Gardens' Bulletin Singapore 70 (Suppl. 1): 123–153. 2018
doi: 10.26492/gbs70(suppl.1).2018-07

Diversity, distribution and habitat characteristics of dragonflies in Nee Soon freshwater swamp forest, Singapore

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ABSTRACT. Biodiversity baselines were established for dragonflies of Nee Soon freshwater swamp forest based on quantitative sampling across the eight sub-catchments. Surveys were conducted from December 2014 to April 2016. Hydrological, physiochemical parameters and habitats were analysed to identify the main drivers structuring the dragonfly community. A total of 1706 odonate specimens were recorded, comprising 49 species of 34 genera in 11 families. The species diversity in each sub-catchment was compared using the Shannon-Wiener Index (H'). Hierarchical clustering and Detrended Correspondence Analysis (DCA) indicated that three main groupings of sites existed, each with a distinct community of associated species. Further analysis by Canonical Correspondence Analysis (CCA) with 12 significant environmental variables showed that these groups were significantly associated with respective environmental variables. Principal Components Analysis (PCA) was performed to analyse the full 23 environmental variables. The first four principal components of the PCA explained 63% of the variation in all the environmental variables. These four axes were input as independent variables into an Ordinary Least Square (OLS) model to test the significance of the link between habitat characteristics and diversity of the dragonfly community. Threats to the odonate fauna of the freshwater swamp forest are identified and conservation management measures are discussed.

Keywords. Community structure, ecology, Odonata, statistical analysis

Introduction

Nee Soon freshwater swamp forest (Fig. 1) is the only primary freshwater swamp forest left in Singapore and is a critical refuge for a large number of Red Listed plant and animal species threatened with national extirpation (Ng & Lim, 1992; Clews et al., 2018). It represents the remaining section of a larger freshwater swamp forest that once existed between Upper Seletar Reservoir and Mandai Road (Corner, 1978; Turner, 1996) and may now be threatened by anthropogenic activities in the surrounding areas. The streams in Nee Soon catchment are shaded and have shallow waters flowing over clay, sand, or mud. Their pH is more acidic than other forest streams due to the decomposition of accumulated leaf litter and woody debris (Ng & Lim, 1992).

Additionally, the soil in Nee Soon freshwater swamp forest is anaerobic and unstable due to periodic flooding (Nguyen et al., 2018). All these factors have resulted in a diverse flora and fauna that are adapted to these unusual conditions. However, it also means that these habitat specialists are sensitive to environmental disturbances such as changes in the drainage system, introduction of non-indigenous species, soil erosion, and disturbances from development (Ng & Lim, 1992; Yeo & Chia, 2010).

Odonates (Order: Odonata) are of increasing applied research interest as potential biological indicators and tools for ecological modelling (Bried & Samways, 2015). They are relatively well known taxonomically and the adults are easy to identify (Simaika & Samways, 2012; Kutcher & Bried, 2014). Hence they are good ecological indicators for the assessment of aquatic environments, especially for wetland and stream quality as they occupy the interface between aquatic and terrestrial ecosystems and are highly sensitive to environmental changes (Carvalho et al., 2013; Monteiro-Júnior et al., 2013; Oliveira-Junior et al., 2015). There is also a major division within the order in terms of the ecophysiological requirements of different species (De Marco et al., 2015). Members of the sub-order Anisoptera (dragonflies) are more useful indicators of degraded environments because they have more efficient homeostatic mechanisms and are more mobile, enabling them to tolerate a wider range of environmental conditions. By contrast, members of the sub-order Zygoptera (damselflies) tend to provide a more useful role as indicators of more preserved environments and higher levels of environmental heterogeneity because of their smaller body sizes, home ranges and greater ecophysiological restrictions (Oliveira-Junior et al., 2015). The structure of odonate communities can shift predictably in response to changes in local environmental conditions (Corbet, 1999; Juen et al., 2007; Juen & De Marco, 2011; Luke et al., 2017).

To date most studies of odonates in Singapore have been taxonomic accounts. There is very little available data on their distribution and abundance in Nee Soon freshwater swamp forest . Murphy (1997) reported Odonata biodiversity in the nature reserves of Singapore by comprehensively reviewing the historical account and providing a list of species found in Singapore. He briefly discussed the distribution and habitat preferences for some of species and, from his list, only 15 species were specified as occurring within the location of Nee Soon, of which eight species were confined to Nee Soon freshwater swamp forest (other widely distributed species might have been found there without being mentioned specifically) Norma-Rashid et al. (2008) updated the list of dragonflies in Singapore, and identified 35 more species from Nee Soon. Tang et al. (2010) further updated the list, with 17 more species occurring at Nee Soon. Cheong et al. (2009) and Dow & Ngiam (2011) added two more species for Nee Soon. Munirah (2013) conducted a biodiversity assessment of Nee Soon freshwater swamp forest aquatic insects and recorded 15 species of larvae from eight odonate families.

In this study, we aim to establish the most up-to-date knowledge on odonate diversity for Nee Soon freshwater swamp forest with an emphasis on abundance. The study may be read in conjunction with the sampling of aquatic insects by Su (2016) and aquatic macroinvertebrates (including odonate larvae) by Ho et al. (2018) concurrent with our study. We also investigate any distinct spatial distribution within

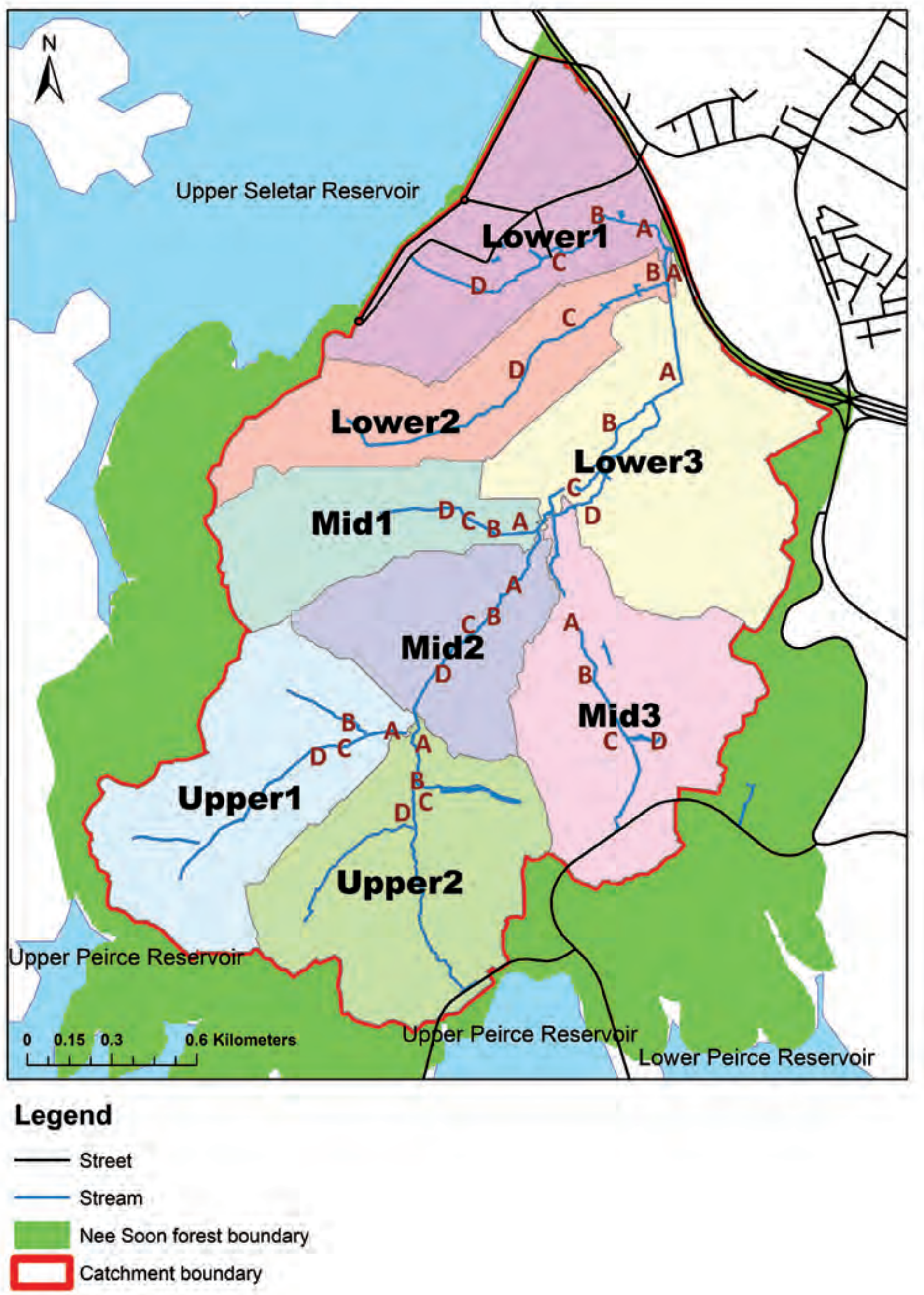

Fig. 1. Sub-catchments and drainage map with spatial survey sites.

the freshwater swamp forest; and the environmental variables that may influence such patterns. From the results, we attempt to identify threats to odonates in Nee Soon and recommend conservation measures.

Methodology

Quantitative environmental and spatial survey

A total of 36 sites were surveyed across all eight sub-catchments of the Nee Soon catchment (see Nguyen et al., 2018; Sun et al., 2018), together with a separate stream system that flowed into Lower Peirce Reservoir representing a comparable sub-catchment adjacent to Nee Soon freshwater swamp forest. For each sub-catchment, four sampling stations were selected at intervals from lower stream to upper stream. The locations were chosen based on how representative of available habitats each was in that sub-catchment, together with considerations of accessibility. Study sites were named and ordered alphabetically according to the location of the site within the sub-catchments of Nee Soon, starting from the lower to the upper reaches.

Surveys were conducted from December 2014 to April 2016. Hydrological, physiochemical and habitat characteristics were recorded to analyse environmental factors that may determine the associated odonate community. Samplings of odonates were conducted between 10:30 and 13:00 h mostly during sunny weather conditions. For each location, sightings were recorded over 30 minutes along a 20 m transect of the stream and 3 m of riparian zone on either side of the stream bank. The transect was surveyed at a slow pace along the stream channel, counting every individual either perched or in flight. Species that could not be identified with certainty by sight were caught with an insect net and released after identification. Occasionally, unidentified specimens were collected for further examination.

To further investigate the habitat characteristics of the odonate fauna, which has a life cycle involving an aquatic larval stage and a terrestrial adult stage, a number of physical and biological characteristics of the stream were quantified. Stream parameters were measured using measuring tape, a multiparameter and a flow meter. Hydraulic parameters measured included stream dimension (depth, width), proportion of pools and riffles, in-stream woody debris, macrophytes, leaf litter, and substrate (sand, silt, clay and rock). Physiochemical parameters recorded included pH, Dissolved Oxygen (DO), Oxidation-Reduction Potential (ORP), Total Dissolved Solids (TDS), Salinity (S), and Temperature (T). Riparian vegetation heterogeneity, bank form, and canopy cover were also assessed and recorded for all quantitative survey sites. The stream cross-section of each site was measured multiple times to obtain the average values. The surrounding habitat types, i.e. swamp, open canopy and distance to forest edges were also recorded (see appendix 2 for details).

Identifications of adults were primarily based on Tang et al. (2010) and Orr (2005). Taxonomic classification follows Schorr & Paulson (2017). Local species updates and conservation status follow Ngiam & Cheong (2016).

Odonate larvae were caught and identified to the family level. Specimens were caught by tray net sampling, moving upstream and disturbing the water. These specimens were caught together with other aquatic insect specimens and preserved in 75% ethanol for microscopic examination. These collections were separate from and supplementary to those of Ho et al. (2018).

Qualitative surveys
Additional species not otherwise recorded during the quantitative surveys were included to compile a full species list. Species spotted during reconnaissance trips were also added to provide a comprehensive updated inventory for Nee Soon freshwater swamp forest.

Data analysis
All data were analysed using Palaeontological Statistics (PAST 3.15) (Hammer, 2017). Three of the 36 sites were not included in the analysis due to incomplete environmental data. Habitat parameter data were transformed either by square root or by log (x+1). The community count data was log (x+1) transformed before analysis.

The Shannon-Weaver Index (H') was used as a measurement of species diversity. The index is calculated as , where p_i is the proportion of individuals found of species *i* and *n* is the total number of species. Species Richness (R) refers to the number of species found at each site.

Ward's hierarchical clustering using Bray-Curtis dissimilarities was carried out according to abundance and species composition of the odonate assemblage to examine if there were any natural groupings in the data. The results of the cluster analysis were overlaid onto other multivariate analysis plots to indicate graphical representation of groupings in the community. The significance of the groupings was then tested using Non-parametric Multivariate Analysis of Variance (PERMANOVA).

Detrended correspondence analysis (DCA) was carried out to show the distribution of odonate communities across all sites. DCA is a multivariate statistical technique widely used by ecologists to find the main factors or gradients in the large, species-rich but usually sparse data matrices that typify ecological community data. Canonical correspondence analysis (CCA) (Legendre & Legendre, 1998) was performed to determine correlations between odonata abundance and environmental parameters. CCA is correspondence analysis of a site/species matrix where each site has given values of environmental variables. The ordination axes are linear combinations of the environmental variables. CCA is thus an example of direct gradient analysis, where the gradient in environmental variables is known a priori and the species abundances are considered to be a response to this gradient (Hammer, 2017). The CCA model significance was tested using a Monte Carlo permutation test (1000 iterations). Environmental variables were filtered through a Multivariate Liner Regression model where each individual environmental variable was treated as one independent variable and the raw scope of the two DCA Axes (DCA 1 & DCA 2) were loaded as dependent variables. Results of the regression indicate how relevant the given environmental variable is in driving the overall gradient order of site and species. Selection of the variables was then based on the statistical results of R square and *p* value (*F*-test).

Principal components analysis (PCA) was applied to analysis of the 23 environmental variables. The results were used to summarise environmental conditions. The significant axes were determined by eigenvalues which are expected to be above a random model (Broken Stick) curve (Jackson, 1993; Hammer, 2017). These significant axes (in this case the first four, which explained 63% of the variation in the environmental data) were retained and analysed. The four axes were then input as independent variables into an Ordinary Least Square (OLS) model to test the significance of the link between habitat characteristics and diversity of the odonate community, represented by Shannon-Weaver Index (H') and Species Richness (R). Spatial autocorrelation and homoscedasticity of the residuals were investigated with a Durbin-Watson test and Breusch-Pagan test respectively. The significant PCA axes were then further examined to understand the major environmental variables influencing the community diversity.

Results

Abundance and diversity of odonates in Nee Soon

A total of 1706 odonate specimens were sampled, comprising 49 species of 34 genera in 11 families. The suborder Zygotera was represented by 1014 individuals, distributed in seven families (Argiolestidae, Calopterygidae, Chlorocyphidae Coenagrionidae, Euphaeidae, Platycnemididae, and Platystictidae), 14 genera and 22 species. Suborder Anisoptera contributed 702 individuals, distributed in four families (Aeshnidae, Gomphidae, Libellulidae and Macromiidae), 20 genera and 27 species. *Prodasineura* was the most abundant Zygopteran genus (n=552 specimens) followed by *Pseudagrion* (n=111). *Neurothemis* was the most abundant Anisopteran genus (n=334) followed by *Orthetrum* (n=138). Relative species richness per survey site varied from two to 13, mean abundance of individuals recorded per survey site varied from three to 106. An updated species list of Nee Soon freshwater swamp forest odonates, with 68 species of 47 genera in 11 families could be found in appendix 1.

1. Distribution of odonates within Nee Soon freshwater swamp forest

The species found in each of the sub-catchments are summarised in Table 1. The most widely distributed species was *Prodasineura notostigma* which was present at 21 of the 32 sites, distributed across all the eight sub-catchment regions. *Prodasineura interrupta* and *Orthetrum chrysis* were found at seven of the eight sub-catchments in Nee Soon. Fourteen species were only found from one sub-catchment viz, *Libellago lineata* (LP), *Podolestes orientalis* (L2), *Argiocnemis rubescens* (L2), *Pseudagrion australasiae* (L2), *Pseudagrion pruinosum* (L1), *Anax guttatus* (LP), *Macrogomphus quadratus* (M1), *Acisoma panorpoides* (L1), *Crocothemis servilia* (L1), *Nannophya pygmaea* (L3), *Orchithemis pulcherrima* (L1), *Pseudothemis jorina* (L2) *Rhyothemis obsolescens* (L2), and *Trithemis festiva* (L1).

2. Spatial variation in odonate abundance, species richness and diversity

The species richness and abundance of odonates in each sub-catchment were summed up from the four sampling stations and the total results are presented in Fig. 2. Species richness is further analysed by the average value of the four sampling sites within each sub-catchment (Fig. 3). Among the eight sub-catchments, the three middle sub-catchments all showed low abundance and species richness whereas the three lower

Table 1. Abundance and distribution of odonates in Nee Soon (+++: Very Common (> 10) ++: Common (5-10); + : Uncommon (< 5); - : Not present (0)). *Species found in the qualitative survey.

	Species	Common name	L1	L2	L3	M1	M2	M3	U1	U2	LP
	Argiolestidae										
1	*Podolestes orientalis*	Blue-spotted Flatwing	-	+	-	-	-	-	-	-	-
	Calopterygidae										
2	*Vestalis amoena*	Charming Flashwing	-	+	++	-	++	+	++	+	-
3	*Vestalis amethystina*	Common Flashwing	-	-	+	-	+	-	-	+	-
	Chlorocyphidae										
4	*Libellago aurantiaca*	Fiery Gem	-	+	++	+	++	-	++	++	-
5	*Libellago lineata*	Golden Gem	-	-	-	-	-	-	-	-	+
6	*Libellago hyalina*	Clearwing Gem	-	+	+	-	-	-	-	-	-
	Coenagrionidae										
7	*Agriocnemis femina*	Variable Wisp	+++	+	-	-	-	-	-	-	-
8	*Amphicnemis gracilis*	Will-o-wisp	-	-	+	+	-	+	++	+	-
9	*Archibasis viola*	Violet Sprite	-	+	++	-	-	-	-	-	-
10	*Argiocnemis rubescens*	Variable Sprite	-	+	-	-	-	-	-	-	-
11	*Ceriagrion cerinorubellum*	Ornate Coraltail	+	-	++	-	-	-	-	+	-
12	*Pseudagrion australasiae*	Look-alike Sprite	-	+	-	-	-	-	-	-	-
13	*Pseudagrion microcephalum*	Blue Sprite	+++	+	+	-	-	-	-	-	+++
14	*Pseudagrion pruinosum*	Grey Sprite	+	-	-	-	-	-	-	-	-
	Euphaeidae										

Table 1. Continuation.

	Species	Common name	L1	L2	L3	M1	M2	M3	U1	U2	LP
15	*Euphaea impar*	Blue-sided Satinwing	-	-	+	-	+	+	+	+	-
	Platycnemididae										
16	*Coeliccia octogesima*	Telephone Sylvan	-	+	-	-	-	+	-	-	-
17	*Copera marginipes*	Yellow Featherlegs	+	-	-	-	+	+	-	-	++
18	*Prodasineura collaris*	Collared Threadtail	++	+	++	-	-	-	-	-	-
19	*Prodasineura humeralis*	Orange-striped Threadtail	+++	++	+	-	-	+++	-	-	+++
20	*Prodasineura interrupta*	Interrupted Threadtail	+	+	+	+	+++	-	+++	+++	-
21	*Prodasineura notostigma*	Crescent Threadtail	+	++	++	+	+++	++	+++	+++	-
	Platystictidae										
22	*Drepanosticta quadrata*	Singapore Shadowdamsel	-	-	-	+++	-	++	-	+	-
	Aeshnidae										
23	*Anax guttatus*	Emperor	-	-	-	-	-	-	-	-	+
24*	*Tetracanthagyna plagiata*	Giant Hawker					+			+	
	Gomphidae										
25	*Ictinogomphus decoratus*	Common Flangetail	+	+	-	-	-	-	-	-	++
26	*Macrogomphus quadratus*	Forktail	-	+	-	+	-	-	-	-	-
27	*?Paragomphus capricornis*	Banded Hooktail	-	-	-	-	-	-	-	+	-
	Libellulidae										
28	*Acisoma panorpoides*	Trumpet Tail	+	-	-	-	-	-	-	-	-
29	*Brachydiplax chalybea*	Blue Dasher	+	+++	+	-	-	+	-	-	-

Table 1. Continuation.

30	*Cratilla metallica*	Dark-tipped Forest Skimmer	+	+	-	-	-	-	-	-	-
31	*Crocothemis servilia*	Common Scarlet	+	-	-	-	-	-	-	-	-
32	*Lathrecista asiatica*	Scarlet Grenadier	+	+	+	+	-	-	-	-	-
33	*Nannophya pygmaea*	Scarlet Pygmy	-	-	+	-	-	-	-	-	-
34	*Neurothemis fluctuans*	Common Parasol	+++	+++	++	-	-	++	-	-	+++
35	*Orchithemis pulcherrima*	Variable Sentinel	+	-	-	-	-	-	-	-	-
36	*Orchithemis pruinans*	Blue Sentinel	-	+	+	+	-	-	-	-	-
37	*Orthetrum chrysis*	Spine-tufted Skimmer	++	++	++	+	-	++	+	+	+++
38	*Orthetrum glaucum*	Common Blue Skimmer	+	+	-	-	-	+	-	-	-
39	*Orthetrum sabina*	Variegated Green Skimmer	-	+	-	-	-	-	-	-	+
40*	*Orthethrum testaceum*	Scarlet Skimmer	+	+							
41	*Pseudothemis jorina*	Banded Skimmer	-	+	-	-	-	-	-	-	+
42	*Rhodothemis rufa*	Common Redbolt	+	+	-	-	-	-	-	-	++
43	*Rhyothemis obsolescens*	Bronze Flutterer	-	+	-	-	-	-	-	-	-
44	*Rhyothemis phyllis*	Yellow-Barred Flutterer	+	++	-	-	-	-	-	-	+
45	*Rhyothemis triangularis*	Sapphire Flutterer	-	+	-	-	-	-	-	-	-
46	*Trithemis aurora*	Crimson Dropwing	++	-	-	-	-	-	-	-	+++
47	*Trithemis festiva*	Indigo Dropwing	+	-	-	-	-	-	-	-	-
48	*Tyriobapta torrida*	Treehugger	-	++	+	-	-	-	-	-	-
	Macromiidae										
49	*Epophthalmia vittigera*	Pond Cruiser	+	-	+	-	+	-	+	-	-

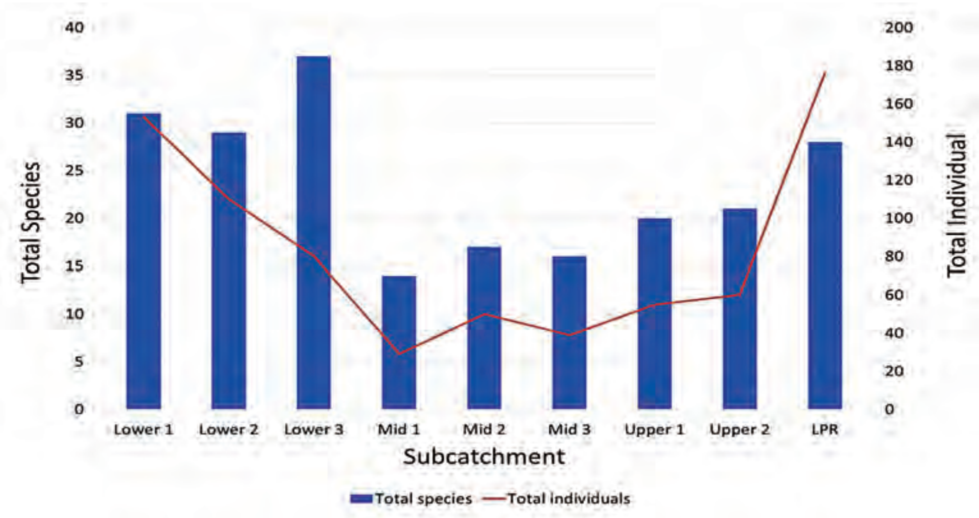

Fig. 2. Species richness and abundance graph of odonates at various sub-catchments.

sub-catchments had high abundance and species richness. The comparative site in Lower Peirce sub-catchment had the highest abundance and relatively high species richness. Mean species richness ranged from 3.5 to 9.25 species/site with the highest mean species richness at Lower 3 and the lowest at Mid 1.

The mean species diversity at each sub-catchment was plotted using Shannon-Wiener Index (H’) (Fig. 4). Lower 3, with H’ value of 0.88, had the greatest species diversity among the sub-catchments, while Mid 1, with H’ value of 0.46, had the lowest species diversity.

Odonate larvae

Larvae were collected together with aquatic fauna surveys. The specimens were identified to family level. Table 2 shows the mean abundance of larvae collected from each survey site. The most abundant family was that of Libellulidae, with a total of 33 identified at six of the eight sites surveyed.

Distribution pattern and habitat characteristics

Hierarchical clustering (Fig. 5) and DCA (Fig. 6) indicated that three main groupings of sites existed, each with a distinct community of associated species. Based on one-way PERMANOVA test, all groups different significantly from each other (p=0.0001). Further analysis by CCA (Fig. 7, Table 4) with 12 significant environmental variables which were selected based on a multivariate liner regression model test (Table 3). Results showed that these groups were significantly associated with several environmental variables. The first group of sites are mostly located at the outskirts of the Nee Soon freshwater swamp forest, including Lower 1 A, B, C; Lower 2 A, B; Lower 3 D and LPS. Species representative to this group were mainly *Neurothemis fluctuans*, *Acisoma parnorpoides*, *Trithemis festiva*, *Cratilla metallica*, *Pseudagrion*

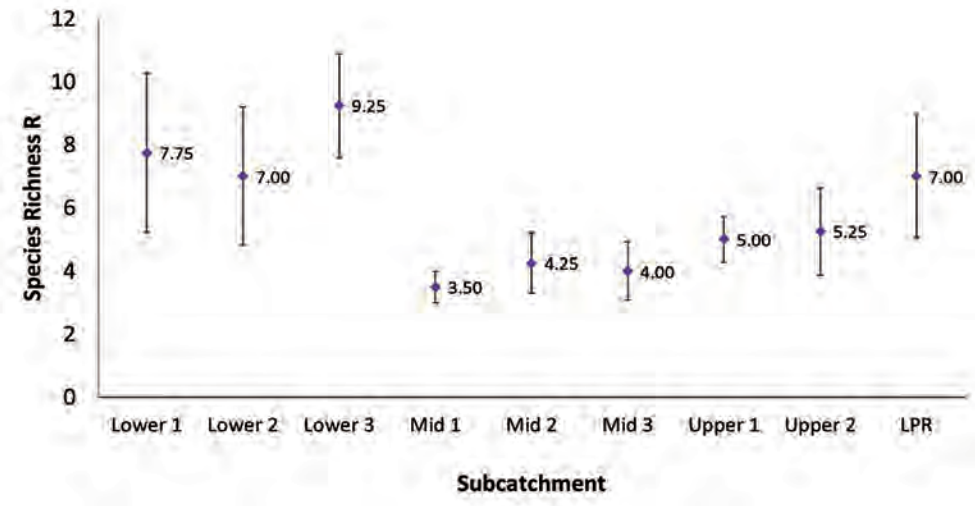

Fig. 3. Mean species richness graph of odonates at various sub-catchments (N=4, Error Bar=±1 SE).

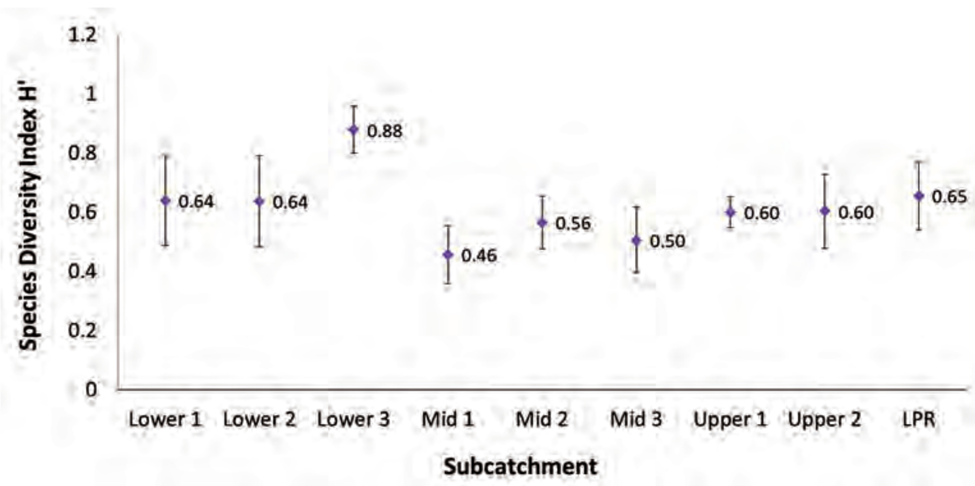

Fig. 4. Mean species diversity index graph of odonates at various sub-catchments (N=4, Error Bar=±1 SE).

microcephalum, *Ceriagrion cerinorubellum*, *Trithemis aurora*, *Ictinogomphus decoratus*, and *Prodasineura humeralis*. Most of these species are open canopy species. Environmental variables that best described this group are locations at or close to forest edges (-FE) or/and open area (-OA), with less riparian canopy cover (-RCA), stream water with high temperature (Tem), high pH, and low ORP, stream with deep water channel. The second group of sites are mostly located along the main stream (stem channel) at the central or middle part of the Nee Soon catchment. Species

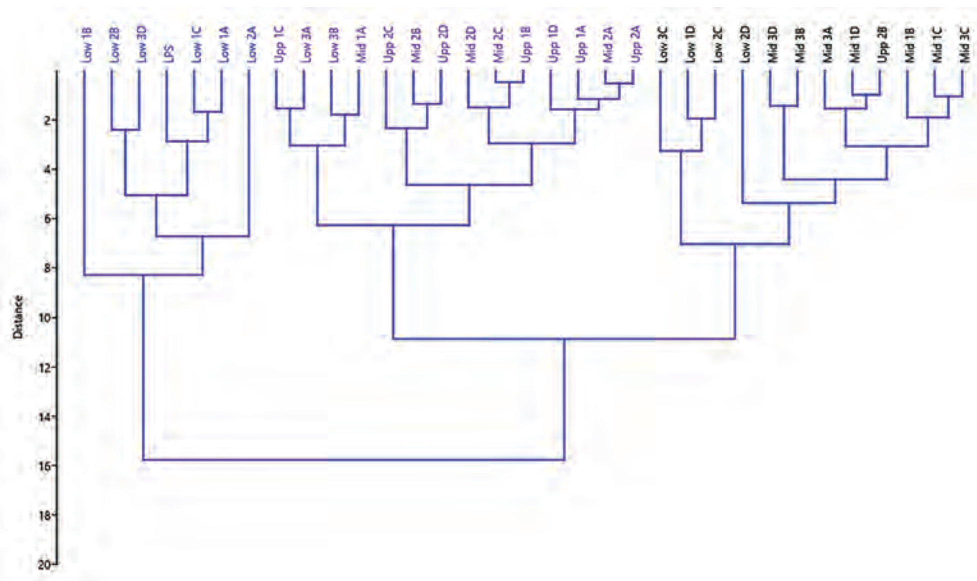

Fig. 5. Hierarchical clustering of sites according to odonate assemblage. Three clusters were recognised, colour coded in blue, purple and black.

Table 2. Species composition and mean abundance of odonate larvae at each site in Nee Soon: +++ Very Common (> 5); ++ Common (1-5); + Uncommon (< 1); - Not present (0);

	Site							
Family / Species	**Low1C**	**Low2B**	**Low3C**	**Low3D**	**Mid2A**	**Mid3C**	**Up1C**	**Up2C**
Zygoptera								
Calopterygidae	-	+	-	-	-	-	-	-
Chlorocyphidae	-	+	-	-	-	-	-	+
Coenagrionidae	+++	+	+	+	-	-	-	-
Euphaeidae	-	-	-	-	-	-	-	-
Platycnemididae	+	-	-	-	-	-	-	-
Platystictidae	-	-	-	-	-	-	-	-
Protoneuridae	+	-	-	-	-	-	-	-
Anisoptera								
Aeshnidae	+	+	-	+	+	-	+	-
Gomphidae	-	-	+	-	++	+	+	+
Libellulidae	+++	-	+	+++	+	-	+	+

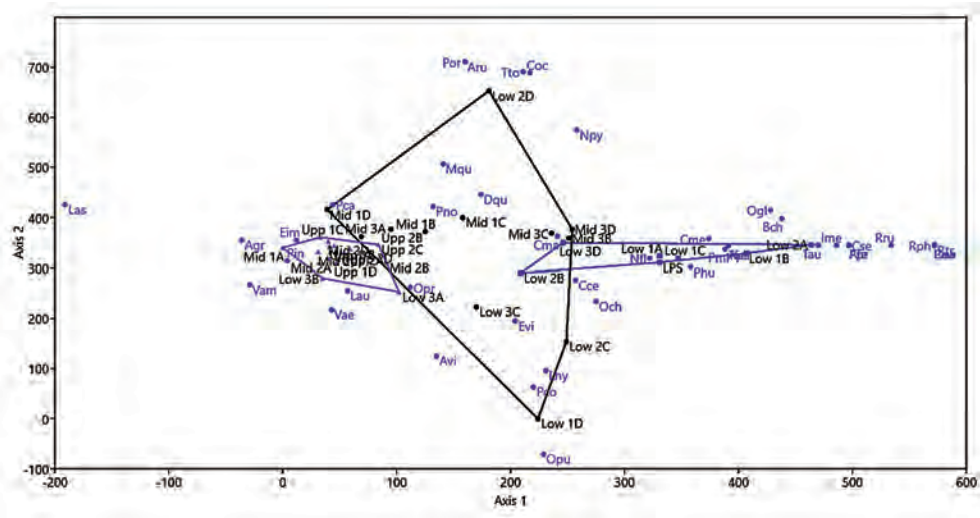

Fig. 6. Detrended correspondence analysis (DCA) results showing the distribution of odonate communities across all sites. Sites are grouped into group 1 in blue, group 2 in purple and group 3 in black corresponding to results of cluster analysis. (Please refer to Appendage 2 for abbreviation and sites and species).

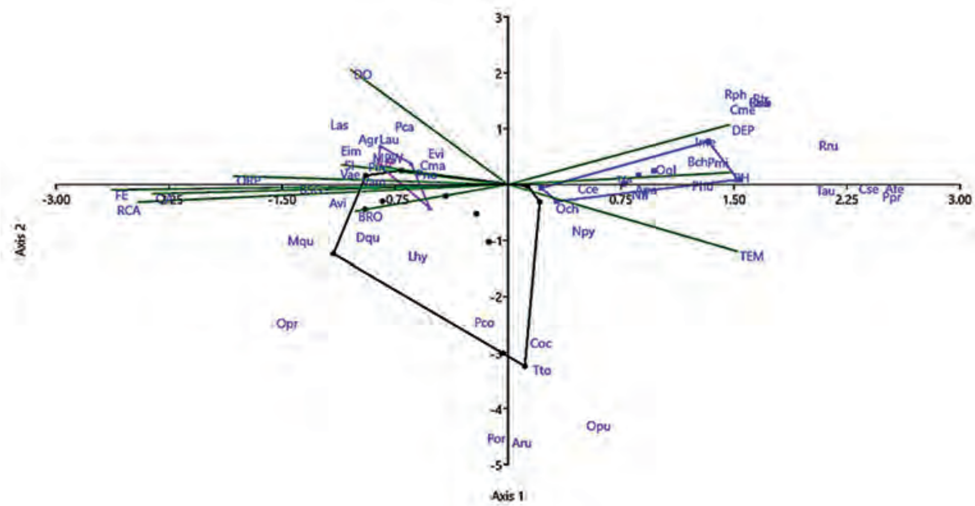

Fig. 7. Canonical correspondence analysis (CCA) results showing correlations between odonate abundance and the environmental parameters. Sites are grouped into group 1 in blue, group 2 in purple and group 3 in black corresponding to results of cluster analysis. (Please refer to Appendage 2 for abbreviation and sites and species).

Table 3. A summary of the multivariate linear regression model performed on environmental variables at Nee Soon against the raw scope of the first two DCA axes. Listed here only the significant environmental variables.

	RCA	FE	OA	TEM	ORP	DO	PH	DEP	SI	BSG	BRO	MPW
R squares	0.312	0.321	0.280	0.222	0.159	0.120	0.123	0.093	0.063	0.063	0.055	0.054
p-value	0.000	0.000	0.000	0.000	0.006	0.018	0.020	0.041	0.128	0.169	0.210	0.224

Table 4. A summary of eigenvalues, percentage (%) of total variation represented and p value of permutation test for the first four axes resulting from the CCA for odonates at Nee Soon freshwater swamp forest.

Axis	Eigenvalue	Percentage %	Permutation (*p*)
1	0.6294	26.24	0.003
2	0.4757	19.83	0.018
3	0.3258	13.58	0.091
4	0.2211	9.216	0.315

association included *Euphaea impar, Prodasineura interrupta, Libellago aurantiaca, Vestalis amethystina, Vestalis amoena* and *Amphicnemis gracilis*. All these are typical forest damselfly species. Environmental variables that best described this group were stream water with high DO, stream channel with high amount of in-stream macrophytes and woody debris, stream substrate with high proportion of silt, and with low water temperature and high ORP. The third group of sites are mostly found at headwater areas of various stream branches; dominant species in this group are *Drepanosticta quadrata, Prodasineura notostigma, Orchithemis pruinans, Prodasineura collaris, Libellago hyalina, Copera marginipes*. Environmental variables associated with this group were locations away from forest edges and open areas, with high riparian canopy cover, stream banks with significant adventitious roots into water, shallow water depth with low pH. The ordination points for this group of sites were spread out, with small areas of overlap. The majority of survey sites were in the second and third group, which covers most of the Nee Soon catchment. In terms of species composition and associated environmental variables, the three groups were very distinct from each other.

Principal components analysis (PCA) was performed to analysis the 23 environmental variables (Fig.8. The results were used to summarise environmental conditions for Nee Soon odonates. The significant axes were determined by percentage of eigenvalues which are expected to be above a random model (Broken Stick) curve (Fig. 9). The first four principal components of the PCA explained 63% of the variation in all the environmental variables (Table 5). PC 1 explained the 26% of the total environmental variation, was positively correlated to distance from forest edges

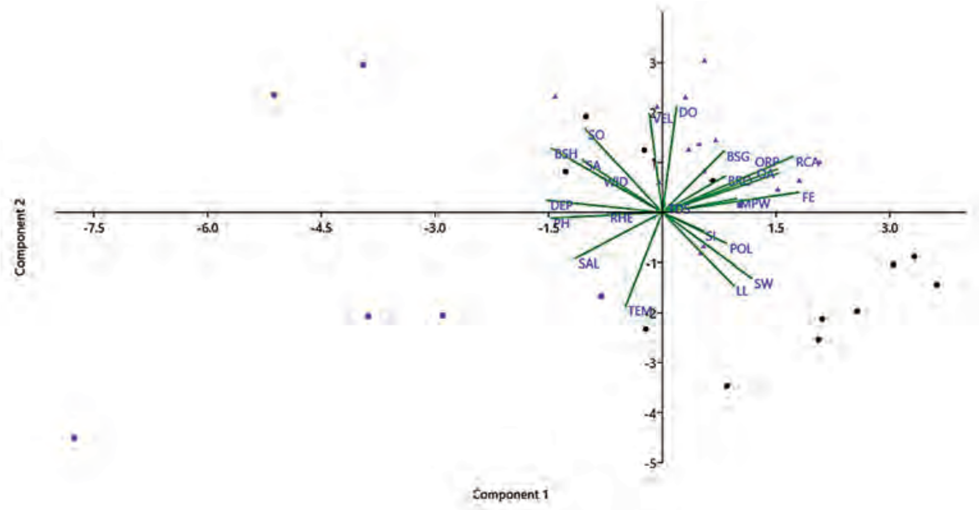

Fig. 8. Principal components analysis (PCA) results showing the loading of the 23 environmental variables to the first two PC axes. Square (blue): sites in group 1; Triangle (purple): sites in group 2, round (black): sites in group 3.

(FE), riparian canopy cover (RCA), distance to open area (OA), and stream water with high value of ORP, but negatively correlated to water depth, water with high pH and stream with steep bank shape. PC 2 explained 17% of the total environmental variation, and was positively correlated with water DO, stream velocity and stream order, but negatively correlated with water temperature (Tem) and high levels of leaf litter (LL) in the substrate. PC 3 explained 11% of the total environmental variation, and was positively correlated with existence of pools in water channel and stream substrate with high amount of silt, but negatively correlated with stream substrate with high amount of sand and stream bank with overhanging tree root. PC 4 explained 9% of the total environmental variation, and was positively correlated with riparian vegetation heterogeneity, in-stream macrophytes, woody debris and negatively correlated with silt substrate.

These four axes were input as independent variables into an Ordinary Least Square (OLS) model to test the significance of the link between habitat characteristics and diversity of the odonate community, represented by Shannon-Weaver Index (H') and Species Richness (R). Spatial autocorrelation and homoscedasticity of the residuals were investigated with Durbin-Watson test and Breusch-Pagan test respectively.

OLS results (Table 6, Fig. 10–12) show that only PC 1 and 3 are significantly correlated with overall odonate diversity in Nee Soon freshwater swamp forest. PC 1 was negatively correlated with both Species Diversity Index and with Species Richness, while PC3 was positively correlated with only Species Diversity index H'. Its correlation with Species Richness was rejected due to high spatial autocorrelation. In summary, distance from forest edge, canopy cover of the riparian vegetation, distance from nearby open area, shallow water depth, water with high ORP reading, water with

Table 5. A summary of eigenvectors of each environmental variable, eigenvalues, percentage (%) of variance explained by the first four axes resulted from the PCA for odonates at Nee Soon freshwater swamp forest.

Environmental variable	Abbreviation	PC 1	PC 2	PC 3	PC 4
Acidity	pH	-0.277	-0.022	0.050	-0.173
Dissolved oxygen (%)	DO	0.035	0.399	0.124	0.066
Stream velocity	VEL	-0.032	0.373	-0.038	-0.159
Stream width	WID	-0.153	0.134	0.261	-0.235
Stream depth	DEP	-0.288	0.046	0.226	-0.024
Macrophytes and Woody Debris	MPW	0.185	0.052	0.204	0.417
Leaf litter (%)	LL	0.177	-0.275	-0.010	-0.069
Sand (%)	SA	-0.198	0.197	-0.352	0.158
Silt (%)	SI	0.103	-0.070	0.341	-0.402
Bank shape	BSH	-0.276	0.243	0.077	-0.080
Bank with hanging root	BRO	0.157	0.137	-0.330	0.209
Bank covered with shrub and grass	BSG	0.154	0.231	0.174	0.028
Riparian vegetation heterogeneity	RHE	-0.138	-0.001	0.279	0.506
Riparian canopy cover	RCA	0.325	0.211	-0.186	-0.040
Stream order	SO	-0.192	0.314	0.181	-0.027
Distance from forest edge	FE	0.341	0.076	-0.027	-0.018
Distance from nearby open area	OA	0.290	0.148	-0.132	-0.148
Distance from nearby swampy area	SW	0.223	-0.248	0.141	-0.214
Oxidation-Reduction Potential	ORP	0.287	0.163	0.256	0.148
Total Dissolved Solids	TDS	0.008	0.033	0.091	0.220
Salinity	SAL	-0.217	-0.174	-0.131	0.150
Temperature	TEM	-0.092	-0.352	-0.016	0.147
Pool (%)	POL	0.160	-0.118	0.402	0.171
	Eigenvalue	6.056	3.823	2.613	1.961
	% variance	26.328	16.621	11.363	8.525

low pH value, stream with low angle smooth bank and stream surrounded by swampy area primarily explained the low diversity and richness of the odonate community in most of Nee Soon freshwater swamp forest. The presence of pool habitats, substrate with more silt, less sand, less overhanging root in stream bank, high heterogeneity of riparian vegetation and the wider channel will partially explain the high diversity level of odonates in the outskirts and open areas of the Nee Soon freshwater swamp forest.

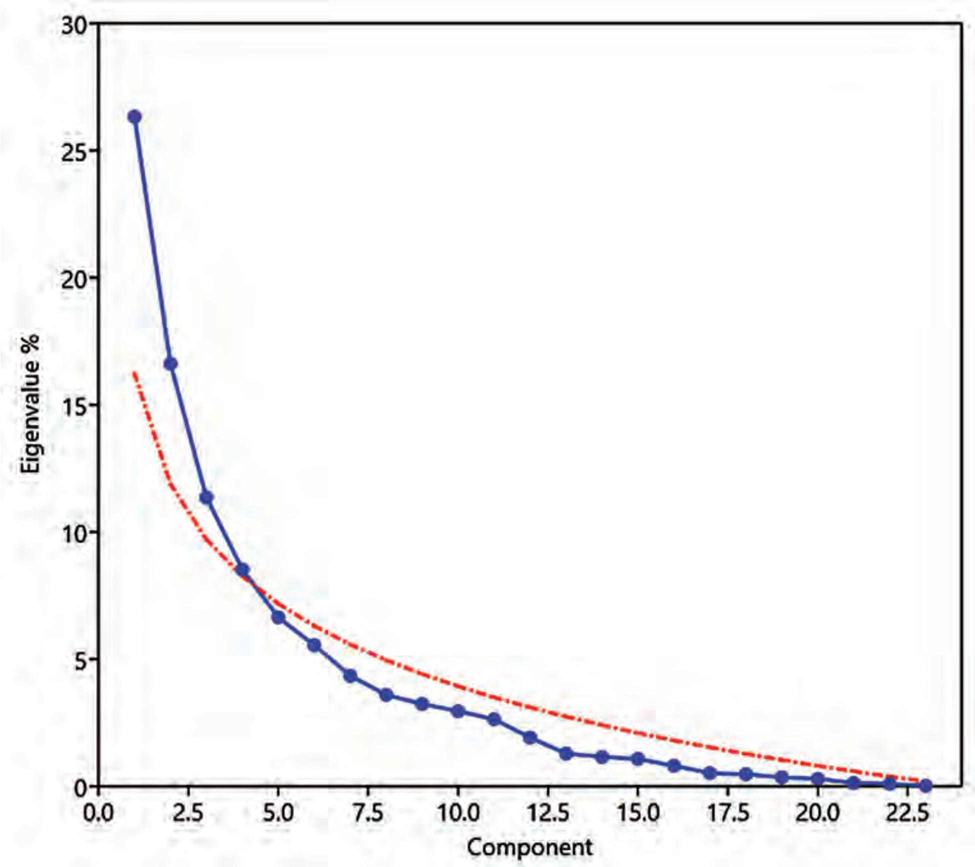

Fig. 9. Scree plot with a random model (broken stick), indicating that only the first four PCAs are statistically significant.

Table 6. Result of Ordinary Least Square (OLS) test on the significance of the link between habitat characteristics represented by the four PC axes and diversity of the odonate community at sampling locations in Nee Soon freshwater swamp forest, represented by Shannon-Weaver Index (H') and Species Richness (R).

	PC1		**PC2**		**PC3**		**PC4**	
	H'	R	H'	R	H'	R	H'	R
Permutation *p*	0.0093	0.0005	0.9271	0.3365	0.0082	0.013	0.2936	0.3787
Durbin-Watson test *p*	0.32	0.0913	0.3122	0.0995	0.4073	0.0055	0.1725	0.0115
Breusch-Pagan test *p*	0.649	0.164	0.0642	0.00395	0.2938	0.3069	0.9548	0.6238

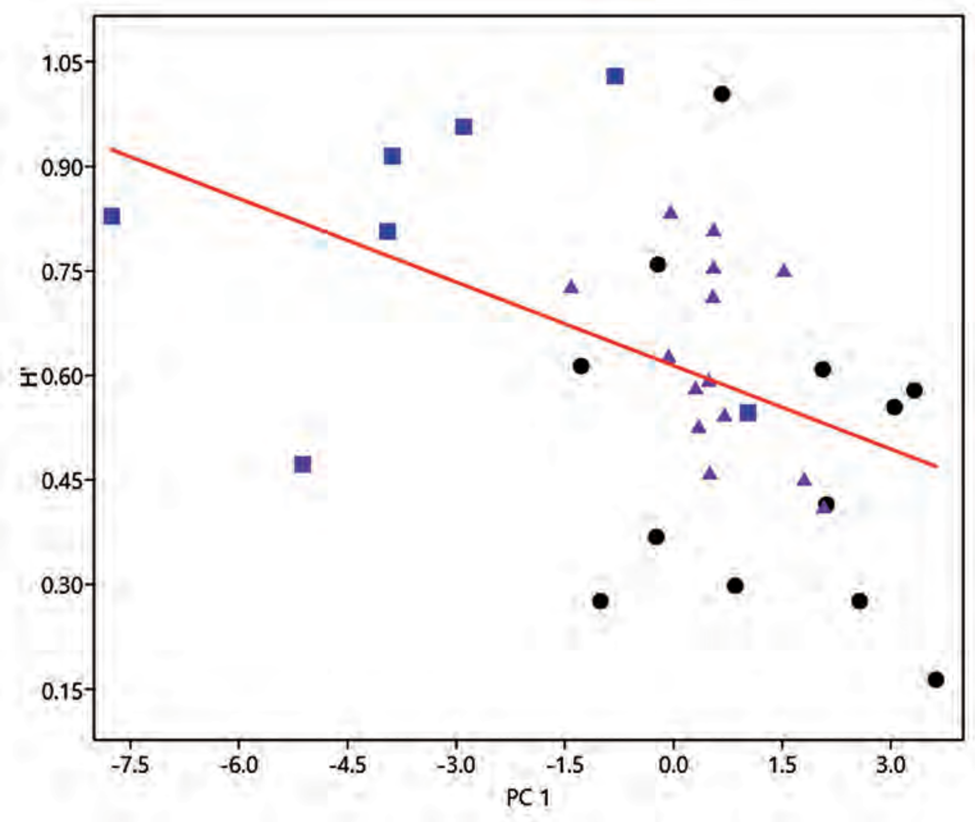

Fig. 10. Plot results of the ordinary linear square test on environmental variables PC1 to species diversity index (H'), with slope at -0.04, intercept 0.62.

Discussion

Biodiversity baselines for odonates of Nee Soon freshwater swamp forest

Altogether, we recorded 49 species of 34 genera in 11 families for our current study. Relative species richness per survey site varied from two to 13, and mean abundance of odonate individuals recorded per survey site varied from three to 106. An updated species list of Nee Soon dragonflies is provided for future reference, with 67 species of 47 genera in 11 families, representing about half of all odonates ever recorded in Singapore. Among the eight sub-catchments, the three mid sub-catchments all show low abundance and species richness. This is followed by the two upper sub-catchments. The three low sub-catchments all had high abundance and species richness. Species richness ranges from 3.5 to 9.25 species/site with the highest species richness at Lower 3 sub-catchment and the lowest at Mid 1 sub-catchment.

Compared to historical records, the change in distribution of *Prodasineura* is quite remarkable. Murphy (1997: 343, Fig. 4) plotted records of the three *Prodasineura* species and commented that: “none of these have been found outside the CCNR

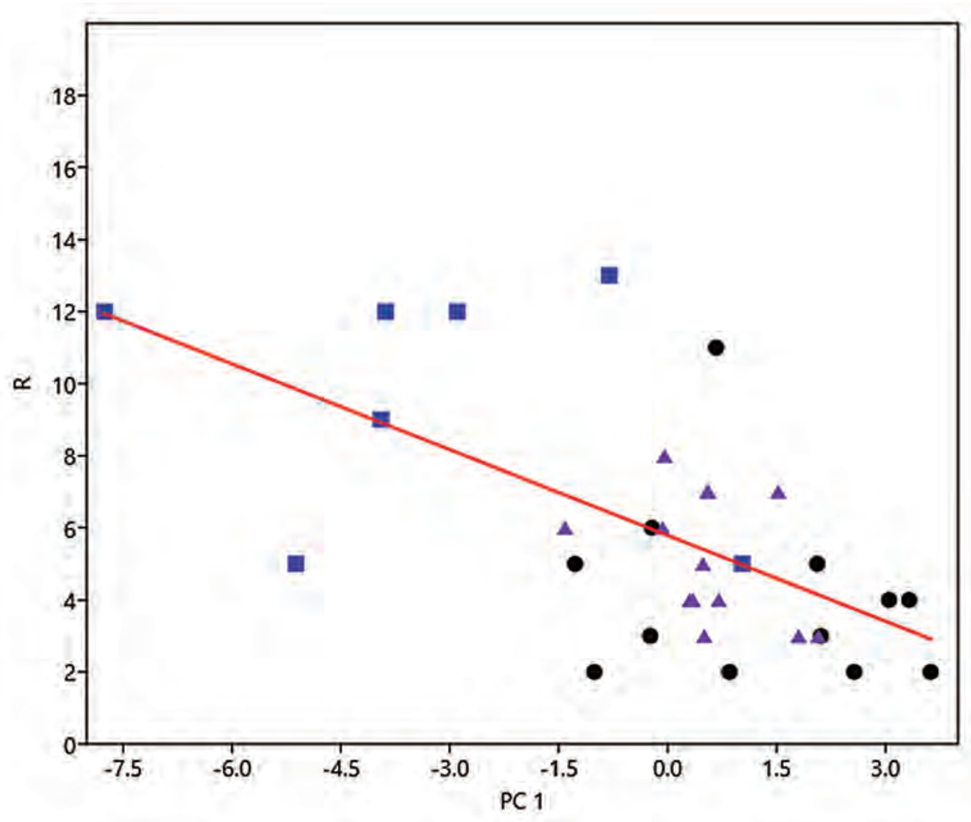

Fig. 11. Plot results of the ordinary linear square test on environmental variables PC1 to species Richness (R), with slope at -0.79, intercept 5.79.

[Central Catchment Nature Reserve, including Nee Soon freshwater swamp forest] in Singapore and the genus is not known from Bukit Timah." "*Prodasineura collaris* is widely scattered and appears associated with still waters choked with leaves. *Prodasineura notostima* is common over deeply-shaded open streams. *Prodasineura interrupta* occurred together with *P. notostigma* in the lower part of Nee Soon Swamp Forest and was widespread in the upper Nee Soon basin where it was the only species seen. It remains unexplained why this species is, on present evidence, confined to the Nee Soon catchment, since it is found in riparian galleries not obviously different from those in other drainage systems. The absence of *P. notostigma* from the upper Nee Soon basin is also remarkable." Two decades later, we found that the genus has spread beyond the Central Catchment Nature Reserve. *Prodasineura notostigma* has been commonly found in forest streams in Bukit Timah and other nature areas in Singapore. However, statements for *Prodasineura collaris* and *P. interrupta* remain valid except that the latter species is no longer the only species found in the upper Nee Soon basin. *Prodasineura notostigma* has become the dominant species there. The restriction of *Prodasineura interrupta* to Nee Soon freshwater swamp forest is probably related

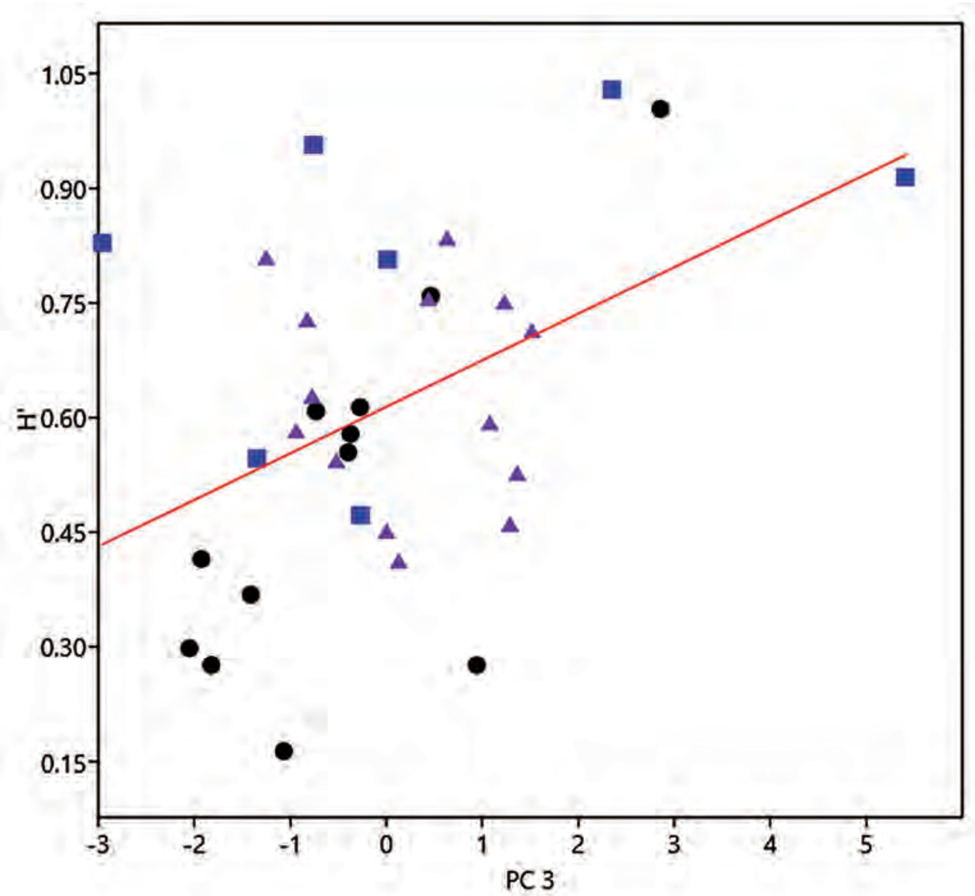

Fig. 12. Plot results of the ordinary linear square test on environmental variables PC3 to species diversity index (H'), with slope at 0.06, intercept 0.61.

to the particular environmental variables that it requires either as an adult or larva. Localised movement behaviour may limit its dispersal capability. This remains a subject for future investigation.

Prodasineura humeralis was not found in Murphy's island wide odonate survey (Murphy, 1997). Murphy et al. (2008: 247), recognising it at the rank of subspecies, red-listed *Prodasineura verticalis humeralis* as Critically Endangered (CR) for Singapore. Tang et al. (2010: 92) stated that it was only first recorded in Singapore in October 2006, and classified the taxon as uncommon. Lok (2008) suggested habitat fragmentation as a possible cause for its limited distribution. Ngiam & Cheong (2016: 161) revised the conservation status of all odonate species found in Singapore and treated *Prodasineura humeralis* as being of least concern as it is currently a common and widespread species. Tang et al (2010: 92) described *Prodasineura humeralis* as being "associated with shaded forest streams with fast flowing water." Observations from the present study show that the species is abundant in the outskirts and stream stretches that are associated with an open canopy. It is commonly associated with fast flowing water, but hardly found in shaded forest streams with high canopy cover. When they described a new species of freshwater snapping shrimp *Potamalpheops amnicus*, Yeo & Ng (1997: 171, 172) commented that "Interestingly, there is a high likelihood that these shrimps originated from unintentional introductions from Peninsular Malaysia. This is because the Sedili drainage in Kota Tinggi, Johore, is one of the water sources for Singapore with water from there being transported via pipeline to the Upper Pierce Reservoir. The Sedili drainage is where *Potamalpheops amnicus* is found in far greater abundance than in Singapore. It is therefore entirely possible for the shrimps to enter Singapore via the pipeline and become established in certain areas suitable to their habitat preference like the present stretch of stream." *Prodasineura humeralis* has long been a common and widespread species of forest streams in Peninsular Malaysia (Orr, 2005). There is, therefore, a likelihood of larvae being incidentally transported from Malaysia via pipeline into Singapore waters. Both its rapid dispersal history, and the current distribution patterns mainly in open forest streams at the outskirts of the nature reserves, mirror those of many aquatic introduced species in Singapore (Yeo & Chia, 2010). Its potential impact upon other native damselfly species needs to be closely monitored.

Community structures and distribution patterns

Odonates of Nee Soon freshwater swamp forest can be grouped into three distinct community assemblages: 1) headwater, 2) mainstream channel, 3) outskirts and/or lower stream communities. Each of these community assemblages is linked to a distinctive suite of riparian vegetation, hydrological and physicochemical characteristics.

Community assembly theory is founded on the premise that the relative importance of local environmental processes and dispersal shapes the compositional structure of metacommunities. Four general models describe interesting combinations of these factors and are frequently used to interpret observed communities: 1) neutral model, 2) patch dynamics, 3) mass-effect, and 4) species sorting (cf. De Marco et al., 2015). The species sorting model predicts that assemblages are dominated by the environmental filtering of species that are readily able to disperse to suitable sites. De Marco et al. (2015) propose an eco-physiological hypothesis for the mechanism underlying the organisation of species-sorting odonate metacommunities based on the interplay of thermoregulation, body size and the degree of sunlight availability in small-to-medium tropical streams. They considered that narrow streams are more affected by riparian vegetation than are wide streams, which reduces light input but also generates a more stable thermal environment. They considered these characteristics favour small species that are less dependent on exposure to direct sunlight for thermoregulation, and limit the colonisation of larger, heliothermic species. To quote directly: "The taxonomic distinction between small streams (dominated by Zygoptera) and larger rivers (by Anisoptera) is an incidental consequence of differences in body size and associated thermal properties between these two groups" (De Marco et al., 2015). The species composition and distribution patterns of odonates observed in Nee Soon support such a hypothesis. The dominance of small Zygoptera in forested headwaters and the increased number of Anisoptera in the lower streams and outskirts of Nee Soon can be partially explained by species sorting through eco-physiological mediation.

Threats identified and conservation implications

Variations in the hydrology and ecology of the Nee Soon freshwater swamp forest over the last few decades have made it difficult to determine the conservation actions that are needed to ensure the long-term sustainability of the ecosystem. Both the forest and the surface waters of the Nee Soon freshwater swamp forest have changed considerably over the last two decades, with stream banks experiencing raised water levels in some parts and drying up in others resulting in a shifting of boundaries between the swampy and the dryland forests. The changes in hydrological characteristics have altered the dimensions and profile of stream channels as well as the instream macrophytes, woody debris and the complexity of the riparian zone in many parts of the drainage system. The changes pose significant threats to ecological health of the swamp forest, as well as the aquatic and semi-aquatic life that forms part of this integrated ecosystem. Recent eco-hydrological modelling conducted by Sun et al. (2018) confirms that future hydrological conditions of Nee Soon freshwater swamp forest will be further impacted by global climate change, and they projected 12 scenarios which, according to the extent of rainfall and operational water level of reservoirs surrounding the catchment, range from almost total disappearance of surface water to flooding events that covers most of the swamp forest. The effects of the two inputs (water drawdown versus flooding) differ by location. A shift in odonate community structure will thus be inevitable should such hydrological scenarios materialise. As hydrological changes following climate change may be sudden and drastic, many odonate species may not be able to find suitable breeding grounds for recruitment and recolonisation even when conditions have recovered to their original status.

The River Continuum Concept (RCC) (Vannote et al., 1980) is the dominant concept of how stream ecosystems vary from headwaters downstream to large rivers. The basic idea is that aquatic communities and ecological processes of the stream ecosystem change predictably along the downstream gradient of increasing channel dimensions and canopy opening over the stream. While the River Continuum Concept is typically viewed as a global stream ecosystem theory, it can be applied to forested landscapes to depict forest-stream interactions with widening canopy opening over the stream and shifting geomorphology in the downstream direction. Recognition of the importance of these linkages between streamside forests and instream communities has resulted in the creation and protection of riparian buffers as best management practice in many regions. With a life cycle spanning both aquatic (larvae) and terrestrial (adult) phases, odonates are more sensitive than purely aquatic or purely terrestrial invertebrates to the stability of the vegetation at the aquatic and terrestrial interface, be it as oviposition sites or as perches for both adults and larvae. Changes in distribution and cover of instream macrophytes, woody debris, as well as aquatic or riparian vegetation along a river system, either naturally or due to human interference, would have significant impacts on odonate populations. For example, one of the sampling sites at Nee Soon, Lower 3D, was at a position along the main stream, adjacent to Mid

2 and Mid 3 sub-catchments. The statistical clustering results indicated that the site's odonate community was grouped into group 1, together with most of the sites located at the Nee Soon outskirts, rather than with those of Mid 2 and Mid 3 sub-catchments. Close examination shows that the Lower 3D site is right alongside a pipeline service trail which, although it is near the middle of the freshwater swamp forest, has created an approximately 10–15 m width gap in the canopy, creating a significant access path for many heliothermic species penetrating the forest to colonise the site and disturb the overall RCC distribution pattern. The changes in community assemblage suggest that the shift in habitats and its long term impact will need to be monitored closely.

There may be more threats posed by the pipeline service trail to the odonate fauna in Nee Soon. Results from the recent hydrological baseline study of Nee Soon freshwater swamp forest show that water quality in the stream parallel to the pipeline has high calcium concentrations (A. D. Ziegler, pers. comm.; Nguyen et al., 2018) as compared to other sub-catchments. This is probably linked to the construction and material used for the pipeline. Soil erosion along the pipeline has also been observed to wash down sediment to the stream during heavy rainfall and occasionally pipe leakage events. Whether such anthropogenic impacts on water quality have negative effects on the odonate fauna in Mid 3 sub-catchment (which happened to have low species richness and low species diversity H' in our study) should be determined. Additionally, with the opening of the forest canopy as well as the creation of ephemeral water bodies along the pipeline, exotic species of odonates may find suitable pathways into the freshwater swamp forest.

Evaluation of sampling protocol

An updated species list indicated 67 species of odonate have been recorded in the Nee Soon freshwater swamp forest (Appendix 1), and many species reported previously were not captured by the current study. These include the majority of rare and nationally Critically Endangered species so far found in Singapore only within Nee Soon freshwater swamp forest.

The main focus of the study was on adult odonates, as larvae were collected as a secondary sampling during the aquatic insect surveys which took place simultaneously (Su, 2016). When larvae are factored in, the data show the possible presence of odonates of which the adults were not observed. For example, although only one adult *Tetracanthagyna plagiata* was spotted at site 1C, the larvae of this species (identified as Anisoptera sp.) were found at sites Low 1C, Low 2B, Low 3D, Mid 2A, and Up 1C. With the combined records, the biodiversity of the survey sites may be assessed more accurately. Patten et al. (2015), in their study of USA odonates, pointed out that ecological models for adults were broader geographically and had a wider, more equitable (higher evenness) balance of contributing environmental variables (niche dimensions) than did models for larvae, which tended to be more ecologically specialised. They suggested that surveys of adult dragonflies, which are relatively easy to conduct because of organised efforts to encourage observations by citizen scientists, can paint a misleadingly broad picture of a species' ecological niche. They recommended that evidence of breeding, especially the presence of tenerals or exuviae, be used to outline ecological requirements when questions of conservation or population monitoring arise. Hence, future studies should dedicate more effort towards the collection and identification of larvae, including barcoding and environmental DNA (Kutty et al., 2018), to complement the adult surveys thus presenting a more representative odonate community in Nee Soon freshwater swamp forest.

Conclusion

This study has provided an overview of the odonate diversity within Nee Soon freshwater swamp forest, as well as the overall condition of the freshwater streams. Nee Soon holds the only primary freshwater swamp habitat left in Singapore and much of its biodiversity, including odonates, is severely threatened with extirpation at the national level. The continued survival of the indigenous freshwater fauna in the freshwater swamp forest will require conservation actions at local level as part of the on-going efforts aimed at sustaining forest biodiversity in the densely populated island of Singapore. These actions will require in-depth studies of the microhabitat-dependent distribution of odonates as well as studies of their complex interactions with other species. Future conservation management actions can include stream rehabilitation and forest enhancement, the reintroduction of native species to their original habitats, formulation of long-term monitoring programmes, increased and stricter enforcement on the protection of Nee Soon freshwater swamp forest.

ACKNOWLEDGEMENTS. We would like to thank Drs Lena Chan, Geoffrey Davison and Liong Shie-Yui for their support, Dr Liong Shie-Yui for the map, Dr Chong Kwek Yan for discussion on statistics, and Mr Lim Weihao, Ms Li Tianjiao, Mr Su Weijie and colleagues from the National Biodiversity Centre for their help with field surveys. This study forms part of the Nee Soon Swamp Forest Biodiversity and Hydrology Baseline Studies Project funded by the National Parks Board of Singapore (FC 12302501).

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Appendix 1. Species checklist of dragonflies in Nee Soon freshwater swamp forest (number under the author column indicates the page number on which the species was indicated)

Family	Species	Common name	Murphy, 1997	Norma-Rashid et al., 2008	Tang et al., 2010	Others	Current study	Conservation status (cf Ngiam & Cheong, 2016)
Argiolestidae	*Podolestes orientalis*	Blue-spotted Flatwing					y	VU
Calopterygidae	*Vestalis amethystina*	Common Flashwing		3			y	VU
	Vestalis amoena	Charming Flashwing	337, 341	3	34		y	EN
Chlorocyphidae	*Libellago aurantiaca*	Fiery Gem	337, 341	3	35		y	CR
	Libellago hyaline	Clearwing Gem	337, 341	3	37		y	CR
	Libellago lineata	Golden Gem					y	VU
Coenagrionidae	*Agiocnemis femina*	Variable Wisp		4			y	LC
	Amphicnemis bebar	Bebar Wisp			Dow & Ngiam, 2011:394		CR	
	Amphicnemis gracilis	Will-o-wisp	341				y	VU
	Archibasis melanocyana	Blue-nosed Sprite		4	61			EN
	Archibasis viola	Violet Sprite		4			y	LC
	Argriocnemis rubescens	Variable Sprite					y	LC
	Ceriagrion cerinorubellum	Ornate Coraltail		4			y	LC
	Pericnemis stictica	Dryad		5				VU
	Pseudagrion australasiae	Look-alike Sprite					y	LC
	Pseudagrion microcephalum	Blue Sprite					y	LC
	Pseudagrion pruinosum	Grey Sprite			79		y	VU
	Pseudagrion rubricaps	Orange-faced Sprite		5	81	Ngiam, 2009:212		VU
	Teinobasis cryptica	Cryptic shade sprite				Dow & Ngiam, 2011:393		CR
Euphaeidae	*Euphaea impar*	Blue-sided Satinwing		5			y	LC
Platycnemididae	*Coeliccia albicauda*	White-tailed Sylvan			83			CR

Appendix 1. Continuation.

Family	Species	Common name	Murphy, 1997	Norma-Rashid et al., 2008	Tang et al., 2010	Others	Current study	Conservation status (cf Ngiam & Cheong, 2016)
	Coeliccia octogesima	Telephone Sylvan		5			y	VU
	Copera marginipes	Yellow Featherlegs					y	LC
	Onychargia atrocyana	Shorttail					y	LC
	Prodasineura collaris	Collared Threadtail	341	6			y	EN
	Prodasineura humeralis	Orange-striped Threadtail					y	LC
	Prodasineura interrupta	Interrupted Threadtail	338, 341	6			y	CR
	Prodasineura notostigma	Crescent Threadtail	341				y	LC
Platystictidae	*Drepanosticta quadrata*	Singapore Shadow-damsel		6			y	VU
Gomphidae	*Heliogomphus kelantanensis*	Malay Grappletail	338					CR
	Ictinogomphus decoratus	Common Flangetail		6			y	LC
	Macrogomphus quadratus	Forktail	341	7			y	VU
	Merogomphus femoralis	Malayan Spineleg			119			CR
	Microgomphus chelifer	Tiny Sheartail	339		120	Ngiam et al., 2011:95		VU
	Burmagomphus plagiatus	Lesser Splayed Clubtail	347		113			EX
	Burmagomphus divaricatus	Splayed Clubtail	338		114			EX
	Paragomphus capricornis	Banded Hooktail		7	122			EN
Aeshnidae	*Anax guttatus*	Emperor		7				LC
	Oligoaeschna foliacea	Leaftail			110			CR
	Tetracanthagyna plagiata	Giant Hawker	338, 341	7	111		y	VU
Libellulidae	*Acisoma panorpoides*	Trumpet Tail					y	LC
	Aethriamanta aethra	Blue Adjudant		8				LC
	Agrionoptera sexlineata	Handsome Grenadier		8				LC
	Brachydiplax chalybea	Blue Dasher		8			y	LC

Appendix 1. Continuation.

	Cratilla metallica	Dark-tipped Forest Skimmer		8		y	LC
	Crocothemis servilia	Common Scarlet				y	LC
	Lathrecista asiatica	Scarlet Grenadier				y	LC
	Nannophya pygmaea	Scarlet Pygmy		9		y	LC
	Neurothemis fluctuans	Common Parasol				y	LC
	Orchithemis pruinans	Blue Sentinel			170	y	CR
	Orchithemis pulcherrima	Variable Sentinel	341	10		y	LC
	Orthetrum chrysis	Spine-tufted Skimmer		10		y	LC
	Orthetrum glaucum	Common Blue Skimmer		10		y	LC
	Orthetrum luzonicum	Slender Blue Skimmer				y	LC
	Orthetrum sabina	Variegated Green Skimmer				y	LC
	Orthetrum testaceum	Scarlet Skimmer		10		y	LC
	Pantala flavescens	Wondering Glider		10			LC
	Psedothemis jorina	Banded Skimmer				y	LC
	Rhodothemis rufa	Common Redbolt		11		y	LC
	Rhyothemis obsolescens	Bronze Flutterer		11		y	LC
	Rhyothemis phyllis	Yellow-Barred Flutterer		11		y	LC
	Rhyothemis triangularis	Sapphire Flutterer				y	LC
	Risiophlebia dohrni	Potbellied Elf	341	11	193		EN
	Tetrathemis irregularis hyalina	Elf			194		CR
	Trithemis aurora	Crimson Dropwing				y	LC
	Trithemis festiva	Indigo Dropwing				y	LC
	Tyriobapta torrida	Treehugger				y	LC
Macromiidae	*Epophthalmia vittigera*	Pond Cruiser		7		y	LC

Appendix 2. Abbreviation and quantification of environmental variables.

Parameters		Abbreviation
Water parameters	pH	PH
	Do (%)	DO
	Temperature	TEM
	ORP	ORP
	Mean Velocity	VEL
	TDS	TDS
	Salinity	SAL
Stream dimension	Mean Width	WID
	Mean Depth	DEP
	Pool (%)	POL
In-stream	Macrophyte+Woody debris (%)	MPW
Substrate	Leaf litter (%)	LL
	Sand (%)	SA
	Silt (%)	SI
Bank	Shape (smooth 1- vertical 4)	BSH
	Root (0-3)	BRO
	shrubs/grass (0-3)	BSG
Riparian	Heterogeneity (0-3)	RHE
	Canopy (%)	RCA
Connectivity	Stream order	SO
	Forest edge (0-3)	FE
	Open area (0-3)	OA
	Swamp (0-3)	SW

Appendix 3. Abbreviations of dragonfly species.

Abbreviation	Species	Common name
Afe	*Agriocnemis femina*	Variable Wisp
Agr	*Amphicnemis gracilis*	Will-o-wisp
Agu	*Anax guttatus*	Emperor
Apa	*Acisoma panorpoides*	Trumpet Tail
Aru	*Argiocnemis rubescens*	Variable Sprite
Avi	*Archibasis viola*	Violet Sprite
Bch	*Brachydiplax chalybea*	Blue Dasher
Cce	*Ceriagrion cerinorubellum*	Ornate Coraltail
Cma	*Copera marginipes*	Yellow Featherlegs
Cme	*Cratilla metallica*	Dark-tipped Forest Skimmer

Appendix 3. Continuation.

Coc	*Coeliccia octogesima*	Telephone Sylvan
Cse	*Crocothemis servilia*	Common Scarlet
Dqu	*Drepanosticta quadrata*	Singapore Shadowdamsel
Eim	*Euphaea impar*	Blue-sided Satinwing
Evi	*Epophthalmia vittigera*	Pond Cruiser
Ide	*Ictinogomphus decoratus*	Common Flangetail
Las	*Lathrecista asiatica*	Scarlet Grenadier
Lau	*Libellago aurantiaca*	Fiery Gem
Lhy	*Libellago hyalina*	Clearwing Gem
Lli	*Libellago lineata*	Golden Gem
Mqu	*Macrogomphus quadrata*	Forktail
Nfl	*Neurothemis fluctuans*	Common Parasol
Npy	*Nannophya pygmaea*	Scarlet Pygmy
Och	*Orthetrum chrysis*	Spine-tufted Skimmer
Ogl	*Orthetrum glaucum*	Common Blue Skimmer
Opr	*Orchithemis pruinans*	Blue Sentinel
Opu	*Orchithemis pulcherrima*	Variable Sentinel
Osa	*Orthetrum sabina*	Variegated Green Skimmer
Pau	*Pseudagrion australasiae*	Look-alike Sprite
Pca	*?Paragomphus capricornis*	Banded Hooktail
Pco	*Prodasineura collaris*	Collared Threadtail
Phu	*Prodasineura humeralis*	Orange-striped Threadtail
Pin	*Prodasineura interrupta*	Interrupted Threadtail
Pjo	*Pseudothemis jorina*	Banded Skimmer
Pmi	*Pseudagrion microcephalum*	Blue Sprite
Pno	*Prodasineura notostigma*	Crescent Threadtail
Por	*Podolestes orientalis*	Blue-spotted Flatwing
Ppr	*Pseudagrion pruinosum*	Grey Sprite
Rob	*Rhyothemis obsolescens*	Bronze Flutterer
Rph	*Rhyothemis phyllis*	Yellow-Barred Flutterer
Rru	*Rhodothemis rufa*	Common Redbolt
Rtr	*Rhyothemis triangularis*	Sapphire Flutterer
Tau	*Trithemis aurora*	Crimson Dropwing
Tfe	*Trithemis festiva*	Indigo Dropwing
Tto	*Tyriobapta torrida*	Treehugger
Vae	*Vestalis amethystina*	Common Flashwing
Vam	*Vestalis amoena*	Charming Flashwing