Evaluation of Partial Stream Water Release Trial at Tung Chung Au Water Intake (2nd Edition)

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Abstract

1. Green Power, with the support of the Water Supplies Department (WSD), attempted to partially restore water flow at water intakes and thus ecological connectivity along streams on Lantau, and conducted a water release trial at Tung Chung Au water intake in the upstream section of the ecologically important Tung Chung River.

2. To evaluate the effectiveness of the water release trial, Green Power conducted surveys on two major aquatic taxa groups, namely freshwater fishes and aquatic insects, as well as abiotic attributes of stream sections upstream and downstream of the water intake before and after the water release trial started.

3. The reaches differed in abiotic attributes before and right after the start of the water release trial, as well as during dry seasons when flow was low. The downstream reach was generally lower in dissolved oxygen and pH, and higher in specific conductance, and more variable in some of these parameters compared with the upstream reach. These parameters appeared to be similar between reaches one year after the trial started, although occasional deviation of some parameters from those upstream of the water intake still occurred near the end of the study. Wetted width continued to be lower along the downstream reach, which on average being 4-7m narrower than the upstream reach throughout the study.

4. Higher density of fish was observed downstream both before and after the water release trial, but fish compositions became more similar between reaches when some of the rheophilic benthic fishes appeared along the downstream reach a year after the trial started. Adult aquatic insects also showed sign of recovery in terms of abundance and community composition towards the end of the study.

5. The current study showed that water abstraction at Tung Chung Au water intake had significantly altered stream abiotic and biotic attributes in the downstream section. Dewatering caused changes in stream water quality and physical attributes, which may in turn alter organism densities, overall abundance and community structure via reduction of habitat size, selection of more tolerant species and/or biotic interactions. The water release trial conducted appeared to allow initial improvement of water quality and recovery of the stream community, although such changes only occurred at least one year after the trial started. Continuous monitoring and more detailed studies are needed to confirm the long-term responses of the abiotic and biotic components, and how the method could be better evaluated or adapted to other streams in the region.

Contents

1. Introduction

1.1 Restoration of Stream Flow

Water abstraction from streams for human use has long been a major type of human disturbance to stream ecosystems (Allan et al. 2021, Dudgeon et al. 2006, Malmqvist & Rundle 2002), and has been aggressively implemented in natural streams in tropical Asian regions (Dudgeon 1999, Dudgeon 2000) including Hong Kong (Dudgeon 1996). Flow modification alters the availability and physiochemical attributes of stream water and habitats, which in turn affect ecological processes and cause changes to stream communities via various mechanisms (Dewson et al. 2007, Rolls et al. 2012). Flow restoration in natural streams for sustaining ecological processes and biodiversity is a major realm in river management, and its implementation and development have been widely requested and contributed by scientists and practitioners around the world (Brisbane Declaration 2007).

1.2. Tung Chung River

Tung Chung River (TCR) in North Lantau is rare among large-scale rivers in Hong Kong, as most of its parts are preserved in a natural state. It is also ecologically rich, as indicated by the presence of rare species and more than 70 species of fish within its catchment (Green Power 2023). Each of its two main branches, the East Stream and the West Stream, has a section being designated as Ecologically Important Stream (no. 27) by the Agriculture, Fisheries and Conservation Department (AFCD).

Water within the Water Gathering Ground (WGG) is collected at the Water Supplies Department (WSD) 's water intakes at the upstream of TCR, then transferred to Shek Pik Reservoir through waterworks. This leads to significantly reduced flow or even drying out of sections downstream of these water intake facilities, especially during dry seasons, and thus lotic habitat fragmentation and degradation of their ecological integrity. Green Power, with WSD's support, attempts to partially restore water flow at water intakes and thus ecological connectivity along streams on Lantau. We conducted a trial at Tung Chung Au water intake at the upstream section of the East Stream. The site was one of the study sites sampled by Niu (2009) in 2007-2008 with the aim of establishing environmental flow allocation standards in Hong Kong streams and was found to suffer from mean discharge reduction of over 80% during both the wet and dry seasons (Niu 2009). WSD replaced concrete gratings (Plate 1) above the intake tunnel with grooved glass-reinforced plastic (GRP) gratings on 14th January 2019, which allow some stream water to bypass the intake and flow downstream (Plate 2).

1.3. The Current Study

Studies on the recovery of stream communities after flow restoration in different river systems gave variable results (Davies et al. 2013, Thompson et al. 2018). As a lot of uncertainty remains with system responses to environmental flow restoration efforts, monitoring is needed to evaluate if flow restoration exercise is effective (Poff et al. 2010). To evaluate the effectiveness of the water release trial at Tung Chung Au water intake, Green Power conducted surveys on two major aquatic taxa groups, namely fishes and aquatic insects, of stream sections upstream and downstream of the water

intake before and after the water release trial started. Fishes and aquatic macroinvertebrates, with the majority of the latter being aquatic insects, have been observed to respond in terms of abundance and diversity, as well as changes in community composition to flow alterations (Dewson et al. 2007, Gore et al. 2001, Perkin et al. 2015, Poff et al. 2010).

We aim at examining the effectiveness of the water release exercise in restoring ecological conditions of the downstream section by determining stream fauna responses to the water release trial. In particular, we would like to answer the following questions through the study:

i. How does water abstraction affect the biotic component and physiochemical stream attributes in the section downstream of the water intake?

ii. Would the stream community recover and become more similar to that of the natural upstream section? If yes, how long would it take?

2. Materials and Methods

2.1. Survey Site

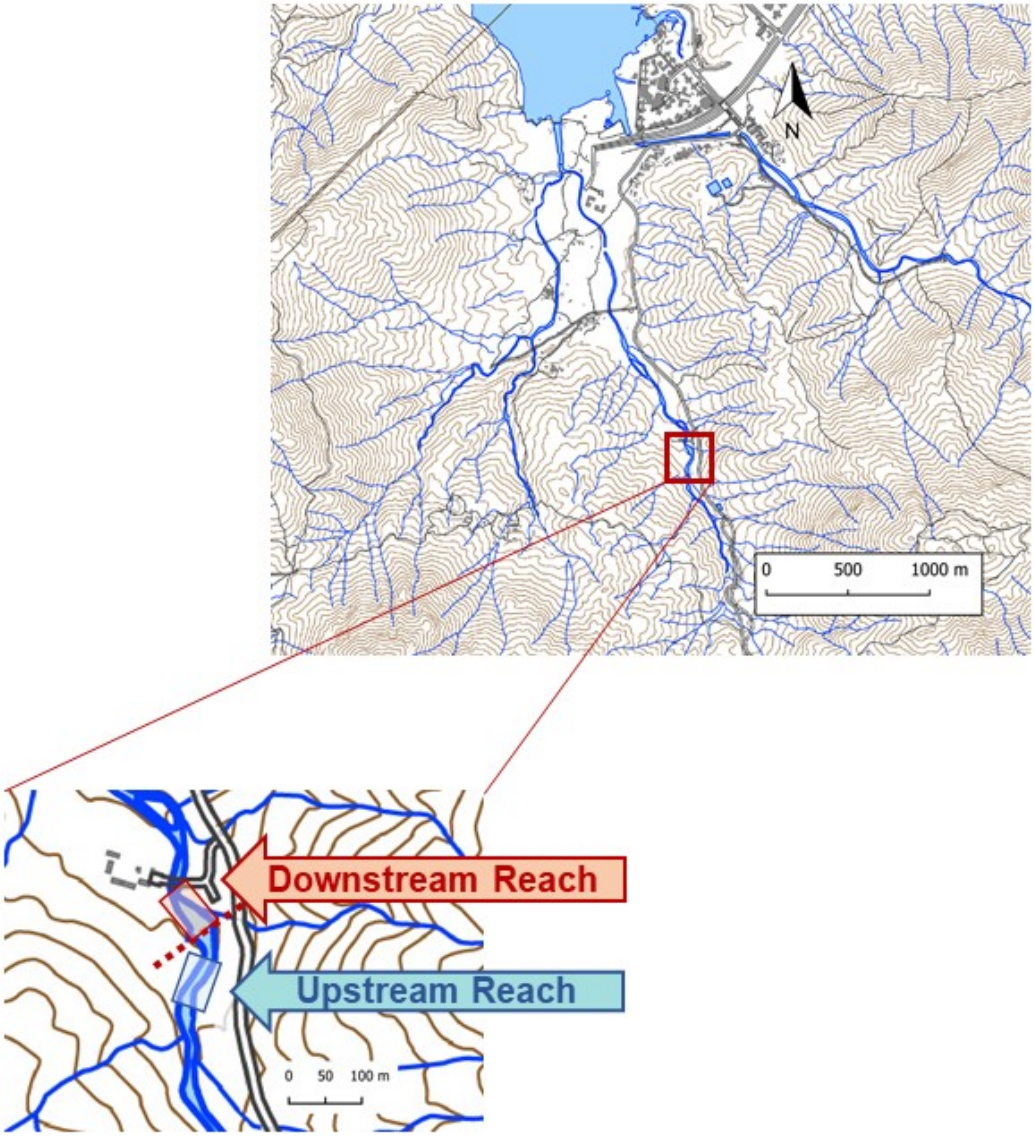

Figure 2.1. Location of study reaches upstream and downstream of Tung Chung Au water intake.

The study was conducted at Tung Chung Au water intake (22°15'44"N, 113°56'17"E, ~100m a.s.l.) along Tung Chung River East Stream (Figure 2.1). We surveyed two 50m study reaches, one upstream (the "upstream reach", Plate 3) and one downstream (the "downstream reach", Plate 4) of the water intake respectively.

Both study reaches had low canopy coverage (<30%) and surrounded by secondary forests and shrublands, with no obvious human settlements in the nearby riparian area except for AFCD's Tung Chung Au Management Office situated on the western bank of section downstream of the downstream reach. Channel substates of both reaches consisted of large boulders, cobbles and gravels.

2.2. Sampling Procedures

We surveyed freshwater fishes and adult aquatic insects four times along each study reach during each wet season (May-Sep) between 2018-2022 and each dry season (Nov-Mar) between 2018-2021, with each survey separated by at least 14 days to ensure data independency. Water quality were also surveyed once during each season, including dry season 2021-22. Both study reaches were surveyed for the same parameters on the same dates throughout the study.

2.2.1. Stream Attributes

We surveyed wetted width as well as water quality parameters including dissolved oxygen, specific conductance, pH and water temperature using a multiparameter meter (Pro Plus, YSI Inc., USA) along each study reach once during each wet and dry seasons, with three replicates of each parameter taken during the day.

2.2.2. Freshwater Fishes

During each survey, visual counts of fishes in each study reach were conducted using five randomly thrown quadrats (0.5 x 0.5m^2, Plate 5) and a viewing chamber. Counting was started at least 10 minutes after the deployment of the quadrats to minimize the effect of surveyor disturbance on the fishes. All fishes observed were identified to species and had their abundances recorded.

2.2.3. Adult Aquatic Insects

During each survey, adult aquatic insects were sampled using ultraviolet light traps, each consisted of two 15 cm-long 4W ultraviolet light tubes suspended over a white plastic tray (surface area = 33cm x 25cm, height = 9cm) containing 4cm stream water with two drops of detergent added (Plate 6). Two traps separated by at least 40m apart from each other were deployed for three hours after sunset. Trapping was avoided on nights when the moon was full, as this has been reported to reduce catches of some insect taxa (Wolda and Flowers 1985, Young 2005).

Captured insects were sieved through 0.5mm-mesh and preserved in 75% alcohol for storage before being processed in the laboratory. Aquatic insects from orders Ephemeroptera, Plecoptera and Trichoptera (EPT), which are widely considered as major benthic taxa sensitive to changes or degradation of water quality and habitat (Clements et al. 2000, Resh & Rosenberg 1993, Stone & Wallace 1998), were chosen as indicator taxa. Their abundance, biomass and diversity, among other metrics, were reported to be related to stream and riparian habitat and water quality (Clements et al. 2000, Collier et al 2009, Houghton 2006, Moya et al. 2007). Insects were sorted to order under 10X light-microscope and counted. Samples collected on three randomly selected survey dates in wet season 2020 and all samples from wet seasons 2021 and 2022 were identified down to family, sorted into morphospecies and counted to provide after-trial community data of the two reaches. We then obtained the dry mass of each order by oven-drying the samples at 60 °C for 48 hours.

2.3. Data Analysis

2.3.1. Defining Sampling Phases

Placement of GRP gratings as part of the water release trial was completed by WSD on 14th January 2019, thus immediately before the dry season survey of 2018-2019 started. To include more data collected before grating placement for before-and-after comparison of target taxa response, an extra set of data collected between late October 2017 and February 2018 (on four survey dates each separated by at least 14 days) using the same methods as above was included in the analysis. The sampling periods of dry season 2017-18 and wet season 2018 represent the conditions before the water release trial began. Consecutive wet and dry seasons starting from wet season 2019 represent periods after the water release trial started (Table 2.1).

	Before Trial		**After Beginning of Trial**							
Season	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Phase	2017-18	2018	2018-19	2019	2019-20	2020	2020-21	2021	2021-22	2022
Stream Attributes	*	*	*	*	*	*	*	*	*	*
Freshwater Fishes	*	*	*	*	*	*	*	*		*
Adult Aquatic Insects	*	*	*	*	*	*	*	*		*

Table 2.1. Sampling periods between 2017-2022, with the types of sampling conducted denoted by asterisks.

2.3.2. Freshwater Fishes

Density

Mean fish density along each study reach was calculated by averaging data on each survey date, with different survey dates taken as individual samples. Fish density was then compared between reaches and among sampling periods.

Community Composition

We tested the effects of reach, phase and their interaction on freshwater fish composition using permutational multivariate analysis of variance (PERMANOVA) with 999 permutations based on Bray-Curtis dissimilarity. We then visualize the differences between freshwater fish compositions using non-metric multidimensional scaling (NMDS) plots based on Bray-Curtis dissimilarity.

2.3.3. Adult Aquatic Insects

Abundance and Dry Weight

We calculated mean abundances and dry masses of the three target insect orders and their overall sums by averaging data of trap captures collected within each survey date, then compared the metrics between reaches and across phases.

Community Composition in Wet Seasons 2020 - 2022

We tested the effects of reach, phase and their interaction on adult aquatic insect composition of samples from wet seasons 2020 – 2022 at both the family and morphospecies levels using PERMANOVA with 999 permutations based on Bray-Curtis dissimilarity. The composition differences between reaches and phases are then visualized using NMDS plots based on Bray-Curtis dissimilarity.

As the presence of species represented only by a single individual in the dataset was likely due to chance (Queheillalt et al. 2002, Sgarbi & Melo 2018), such species were removed before the multivariate analysis. Homogeneity of multivariate dispersions between groups was checked prior to PERMANOVAs (Anderson, 2006). Post-hoc comparisons among groups were done by multilevel pairwise analysis using the “pairwise.adonis2()” function. All analyses were performed using R version 4.2.1 (R Development Core Team, 2022). Packages “vegan” (Oksanen et al. 2019) and “pairwiseAdonis” (Martinez 2020) were used for multivariate analysis and the associated post-hoc procedures respectively. Significant levels of statistical tests were set at $\alpha = 0.05$.

3. Results

3.1. Stream Attributes

Temporal patterns of water quality parameters were similar between reaches, despite larger within-reach variation along the downstream reach, as well as apparent inter-reach differences before and right after the water release trial and during dry seasons when flow was low (Figure 3.1). The downstream reach was generally lower and more varied in dissolved oxygen (minima occasionally dropped to below 5 mg/L, and reached 2.3mg/L during dry season 2018-19), slightly higher and occasionally more varied in terms of specific conductance, and lower in pH before wet season 2020. Day-time stream water temperature was occasionally higher along the downstream reach, which was on average 1.2-2.0°C warmer than the upstream reach in wet season 2019, dry season 2020-21 and dry season 2021-22. Mean stream wetted width difference between reaches was the lowest (400cm) in wet season 2019 when both reaches were low in wetted width, but remained between 460-710cm in the rest of the sampling periods. No consistent reduction of wetted width difference was observed after the water release trial.

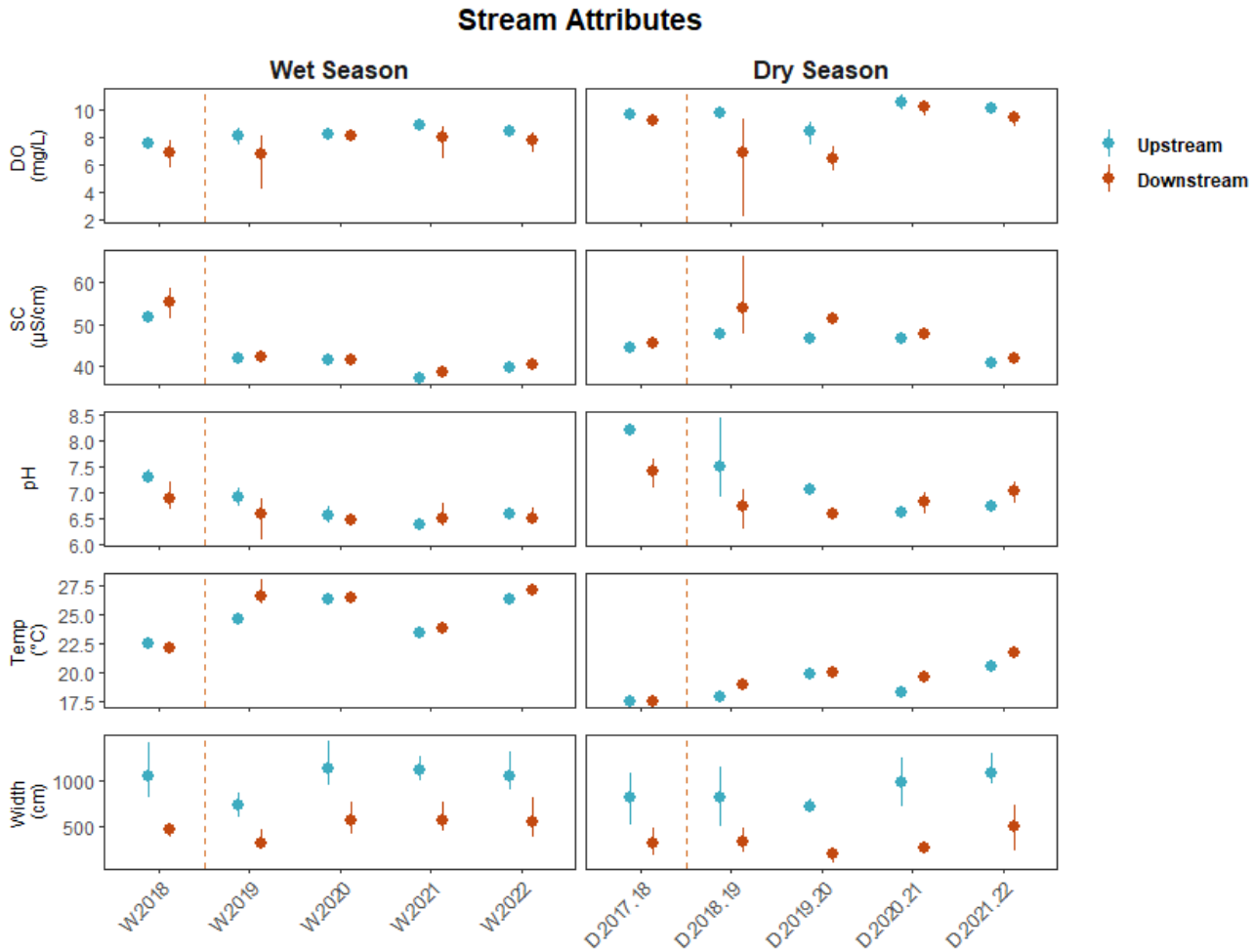

Figure 3.1. Stream attributes of the two study reaches recorded in different sampling periods. "DO" = dissolved oxygen, "SC"=specific conductance, "Temp"=water temperature, "Width"=wetted width . Data points denote mean values while upper and lower lines denote the ranges of the parameters. Orange dashed lines denote the start of water release trial.

3.2. Freshwater Fishes

A total of 1167 counts of 10 freshwater fishes were observed in the current study, with nine species observed along each study reach (Appendix 1). The upstream reach was mainly inhabited by native species typically found in pristine local hill streams, with over 90% of all fish captures composed of the pelagic Predaceous Chub (*Parazacco spilurus*) (47%) and four rheophilic benthic fishes, namely Broken-band Hillstream Loach (*Liniparhomaloptera disparis*), Sucker-belly Loach (*Pseudogastromyzon myersi*, Plate 7), Striped Loach (*Schistura fasciolata*) and White-cheeked Goby (*Rhinogobius duospilus*) (together made up 46% of upstream captures). The downstream reach was highly dominated by pelagic species preferring slow-flowing pools, mainly the invasive Swordtail (*Xiphophorus helleri*, 46%) and the native *P. spilurus* (44%); the rheophilic benthic fishes made up only about 3% of the overall captures downstream.

Three of the rheophilic benthic fishes, including *L. disparis*, *Ps. myersi* and *R. duospilus*, were recorded downstream only after wet season 2019 (1 year after the water release trial, Appendix 1). Their overall density downstream was the highest (>3 individuals / m^2) during dry season 2019-2020, but only attained ≤0.8 individual/m^2 in subsequent survey periods (Appendix 1). *Schistura fasciolata* was only observed along the upstream reach throughout the study.

Fish densities showed temporal variation along both reaches, with the inter-year variation particularly apparent for the downstream reach (Figure 3.2). The upstream reach was relatively low in fish density (<20 individuals / m^2 recorded on all survey dates) in both seasons, with the density being relatively stable across the wet seasons but showed a mild decreasing trend across the dry seasons (Figure 3.2). The downstream reach, on the other hand, showed a conspicuous decreasing trend in fish density across the wet seasons, but the metric increased across the dry seasons as it approached the end of the study (Figure 3.2). Examination of fish composition of the downstream reach reveals the high density was mainly due to high number of invasive *X. helleri* during the wet seasons before and right after the water release trial; during the last two dry seasons, however, the downstream captures were dominated by *P. spilurus* (Figure 3.2).

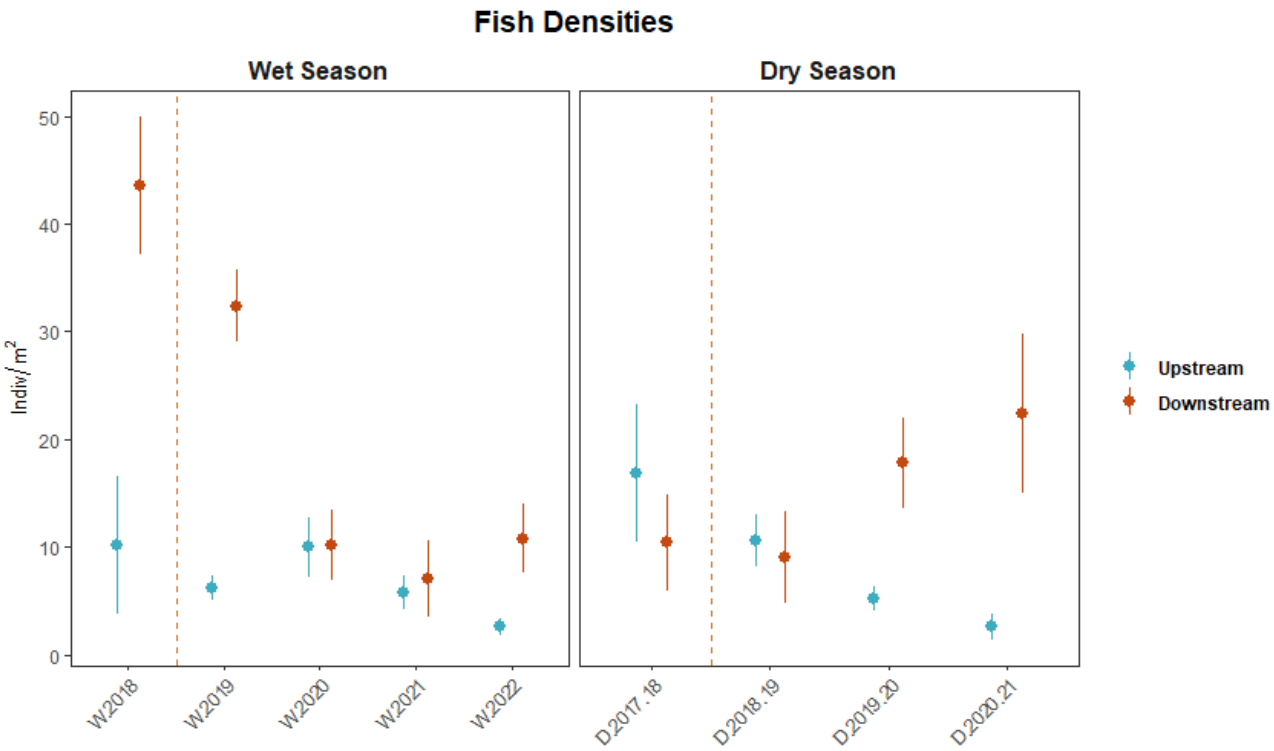

Figure 3.2. Mean freshwater fish densities (±SE) of the two study reaches recorded in different sampling periods. Orange line denotes the start of water release trial.

Results of two-way PERMANOVA showed significant effects of reach (wet season: *Pseudo-F* = 9.0123, *p*=0.001; dry season: *Pseudo-F* = 9.9273, p=0.001) and phase (wet season: *Pseudo-F* = 2.1398, *p*=0.006; dry season: *Pseudo-F* = 2.8927, p = 0.001) on fish composition (Table 3.1). Significant interaction was detected between the two factors (wet season: *Pseudo-F* = 2.2080, *p*=0.005; dry season: *Pseudo-F* = 3.2998, p = 0.002), suggesting the effect of reach differed among phases (Table 3.1). Multilevel pairwise analysis procedures showed fish composition differed between reaches before wet season 2019 (p_{adj}=0.023 – 0.031) but not there after (p_{adj} > 0.05).

NMDS biplots showed distinct reach-phase groups, with fish communities of the downstream reach being well separated from those of the upstream reach before dry season 2019-20, but became more similar to the latter in subsequent sampling periods (Figure 3.3). *Xiphophorus helleri* and the four rheophilic benthic fishes (*L. disparis*, *P. myersi*, *S. fasciolata* and *R. duospilus*) were apparent contributors of inter-reach differences. The two reaches became more similar when some of the rheophilic benthic fishes appeared and relative abundance of *X. helleri* decreased along the downstream reach starting from dry season 2019-20 (Figure 3.3).

	Wet Season					Dry Season				
	df	SS	R^2	Pseudo - F	p	df	SS	R^2	Pseudo - F	p
Reach	1	1.6664	0.1627	9.0123	0.001	1	1.6992	0.2010	9.9638	0.001
Phase	4	1.5826	0.1545	2.1398	0.002	3	1.4809	0.1752	2.8945	0.002
Reach x Phase	4	1.6331	0.1594	2.2080	0.003	3	1.6925	0.2002	3.2082	0.001
Residuals	29	5.3623	0.5234			21	3.5813	0.4236		

Table 3.1. Two-way PERMANOVA for testing the effects of reach, year and their interaction on freshwater fish composition. α=0.05.

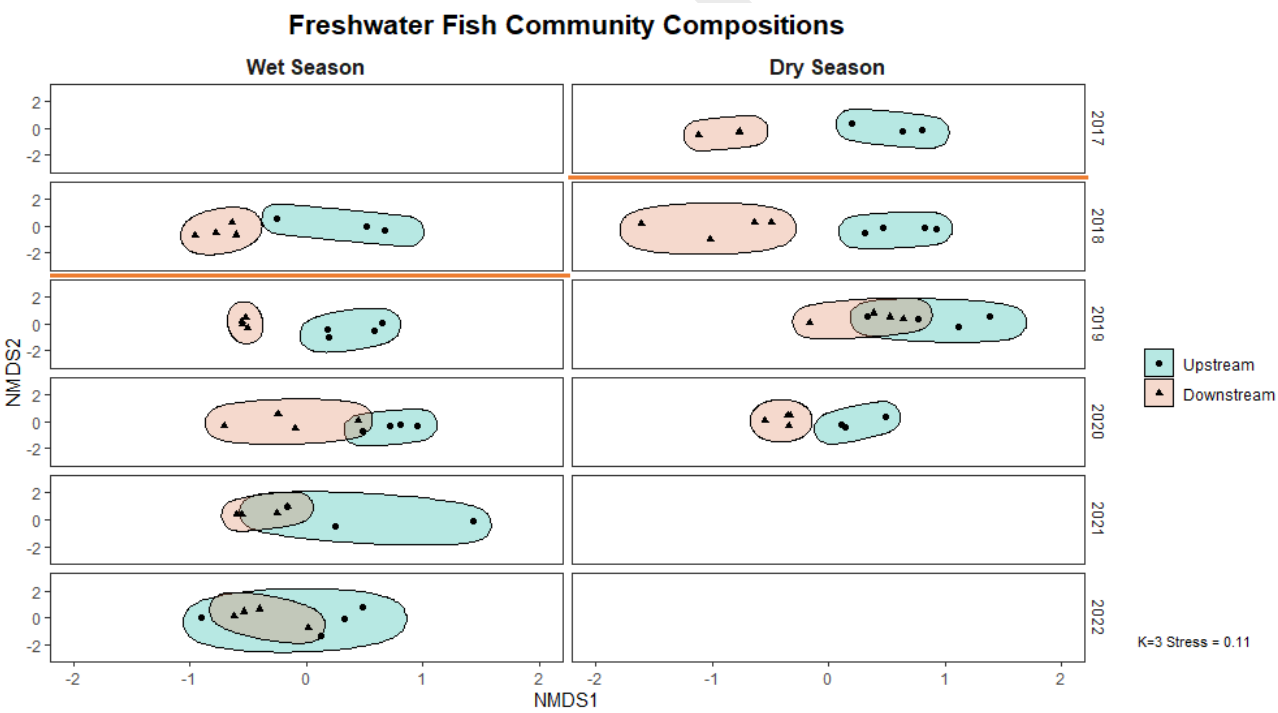

Figure 3.3. NMDS plots of freshwater fish compositions along the two study reaches during wet and dry seasons of different sampling periods. Orange lines denote the point before which are periods before the water release trial.

3.3. Adult Aquatic Insects

A total of 34624 target adult aquatic insects were captured during the study, with the majority of the captures (96%) collected during the wet season. Spatial-temporal patterns of overall EPT abundance and dry mass followed closely those of trichopterans (Figure 3.4), as the order constituted over 80% of the captures in terms of both abundance and dry mass during most of the survey periods. Ephemeropterans constituted 10% in terms of abundance and 7% in terms of dry mass, while plecopterans made up less than 0.2% in terms of abundance and 4% in terms of dry mass of the overall captures.

Overall EPT abundance was apparently higher along the upstream reach (mean abundance / trap ~ 400 individuals upstream vs 200 individuals downstream) before and right after the water release trial (Figure 3.4). Since wet season 2020, EPT abundance along the upstream reach showed a decreasing trend while that along the downstream reach attained relatively high levels similar to those of the upstream reach in previous sampling periods (Figure 3.4). Insect dry mass captured along the upstream reach appeared to decrease across phases while that along the downstream reach remained low (mean dry mass <0.2mg / trap) throughout the study (Figure 3.4).

A total of 18726 individuals (8566 individuals upstream and 10160 individuals downstream) of target insect taxa collected in wet seasons 2020 - 2022 were sorted into morphospecies for examination of aquatic insect community composition after the trial began. Fifty-eight morphospecies from 13 families (Table 3.2) were recorded, with 48 and 52 morphospecies observed in the upstream and downstream reaches respectively.

Results of two-way PERMANOVA showed no effect of reach but significant effect of phase at both family and morphospecies levels (family level: *Pseudo-F* = 2.5211, p=0.016; morphospecies level: *Pseudo-F* = 2.6368, p = 0.003) on adult aquatic insect composition; no interaction was detected between the two factors at both levels (Table 3.3). Multilevel pairwise analysis showed insect compositions differed between 2020 and each of the other two years (p_{adj} <0.02), but not between 2021 and 2022.

NMDS plots showed mild between-reach composition difference in wet season 2020 (Figure 3.5) when the upstream reach was characterized by higher relative abundances of baetid and leptophlebiid mayflies, and leptocerid and philopotamid caddisflies, while the downstream reach was featured by higher relative abundances of hydroptilid (Plate 8) and psychomyiid caddisflies during wet season 2020. The insect compositions of the two reaches became more similar in wet seasons 2021 and 2022 at both levels (Figure 3.5).

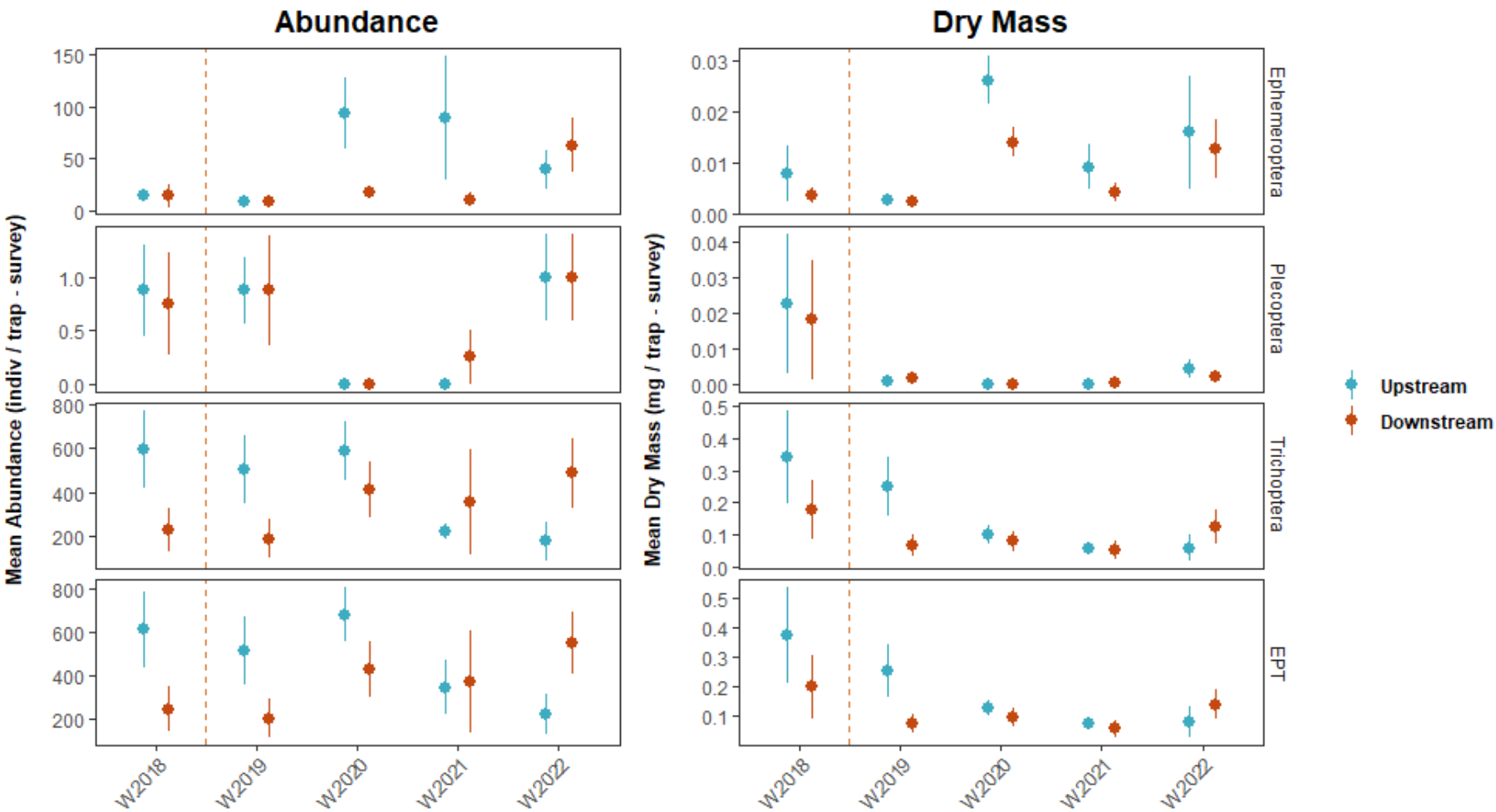

Figure 3.4. Mean abundance and dry mass (±SE) of adult aquatic insects captured in different wet seasons. Orange lines denote the start of the water release trial.

Order	Family	Upstream	Downstream
Ephemeroptera	Baetidae	9.4 (±2.3)	5.2 (±1.4)
	Ephemeridae	0.1 (±0.0)	0.0 (±0.0)
	Heptagendiidae	0.2 (±0.1)	0.4 (±0.2)
	Leptophlebiidae	14.2 (±7.7)	2.1 (±1.9)
Plecoptera	Leutridae	0.1 (±0.1)	0.1 (±0.0)
	Perlidae	0.0 (±0.0)	0.0 (±0.0)
Trichoptera	Calamoceratidae	0.1 (±0.1)	0.1 (±0.0)
	Hydropsychidae	16.1 (±1.3)	13.6 (±1.7)
	Hydroptilidae	9.0 (±1.9)	33.2 (±9.0)
	Lepidostomatidae	0.0 (±0.0)	0.0 (±0.0)
	Leptoceridae	19.5 (±6.3)	12.8 (±4.9)
	Odontoceratidae	0.1 (±0.0)	0.0 (±0.0)
	Philopotamidae	21.5 (±11.6)	16.0 (±7.4)
	Psychomyiidae	9.7 (±1.7)	16.5 (±3.8)
	Stenopsychidae	0.0 (±0.0)	0.0 (±0.0)

Table 3.2. Mean relative abundance in % (±SE) of adult aquatic insects captured in wet seasons 2020 - 2022.

	Family Level					Species Level				
	df	SS	R^2	Pseudo - F	p	df	SS	R^2	Pseudo - F	p
Reach	1	0.1898	0.0512	1.2661	0.257	1	0.2243	0.0498	1.2348	0.239
Phase	2	0.7557	0.2040	2.5211	0.016	2	0.9579	0.2126	2.6368	0.003
Reach x Phase	2	0.3614	0.0976	1.2056	0.283	2	0.4174	0.0926	1.1489	0.294
Residuals	16	2.3980	0.6473			16	2.9062	0.6450		

Table 3.3. Two-way PERMANOVA for testing the effects of reach, phase and their interaction on adult aquatic insect composition at family and species levels. α=0.05.

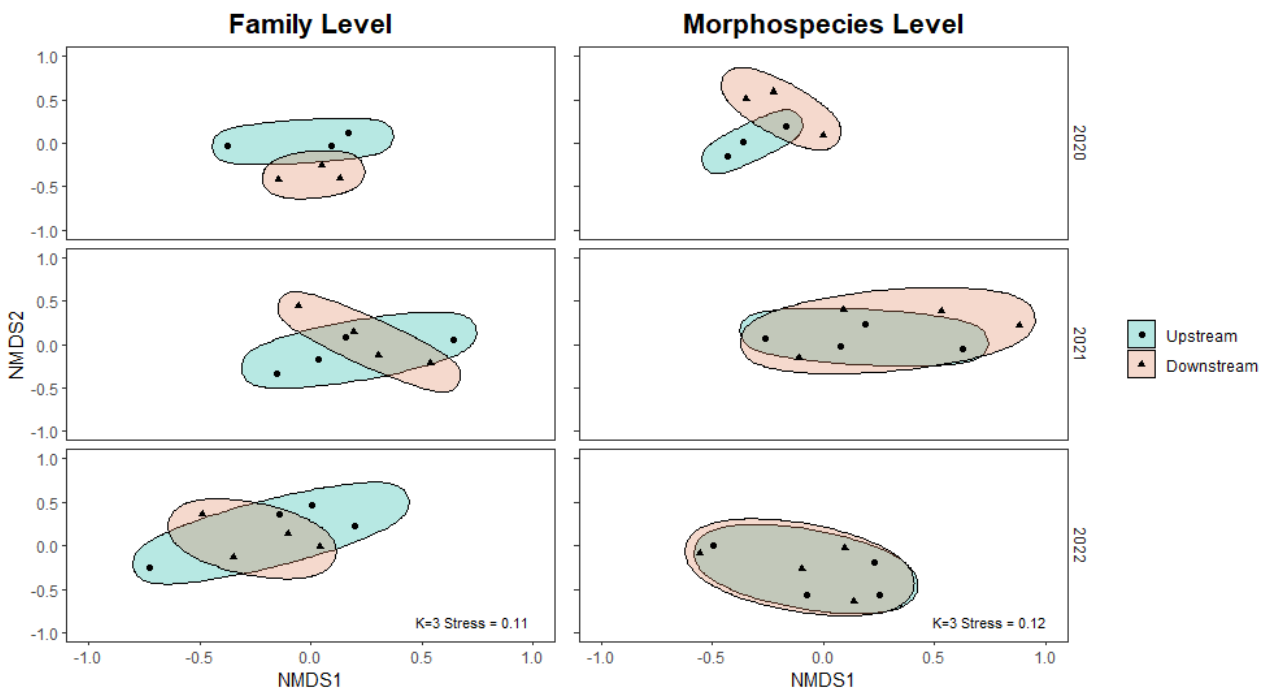

Figure 3.5. NMDS plots of adult aquatic insect compositions at family and morphospecies levels along the two study reaches captured in wet seasons 2020, 2021 and 2022.

4. Discussion

4.1. Water Abstraction Altered Stream Attributes

4.1.1. Abiotic Attributes

Stream water quality parameters showed apparent difference between the study reaches before and right after the water release trial as well as during the dry season when flow was low. Low DO levels were detected along the downstream reach. This could be the results of both reduced circulation of oxygen through decreased aeration, and increased consumption of oxygen during decomposition of accumulated organic matter, and may be exemplified under higher temperatures when stream water carrying capacity of DO is reduced by insolation. Water quality was surveyed during the day in the current study, and we anticipate DO levels would be even lower at night when stream autotrophs including algae and cyanobacteria carry out respiration instead of photosynthesis and consume oxygen. As the growth of these autotrophs may be enhanced by reduced flow (Biggs 2000, Biggs & Close 1989, Stevenson 1990), diurnal fluctuation in DO may be more prominent downstream of the water intake. The downstream reach was also slightly higher and more variable in specific conductance, and lower in pH levels before and right after the trial. This accorded with observations in low-flow sections in some previous studies (Caruso 2002, Kinzie et al. 2006, McIntosh et al. 2002) and may be attributed to decreased dilution of ions or accumulation of degrading organic matter when flow was low. Slightly higher temperatures were recorded downstream even in periods near the end of the study, as in some streams with reduced flows compared with reference sections in other studies (Meier et al. 2003, Rader and Belish 1999). Under water abstraction, the volume of the water column downstream may be reduced, and thus is more prone to heating up by sunlight during the day, leading to higher water temperatures as observed in the current study.

Although water quality downstream showed signs of recovery after the water release trial, occasional deviation of some parameters from those upstream of the water intake still occurred near the end of the study. It should be noted that the wetted width of the downstream reach was still obviously lower than that of the upstream reach even during the last wet and dry seasons, and a large portion of its channel floor was still covered by terrestrial vegetation when the last round of survey was completed, indicating ample room for improvement in abiotic attributes of the downstream reach even after four years since the trial started.

4.1.2. Biotic Attributes

Dewatering reduced the size of downstream habitats (Stanley et al. 1997, Brasher 2003), and may be a major reason for the higher density of freshwater fishes detected along the downstream reach. In addition, suitable habitats may be reduced for some species but increased for others by the reduced flow (Gore et al. 2001), thus causing changes in community composition. Reduced flow is particularly detrimental to rheophilic taxa, as reported in studies in local (Niu & Dudgeon 2011) and foreign streams (Englund et al. 1997, McIntosh et al. 2002). Slower flows alter physiochemical attributes of streams, thus reducing the abundance of rheophilic taxa and their importance as the community switches to one which is lentic or more tolerant to altered conditions (Cortes et al. 2002). This accords with the observed absence of fishes commonly found in local hill streams along the downstream reach

before and right after the water release trial, and the fact that these species only started to appear in the section one year after the trial started. The dominance of the invasive Swordtail, which is known to tolerate a wide range of environmental conditions, including low dissolved oxygen level (Magalhães & Jacobi 2013), and is highly reproductive (Milton & Arthington 1983), along the downstream reach before the water release trial further suggests that alteration of streamflow may alter stream community composition by selecting more tolerant species.

The composition of freshwater fishes became more similar between reaches when the rheophilic species appeared, and the dominance of the invasive Swordtail dropped when the relative abundance of the native Predaceous Chub increased along the downstream reach one year after the beginning of water release trial. Although the relative abundance of the rheophilic benthic species remained low until the end of the study, and the dominance of the Swordtail started to be shared by a native species of a similar niche (a pelagic species preferring slower-flowing regions such as pools), the results of the study suggest signs of recovery in terms of freshwater fish compositions along the downstream reach.

The abundance of adult aquatic insect downstream increased since wet season 2020 to levels similar to those of the upstream reach before and right after the trial, and this was accompanied by a decreasing trend in abundance upstream as the study progressed. Although the reason for the latter was unclear, the result showed potential recovery in aquatic insect abundance in the latter part of the study. Examination of adult aquatic insect composition since wet season 2020 also revealed general similarity between reaches, especially during the last two wet seasons.

The general between-reach differences in abundance and composition of stream fauna before dry season 2019 - 2020 indicated lagged responses of the stream community to the water release trial. The reduction in such differences in later sampling periods, however, suggested the stream fauna responded to the water release treatment, although there are still room for recovery.

4.2. Limitations of the Current Study and Way Forward

The concept of “environmental flow” has long been developed to determine the quantity, quality and pattern of river flows needed to sustain core ecological processes and functions of lotic systems as well as human wellbeing (Richter et al. 1997, Davies et al. 2014, Arthington et al. 2018). Conditions of biota in intercepted sections relative to their counterparts in natural sections change with various degree of water abstraction (Poff & Zimmerman 2010). The current study determined the effectiveness of a water release method with limited control over the amount of water to be released downstream. Discharge along the downstream reach was highly dependent on the availability of sufficient flow upstream, which in turn determined the amount of stream water allowed to bypass the intake via the grooved GRP gratings passively. Also, the flow rates of the study reaches, the major driver of changes in abiotic and biotic attributes in the intercepted stream, were not measured in the current study as no sensitive flow meter was available. Although the current study could indicate how the presence of GRP gratings had contributed to the recovery of the abiotic and biotic components downstream during the study period, the results cannot be translated to flow-ecological relationships, making it hard to replicate the method in streams of different sizes and flow regimes, or even predict

its effectiveness at the same location when flow conditions and patterns vary.

Nonetheless, the current study reveals that biotic and abiotic components of the downstream reach became more similar to those upstream near the end of the study, and provides evidence that the stream community has potential to recover after flow was, even when only partially, restored. Continuous monitoring of these components is needed to confirm how the stream community responds in the long run, and further studies which can establish relationships between actual restored flow and degree of recovery would be required if the water release method is to be adapted to other streams in the region.

4.3. Conclusion

The current study shows that water abstraction at Tung Chung Au water intake had significantly altered stream abiotic and biotic attributes in the downstream section. Dewatering caused changes in stream water quality and physical attributes, which may in turn alter organism densities, overall abundance and community structure via reduction of habitat size and selection of more tolerant species. The water release trial conducted through the placement of GRP gratings which allow stream water to bypass the water intake since January 2019 appeared to result in initial improvement of water quality and recovery of the stream community, although such changes only occurred at least one year after the trial started. Continuous monitoring and more detailed studies are needed to confirm the long-term responses of the abiotic and biotic components, and how the method could be better evaluated or adapted to other streams in the region.

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Plates

Plate 1. Original concrete gratings covering the intake tunnel to Shek Pik Reservoir.

Plate 2. Grooved glass-reinforced plastic (GRP) gratings were installed to replace the original concrete gratings on 14th January 2019.

Plate 3. Environment along the upstream reach.

Plate 4. Environment along the downstream reach.

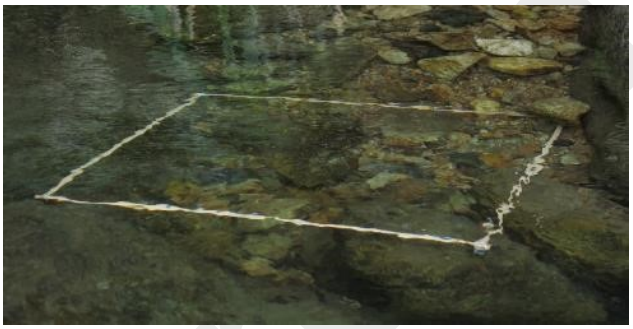

Plate 5. Quadrats (0.5 x 0.5m^2) used for visual counts of freshwater fishes.

Plate 6. Ultraviolet light traps used for capturing adult aquatic insects.

Plate 7. Sucker-belly Loach (*Pseudogastromyzon myersi*) was recorded along the downstream reach one year after the trial started.

Plate 8. Hydroptilid caddisflies were relatively more abundant along the downstream reach.

Appendix

Family	Species	Common Name	Upstream									Downstream								
			2017-18	2018	2018-19	2019	2019-20	2020	2020-21	2021	2022	2017-18	2018	2018-19	2019	2019-20	2020	2020-21	2021	2022
			Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Wet
Cobitidae	*Misgurnus anguillicaudatus*	Oriental Weatherfish	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)	0.2 (±0.2)	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)
Cyprinidae	*Acrossocheilus beijiangensis*	Beijiang Thick-lipped Barb	0.4 (±0.2)	0.2 (±0.2)	0.4 (±0.2)	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)	0.6 (±0.4)	0.2 (±0.2)	0.6 (±0.4)	0.0 (±0.0)	0.0 (±0.0)	0.2 (±0.2)	0.2 (±0.2)	0.2 (±0.2)	0.4 (±0.2)	2.2 (±0.9)	0.2 (±0.2)	0.2 (±0.2)
Cyprinidae	*Parazacco spilurus*	Predaceous Chub	10.2 (±3.9)	5.8 (±2.8)	3.4 (±1.3)	2.2 (±0.6)	2.0 (±1.2)	4.6 (±1.8)	0.6 (±0.4)	3.4 (±1.5)	0.6 (±0.4)	0.6 (±0.4)	4.4 (±2.0)	3.6 (±3.1)	18.4 (±3.3)	12.8 (±3.4)	5.2 (±1.7)	17.6 (±6.9)	3.6 (±1.0)	5.4 (±2.4)
Cyprinidae	*Puntius semifasciolatus*	Chinese Barb	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)	0.2 (±0.2)	0.0 (±0.0)	0.2 (±0.2)	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)	1.6 (±0.7)	2.6 (±1.2)	0.0 (±0.0)	1.4 (±0.9)	0.0 (±0.0)	1.0 (±1.0)	0.2 (±0.2)	0.0 (±0.0)	0.0 (±0.0)
Gastromyzontidae	*Liniparhomaloptera disparis*	Broken-band Hillstream Loach	1.6 (±1.3)	2.8 (±2.8)	3.4 (±1.3)	0.6 (±0.4)	1.6 (±0.7)	0.8 (±0.5)	0.0 (±0.0)	0.2 (±0.2)	0.4 (±0.2)	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)	2.8 (±1.2)	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)
Gastromyzontidae	*Pseudogastromyzon myersi*	Sucker-belly Loach	2.2 (±1.4)	0.6 (±0.4)	1.0 (±0.8)	0.8 (±0.6)	1.2 (±0.4)	1.8 (±0.6)	0.2 (±0.2)	0.4 (±0.2)	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)	0.4 (±0.2)	0.2 (±0.2)	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)
Nemacheilidae	*Schistura fasciolata*	Striped Loach	0.2 (±0.2)	0.0 (±0.0)	0.4 (±0.4)	0.2 (±0.2)	0.0 (±0.0)	1.6 (±0.6)	0.0 (±0.0)	1.2 (±0.8)	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)
Oxudercidae	*Rhinogobius duospilus*	Stream Goby	2.0 (±1.1)	0.6 (±0.4)	2.0 (±0.2)	1.2 (±0.5)	0.4 (±0.4)	1.0 (±0.2)	1.2 (±1.0)	0.0 (±0.0)	0.4 (±0.2)	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)	0.2 (±0.2)	0.4 (±0.2)	0.2 (±0.2)	0.0 (±0.0)	0.8 (±0.8)
Poeciliidae	*Xiphophorus hellerii*	Swordtail	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)	0.8 (±0.8)	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)	0.2 (±0.2)	0.2 (±0.2)	8.0 (±4.0)	35.6 (±7.1)	5.0 (±1.5)	12.0 (±1.4)	1.4 (±1.4)	3.0 (±2.3)	2.0 (±0.8)	3.2 (±2.7)	4.4 (±1.9)
Siluridae	*Pterocryptis anomala*	Nim	0.0 (±0.0)	0.2 (±0.2)	0.0 (±0.0)	0.2 (±0.2)	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)	0.2 (±0.2)	0.4 (±0.4)	0.0 (±0.0)	1.0 (±0.5)	0.2 (±0.2)	0.4 (±0.4)	0.0 (±0.0)	0.0 (±0.0)	0.2 (±0.2)	0.0 (±0.0)	0.0 (±0.0)
Total. No. of Species		**10**	**6**	**6**	**6**	**8**	**4**	**6**	**4**	**7**	**6**	**4**	**4**	**4**	**5**	**6**	**6**	**6**	**3**	**4**

Mean densities (±SE) (indiv / m^2) of freshwater fishes recorded along the two study reaches in different survey periods.