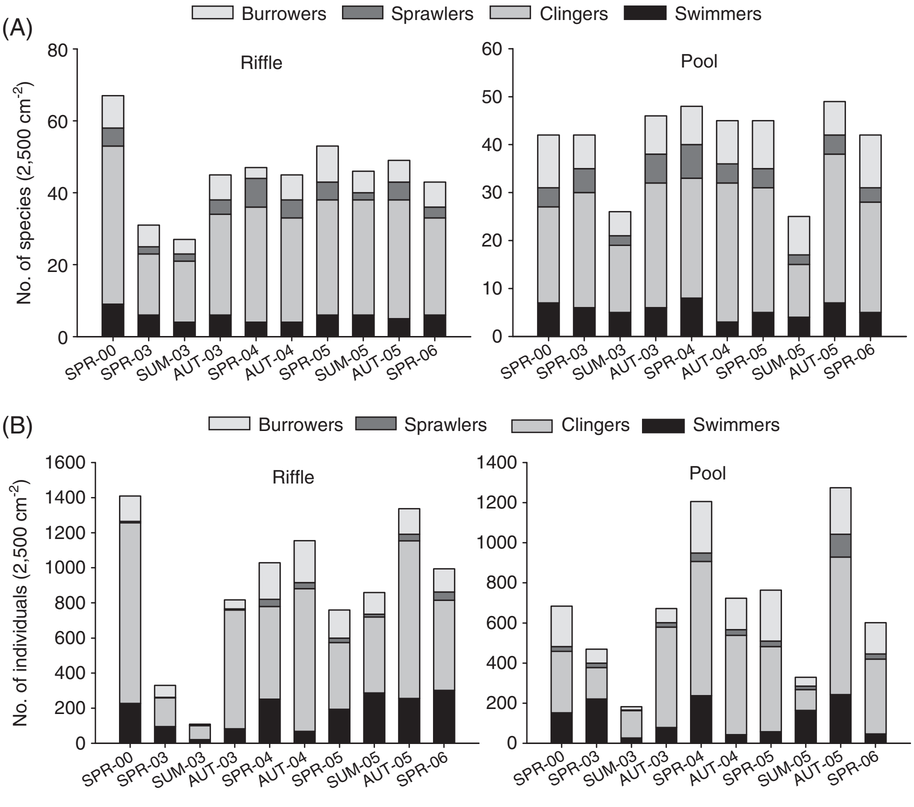

Figure 5. Taxa richness (A) and density (B) of habitat orientation groups (HOGs) between the samples.

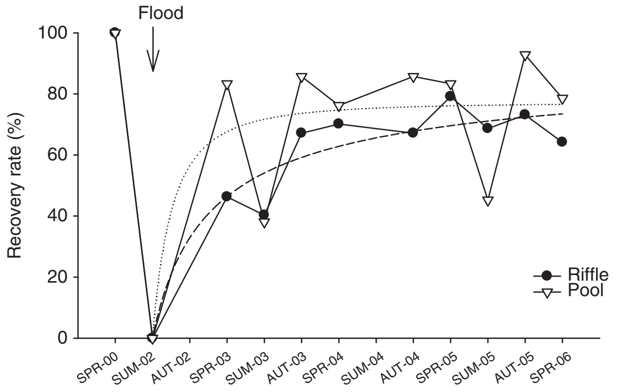

Figure 6. Recovery rate between the samples after the catastrophic flood event.

Discussion

Abiotic factors, including droughts and floods, perform a major function in the determination of the community structure of aquatic organisms in stream ecosystems (Allan 1995). In the East Asian region that has a monsoon climate, a predictable flood event in the rainy season is considered to be the major factor of natural disturbance in stream ecosystems (Ward 1992). Although both the magnitude and frequency of floods may be associated with the degree of flood impacts on stream communities, the magnitude of a flood, rather than the frequency, may prove to be a more important determinant of flood intensity in Northeast Asian streams, including Korean streams, due to the characteristics of precipitation patterns in this region. The Korean Peninsula and adjacent areas receive the majority of precipitation, approximately 70% of the annual amount of precipitation, during a relatively short rainy season from late June to mid-July. Although this precipitation pattern has become more unpredictable in recent years due to global warming, the magnitude of these floods indicates a tendency toward stronger and more frequent catastrophic floods.

When catastrophic floods occur, torrential flows carrying abundant debris can completely reshape the stream channel with huge deposits of bank sediments (Snyder and Johnson 2006). The catastrophic flood events also inflict multiple impacts on aquatic organisms, including communities of aquatic insects. If the flood events are predictable and regular in intensity and frequency, partial losses of taxa richness and density may occur and recovery may occur under normal patterns, as the aquatic organisms have adapted over considerable geological time. In catastrophic flood events, however, losses in taxa richness and density tend to be severe, and recovery tends to occur much more slowly (Lepori and Hjerdt 2006). Our study also showed that the catastrophic flood of the Gapyeong stream completely destroyed the aquatic insect communities, and they have not recovered for a considerable period of time. Although we do not have seasonal sampling data in the reference year 2000, other quantitative data sampled previously in the Gapyeong stream (Yoon et al.1990), which showed similar faunistic and community composition of aquatic insects to that of the reference year, show that the taxa richness and density greatly decreased in the year 2003, immediately after the flood (Table 1).

Riffle habitats featuring diverse microhabitats have higher taxa richness and density than are observed in pool habitats (Brown and Brussock 1991). A close relationship has been reported between the size of streambed particles and habitat stability (Duncan et al. 1999), and large stable boulders in the riffle area are known to function as a refuge during floods (Matthaei and Huber 2002). Also, riffle habitats show enhanced resistance to floods, and may be more physically stable than pools and runs (Lytle 2000; Robinson et al. 2004). However, in pool habitats after flood events, when flow rates are reduced, fine sediment can accumulate, and those may fill interstices that would provide a suitable habitat and refuge (Brown and Brussock 1991). In this study, however, taxa richness and density were higher in the pools than in the riffles for a period of approximately one year after the catastrophic flood event in 2002 (Figure 3A,B). As we observed in this study, a catastrophic flood event may completely displace stream substrates, even very large stones in riffles, and the recovery pattern is not the same as reported in other previous studies. A faster recovery rate during the early recovery period is attributed largely to the fast colonizers, including *Ecdyonurus kibunensis* and *Paraleptophlebia chocolata*, in pool areas where detritus is deposited.

Although disruption due to flood events has been shown to result in changes in the species composition of aquatic insects, the FFGs and HOGs compositions appear to be similar to those of the reference year (Figure 4 and 5). This may be explained by the increase in the drift activities of aquatic insects from the upstream tributaries, in which the food sources are also limited after floods (Scrimgeour et al. 1988).

In general, species with early reproduction, short lifespans, small body size, streamlined or flattened bodies, high mobility, and the presence of resistance stages are considered to be advantageous in terms of recovery (Lepori and Hjerdt 2006). Species with flood resistance and opportunistic characteristics appear predominantly after disturbances (Bradt et al. 1999). This study indicated that major functional groups with opportunistic characteristics operate as gatherers (FFGs) and clingers (HOGs) in the stream. Also, this study showed that *Baetis fuscatus*, *Ecdyonurus* *kibunensis*, *Paraleptophlebia chocolate*, Chrionomidae sp., and *Goerodes* sp. are considered to be typical species with opportunistic characteristics in the study stream.

Our study, which was conducted over a 6-year period (2000-2006) in a temperate monsoon stream in Korea, demonstrated that a catastrophic flood had a significant impact on aquatic insect communities, and also showed that a significant proportion (approximately 30%) of species richness has yet to recover (Figure 6). As localized torrential rainfalls and catastrophic floods in East Asia have increased in recent years, the degree of biodiversity losses of aquatic organisms may increase in the future, if the recovery processes cease to function normally.

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