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Ain't no mountain high enough: the impact of severe typhoon on montane stream fishes

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Abstract Typhoons are a regular occurrence in tropical Taiwan. Local flora and fauna should be adapted to typhoons, however more severe storms in the past decade most likely due to climate change have caused an apparent impact on local ecosystems and diversity. Heavy rainfall from typhoon events has been associated with declines in density and biodiversity of low altitude freshwater fish. Montane streams on the other hand are assumed to be more resilient to typhoons as these habitats receive less washed-off pollutant and is buffeted by established vegetation. However, as access to isolated montane streams, especially after a typhoon, is difficult, the effects of typhoons on these habitats are rarely studied. In this study, we overcame many obstacles to survey montane freshwater fishes in Beikeng Creek shortly after a typhoon event. We demonstrated extreme changes in physical characteristics, but little changes in chemical characteristics of the stream. We also documented the absence of the endemic *Rhinogobius rubromaculatus* (red spotted goby) and the crashed population of *Onychostoma barbatulum*, (Taiwan shovel-jaw carp) after typhoon. Although these two endemic species are expected to survive in other unaffected montane creeks and streams in the vicinity, the dramatic decline in montane fish population in Beikeng Creek suggests that conservation management may need to be reconsidered to prevent possible extinction under increasing human and natural perturbations.

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Introduction

Globally, freshwater fishes are threatened by increasing habitat loss from human development (Abell 2002; Allan 2004). Urban and agricultural demands (Bond et al. 2008), contamination (Dudgeon et al. 2006), introduced alien fish species (Ogutu-Ohwayo 1990) and river modifications (Brasher 2003) are reducing the habitats of and resources available to freshwater species. Anthropogenic effects, coupled with the inherent spatial limitation and restricted connectivity of freshwater systems, makes such ecosystems more susceptible to human development and less resilient to acute perturbations than marine ecosystems (Fausch et al. 2002; Pratchett et al. 2011). As such, many freshwater fishes may become locally extinct before they were recorded (i.e. Ogutu-Ohwayo 1990; Xenopoulos et al. 2005). Past studies of freshwater ecosystems in remote areas such as isolated mountain regions have focused on species composition. The ecological responses of montane fish species to anthropogenic or natural disturbance are rarely studied (Thieme et al. 2007; McDowall 2010).

Climate change has been associated with increased incidence and severity of strong tropical low pressures systems, termed tropical cyclone or typhoon in Pacific region (Webster et al. 2005). Modeled storm activity based on IPCC-projected sea surface temperatures suggests further increase in storm intensities in the near future (Bengtsson et al. 2006). The most common typhoon-related impacts on aquatic animals are terrestrial pollution and sedimentation (Saunders et al 2002; Allan 2004), resulting in physiological and ecological consequences such as reduced respiration through clogged gills (Sandström and Karås 2002) and altered foraging and predation behavior (Ferrari et al. 2010; Li et al. 2013). Heavy rainfall also exposes aquatic fauna downstream to sudden increases in water velocity and washes away habitats (Yoon et al. 2011). Meanwhile high water velocity and turbidity affects aquatic benthos such as algae and aquatic insects, which also form the basis of freshwater food webs (Richardson and Jowett 2002; Leigh et al. 2010). A large proportion of freshwater fish depend on such food resources and are in turn important prey for higher trophic level predators like birds (Steinmetz et al. 2003, 2008). The losses of habitat, fishes and other lower trophic levels have the potential to affect higher trophic levels and hence influence the entire stream ecosystem. However, few studies have documented the impact from consequent rainfall of typhoon on mountain stream habitats and inhabitants.

The consequent heavy rainfall from typhoons can alter mountain stream fish assemblages (South Korea; Yoon et al. 2011), decrease abundance of a montane species with limited distribution (e.g. mountain landlocked salmon-*Oncorhynchus masou* in Japan; Kano et al. 2010) and affect the foraging behavior of fishes (China; Lin and Jeng 2000). Like other tropical and subtropical countries, Taiwan is prone to typhoons especially during the summer seasons (Knaff et al. 2005). The montane region in western Taiwan is sheltered from easterly typhoons by the Central Mountain Range and rarely affected by human activities (Chung et al. 2008). Despite human development and increased severity and frequency of typhoons, there are hardly any ecological and biological studies of high-mountain (>1,000 m) stream freshwater fishes due to inaccessibility of these areas (but see Yoon et al. 2011). Montane fish species in Taiwan have been moderately documented, but ecological and biological studies are still limited (i.e. Fang et al. 1993; Tzeng et al. 2006). Except the endangered Taiwanese landlocked salmon (*Oncorhynchus masou formosanus*), for which there have been plenty of studies (Reviews in Lin et al. 2012). Most of montane stream fishes are frequently overlooked due to low diversity and inaccessibility (but see Han et al. 2000). A study during typhoon season revealed that the Taiwanese landlocked salmon seek shelter in deeper water bodies possibly alleviating the effects of the event (Makiguchi et al. 2009). However, whether other montane fish species in Taiwan also display such behavioral response to typhoons remains to be seen.

In this study, we documented the physical and ecological effects of Typhoon Aere in 2004, which brought 1,546 mm rainfall in Taiwan in 3 days and caused several landslides in the mountainous region of Taiwan, China and Okinawa, Japan. It cost Taiwan USD 313, 000 in damages and took 24 lives, mainly due to the heavy rainfall. Severe typhoons frequently occur in Taiwan. In the past 20 years, 59 above category-two typhoons made landfall on the island. Eleven of them caused severe damage to Taiwan, including Typhoon Aere.

By characterizing changes in leeward montane stream habitats and fish assemblages, we aim to evaluate the ecological damage caused by heavy rainfall from Typhoon Aere and hence provide some insight into the possible ecological damage caused by projected increased storm activity due to climate change. Specifically we evaluated typhoon damage by (1) quantifying stream habitats (2) analyzing water quality and (3) estimating fish assemblage pre- and post-typhoon. Ecological data sets often do not meet the normality assumption of traditional analyses and in studies of strong human or natural perturbation; a large number of zeroes in the data set is common. Hence non-linear regression models are increasingly popular for ecological research (Joseph et al. 2009). Several models were suggested for such data sets, for instance, zero-inflated Poisson and zero-inflated negative binomial. However, few studies have examined the performance of different N-mixture models on populations under severe impacts. A secondary aim of this study is to find the optimal model for evaluating catastrophic event on an ecological system by comparing the goodness-of-fit among different N-mixture models.

Methods

Sampling sites

The "Before and After" sampling design (Green 1993; Underwood 1994) was conducted at the Beikeng Creek within the Xuejian Reserve of Shei-Pa National Park in Taiwan, in 2004. Beikeng Creek is located on the western side of Mt. Shei (also known as Mt. Xue) and Mt. Dabajan, which should be sheltered from most typhoons. Two sampling trips pre-typhoon (4 months and 1 month before typhoon) and post-typhoon (3 months and 5 months after typhoon) were carried out. Beikeng Creek was chosen as a pristine study site as it is largely isolated from human disturbance (30 km from nearest human settlement) and protected under National Park regulation.

Four locations were surveyed along Beikeng Creek based on four different historic police stations (Shuguang, Beikeng, Xingyuan and Xuejian) along the Beikeng Creek Historic Trail. The sites were designated A to D, with site A being the most upstream and site D, the most downstream. Two 10 m transects (termed 1 and 2) approximately 500 m apart were conducted at each site. The coordinate locations (GPS) and altitude of these eight survey transects were recorded for comparing the difference before and after typhoon (Photo 1S). The distance between A and D is approximately 5.2 km according to GIS measurement. However, site C and D were not accessible during the first trip after typhoon due to the extreme damage and strong stream current. We sampled fish at two nearby sites to represent the possible fish assemblages at that point. We managed to sample the original locations during the second post-typhoon survey.

The Beikeng Creek Historic Trail has been officially closed to any visitor (including scientists) for safety reasons since serious damage by Typhoon Aere. Hence the post-typhoon survey conducted in this study remains the only survey documenting the damage from Typhoon Aere on stream fishes of Beikeng Creek.

Environmental, hydrographical parameters and fishes sampling

Water temperature, dissolved oxygen (DO) and velocity of creek were measured at beginning of each transect. Three 500 ml water samples were collected at beginning of each transect and chilled for later analysis in the laboratory for nutrient content and heavy metals. The cross-section profiles (depth) and velocity of each transect were measured and compared. Other geological and topographical descriptions were also recorded for each survey. Other chemical such as ammonia, nitrate, nitrite and phosphate were analyzed by a Flow Injection Analyzer (FIA) and spectrophotometer (Hitachi model U-300) following Meng et al. (2008).

Fish was sampled using a combination of three techniques to compensate for sampling limitations of each technique. Electrofishing is first conducted over 10 m along each transact with one researcher zig-zagging along the creek operating a backpack electrofishing device (8 volt) followed by two assistants using hand nets to collect the stunned fishes. The width of each transect was recorded to standardize the abundance of fishes. The total length (TL, +/− 0.5 mm) and wet weight (+/− 0.05 g) of each fish was measured before release. Nocturnal species were sampled with three shrimp-baited one-way cylinder fish traps measuring 36 cm in length, 16 cm in radius, fastened under relatively large rocks at the end of each transect after electrofishing. All traps were left overnight and collected early next morning. To compensate for the limited effective sampling area of electrofishing, underwater visual census (UVC) was also conducted during each survey.

Data analysis

Univariate analysis – two-way ANOVA (analysis of variation) was used to examine the difference in water quality with respect to two factors (before vs after typhoon and sites). Environmental data was log-transformed before analysis to satisfy the normality assumption. Benjamini & Hochberg adjustment (so-called False Discovery Rate) of p value is also used and as it is a less stringent condition than the family-wise error rate, this method is more powerful compared to others (Benjamini and Hochberg 1995).

Four variants of the N-mixture models (Poisson, negative binomial, zero-inflated Poisson and zero-inflated negative binomial) were used to examine the difference between (1) fish abundance, (2), biomass and (3) richness with respect to typhoon (before-and-after) and sites (site A, B, C and D). Factors were examined in a non-linear regression model framework using maximum likelihood to estimate parameters. This approach was taken as no prior assumption of homogeneity was necessary. A log-link function was chosen as data was not normally distributed. The null model (no factor) and alternative models (typhoon and site factors) were compared with Akaike's information criterion (AIC; Symonds and Moussalli 2011). AIC corrected (AICc) was used in this study due to the small sample replicates and low fish abundance. The model with the greatest Akaike weight was selected for the best goodness of fit. N-mixture models and AIC analyses were conducted in R language (v. 3.0.1; R Core Team 2013).

Size-frequency distribution and body length-weight regression

Only the most abundant species, Taiwanese shovel-jaw carp (*Onychostoma barbatulum*), was selected for size-frequency distribution and length-weight regression analysis. Size-frequency distributions of *O. barbatulum* before and after typhoon were illustrated using histograms with kernel density estimation (KDE). The non-parametric KDE method was used as non-normal distribution of data (Sheather and Jones 1991). The statistical test of size distributions before and after typhoon are examined based on a null model of no difference before and after typhoon with a permutation test. We implemented the statistical test following Langlois et al. (2012) using the function of "sm.density.compare" in the package "sm" of R language (Bowman and Azzalini 2013). The size frequency histograms were conducted by PAST v3.0 (Hammer et al. 2001).

Length-weight regressions of *O. barbatulum* before-and-after typhoon were compared to examine the change of body weight after the typhoon. Both length and weight data were log-transformed to meet the assumptions of homogeneity and linearity (F=0.056, p= 0.8119; Zar 1999). ANCOVA (analysis of covariance) was used to compare before and after length-weight regressions with log-length as covariate and log-weight as dependent variable. Body weight was also tested using Fulton's condition factor [K = body weight/(body length)^3] where lower K factors suggest less than standard weight (Bolger and Connolly 1989). Non-parametric Kruskal-Wallis test was used to test for significant difference in K factors before and after the typhoon. Benjamini & Hochberg adjustment was also used for Kruskal-Wallis test due to the fewer number of samples after typhoon. The ANCOVA and K-S test statistical analyses were performed using PAST v3.0 (Hammer et al. 2001).

Results

A total of 305 individual fishes were sampled over four fieldtrips at Beikeng Creek, with the majority (84 %) collected before the typhoon (Table 1). No fish was found after the typhoon, however, a small number of individuals were sampled at one site after the disturbance. The most abundant species across all transects was *O. barbatulum. Rhinogobius rubromaculatus* (red spotted goby) was less abundant before the typhoon but none were found after the event. Two other species (*Acrossocheilus paradoxus* and *Hemimyzon formosanus*) were only observed after the typhoon.

Environmental and hydrographical parameters

Several environmental parameters showed significant change after typhoon, but only temperature was significantly different between sites (Table 2). For chemical parameters, significant increases in NO_3-N and specific conductivity (dissolved-solids concentration) suggest terrestrial runoff after the typhoon. The higher pH value

Table 1 Sampled average number (± S.E.)/100-meter square of each fish species before and after typhoon at Beikeng Creek, Taiwan in 2004

Scientific name	Common name	Sampling of typhoon event			
		Pre 1st (March)	Pre 2nd (July)	Post 1st (October)	Post 2nd (December)
Onychostoma barbatulum	Taiwan shovel-jaw carp	37.0±8.5	21.8±6.6	0±0	4.8±4.2
Rhinogobius rubromaculatus	Red spotted Goby	2.2±1.0	3.2±1.4	0±0	0±0
Acrossocheilus paradoxus	Taiwan striped barb	0±0	0±0	0±0	2.2±1.5
Hemimyzon formosanus	Formosan river loach	0±0	0±0	0±0	5.0±2.7

(higher alkalinity) post-typhoon also suggests increased terrestrial alkaline element runoff.

For physical parameters, the measured temperature of Beikeng Creek increased after the typhoon although post-typhoon samplings were conducted during autumn and winter. The increased temperatures may be a consequence of reduced shading due to loss of riparian vegetation (pers. obs.). Mean and maximum velocities increased significantly after typhoon as a result of high volume of water from heavy rainfall. Although no significant difference in velocity was detected among sites, the average velocity increased slightly at downstream sites. The measured cross-section profile (width, mean-depth and maximum depth) also increased significantly after the typhoon due to erosion (Table 2). We also archived and photographed creek habitats of Beikeng Creek before vs after typhoon (Photo 1S) and observed that the size of pebbles in creek were much larger post-typhoon. The benthos (i.e. turf algae) and invertebrates (i.e. aquatic insects) were not present after

Table 2 ANOVA results of chemical and physical parameters, which were analyzed from laboratory and record in situ during field trips significant results were indicated with asterisk in bold font

	Pre	Post	Typhoon		Sites	
	Mean ± SE	Mean ± SE	*F*	*p*	*F*	*p*
Chemical parameters						
Salinity (psu)	0.21±0.004	0.32±0.020	34.759	**0.018***	1.378	0.554
DO (ppm)	6.59±0.106	6.56±0.101	0.023	0.916	0.419	0.843
Specific conductivity (μS/cm)	477.5±13.89	635.4±29.98	32.472	**0.020***	1.643	0.510
pH	8.24±0.047	8.44±0.036	19.225	**0.038***	1.620	0.510
NH_3-N (mg/L)	0.036±0.013	0.063±0.008	4.703	0.236	1.150	0.597
PO_4-P (mg/L)	0.030±0.023	0.012±0.004	0.893	0.554	0.767	0.683
NO_2-N (mg/L)	0.004±0.0014	0.001±0.0007	3.460	0.311	1.743	0.510
NO_3-N (mg/L)	0.105±0.005	0.039±0.008	53.197	**0.013***	1.021	0.615
Fe (μg/L)	2.79±1.66	2.34±0.49	0.144	0.798	1.651	0.510
Physical parameters						
Turbidity (ntu)	0.34±0.039	8.8±7.72	1.199	0.510	1.000	0.615
Temperature (°C)	19.36±0.56	20.72±0.86	18.386	**0.038***	20.054	**0.025***
Velocity (mean; km/h)	2.4±0.33	9.96±0.85	18.910	**0.008***	2.029	0.346
Velocity (Max; km/h)	3.02±0.33	13.36±0.93	40.320	**0.008***	3.352	0.168
Creek width (m)	8.22±0.36	4.79±0.36	28.090	**0.008***	2.174	0.329
Creek depth (mean; cm)	14.44±0.41	21.22±1.21	40.330	**0.008***	0.898	0.615
Creek depth (max; cm)	23.3±1.7	36.0±2.5	14.150	**0.018***	0.050	0.980

Table 3 Best goodness-of-fit models of fish abundance, biomass and richness from four N-mixture models

Selected candidate formula	Model	df	AICc	Akaike weight
Fish abundance ~ Typhoon* Site	ZINB	10	171.70	1
Fish biomass ~ Typhoon* Site	ZINB	10	276.34	0.47
Fish richness ~ Typhoon	GLM	2	70.25	0.55

typhoon. The variety of habitats has decreased as deep pools and waterfalls have been eroded away. The meandering flow of Beikeng Creek became much straighter at all surveyed sites.

Freshwater fish assemblage

N-mixture models results suggested that the abundance, biomass and richness of fishes collected in Beikeng Creek differed pre- and post-typhoon (Table 3). The best-fit models for abundance and biomass of fish were both the ZINB model with the formula = Typhoon * Site (Table 3S). The models suggested that both abundance and biomass of the fish were affected by both the typhoon event and the sampling location. The best-fit model for species richness is the GLM with the formula = Typhoon, indicating that only the event and not the location affects species number (Table 3).

The population of *O. barbatulum* declined significantly after typhoon for all the size categories (Fig. 1). The KDE comparison for before and after size-frequency distribution was significant different ($p<0.001$). The body length-weight regressions of *O. barbatulum* also differed pre- and post-typhoon (Fig. 2, $F=276.4$, $p<0.001$). Fulton's condition factor (K) of shovel-jaw carp decreased significantly from 1.009±0.04 to 0.221±0.01 after typhoon ($p<0.001$). For example, a 15 cm (TL) *O. barbatulum* weighed less than 10 g after the typhoon, compared to around 40 g before the event.

Discussion

In this study, we demonstrated that a typhoon (Typhoon Aere) caused damage to critical creek habitats and dramatic decline of two endemic fishes in the Beikeng Creek of montane region of Taiwan (1,000~1,500 m), an environment previously thought to be resilient to typhoons. With professional field support, we overcame an arduous journey to access the montane stream post-typhoon, a rare occurrence in freshwater fish studies. We also found that zero-inflated negative binomial model (ZINB) can successfully and statistically examined the severe damage on montane steam fishes in a data set with many zeros. The N-mixture model approach proved to be a useful advanced statistical analysis to study the effects of a disaster on the endemic species.

Environmental chemical parameters in freshwater systems can vary depending on the geological composition of the riverbed and valley. Most chemical parameter values in this survey before typhoon were within the good to excellent environmental water quality level (Alabaster and Lloyd 1980; ANZECC 2000; Liou et al. 2004). The exceptions are slightly higher iron levels and pH levels (pH 8.2), which are typical of creeks in the region (Cheng et al. 1996) and still within the tolerance range for aquatic animals (ANZECC 2000). While several chemical parameters changed significantly post-typhoon due to heavy rainfall and land-source wash-off, the levels were still below critical levels for aquatic animals. As such, altered chemical

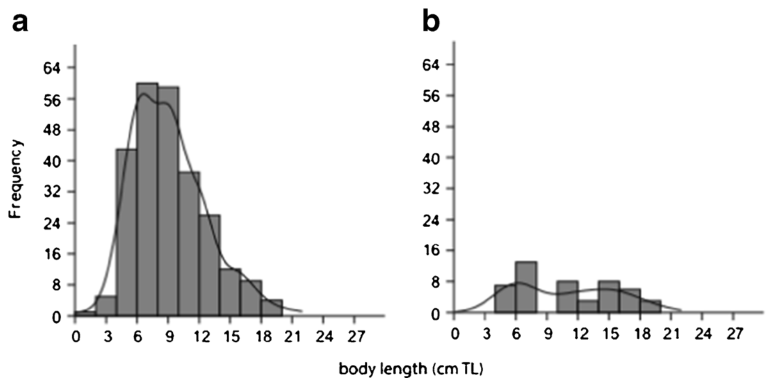

Fig. 1 The size-frequency distribution histograms of *Onychostoma barbatulum* **a** before and **b** after typhoon

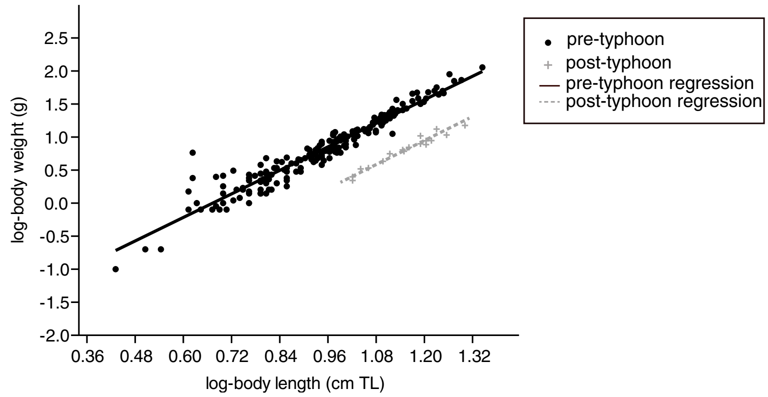

Fig. 2 The body length-weight regressions of *Onychostoma barbatulum* before and after typhoon

conditions and increased temperature are unlikely to be the main driver behind the post-typhoon decline in fish populations in Beikeng Creek.

We suggest that other physical parameters of Beikeng Creek such as velocity, depth and width of creek and loss of habitats were the main reasons behind the shift in fish assemblages and population decline (also see Yoon et al. 2011). The velocities of Beikeng Creek increased by 1.7 times (5.84±0.38 to 9.96±0.85) 3 months after the typhoon. The erosive power of the river as a result of heavy rainfall in the water basin dramatically changed riverine topography and riparian habitats (Photo 1S). This might affect freshwater fish in two ways, 1) by drastically altering piscine habitat and 2) by removing algae and other aquatic plants from the riverbed, therefore destroying habitats of aquatic insects and thus depleting food resources (i.e. Lin and Jeng 2000). In addition, extreme high turbidity at maximum of 39.7 ntu after the typhoon, as compared to fresh water, which should have an ntu less than 4, might be another reason for declining fish populations (Alabaster and Lloyd 1980). The measured turbidity was almost four times higher than levels with no effect or limited effect for fishes (10 ntu), (Alabaster and Lloyd 1980). High turbidity reduces breathing efficiency (Sutherland and Meyer 2007), and foraging success (Power 1984; Richardson and Jowett 2002). Indirectly, high turbidity also affects fish by degrading food availability (aquatic insect or algae) and increasing predation risk (Leahy et al. 2011). It is likely that herbivorous *O. barbatulum* and the insectivorous *R. rubromaculatus* lost food resource and were under turbidity-related stresses after typhoon, a plausible reason for the undernourished *O. barbatulum* and disappearance of *R. rubromaculatus*.

The traditional statistical analysis (i.e. ANOVA) cannot be applied to ecological datasets with missing data due to the assumption of normality. This is a common occurrence in count data of species after a dramatic natural or human-induced disturbance (i.e. Guarino et al. 2012). In this study, both *O. barbatulum* and *R. rubromaculatus* can be found across all sampling sites before the typhoon. However, the consequent heavy rain from severe typhoon have washed them downstream or even eliminated them from Beikeng Creek. Even though there is a possibility that they may be retained in downstream or low altitude stream region, these species may not survive in the long term due to unavailability of suitable habitats. *O. barbatulum* and *R. rubromaculatus* from other connected stream systems have the potential to replenish Beikeng creek, but we did not see this happening in the last trip, which is 5 months after typhoon. Hence we have documented the dramatic decline of two montane stream fish species after a typhoon event, although recovery of these fish populations in future is possible.

Although there is possible temporal bias in this study due to absence of control survey during typhoon, we can confidently excluded the possibilities of the seasonal reproduction and immigration as the reason of weight-change in *O. barbatulum* and disappearance of *R. rubromaculatus* based on previous studies (Chang 1994; Cheng et al. 1996). Chang (1994) showed that body weight and body length ratio of *O. barbatulum* remains consistent throughout the whole year including breeding season. Cheng et al (1996) found wide distribution of *R. rubromaculatus* and no seasonal migration. Another two fish species (*A. paradoxus* and *H. formosanus*), which are common species in low altitude stream of Taiwan were only found in our samples after typhoon. We suggested that is because the boundary (natural waterfall) between the high altitude and low altitude streams was destroyed by the typhoon (Photo 1S) and these two species can swim to our upstream sampling sites.

Biodiversity or richness has usually been used as an index to judge the conservation value in terrestrial and marine environments (Freitag et al. 1997). Biodiversity hotspots or habitat (i.e. coral reefs) have always been regarded as critical habitats for conservation (Myers et al. 2000). Recently, the potential extinction, or extinction debt, of endemic species after perturbations have been regarded as another important consideration for conservation management (Pressey 2004; Kuussaari et al. 2009). Beikeng Creek in this study would not be valued as a diversity hotspot as only two fish species occur here. However, these two endemic freshwater fishes underwent dramatic population decline or were completely absent after typhoon. With predictions of more frequent severe typhoons under climate change scenarios, the extinction debt incidents in montane streams are expected to occur more frequently in the near future (Thomas et al. 2004; Webster et al. 2005). The community of the montane ecosystem may be not as resistant and resilient as thought (Pauchard et al. 2009; Januchowski-Hartley et al. 2011). Conservation management of montane ecosystem in Taiwan should be reassessed, taking possible climate change-related perturbations into account to prevent possible local extinction (Dullinger et al. 2012).

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