



Biological Traits: Application to the Auckland Council River Ecology Monitoring Programme

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Biological Traits: Application to the Auckland Council River Ecology Monitoring Programme

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Prepared for
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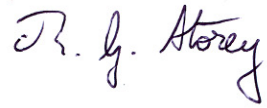
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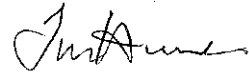
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Executive Summary

As part of the Auckland Council's Freshwater Ecology Programme, metrics based on macroinvertebrate taxonomic composition are used to describe the ecological health of the region's aquatic resources. An alternative approach is to use the biological traits of macroinvertebrates, as these reflect changes in ecosystem function rather than just changes in macroinvertebrate composition.

In this project we determined the response of both metrics and traits to a gradient of landuse intensity (native forest, exotic forest, rural and urban) for Auckland streams. We developed *a priori* hypotheses of likely responses of traits to these stressors. We then compared the effectiveness of metric and trait measures for differentiating levels of impact. We also examined the potential influence of regional variation in taxonomy on the ability of metrics and traits to detect the impacts of rural development, by combining Auckland and Waikato data sets. Finally, we investigated the potential use of traits as a mechanistic tool.

As a first step, we examined the natural variability of metrics and traits in undisturbed (native forest) sites, focusing on the differences between stream types (hard vs. soft bottomed). We found significantly higher values for taxon richness and EPT richness and %EPT richness in hard bottomed streams compared to soft bottomed streams. There was no difference for MCI (Macroinvertebrate Community Index) or QMCI (Quantitative Macroinvertebrate Community Index). We also found significant differences in some trait categories (ie, the type of trait eg, reproductive technique) and trait modalities (ie groupings of organisms based on characteristics of a trait category eg, sexual or asexual reproduction).

Land use explained a greater proportion of the variation than stream type in all metrics except for taxon richness. Landuse was found to explain a greater amount of variation than stream type for 73% of trait categories and 75% of trait modalities.

Landuse explained a greater amount of variation in hard-bottomed (58-71%) than soft-bottomed streams (31-47%) for all metrics. However, the general pattern of response to land use intensity was similar for both stream types (ie decreasing values with increasing landuse intensity). A similar pattern was observed for traits, with landuse explaining between 13 and 100% of the variation in trait categories in hard bottomed streams and 2.1 – 15.4% in soft bottomed streams. The response to increasing land use intensity observed in both stream types was an increase in taxa that reproduced multiple times per year (plurivoltinism), had greater than one reproductive cycle/individual, reproduced asexually, deposited eggs under water (submerged) or within macrophytes (endophytic), moved by burrowing, were highly flexible, were spherical in body form, had more specialized diets (eg, algal piercers), were plastron respirers and had both adult and larval stages in aquatic form. Traits as categories or as individual modalities were found to be as powerful at detecting impacts of landuse intensity as metrics (as measured by partial η^2 values).

When examined across all streams, all metrics other than taxon richness were found to be effective at differentiating between levels of impact. Almost all trait categories were found to be effective in differentiating between high and low levels of impact, but had differing levels of effectiveness for medium impact levels. Particularly effective traits included the number of reproductive cycles/individual, reproductive technique, oviposition site, body flexibility and aquatic stages.

Analysis of combined Auckland and Waikato datasets indicated that landuse explained more of the variation than region or stream type in most metrics. For all metrics, sites subject to rural landuse had lower values than those in native forest. Landuse also explained more of the variation than region or stream type for most trait categories and modalities. Taxa typical of rural streams reproduce more than once a year, reproduce more than once per individual, tend to live longer, reproduce asexually, lay submerged eggs and have both adult and larval forms that were aquatic.

We have identified significant differences in the frequencies of trait modalities that allow us to distinguish native forest sites from urban sites. Further refinement of traits as a diagnostic tool requires more detailed environmental disturbance measures. However, the present data indicate that trait profiles could be employed to detect trends over time in recovery following restoration or degradation following landuse changes.

Trait-based biomonitoring would fit readily into existing biomonitoring frameworks employed by regional authorities, as the basic information (site by species composition matrices) is already collected. For traits (categories or modalities) to be considered for integration into existing biological monitoring programmes, they would ideally need to satisfy the following criteria:

- a) Display low levels of variation within categories of landuse intensity, and significant power to discriminate medium from low or high levels of development.
- b) Display greater discriminatory power than that achieved by standard metrics.
- c) Possess the ability to diagnose causal factors.

A set of trait categories that consistently met all three of the above criteria included: number of reproductive cycles/individual, reproductive technique, egg mass location, oviposition, flexibility and aquatic stages. These trait categories (and their associated modalities) could be integrated into existing bio-monitoring programmes run by regional authorities.

Based on this assessment of trait and metric responses to increasing landuse intensity, recommendations for further development of the trait approach to bio-monitoring include:

- Further investigation of diagnostic traits/trait profiles by using more specific measures of disturbance (eg, contaminant concentrations).
- Investigation and development of stressor-specific traits, derived either empirically or through relational analysis of existing datasets.
- Investigation of the development of a trait-based multi-metric using existing datasets.
- Expansion of the regional analysis to encompass a broader range of landuse types (eg,, through integration with other regional councils to provide sufficient numbers of sites with urban and forestry sites).
- Development of a method for integrating a traits approach into standard monitoring protocols.

1 Introduction

Auckland Council (AC) undertakes annual assessments of invertebrate community composition in streams and rivers in the Auckland region (Moore and Neale 2008). From this base data set a number of metrics are derived to describe the relative ecological health of the region's aquatic resources. Associated habitat and water quality metrics are also derived, and relationships between invertebrate and physical metrics examined to investigate possible causal associations.

One of the aims of this programme is to assist with the identification of large scale or cumulative impacts of contaminants and disturbance associated with varying land uses. The ability to differentiate between levels of impact is often hampered by the natural variability of ecological communities in time and space (Statzner and Beche 2010). Traditional taxonomic-based invertebrate measures focus on diversity or on the presence or absence of key indicator taxa (Sponseller et al. 2001, Townsend and Townsend 2004). Measures such as abundance, taxon richness and number of EPT (sensitive Ephemeroptera, Plecoptera and Trichoptera) taxa are often highly variable over both space and time (Scarsbrook 2002, Pollard and Yuan 2010). Furthermore, such measures generally describe the structural characteristics of a community, but provide little insight into ecosystem functioning.

There is growing interest in the use of macroinvertebrate biological traits as an assessment tool for monitoring human impacts on stream ecosystems (Dolédec et al. 2006, Dolédec et al. 1999, Stark and Phillips 2009, Statzner et al. 2005). Biological traits describe the biological characteristics of organisms (including morphological characters with biological implications). The use of biological traits offers a fundamentally different way of examining ecosystem responses to human impacts than taxonomic-based measures, as traits reflects the functional role that species play within the ecosystem and how disturbance affects this through direct effects on organism performance (McGill et al. 2006). The habitat template model (Southwood 1977, 1988) provides the theoretical basis for this approach. It predicts that where environmental conditions are similar, species trait composition should also be similar, regardless of biogeographical differences in taxonomic composition. Townsend and Hildrew (1994) adapted this model for streams, suggesting that benthic communities should consist of species possessing traits well suited to both the temporal and spatial variability of their local habitats. This model has been used in numerous studies to examine the relationships between traits and environmental drivers (eg, Scarsbrook and Townsend 1993, Statzner et al. 1997, Townsend and Scarsbrook 1997, Heino 2005, Beche et al. 2006). The approach is simple, intuitive and the effects of individual stressors are often *a priori* predictable. In general, traits have been found as effective, and in some cases, more effective, than traditional biomonitoring methods in differentiating human impacts (Dolédec et al. 2006, Magbanua et al. 2010, Rubach et al. 2010), even over large geographic areas (Charvet et al. 2000, Statzner et al. 2001, Lamouroux et al. 2004, Statzner et al. 2005, Dolédec et al. 2011).

Biological traits may also be useful for establishing mechanistic linkages between biotic responses and environmental conditions (Baird et al. 2010, Culp et al. 2010, Van den Brink et al. 2010). In contrast, taxonomic-based measures generally only indicate that an ecological change has occurred (Culp et al. 2010). Due to the mechanistic basis of the trait approach, the biological trait approach has recently been proposed for use in

ecological risk assessment (Baird et al. 2010, Culp et al. 2010, Van den Brink et al. 2010). A trait-based approach could also provide a framework for mechanistically connecting the occurrence of traits in a community to major environmental drivers. This mechanistic framework may help us better understand and predict response patterns associated with particular stressors, a goal of particular interest for environmental managers.

In this project we aimed to address these specific questions:

- How naturally variable are traits in comparison to metrics?
- How do traits and metrics compare in their ability to differentiate impacted sites?
- Can traits be used to diagnose the mechanisms of impact, by providing linkages between physiological/life history characteristics and potential causal factors?
- Are there specific traits or suites of traits that could be added to the existing suite of invertebrates metrics used in the invertebrate component of monitoring programmes to improve the ability to detect impacts?

Our approach to addressing these questions involved:

- analysis of a 3 year data set of macroinvertebrate abundance for multiple sites within the Auckland region
- derivation of trait base metrics to identify specific traits or suites of traits that could be added to the existing suite of invertebrate metrics used in the Auckland Council's monitoring programme to improve the ability to detect impacts
- comparison of the relative power of metrics and traits to detect impacts, and
- investigation of the potential of traits to diagnose mechanisms of impact, by examining linkages between landuse and trait frequency.

In addition, a recent analysis of landuse impacts on taxonomic and trait-based measures across a large geographic scale (the whole of New Zealand) (Dolédéc et al. 2011), showed ecoregional differences in taxonomic, but not trait, composition. We therefore examined the potential for ecoregional influences on metric and trait responses to rural landuse by undertaking a regional analysis of a combined Auckland Council/ Waikato Regional Council dataset.

2 Methods

2.1 Data preparation

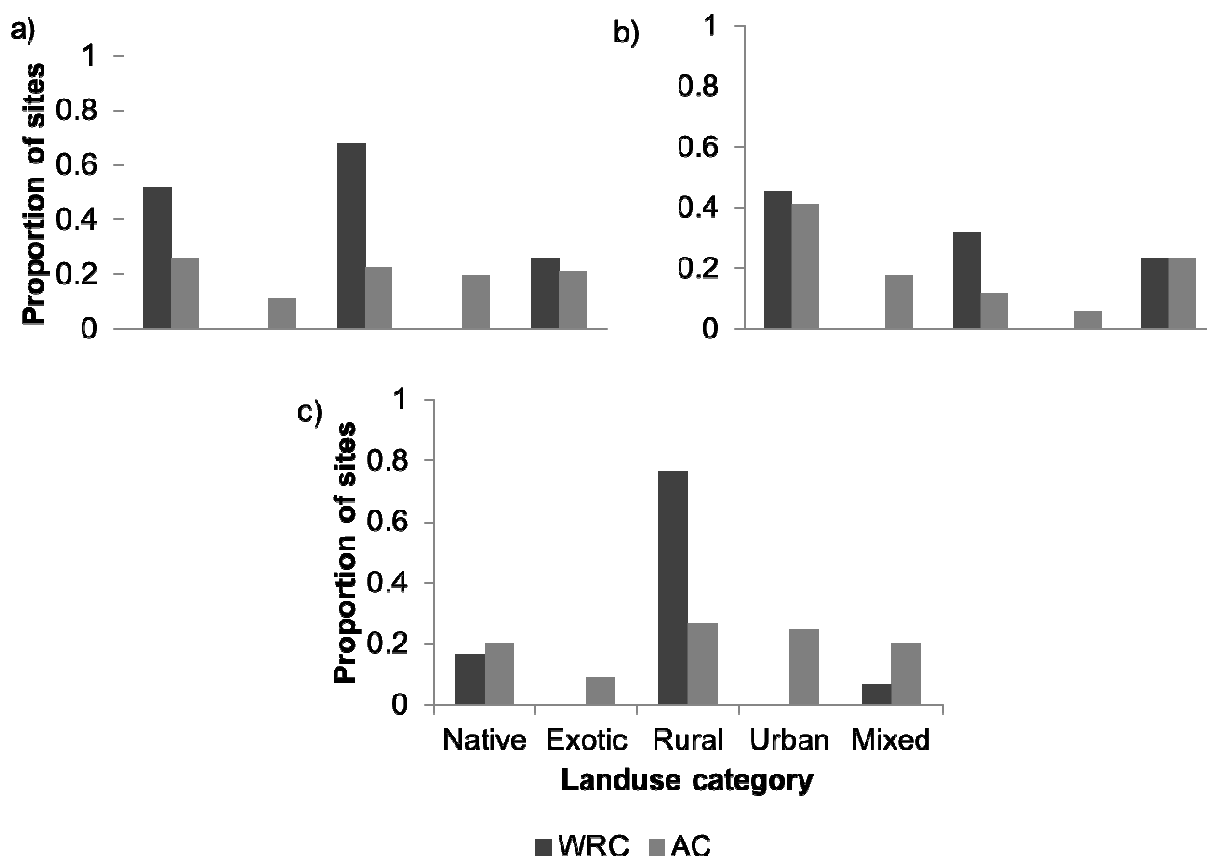
Existing data from the Auckland Council's Freshwater Ecology Programme were used for our analyses (Moore and Neale 2008). The dataset comprised a subset of 62 sites (representing 45 soft bottomed and 17 hard bottomed streams) where samples had been collected over the period 2008 to 2010. Landuse in the upstream catchments of the sites varied from 100% native forest, to almost 100% urban to over 90% rural development. The distribution of landuse types varied slightly between hard and soft bottomed stream types (Fig. 2.1).

The macroinvertebrate sampling programme involves sampling in accordance with standard New Zealand protocols (protocol C1 for hard-bottomed streams, protocol C2 for soft-bottomed streams) (Stark et al. 2001). Samples are processed using Protocol P1 and invertebrates identified to MCI level, with taxa counts being placed into semi-quantitative abundance categories (ranging from rare for 1-4 individuals and very, very abundant for 500+ individuals). From these counts, a range of standard metrics was derived: number of EPT taxa (Ephemeroptera, Plecoptera and Trichoptera), % EPT (% of the total number of taxa), MCI (Macroinvertebrate Community Index (Stark 1985) – a measure of relative sensitivity or tolerance to nutrient pollution based on presence or absence of taxa; hard or soft bottomed specific as appropriate) and taxa richness. As suggested by Maxted et al. (2003), Hydroptilidae caddisflies were excluded from the calculation of %EPT richness, as they are known to proliferate in filamentous algal blooms and so are not representative of sensitive taxa. MCI tolerance scores relevant to stream type (hard or soft bottomed) were used (Stark and Maxted, 2004).

Metrics were standardised by the maximum value for each metric to generate values between 0 and 1.0. Abundance data were derived for use in the calculation of abundance-weighted trait frequencies (see below). Categorical data were transformed into numerical measures by using the median value for each abundance category, other than the 500+ category (very, very abundant), where a median could not be calculated. In this case, the abundance value was set at 500. Abundance values derived were: rare=2.5, common = 12.0, abundant = 59.5, very abundant = 299.5, very, very abundant =500. Data were then $\log(x+1)$ transformed to approximate normality.

Figure 2.1:

Distribution of landuse for the Auckland (AC) and Waikato (WRC) regions for a) all sites, b) hard bottomed sites and c) soft bottomed sites.



For the regional analysis, we combined data from Auckland Council's Freshwater Ecology Programme (62 sites, 2008-2010) (Moore and Neale 2008) and Waikato Regional Council's (WRC) Regional Environmental Monitoring programme (2005-2008, 90 sites). The Waikato Regional Council's programme involves sampling in accordance with standard New Zealand protocols (Stark et al. 2001), with some modifications specific to the Waikato region (Collier and Kelly 2006). Samples are processed using a fixed count method of at least 200 individuals plus a scan for rare taxa. All invertebrates are identified to MCI level where possible. A range of taxonomic metrics are derived from this dataset, including those described above for the Auckland Council dataset. Due to differences in macroinvertebrate sampling protocols between the regions, this analysis was necessarily based on presence/absence weighted trait frequencies rather than being weighted by abundance. Landuse varied between the Auckland and Waikato datasets, with substantially more exotic vegetation and urban development in the Auckland region, and more rural development in the Waikato region (Fig. 2.1).

2.2 Biological trait data

For each of the taxa collected, we employed 15 biological trait categories (eg, maximum potential body size) divided into 55 trait modalities (eg, for body size: $\leq 5\text{mm}$, 5-10mm, 10-20mm, 20-40mm, $>40\text{mm}$). Trait information was generally coded at the generic level, with the exception of some Diptera and non-insect taxa, which were coded at the family or order level. The 15 traits relate to the life history of organisms (eg, size, number of reproductive cycles) or features that confer resilience or resistance beyond that provided by life history traits (eg, attachment, body shape), as well as more general biological and physiological features (eg, feeding habits, respiration; see Appendix A and also the glossary for a definition of the terms used). As a consequence of variation in the source of information used to derive the traits, we used 'fuzzy coding' to quantify the affinity of each taxon for each modality that contributed to a trait (Chevenet et al. 1994). Fuzzy coding allows data from a variety of sources (eg, quantitative, qualitative, observational) to be used and compared statistically. An affinity score of zero indicates no association of the taxon with a trait category, whilst a score of three indicates a high affinity for a given trait category. This approach acknowledges the variability in traits that often occurs at different life stages. For example, a species that is predominantly a predator but feeds by scraping algae in early instars would be given an affinity of three for the feeding category 'predator' and one for the category 'scraper'. We scored traits as zero for any category of a given trait for which information was not available. A description of traits is available at <https://secure.niwa.co.nz/fbis/displaycommonsearches.do>

Affinity scores were further treated as frequency distributions:

$$q_k = \frac{a_k}{\sum_{k=1}^h a_k} \text{ with } q_k \geq 0 \text{ and } \sum_{k=1}^h q_k = 1$$

where q_k is the frequency of trait category k ($1 \leq k \leq h$), h is the total number of categories of a given trait, and a_k is the assigned affinity. We described the functional composition of communities in terms of trait abundance, by multiplying the frequency of each category per trait by the abundance of species at the site. The resulting trait-by-site array contained the relative frequency of each category per trait in each site. The ade4 library (Thioulouse et al. 1997, Dray and Dufour, 2007) implemented in R freeware (R Development Core Team, 2010) was used to derive the trait frequencies. For the regional analysis encompassing the dataset from Auckland and Waikato, trait frequency calculations were based on presence/absence data only, to account for differences in the enumeration methods used by the two agencies.

2.3 Environmental data

The disturbance gradient employed the following landuse categories: native forest, exotic forest, rural and urban development, with the assumption being made that sites in urban development represent the most disturbed. The landuse designations were derived from an assessment of dominant landuse defined by the New Zealand Land Classification database (LCDB2, 2004) and were provided by AC.

For the regional analysis, only the native forest and rural development categories were used, reflecting the more limited range of landuses represented in the WRC data set.

2.4 *A priori* predictions for trait responses

When exposed to an environmental disturbance, populations with traits conferring resilience (the capacity to return toward the state prior to disturbance) or resistance (the capacity to withstand the disturbance) are predicted to increase (Townsend et al. 1997a). For rural and exotic vegetation, the following predictions can be made, based on previous studies on trait forest landuses (Dolédec et al. 2006, Dolédec and Stutzner, 2008, Thompson et al. 2009, Magbanua et al. 2010, Dolédec et al. 2011):

- increase in traits associated with population resilience (small size, short generation time, asexual reproduction) responding to increased temperature, habitat simplification, increased runoff and increased nutrient concentration
- increase in autroph feeders (scrapers, algal piercers) and an overall change in the composition of functional feeding groups to reflect the loss of riparian shading and increased nutrient concentrations
- burrowing and detrital-feeding organisms should be more common, and filter feeders and grazing organisms should be reduced, in sediment-affected patches, and
- decrease in surface egg laying and an increase in laying of protected eggs associated with increased sedimentation.

For urban development, further responses related to toxicants would be expected (Archambault et al. 2010), including:

- increased frequency of asexually reproducing taxa
- decrease in frequency of aquatic adults
- increase in rapidly reproducing taxa
- increase in protected eggs, and
- decrease in gill respiration and an increase in plastron respiration.

We also predicted that differences in functionality and community composition between hard and soft bottomed streams (Stark et al. 2001, Stark and Maxted, 2004) would be reflected in variation in some trait responses in these different stream types.

2.5 Statistical analysis

An initial assessment of variability within reference sites (>90% native vegetation) (using One Way ANOVA) was undertaken to determine natural variability of metrics and traits in relation to stream type (hard or soft bottomed).

For comparison of the overall effectiveness of taxonomic metrics and trait-based measures for detecting increases in landuse impact, one-way Analysis of Variance (ANOVA) was performed on taxonomic metrics and individual trait modalities, and

Multiple Analysis of Variance (MANOVA) was performed on biological trait composition (groups of trait modalities or trait categories). For each ANOVA/MANOVA, we report effect sizes (partial eta-square values, range 0-1; Nakagawa, 2004) to compare the magnitude of effects using taxonomic versus trait measures. Eta-square values are analogous to r^2 -values in regressions and are interpreted as the percentage of variance in the dependent variable uniquely attributable to the given effect variable. We used this approach for both the Auckland-only analysis and the regional analysis.

Variability of each response measure (metric and trait category or individual trait) was determined by calculating % similarity within each landuse category, with Bray-Curtis as the similarity measure) using SIMPER analysis (PRIMER-E, v6.17, 2007). Although a multivariate measure was not required for the metrics, use of the Bray-Curtis similarity measure allowed direct comparison between metrics and traits (both combine modalities within categories and individual modalities). This measure provides an indication of the overall sensitivity of each measure to the disturbance gradient. We then calculated the % dissimilarity between pairs of landuse categories for each measure (metrics and traits), with Bray-Curtis as the dissimilarity measure. One-way ANOVA (for taxonomic measures) or ANOSIM (Analysis of Similarity) (PRIMER-E v6.17, 2007) (for trait measures) were conducted, with Bray-Curtis as the similarity measure and landuse category (native forest, exotic forest, rural and urban development) as the factors for the analyses. Global R and p values are presented for each analysis. The ANOSIM Global R statistic fall between -1 and 1 with R = 0 indicating completely random grouping while R = 1 indicates that all replicates of a site type are more similar to each other than to any replicates of another site type. R>0.75 indicates large differences between groups, R>0.5 indicates overlapping but clearly different groups and R<0.25 (and negative vales) indicates barely separable groups (Clarke and Gorley 2001). A significant Global R ($p<0.05$) indicates that there are differences between site types somewhere in the analysis. Results of post-hoc pairwise analyses are also presented. This analysis allowed us to compare the effectiveness of the measures in detecting different levels of impact.

For the regional analysis, a Three-Way Analysis of Variance (ANOVA) was performed on the overall dataset to explore the consistency of any differences associated with stream types across the set of metrics/traits, using region (Auckland, Waikato), landuse category (native, exotic, rural, urban) and stream type (hard or soft bottomed) as our factors.

To assess the potential diagnostic ability of the trait approach we calculated Pearson Moment-Product Correlations between trait modalities and % landuse.

3 Variability associated with stream type

As a first step before examining metric and trait responses to different landuses, we examined the potential influence of stream type (hard versus soft-bottomed). We predicted that differences in functionality and community composition between hard and soft bottomed streams (Stark et al. 2001, Stark and Maxted, 2004) would be reflected in differences in some trait occurrences between these different stream types. Analysis of native forest (reference) sites provides an indication of the natural variability of the metrics and traits, in the absence of human disturbance.

3.1 Reference site variability

Sites with >90% native vegetation were designated as reference sites, resulting in 9 hard and 8 soft-bottomed streams being used for the analysis. Analyses indicated that there were significant differences between hard and soft bottomed streams for taxon richness, EPT richness and %EPT richness (Table 3.1), with lower values of these metrics being recorded for soft-bottomed streams (Fig. 3.1). MCI and SQMCI were not significantly different between stream types, reflecting the differences in sensitivity scoring system used for each stream type, which is designed to produce similar results for hard and soft-bottomed reference sites.

The difference in trait frequencies between hard and soft bottomed streams was also investigated. Significant differences were observed for most trait categories, with only dispersal and body flexibility not recording a difference (Table 3.2). Oviposition site and body form both recorded highly significant partial eta² values compared to other traits.

Not all trait modalities within a trait category contributed to the observed differences. For example, for the trait category “maximum number of reproductive cycles/year”, univoltine (1/year) and plurivoltine (many times/year) varied between hard and soft bottomed streams, while semivoltine taxa (<1/year) did not (Table 3.2). Similarly, for the trait category “oviposition site”, terrestrial and endophytic (inserted in plants) oviposition was significantly different between stream type, but surface or submerged oviposition was not.

On the basis of this assessment, reference hard bottomed stream types were characterized by having a greater proportion of taxa that were larger, reproduced once or less a year, reproduced once per individual, were shorter lived, produced eggs that were free or cemented (but not protected), were predominantly crawlers and were less likely to have both adult and larval aquatic stages. In comparison, soft bottomed streams were characterized by having a greater proportion of taxa that were smaller, reproduced multiple times per year, reproduced greater than once per individual, tended to longer lived, had protected eggs, were swimmers, were cylindrical in body form, and had both adult and larval aquatic stages. The relative importance of stream type may therefore need to be taken into account when interpreting both metric and trait analysis in relation to other factors (eg, landuse impacts).

Table 3.1:

Partial eta2 values for metrics vs stream type (hard or soft bottomed). Significant values ($p < 0.05$) are highlighted in bold.

Metric	Stream type
Taxon richness	0.55
EPT richness	0.62
%EPT richness	0.54
MCI	0.01
SQMCI	0.02

Figure 3.1:

Plots of metrics recorded from reference sites for each stream type (HB = hard bottomed, SB = soft bottomed) (\pm S.E.)

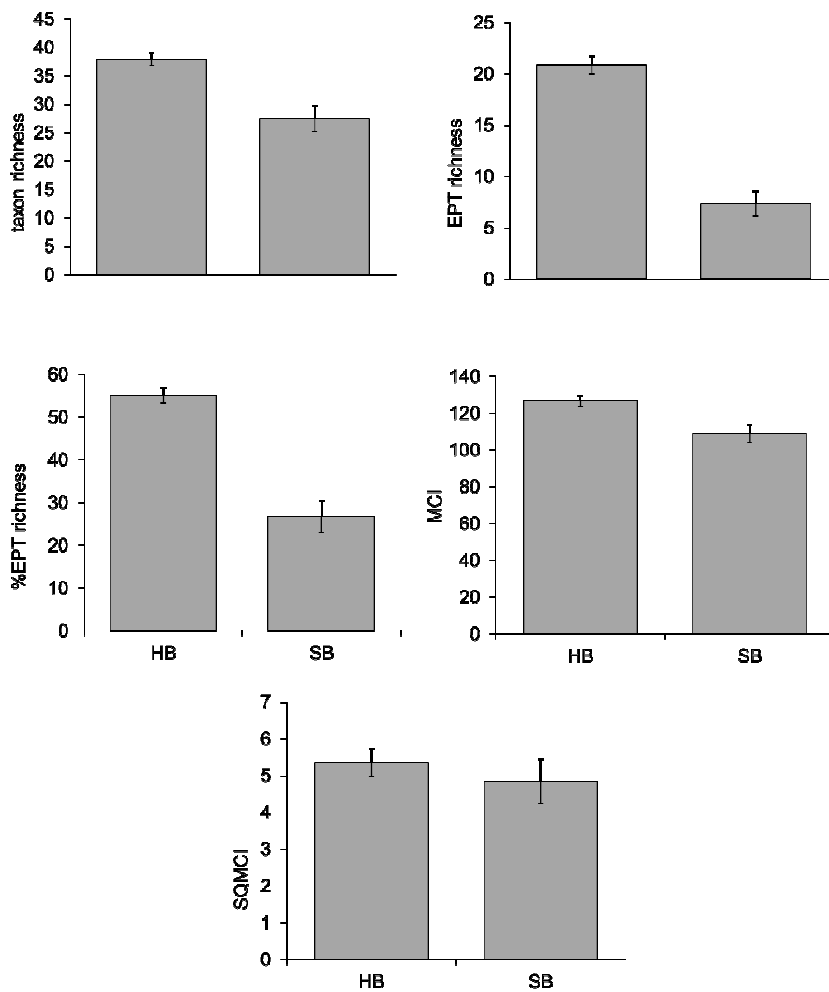


Table 3.2:

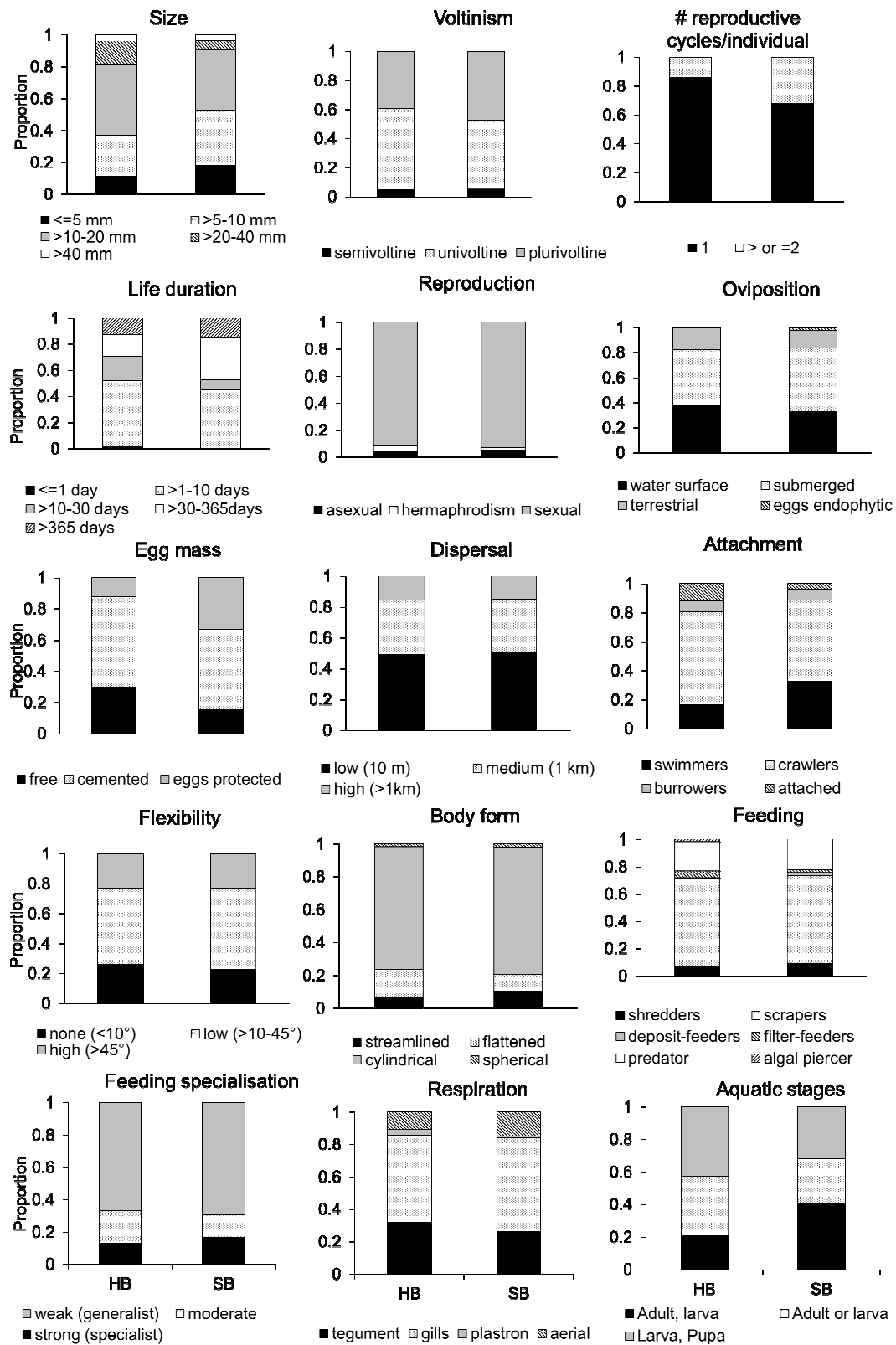
Partial eta² values for traits (category, modality) vs stream type (hard or soft bottomed). Significant values (P<0.05) for each trait category/modality are in bold.

Trait category	Partial eta ²	Trait modality	Partial eta ²
Life history traits			
Maximum potential size (mm)	0.55	≤5	0.23
		≥5-10	0.31
		≥10-20	0.21
		≥20-40	0.47
		>40	0.005
Maximum number of reproductive cycles per year	0.36	semivoltine	0.009
		univoltine	0.35
		plurivoltine	0.25
Number of reproductive cycles per individual	0.53	1	0.52
		≥2	0.52
Life duration (days)	0.69	≤1	0.61
		1-10	0.19
		10-30	0.61
		30-365	0.54
		>365	0.05
Reproductive technique	0.39	asexual	0.06
		hermaphroditism	0.20
		sexual	0.07
Oviposition site	1.00	water surface	0.04
		beneath the water surface	0.09
		terrestrial	0.24
		eggs laid within plants	0.44
Egg/egg mass location	0.62	cemented eggs	0.27
		eggs protected in/or female	0.60
		free eggs	0.44
Resilience/resistance traits			
Dispersal	0.02	low (10 m)	0.01
		medium (1 km)	0.001
		high (>1km)	0.006
Attachment to substrate	0.69	swimmers	0.66
		crawlers	0.52
		burrowers	0.02
		attached	0.66
Body flexibility	0.12	none (<10°)	0.10

Trait category	Partial eta ²	Trait modality	Partial eta ²
		low (>10-45°)	0.06
		high (>45°)	0.001
Body form	1.00	streamlined	0.24
		flattened	0.43
		cylindrical	0.14
		spherical	0.01
		General physiological traits	
Feeding habits	0.53	shredders	0.29
		scrapers	0.01
		filter-feeders	0.28
		deposit feeder	0.34
		predators	0.02
		algal piercers	0.17
Dietary preferences	0.50	strong (specialist)	0.16
		moderate	0.46
		weak (generalist)	0.07
Respiration of aquatic stages	0.47	tegument	0.20
		gills	0.06
		plastron	0.35
		aerial	0.26
Aquatic stages	0.55	adult and larva	0.47
		adult or larva	0.09
		larva or pupa	0.38

Figure 3.2:

Plots of traits recorded from reference sites for hard (HB) and soft-bottomed (SB) streams.



4 Comparison of metric and trait responses to landuse intensity

4.1 Analysis of stream type versus landuse

An initial analysis of the contribution of stream type and landuse to observed variation across all sites was undertaken. This analysis provides an indication of the relative importance of these factors, and hence indicates the suitability of a measure as an indicator of landuse impacts.

4.1.1 Metrics

For all metrics other than taxon richness, landuse intensity explained more of the variation at sites than stream type (Table 4.1). For EPT richness however, this difference was very minor (1.6%). In addition, while landuse explained 58% of the variation in %EPT richness across sites, stream type alone also explained 27.3%. In contrast, for MCI and SQMCI stream type explained very little of the variation amongst sites. This suggests MCI and SQMCI were more suitable metrics for differentiating between landuse types than the other metrics.

Table 4.1:

Partial η^2 values for stream type vs landuse intensity. Highest value for each metric is in bold. Number of sites in brackets.

Metric	Stream type (Soft bottomed=45, hard bottomed=17)	Landuse (Native=13, Exotic =8, Rural=29, Urban=12)
Taxon richness	0.356	0.267
EPT richness	0.473	0.489
%EPT richness	0.273	0.580
MCI	0.088	0.588
SQMCI	0.005	0.558

4.1.2 Traits

Analysis of the relative importance of landuse and stream type to the variation in trait composition provides an indication of how reliable a trait will be in differentiating landuse impacts. Based on the results presented in Table 4.2, it can be seen that the trait categories maximum potential size, life duration, egg mass/location and attachment to substrate were explained more by stream type than by landuse. This suggests these traits may not be suitable as indicators of landuse impacts in Auckland streams. However, individual trait modalities within these trait categories may be more sensitive to landuse than stream type, and thus a multi-indicator approach would be prudent. For example, proportion of cemented eggs was found to be explained more by

landuse than by stream type. Equally, burrowing taxa were also found to be more sensitive to landuse than to stream type.

Table 4.2:

Partial eta² values for stream type vs landuse intensity across hard and soft bottomed streams. Highest value for each trait category/modality is in bold

Trait category	Stream type	Landuse	Trait modality	Stream type	Landuse
Life history traits					
Maximum potential size (mm)	0.366	0.137	≤5	0.119	0.023
			≥5-10	0.060	0.150
			≥10-20	0.191	0.104
			≥20-40	0.242	0.093
			>40	0.010	0.157
Maximum number of reproductive cycles per year	0.078	0.219	semivoltine	0.004	0.064
			univoltine	0.073	0.358
			plurivoltine	0.076	0.279
Number of reproductive cycles per individual	0.292	0.564	1	0.292	0.564
			≥2	0.292	0.564
Life duration (days)	0.483	0.268	≤1	0.214	0.173
			1-10	0.117	0.379
			10-30	0.377	0.189
			30-365	0.296	0.475
			>365	0.066	0.067
Reproductive technique	0.104	0.382	asexual	0.057	0.342
			hermaphroditism	0.013	0.603
			sexual	<0.001	0.606
Oviposition site	0.218	0.299	water surface	0.104	0.569
			beneath the water surface	0.081	0.501
			terrestrial	0.076	0.136
			eggs endophytic	0.178	0.155
Egg/egg mass location	0.449	0.166	cemented eggs	0.136	0.269
			female bears eggs in/on body	0.429	0.191
			free eggs	0.277	0.058
Resilience/resistance traits					
Dispersal	0.042	0.328	low (10 m)	0.015	0.180
			medium (1 km)	0.011	0.546
			high (>1km)	0.042	0.131
Attachment to	0.417	0.194	swimmers	0.385	0.051

Trait category	Stream type	Landuse	Trait modality	Stream type	Landuse
substrate			crawlers	0.105	0.169
			burrowers	0.002	0.231
			attached	0.284	0.095
Body flexibility	0.028	0.409	none (<10°)	0.023	0.278
			low (>10-45°)	<0.001	0.637
			high (>45°)	0.017	0.013
Body form	0.083	0.210	streamlined	0.024	0.013
			flattened	0.007	0.203
			cylindrical	0.002	0.281
			spherical	0.029	0.406
General physiological traits					
Feeding habits	0.092	0.197	shredders	0.001	0.117
			scrapers	0.032	0.259
			filter-feeders	<0.001	0.241
			deposit feeder	0.066	0.082
			predators	0.012	0.099
			algal piercers	0.003	0.099
Dietary preferences	0.322	0.272	strong (specialist)	0.095	0.312
			moderate	0.300	0.349
			weak (generalist)	<0.001	0.100
Respiration of aquatic stages	0.057	0.256	tegument	0.044	0.229
			gills	0.018	0.400
			plastron	0.019	0.460
			aerial	0.020	0.013
Aquatic stages	0.279	0.338	adult and larva	0.279	0.396
			adult or larva	0.120	0.509
			Larva or pupa	0.167	0.098

4.2 Landuse impacts

4.2.1 All streams - metrics

A significant amount of variation in all metrics was explained by increasing landuse intensity (Table 4.3). Landuse explained the greatest amount of variation in MCI values (64.3%). Taxon richness was the least responsive to landuse, with 33.7% of variation in this metric being explained. In general there was a decrease in the value of all metrics with increasing level of landuse intensity for both stream types (Fig. 4.1).

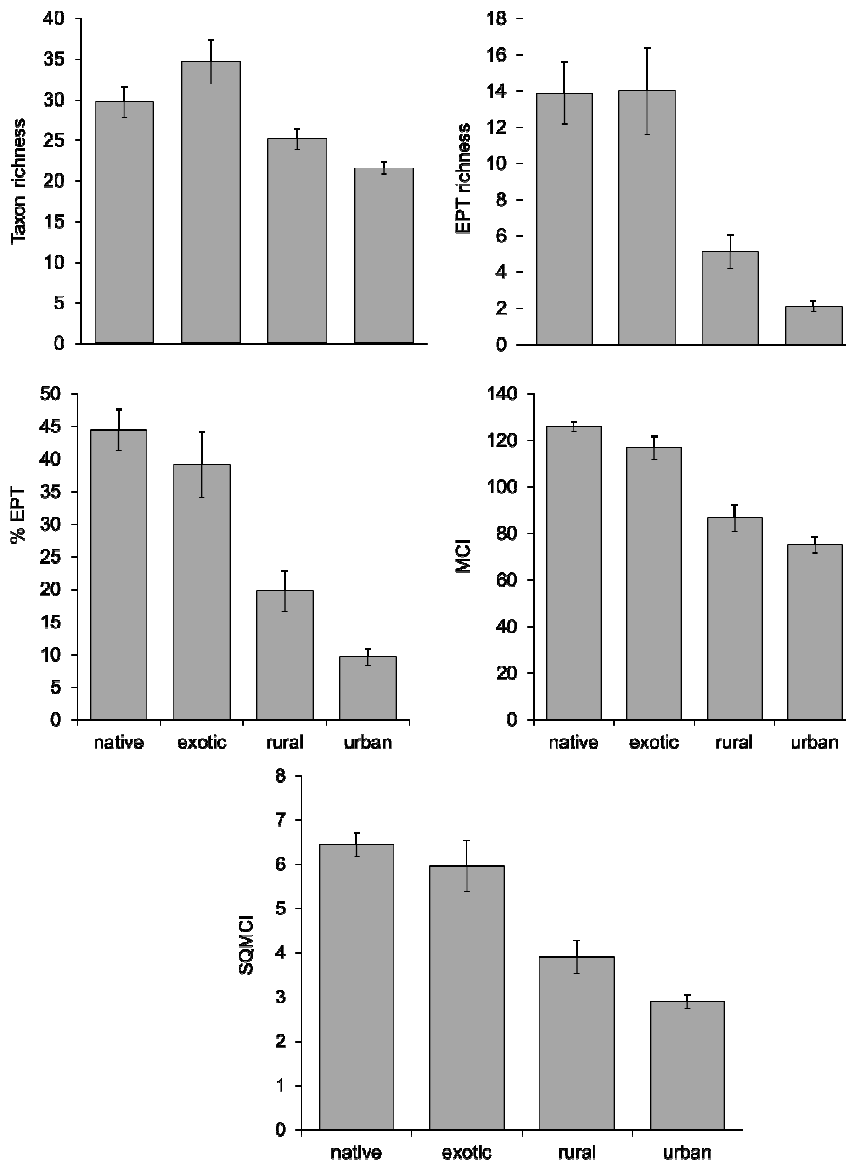
Table 4.3:

Partial eta² values for metrics vs landuse intensity for all streams.

Metric	Landuse
Taxon richness	0.337
EPT richness	0.518
%EPT richness	0.621
MCI	0.643
SQMCI	0.625

Figure 4.1:

Plots of metrics recorded from all streams versus landuse intensity (± 1 S.E.).



4.2.2 All streams - Traits

When considered at the trait category level, it is evident that many traits were responsive to increasing landuse intensity (Table 4.4), with number of reproductive cycles/individual recording the highest % variation explained (60.2%) and size the lowest value (11.7%). These values were comparable with those recorded for metrics.

Table 4.4:

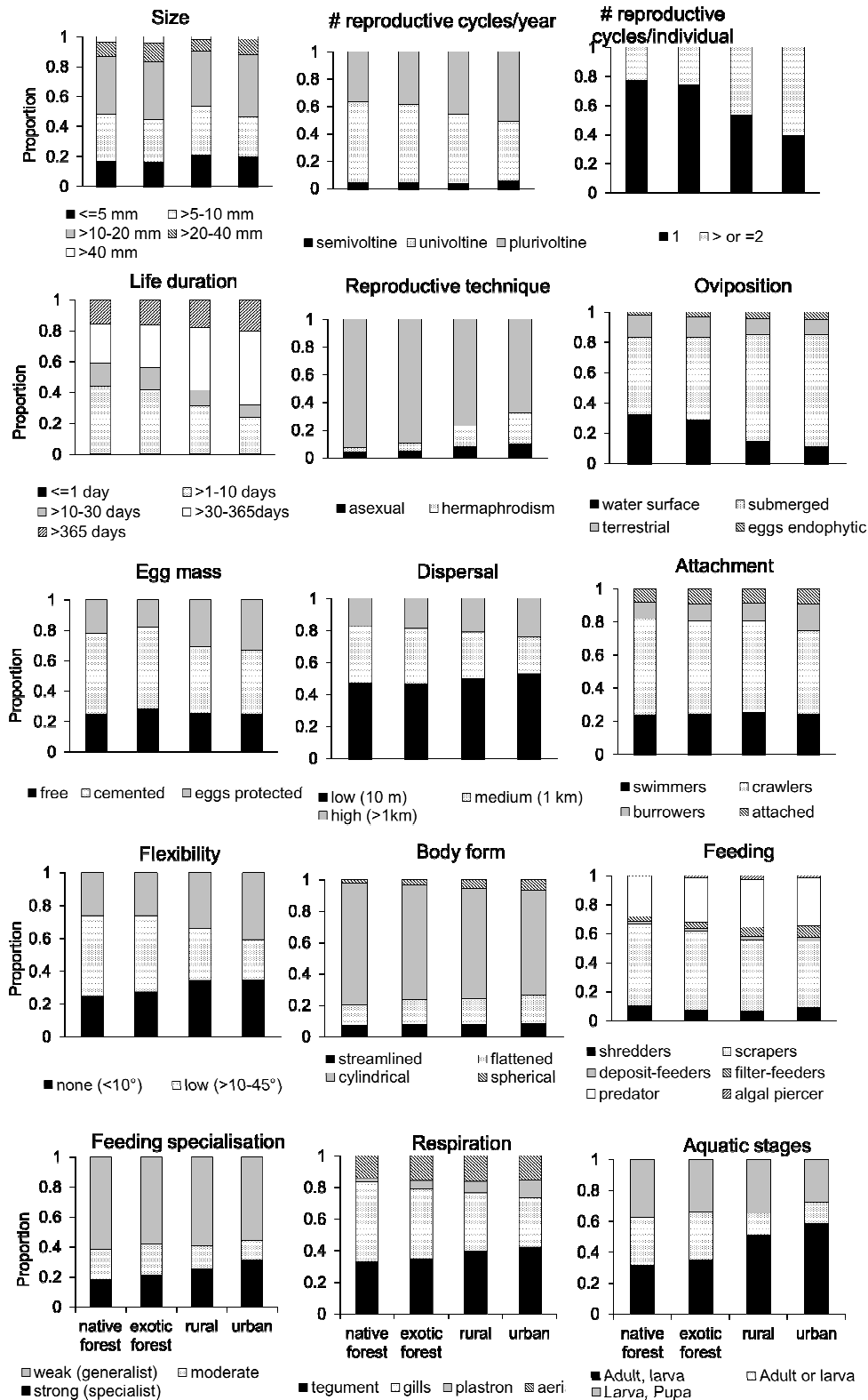
Partial η^2 values for traits vs landuse intensity across all streams. Highest value for each trait category/modality is in bold.

Trait category	Landuse	Trait modality	landuse
Life history traits			
Maximum potential size (mm)	0.117	≤ 5	0.069
		$\geq 5-10$	0.090
		$\geq 10-20$	0.050
		$\geq 20-40$	0.076
		>40	0.152
Maximum number of reproductive cycles per year	0.263	semivoltine	0.060
		univoltine	0.428
		plurivoltine	0.356
Number of reproductive cycles per individual	0.602	1	0.602
		≥ 2	0.602
Life duration (days)	0.289	≤ 1	0.258
		1-10	0.456
		10-30	0.292
		30-365	0.531
		>365	0.118
Reproductive technique	0.405	asexual	0.416
		hermaphroditism	0.616
		sexual	0.638
Oviposition site	0.336	water surface	0.625
		beneath the water surface	0.566
		terrestrial	0.208
		eggs endophytic	0.245
Egg/egg mass location	0.214	cemented eggs	0.360
		female bears eggs in/on body	0.287
		free eggs	0.029
Resilience/resistance traits			
Dispersal	0.362	low (10 m)	0.168
		medium (1 km)	0.591
		high (>1 km)	0.187
Attachment to substrate	0.173	swimmers	0.014
		crawlers	0.235

Trait category	Landuse	Trait modality	landuse
		burrowers	0.235
		attached	0.015
Body flexibility	0.437	none (<10°)	0.338
		low (>10-45°)	0.667
		high (>45°)	0.375
Body form	0.245	streamlined	0.022
		flattened	0.202
		cylindrical	0.317
		spherical	0.468
General physiological traits			
Feeding habits	0.227	shredders	0.118
		scrapers	0.323
		filter-feeders	0.134
		deposit feeder	0.262
		predators	0.129
		algal piercers	0.115
Dietary preferences	0.313	strong (specialist)	0.384
		moderate	0.429
		weak (generalist)	0.104
Respiration of aquatic stages	0.254	tegument	0.194
		gills	0.400
		plastron	0.459
		aerial	0.021
Aquatic stages	0.379	adult and larva	0.469
		adult or larva	0.570
		Larva or pupa	0.141

Figure 4.2:

Trait frequencies (annual averages) for each landuse category for all streams.



4.2.3 Hard and soft-bottomed streams - metrics

As stream type was found to be an important factor determining variation in at least some metrics and traits (section 4.1), even in reference sites (section 3), analysis of landuse impacts were conducted on hard and soft bottomed stream separately.

For both hard and soft bottomed streams, a significant amount of variation in all metrics was explained by increasing landuse intensity (Table 4.5). A greater amount of variation was explained for hard versus soft bottomed streams. Landuse explained 71% of MCI values in hard bottomed streams, but only 47% in soft bottomed streams. Taxon richness was the least responsive to landuse, with 59% and 31% of variation in this metric being explained in hard bottomed and soft bottomed streams, respectively. In general there was a decrease in the value of all metrics with increasing level of landuse intensity for both stream types (Fig. 4.3).

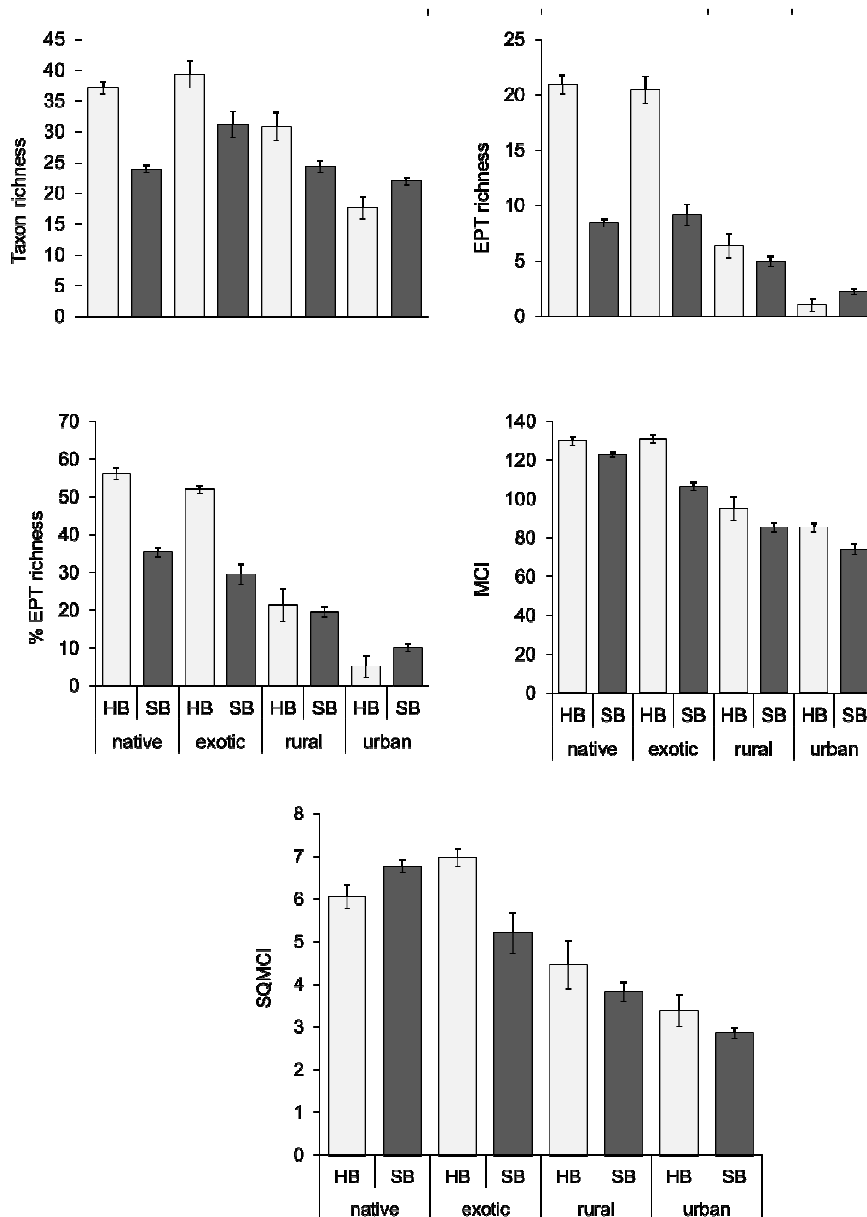
Table 4.5:

Partial eta² values for metrics vs landuse intensity for hard and soft bottomed streams. Highest value for each metric is in bold.

Metric	Soft bottomed	Hard bottomed
Taxon richness	0.306	0.591
EPT richness	0.465	0.713
%EPT richness	0.463	0.679
MCI	0.468	0.709
SQMCI	0.481	0.615

Figure 4.3:

Plots of metrics recorded from hard bottomed (HB) and soft bottomed (SB) streams versus landuse intensity (± 1 S.E.).



4.2.4 Hard and soft bottomed streams - Traits

When considered at the trait category level, it is evident that many traits were responsive to landuse intensity in both stream types, with these relationships being much stronger for hard bottomed (Table 4.6). The degree of responsiveness varies. Traits more strongly associated with landuse intensity in soft bottomed streams include attachment to substrate (10.4%), feeding (15.4%) and aquatic stages (11.2%).

Table 4.6:

Partial η^2 values for comparison of trait frequencies for each landuse intensity across hard and soft bottomed streams. Highest value for each trait category/modality is in bold.

Trait category	Hard bottomed	Soft bottomed	Trait modality	Hard bottomed	Soft bottomed
Life history traits					
Maximum potential size (mm)	0.407	0.097	≤5	0.205	0.055
			≥5-10	0.142	0.302
			≥10-20	0.140	0.273
			≥20-40	0.227	0.117
			>40	0.280	0.092
Maximum number of reproductive cycles per year	0.167	0.044	semivoltine	0.174	0.041
			univoltine	0.354	0.031
			plurivoltine	0.398	0.023
Number of reproductive cycles per individual	0.404	0.050	1	0.513	0.519
			≥2	0.513	0.519
Life duration (days)	0.387	0.078	≤1	0.244	0.123
			1-10	0.248	0.521
			10-30	0.419	0.098
			30-365	0.435	0.503
			>365	0.077	0.051
Reproductive technique	0.147	0.021	asexual	0.605	0.365
			hermaphroditism	0.615	0.532
			sexual	0.635	0.548
Oviposition site	0.999	0.051	water surface	0.564	0.481
			beneath the water surface	0.605	0.465
			terrestrial	0.196	0.238
			eggs endophytic	0.087	0.172
Egg/egg mass location	0.415	0.058	cemented eggs	0.291	0.106
			female bears eggs in/on body	0.371	0.309
			free eggs	0.212	0.204
Resilience/resistance traits					
Dispersal	0.297	0.019	low (10 m)	0.162	0.244
			medium (1 km)	0.620	0.521
			high (>1km)	0.298	0.134
Attachment to substrate	0.471	0.104	swimmers	0.167	0.286
			crawlers	0.171	0.002
			burrowers	0.686	0.325
			attached	0.110	0.158

Trait category	Hard bottomed	Soft bottomed	Trait modality	Hard bottomed	Soft bottomed
Body flexibility	0.141	0.025	none (<10°)	0.400	0.368
			low (>10-45°)	0.681	0.489
			high (>45°)	0.611	0.216
Body form	0.271	0.043	streamlined	0.225	0.034
			flattened	0.360	0.150
			cylindrical	0.223	0.139
			spherical	0.265	0.225
General physiological traits					
Feeding habits	0.327	0.154	shredders	0.242	0.049
			scrapers	0.307	0.375
			filter-feeders	0.785	0.169
			deposit feeder	0.125	0.217
			predators	0.153	0.100
			algal piercers	0.205	0.106
Dietary preferences	0.131	0.021	strong (specialist)	0.398	0.425
			moderate	0.435	0.198
			weak (generalist)	0.133	0.276
Respiration of aquatic stages	0.232	0.082	tegument	0.231	0.154
			gills	0.444	0.168
			plastron	0.714	0.394
			aerial	0.109	0.188
Aquatic stages	0.363	0.112	adult and larva	0.476	0.354
			adult or larva	0.626	0.374
			Larva or pupa	0.177	0.142

These traits were also significantly influenced by land use in hard bottomed streams. In addition, oviposition site (99.0%), maximum size (41%), number of reproductive cycles per individual (40%), life duration (38.7%) and egg mass (41.5%) were strongly influenced by increasing land use intensity.

For both stream types (Figs 4.4 and 4.5), the responses to increasing landuse intensity observed was an **increase** in taxa that:

- reproduced multiple times per year
- had greater than one reproductive cycle/individual
- reproduced asexually
- deposited eggs under water (submerged) or within aquatic or riparian plants (endophytic)
- burrowed
- were highly flexible

- were spherical in body form
- had more specialized diets (eg, algal piercers)
- were plastron respirers, and
- had both adult and larval stages in aquatic form.

In addition, for hard bottomed streams, there was a **decrease** in taxa that:

- were larger sized
- crawled
- had low flexibility, and
- respired using gills.

Finally, for soft bottomed streams, there was a **decrease** in taxa that:

- were smaller sized
- lived less than 30 days
- cemented their eggs
- had high flexibility, and
- respired using gills.

A comparison of the difference in response between hard and soft bottomed streams enables the identification of trait categories/modalities which may be less effective in differentiating land use impacts, due to confounding responses associated with stream type (Table 4.7). The responses to landuse observed in the trait categories maximum potential size, egg mass location, body flexibility, and feeding habits were significantly different between stream types. This suggests if these trait categories are used to assess the effects of landuse, then each stream type may need to be analysed separately.

Table 4.7:

Comparative analysis of changes in trait profiles of hard and soft bottomed streams with increasing landuse intensity

Trait category	HB	SB	Comment
Life history			
Maximum potential size	↑ >=5mm, ↓ >20-40, >40mm	↑ >10-20, 20-40	Proportion of larger taxa higher in SB
Maximum number of reproductive cycles per year	No difference		
Number of reproductive cycles per individual	No difference		
Life duration	No difference		
Reproductive technique	No difference		
Oviposition site	No difference		
Egg/egg mass location		↑ protected, ↓ cemented	Greater proportion of protected eggs in SB
Resilience/resistance traits			
Dispersal	No difference		
Attachment to substrate		↓ swimmers,	Difference not large
Body flexibility	↓ low	↑ low	Greater proportion of high flexibility in SB
Body form	↓ spherical	↑ spherical	Difference not large
General physiological traits			
Feeding habits	↑ predators	↑ filter feeders	Greater proportion of filter feeders in HB
Dietary preferences	No difference		
Respiration of aquatic stages	↑ aerial	↓ aerial	Difference not large
Aquatic stages	No difference		

Figure 4.4:

Trait frequencies (annual averages) for each landuse category for hard bottomed streams.

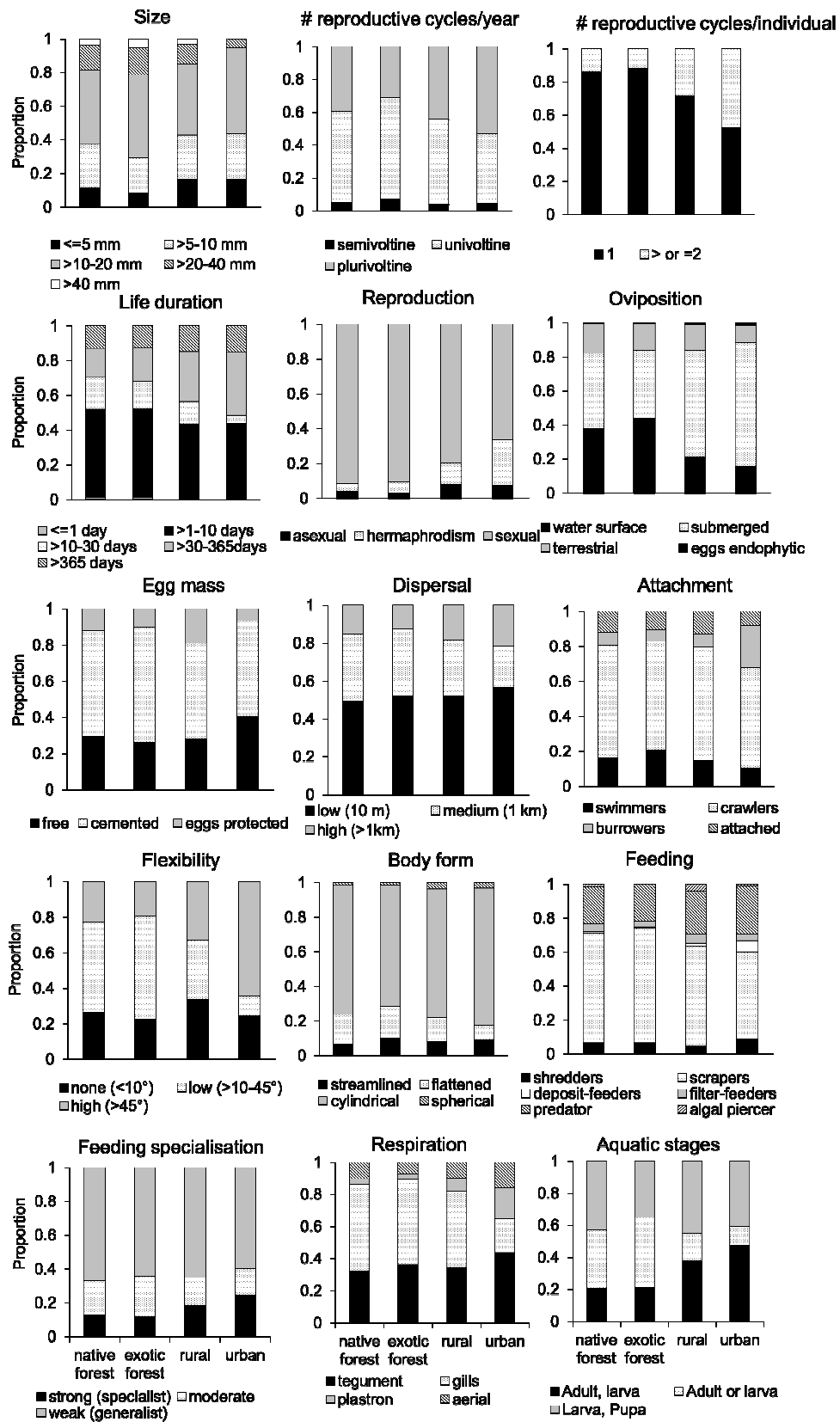
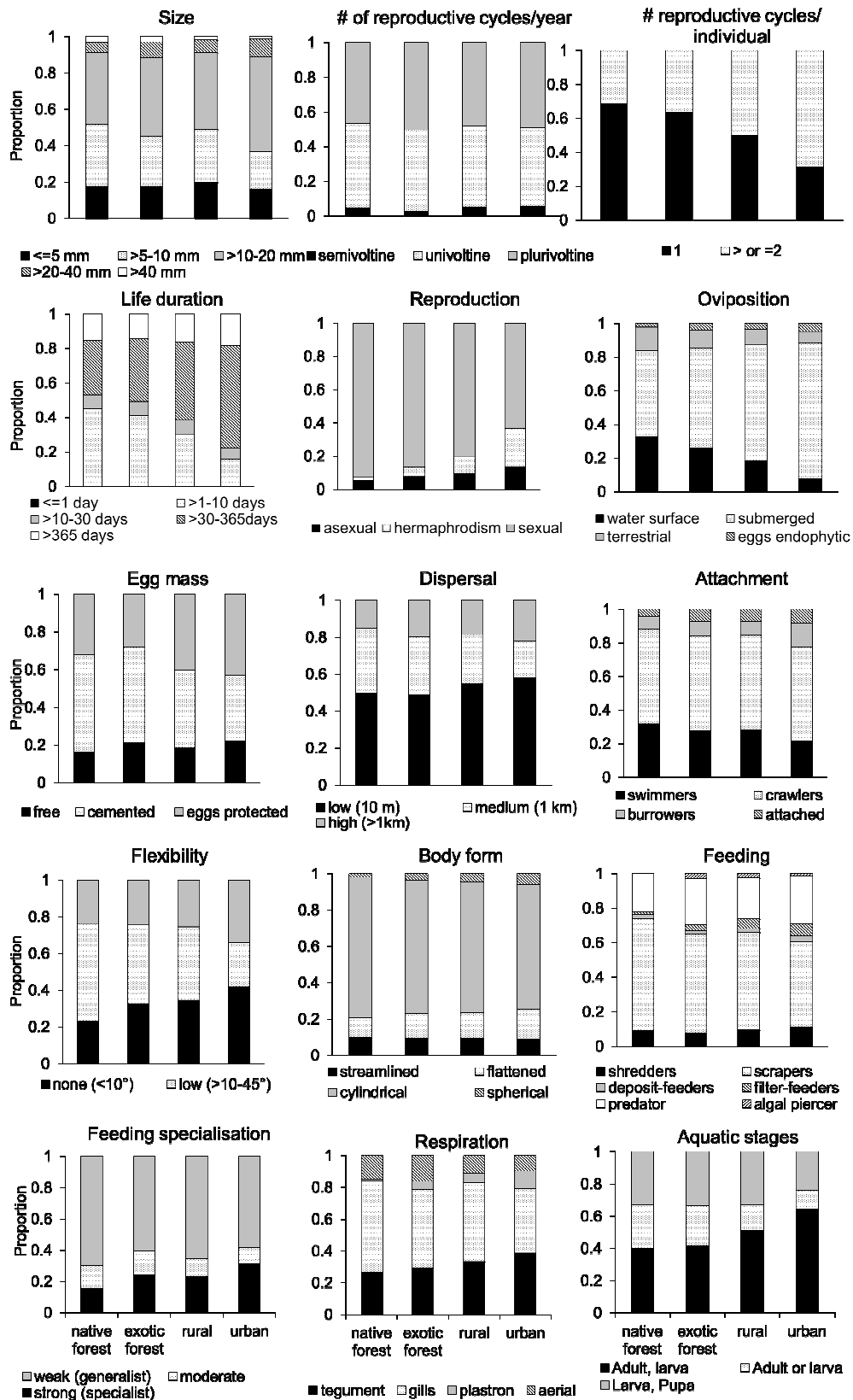


Figure 4.5:

Trait frequencies (annual averages) for each landuse category for soft bottomed streams.



5 Ability to differentiate impacted state

5.1 Basis for determining effectiveness in detecting impact state

The effectiveness of each metric and trait was examined by considering a) how much variability there is amongst sites within each landuse category (ie, native, exotic, rural and urban) and b) how much variability there is between landuse categories for a given measure. To assess these characteristics we calculated Bray Curtis **similarity** values to test for variation **within** each land use category and **dissimilarity** values to test for differences **between** land use categories.

The Bray Curtis similarity values provide a measure of how similar or different two samples are. Bray Curtis similarity values were calculated for each metric and trait frequency, using land use as the categorical factor. Thus we obtained a measure which described variation across multiple sites and years for each metric or trait, for each land use category.

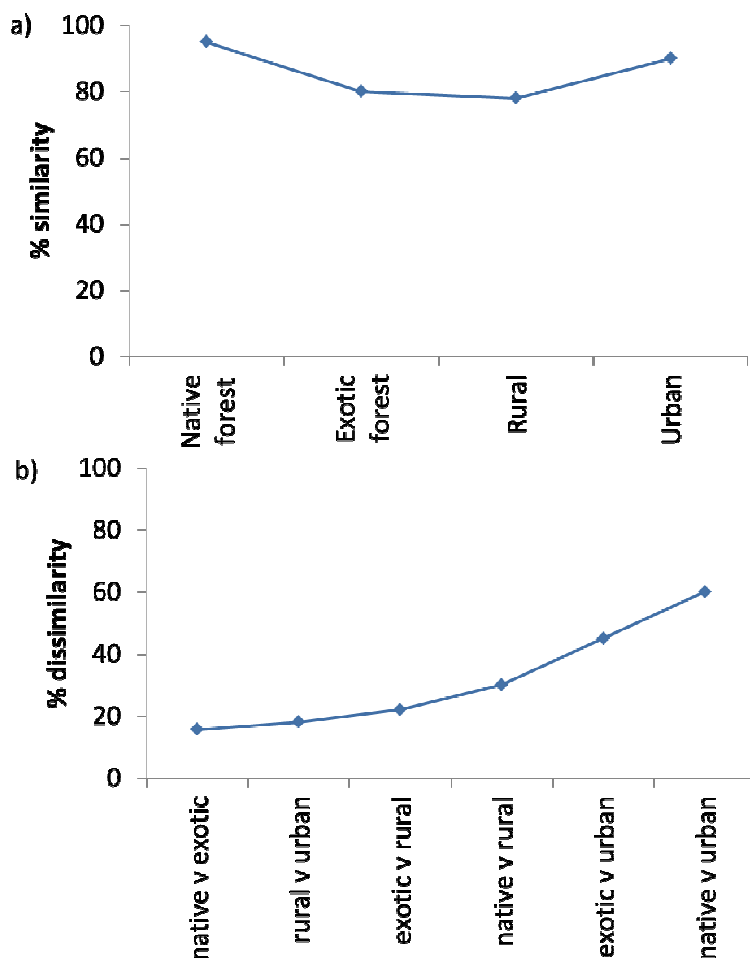
Ideally, variation within all land use categories should be low, with no overlapping values between categories. This would allow detection of differences between categories. However, we may expect some differences, based on the intermediate disturbance hypothesis, which predicts lowest stability in moderately disturbed communities (Connell 1978), (Townsend and Scarsbrook 1997). Using this hypothesis, it would be expected that the native (low impact) and urban (high impact) categories to have the lowest variation, while the exotic (low-moderate impact) and rural (moderate-high impact) categories would be most variable. These predictions assume that our land use categorization represents an increasing gradient of disturbance, from native through to urban land use (Fig. 5.1a). For variation between land use categories, an effective measure of impact would show:

- greatest dissimilarity between sites in the native and urban landuse categories, and
- least dissimilarity between site groupings with native and exotic forest and between rural and urban land use (Fig. 5.1b).

The extent to which each of the taxonomic and trait measure addresses these predictions was explored. ANOSIM analyses were conducted to test the significance of any observed differences. Analyses are presented across all stream types and for hard and soft bottomed streams separately, consistent with previous chapters indicating some differences in response associated with stream type. For visual clarity, results are presented as line graphs rather than bar graphs to enable easier detection of trends related to land use for multiple metrics/traits on the same graph.

Figure 5.1:

Example of the % similarity within land use categories and % dissimilarity between land use categories for an idealized metric.

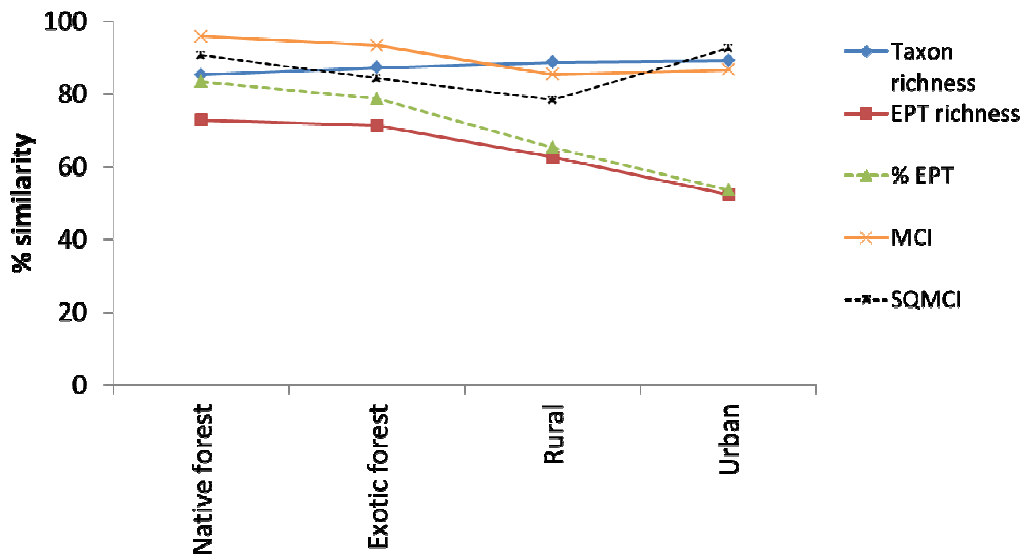


5.2 Metrics – all streams

For the analysis across all sites the number of sites within each land use category was: Native=13, Exotic =8, Rural=29, Urban=12.

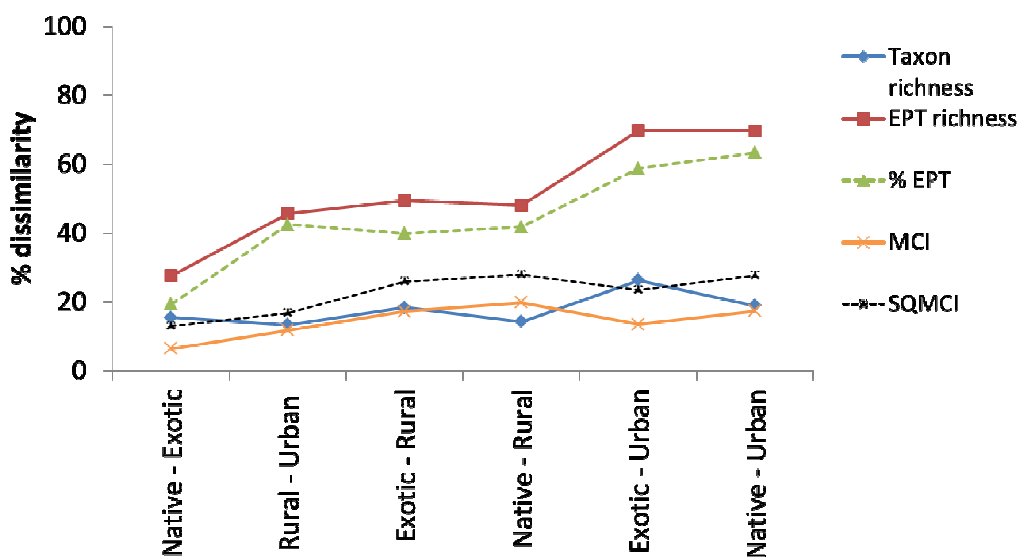
There was little variation within land use categories for taxon richness, MCI and SQMCI (Fig. 5.2), with % similarity values of greater than 75% for all three measures. In contrast, both EPT richness and %EPT richness showed decreasing % similarity with increasing land use intensity.

Figure 5.2:
% similarity within land use categories for individual metrics for all data.



Not surprisingly, % dissimilarity between all land use categories was low for taxon richness, MCI and SQMCI (Fig. 5.3). Lowest dissimilarity between land use category pairings for EPT richness and %EPT richness was for native - exotic land uses. Greatest % dissimilarity was detected for the native-urban pairing for EPT richness and the native-urban and exotic-urban pairing for %EPT richness. Percentage dissimilarity generally increased with increasing difference in land use intensity (ie, percentage similarity between native and urban land use was higher than between native and exotic forest).

Figure 5.3:
% dissimilarity between land use categories for individual metrics for all stream types.



AN OSIM analyses were used to determine the relative effectiveness of the different metrics in differentiating land use intensity. The Global R value provides an indication of the strength of the relationship between land use and metric, with higher values indicating a stronger relationship. A significant deviation from random was observed for all metrics (Table 5.1). When pairwise tests were examined, the “ideal” pattern of response for an effective measure (section 5.1) was not seen for taxon richness, with the strongest relationship being seen for exotic versus urban, rather than native versus urban (Table 5.1). For other metrics effective differentiation of land use impacts is generally seen for the extremes of the impact spectrum (native versus urban and exotic versus urban), with variable effectiveness at intermediate levels of impact.

Table 5.1:

ANOSIM results for comparisons amongst land use types (N=native, E=exotic, R=rural, U=urban), using all data. Only pairwise comparisons with $p < 0.05$ are presented. Highest Global R values for the pairwise comparisons are highlighted in bold.

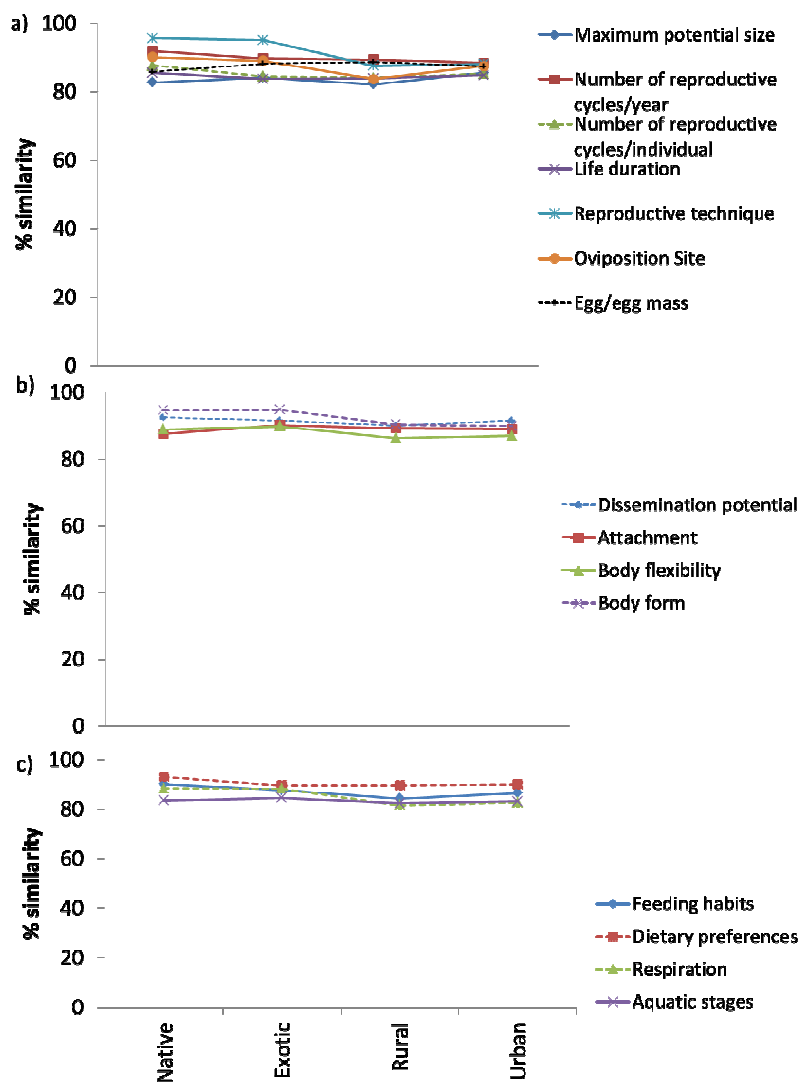
Variable	Global R	P value	Pairwise tests (Global R, p)
Taxon richness	0.180	0.010	E v N (0.060, 0.044)
			E v R (0.369, 0.001)
			E v U (0.660, 0.001)
			N v R (0.102, 0.001)
			N v U (0.179, 0.001)
EPT richness	0.276	0.010	E v R (0.144, 0.009)
			E v U (0.580, 0.001)
			N v R (0.147, 0.001)
			N v U (0.716, 0.001)
			R v U (0.299, 0.002)
% EPT	0.239	0.001	E v U (0.492, 0.001)
			N v R (0.112, 0.002)
			N v U (0.773, 0.001)
			R v U (0.299, 0.001)
MCI	0.311	0.001	E v N (0.118, 0.004)
			E v R (0.121, 0.013)
			E v U (0.684, 0.001)
			N v R (0.306, 0.001)
			N v U (0.880, 0.001)
			R v U (0.119, 0.002)
SQMCI	0.272	0.001	E v N (0.141, 0.006)
			E v R (0.188, 0.005)
			E v U (0.515, 0.001)
			N v R (0.264, 0.001)
			N v U (0.710, 0.001)
			R v U (0.159, 0.001)

5.3 Traits – all streams

There was little variation within land use categories for most traits (Fig. 5.4), with % similarity values of greater than 80% for all traits. Rural land use showed the lowest % similarity for 10 of the 15 traits. In contrast native land use sites were the most similar across 9 of the 15 traits, with exotic land use showing the highest similarity for a further 4 traits. The maximum difference between % similarity across land use categories was for the trait respiration (7.55%).

Figure 5.4:

% similarity within land use categories for a) life history, b) resilience/resistance and c) general biological trait categories for all stream types.

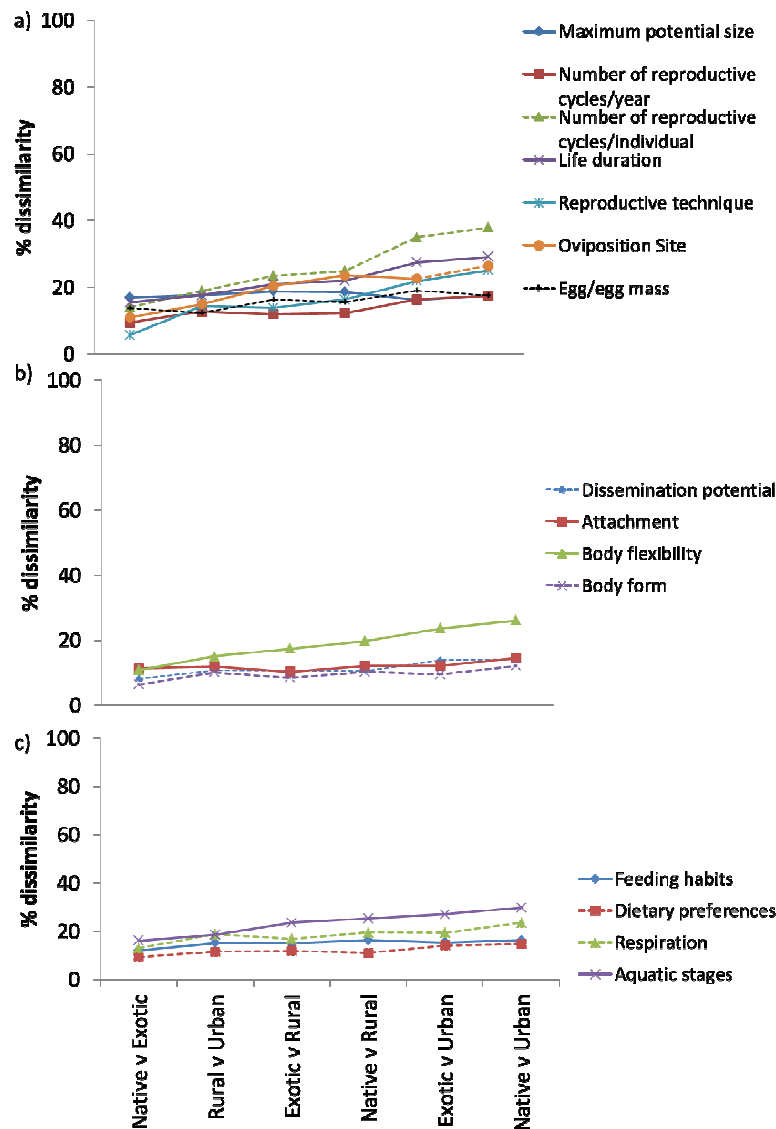


Percent dissimilarity was lowest between native and exotic land use categories for 12 of the 15 trait categories, with only maximum potential size, egg mass and attachment not following this pattern (Fig. 5.5). Minimum values ranged between 5.6% (reproductive technique) and 16.1% (size). The maximum percent similarity for the same 12 traits was observed between native and urban land uses. Maximum values ranged between 12.1% (body form) and 37.9% (# of reproductive cycles/individual). Percentage

dissimilarity generally increased with increasing difference in land use intensity (ie, percentage similarity between native and urban land use was higher than between native and exotic forest).

Figure 5.5:

% dissimilarity within land use categories for a) life history, b) resilience/resistance and c) general biological trait categories for all stream types.



ANOSIM analyses indicated significant deviation from random similarity for all traits (Table 5.2). Global R values varied between trait categories, with the highest value recorded for reproductive technique (0.470). In general, highest Global R values were observed for the native vs urban pairwise tests, although high Global R values (>0.60) were also observed for the exotic vs urban pairwise test for many trait categories.

Table 5.2:

ANOSIM results for comparisons among land use categories (N=native, E=exotic, R=rural, U=urban) using all data. Only pairwise comparisons with $p < 0.05$ presented. Highest Global R values in bold.

Trait	Global R	Significance (p)	Pairwise tests (Global R, p)
Life history traits			
Size	0.008	0.001	NvR (0.076, 0.003)
			NvU (0.091, 0.003)
			EvR (0.117, 0.014)
			EvU (0.116, 0.005)
			RvU (0.103, 0.001)
# of reproductive cycles/year	0.250	0.001	EvU (0.328, 0.001)
			NvU (0.543, 0.001)
			NvR (0.223, 0.001)
# reproductive cycles/individual	0.407	0.001	RvU (0.123, 0.001)
			NvU (0.800, 0.001)
			NvR (0.420, 0.001)
Life duration	0.345	0.001	EvR (0.288, 0.001)
			EvU (0.639, 0.001)
			NvU (0.663, 0.004)
Reproductive technique	0.470	0.001	NvR (0.346, 0.001)
			EvR (0.271, 0.001)
			RvU (0.113, 0.001)
			NvE (0.215, 0.001)
			EvU (0.673, 0.005)
Oviposition	0.406	0.001	NvU (0.880, 0.001)
			NvR (0.532, 0.001)
			EvR (0.184, 0.003)
			RvU (0.105, 0.003)
			EvU (0.558, 0.001)
Egg mass	0.186	0.001	NvU (0.798, 0.001)
			NvR (0.515, 0.001)
			EvR (0.254, 0.001)
			EvU (0.445, 0.001)
			NvU (0.239, 0.001)
			NvR (0.171, 0.001)
			EvR (0.374, 0.001)
			RvU (0.549, 0.024)

Trait	Global R	Significance (p)	Pairwise tests (Global R, p)
Resilience/resistance traits			
Dissemination	0.297	0.001	NvU (0.659, 0.001)
			NvR (0.207, 0.001)
			EvU (0.577, 0.001)
			EvR (0.091, 0.039)
			RvU (0.145, 0.001)
Attachment	0.087	0.001	NvU (0.234, 0.001)
			NvR (0.051, 0.0012)
			RvU (0.096, 0.024)
			EvU (0.142, 0.003)
			NvU (0.803, 0.001)
Flexibility	0.410	0.001	NvR (0.468, 0.001)
			RvU (0.089, 0.003)
			EvR (0.267, 0.001)
			EvU (0.677, 0.005)
			NvU (0.425, 0.001)
Body form	0.211	0.001	EvN (0.101, 0.046)
			NvR (0.348, 0.001)
			EvU (0.192, 0.001)
			NvE (0.169, 0.004)
			NvU (0.459, 0.001)
Feeding	0.227	0.015	NvR (0.298, 0.009)
			EvU (0.332, 0.001)
			NvE (0.205, 0.003)
			EvR (0.120, 0.012)
			NvU (0.590, 0.001)
Dietary preference	0.279	0.001	NvR (0.246, 0.001)
			RvU (0.083, 0.015)
			NvU (0.539, 0.001)
			EvU (0.201, 0.001)
			NvE (0.097, 0.048)
Respiration	0.230	0.001	NvR (0.261, 0.011)
			RvU (0.040, 0.045)
			NvR (0.370, 0.001)
			NvU (0.529, 0.001)
			EvR (0.304, 0.001)
Aquatic stages	0.292	0.001	EvU (0.467, 0.001)

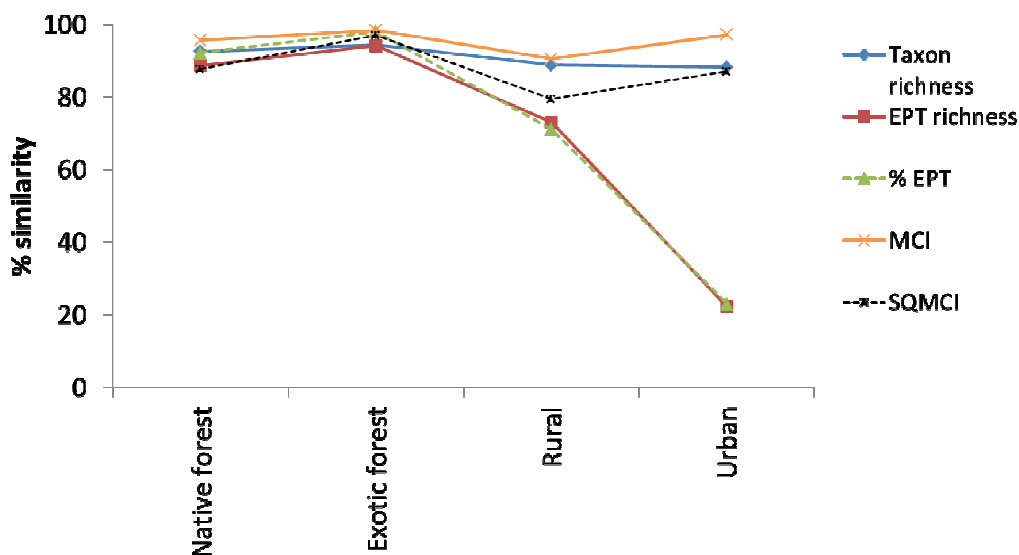
5.4 Metrics – hard bottomed streams

For the analysis across hard bottomed streams the number of sites within each land use category was: Native=7, Exotic =3, Rural=6, Urban=1.

For taxon richness, EPT richness and %EPT richness, % similarity was lowest for the urban land use (Fig. 5.6), whereas rural land use showed the lowest % similarity for MCI and SQMCI. For all metrics, exotic forest land use showed the greatest similarity. There was relatively limited variation in % similarity between impact groups based on MCI, with greatest variation between impact groups based on EPT richness and %EPT richness. Urban sites in particular showed considerable variability for these metrics.

Figure 5.6:

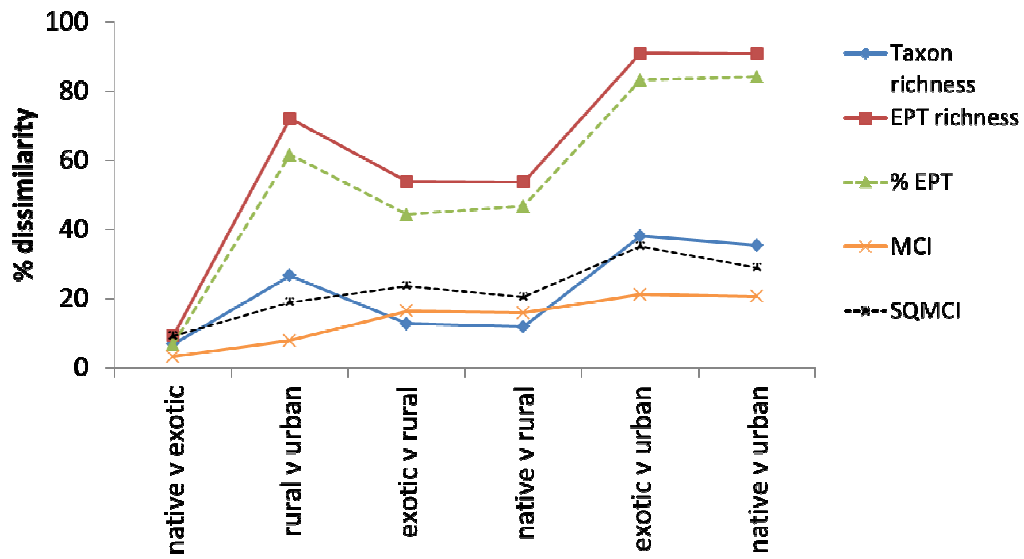
% similarity within land use categories for individual metrics for hard bottomed streams.



For all metrics other than SQMCI, greatest dissimilarity was found between urban and native land use and between exotic and urban land use (Fig. 5.7). For MCI, the pattern of % dissimilarity between land use categories was as predicted ie, native-urban was most dissimilar, with decreasing dissimilarity associated with more similar land use intensities. For taxon richness, EPT richness and % EPT, % dissimilarity values for rural-urban land use was higher than predicted (see section 5.1).

Figure 5.7:

% dissimilarity between land use categories for individual metrics for hard bottomed streams.



ANOSIM analyses indicated significant deviation from random similarity for all metrics (Table 5.3), with significantly high Global R values. For EPT richness and %EPT richness, the highest Global R value was for the native-urban comparison. For MCI, SQMCI and taxon richness the exotic-urban pairing had a slightly higher Global R values, although both were highly significant. In general a strong pattern in Global R values from least to most similar pairings of land use did not follow.

Table 5.3:

ANOSIM results for comparisons among land use categories for hard bottomed streams (N=native, E=exotic, R=rural, U=urban) in terms of each metric. Only pairwise comparisons with $p < 0.05$ presented. Highest Global R values in bold.

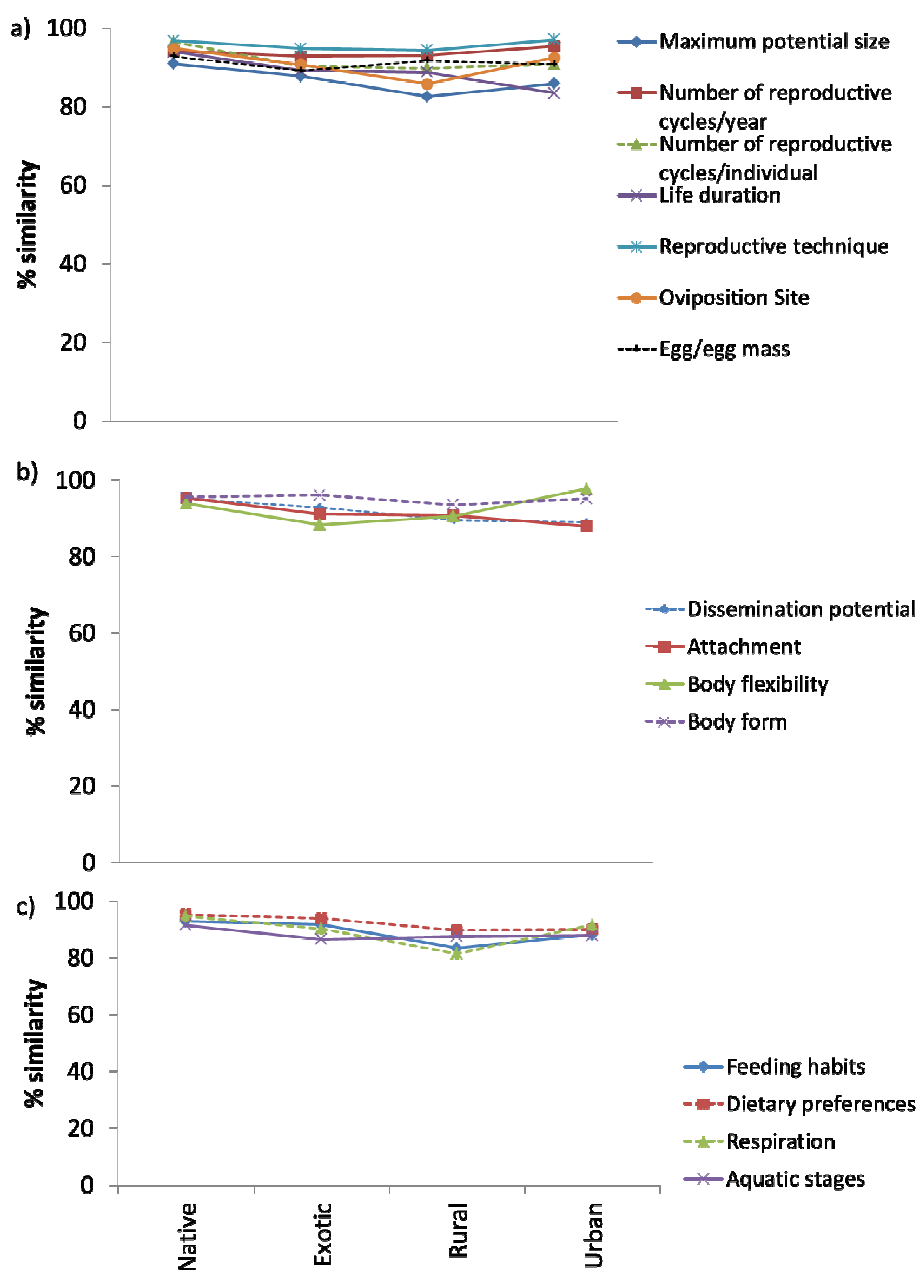
Variable	Global R	P value	Pairwise tests (Global R, p)
Taxon richness	0.314	0.001	EvR (0.272, 0.009)
			EvU (1.000, 0.005)
			NvR (0.273, 0.001)
			NvU (0.982, 0.001)
			RvU (0.727, 0.002)
EPT richness	0.422	0.001	EvR (0.312, 0.002)
			EvU (0.915, 0.005)
			NvR (0.492, 0.001)
			NvU (0.984, 0.001)
			RvU (0.915, 0.002)
% EPT	0.345	0.001	EvU (0.915, 0.005)
			NvR (0.367, 0.001)
			NvU (0.984, 0.002)
			RvU (0.832, 0.002)
MCI	0.494	0.001	EvR (0.736, 0.001)
			EvU (1.000, 0.005)
			NvR (0.631, 0.001)
			NvU (0.927, 0.001)
SQMCI	0.412	0.001	RvU (0.372, 0.001)
			EvR (0.599, 0.001)
			EvU (1.000, 0.005)
			NvR (0.397, 0.001)
			NvU (0.905, 0.001)
			RvU (0.777, 0.001)

5.5 Traits – hard bottomed streams

There was little variation within land use categories for most traits (Fig. 5.8), with % similarity values of greater than 80% for all traits. Rural land use showed the lowest % similarity for 8 of the 15 traits. In contrast native land use sites were the most similar across 11 of the 15 traits. The maximum difference between % similarity of across land use categories was for the trait respiration (13.22%).

Figure 5.8:

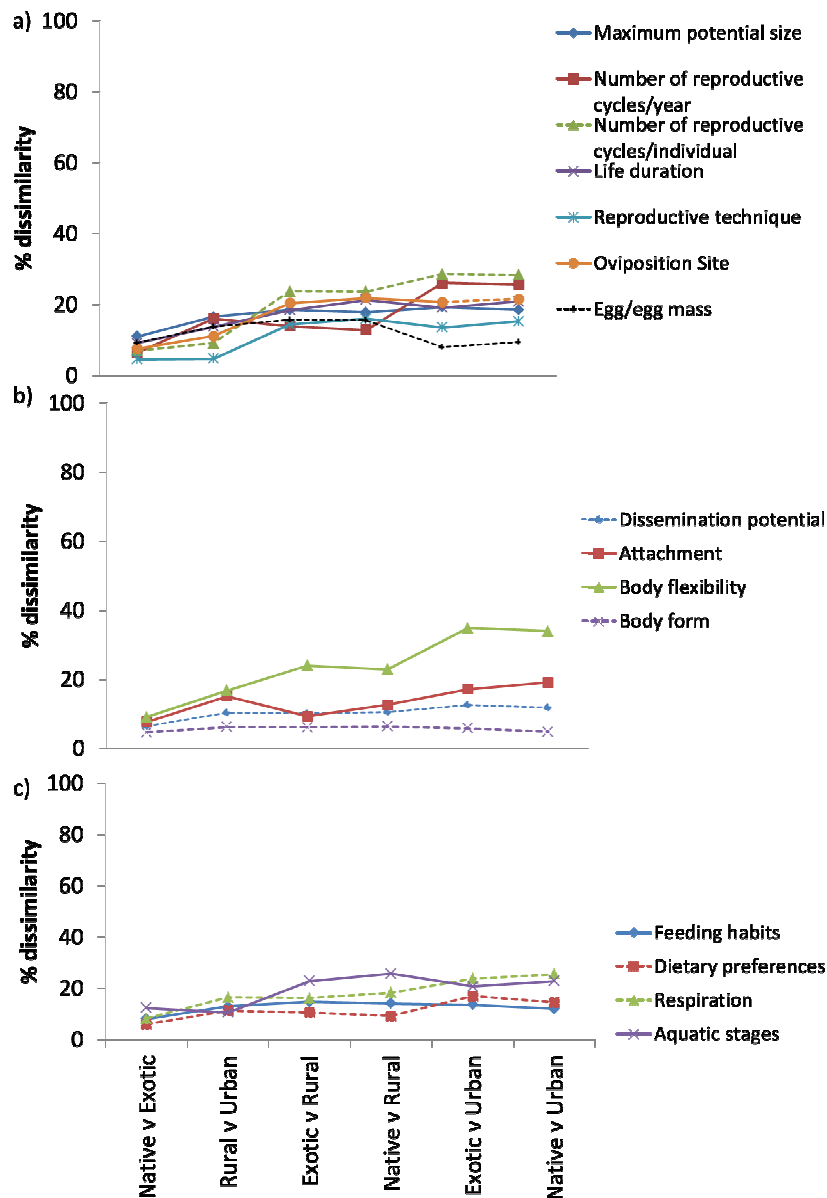
% similarity within land use categories for a) life history, b) resilience resistant and c) general biological trait categories for hard bottomed streams.



Percent dissimilarity was lowest between native and exotic land use categories for 13 of the 15 trait categories, with only egg mass and aquatic stages not following this pattern (Fig. 5.9). Minimum values ranged between 4.5% (reproductive technique) and 12.3% (aquatic stages). The maximum percent similarity for the same 13 traits was observed between exotic and urban land uses, with marginally lower values for the native-urban land use comparison. Maximum values for the native-urban land use comparison ranged between 7.8% (body form) and 33.9% (body flexibility). For some traits, the % dissimilarity generally increased with increasing difference in land use intensity (ie, percentage similarity between native and urban land use was higher than between native and exotic forest). However, for body form, dispersal, egg mass, feeding habits and aquatic stages, this pattern was not observed.

Figure 5.9:

% dissimilarity between land use categories for a) life history, b) resilience resistant and c) general biological trait categories for hard bottomed streams.



ANOSIM analyses indicated significant deviation from random similarity for all trait categories (Table 5.4). Global R values varied between trait categories, with the highest value recorded for reproductive technique (0.495). Pairwise tests for this trait category indicated a high Global R value (0.921) for the native-urban land use comparison (Table 5.4). For all trait categories other than egg mass, the exotic-urban land use comparison yielded the highest Global R values. Native-urban land use comparisons generally had only slightly lower Global R values than the exotic-urban pairings.

Table 5.4:

ANOSIM results for trait comparisons among land use categories (N=native, E=exotic, R=rural, U=urban) for hard bottomed streams. Only pairwise comparisons with $p < 0.05$ presented. Highest Global R values in bold.

Trait	Global R	Significance (p)	Pairwise tests (Global R, p)
Life history traits			
Size	0.298	0.001	NvR (0.477, 0.001)
			NvU (0.607, 0.001)
			EvR (0.639, 0.001)
			EvU (0.903, 0.001)
# of reproductive cycles/year	0.414	0.001	EvU (1.000, 0.005)
			EvR (0.729, 0.001)
			NvU (0.998, 0.001)
			NvR (0.561, 0.001)
# reproductive cycles/individual	0.404	0.002	RvU (0.827, 0.012)
			NvU (0.829, 0.003)
			NvR (0.715, 0.001)
			EvR (0.948, 0.001)
Life duration	0.385	0.001	EvU (1.000, 0.005)
			EvU (0.901, 0.001)
			NvU (0.716, 0.004)
			NvR (0.745, 0.001)
Reproductive technique	0.495	0.001	EvR (0.902, 0.001)
			EvU (1.000, 0.005)
			NvU (0.921, 0.001)
			NvR (0.885, 0.001)
Oviposition	0.404	0.001	EvR (0.959, 0.002)
			EvU (0.998, 0.005)
			NvU (0.850, 0.001)
			NvR (0.730, 0.001)

Trait	Global R	Significance (p)	Pairwise tests (Global R, p)
			EvR (0.792, 0.001)
			NvR (0.412, 0.004)
Egg mass	0.152	0.005	EvR (0.746, 0.001)
			RvU (0.549, 0.024)
Resilience/resistance traits			
			NvU (0.489, 0.001)
			NvR (0.382, 0.008)
Dissemination	0.225	0.001	EvU (0.770, 0.005)
			EvR (0.495, 0.001)
			EvU (0.966, 0.005)
			NvU (0.753, 0.001)
Attachment	0.319	0.002	NvR (0.410, 0.007)
			EvR (0.496, 0.005)
			RvU (0.531, 0.024)
			NvU (0.965, 0.001)
			NvR (0.725, 0.001)
Flexibility	0.440	0.001	RvU (0.790, 0.003)
			EvR (0.985, 0.001)
			EvU (1.000, 0.005)
Body form	0.294	0.001	NvU (0.538, 0.001)
General physiological traits			
			EvU (0.694, 0.009)
			EvR (0.319, 0.017)
			NvU (0.469, 0.001)
Feeding	0.228	0.015	NvR (0.404, 0.009)
			EvU (0.934, 0.005)
			EvR (0.486, 0.001)
			NvU (0.788, 0.003)
Dietary preference	0.305	0.001	NvR (0.337, 0.007)
			NvU (0.913, 0.003)
Respiration	0.356	0.001	NvR (0.135, 0.002)
			NvE (0.511, 0.001)
			NvU (0.534, 0.001)
			EvR (0.537, 0.001)
Aquatic stages	0.157	0.001	EvU (1.000, 0.005)

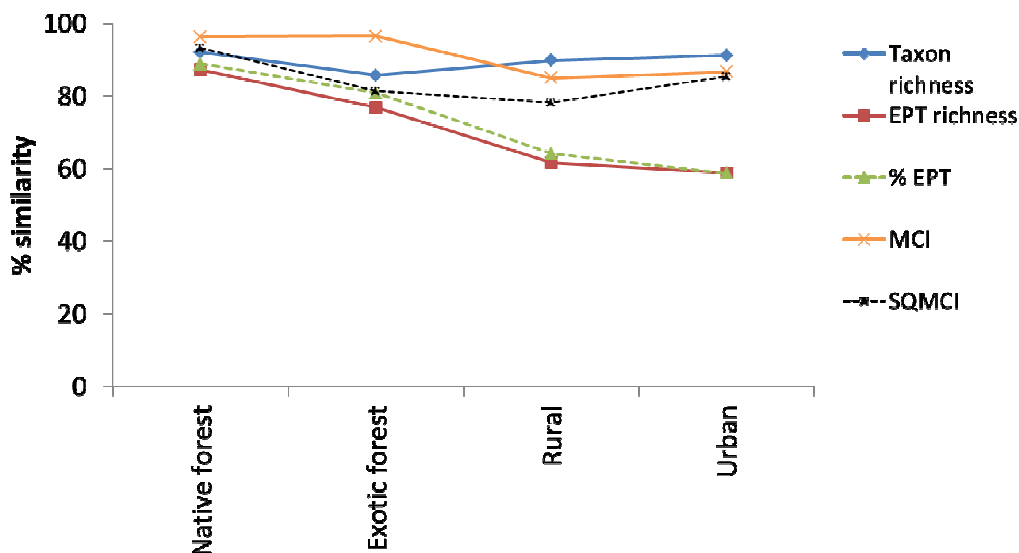
5.6 Metrics – soft bottomed streams

For the analysis across soft bottomed streams the number of sites within each land use category was: Native=9, Exotic =5, Rural=20, Urban=11.

For EPT richness and %EPT richness, % similarity was lowest for the urban land use category (Fig. 5.10). The native land use category showed the greatest similarity for all traits. There was relatively limited variation in % similarity between impact categories based on taxon richness, MCI and SQMCI, while greatest variation between impact categories was based on EPT richness and %EPT richness.

Figure 5.10:

% similarity within land use categories for individual metrics for soft bottomed streams.



For all metrics other than MCI and taxon richness, greatest dissimilarity was found between native and urban land use categories (Fig. 5.11) and the pattern of % dissimilarity between impact categories was as predicted (i.e., increasing dissimilarity with increasing land use intensity).

ANOSIM analyses indicated significant deviation from random similarity for all metrics (Table 5.5), with significantly Global R values. In most cases, the highest Global R value was for the native vs urban comparison (other than for taxon richness).

Figure 5.11:

% dissimilarity within land use categories for individual metrics for soft bottomed streams.

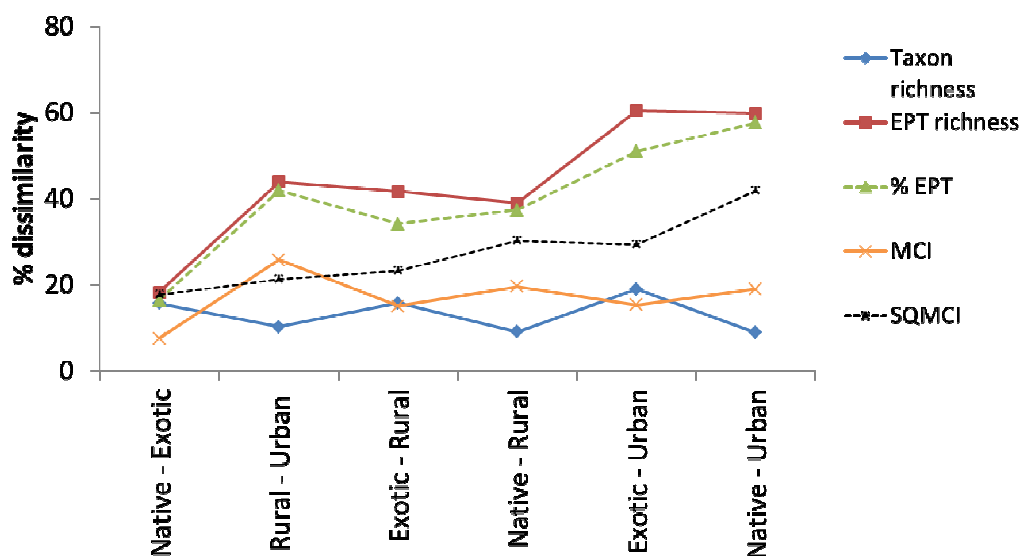


Table 5.5:

ANOSIM results for comparisons among land use categories for soft bottomed streams (N=ative, E=exotic, R=rural, U=urban) in terms of each metric. Only pairwise comparisons with p<0.05 presented. Highest Global R values in bold.

Variable	Global R	P value	Pairwise tests (Global R, p)
Taxon richness	0.102	0.00	EvN (0.435, 0.001)
			EvR (0.376, 0.001)
			EvU (0.529, 0.001)
EPT richness	0.215	0.001	EvN (0.167, 0.007)
			EvU (0.510, 0.001)
			NvU (0.635, 0.001)
% EPT	0.179	0.001	RvU (0.225, 0.001)
			EvU (0.371, 0.001)
			NvU (0.627, 0.001)
MCI	0.201	0.001	EvN (0.658, 0.001)
			EvU (0.331, 0.001)
			NvR (0.108, 0.020)
SQMCI	0.249	0.001	NvU (0.748, 0.001)
			RvU (0.142, 0.002)
			EvN (0.447, 0.001)
SQMCI	0.249	0.001	EvU (0.491, 0.001)
			NvR (0.129, 0.011)
			NvU (0.927, 0.011)
			RvU (0.160, 0.001)

5.7 Traits – soft bottomed streams

There was little variation within land use categories for most traits (Fig. 5.12), with % similarity values of greater than 80% for all traits. Rural land use showed the lowest % similarity for 12 of the 15 traits. Native land use sites were the most similar across 12 of the 15 traits (although not exactly the same trait set as for the rural sites). The maximum difference between % similarity of across land use categories was for the trait reproductive technique (11.4%).

Percent dissimilarity was lowest between native and exotic land use categories for 13 of the 15 trait categories, with only body flexibility and feeding preference not following this pattern (Fig. 5.13). Minimum values ranged between 7.2% (body form) and 15.7% (size). The maximum percent similarity for a slightly different set of 13 traits was observed between native and urban land uses. Maximum values for the native-urban land use comparison ranged between 11.9% (body form) and 37.4% (# reproductive cycles/individual). For some traits, the % dissimilarity generally increased with increasing difference in land use intensity (ie, percentage similarity between native and urban land use was higher than between native and exotic forest). However, for # of reproductive cycles/year, and egg mass, this pattern was not observed.

ANOSIM analyses indicated significant deviation from random similarity for all traits (Table 5.6). Global R values varied between traits, with the highest value recorded for reproductive technique (0.406). In general, highest Global R values were observed for the native vs urban pairwise tests.

Figure 5.12:

Similarity between land use categories for individual trait categories for soft bottomed streams.

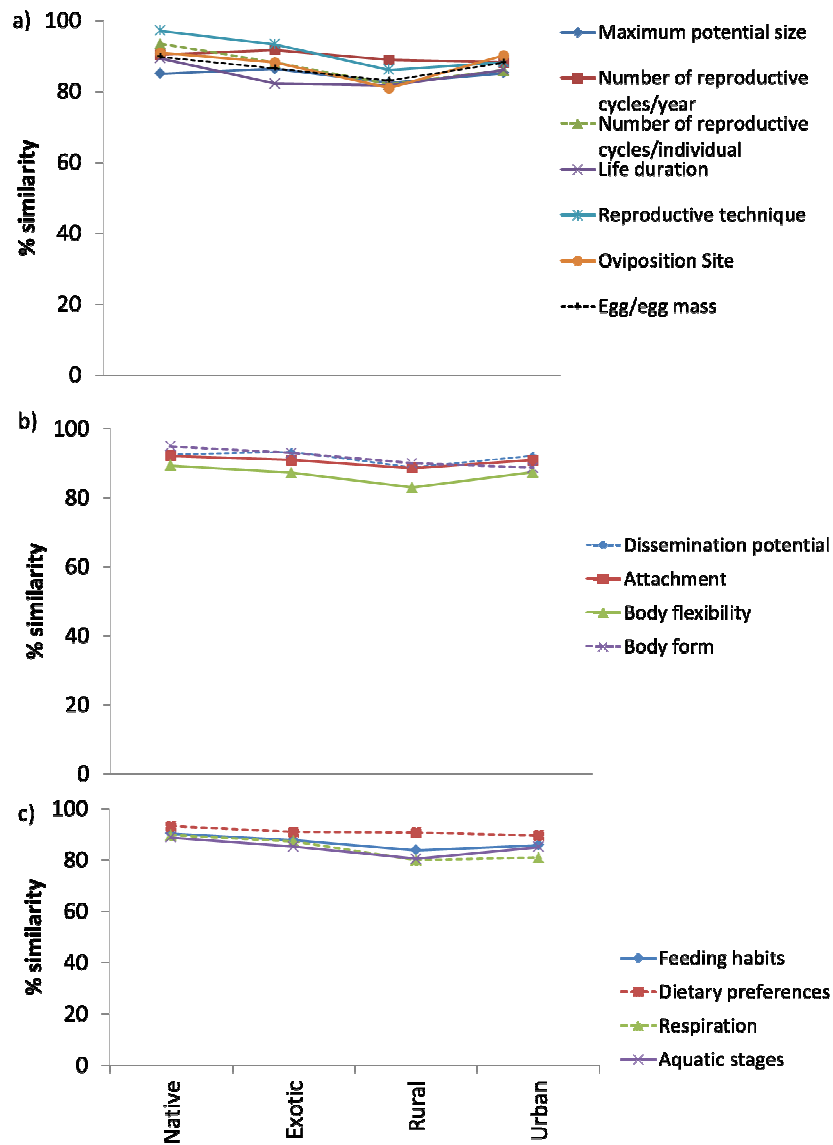


Figure 5.13:

% dissimilarity between land use categories for individual trait categories for soft bottomed streams.

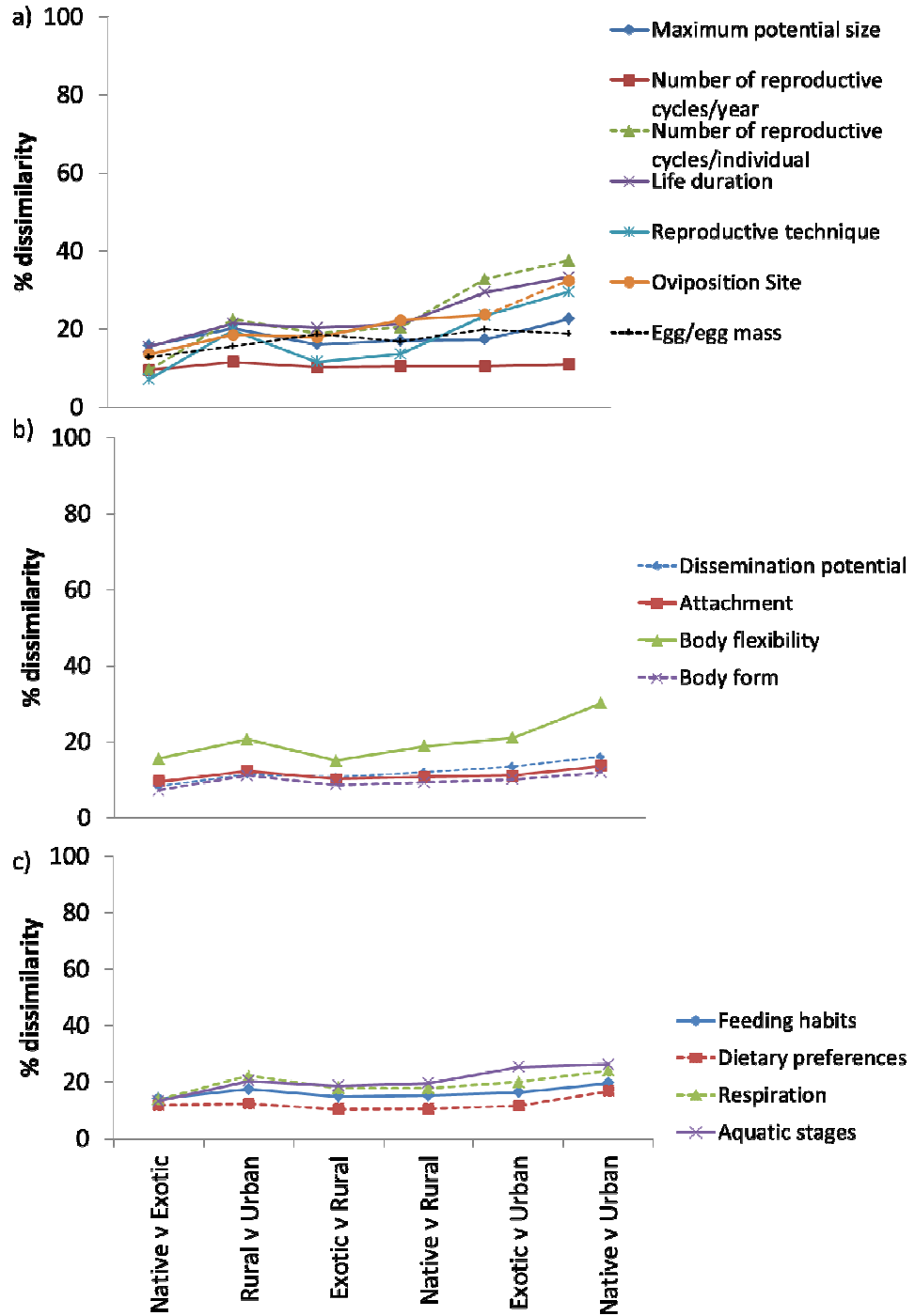


Table 5.6:

ANOSIM results for comparisons among land use categories (1=native, 2=exotic, 3=rural, 4=urban) for soft bottomed streams. Only pairwise comparisons with $p < 0.05$ presented.

Variable	Global R	Significance (p)	Pairwise tests (Global R, p)
Life history traits			
Size	0.121	0.001	NvU (0.303, 0.001) EvR (0.117, 0.001)
# of reproductive cycles/year	0.117	0.001	NvU (0.352, 0.001) NvR (0.072, 0.025) RvU (0.069, 0.016)
# reproductive cycles/individual	0.359	0.001	NvU (0.882, 0.001) NvR (0.353, 0.001) RvU (0.112, 0.004) EvU (0.639, 0.001)
Life duration	0.299	0.001	NvU (0.681, 0.001) NvE (0.418, 0.002) NvR (0.229, 0.001) EvU (0.528, 0.001) RvU (0.109, 0.001)
Reproductive technique	0.406	0.001	NvE (0.418, 0.002) EvU (0.619, 0.001) NvU (0.850, 0.001) RvU (0.123, 0.003)
Oviposition	0.308	0.001	NvE (0.188, 0.008) EvU (0.367, 0.001) NvU (0.727, 0.001) NvR (0.394, 0.001)
Egg mass	0.165	0.001	NvE (0.278, 0.002) NvU (0.244, 0.001) NvR (0.124, 0.002) EvU (0.405, 0.001)
Resilience/resistance traits			
Dissemination	0.279	0.001	NvU (0.636, 0.001) NvR (0.136, 0.003) EvU (0.519, 0.001) NvE (0.143, 0.034) RvU (0.175, 0.001)
Attachment	0.099	0.001	NvU (0.313, 0.001) NvR (0.065, 0.017)
Flexibility	0.374	0.001	NvU (0.882, 0.001) NvE (0.129, 0.001)

Variable	Global R	Significance (p)	Pairwise tests (Global R, p)
			NvR (0.407, 0.001)
			RvU (0.111, 0.002)
			EvU (0.564, 0.001)
			NvU (0.477, 0.001)
Body form	0.202	0.001	EvN (0.318, 0.003)
			NvR (0.340, 0.001)
General physiological traits			
			EvU (0.192, 0.001)
			NvE (0.169, 0.004)
			NvU (0.459, 0.001)
Feeding	0.191	0.015	NvR (0.298, 0.009)
			NvE (0.494, 0.001)
			NvU (0.393, 0.001)
			NvR (0.262, 0.001)
Dietary preference	0.176	0.001	RvU (0.045, 0.044)
			NvU (0.438, 0.001)
			NvE (0.370, 0.048)
			NvR (0.124, 0.011)
Respiration	0.217	0.001	RvU (0.062, 0.026)
			NvR (0.313, 0.001)
			NvU (0.332, 0.001)
			EvU (0.307, 0.048)
Aquatic stages	0.236	0.001	RvU (0.044, 0.035)

6 Combined analysis - Auckland Council and Waikato Regional Council datasets

6.1 Introduction

Stream macroinvertebrates have a range of environmental preferences and represent a diverse group that integrates ecosystem changes over time. Therefore, they are widely used as indicators of environmental disturbance (Wright et al. 1993, Stark et al. 2001, Metzeling et al. 2003). However, an important limitation in their use is that taxonomic composition and abundance vary considerably as a consequence of biogeography (eg, Poff 1997, Heino 2001, Bonada et al. 2007) and the observed patterns are, in fact, the product of natural stochastic variation and independent deterministic changes associated with disturbance from human activities. Thus, the use of taxonomic composition alone may be insufficient to unambiguously distinguish local land use effects from natural biogeographic variation of populations. Ecoregional differences in macrofaunal communities have been observed in New Zealand rivers (Harding and Winterbourn, 1997).

We investigated the influence of regional differences on the potential to differentiate impacts on streams affected by differing land uses in the Auckland (AC) and Waikato (WRC) regions. Due to differences in the number of sites in each land use within each region, this analysis was only undertaken using sites in predominantly native forest or rural land uses. In addition, as different enumeration methods were used to derive abundance data, presence/absence data were used. Because of differences in stream type amongst reference sites, we also included stream type as a factor in our analysis.

6.2 Variation in Metrics

Land use explained a greater proportion of variation than region or stream type for all metrics (Table 6.1), with percentage variation explained by land use ranging from 15.2% (taxon richness) to 45% (EPT richness). However, variation in taxon richness was almost equally explained by land use (15.2%), region (12.2%) and stream type (10%).

Table 6.1:

Results (partial η^2) of a three-way ANOVA to test for differences between regions, land use and stream type. Values in bold indicate highest values for each metric. Number of sites for each analysis is indicated in brackets.

All (103)			
Metric	Land use (Native=56, Rural=47)	Region (WRC=74, AC=29)	Stream type (HB=69, SB=44)
Taxon richness	0.152	0.122	0.100
EPT richness	0.450	0.001	0.190
MCI	0.410	0.020	0.030

Figures 6.1 - 6.3 illustrate the differences in metric values based on region (Fig. 6.1), land use (Fig. 6.2) and stream type (Fig. 6.3). As described above, there was little difference between any of the metrics based on region. In contrast, native stream sites recorded significantly higher values than rural streams for all metrics. Differences in MCI and EPT Richness were also noted based on stream type. However, in general land use is the strongest driver of invertebrate metric scores.

Figure 6.1:

Metrics based on region (Auckland Council – AC, Waikato Regional Council – WRC) (± 1 S.E.).

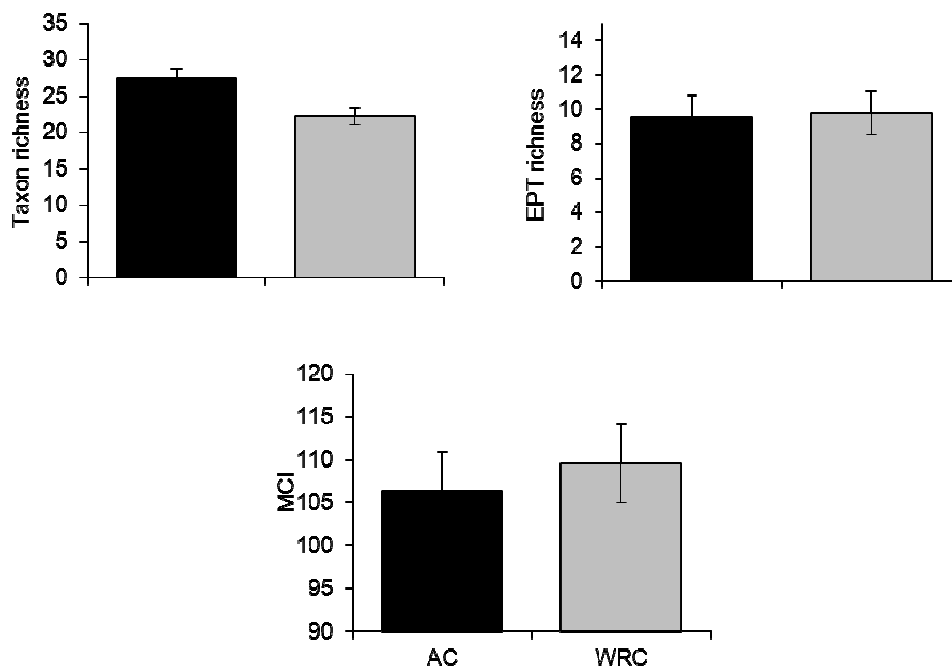


Figure 6.2:

Metrics based on land use (native and rural) across Auckland and Waikato regions (± 1 S.E.).

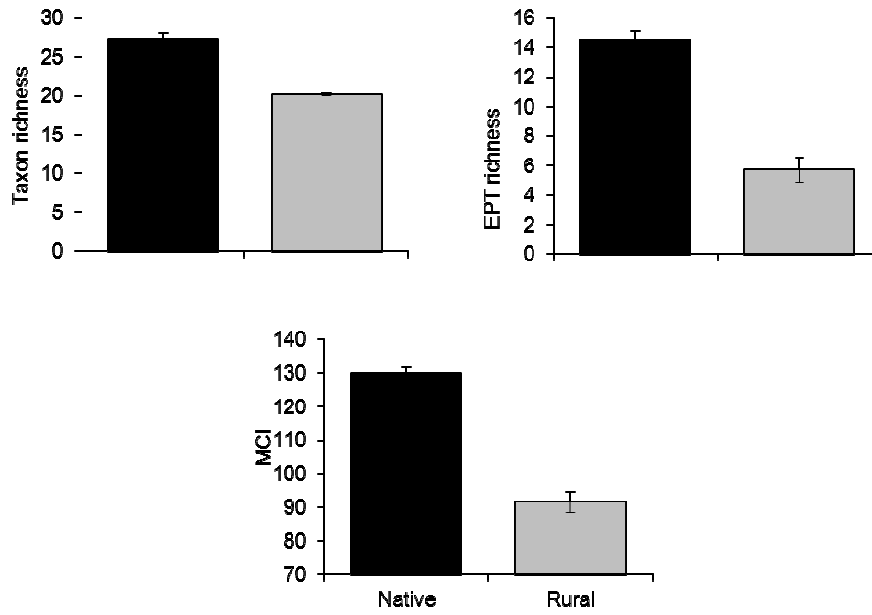
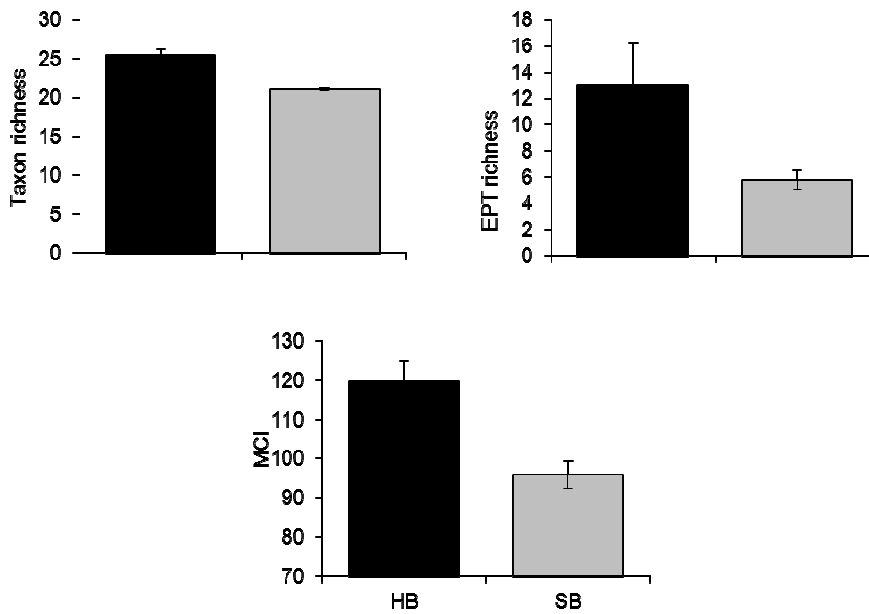


Figure 6.3:

Metrics based on stream type (soft and hard bottomed) across Auckland and Waikato regions (± 1 S.E.).



6.3 Variation in Traits

When examined across all sites (regardless of stream type), land use explained more variation than region or stream type for almost all trait categories (Table 6.2), with percentage variation explained ranging from 17% (dispersal, body form) to 37% (oviposition). Region explained more of the variation in size (16%) and attachment to substrate (16%), while stream type explained more of the variation in egg mass location (23%).

Examination of individual trait modalities provides insight into specific mechanisms of response, as well as variability in sensitivity of specific traits/trait modalities to specific stressors. A greater proportion of variation was explained by land use than regional differences in 36 of the 55 trait modalities examined. This result indicates that, in general, land use is a much more significant driver of macroinvertebrate trait profiles than any differences associated with regionality.

These results are illustrated graphically in Figs 6.4 - 6.6. There is little difference between regions for most trait categories. In contrast, there were clear differences in the trait profiles of streams based on native and rural land uses (Fig. 6.4). The traits of taxa typical of rural streams include those that:

- reproduce more than once per year (plurivoltine)
- reproduce more than once per individual
- tend to live longer
- reproduce asexually (or through hermaphroditism)
- lay submerged eggs, and
- have both adult and larval aquatic forms.

The similarity in plots between land use and stream type reflects the predominance of hard bottomed streams in native land use (61%) and soft bottomed streams in rural land use (also 61%). These results from Table 6.2 indicate that land use, rather than stream type, was the dominant driver for most traits. These results also suggest that trait analysis can be reliably undertaken across regions (other than for size and attachment, where region explained more of the variation).

Table 6.2:

Partial eta² values for traits (category, modality) vs region for the combined data set for all streams. Values in bold indicate highest values for a specific trait category or modality.

Trait category	Land use	Region	Stream type	Trait modality	Land use	Region	Stream type
Life history traits							
Maximum potential size (mm)	0.09	0.16	0.12	≤5	0.03	0.08	0.07
				≥5-10	0.01	<0.01	0.03
				≥10-20	<0.01	0.02	0.02
				≥20-40	0.02	0.06	0.10
				>40	0.06	0.01	0.01
Maximum number of reproductive cycles per year	0.18	<0.01	0.04	semivoltine	<0.01	<0.01	<0.01
				univoltine	0.17	<0.01	0.03
				plurivoltine	0.18	<0.01	0.04
Number of reproductive cycles per individual	0.24	0.07	0.12	1	0.24	0.07	0.12
				≥2	0.24	0.07	0.12
Life duration (days)	0.25	0.18	0.15	≤1	0.10	0.11	0.06
				1-10	0.09	0.03	0.07
				10-30	0.18	0.09	0.07
				30-365	0.18	0.09	0.12
				>365	0.04	0.01	0.02
Reproductive technique	0.25	0.03	0.05	asexual	0.17	<0.01	0.04
				hermaphroditism	0.23	0.02	<0.01
				sexual	0.25	0.01	<0.01
Oviposition site	0.37	0.03	0.14	water surface	0.36	0.02	0.06
				beneath the water surface	0.32	0.01	0.10
				terrestrial	0.05	<0.01	0.11
				eggs endophytic	0.07	0.03	0.07
Egg/egg mass location	0.14	0.18	0.23	cemented eggs	0.10	0.11	0.03
				female bears eggs in/on body	0.12	0.17	0.22
				free eggs	<0.01	0.01	0.13
Resilience/resistance traits							
Dispersal	0.17	0.02	0.02	low (10 m)	0.02	0.01	0.02
				medium (1 km)	0.17	0.01	<0.01
				high (>1km)	0.06	<0.01	0.01
Attachment to substrate	0.07	0.21	0.16	swimmers	<0.01	0.19	0.15
				crawlers	0.05	0.14	0.06

Trait category	Land use	Region	Stream type	Trait modality	Land use	Region	Stream type
Body flexibility	0.31	0.02	<0.01	burrowers	0.01	0.02	<0.01
				attached	0.02	0.06	0.06
				none (<10°)	0.14	<0.01	<0.01
				low (>10-45°)	0.31	0.02	<0.01
				high (>45°)	0.13	<0.01	<0.01
Body form	0.17	0.10	0.03	streamlined	<0.01	0.01	<0.01
				flattened	0.02	<0.01	<0.01
				cylindrical	0.06	0.02	<0.01
				spherical	0.16	0.08	0.01
General physiological traits							
Feeding habits	0.21	0.09	0.09	shredders	0.13	<0.01	0.03
				scrapers	0.06	0.02	0.03
				filter-feeders	0.09	<0.01	<0.01
				deposit feeder	0.06	0.06	0.03
				predators	0.03	0.03	<0.01
				algal piercers	0.07	0.01	<0.01
Dietary preferences	0.18	0.05	0.12	strong (specialist)	0.09	0.02	0.12
				moderate	0.13	0.03	0.09
				weak (generalist)	<0.01	<0.01	0.05
Respiration of aquatic stages	0.21	0.03	<0.01	tegument	0.03	0.01	<0.01
				gills	0.13	<0.01	<0.01
				plastron	0.15	<0.01	<0.01
				aerial	0.02	0.11	<0.01
Aquatic stages	0.24	0.10	0.11	adult and larva	0.24	0.10	0.11
				adult or larva	0.36	0.03	0.05
				Larva or pupa	<0.01	0.05	0.05

Figure 6.4:

Trait profiles based on region (across all stream types and land uses).

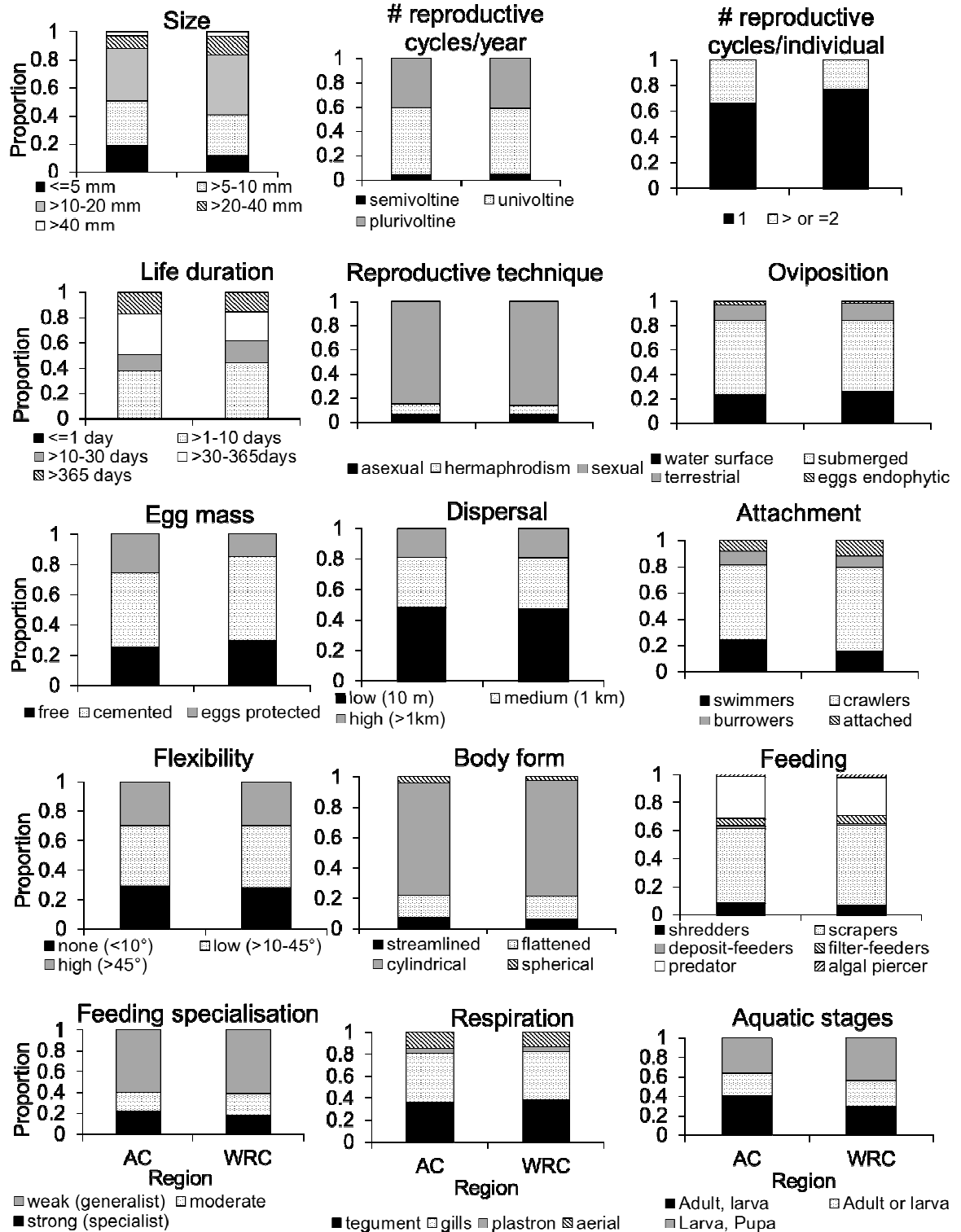


Figure 6.5:

Trait profiles based on land use (across all regions and stream types).

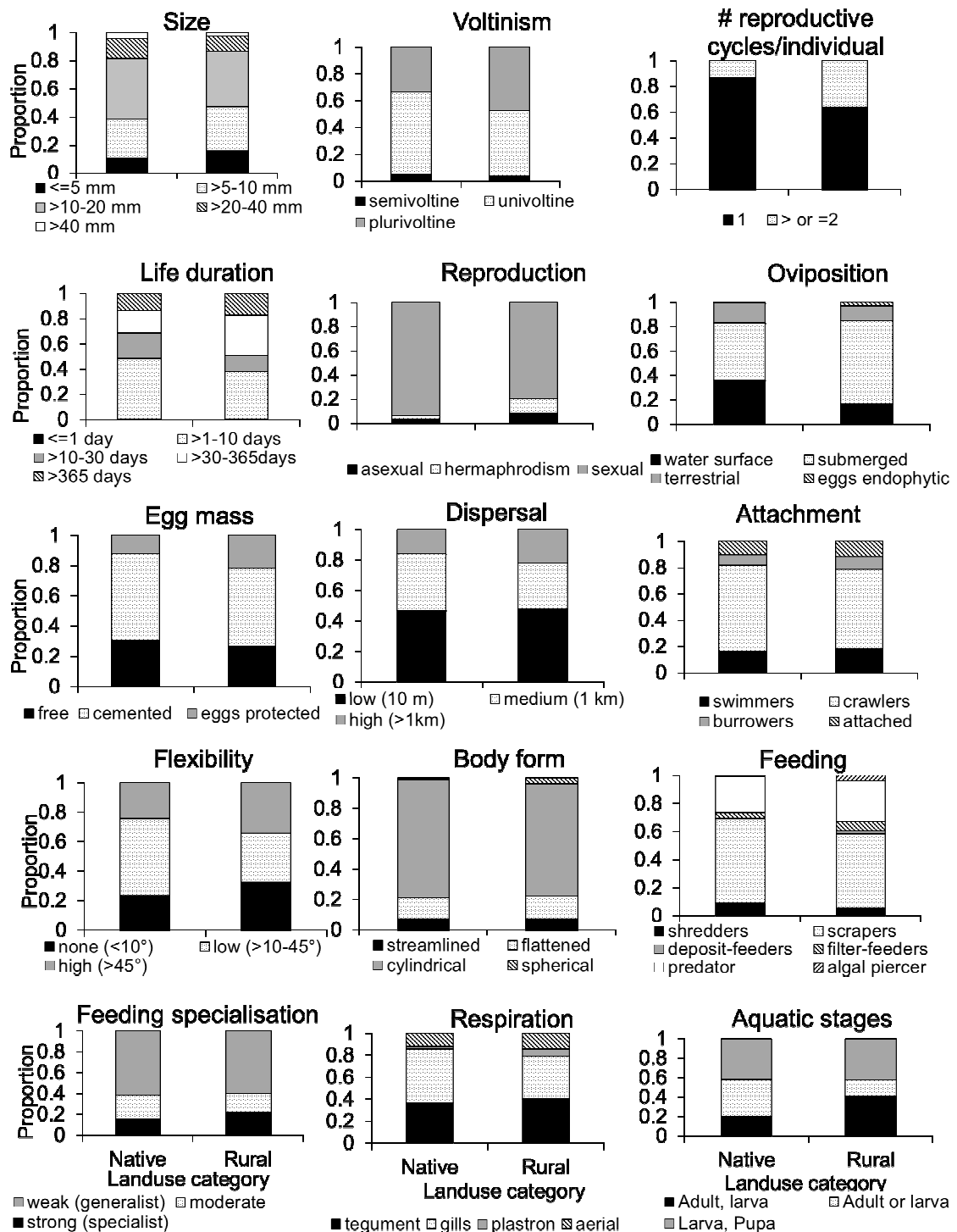
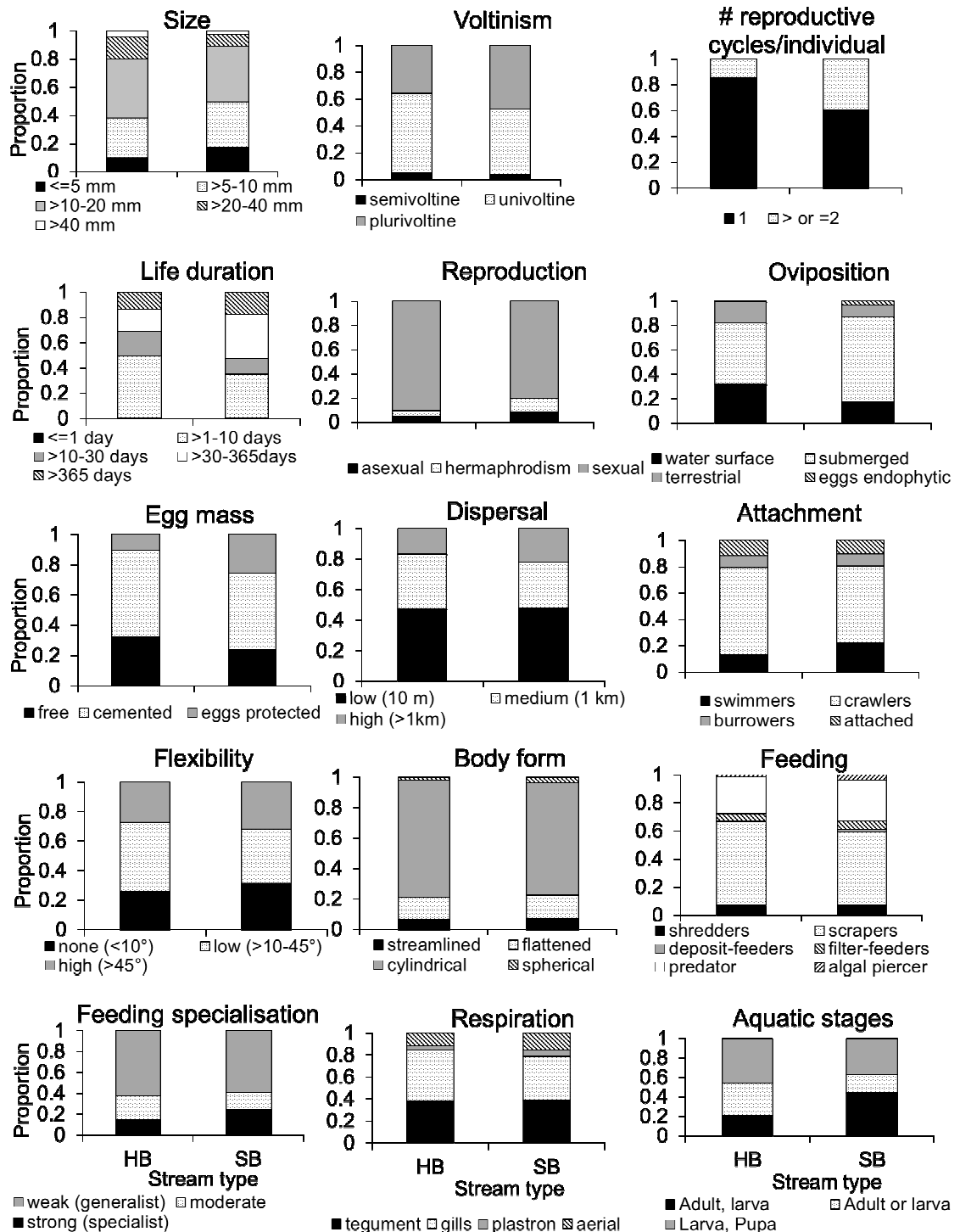


Figure 6.6:

Trait profiles based on stream type (across all regions and land uses).



7 Diagnostic value of traits

One of the potentially valuable applications of the trait approach to biomonitoring is its ability to diagnose different land use impacts. In previous chapters we have identified significant changes in the frequencies of trait modalities in association with increasing land use intensity. In general, the complete absence of a trait modality is not observed; rather there is a change in frequency. By identifying the dominant trait modality indicative of a particular land use it should be possible to track changes in the functional profile of sites associated with changes in land use. As an initial step in this process, we examined the relationship between land use intensity and individual trait modalities by calculating Pearson's Product-Moment Correlations.

Table 7.1 presents those trait modalities for which correlations ≥ 0.50 or ≤ -0.50 were detected. These cutoff values were chosen as the aim was to determine the predominant trait modalities. Native forest land use showed the greatest number of correlations matching the criteria (17), with urban land use recording 11 correlations. Rural land use recorded only 4 correlations, while there were no correlations fitting our criteria for exotic forest. When a cutoff of R value of ≥ 0.40 or ≤ -0.40 was employed, the number of significant correlations increased to 20 in each of the native, urban and rural land use categories, with no significant correlations for exotic forest.

The relative frequency of each dominant trait modality identified in Table 7.1 (>0.50 only) is plotted to illustrate the changes associated with increasing land use intensity (Fig. 7.1). On this basis it can be concluded that, in comparison to sites in native forest, sites subject to urban land use were more likely to have a greater proportion of taxa that;

- reproduce more than once per year
- reproduce asexually (or through hermaphroditism)
- lay submerged eggs
- burrow
- use a plastron for respiration
- have both adult and larval aquatic forms.

In contrast, native stream sites were more likely to have a greater proportion of taxa that;

- reproduce only once per year
- reproduce only once in the lifetime
- reproduce sexually, and
- use gills for respiration.

From this analysis it was also evident that there were relatively small differences in trait frequencies between native and exotic forest stream sites. Similarly, trait frequencies in rural sites tended to be more similar to urban sites.

The ability to identify trait modalities that are responding to specific land uses requires analysis of the environmental measures specifically associated with these land uses, as at some measures will be common to more than one land use. For example, urban streams are often characterized as having high temperatures, though loss of riparian vegetation (Walsh et al. 2001). This is also a characteristic of rural streams (Quinn et al. 1997). Identifying key drivers will be an important next step in developing traits as a diagnostic tool.

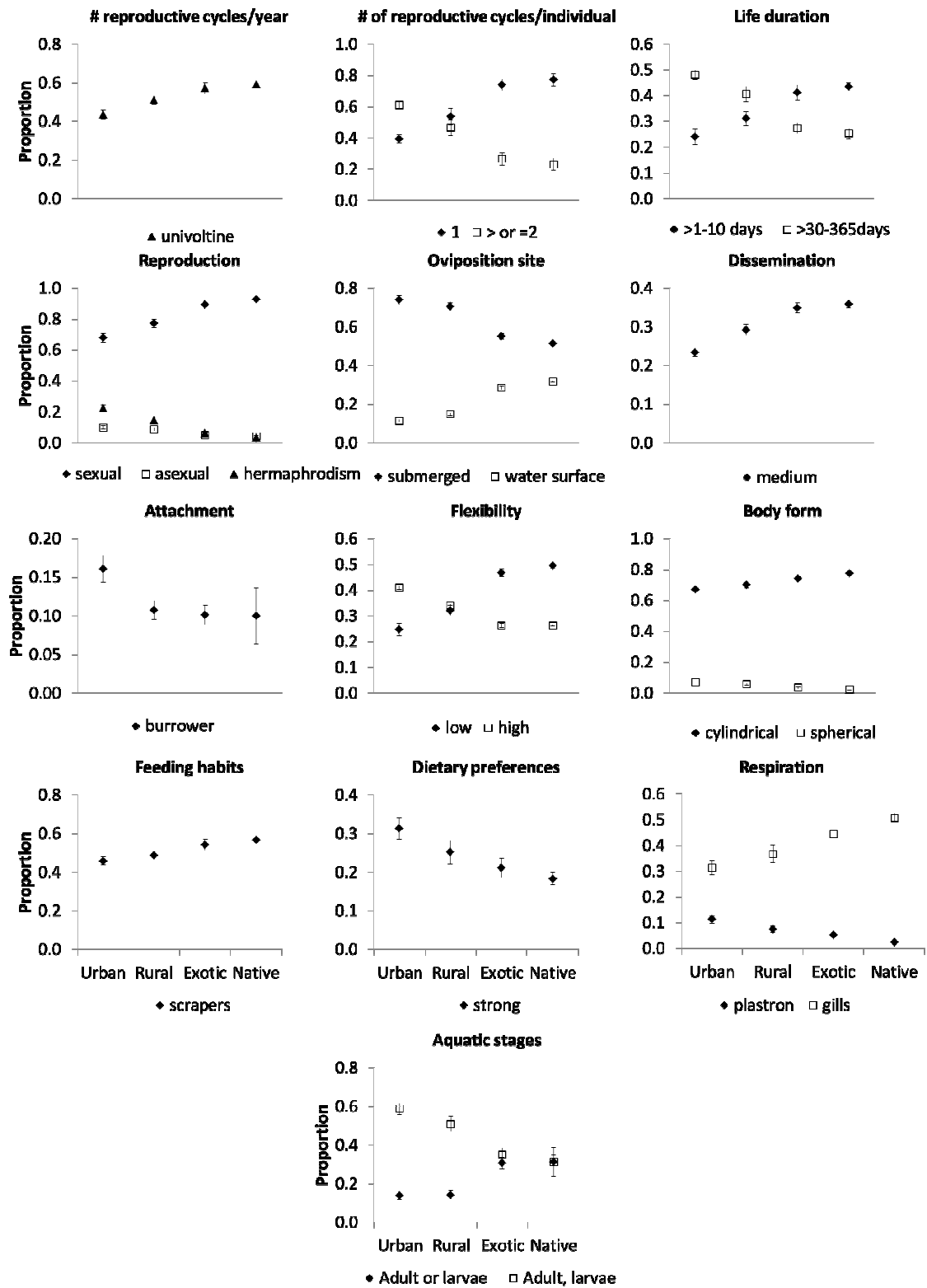
Table 7.1:

Pearsons Product-Moment Correlation coefficients for land use/trait modality correlations for all sites in urban (n=12), rural (n=14), exotic (n=7) and native (n=14) land uses. The yellow cells are those with R values ≥ 0.50 or ≤ -0.50 . Green shading indicates R values ≥ 0.40 or ≤ -0.40

Trait category	Trait modality	Native	Exotic	Rural	Urban
Life history traits					
# reproductive cycles/year	Plurivoltine (2)	-0.48	-0.15	0.35	0.42
	Univoltine (1)	0.46	0.17	-0.27	-0.52
# reproductive cycles/individual	1	0.58	0.21	-0.45	-0.53
	> or =2	-0.58	-0.21	0.45	0.53
Life duration	>1-10 days	0.54	0.18	-0.45	-0.44
	>30-365days	-0.55	-0.21	0.46	0.48
Reproductive technique	asexual	-0.52	-0.19	0.51	0.33
	hermaphrodism	-0.60	-0.21	0.43	0.59
	sexual	0.62	0.22	-0.48	-0.56
Oviposition site	water surface	0.64	0.19	-0.54	-0.46
	submerged	-0.63	-0.19	0.55	0.43
	terrestrial	0.46	0.08	-0.41	-0.22
Egg mass	eggs endophytic	-0.48	-0.01	0.35	0.27
	cemented	0.44	0.21	-0.43	-0.35
Resilience/resistance traits					
Dispersal	medium	0.50	0.22	-0.37	-0.56
Attachment	burrowers	-0.17	-0.12	-0.08	0.53
	crawlers	0.36	0.07	-0.12	-0.45
Body flexibility	none	-0.52	-0.09	0.49	0.26
	low	0.62	0.23	-0.49	-0.56
	high	-0.38	-0.23	0.24	0.52
Body form	flattened	-0.46	0.01	0.31	0.27
	cylindrical	0.54	0.03	-0.41	-0.32
	spherical	-0.56	-0.13	0.47	0.41
General physiological traits					
Feeding habits	scrapers	0.51	0.10	-0.36	-0.38
	filter feeders	-0.40	-0.12	0.35	0.30
Dietary specialisation	moderate	0.40	0.24	-0.33	-0.44
	strong	-0.53	-0.09	0.26	0.52
Respiration	gills	0.59	0.09	-0.45	-0.39
	plastron	-0.58	-0.07	0.34	0.53
Aquatic stages	Adult or larvae	0.58	0.25	-0.59	-0.38
	Adult, larva	-0.56	-0.17	0.48	0.42

Figure 7.1:

Plots of frequencies of trait modalities with correlation coefficients' ≥ 0.50 for different land uses



8 Discussion

In this project we determined the response of both metrics and traits to a gradient of land use intensity (native forest, exotic forest, rural and urban) for Auckland streams. Based on existing information, we developed a priori hypotheses of likely responses of traits to these stressors. As part of this analysis we also compared the effectiveness of metric and trait measures for differentiating levels of impact. We examined the potential influence of regional differences in invertebrate communities on the ability of metrics and traits to detect the impacts of rural development. Finally, we investigated the potential use of traits as a mechanistic tool.

The aim of this study was not simply to determine whether traits were “better” or “worse” than taxonomic-based metrics at differentiating between impacted sites. Rather it was aimed at determining how traits could “add value” to existing, well established monitoring tools.

Analysis of metrics and traits in reference sites (native vegetation >90% of the catchment) identified significant differences associated with stream type (hard vs. soft bottomed streams) for at least some measures. Hard bottomed streams recorded, on average, higher values for taxon richness, EPT richness and %EPT richness, likely reflecting differences in micro-habitat which support different species (for example, both EPT richness and % EPT have been found to be negatively correlated with stream order, Collier, 2008). Similarly stream type explained a significant amount of variation in most trait categories and some trait modalities. Taken in isolation, the findings of differences associated with stream type may be of concern for biomonitoring purposes for both metrics and traits, requiring the factoring out of stream type analyses where sampling includes both stream types. However, the importance of this result needs to be considered in the context of multiple environmental drivers ie, what is the relative contribution of stream type compared to other drivers?

When the relative contribution of stream type and land use to metric and trait values was investigated, land use was found to be the predominant factor in all metrics other than taxon richness. Similarly land use explained more of the variation in 73% of trait categories and trait modalities. Dolédec et al. (2006) found 26% of trait categories differed significantly amongst land use practices (from ungrazed tussock land to highly intensive deer and dairy farming), so our result is significant.

Many traits were found to be responsive to land use intensity. Traits more strongly associated with land use intensity included number of reproductive cycles per year and per individual, reproductive technique, oviposition, dispersal, body flexibility and form, feeding habits and specialization, respiration and aquatic stages. Dolédec et al. (2006) found traits relating to life history (number of reproductive cycles/individual and year, life duration, egg laying modes and parental care behaviour) provided the strongest separation along the land use gradient. Weaker but significant relationships were found with feeding ecology, body shape and respiration. Previous studies have demonstrated that traits related to body size shape and feeding strategies were more weakly related to perturbations (Dolédec et al 1999, 2006). However, Townsend and Thompson (2007) suggested that average invertebrate body size would increase with agricultural intensity because of the relationship between growth and nutrient-induced stream productivity.

A comparison of the ranges of partial eta 2 values derived for metrics and traits suggests that traits (as categories or as individual traits) were as powerful at detecting impacts of land use intensity as metrics (Table 8.1). Traits displayed a much greater range of partial eta 2 values than metrics, indicating that not all trait categories/modalities were equally effective. Differences in the “best” metric or trait category were observed when considered separately for stream type versus across all stream types. While hard bottomed streams had much higher partial eta 2 values than soft-bottomed streams, the patterns of response were the same in both stream types.

Table 8.1:

Ranges of partial eta2 values derived from tests of metric and trait responses to increasing land use intensity for Auckland streams.

Stream type	Metrics		Trait category		Individual trait	
	Range	Best	Range	Best	Range	Best
All	0.34-0.63	MCI	0.12-0.60	# reproductive cycles/individual	0.05-0.64	Sexual reproduction
Hard bottomed	0.59-0.71	EPT richness	0.13-0.99	Oviposition	0.08-0.79	Filter feeders
Soft bottomed	0.31-0.48	SQMCI	0.02-0.15	Feeding habits	0.002-0.55	Sexual reproduction

In our study we predicted a number of trait responses based on the potential influences of multiple environmental stressors. Table 8.2 summarises the trait responses to increasing land use intensity observed for Auckland streams and assesses these responses against our *a priori* predictions. For many traits, our prediction held true, although short generation time and small size did not increase with % rural development, as would have been predicted from previous studies (and from ecological theory).

For some traits, a more complex response was evident e.g., while highly dispersive taxa increased, low dispersing taxa also increased. Similarly, while algal piercers increased (a response to increasing algal biomass typical of rural streams), filter feeders also increased (an unexpected result given the anticipated increase in sedimentation with increasing rural development). Dolédec et al. (2010) found no relationship between the frequency of filter feeders and increasing land use intensification.

Table 8.2:

Summary of trait responses to land use intensity compared to *a priori* predictions.

Factor Variable	Predictions (section 2.4)	Ecological basis ¹	Change in relation to increasing land use development			Prediction supported?
			All stream types	Hard bottomed	Soft bottomed	
Size	↑small sizes	Increased resilience ¹	↑>5mm, ↓>5-10mm, >40mm	↑>5mm, ↓>20-40mm, >40mm	↑>10-20mm, ↓>5-10mm, >20mm	Yes
# reproductive cycles/year	↑plurivoltinism (multiple of reproduction cycles/year)	Increased resilience ¹	↑plurivoltinism	↑plurivoltinism	↑plurivoltinism	Yes
# reproductive cycles/individual	↑in rapidly reproducing taxa	Rapid population turnover ¹	↑>1, ↓1	↑>1, ↓1	↑>1, ↓1	Yes
Life duration	↑short generation time	Rapid population turnover ¹	↑>30-365 days, ↓>1-10, >10-30 days	↑>30-365 days, ↓>1- 10, >10-30 days	↑>30-365 days, ↓>1-10, >11-30 days	No
Reproductive technique	↑asexual	Rapid recolonisation in variable environments ¹	↑asexual, hermaphroditism, ↓sexual	↑asexual, hermaphroditism, ↓sexual	↑asexual, hermaphroditism, ↓sexual	Yes
Oviposition	↓surface egg laying	Increased sediment cover smothers eggs ²	↑submerged, endophytic, ↓water surface, terrestrial	↑submerged, endophytic, ↓water surface, terrestrial	↑submerged, endophytic, ↓water surface, terrestrial	Yes
Egg mass	↑in protected eggs	Increased sediment cover smothers eggs ²	↑free, protected eggs , ↓cemented	↑free, ↓cemented	↑free, protected eggs, ↓cemented	Yes
Dissemination	↑highly dispersive taxa	Promotes refuge use and recolonisations ¹	↑low, high ↓medium	↑low, high, ↓medium	↑low, high ↓medium	Yes

Factor Variable	Predictions (section 2.4)	Ecological basis ¹	Change in relation to increasing land use development			Prediction supported?
			All stream types	Hard bottomed	Soft bottomed	
Attachment	↑ burrowers	Increased sediment ²	↑burrowers, ↓crawlers	↑burrowers, ↓swimmers, crawlers	↑ burrowers, attached, ↓swimmers	Yes
Flexibility	↑ flexibility ¹	Response to high flows ¹	↑none, high, ↓low	↑high, ↓low	↑none, high, ↓low	Somewhat
Body form	↑ Flattened ¹	Response to high flows ¹	↑spherical, flattened, ↓cylindrical	↑spherical, streamlined, ↓cylindrical	↑spherical, flattened, ↓cylindrical	Yes
Feeding	↑algal piercers, detritivores, ↓scraper, filter feeders	increase in autrophic feeders ²	↑filter feeder, algal piercer, deposit feeder, ↓scraper	↑deposit feeder, ↓scraper	↑filter feeder, algal piercer, deposit feeder, ↓scraper	Yes
Dietary preference	↓specialist	Generalists more successful in disturbed environments ³	↑specialist, ↓generalist	↑specialist, ↓ generalist	↑specialist, ↓ generalist	No but may reflect how specialist defined
Respiration	↑plastron, ↓gills	Increased sediment ²	↑tegument, aerial, plastron, ↓gills	↑tegument, plastron, aerial, ↓gills	↑tegument, plastron, ↓gills, aerial	Yes
Aquatic stages	↓adults aquatic	Aerial adults for increased dispersal ¹	↑adult and larvae, ↓adult or larvae, larvae or pupae	↑adult and larvae, ↓adult or larvae	↑adult and larvae, ↓adult or larvae, larvae or pupae	Yes

¹ Based on Townsend and Hildrew (1994), ² Dolédec et al. (2006), ³ (Statzner et al. 2001)

The observed increase in spherical body form was consistent with previous studies and may be related to a reduction in flow associated with increased land use intensification (Dolédec et al. 2010). However, the increase in flattened form was more consistent with increased flow. The increase in the laying of free eggs was inconsistent with the predicted increase in bed sediment cover associated with land use intensification and was contrary to previous findings (Dolédec et al. 2010). Tomanova et al. (2008) have suggested that inconsistencies in functional responses to anthropogenic impacts could be due to the simultaneous operation of several stressors. Given that our data set was comprised of sites exposed to a diversity of land use types, our results were perhaps not surprising.

Both metrics and traits were found to be effective in differentiating between levels of impact. Particularly effective traits included # of reproductive cycles/individual, reproductive technique, oviposition site, body flexibility and aquatic stages.

Dolédec et al. (2011) examined variation in taxonomic metrics and biological traits over a broad regional scale (the whole of New Zealand) in relation to land use intensification. They found a greater proportion of taxonomic metrics were influenced by ecoregional differences than biological traits. In addition, they found land use explained twice as much variation in traits as in taxonomic metrics. In our study we found that land use explained more of the variation in metrics than regional differences, with between 26 and 59% of the total variation explained. A similar result was recorded for most trait categories (with 22 – 59% of variation explained) and many individual traits (with 1 – 59% of variation explained). Collectively this suggests that both metrics and traits can be used to differentiate land use effects across Auckland and Waikato regions. Inclusion of additional regional datasets would provide a more robust analysis of this issue, as the dataset available was limited due to the need to match land use intensity.

Another outcome of the regional analysis was the observation of a consistent response by trait categories and modalities to land use intensity between presence/absence (for the Auckland/Waikato comparison) and abundance data (for the Auckland only analysis). Gayraud et al (2003) found log abundance and presence/absence data to be equally effective at differentiating impacts of a range of disturbances, whereas raw abundance data was found to be less effective.

There is growing interest in the use of traits for diagnosing causal mechanisms of response in benthic invertebrate communities (Culp et al. 2010). In our study, we have identified significant differences in the frequencies of trait modalities that allow us to distinguish native forest sites from urban sites. However, the measures of land use employed (% land use) were insufficient to identify specific causal mechanisms such as reduced oxygen, increased temperature, increased contaminant concentrations, which would commonly be associated with a change from native to urban land use. Further investigation is required to refine these results. Existing data sets are likely to be available to undertake such analyses. Notwithstanding this, trait profiles based on mode and frequency of reproduction, oviposition characteristics, movement, respiration and aquatic stages could be employed to detect trends over time in recovery following restoration or degradation following land use changes.

Trait-based biomonitoring would fit readily into existing biomonitoring frameworks, as the basic information (site by species composition matrices) is already collected. Challenges exist for the general application at a national level, for example, due to inconsistencies in the way invertebrate data are collected and enumerated (coded abundance versus fixed count data). The use of presence/absence data may address this challenge. Other challenges related to consistency, availability, applicability and understanding of the trait data (Culp et al. 2010).

9 Conclusions and recommendations

For traits to be considered for integration into existing biological monitoring programmes, they would ideally need to satisfy the following criteria:

- a) display low levels of variation at high and low levels of land use intensity, and significant discriminatory power at intermediate levels
- b) display greater discriminatory power over and above that achieved by standard metrics
- c) possess the ability to diagnose causal factors.

Almost all trait categories were found to be effective in differentiating between high and low levels of impact, with differing levels of effectiveness for medium impact levels. Particularly effective traits included number of reproductive cycles/individual, life duration, reproductive technique, egg mass location, oviposition, flexibility and aquatic stages.

Traits (as categories or as individual traits) were found to be as powerful at detecting impacts of land use intensity as metrics. The trait categories number of reproductive cycles/individual, reproductive technique, oviposition, dispersal, flexibility and aquatic stages were especially effective.

We have identified significant differences in the frequencies of trait modalities that allow us to identify native forest sites from urban sites. Further refinement of traits as a diagnostic tool requires further analysis using specific environmental variables associated with disturbance. However, trait profiles based on mode and frequency of reproduction, oviposition characteristics, movement, respiration and aquatic stages could be employed to detect trends over time in recovery following restoration or degradation following land use changes.

A set of trait categories consistently meeting all three of the above criteria includes: the number of reproductive cycles/individual, reproductive technique, egg mass location, oviposition, flexibility and aquatic stages. These traits categories (and their associated modalities) could be integrated into existing biomonitoring programmes.

The effectiveness of a trait-based measure in detecting a stressor will depend on the specificity of the stressor under investigation. The development of *a priori* predictions based on an understanding of likely ecological and physiological responses of individual taxa significantly enhances the value of this approach. A number of studies derived stressor-specific traits or suites of traits (eg, salinity - Schafer et al. 2011, metals and cargo-ship traffic – Dolédec and Stutzner 2008, toxic substances – Archambault et al. 2010). In reality, few stressors operate in isolation and one of the advantages of the trait approach is the ability to detect multiple stressor responses. Stutzner and Beche (2011) have suggested that resolving the effects of multiple human-caused stressors on ecosystems requires a high diversity of response variables that react mechanistically to specific stressors so that their responses can be *a priori* predicted. They further suggest that using multiple biological traits is the only feasible way of addressing this challenge.

Based on the results of this preliminary assessment of trait and metric responses to increasing land use intensity, recommendations for further development of this approach for use in biomonitoring are detailed below and include:

- Further investigation of diagnostic traits/trait profiles by examination of stressor-specific responses, using more specific measures of disturbance (eg, contaminant concentrations).
- Investigation and development of stressor-specific traits, derived either empirically (eg, Rubach et al. 2010, Schäfer et al. 2011) or through relational analysis of existing datasets.
- Investigation of the development of a trait-based multi-metric (Archambault et al. 2010) using existing datasets.
- Expansion of the regional analysis to encompass a broader range of land use types (eg, through integration with other regional councils).
- Development of a method for integrating a traits approach into standard monitoring protocols.

Glossary of abbreviations and terms

Aquatic stages - Are all stages of the life cycle of the animal aquatic? Eg, All stages of Dytiscidae are aquatic, whereas only larvae of Megaloptera are aquatic.

Attachment to substrate of aquatic stages (excluding eggs) - How does the animal move within its' habitat? Does it swim, crawl, burrow or is it attached?

Body flexibility - How flexible is the animal? Not flexible (<10°), low (>10 - 45°) or high (>45°)? Eg, snails are not flexible, worms have high flexibility

Body form - What is the shape of the animal? Is it streamlined, flattened (dorso-ventral or lateral), cylindrical or spherical?

Dietary preferences - Does the animal specialise in a particular species or type of food (eg, wood feeder) or is it more generalised?

Dispersal (all stages) - How far can the larvae, pupae and adults move? Upto 10 m (low dispersion potential), 1 km (medium) or >1 km (high dispersion potential).

Egg/egg mass - Do the eggs float freely on the water surface or stream bed or are they cemented to rocks and other debris or to plant material? Are they retained within the body (protected)?

Feeding habits - How does the animal feed? Is it a shredder, scraper, deposit-feeder, filter-feeder, predator or algal piercer?

Habitat - Where are the animals found?

Life duration of adults (including subimago of Ephemeroptera) - How long do adults live? Short (eg, 1 day) to long (eg, greater than 1 year)?

MCI - A measure of the relative sensitivity or tolerance of an organism to pollution (Stark et al. 2001). Ranges from 1 (pollution tolerant) to 10 (pollution sensitive)

Number of reproductive cycles per individual - How many times does an animal reproduce before it dies?

Oviposition site - Where are the eggs deposited? On or under water, on land or are they inserted into plants (endophytic)?

Potential number of descendants per reproductive cycle - Generally measured as the number of eggs (or number of individuals if live-bearing) produced per reproductive cycle.

Potential size - Refers to the maximum recorded size of the animal

Reproductive technique - May be sexual, asexual (through budding or cloning) or may be hermaphroditic (so male and female sexual organs are both present on the animal)

Respiration of aquatic stages (not including eggs) - How does the animal obtain its' oxygen? If in dissolved form, then respiration will be by gills or over the general body surface (tegument and spiracles). If in atmospheric form, then the animal may have a respiratory siphon or may be able to take bubbles of air under its wings (plastron; temporary air storage) or other structures to use while under water.

Trait category – the type of trait eg reproductive technique, size

Trait modality – groupings of organisms based on characteristics of a trait category eg sexual or asexual reproduction

Voltinism (Potential number of reproductive cycles per year) - May be less than once a year (semi-voltine), once a year (univoltine) or greater than once a year (plurivoltine). This measure is known to vary with temperature and hence latitude.

10 References

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11 Appendices

11.1 Appendix A Biological traits and trait categories and their codes

Biological trait	Code	Trait category
Life history traits		
Maximum potential size (mm)	SIZE1	≤5
	SIZE2	≥5-10
	SIZE3	≥10-20
	SIZE4	≥20-40
	SIZE5	>40
Maximum number of reproductive cycles per year	SEMI	semivoltine
	UNIV	univoltine
	PLURIV	plurivoltine
Number of reproductive cycles per individual	CPI1	1
	CPI2	≥2
Life duration (days)	LDA1	≤1
	LDA2	1-10
	LDA3	10-30
	LDA4	30-365
	LDA5	>365
Reproductive technique	SINGLE	asexual
	HERMA	hermaphroditism
	TWO	sexual
Oviposition site	SURFACE	water surface
	SUBMERGED	beneath the water surface
	TERRESTRIAL	terrestrial
Egg/egg mass location	EGGFREE	free eggs
	EGGCEMENT	cemented eggs
	EGGPROTECTED	female bears eggs in/on body
	EGGENDO	eggs endophytic
Resistance and resilience traits		
Dispersal (all stages)	DISSLOW	low (10 m)
	DISSMEDIUM	medium (1 km)
	DISSHIGH	high (>1km)
Attachment to substrate of aquatic stages (excluding eggs)	SWIMMER	swimmers (water column)
	CRAWLER	crawlers (epibenthic)
	BURROWER	burrowers (infauna)
	ATTACHED	attached

Biological trait	Code	Trait category
Body flexibility	NOFLEX	none (<10°)
	LOWFLEX	low (>10-45°)
	HIGHFLEX	high (>45°)
Body form	STREAMLINED	streamlined
	FLATTENED	flattened (dorso-ventral or lateral)
	CYLINDRICAL	cylindrical
	SPHERICAL	spherical
General physiological traits		
Feeding habits	SHREDDER	shredders
	SCRAPER	scrapers
	FILTERFEED	filter-feeders
	DEPOSIT	deposit feeder
	PREDATOR	predators
Dietary preferences	ALGALP	algal piercers
	SPECIALIST	strong (specialist)
	MODERATESPE	moderate
Respiration of aquatic stages (excluding eggs)	GENERALIST	weak (generalist)
	TEGUMENT	tegument
	GILL	gills
Aquatic stages	PLASTRON	plastron
	AERIAL	aerial
	ADUANDLAR	adult and larva
	ADUORLAR	adult or larva
	LARANDPUP	larva and pupa