In-stream Vegetation of Upland Streams in the Western ACT in Summer-Autumn 2022

Jane Roberts and Julian Reid

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Report to ACT Government Office of Nature Conservation Branch

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COVER PHOTOGRAPH

Myriophyllum community, Naas Creek, downstream of Old Boboyan Road, on 23 March 2022.

For Further Information on stream and aquatic ecology in the ACT, contact:

Dr Lisa Evans, lisa.evans@act.gov.au or ACT Government, Office of Nature Conservation Branch, GPO Box 158 Canberra ACT 2601

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Executive Summary

INTRODUCTION

1: Introduction. Macrophytes are plants adapted to grow in aquatic systems such as streams, rivers and wetlands, where they provide habitat and are primary producers. Despite their importance as ecosystem engineers, riverine macrophytes are little known in Australia, and are poorly documented.

The project had three aims: to survey streams and rivers in the western ACT (ie west of the Murrumbidgee River) for riverine macrophytes; to identify which site characteristics influence occurrence, abundance and richness; and to draw out management implications.

The focus for this project was riverine macrophytes, meaning submerged and floating-leafed forms but not emergent. This project also considered in-stream vegetation meaning all plants so included all types of macrophytes as well as charophytes, liverworts, mosses, gelatinous and filamentous algae.

2: Context. The survey in summer-autumn 2022 followed a sequence of extreme environmental events: drought in 2018-2019, hot days and heat waves in 2019-2020, bushfires in summer 2020, and heavy rainfall and flooding in 2021 and 2022. Evidence of these events noted during the survey were: debris trails, log jams, charcoal, and sand deposits. River flows during the survey were unusually high, which limited the survey to streams and rivers that were not hazardous, and that could be readily accessed. Road closures prevented access to parts of the Cotter, Orroral and Naas valleys.

METHODS

3: Field Methods. A total of 72 sites were surveyed in summer-autumn 2022, fewer than the target of 90 sites. Each site was on a stretch of channel, relatively homogeneous in geomorphic characteristics and adjacent riparian vegetation. A site was 20-25 m long, but longer, 30+ m, if channel was wider than 5 m. Each site had five quadrats. Each quadrat was as wide as the channel wetted perimeter (ie variable width), and 2 m long, with quadrats separated by 2-3 m. On channels wider than 5 m, quadrats were 3 m long, separated by 3-4 m.

Two approaches were used, VIS and BET. These targeted different groups of in-stream plants and used different measures for abundance. For VIS (for Vascular In-stream Species), abundance was recorded using 3-category metric at the site-scale: absent, present, dominant for species occupying 30% of more of the quadrats per site. For BET (Broad Ecological Types, roughly equivalent to growth form, referring to in-stream vegetation), abundance was recorded per quadrat as % cover, then averaged for the site-scale.

Site characteristics recorded per quadrat then averaged per site were: wetted width (m); maximum thalweg depth (cm); lateral shading (% of water surface); overhead shading (% of water surface). Site characteristics recorded at the site-scale were: geomorphic reach type (following classification in Buffington and Montgomery (2021)); substrate composition, being % of substrate in each of eight categories; slope, calculated from the distance between contours, shown on aerial imagery (ACT mapi). Altitude and co-ordinates were taken from i-phone images, taken routinely per site. Site disturbance (evidence of fire; evidence of flood; and channel in-filling with sand) was noted.

Landscape context for each site taken from maps and geospatial layers in ACTmapi were: sub-catchment; HGL (hydrogeological landscape) category; vegetation community.

4: Data Analysis. Analyses were done in the R statistical environment.

Numerical classification supported by non-metric multi-dimensional ordination was used to identify groupings, referred to as plant communities (for VIS data) and assemblages (for BET data).

Uni-variate generalised linear models were used to determine significant associations between plant responses and environmental variables. For VIS data, the plant responses investigated were occurrence of species, occurrence of plant communities, and species richness. For BET data, the plant responses investigated were occurrence and abundance of individual BET, and occurrence of assemblages, with abundance recoded on an ordinal scale. The environmental variables were all at site-scale and comprised 17 site characteristics in five broad categories (stream size, landscape setting, shading of water surface, substrate composition, disturbance). Modelling the macro-scale environmental variables, which were multi-level factors, was unsuccessful.

5: Terminology. Terms and use of capitals in names is explained.

RESULTS

6: Results for VIS. A total of 23 species were recorded, mostly (21 species) perennial, and mostly native to the ACT (16 species). These comprised 7 submerged macrophytes, 2 floating-leaf macrophytes, and 14 amphibious dicots. The most frequently-recorded species were two amphibious dicots: *Gratiola peruviana* at 38 sites, and *Myosotis laxa var caespitosa* at 30 sites. Nine species were noted as being reproductive (ie with buds, flowers or fruits) but only two of these were actively regenerating, *Myosotis laxa var caespitosa* and *Veronica anagallis-aquatica*, both introduced amphibious dicots.

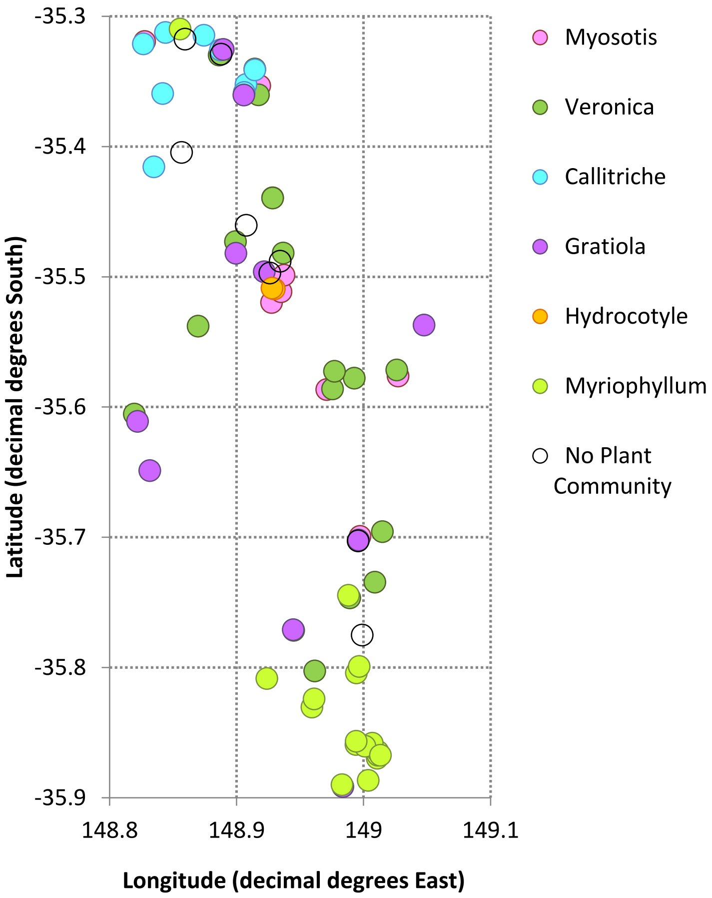
Phenological observations were made of 21 species at 58 sites. In summary, 4 species were vegetative (no evidence of regeneration or reproduction), 9 species were reproductive (had buds, flowers or fruits) and 2 species were regenerating (seedlings, or young plants present). The two species that were actively regenerating, *Myosotis laxa var caespitosa* and *Veronica anagallis-aquatica*, were also reproductive: both these are introduced amphibious dicots.

Six plant communities were recognised, differing in form, abundance, richness and nativeness (% species native) and these were named after their characteristic species as *Myosotis*, *Veronica*, *Callitriche*, *Gratiola*, *Hydrocotyle* and *Myriophyllum* communities. The *Myriophyllum* community was distinctive for the prevalence of submerged macrophytes, and stoloniferous amphibious dicots, for its high abundance (measured by % of sites where a species covered 30% or more), high species richness (mean per site = 6.2), and moderately high nativeness (76% of species). Amongst the other five communities, one was a floating-leaf form (*Callitriche* community) and the others were amphibious dicots. These five had much lower abundance, low species richness (mean = 1.8 to 3 per site) and variable nativeness (38 to 88%).

The relevance of macro-scale factors in community distribution was qualitatively explored. Mapping these six communities across the study area (Map 1, below) showed some geographic patterns, with the *Callitriche* community concentrated in the north-west, the *Myriophyllum* community in the south, and the amphibious dicot communities of *Myosotis*, *Veronica*, *Gratiola* and *Hydrocotyle* in-between. These patterns roughly corresponded to sub-catchments: Pierces and Condor, for the *Callitriche* community and Naas system for the *Myriophyllum* community. Cross-tabulation suggested geomorphic reach type was also an influence.

7: Modelling using VIS data. Only 9 of the 23 species were modelled. These differed in the number of environmental variables (all site-scale characteristics) that were significantly associated with occurrence, ranging from none for *Gratiola peruviana*, to 4 and 5 for two submerged macrophytes, *Montia australasica* and *Myriophyllum variifolium*. Disturbance was of mixed significance: % sand and sand-infilling had a negative association with occurrence of *Hydrocotyle rivularis* and *Myriophyllum variifolium*, but a positive association with *Veronica anagallis-aquatica*.

Five of the six plant communities were modelled, as the *Hydrocotyle* community occurred at too few sites (only 2). As with VIS species, communities differed in the number of environmental variables that were significantly associated with their occurrence. This ranged from a low of 1-2 for the *Myosotis*, *Veronica* and *Gratiola* communities, all amphibious dicots, to 4 and 5 for the two macrophyte communities, *Callitriche* and *Myriophyllum* respectively. Sand and sand-infilling were positively associated with occurrence of the *Veronica* community.



Map 1: Distribution of six plant communities in the study area

8: Results for BET. Nine BET were recorded: Submerged, Floating-Leaf, Emergent, Amphibious Dicot, Charophytes, Filamentous Algae, Gelatinous Algae, Moss and Liverwort BET. The most frequently occurring BET were Amphibious Dicot, Emergent and Filamentous Algae, present at 60, 58 and 55 sites respectively: Liverwort BET was the least frequent. The most abundant BET was Submerged, with a mean cover across all 72 sites of 8.5%, followed by Emergent (7.2%), Amphibious Dicot (6.1%) then Filamentous Algae (5.8%).

Eight assemblages were recognised, and named for their average abundance and characteristic BET: Very Low Filamentous Algae, Very Low Emergent Macrophytes, Low Mosses, Low Amphibious dicots, Low Emergent Macrophytes, Moderate Floating Leaf, High Mixed, and Moderate Filamentous Algae. The first five had low abundance (0.6% to 3.7% cover per site), low to moderate richness (1 to 3.25 BET per site) and low occurrence (only 1 to 4 sites). The High Mixed assemblage, was distinctive in being characterised by submerged macrophytes, and for its high abundance (66.8% per site), its high richness (5.1 BET per site) and it occurred at 23 survey sites. The Moderate Filamentous Algae assemblage had moderate abundance (16.3% per site) and moderate richness (4.2 BET per site), and occurred at 30 sites, making it the most widely distributed assemblage in the survey.

As with plant communities, the relevance of macro-scale factors in determining the distribution of assemblages was qualitatively explored. Mapping revealed a few geographic patterns (Map 2): High Mixed assemblage was concentrated in the south, Moderate Floating-Leaf assemblage in the north-west, and Moderate Filamentous Algae assemblage occurred widely through the study area. Sub-catchment was an influence only for Moderate Floating-Leaf assemblage which was concentrated in Pierces Creek, and High Mixed which was concentrated in Naas sub-catchment. Assemblages characterised by macrophytes (Moderate Floating-Leaf, High Mixed assemblages occurred rarely in Step-Pool geomorphic reaches.

9: Modelling using BET data. Only four BET were analysed: Submerged, Floating-Leaf, Amphibious Dicot and Filamentous Algae. These differed in the number of site characteristics significantly associated with abundance, ranging from none for Filamentous Algae to eight for Submerged BET. Disturbance was negatively associated with abundance of two BET: sand-infilling for Submerged BET, and evidence of fire for Floating-Leaf BET.

The occurrence of three assemblages was analysed: Moderate Floating-Leaf, High Mixed, and Moderate Filamentous Algae. For Moderate Floating-Leaf and High Mixed assemblages, the site characteristics significantly associated with occurrence were broadly similar to the site characteristics significantly associated with abundance of individual BET, except for disturbance which was not significant.

DISCUSSION

10: Plant environmental relationships. Profile, as used here, means the environmental variables found to be positively or negatively associated with plants, whether as species, BET, community or assemblage. Submerged and floating-leaf macrophytes typically had more complex profiles than amphibious dicots or filamentous algae, as indicated by number of significant site characteristics.

With VIS, the nine species had differing environmental profiles but, not surprisingly, the profiles of co-occurring species were similar, differing in fine detail. The species profiles established in this study were variably consistent with other studies. Consistency was high in the case of *Veronica anagallis-aquatica*, an introduced amphibious dicot known to be an invasive coloniser, but low for two native species, *Myriophyllum variifolium* and *Gratiola peruviana*. Inconsistencies were in part attributed to using different array of environmental variables in analyses. In addition, profiles established in this study were time-specific, in that they were determined subsequent to a series of major environmental disturbances.

The most important environmental variables were those with the highest number of significant associations: for species occurrence, these were altitude and % mud and silt. Although altitude is often interpreted as a proxy for climate, it was here assumed to be a proxy for landscape setting and substrate characteristics. Altitude and substrate were also among the most important variables for predicting the occurrence of plant communities, and the abundance of individual BET.

The profiles are useful for understanding distribution of species, forms and floristic groupings within the study area but not for anticipating changes in climate or water quality.

11: Two approaches – VIS and BET. The six plant communities and eight assemblages recognised here were based on data sets differing in how vegetation was recorded (as VIS or BET) and how abundance was recorded (categorical data, or percentage cover averaged). Compared with BET data, the VIS data had finer ecological resolution (24 species v 9 growth forms), coarser measures of abundance, and resulted in a smaller coverage (64 sites v 72). Plant communities and assemblages were distinct and not interchangeable.

The two approaches were complementary in the field. Using both did not increase field effort but did add considerably to data processing and interpretation, without a commensurate gain in information. Being species-based, the VIS approach is closer to conventional needs of conservation and management and therefore more suitable for future studies of in-stream vegetation. However, two refinements are suggested. One is to record categorical abundance at the quadrat scale, and then derive abundance at the site-scale. The other is to expand the range of plants beyond VIS, and to also record charophytes and filamentous algae. The sampling protocol, with quadrats as wide as channel wetted perimeter is suitable for smaller channels, but impracticable for large rivers.

12: Disturbance

In the absence of any 'before' data, the possible effects of recent major environmental disturbances on in-stream vegetation was explored by treating three disturbance indicators (evidence of flood, evidence of fire, sand-infilling) as environmental variable in regression modelling. Sand infilling was the most important of these. It had five significant associations with plant responses, compared with just one for fire and none for flood. The five plant responses were occurrence of two species, occurrence of one community, species richness, and abundance of one assemblage. Associations with *Veronica anagallis-aquatica*, an exotic amphibious dicot, and the *Veronica* community were positive, indicating that sandy beds and sand deposits favoured this species, a finding consistent with its reputation as a colonising species, and of being associated with poor geomorphic condition.

The lack of significant associations between plant responses and evidence of fire or evidence of flood does not mean that fire and flood had no impact on in-stream vegetation: only that there was no correlation with plant distributions, due being sampled two years after the fire and to flooding affecting nearly all study sites.

13: The *Myriophyllum* community. The *Myriophyllum* community was distinctive among the plant communities described here and in Australian studies elsewhere, for its structure which comprised long dense trailing stems filling the stream, for its high species richness, and for its character species *Myriophyllum variifolium* being associated with good geomorphic condition. It shared several sites with the High Mixed assemblage which averaged 67% cover. This *Myriophyllum* community typically occurred in streams flowing through open wet grasslands in gentle valleys at altitudes 1000-1200 m AHD, sites that in this survey were mostly in the Naas sub-catchment. This community likely also occurs in comparable streams in NSW. Prior to fires and floods, the community was probably more extensive in ACT, as there is evidence of it occurring in the Cotter and Gudgenby sub-catchments. The high cover and distinctive structure of this *Myriophyllum* community make it an unusual habitat for in-stream fauna, and potentially important in aquatic biodiversity.

Management imperatives are to confirm the dependent fauna, determine the longitudinal extent of the plant community, track the recovery on streams where it is known to have been lost, and protect from damage such as trampling, scour and inappropriate infrastructure. Protecting existing stands of this community is particularly relevant, as so little is known about refugia and recovery trajectories for submerged macrophytes in streams.

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1 Introduction

1.1 Study Context

Plants adapted to grow and complete their life-cycle growing in, under, or on water are generally referred to as 'macrophytes'. In monographs and text books (eg Cronk and Fennessy 2001), four main types are recognised: submerged macrophytes, with leaves under water; floating-leaf macrophytes, rooted in substrate with leaves floating on the water surface; free-floating macrophytes, float on the water surface, their roots dangling; emergent macrophytes, rooted in the substrate and with leaves growing through the water in to the atmosphere. The term 'macrophyte' is flexible, not fixed: it sometimes means vascular species only, and sometimes includes non-vascular plants such as charophytes. This ambiguity means authors generally explain the scope intended.

Macrophytes are functionally important in rivers and streams. They provide shelter and foraging habitat for aquatic biota (eg Humphries 1996), and they modify the physical and chemical characteristics of the water around them (eg Wilcock et al 1999). Because of these functions, they can be thought of as 'ecosystem engineers' (Mackay and James 2016). Yet, despite the widespread acceptance of their functional importance in stream ecology, river and stream macrophytes have been little studied in Australia. Knowledge of their physiology and ecology is reliant on the international literature (Mackay and James 2016). However studies done in different landscapes and climates, or under differing management systems, do not necessarily apply to regional Australia. In addition, the international literature does not cover the distribution of Australian species, descriptions of Australian plant communities, or life-history and growth of Australian species. Some mapping has been done of problem species such as *Egeria densa* (Vincent et al 2016) and of macrophyte patches as fish habitat (Davis et al 2018, Beyer et al 2010), but the distribution of macrophytes and description of plant communities is largely undocumented. To date, only four descriptions of macrophyte communities have been published, and these are from very different parts of Australia: streams in agricultural catchments on the Swan Coastal Plain WA (Paice et al 2017); minimally-modified tributaries to the Mary River, south-east Queensland (Mackay et al 2003); Swan and Apsley Rivers in eastern Tasmania (Hughes 1988); streams in far north Queensland (MacKay et al 2010). Just two investigations of macrophyte-environment relationships have been published: one being a study of species-environment relationships (Chessman and Royal 2010), and the other linking species to stream condition (Chessman et al 2006). There have been no regional or state-wide surveys dedicated to mapping or describing in-stream macrophyte communities. Macrophytes are not targeted in regional vegetation surveys or vegetation mapping, and are included only rarely: the one example known is the "waterways" plant community of the Upper Murrumbidgee catchment (Armstrong et al 2013).

Streams in upland landscapes of south-eastern Australia are distinct from lowland rivers. They differ in terms of their physiographic and hydrologic characteristics, ie in climate, slope, flow regime, hydraulics and stream size. They also differ in the types of anthropogenic disturbances. In general, upland rivers and streams are 'above' large water storages that make irrigation releases, so are not subject to regulated flows and altered flow regimes that favour exotic species (Greet et al 2012a). Common Carp *Cyprinus carpio* is an introduced fish which is implicated in the decline and disappearance of submerged and floating-leaf macrophytes from lowland rivers. These fish are not so prevalent in upland systems, as although present in larger rivers, they are generally absent from smaller streams (Lintermans 2007; Mark Lintermans, pers. comm. 15 June 2022). In much of Australia, large towns, urban areas and industry are at lower altitudes which may protect upland streams from inputs of pollutants, nutrients or sediment. In addition, many upland areas are managed for nature conservation and as catchments for water supply. However, uplands are not pristine. Historic land uses such as forestry, cattle grazing and gold mining have all left environmental legacies, and feral animals (deer, pigs, horses) and invasive plants continue to impact stream systems.

In the last five years, south-eastern Australia has been subject to a series of major environmental disturbances: extreme heat and dry conditions in December 2019-January 2020; extensive and severe wildfires in January-February 2020; intense rain storms on burnt catchments caused flash flooding and severe erosion; above average rainfall resulting from consecutive years with La Nina led to high flows in 2021 followed by above-average stream discharge in 2022. The effect on streams of severe fires followed by intense rainfall and floods can be dramatic: they may be altered as habitat, stream metabolism may be changed, and the relative importance of different primary producers changed (Smith et al 2011). The effects of fire, flood and erosive flows on macrophytes have not been specifically studied in Australia but are likely to include: modified flow regime due to increased run-off; abrasion, burial and loss of habitat through sediment influx and deposition; eutrophication and increase in fast-growing competitors due to nutrient influx; growth inhibition due to toxic effects of ash influx; improved growing conditions through higher irradiance and increased temperature due to loss of riparian canopy. These effects are likely to be temporary, lasting 3-5 years as the stream recovers (Smith et al 2011) however the residual effect on biota is uncertain.

The ecological and conservation value of upland areas is high. In eastern Australia, two upland vegetation communities are recognised as significant at the federal level, “Alpine Sphagnum Bogs and Associated Fens” and “Upland Wetlands of the New England Tablelands and the Monaro Plateau”, and one wetland, Ginnini Flats in the ACT, is listed as a significant wetland under the Ramsar convention. Recognition of the importance of upland wetlands was underpinned by several vegetation studies and surveys (eg Benson and Jacobs 1994, Whinam and Chilcott 2002, Bell et al 2008, Hunter and Bell 2009). In contrast, the vegetation of upland streams is very little known.

1.2 Aims

The aims of this project, as specified in the contract, were to:

[a] Survey streams and rivers in western ACT for riverine macrophytes and site characteristics

[b] Analyse findings of the survey on spatial variability of riverine macrophytes, focusing on:

- Site characteristics associated with defining Presence/Absence of in-stream vegetation
- Species richness and growth-form richness: and associated site characteristics
- Individual species and relationship to environmental factors

[c] Draw out implications for management such as biodiversity patterns, hot-spots for conservation, monitoring for ecological changes.

1.3 General Approach

Riverine macrophytes of specific interest here were plants growing in the stream, meaning submerged and floating-leaf macrophytes, and amphibious plants along the margins, but not emergent macrophytes which tend to be included in terrestrial vegetation studies, and not species deemed to be terrestrial. The term ‘western ACT’ was interpreted as upland areas in the ACT west of the Murrumbidgee River. Primary interest was streams within the ACT conservation reserve, rather than those on cleared or agricultural land.

The general approach to meet objectives of conducting a survey and determining species-environment relationships was to maximise the number of sites surveyed: and to achieve this by reducing effort per site. The strategy for doing this was to minimise the search and identification time at a site by sacrificing the level of precision usual in vegetation surveys, which is to record abundance as % cover for each species per quadrat, and to use multiple small quadrats per site. For example, because macrophyte cover is generally patchy in streams, Mackay et al (2010) considered that up to 30 randomised quadrats could be needed per site. The approach used was to use larger quadrats, following Chessman and Royal (2010), and avoid recording % cover for each species. Accordingly, two methods were devised, both using the same few stream-wide quadrats per site. One recorded vascular plant species, referred to as VIS for Vascular In-stream Species but limited to submerged and floating-leaf macrophytes and amphibious dicots (defined Section 2.2) and recorded abundance using a coarse measure of abundance per species. The other considered the full range of plants growing in streams, from filamentous algae to vascular plants, and estimated their abundance as percentage cover for each type of plants, referred to as BET for Broad Ecological Types (described in Section 2.2 Field Methods). The rationale for using BET was that species with similar morphology (ie similar growth form, similar life-history) would have similar habitat requirements and responses to the environment. Both methods were used concurrently in the field, using the same field protocol and data sheet.

Australian studies investigating the environmental relationships of river plants have used 20-30 environmental variables, covering water quality, hydrology and hydraulics, site and channel characteristics, catchment and land use, disturbance and condition (Chessman et al 2006, Chessman and Royal 2010, Mackay et al 2003, Mackay et al 2010, Paice et al 2017). For this study, pragmatic considerations and resourcing prevailed, with environmental variables considered at two scales: macro-scale, meaning catchment and regional factors; and site-scale, where a relatively small set of physical characteristics was recorded (Section 2.2 Field Methods). Multivariate techniques were used to identify groups of sites, and generalized linear modelling was used to determine which environmental variables and factors were associated with distribution.

Distribution of communities and assemblages through the study area is shown as a 2-dimensional grid (longitude x latitude) and was plotted in Excel. The authors did not have the resources to produce distribution maps.

2 Methods

2.1 Study Area

The study area was the Australian Capital Territory (ACT) west of the Murrumbidgee River, an upland area, comprising the Brindabella Ranges and footslopes. The Murrumbidgee River Corridor and the Bullen Range were not included. This is an elevated dissected upland landscape, with a mean annual rainfall of 1000-1600 mm, and mean annual temperatures ranging from 3 to 12^{o}C. The Ranges are mainly Ordovician metasediments or Silurian intrusives (Table 2 in Cowood et al 2017) with an altitudinal range of nearly 1500 m, from 450 m at the confluence of the Cotter and Murrumbidgee Rivers, to 1913 m at the top of Mt Bimberi. The area has numerous low-order ephemeral and seasonal streams, which become tributaries to the four main rivers: Paddys, Gudgenby, Naas, and Cotter. Conservation is the principal land use by area, the largest reserves being Namadgi National Park and Tidbinbilla Nature Reserve. Other land uses are water supply, with some pastoralism and forestry on lower slopes. Some upland areas that were cleared for early settlement or forestry are being returned to natural bush. The area has been mapped into landscape units known as Hydrogeological Landscapes (HGL) based on geology, climate, hydrology, topography and stream network (Cowood et al 2017). Vegetation has been mapped at formation and community level and can be inspected on the ACT Government geo-spatial platform (ACTmapi).

2.2 Methods

Site Selection: The study area was stratified by sub-catchment (Condor, Cotter, Gibraltar, Gudgenby, Honeysuckle, Naas, Paddys, Pierces, Tidbinbilla). These are minor streams, except for the Cotter River, which are all ultimately tributaries to the Murrumbidgee River. Note that sub-catchment as used here differs from sub-catchment in Schedule 1 of *Water Resources (Water Areas) Determination 2019* which partitions only Cotter but not Paddys, Gudgenby or Naas Water Management Areas. The aspirational target was 90+ sites for the survey (10 sites per sub-catchment), however an even distribution of sites per sub-catchment was unlikely as sub-catchments differed in size (area) and accessibility.

Potential sites on streams or rivers within (1-2 km) walking distance of a public road or walking trail were identified using Rooftop's *Namadgi – ACT South Activities* 1:50,000 map, dated 2011. This map shows 10 m contours, land use, roads, vehicle and forestry and 4WD trails, as well as walking trails and locked gates. Suitability criteria were: flowing water (not dry or ponded), a well-defined channel (not a marsh or delta), not overgrown by blackberries, safely accessible (feasible to get in and out unassisted), and flow conditions that were non-hazardous for working in (a subjective appraisal of depth, flow rate and stability of substrate). Sites were positioned away from the influence of bridges, fords, culverts, road crossings and road workings, as judged in the field, however, the effects of these could not always be avoided.

Sampling: A site was a stream reach that was relatively homogeneous in geomorphic characteristics and adjacent riparian vegetation, and was at least 20-25 m long for smaller channels (less than 5 m wide) and 30+ m long for wider channels (=>5 m wide).

Sampling design was influenced by the approach developed by Chessman and Royal (2010). Quadrats (five per site) were as wide as the wetted perimeter, ie they stretched from waterline on left bank to waterline on the right bank so quadrat width was variable not fixed. Quadrats extended downstream for 2 m on smaller streams and 3 m on larger ones, and were spaced 2-3 m apart and 3-4 m apart on smaller and larger streams respectively.

Plants growing in stream flow within the wetted perimeter were sampled as follows. For VIS, species of submerged and floating-leaf macrophytes and amphibious dicots were recorded as ***present***, and species covering more than 30% of the site were recorded as ***dominant***. Presence was determined by looking at and into the water, and by hand-searching under water. Hand-searching was particularly valuable when macrophytes were dense in-stream: small and inconspicuous species were detectable by touch, and some such as *Isoetes muelleri* and Charophytes have a distinctive feel. For BET, the abundance (as percentage cover) of each BET growing in the quadrat was visually estimated, and then summed to give BET total cover per quadrat; quadrat total cover was then averaged to give BET total cover per site.

VIS: Phenological status of VIS was recorded from 3 February onwards, at 47 sites (out of 72 surveyed). There were three phenological states: Vegetative (none of a species had any reproductive structures, and no seedlings or juvenile plants were present); Regenerating (seedlings, juvenile and/or immature plants were present); Reproductive (some plants present had buds, flowers and/or recent fruits). The incidence of being reproductive was the number of sites where a species was reproductive as a % of sites where observations were made of that species.

Nomenclature for VIS follows ACT Plant Census 4.1 (Lepschi et al 2018). Plants were identified in the field, when possible (ie if flowering), or by growing-out material at home, or by the Duty Botanist (Dave Albrecht) at the National Herbarium, Canberra. *Callitriche* sp was treated as *Callitriche stagnalis*, as this is the only *Callitriche* species on the ACT Plant Census Version 4.1: all *Callitriche* plants inspected were vegetative. *Hydrocotyle* sp was treated as a single taxon, *Hydrocotyle rivularis*, rather than *Hydrocotyle tripartita*, based on habitat occurrence in montane streams (VICFlora) and distribution patterns (Atlas of Living Australia).

The ACT Census was the source for common names and origin. Life-span was taken from VICFlora (2022).

Four example of VIS are given in Photo 1 below (Section 2.6).

BET: There were nine BET: Submerged, Floating leaf, Amphibious Dicots, Emergent, Moss, Filamentous Algae, Gelatinous Algae (blobs), Liverworts, and Charophytes. Collectively these encapsulated the range and diversity of photosynthetic organisms growing in the stream. These are summarised below (Table 1), with examples from the survey.

Only plants growing in water and dependent on stream flow were considered. Plants known to be terrestrial (ie with no adaptation for growing in water, and no life-cycle dependency on flowing water) were not included, even if present. Also excluded were plants growing on the bank with foliage drooping into the water, and stream drift and floating fragments.

Assigning a vascular plant to a BET was straightforward, being based primarily on growth form, and informed by the categorisations in *Waterplants in Australia* (Sainty and Jacobs 2003), with the exception of *Isolepis* species. These were resolved as follows. *Isolepis inundata* growing in-stream but with culms trailing (ie superficially similar to *Isolepis fluitans*) was treated as an Emergent. The rationale was that these were trailing due to being entrained by high flows, and would likely survive if flows receded. *Isolepis crassiuscula* and *Isolepis fluitans* are described as 'aquatic perennials' in VICFlora so were recognised as Submerged: these were not expected to survive if flows receded. Two stoloniferous plants, *Ranunculus amphitrichus* and *Hydrocotyle rivularis*, sometimes look like Floating leaf as they can develop floating leaves with a glossy upper surface, but were treated as Amphibious Dicots. *Montia australasica*, present in-channel only with its etiolated leaves trailing in flowing water, was recognised as submerged macrophyte: squat amphibious forms of this species occur in soaks and shallow wetlands, but were not seen on this survey.

Four examples of BET are given in Photo 2 below (Section 2.6).

Table 1: Nine BET recorded in survey

BET	Description	Examples from this survey
Submerged	Plants with all of most of their foliage underwater. May have fine roots and small root mass: some are stoloniferous. Not tolerant of being exposed, and soon die if stranded by falling water levels	Seven species in this survey. *Isolepis fluitans, Isolepis crassiuscula, Isoetes muelleri, Montia australica, Myriophyllum variifolium*, *Potamogeton ochreatus*, *Ranunculus trichophyllus*.
Floating-leaf	Plants growing in water with one of more leaves floating on the water surface: sometimes with submerged leaves also.	Two species in this survey. *Callitriche stagnalis, Potamogeton cheesemanii*
Emergent	Plants rooted in saturated soil or under water, growing through water with foliage in the air. Tolerant of being exposed and can survive exposure lasting months. Tolerant of being completely submerged for days to weeks during the growing season.	Species were not routinely recorded but the most frequently occurring were: *Carex fascicularis, Carex gaudichaudii, Carex polyantha, Cyperus eragrostis, Eleocharis acuta, Isolepis inundata, Isolepis gaudichaudii, Juncus articulatus, Phragmites australis, Scirpus polystachyus.*
Amphibious Dicots	Plants (other than rushes, sedges or grasses) growing in shallow water, often at edges of a waterbody. Tolerant of being submerged or stranded for short periods (ie days-weeks rather than months).	Fourteen species in this survey. *Crassula helmsii, Gratiola peruviana, Hydrocotyle rivularis, Isotoma fluviatilis, Lilaeopsis polyantha, Ludwigia palustris, Lycopus australis, Myosotis laxa var caespitosa, Nasturtium officinale, Persicaria decipiens, Persicaria hydropiper, Ranunculus amphitrichus, Ranunculus inundatus, Veronica anagallis-aquatica.*
Mosses	Mossy patches were either on rocks or on earthen banks. Tolerant of being submerged and splashed. If exposed, dies back.	Not recorded at species level.
Filamentous Algae	Long trailing skeins of algae. Grow submerged or in micro-sites where continuously splashed by water. Filamentous algae are obligate aquatic plants. They die very quickly if stranded by falling water levels.	Not recorded at species level. These varied in form (smooth, rough, branched, unbranched), colour (bright green, dull green, blue-grey and brown) and substrate (aquatic plants, stones and rocks, woody debris) suggesting high diversity.
Gelatinous Blobs	Gelatinous blobs are a type of macro-algae, commonly a "blue-green algae" or Cyanobacteria.	Not recorded at species level. Two types present. One: small, dark bluish-black nodules, on rocks and stones in stream, washed over by stream flow. Two: large dull pink blobs, abundant and dense on trailing stems of only *Myriophyllum variifolium,* nearly always in fast-flowing water. The two types correspond to *Nostoc* and *Rivularia* sp (Entwistle et al 1997).
Liverworts	Liverworts were mostly at or near the waterline, often shaded by bank vegetation or protected by undercutting. Not tolerant of being exposed.	Not recorded at species level. Most of liverworts in the survey looked like a *Marchantia* sp
Charophytes	Macro-algae that grow and reproduce completely under water. Obligate aquatics that die when exposed.	Not recorded at species or genus level. Both *Chara* sp and *Nitella* spp were present.

Environmental Variables: Environmental variables recorded on site were as follows:

In each quadrat, wetted width (in metres) was measured from wetted perimeter on left bank to wetted perimeter on right bank. Wetted width thus included undercut banks, overhanging rocks and flooded emergent macrophytes. Thalweg depth (in cm) was the deepest part of the flowpath per quadrat. Bank (ie lateral) shading was the percentage of the wetted width overhung by bank and/or bank vegetation. Overhead shading was the shade cast vertically onto the quadrat water surface by shrubs and trees, both live and dead. This was estimated as canopy area X canopy density, with area being % of quadrat, and density being value between 0.1 and 1 (from sparse to dense), and giving a theoretical maximum of 100% (ie all water surface was shaded). Quadrat data were averaged to give site values for these environmental variables.

In the field, each site was assigned to one of eight reach types, using the geomorphic classification as presented in Table 2 of Buffington and Montgomery (2021). This is a hierarchical process-based stream classification, suitable for mountainous areas. The geomorphic process is sediment flux, and the eight reach types can be arranged on a gradient from transport limited to supply limited (colluvial, braided, dune-ripple, pool-riffle, plane-bed, step-pool, cascade and bedrock). An additional "type" was added for this study, called "Sand Obscured", for sites so deeply infilled by sand that their geomorphic features were hidden and could not be classified. Substrate composition of each site was visually estimated as percentage of stream bed per substrate size class. Substrate size classes used were Bedrock, Boulders (>256 mm), Cobbles (64-256 mm), Pebbles (16-64 mm), Granules (4-16 mm), Sand (< 4 mm), Mud and Silts, and Organic Material. The types of organic material present were noted (leaves, matted roots, branches, twigs), but not used in analyses. Pebbles and Granules as used here were based on Chessman and Royal (2010) and differ from the Wentworth scale.

Slope at each site was estimated from ACTmapi, the ACT Government portal for geo-spatial natural resource information. It was the mean of three estimates; each estimate was the change in altitude between a contour upstream of the site and a contour downstream (in metres) divided by the stream length between contours (in metres) x 1000. Altitude (m AHD) and geo-coordinates (decimal degrees South and East) were read from file details of digital photos taken with an I-phone routinely at each site.

Also at each site, field observations were made of recent disturbances. Sand-infilling was whether the flowpath looked as if recently filled with sand (Yes, No). The likelihood of the site having been subject to recent disturbances (Fire or High Flows) was appraised using a checklist on the field sheet.

Landscape variables such as HGL and vegetation community were taken from layers in ACTmapi. Vegetation communities are referred to by their mapping unit codes (eg u118). Full names, where used, are taken from *ACT Vegetation Communities.xls*, spreadsheet downloaded from ACT Mapi on 11 August 2021, but now superseded in content. Vegetation communities coded in ACTmapi as DNS (derived native shrubland), DNW (derived native woodland), EXS (exotic shrubland) or EXG (exotic grassland) are here referred to collectively as "d & m" for disturbed and modified.

A copy of the field sheet is given in Appendix 1.

2.3 Data Analysis

All statistical analyses were done in the R statistical environment (R Core Team 2021) which, upon loading, offers many summary and graphical functions, and hypothesis testing routines (through the Comprehensive R Archive Network, 'CRAN'). Specialized analytical packages, documented below, were accessed by the library() function. Basic data processing was done in Excel, including the formatting of data tables for input to R.

Multivariate Analyses

Indirect gradient analyses (ordination) were done with the ‘vegan’ package in R (Oksanen et al 2020). Classification of objects used clustering algorithms available on the R platform.

Ordination – Indirect Gradient Analysis: Nonmetric multidimensional scaling (NMDS) in two and three dimensions (2d, 3d) used the vegan routine, ‘*metaMDS*’, and up to 50 random starts were specified to strengthen the chances of obtaining a convergent solution; otherwise default settings were applied (Oksanen et al 2020). The Bray-Curtis dissimilarity matrix was formed using the routine ‘*vegdist*’ in vegan (Oksanen et al 2020). Stress is the measure of fit between the Bray-Curtis distances and Euclidean distances of objects (sites) in reduced space. Stress values less than 0.2 were considered acceptable. Plots of sites and species in ordination space were inspected to see if any sites or taxa caused major disruption to their dispersion, so that these could be removed, if necessary, and the analyses repeated.

VIS Data: All sites with the presence of any VIS species were retained. One species, an unknown dicot, occurred just once, and was deleted. The resulting data matrix had 64 sites and 23 species. The data was a modified form of abundance, coded 0, 1 and 2, representing field observations of absence, presence, and dominance.

BET Data: Preliminary analysis identified one site (MF060) as an outlier and it was removed from the BET data set. This site had the only occurrence of a fern in the survey: singleton taxa are routinely removed for the purposes of exploratory pattern analysis as they cannot contribute to inferring species’ associations (Belbin 1991). Growth forms occurring at two or more sites were retained as a review of aquatic studies concluded that rare species’ relationships, whether as associations with other taxa or in relation to environmental gradients, can provide useful insights into distributional gradients and the effects of environmental perturbations (Cao et al 2001). The resulting data matrix had 71 sites as objects and 9 growth forms as the variables (“*q*-mode” analysis). Cover estimates were log-transformed (new_Y = ln(observed_Y + 1)) prior to forming the Bray-Curtis dissimilarity matrix and NMDS.

Classification – Vegetation associations based on sites’ compositional similarities: Classification was used to recognise associations of VIS and BET: these associations are henceforward referred to as plant communities (for VIS) and assemblages (for BET) respectively. Applying the average linking, agglomerative clustering algorithm, “*upgma*” in the ‘hclust’ routine (base R) to the between-sites Bray-Curtis distances, the dendrogram was plotted to examine whether distinct clusters of sites could be recognized based on their compositional similarity and at what level of agglomerative distance an objective classification of sites could be defined (Belbin 1991). This last step was assisted by inspection of patterns of site clustering and dispersion in the ordination space as well as by the following steps.

VIS Data: Patterns in the association of VIS species were examined by transposing the VIS data table, and applying upgma agglomerative clustering to the Bray-Curtis distances matrix (hclust). Plots of the ordination of the species’ distances allowed the associations between VIS species to be more clearly represented visually, and helped guide the process of defining VIS vegetation associations. Vegan’s metaMDS ordination (50 random starts) was used for the ordination of taxa.

BET Data: The data matrix of log-transformed BET cover values was transposed, the Bray-Curtis distance matrix computed and upgma dendrogram constructed (in hclust). Plots of the ordination of the species’ distances allowed associations between BET taxa to be more clearly represented visually, and helped guide the process of defining BET vegetation associations. Vegan’s metaMDS ordination (50 random starts) was used for the ordination of taxa.

Regression Modelling of Univariate Responses

Univariate modelling was used to investigate the relationships between VIS or BET plant responses (occurrence, abundance etc) and site characteristics (as independent variables). The data set had too few sites to allow multiple variable analyses that included factors. Generalised linear models (glm, in base R) were used to determine significant relationships between plant responses and environmental variables.

VIS Data: For VIS, three plant responses were modelled: occurrence of individual species, using logistic regression for species recorded at 10 or more sites; species richness of growth forms using Poisson and quasi-Poisson models, as described above; and occurrence of communities, using logistic regression.

BET Data: For BET, three plant responses were modelled: occurrence and abundance of individual BET, and occurrence of BET assemblages. Presence-absence was modelled as Bernoulli functions (binomial distribution), i.e. logistic regression with the logit link function. For modelling purposes, abundance which was recorded in the field as percentage cover was recoded to an ordinal scale (0 to 4) and modelled as counts, specifying the Poisson or quasi-Poisson distribution and with a logarithmic link function (Venables and Ripley 2002). Percentage cover was re-coded as follows: 0% cover = 0, >0 and <=3% cover = 1, >3 and <=15% = 2, >15 and <=40 = 3, and >40% = 4.

Model fits are reported using the following convention: *** for P<=0.001, ** for P<=0.01, * for P<=0.05, M (for marginal) for P<=0.1, and all other P values as NS (Not Significant). Models that failed to converge or gave spurious findings are shown as UnS (unsuccessful).

It was anticipated that small sample sizes or factors with more than 3 levels could result in 'complete separation' issues, where the binomial response was invariant within levels of a factor (e.g. Zorn 2005; Zuur et al 2009; Fukuda et al 2015). Where this occurred, the response was modelled as a Poisson variate, using the logarithmic link function (Zuur et al 2009); and if the output was over dispersed (exceeded 1.2), the models were re-fit with a "quasi-Poisson" distribution to account for inflated estimates of significance (Zuur et al 2009). No such adjustments were used if modelled responses were under-dispersed, as these gave conservative estimates of probabilities.

Independent Environmental Variables: Independent environmental variables used in regression analyses comprised 17 site characteristics, in the following broad categories: stream size (wetted width, thalweg depth), position in landscape (altitude, slope), shade (overhead, lateral or bank), substrate (bedrock, boulder, cobble, pebble, granule, sand, mud & silt, organic matter), and recent disturbance (sand-infilling, evidence of fire, evidence of flood affected).

Modelling geomorphic reach and landscape characteristics (sub-catchment, HGL, vegetation formation and mapped community) was generally unsuccessful. These were multi-level factors and resulted in unstable outcomes. These outcomes are not reported.

2.4 Archive

Appendix 1 stores a copy of the Field Sheet. Appendix 2 has a table of Site Details, showing for each site: Site Number (MF001 to MF072); Date Sampled; Site Name; Decimal Co-ordinates for each site (South, East); Code Name as used in multivariate analyses; VIS plant community; BET assemblage.

An Excel spreadsheet (*ROBERTS & REID 2023 Macrophyte survey western ACT 2022 Field Data.xls*) with all field data (including some not used in analyses) was submitted to the ACT Government on 6 July 2023.

2.5 Terminology and Capitals

Terminology: The list below summarises terms as used in this report. Where appropriate, these are cross-referenced to categories used in "*Waterplants in Australia: a field guide*" (Sainty and Jacobs 2003).

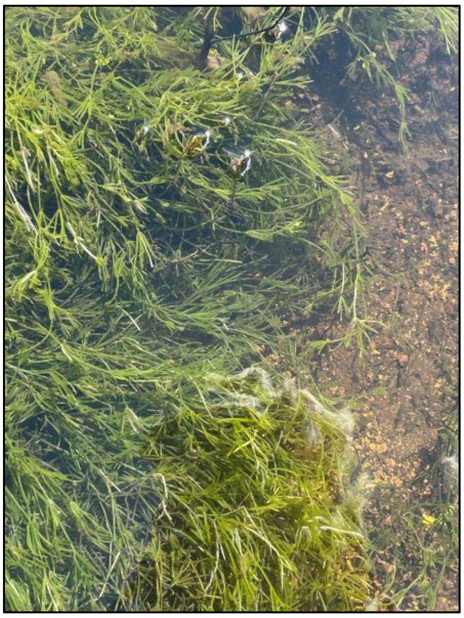
Term	As used in this report
Amphibious dicots	Plant species adapted to growing in water and dependent on water to grow and to complete their life-cycle, but not usually recognised as macrophytes. Equivalent category in Sainty & Jacobs (2003): Emergent broad-leaf.
Assemblage	An association of BET, occurring in the study area and identified from survey data by numerical classification.
BET	Abbreviation for "broad ecological types", specifically the range of growth forms used in this report.
Exotic	Plant species not native to the study area.
Growth form	Sometimes known as life-form. Equivalent to the 'categories by habitat and growth form' in Sainty & Jacobs (2003).
In-stream vegetation	A non-specific term referring to all plants growing in-stream but excluding terrestrial plants: collectively macrophytes, amphibious dicots, charophytes, algae, mosses, liverworts.
Macrophytes	Used generically to refer to plants adapted to growing in-stream but excluding amphibious dicots, algae, mosses and liverworts. Refers to the four main types of macrophytes (submerged, free-floating, floating-leaf, and emergent). Charophytes are included as submerged macrophytes. Equivalent categories in Sainty and Jacobs (2003): Submerged or plants with very fine or feathery leaves; Submerged not feathery; Floating attached; Free floating; Emergent narrow-leaf.
Plant community	An association of VIS, occurring in the study area and identified from survey data by numerical classification.
Riverine macrophytes	Macrophytes of specific interest in this project. As used here, collective term for submerged and floating-leaf macrophytes. Does not include charophytes. Equivalent categories in Sainty and Jacobs (2003): Submerged or plants with very fine or feathery leaves; Submerged not feathery; Floating attached.
VIS	Abbreviation for "vascular in-stream species". As used here, collective term for riverine macrophytes and amphibious dicots.

Capitals: Words are lower case when used in a general sense, but when used to refer to a specific group, then words are capitalised. This makes submerged macrophytes distinct from Submerged BET, and moderate cover distinct from Moderate Filamentous Algae.

2.6 Photo examples of VIS and BET

Photo 1: VIS - four examples

Top Left: *Gratiola peruviana* at Wombat Creek, 3 February 2022. Top right: *Myriophyllum variifolium* in Grassy Creek, 28 January 2022. Bottom left: *Callitriche stagnalis* at Pierces Creek on East-West Road, 18 February 2022. Bottom right: *Lilaeopsis polyantha*, Little Dry Creek, 30 March 2022.



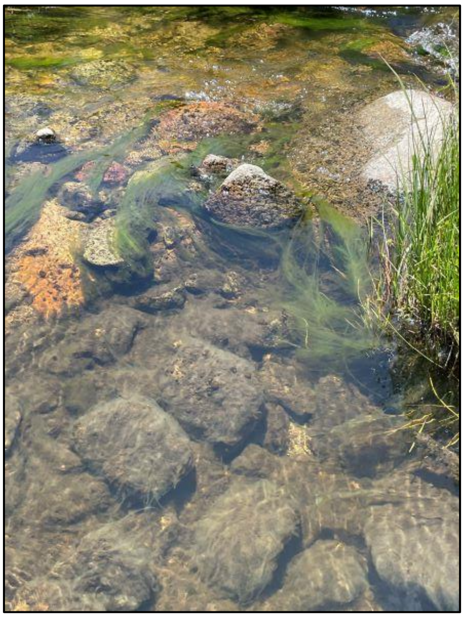


Photo 2: BET – four examples

Top Left: Charophyte beds in Naas Creek, western end of Naas valley, 23 March 2022. Top Right: Moss on boulder mid-stream of Gibraltar Creek, 20 January 2022. Bottom Left: pinkish gelatinous blobs (probably *Rivularia* sp) on *Myriophyllum variifolium* in Grassy Creek, 28 Jan 2022. Bottom Right: various filamentous algae, Honeysuckle Creek, 27 January 2022.

3 Results

3.1 Conditions prior to and during Survey

In the four years preceding the field survey, the study area was subject to four of the six types of extreme events recognised as major threats to Australian riverine ecosystems (Leigh et al 2014): drought, heat waves and hot days, fire, heavy rainfalls and floods. .

For two consecutive years, annual rainfall was 441.9 and 372.8 mm respectively in 2018 and 2019, which was in the bottom 10%ile and well-below the long-term mean of 693 mm (Station 070247: Australian National Botanic Gardens). Spring-summer 2019-20 was exceptionally hot and dry across Australia including the ACT. Extensive bushfires in January-February 2020 burned approximately 90,000 ha of western ACT. Intense rainstorms in February 2020 ceased the fires, but produced a hillside run-off that was a slurry of sediment, ash and organic matter that flowed into streams and rivers. High flows stripped vegetation from stream beds and banks, and then deposited slurry or sand downstream. In mid-2020, with cooler and wetter conditions, stream flows began to increase, and continued to increase through 2021 and 2022 in response to on-going wet seasons.

The shift from extreme hot and dry to sustained wet meant that the larger streams and rivers went from barely running or ponded to sustained high flows. Smaller and headwater streams that almost certainly dried up by summer 2019-20 were flowing persistently by summer 2021-22. Water levels at gauges on Gudgenby (GS 410731) and Orroral Rivers (GS 410736) were consistently below the 25%ile in 2019, then in 2021 exceeded the long-term 75%ile in every month. During the survey (January to April 2022), gauge levels for the Cotter River at Gingera (GS 410730) were approximately 20-40 cm higher than the long-term median, and for Gudgenby River at Crossing (GS 410731) were 0.8 to 1 m higher than long-term median (Figure 1).

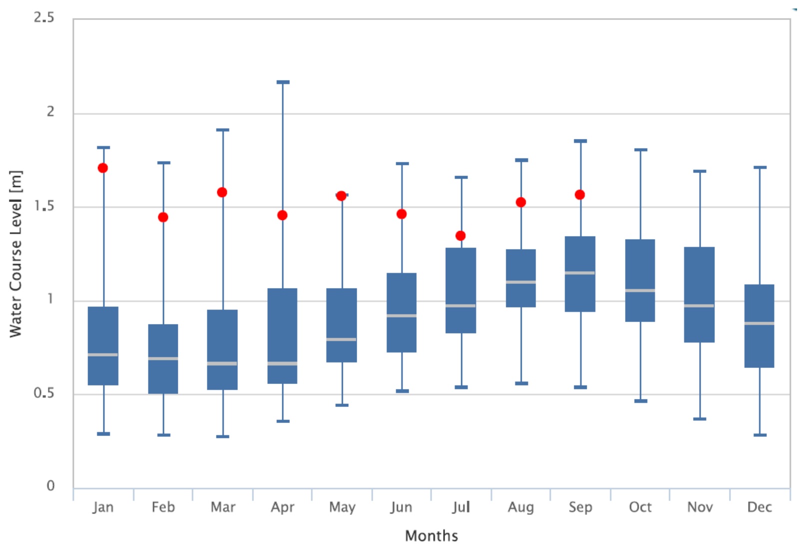


Figure 1: Water levels in Gudgenby River (GS 410731)

Median monthly levels for 2022 (red dot) plotted over box whisker plot summarising gauged water levels from 13 November 1964 to 10 December 2022.

Key: Maximum recorded = top blue line; 75% = top of solid blue bar; median = grey line through solid blue bar; 25% = bottom of solid blue bar; minimum recorded = bottom blue line. Downloaded from Bureau of Meteorology website, 12 December 2022.

Four years of extreme conditions influenced what sites could be sampled. High flows meant that larger rivers such as Gudgenby, Paddys, Naas and Cotter Rivers were too deep and too fast to safely work in. Road and trail closures due to fire and flood damage and road wash-outs meant parts of the study area could not be included, notably Orroral Valley, Naas River downstream of Mt Clear, Naas valley west of Old Boboyan Road, Grassy Creek system, and much of the Cotter system. In contrast, wet conditions made it feasible to sample smaller streams.

Starting in mid-November 2021, over 180 sites were checked for sampling feasibility: some with high flows were visited 2-3 times, in the hope that water levels would fall.

3.2 Sites

A total of 72 sites (MF001 to MF072) were surveyed in summer-autumn 2022, from 12th January to 18th April. This was well short of the aspirational target of 90+ sites. Sampling was ceased, despite the short-fall in number of sites, due to incipient seasonal dieback. Site numbers, names and co-ordinates are in Appendix 2.

Site Characteristics

Physical characteristics are summarised below (Table 2) and also shown as frequency plots to show the spread of the data and help illustrate the relative terms used below (Figure 2).

Survey sites were on streams, rather than rivers. Wetted width ranged from 0.54 to 9.3 m (plus one site 24.4 m wide), and max thalweg depth from 5 to 76 cm. Sites were distributed over a wide altitudinal range, from 587 to 1306 m AHD, with a concentration at 1000 to 1200 m AHD, and were mostly on gentle to moderate slopes: 37 sites had falls of less than 20 m per km of stream channel. The majority of sites were fairly open with little shade: less than 10% of water surface was shaded by trees or shrubs at 52 sites, and by adjacent banks and bank vegetation at 36 sites. The shadiest sites were MF067 (Condor Creek beside Condor wetland) in an unburnt area, where 75% of water surface was shaded by foliage directly overhead, and MF014 (Little Dry Creek at Yerrabi Track) where overhanging tussocks shaded 65% of site water surface. Wildfires of January 2020 burnt the canopy of riparian trees and shrubs and so contributed to the general openness at sites.

Table 2a: Survey Site Characteristics – mean and standard error (SE)

	STREAM SIZE	STREAM SIZE	SETTING	SETTING	SHADING	SHADING
	Wetted width (m)	Thalweg depth (cm)	Altitude (m AHD)	Slope (m per km)	Shade overhead (%)	Shade bank (%)
Mean (SE)	2.9 (0.4)	29.6 (1.7)	931 (24.8)	26.3 (2.4)	14.6 (1.8)	7.7 (1.5)

Table 2b: Survey Site Substrate Characteristics – mean and standard error (SE)

SUBSTRATE	Bedrock (%)	Boulders (%)	Cobbles (%)	Pebbles (%)	Granules (%)	Sand (%)	Mud & Silt (%)	Organic Matter (%)
Mean (SE)	6.6 (1.8)	9.3 (1.9)	18.3 (3.0)	12.1 (2.2)	7.5 (1.9)	24.8 (3.9)	15.1 (3.7)	6.4 (1.2)

Substrate (particle size) was variable, both within and between sites. With few exceptions, sites were dominated (>=40% cover) by one particle size, the most frequent being sand, cobbles, or mud & silt (19, 14 and 13 sites respectively) and the least frequent being bedrock, granules and organic matter which each dominated only 3 sites. The plot below (Figure 2) does not include four sites with two dominant substrates, or eight sites with no clear dominant.

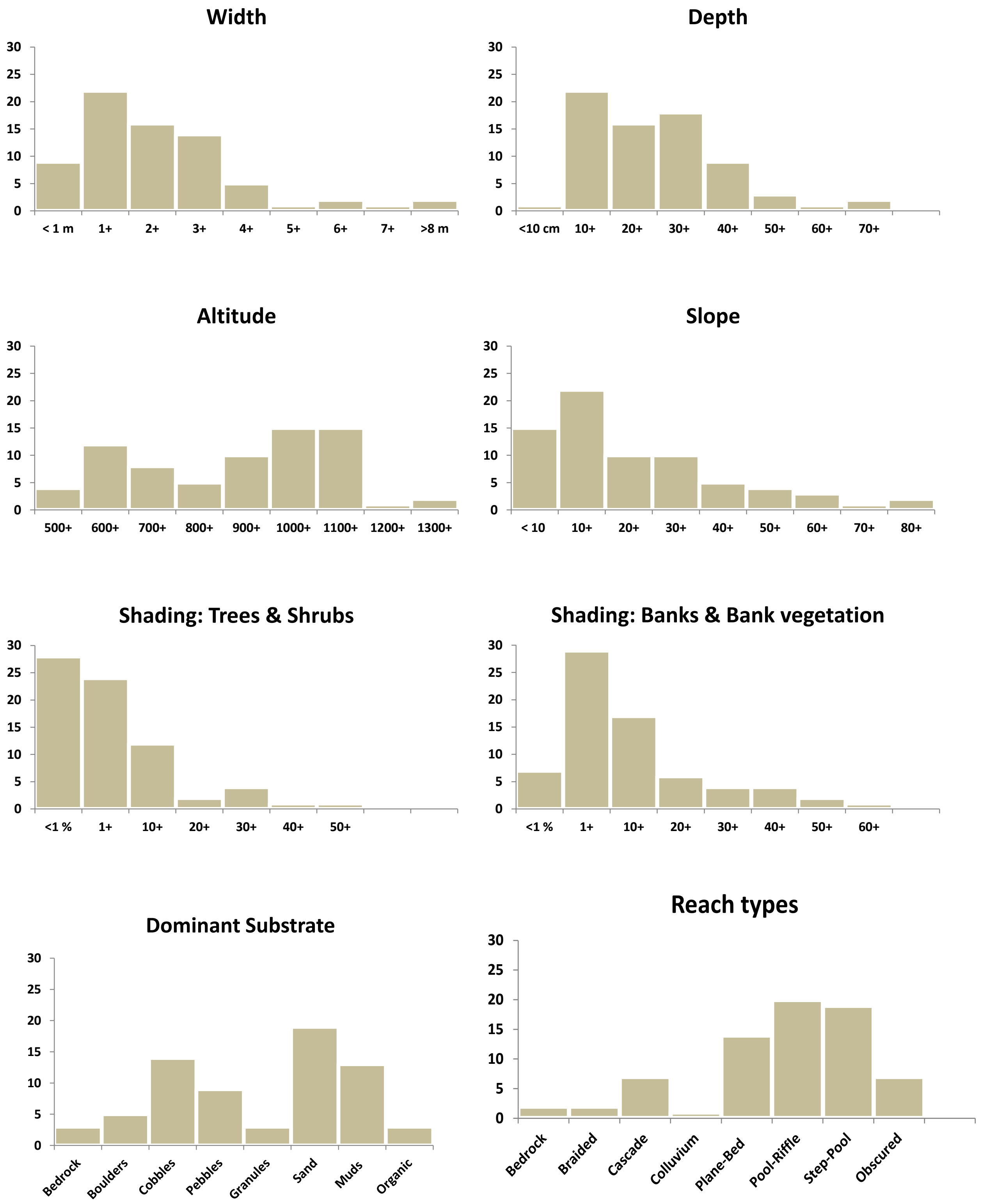


Figure 2: Site Characteristics

Number of sites per category for site characteristics: wetted width (m), max depth (cm) of thalweg, altitude (m AHD), slope (m fall per 1000 m stream length), shading (percentage of water surface shaded) by overhead foliage or laterally by banks and bank vegetation, dominant substrate (particle size covering 40% or more of site), geomorphic reach type. Plots are standardised to 9-categories (x-axis) and 30 counts (y-axis) to facilitate comparisons.

The survey included seven of the eight types of geomorphic reach, the most frequent being plane-bed (14 sites), pool-riffle (20 sites) and step-pool (19 sites) and the least frequent being bedrock, colluvium and braided with 1 or 2 sites each. The braided site was sampled only because of an unscheduled stop due to vehicle problems. Despite its unusual characteristics, of being very shallow and very wide, it was included due to short-fall of sites. One reach type, dune-ripple, a “low gradient, unconfined, sand bed river occupying large alluviated valleys” (Buffington and Montgomery 2021), was not encountered at all. It is unlikely to occur in the streams and rivers in this survey. Seven sites were classified as ‘Sand obscured.”

Convention: This report uses the following relative terms: for wetted width, narrow = < 2m and wide = > 5m; for max thalweg depth, shallow = < 20 cm, and deep => 40 cm; for altitude, low = < 800 m, mid = 800-1100, and high = >1100 m AHD; or slope, gentle = < 20 m and steep = > 50 m fall per 1000 m channel; for shading (overhead or bank), low = < 10 units, some = 10-40, and high = > 40 units (see 2.2 Field Methods).

Macro-scale Characteristics

The 72 sites were in nine sub-catchments and eight hydrogeological landscapes (HGL) (Figure 3). The most intensively sampled sub-catchments were Naas, Gudgenby and Condor, with 14, 14 and 11 sites respectively. These were the only ones that met the design target of 10 sites per sub-catchment. The most frequently sampled HGLs were Namadgi (514 km^2, and the largest within the study area) with 17 sites, and Boboyan (65 km^2, the third smallest) with 16 sites. Several sites were on or close to the border between two HGL (notably Boboyan HGL) which sometimes followed a stream line. Such sites could possibly have been assigned to a different HGL. This ambiguity meant that HGL was not pursued as a characteristic.

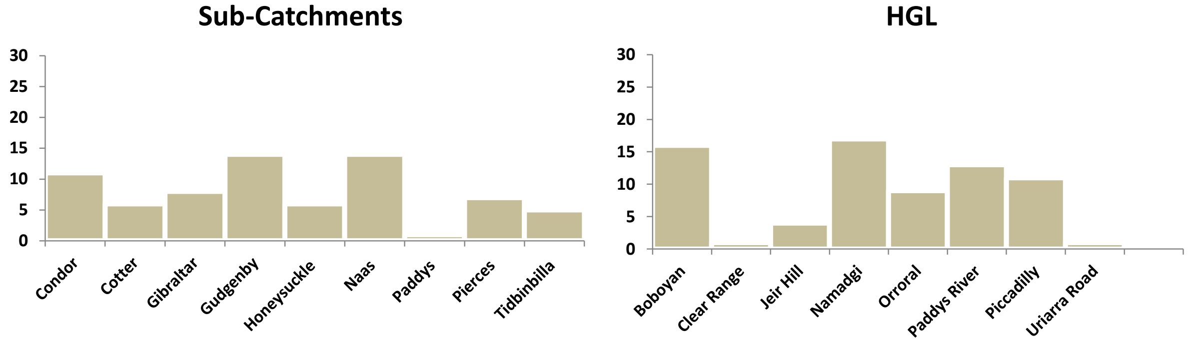


Figure 3: Setting Characteristics

Number of sites per sub-catchment and hydrogeological landscape (HGL).

The geographical distribution of sites by sub-catchments is shown below (Figure 4).

Sites occurred in 6 vegetation formations and 14 vegetation communities (not shown in Figure 3), and were concentrated in two formations (Wet Sclerophyll Forest and Grassy Woodlands, with 23 and 21 sites respectively) and in just three communities: u52 “*Ribbon Gum – Robertson’s Peppermint very tall wet* *sclerophyll open forest*" (23 sites), r2 "*River Tussock – Kangaroo Grass – Rush wet tussock grassland of footslopes, drainage lines and flats*" (11 sites) and u118 "*Black Sallee grass-herb woodland in drainage depression and moist valley flats*" (10 sites). The d & m community grouping had 11 sites, all at relatively low altitudes and clustered in the north-west and centre of the study area, in three sub-catchments: Condor Creek, Pierces Creek and Honeysuckle Creek.

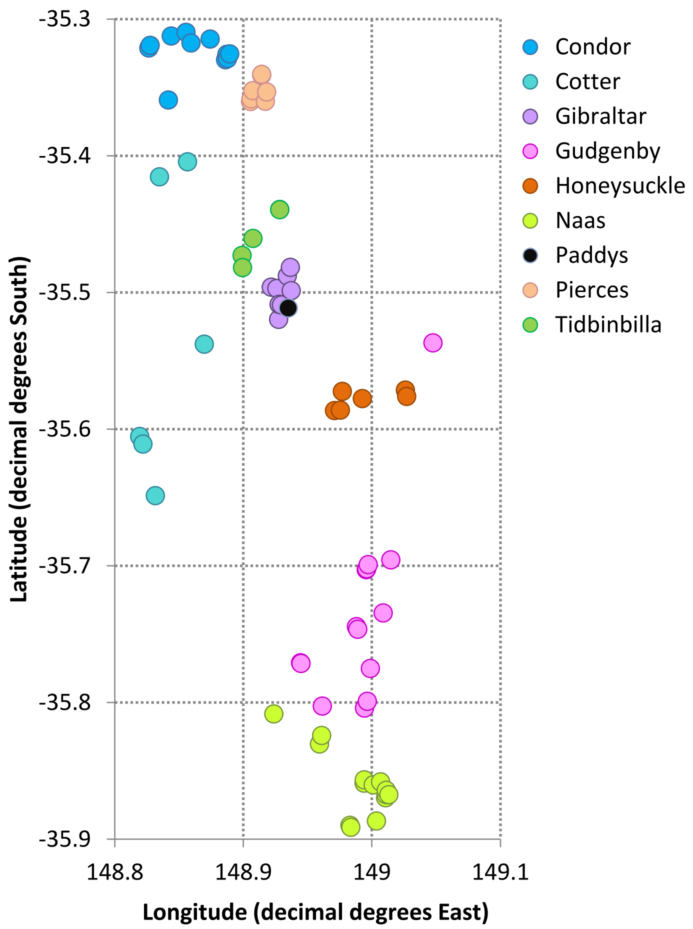


Figure 4: Geographical distribution of sites by sub-catchment

Disturbances

Of the three recent environmental disturbances, flooding (not surprisingly) was the most widespread: its effects were evident at 61 sites (Figure 5) but is likely to have affected all 72 sites. Fire effects were evident at 33 sites: these occurred widely except in the far north-west and extreme south of the study area, a pattern consistent with the official mapping of the Orroral Valley fire (Map 1 in ACT Government 2020). Sand-infilling was evident at 19 sites, mostly towards the centre of the study area: this included the seven Sand obscured sites.

Nearly all sites were affected by one or more disturbances: only four showed no evidence of flood or fire or sand-infilling. Eleven sites showing evidence of all three disturbances were in the Cotter, Gibraltar, Honeysuckle and Gudgenby sub-catchments.

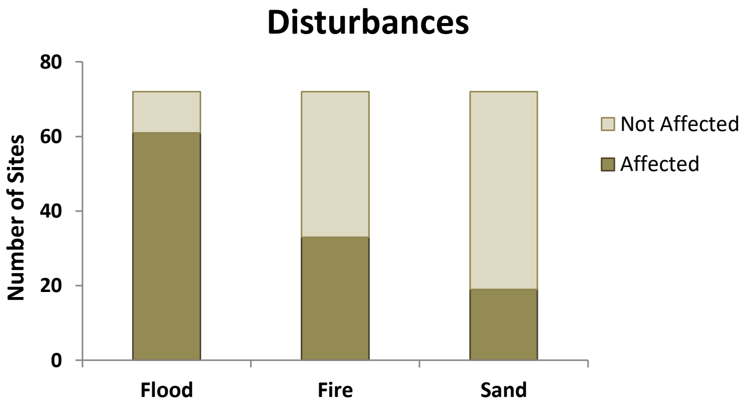


Figure 5: Recent disturbances - incidence

Number of sites affected by each of three environmental disturbances, as observed in summer-autumn 2022.

Although the depth of sand was not routinely surveyed, infilling clearly had local impact. Up to 55 cm was recorded in some smaller streams, and partial burial of perennial plants, such as *Isoetes muelleri* (Photo 3).

Photo 3: Sand-infilling

Left: Approximately 55 cm coarse sand in Honeysuckle Creek upstream of the camping area, 26 January 2022. Right: *Isoetes muelleri* has been partly buried by about 6 cm of coarse sand, as indicated by the non-photosynthetic tissues. Condor Creek at Padovans Crossing, 6 April 2022.

3.3 Vascular In-stream Species (VIS)

Occurrence, Richness and Abundance

Occurrence: A total of 23 vascular species were recorded (Table 3), plus one unidentified dicot which was included in multi-variate analyses but is not in following descriptions. Nearly all (21 species) were perennial, and most (16 species) were native to the ACT. According to the *ACT Advisory list of naturalised alien plants – species assessments* (consulted 29 May 2023), none of the seven non-native plants is high risk.

Table 3: Details of species recorded in survey

Common Name and origin follow ACT Census 4.1 (Lepschi et al 2018). *Persicaria hydropiper* is recognised as exotic in the ACT but native in New South Wales, and unresolved in Victoria. Life-span is taken from species descriptions in Flora Victoria. Three species with no life-span assigned were recognised as perennial: *Callitriche stagnalis* has a life-span that is 'duration-dependent' (ie habitat dependent) and occurs in perennially wet sites; *Isoetes muelleri* is described as a perennial that re-grows from rootstock. *Montia australasica* is recognised as *Neopaxia australasica* in New South Wales; *Nasturtium officinale* is known as *Rorippa nasturtium-aquaticum* in some jurisdictions.

Species	Common Name	Origin	Life-span	Sites Present	Sites Dominant
Submerged macrophytes					
Isoetes muelleri	Common Quillwort	Native	Perennial	4	
Isolepis crassiuscula	Alpine Clubsedge	Native	Perennial	1	
Isolepis fluitans	Floating Clubsedge	Native	Perennial	6	2
Montia australasica	White Purslane	Native	Perennial	14	3
Myriophyllum variifolium	Variable Water Milfoil	Native	Perennial	15	11
Potamogeton ochreatus	Blunt Pondweed	Native	Perennial	1	
Ranunculus trichophyllus	Water Fennel	Exotic	Perennial	2	
Floating-leaf macrophytes					
Callitriche stagnalis	Water Starwort	Exotic	Perennial	14	
Potamogeton cheesemanii	Pondweed	Native	Perennial	5	
Amphibious dicots					
Crassula helmsii	Swamp Crassula	Native	Perennial	1	
Gratiola peruviana	Austral Brooklime	Native	Perennial	38	8
Hydrocotyle rivularis	Pennywort	Native	Perennial	23	8
Isotoma fluviatilis	Swamp Isotome	Native	Perennial	1	1
Lilaeopsis polyantha	Jointed Swampstalks	Native	Perennial	10	3
Ludwigia palustris	Marsh Ludwigia	Exotic	Perennial	1	
Lycopus australis	Native Gypsywort	Native	Perennial	1	
Myosotis laxa var caespitosa	Water Forget-me-not	Exotic	Annual-Biennial	30	2
Nasturtium officinale	Watercress	Exotic	Perennial	1	1
Persicaria decipiens	Slender Knotweed	Native	Perennial	8	
Persicaria hydropiper	Water Pepper	Exotic	Annual	7	1
Ranunculus amphitrichus	Small River Buttercup	Native	Perennial	15	
Ranunculus inundatus	River Buttercup	Native	Perennial	3	
Veronica anagallis-aquatica	Blue Water Speedwell	Exotic	Perennial	20	6

The four most frequently-recorded species were all amphibious dicots: *Gratiola peruviana*, *Myosotis laxa var caespitosa*, *Hydrocotyle rivularis* and *Veronica anagallis-aquatica*, present at38, 30, 23 and 20 sites respectively. The most frequently-recorded submerged and floating-leaf macrophytes were *Myriophyllum variifolium* (15 sites), and *Callitriche stagnalis* (14 sites). Eight species were recorded from one site only. Native Quillwort *Isoetes muelleri*, a rarely observed and often cryptic species in the ACT (ACT Government 2018), was present at 4 sites.

Categorising the 23 species by growth form, in anticipation of the BET analysis (Section 3.5), shows that most were amphibious dicots (14 species), seven were submerged macrophytes, and two were floating-leaf macrophytes.

Richness: The number of species per site (submerged + floating-leaf + amphibious dicot) ranged from 0 to 11 (Figure 6), with 75% of sites having 1 to 5. Five sites had high richness (8 to 11 species), all in the Naas sub-catchment. Eight sites with no VIS were widely distributed, occurring in five sub-catchments and five HGL, and mainly on steep slopes (mean = 36 m fall per km) with relatively high cover of boulders and bedrock.

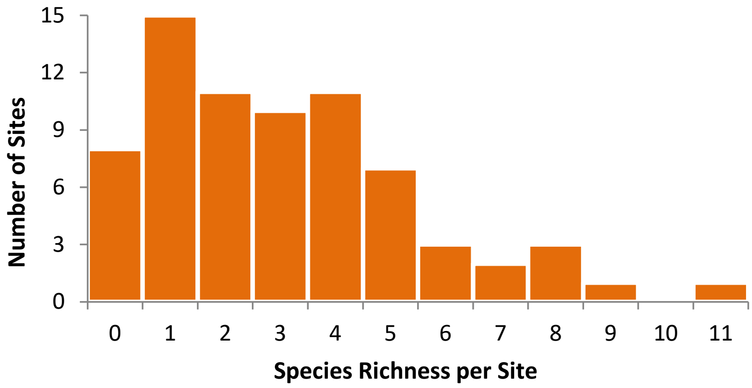


Figure 6: VIS richness - number of species per site

Abundance: Recording species abundance as absent, present or dominant is not amenable to statistical summary, so abundance is instead approximated by the number of sites where a species was dominant.

Eleven species were dominant at one or more sites (Table 3): of these, 3 were submerged macrophytes and 8 were amphibious dicots. The species most frequently dominant were *Myriophyllum variifolium* (at 11 sites) followed by *Gratiola peruviana* and *Hydrocotyle rivularis* at 8 sites each. The growth habit of *Myriophyllum variifolium*, with long submerged stems trailing downstream, contributed to its high cover (Photo 4). The number of species dominant per site ranged from 1 to 3. The four sites with three dominant species were all in southern part of the study area.

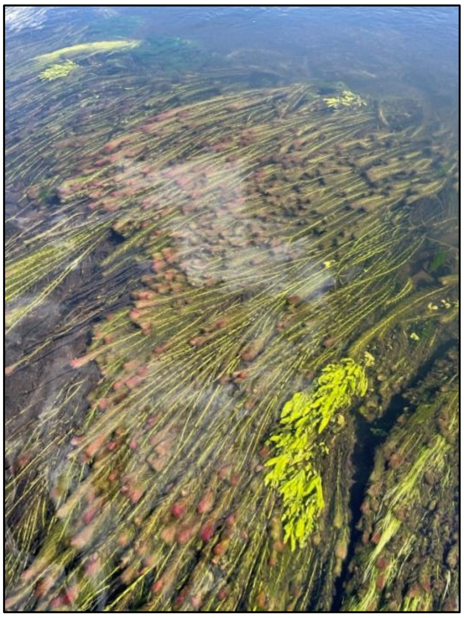


Photo 4: Growth habit of *Myriophyllum variifolium*

Stems of *Myriophyllum variifolium* with reddish tips, trailing downstream: the bright lime green broad leaves are *Myosotis laxa var caespitosa*, and the finer green stems on the extreme right are *Isolepis fluitans*: Naas Creek, 23 March 2022.

Plant Communities

The numerical classification used 64 sites, and 24 VIS (this included one unknown dicot), with species abundance coded as 0, 1 and 2 for absent, present and dominant. The average linking agglomerative clustering algorithm “upgma” was applied to the between sites Bray-Curtis distances, resulting in six groups of associated sites (Figure 7), delineated by red boxes, and ranging in size from 2 to 18 sites.

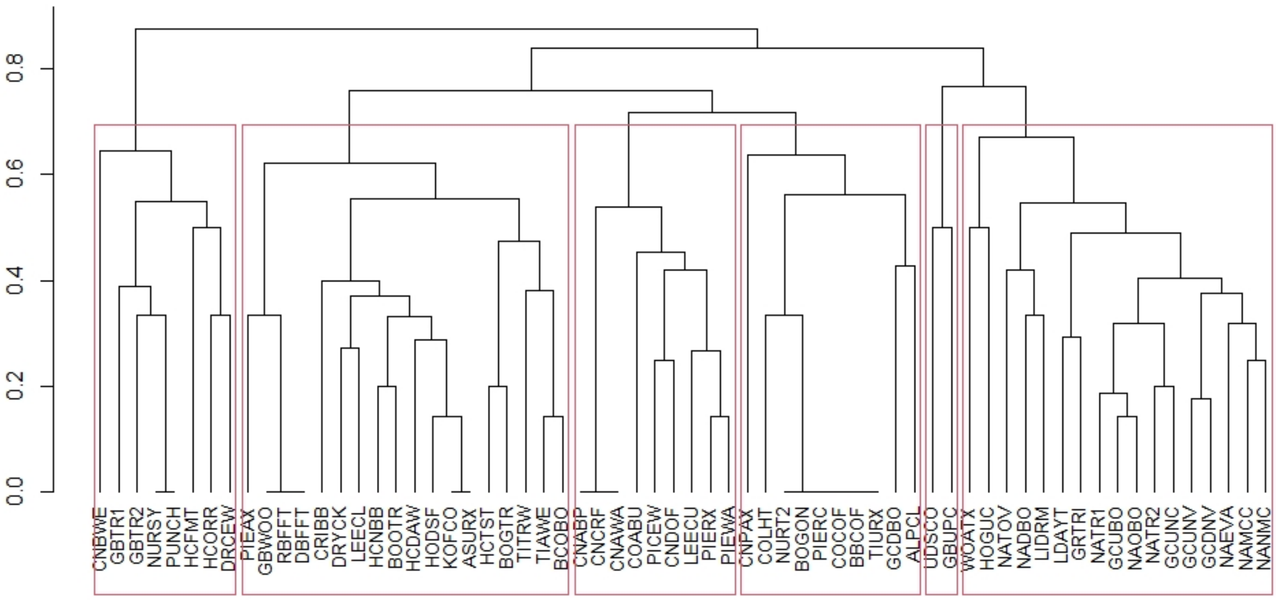


Figure 7: Dendrogram of 24 VIS from 64 sites

Red boxes indicate the six groups of associated sites, referred to as group 1 to group 6 from left to right. Sites are labelled using code names reserved for analyses, and are listed in Appendix 2.

Group 1, on extreme left of the dendrogram, joins groups 2 to 6 at a high level, indicating it is quite distinct. Several sites had similar species and abundance so showed zero difference, notably six sites in group 4.

NMDS ordination had a stress level of 0.13, which was acceptable. Mapping the six groups into 2-dimensional ordination space showed they were reasonably well separated, with a little overlap between groups 2 and 3, and between groups 5 and 6 (Figure 8). Group 1 was not as distinct from the other groups as was indicated by numerical classification.

Henceforward these groups are referred to as plant communities.

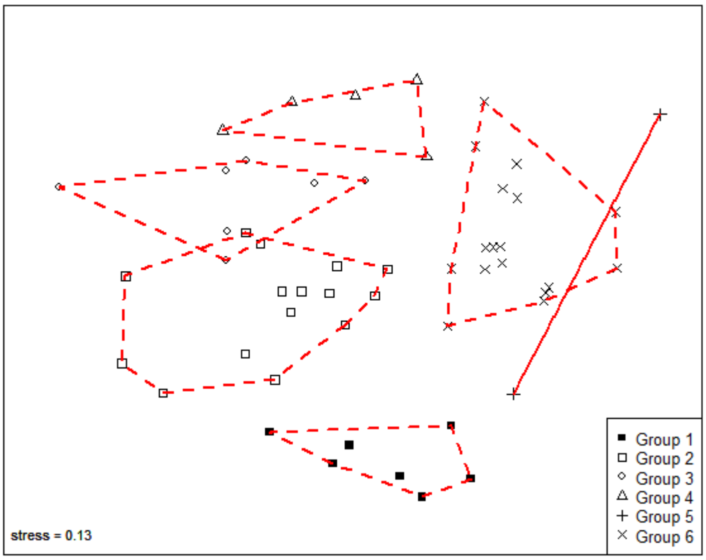


Figure 8: VIS communities imposed on a 2-dimensional ordination of 64 sites

Results of NMDS ordination of 64 sites and 24 VIS, with the six groups identified by numerical classification super-imposed. Groups are numbered 1 to 6, corresponding to the groups shown from left to right in the dendrogram.

Description: The vegetation characteristics of the six plant communities are summarised in Table 4, and described below. The communities are named for their characteristic or dominant species: *Myosotis*, *Veronica*, *Callitriche*, *Gratiola*, *Hydrocotyle* and *Myriophyllum* (from left to right across the dendrogram in Figure 7).

The *Myosotis* community (8 sites) was mainly amphibious dicots, and mainly exotic species. *Myosotis laxa var caespitosa* was present at all sites, sometimes with *Persicaria decipiens*. This community had moderately low abundance (only 2 sites had a dominant species). Species richness was 8 overall and averaged 2.3 per site: nativeness at 38% was the lowest of all six plant communities. Other species were present, but only very occasionally (ie at 1-2 sites per species): two submerged macrophytes *Isolepis crassiuscula* and *Ranunculus trichophyllus*, one floating-leaf macrophyte *Callitriche stagnalis*, and three amphibious dicots, *Nasturtium officinale* and *Persicaria hydropiper* (each dominant at one site) and *Ranunculus amphitrichus*.

The *Veronica* community (18 sites) was also mainly amphibious dicots. It was characterised by three species of amphibious dicots, of which two were exotic: *Veronica anagallis-aquatica* was present at 17 sites (94%) and dominant at five, and *Myosotis laxa var caespitosa*, present at 11 sites and dominant at only one; and the native *Gratiola peruviana*, present at 11 sites was dominant at four. This plant community was slightly more abundant (as indicated by the number of sites with a dominant species) and had higher nativeness (56%) than the *Myosotis* community. Species richness was 9 overall and averaged 3.0 per site. The other species present were amphibious dicots *Hydrocotyle rivularis*, *Persicaria decipiens*, *Persicaria hydropiper* and *Ranunculus* *amphitrichus*, and submerged and floating-leaf macrophytes, *Myriophyllum variifolium*, and *Callitriche stagnalis*.

In the *Callitriche* community (9 sites), the exotic floating-leaf *Callitriche stagnalis* was present at all sites, with *Gratiola peruviana* at 6 sites. Abundance was low (only 1 site had a dominant species and that was *Veronica anagallis-aquatica*). Species richness was 8 overall but only 2.6 per site, however nativeness was fairly high. Several amphibious dicots were also present, each at only 1-2 sites such as *Hydrocotyle rivularis*, *Lilaeopsis polyantha*, *Persicaria decipiens*, *Ranunculus amphitrichus* and *Veronica anagallis-aquatica*, as well as the submerged macrophyte *Isoetes muelleri*.

In the *Gratiola* community (10 sites), *Gratiola peruviana* was present at all sites. This community had low abundance (only one site had a dominant species) and low species richness (mean 1.8 species per site) but high nativeness. Several other species that were present occasionally, ie at 1-2 sites each were three submerged macrophytes, *Isoetes muelleri*, *Montia australasica* and *Myriophyllum variifolium*, and four amphibious dicots, *Hydrocotyle rivularis*, *Isotoma fluviatilis*, *Ludwigia palustris* and *Persicaria decipiens*.

The *Hydrocotyle* community (2 sites) had *Hydrocotyle rivularis* present at both sites. Abundance was low, as was species richness. All species present were amphibious dicots.

Table 4: Plant communities – vegetation characteristics

Cover was not estimated for VIS species, so abundance is approximated by percentage of sites with a dominant species.

Community (number of sites)	*Myosotis* (n=8)	*Veronica* (n = 18)	*Callitriche* (n = 9)	*Gratiola* (n = 10)	*Hydrocotyle* (n = 2)	*Myriophyllum* (n = 17)
% sites with a species dominant	25	56	11	10	0	97
% sites with Submerged dominant	0	0	0	0	0	82
% sites with Floating leaf dominant	0	0	0	0	0	0
% sites with Amphib dicot dominant	25	56	11	10	0	76
Species Richness Overall Mean per site Range per site	 8 2.3 1 to 4	 9 3.0 1 to 7	 8 2.6 1 to 4	 8 1.8 1 to 4	 3 2.0 1 to 3	 17 6.2 4 to 11
Species Nativeness Native species as % overall species	38	56	75	88	67	76
Species Occurrence (in 90-100% sites)	*Myosotis laxa var caespitosa*	*Veronica anagallis-aquatica*	*Callitriche stagnalis*	*Gratiola peruviana*	*Hydrocotyle rivularis*	*Hydrocotyle rivularis*
Species Occurrence (in 70-89% sites)						*Montia australasica* *Myriophyllum variifolium*
Species Occurrence (in 50-69% sites)		*Gratiola peruviana* *Myosotis laxa var caespitosa*	*Gratiola peruviana*			*Gratiola peruviana* *Lilaeopsis polyantha* *Myosotis laxa var caespitosa* *Ranunculus amphitrichus*

The *Myriophyllum* community (17 sites) was characterised by three species: *Hydrocotyle rivularis*, *Montia australasica* and *Myriophyllum variifolium*, present at 88%, 76% and 71% of sites respectively. The community is named for *Myriophyllum variifolium*, in recognition of its visual distinctiveness and its exceptional abundance: it was dominant more often (at 11 sites) than other species. Submerged macrophytes *Isolepis fluitans* and/or *Montia australasica* were present at five sites which did not have *Myriophyllum variifolium* present. This community was distinctive for its high abundance (16 sites had 1 to 3 species dominant), high species richness (17 overall, and averaged 6.2 species per site), and high number of submerged macrophytes (6 species). Nativeness was also fairly high: only one exotic species occurred frequently, *Myosotis laxa var caespitosa,* at 59% sites: the other two exotic species, *Ranunculus trichophyllous* and *Veronica anagallis-aquatica*, were each at only one site. Two species only found in this *Myriophyllum* community were the submerged species *Isolepis fluitans* (6 sites) and the floating-leaf species *Potamogeton cheesemanii* (5 sites).

Site Characteristics: Site characteristics of the six communities is summarised in Table 5 and described below, and includes a brief description of the 'Absent' group (sites with no VIS present). Definitions for relative terms (wide, narrow etc) are given above (Section 3.2).

The *Myosotis* community was on narrow, mostly shallow streams, across a wide altitudinal range (667 to 1255 m AHD), on gentle to steep slopes, mostly with little overhead shade but moderate bank shade, on substrates with high amounts of sand or granules. More than half sites were affected by flood, fire or sand in-filling, and two sites were affected by all three disturbances.

The *Veronica* community was on narrow to moderately wide streams, across a range of depths, on low-mid altitudes (595-1175 m AHD), on all slopes but mostly gentle ones, with little overhead or bank shade, on substrates that had high amounts of sand but sometimes cobbles or pebbles. Nearly all sites were affected by flooding, and at least half by fire or sand-infilling. Four of the sites where this community occurred were affected by all 3 disturbances.

The *Callitriche* community occurred on moderately wide and moderately deep streams, at lower altitudes (593-824 m AHD), on gentle slopes, with some overhead shade but almost no bank shade, on stream beds with high amounts of cobbles or pebbles. Flood was the only disturbance, and all sites showed evidence of having been affected.

The *Gratiola* community occurred on narrow to wide streams that were shallow to deep, at low-mid altitudes (600-1167 m AHD) on shallow to steep slopes, with variable overhead shade and low bank shade, and on stream beds high in sand or, if sand was very low, then on boulders, cobbles or pebbles. Nearly all sites were affected by flooding, and at least half by fire and sand-infilling. Five sites were affected by all 3 disturbances.

The *Hydrocotyle* community occurred on streams that were narrow, shallow, at high altitudes (1193-1196 m AHD), on gentle and steep slopes, with little overhead shade but high bank shade, on stream beds that were mainly sand and/or granules. Fire was the only disturbance, affecting both sites.

The *Myriophyllum* community occurred on narrow-moderately wide and moderately-deep sites at mid-high altitudes (699-1306 m AHD) and on gentle slopes, with very little overhead shade but variable bank shade, on sites high in mud & silt or occasionally on bedrock, cobbles or granules. Sites were affected by flooding and to a lesser extent by fire but with no evidence of any sand-infilling. Two sites showed no evidence of any disturbance.

The Absent group (not shown in Table 8), meaning sites with no VIS present (8 sites), were streams that were narrow-moderately wide, moderately deep, at low-mid altitudes (587-1170 m AHD), on moderately steep slopes, with little-some overhead shade and very little bank shade, and on substrates of large particles (bedrock, boulders, cobbles, pebbles). Nearly all were affected by floods (7 out of 8 sites) but only one was affected by sand-infilling.

Table 5: Plant communities - site characteristics

Summary statistics showing mean and standard error (SE), but only mean for the *Hydrocotyle* due to its small size.

Community Number of sites	*Myosotis* (n=8)	*Veronica* (n = 18)	*Callitriche* (n = 9)	*Gratiola* (n = 10)	*Hydrocotyle* (n = 2)	*Myriophyllum* (n = 17)
Wetted width (m) **Mean** **(SE)**	 1.6 (0.36)	 2.3 (0.3)	 3.6 (0.8)	 3.1 (0.7)	 0.9	 4.0 (1.3)
Thalweg depth (cm) **Mean** **(SE)**	 23.6 (5.3)	 27.6 (2.6)	 30.3 (5.0)	 30.5 (5.9)	 25.5	 36.4 (4.0)
Altitude (m AHD) **Mean** **(SE)**	 965 (81.8)	 884 (43.2)	 689 (25.4)	 913 (57.3)	 1195	 1104 (31.9)
Slope **(m per 1000 m)** **Mean** **(SE)**	 39 (8.8)	 30 (4.4)	 18 (3.5)	 28 (8.3)	 34	 14 (2.9)
Shading (Overhead) **Mean** **(SE)**	 12 (9.2)	 6 (1.9)	 12 (3.6)	 12 (4.9)	 2	 2 (0.9)
Shading (Bank) **Mean** **(SE)**	 26 (5.5)	 18 (3.5)	 4 (1.5)	 8 (2.1)	 40	 16 (4.4)
Dominant Substrate(s) **Mean (% cover)** **(SE)**	Sand 41 (14.7)	Sand 45 (8.1)	Cobbles 45 (9.0)	Sand 41 (12.4)	Sand 56	Muds & Silts 55 (9.8)
Disturbance **(% Sites affected by)** **Flood** **Fire** **Infilling**	 75 62 50	 94 56 50	 100 0 0	 90 70 50	 0 100 0	 79 35 0
Disturbances **Sites affected by none** **Sites affected by all 3**	 1 2	 0 4	 0 0	 1 5	 0 0	 2 0

Modelling Environmental Variables (VIS)

Species Occurrence: Nine of the 24 species were recorded frequently enough to be used in modelling (a minimum of 10 sites out of 72): *Callitriche stagnalis*, *Gratiola peruviana*, *Hydrocotyle rivularis*, *Lilaeopsis polyantha, Montia australasica*, *Myosotis laxa var caespitosa*, *Myriophyllum variifolium,* and *Veronica anagallis-aquatica*. Modelling outcomes, showing which site characteristics were significant for each species, are summarised below (Table 6).

Three species were quite distinct. *Gratiola peruviana* was not associated with any of the 17 site characteristics used in the analysis, *Veronica anagallis-aquatica* was the only species associated positively with sand, and with sand-infilling (indicators of disturbance), and the floating-leaf macrophyte *Callitriche stagnalis* was the only species negatively associated with altitude and with bank shading, and positively with pebble and cobble substrates. The other six species were not as strongly distinctive: all had a positive association with altitude, and five had a positive association with mud & silt. Each of these six had 1-2 associations unlike any other species. For *Myosotis laxa var caespitosa,* this was an association (positive) with bank shade: for *Hydrocotyle rivularis*, an association (negative) with overhead shading; for *Ranunculus amphitrichus,* an association (negative) with boulders; and for *Lilaeopsis polyantha*, an association (positive) with wetted width. The difference between the two submerged macrophytes, *Montia australasica* and *Myriophyllum variifolium*, in terms of environmental variables was minimal. As well as having three associations in common (positive for altitude, negative for slope, positive for mud & silt), they had contrasting relationship to thalweg depth (negative for *Montia australasica*, positive for *Myriophyllum variifolium*).

Habitat preferences can be inferred from these associations. For *Callitriche stagnalis*, the analysis indicates its preferred habitat was shallow-edged pebble & cobble streams at lower altitudes whereas the lack of any significant environmental associations for *Gratiola peruviana* suggests non-specific requirements, making it a generalist species. Disturbances such as flood and fire had no influence on the occurrence of any of these nine species. Sand-infilling affected just two species: negatively for *Hydrocotyle rivularis* and positively for *Veronica anagallis-aquatica*.

Table 6: Species occurrence - significant associations

Significant associations are shown for 9 species recorded in at least 10 sites in the survey. The number of sites where a species was recorded out of 72 is indicated by 'n'.

Species abbreviations are: *Callitriche stagnalis* (C.sta), *Gratiola peruviana* (G.per), *Hydrocotyle rivularis* (H.riv), *Lilaeopsis polyantha* (L.pol), *Montia australasica* (M.aus), *Myosotis laxa var caespitosa* (M.lax), *Myriophyllum variifolium* (M.var), *Ranunculus amphitrichus* (R.amp) and *Veronica anagallis-aquatica* (V.ana).

KEY: *** is p <=0.001, ** is p<=0.01, * is p<=0.05, M (for marginal) is p<=0.1, NS is no significant correlation, UnS is modelling unsuccessful, and a blank indicates modelling was not attempted. Cells shaded to indicate probability: darker shading for *** and **, lighter shading for *: Marginal and NS are unshaded.

SITE VARIABLES	Species C.sta (n=14)	Species G.per (n=38)	Species H.riv (n=23)	Species L.pol (n=10)	Species M.aus (n=14)	Species M.lax (n=30)	Species M.var (n=15)	Species R.amp (n=15)	Species V.ana (n=20)
Wetted width (m)	NS	NS	NS	**+ve	M+ve	NS	NS	NS	NS
Thalweg depth (cm)	NS	NS	NS	NS	**-ve	NS	**+ve	NS	NS
Altitude (m AHD)	***-ve	NS	***+ve	*+ve	**+ve	**+ve	**+ve	**+ve	NS
Slope	M-ve	NS	M-ve	*-ve	*-ve	NS	*-ve	M-ve	NS
Shade - overhead	M+ve	NS	*-ve	NS	M-ve	NS	M-ve	NS	NS
Shade - bank	*-ve	NS	NS	NS	NS	**+ve	NS	NS	NS
Bedrock%	NS	NS	NS	NS	NS	M-ve	NS	M-ve	NS
Boulders%	NS	NS	NS	NS	NS	NS	NS	*-ve	NS
Cobbles%	*+ve	NS	NS	NS	M-ve	*-ve	NS	NS	NS
Pebbles%	**+ve	NS	NS	NS	NS	NS	NS	M-ve	NS
Granules%	NS	NS	NS	NS	NS	M+ve	NS	NS	NS
Sand%	NS	NS	*-ve	M-ve	M-ve	NS	*-ve	NS	*+ve
Mud & Silt%	NS	NS	**+ve	**+ve	***+ve	M+ve	**+ve	***+ve	NS
Organic Matter%	NS	NS	NS	NS	M+ve	NS	NS	NS	NS
DISTURBANCE									
Sand filled	NS	NS	*-ve	NS	NS	NS	UnS	NS	*+ve
Evidence - Fire	NS	NS	NS	NS	NS	NS	NS	NS	NS
Evidence - Flood	NS	NS	M-ve	NS	NS	NS	NS	NS	NS

Community Occurrence: Five of the six communities were modelled. The *Hydocotyle* community occurred too infrequently to be included in the analysis. Modelling outcomes, showing which site characteristics were significant for each plant community, are summarised below (Table 7).

Similar to species, the five communities were quite distinct in which site characteristics were associated with occurrence, and in what way. Occurrence of the *Myosotis* community was negatively associated with stream width and positively with slope. The *Veronica* and *Gratiola* communities had very few associations, with *Veronica* community being positively associated only with sandy substrates, and the *Gratiola* community being negatively associated with boulders. Occurrence of the *Callitriche* community was positively associated with cobbles and pebbles, and negatively with altitude and bank shading. The *Myriophyllum* community was positively associated with altitude, and with fine organic substrates, and negatively with slope and sandy substrate. The *Veronica* community was distinct in that disturbance (sand-infilling) had a positive influence on its occurrence. Communities characterised by amphibious dicots (*Myosotis*, *Veronica*, *Gratiola* communities) had relatively few significant associations with site characteristics (1 to 2), which could be indicative of broad environmental tolerances, whereas for communities characterised by floating-leaf and submerged macrophytes (*Callitriche*, *Myriophyllum* communities), occurrence had more (4 to 5), suggesting these species were more specific in their habitat requirements.

Table 7: Community occurrence – significant associations

The number of sites where a community was recorded out of 72 is indicated by 'n'.

KEY: *** is p <=0.001, ** is p<=0.01, * is p<=0.05, M (for marginal) is p<=0.1, NS is no significant correlation, UnS is modelling unsuccessful, and a blank indicates modelling was not attempted. Cells shaded to indicate probability: darker shading for *** and **, lighter shading for *: Marginal and NS are unshaded.

	Plant Community	Plant Community	Plant Community	Plant Community	Plant Community
SITE CHARACTERISTICS	***Myosotis* (n=8)**	***Veronica* (n=18)**	***Callitriche* (n=9)**	***Gratiola* (n=10)**	***Myriophyllum* (n=17)**
Wetted width (m)	*-ve	NS	NS	NS	NS
Thalweg depth (cm)	NS	NS	NS	NS	M+ve
Altitude (m AHD)	NS	NS	**-ve	NS	**+ve
Slope	*+ve	NS	NS	NS	*-ve
Shade - overhead	NS	NS	NS	NS	M-ve
Shade - bank	M+ve	NS	*-ve	NS	NS
Bedrock%	NS	NS	NS	NS	NS
Boulders%	NS	NS	NS	*+ve	M-ve
Cobbles%	NS	NS	**+ve	NS	NS
Pebbles%	NS	NS	**+ve	NS	NS
Granules%	NS	NS	NS	NS	NS
Sand%	NS	*+ve	NS	NS	**-ve
Mud & Silt%	NS	NS	NS	NS	***+ve
Organic Matter%	NS	NS	NS	NS	**+ve
DISTURBANCE					
Sand filled	NS	*+ve	NS	NS	NS
Evidence - Fire	NS	NS	NS	NS	NS
Evidence - Flood	NS	NS	NS	NS	NS

Occurrence of the *Myosotis* community was negatively associated with stream wetted width and positively with slope, indicating it was more likely in small streams on steep slopes. The *Veronica* and *Gratiola* communities had very few significant associations, being positively associated only with sandy substrates, and negatively only with boulders. Occurrence of the *Callitriche* community was positively associated with cobbles and pebbles, and negatively with altitude and bank shading, indicating it was more likely in open streams with very coarse substrates at lower altitudes. The *Myriophyllum* community was positively associated with altitude Iie more likely at higher altitudes), and with fine organic substrates, and negatively with slope and sandy substrate, indicating it was more likely to occur in low-lying gently-sloping streams such as valley bottoms. With the exception of the *Veronica* community, disturbance was not a significant influence.

Species Richness: Modelling outcomes showing which site characteristics were significantly associated with species richness are summarised below (Table 8).

Table 8: Site-scale species richness – significant associations

The number of sites where a species was recorded out of 72 included in the analysis is indicated by 'n'.

KEY: *** is p <=0.001, ** is p<=0.01, * is p<=0.05, M (for marginal) is p<=0.1, NS is no significant correlation, UnS is modelling unsuccessful, and a blank indicates modelling was not attempted. Cells shaded to indicate probability: darker shading for *** and **, lighter shading for *: Marginal and NS are unshaded.

	Occurrence
SITE CHARACTERISTICS	**All (n=24)**
Wetted width (m)	NS
Thalweg depth (cm)	NS
Altitude (m AHD)	**+ve
Slope	***-ve
Shade - overhead	NS
Shade - bank	NS
Bedrock%	M-ve
Boulders%	*-ve
Cobbles%	*-ve
Pebbles%	NS
Granules%	M+ve
Sand%	M-ve
Mud & Silt%	***+ve
Organic Matter%	*+ve
DISTURBANCE	
Sand filled	**-ve
Evidence - Fire	NS
Evidence - Flood	NS

Species richness was significantly and positively associated with altitude, mud & silt and organic matter, and negatively associated with slopes, boulders and cobbles: stream size, disturbance and shading did not influence species richness. Species richness was higher at higher altitudes, in gently sloping streams flowing over mud & silt substrates, with plant organic matter, and lower in streams with boulders and cobble substrates.

3.4 Phenology

A total of 184 observations were made on 21 species at 58 sites, starting on 13 January 2022, so covered mid-summer to early autumn. The most frequently observed species were three amphibious dicots, *Gratiola peruviana* (36 observations), *Hydrocotyle rivularis* (20 observations) and *Myosotis laxa var caespitosa* (19 observations). Thirteen species had 4 or more observations, and these are used to explore phenological patterns. Six species had just one observation.

Observations of the thirteen species with 4 or more observations (Table 9) are summarised by phenological state, whether vegetative, reproductive or regenerating. Four species (two amphibious and two floating-leaf species) were vegetative only: *Callitriche stagnalis*, *Hydrocotyle rivularis*, *Lilaeopsis polyantha* and *Potamogeton cheesemanii*. Nine species (three submerged macrophytes and six amphibious dicots) were reproductive, with buds or flowers or (less commonly) fruits. Only two species, *Myosotis laxa var caespitosa* and *Veronica anagallis-aquatica,* were regenerating: these had young and juvenile stages at 26% and 78% of sites where they were observed. Both these are exotic amphibious dicots, and both were also reproductive.

Water level influenced flowering in *Gratiola peruviana*: plants on moist soils and extending above water level were flowering vigorously whereas those rooted in the wetted perimeter were vegetative. Amphibious species such as *Persicaria decipiens* and *Persicaria hydropiper* typically regenerate on wet muds but are tolerant of shallow inundation once established, and their occurrence in the wetted perimeter is likely due to a recent rise in water level at the site.

Table 9: Phenological observations

Species with fewer than 4 observations are not included. Table shows the number of species in each phenological category, followed by the number of those that are exotic, and the number per life-form.

Status	Vegetative	Reproductive	Regenerating
	Species with no bud, flower or fruit	**Species with bud, flower and/or fruit**	**Species with seedlings, juveniles, immatures**
	Callitriche stagnalis *Hydrocotyle rivularis* *Lilaeopsis polyantha* *Potamogeton cheesemanii*	*Gratiola peruviana* *Isolepis fluitans* *Montia australasica* *Myosotis laxa var caespitosa* *Myriophyllum variifolium* *Persicaria decipiens* *Persicaria hydropiper* *Ranunculus amphitrichus* *Veronica anagallis-aquatica*	*Myosotis laxa var caespitosa* *Veronica anagallis-aquatica*
Species	4 spp	9 spp	2 spp
Number Introduced	1	3	2

3.5 Broad Ecological Types (BET)

Occurrence, Richness and Abundance

Occurrence: Nine types of BET were recorded, as shown below (Table 10). Some charophytes were in poor condition, being partly degraded and covered by dense algal epiphytic algal growth. During the survey, it was realised that amphibious dicots comprised two types: one being semi-erect to erect, or scrambling with inflorescences held well above the water such as *Gratiola peruviana*, *Veronica anagallis-aquatica* and *Myosotis laxa var caespitosa*, and the other being prostrate, stoloniferous or carpet-forming such as *Crassula helmsii*, *Isotoma fluviatilis, Ranunculus amphitrichus, Ludwigia palustris* and *Hydrocotyle rivularis*, with inflorescences held either floating or just above the water level. For this survey and analysis, both forms were treated as amphibious dicots.

The highest occurring BET were Amphibious Dicot, Emergent and Filamentous Algae, which were present at 83%, 81% and 76% of sites respectively (Table 10). Submerged, Floating-leaf, Charophytes, and Gelatinous Algae BET were much less frequent, occurring at 25 to 35% of sites. Liverwort BET had lowest occurrence, present at only 15% of sites.

Mean cover per site was low (<10%) for all BET when averaged across all 72 sites, however several BET were occasionally quite abundant: Submerged, Emergent, Amphibious Dicots and Filamentous Algae all exceeded 50% cover at one or more sites (Table 10).

Table 10: BET - occurrence and cover

Table gives occurrence (number of sites, % of sites surveyed) and percentage cover (mean per site, and maximum at a site) for each BET.

KEY: Subm = Submerged, Float-Lf = Floating-leaf, Emerg = Emergent, Amphib = Amphibious Dicots, Charo = Charophytes, Fil Alg = Filamentous Algae, Gel-Alg = Gelatinous Algae, Moss = Mosses, Liver = Liverworts.

BET	Subm	Float-Lf	Emerg	Amphib	Charo	Fil Alg	Gel Alg	Moss	Liver
OCCURRENCE									
Number of sites	25	18	58	60	20	55	18	36	11
% survey sites	35	25	81	83	28	76	25	50	15
ABUNDANCE as % Cover									
Mean	8.5	1.4	7.2	6.1	0.8	5.8	0.5	1.0	0.10
(SE)	(2.2)	(0.7)	(1.5)	(0.3)	(0.3)	(1.3)	(0.2)	(0.4)	(0.03)
Max	72.8	32.4	66	67.7	20.6	58.4	7.6	27	1

Richness: Richness ranged from 1 to 8 BET per site. Most sites had 3 to 6 BET (Figure 9). Sites with low richness (1 to 2 BET) mostly had Amphibious Dicots, Filamentous Algae and/or Moss BET. Submerged mostly occurred where BET richness was high, ie at sites with 6 to 8 BET, and rarely when BET richness was low.

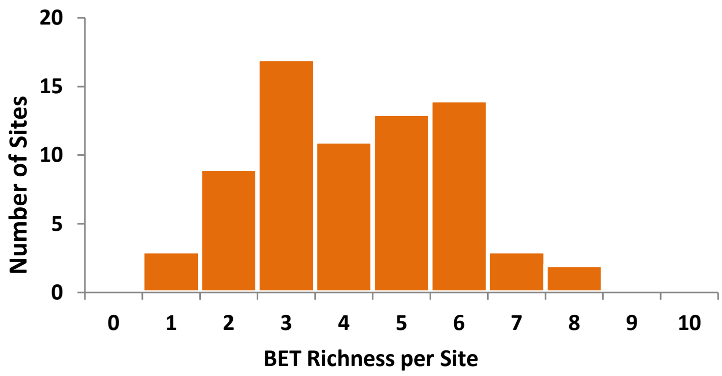


Figure 9: BET richness - number of BET per site

Abundance: Total cover (sum of all BET) per site was highly variable, ranging from very low (<1%) at 3 sites to very high (100%) at 6 sites. The cover frequency plot has a distinctive distribution pattern with many in the very low classes, several in high classes and few in the mid-range (Figure 10).

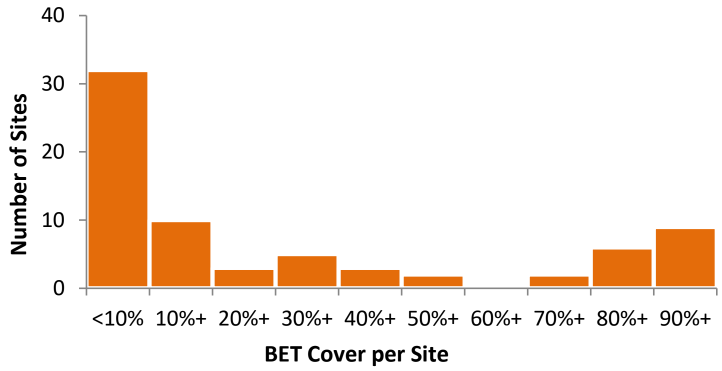


Figure 10: BET total cover classes – number of BET per class

Total cover tended to increase as BET richness increased (Figure 11), but the relationship is noisy suggesting several factors influence total cover and richness. The small group of sites with very high total cover (>90%) and moderately low richness (richness of 3 and 4) comprised only vascular plants (Amphibious Dicots and Emergent BET with either Submerged or Floating-leaf BET).

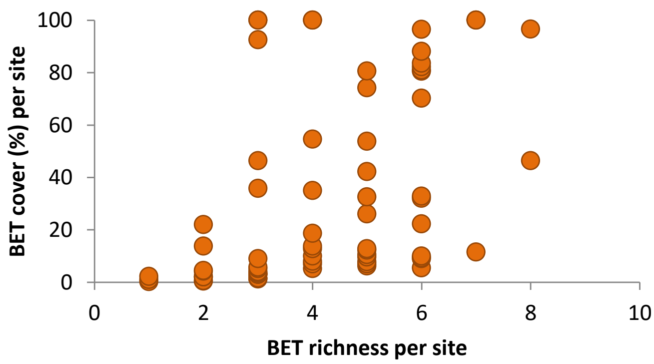


Figure 11: Scatterplot of BET richness and total cover

Assemblages

The numerical classification used 71 sites (one site was removed for analysis: Section 2.3) and 9 BET with BET abundance being log transformed % total cover. The average linking agglomerative clustering algorithm "upgma" was applied to the between sites Bray-Curtis distances, resulting in eight groups of associated sites (Figure 12), delineated by red boxes, and ranging in size from a single site to 30 sites. The two largest groups, with 23 and 30 sites respectively, accounted for 75% of sites in the survey. The dendrogram is labelled by site codes that were unique to the analysis: their identity is given in Appendix 2.

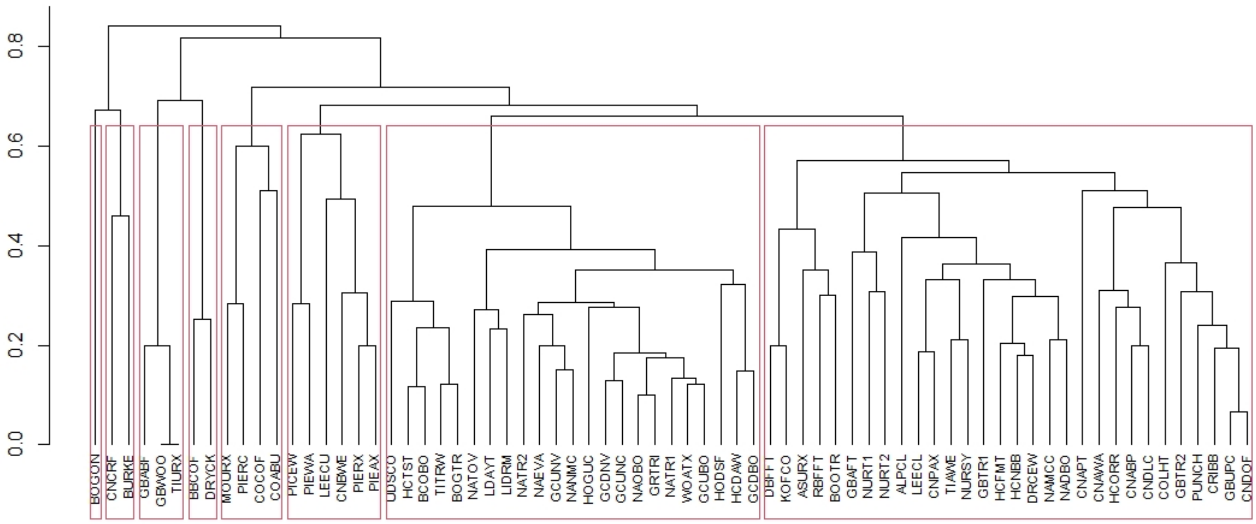


Figure 12: Dendrogram of 9 BET from 71 sites

Red boxes indicate the eight groups of associated sites, referred to as group 1 to 8 from left to right. Sites in each group of associated sites are labelled using code names reserved for analyses: these codes are in Appendix 2.

NMDS ordination had a stress level of 0.22, which was a little high. Mapping the eight groups into 2-dimensional ordination space showed the smallest groups of associated sites were distributed around the larger groups, and well-separated from them. The larger groups overlapped, in particular with group 8.

Henceforward these groups of associated sites are referred to as assemblages, to make them distinct from plant communities described above, which are based on associations of species.

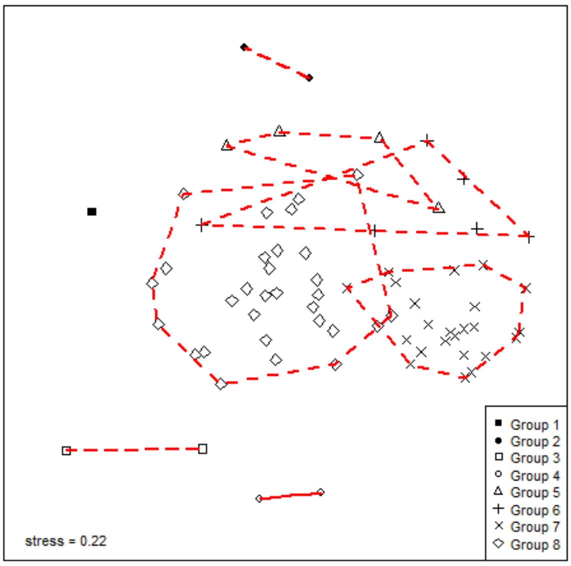


Figure 13: BET assemblages imposed on a 2-dimensional ordination of 71 sites

Results of NMDS ordination of 71 sites and 9 BET, showing the eight groups identified by numerical classification super-imposed. Groups are numbered 1 to 8, corresponding to the groups shown from left to right in the dendrogram.

Description of BET Assemblages: Assemblages are described in the same order as shown across the dendrogram (Figure 12), from left to right. They are named for their abundance (ranging from very low to high cover) and their characteristic BET, meaning the BET with the highest cover and highest occurrence. In one assemblage, the BET with highest cover is not the same as the BET with the highest occurrence, and this assemblage is named Mixed. The vegetation characteristics of BET assemblages, meaning total cover, richness and composition are summarised below (Table 11), using mean and standard error of the mean (SE). The SE is calculated only for assemblages with at least 4 sites. Range for richness is the observed minimum and maximum. Composition is approximated by showing which BET occurred most frequently in each assemblage.

The four assemblages on the left of the dendrogram (Figure 12), ie those with 1, 2, 3 and 2 sites respectively, were generally sparse and depauperate. These assemblages had very low (<1%) or low cover (1 to 5%), and low richness (1 to 2.7 BET per site). The BET present were non-vascular plants (Filamentous Algae, Moss, Liverwort BET), with Amphibious Dicot and Emergent BET scattered on stream margin; Floating-leaf BET was present in trace amounts, and Submerged and Charophyte BET were absent. These assemblages are named (from left, Figure 12) as follows: Very Low Filamentous Algae (henceforward abbreviated to VLow Fil), Very Low Emergent Macrophytes (VLow EmM), Low Mosses (Low Moss), and Low Amphibious Dicot (Low Amp).

The fifth assemblage, Low Emergent (Low EmM) occurred at 4 sites, had slightly higher total cover (3.7% per site) and higher richness (3.3 BET per site) than the first four assemblages, as well as a bigger range of BET overall. Emergent BET was present at all sites, Amphibious Dicot BET at nearly all sites, sometimes with Moss BET. Submerged and Floating-leaf BET were present only occasionally, and Charophyte BET was absent.

The sixth assemblage, Moderate Floating-Leaf BET (Mod FLf), occurred at 6 sites, had moderate total cover (36.0% per site) and moderately high richness (4.5 BET per site). This assemblage was distinctive for the occurrence and abundance of Floating-leaf BET, which was present at all sites, as was Emergent BET. Floating-leaf BET was the most abundant BET in this assemblage, with an average cover of 15.9% per site (compared with <1% in other assemblages). Amphibious Dicot, Charophyte and Filamentous Algae BET occurred at most sites: Moss was rare, and Submerged BET absent.

Table 11: BET assemblages - vegetation characteristics

KEY: VLow Fil = Very Low Filamentous Algae, VLow EmM = Very Low Emergent Macrophytes, Low Moss = Low Mosses, Low Amp = Low Amphibious Dicots, Low EmM =Low Emergent Macrophte, Mod FLf = Moderate Floating leaf, High Mixed = High Mixed, and Mod Fil = Moderate Filamentous Algae.

Assemblage	VLow Fil	VLow EmM	Low Moss	Low Amp	Low EmM	Mod FLf	High Mixed	Mod Fil
Number of sites	1	2	3	2	4	6	23	30
Total cover % Mean (SE)	0.6	0.8	2.7	1.6	3.7 1.4	36.0 14.7	66.8 6.9	16.3 3.7
Highest BET cover Mean per site (SE)	Fil Alg 0.4	Emerg 0.4	Moss 1.0	Amphib 1.6	Emerg 2.3 0.9	Float Lf 15.9 5.8	Subm 25.6 5.4	Fil Alg 10.5 2.7
BET Richness Mean Range	2	2.5 2 to 3	2.7 2 to 3	1	3.25 2 to 5	4.5 3 to 5	5.1 2 to 8	4.2 2 to 7
BET Occurrence (90-100% sites)	Amphib Fil Alg	Fil Alg Emerg	Moss Liver	Amphib	Emerg	Float Lf Emerg	Amphib Emerg	Fil Alg
BET Occurrence (70-89% sites)					Amphib	Amphib	Subm Fil Alg	Amphib Emerg
BET Occurrence (50-69% sites)			Amphib		Moss	Fil Alg Charo		Moss

The seventh assemblage, High Mixed (High Mixed) occurred at 23 sites, and was distinctive for having the highest total cover (66.8%), highest richness (5.1 BET per site), and highest cover of Submerged BET (25.6% per site) of all eight assemblages. Amphibious Dicot and Emergent BET were present at all sites, with Submerged BET at most (78%) of sites. Sites in this assemblage were fringed by Emergent BET which sheltered erect and sprawling amphibious dicots while the flowing water in-between was occupied by stoloniferous amphibious dicots and Submerged BET. The wet margins were where traces of Floating-leaf, Moss and Charophyte BET occurred.

The eighth assemblage, Moderate Filamentous Algae (Mod Fil) occurred at 30 sites, had moderate total cover (16.3%) and moderate BET richness (2.7 BET per site). This assemblage was distinctive for its relatively high cover of Filamentous Algae BET (10.5%) which was higher than other assemblages. Amphibious Dicot and Emergent BET occurred frequently, and Moss only sometimes but, like all other BET in this assemblage, had very low cover.

Site Characteristics: Mean values for eight site characteristics for each assemblage are summarised below (Table 12). As above, SE of mean is calculated only when 4 or more sites are present. Interpretation of relative terms (wide, narrow etc) is given above (Section 3.2).

The Very Low Filamentous Algae assemblage (1 site) was in a moderately wide, moderately deep stream, at mid altitude, on a gentle slope with some overhead shade, and on a sandy substrate. Sand-infilling meant the type of geomorphic reach could not be determined. This site was one of eleven exposed to a triple disturbance (Section 3.2 Disturbances).

Table 12: BET assemblages - site characteristics

Abbreviation for BET assemblages are in Table 11.

Assemblage	VLow Fil	VLow EmM	Low Moss	Low Amp	Low EmM	Mod FLf	High Mixed	Mod Fil
Number of sites	1	2	3	2	4	6	23	30
Wetted width (m) Mean (SE)	2.8	2.6	2.9	1.2	5.0 1.7	2.3 0.2	3.1 1.0	2.8 0.3
Thalweg depth (cm) Mean (SE)	28.8	23.1	30.5	20.6	35.1 12.7	22.4 4.1	31.9 3.2	30.5 2.6
Altitude (m AHD) Mean (SE)	1025	726	896	893	798 78.1	688 36.8	1083 31.5	889 38.2
Slope (m per 1000 m) Mean (SE)	10	25	42	26	15 7.4	25 3.4	19 3.2	32 4.7
Shading (OH) Mean (SE)	19	15	10	9	19 11.3	22 11.8	2 0.7	7 1.7
Shading (Bank) Mean (SE)	5	5	7	19	6 4.0	7 3.1	20 3.7	14 2.8
Dom. Substrate(s) Mean % cover (SE)	Sand 78	Pebbles 30	Sand 59	Sand 91	Cobbles 52	Pebbles 35	Muds Silts 42	Cobbles 26 and Sand 26
Disturbance (% Sites affected by) Flood Fire infilling	100 100 100	100 0 0	100 67 100	50 50 100	50 50 25	83 0 0	78 43 13	90 53 30

The Very Low Emergent Macrophyte assemblage (2 sites) occurred on streams that were moderately wide, moderately deep, at low altitudes (674-777 m AHD), on moderately steep slopes with some overhead shading, at sites dominated by pebbles and cobbles. These sites were disturbed only by floods.

The Low Moss assemblage (3 sites), like the preceding assemblage, was on moderately wide and moderately deep streams at low altitudes (819-995 m AHD) with little shading, but differed in sites being little shaded, on steep slopes with sandy substrate. Disturbance featured as two of the three sites were exposed to all three disturbances: flood, fire and sand-infilling.

The Low Amphibious Dicot assemblage (2 sites) was on narrow streams, at low to mid altitudes (705-1081 m AHD), on moderate slopes, with some bank shading, on very sandy substrates. Disturbance featured strongly for this assemblage, as both sites were affected by sand-infilling, and one site was affected by all three disturbances.

The Low Emergent Macrophyte assemblage (4 sites) was on relatively wide and deep streams, at low to mid altitudes (686-1084 m AHD) on gentle slopes with some overhead shade, on cobble substrates with some sand. Sites in this assemblage were variously disturbed: one site was affected by all three disturbances, and one site unaffected by any.

The Moderate Floating-leaf assemblage (6 sites) was on streams that were moderately wide and moderately deep, at low altitudes (595-824 m AHD), on moderately steep slopes with some overhead shade, on cobble and pebble substrates. Flood was the only disturbance.

The High Mixed assemblage (23 sites) was on moderately wide and moderately deep streams, mostly at high altitudes although a few were low (674-1306 m AHD), on gentle slopes, with very little overhead shade but some bank shade, on mud & silt substrates and also, but rarely, on sand. Sites had variable disturbance histories: two sites were unaffected by any disturbance, and two were sand-infilled.

The Moderate Filamentous Algae assemblage (30 sites) was on moderately wide and moderately deep streams, at a wide range of altitudes (587-1255 m AHD), on moderately steep slopes, on cobbles with sand. Six sites were affected by all three disturbances.

Modelling Environmental Variables (BET)

BET Abundance: The site characteristics that were significantly associated with abundance of four BET (Submerged, Floating-leaf, Amphibious Dicot, and Filamentous Algae BET) are shown below (Table 13).

The four BET differed in the number of site characteristics significantly associated with abundance, which ranged from none for Filamentous Algae to 8 for Submerged BET. They also differed in which site characteristics were significant, and in what way. For Amphibious Dicot and Submerged BET, abundance was positively associated with altitude and mud & silt, but these two BET were differentiated by Submerged BET having a further six characteristics significantly associated with abundance. The Floating-leaf BET was distinctive in that abundance was negatively associated with altitude but positively with overhead shade and pebbles. Disturbance was significant, in diverse ways: sand-infilling was negative for Submerged BET, and evidence of fire was negative for Floating-leaf BET.

BET Assemblages: The site characteristics that were significantly associated with the occurrence of Moderate Floating leaf, High Mixed, and Moderate Filamentous Algae BET assemblages are given below (Table 14). The Moderate Floating-Leaf assemblage occurred at only 6 sites, which is marginal for analysis, findings for this BET are tentative.

The BET assemblages differed in which site characteristics were significantly associated with their occurrence. The two characteristics that were significant for Moderate Filamentous Algae (slope, cobbles) were different from the two significant for Moderate Floating Leaf (altitude, pebbles). For the High Mixed assemblage, five site characteristics were significant: altitude, bank shading, mud & silt and organic matter were all positive and cobbles was negative. The habitats indicated by these associations are: low altitude pebble streams for Moderate Floating Leaf assemblages; higher altitude streams, flowing over mud & silt, and with organic matter present, and shaded by bank or fringing vegetation, for High Mixed assemblage; and steeper cobble streams for Moderate Filamentous Algae.

Table 14: BET assemblage occurrence – significant associations

Abbreviation for BET assemblages are as given for Table 11.

KEY: *** is p <=0.001, ** is p<=0.05, * is p<=0.01, M (for marginal) is p<=0.1, NS is no significant correlation, UnS is modelling unsuccessful, blank indicates modelling was not attempted. Cells shaded to indicate probability: darker shading for *** and **, lighter shading for *, Marginal and NS are unshaded.

	Assemblage	Assemblage	Assemblage
SITE VARIABLES	Mod FLf (n=6)	High Mixed (n=24)	Mod Fil (n=30)
Wetted width (m)	NS	NS	NS
Thalweg depth (cm)	NS	NS	NS
Altitude (m AHD)	*-ve	***+ve	NS
Slope	NS	M-ve	*+ve
Shade - overhead	NS	NS	NS
Shade - bank	NS	*+ve	NS
Bedrock%	NS	NS	NS
Boulders%	NS	NS	NS
Cobbles%	NS	*-ve	*+ve
Pebbles%	**+ve	NS	NS
Granules%	NS	NS	NS
Sand%	NS	NS	NS
Mud & Silt%	NS	*+ve	
Organic Matter%	NS	*+ve	NS
DISTURBANCE			
Sand filled	NS	NS	NS
Evidence - Fire	UnS	NS	NS
Evidence - Flood	UnS	NS	NS

Occurrence and Abundance: Occurrence was compared with abundance for Submerged and Floating-Leaf BET. Their site characteristics and their significance are listed below (Table 15).

The outcome for the two BET was quite different. For Submerged BET, there was very little difference in which site characteristics were significantly associated with occurrence and which with abundance. Six site characteristics were significant for both occurrence and abundance, and in the same way (altitude, slope, overhead shade, cobbles, sand, mud & silt). Two other characteristics (thalweg depth, sand-infilling) had differing associations with occurrence and abundance, but, on consideration, these are discounted for the following reasons. Thalweg depth was inadvertently omitted from regression modelling for occurrence, so there is no result for its influence on occurrence of Submerged BET. Sand-infilling had the same (negative) effect on occurrence and abundance but was only marginally significant for occurrence. Thus for Submerged BET, there was no real difference in the characteristics that influenced occurrence and abundance.

The situation for Floating-leaf BET was different. Three characteristics had the same association on occurrence as abundance (altitude, pebbles, disturbance by fire) and three did not (slope, overhead shade, bank shade). Thus, for Floating-leaf BET, unlike Submerged BET, occurrence and abundance had overlapping but differing site characteristics.

Table 15: BET occurrence and abundance – significant associations

Abbreviations for BET are as given in Table 10.

KEY: *** is p <=0.001, ** is p<=0.05, * is p<=0.01, M (for marginal) is p<=0.1, NS is no significant correlation, UnS is modelling unsuccessful, blank indicates modelling was not attempted. Cells shaded to indicate probability: darker shading for *** and **, lighter shading for *, Marginal and NS are unshaded.

SITE CHARACTERISTICS	Subm Occur (n=25)	Subm Abund (n=72)	Float-Lf Occur (n=18)	Float-Lf Abund (n=72)
Wetted width (m)	*+ve	NS	NS	NS
Thalweg depth (cm)		*+ve		NS
Altitude (m AHD)	**+ve	**+ve	**-ve	**-ve
Slope	**-ve	*-ve	*-ve	NS
Shade - overhead	*-ve	*-ve	NS	*+ve
Shade - bank	NS	NS	*-ve	M-ve
Bedrock%	NS	NS	NS	NS
Boulders%	NS	NS	M-ve	M-ve
Cobbles%	*-ve	*-ve	NS	NS
Pebbles%	NS	NS	**+ve	**+ve
Granules%	NS	NS	M+ve	NS
Sand%	*-ve	**-ve	M-ve	M-ve
Mud & Silt%	**+ve	***+ve	NS	NS
Organic Matter%	NS	NS	NS	
RECENT DISTURBANCE				
Sand filled	M-ve	*-ve	NS	NS
Evidence - Fire	NS	NS	**-ve	**-ve
Evidence - Flood	NS	NS	NS	NS

4 Discussion

4.1 In-stream Plant Communities

Survey Perspective

This is the first survey of in-stream vegetation in the ACT: it is also one of the very few in Australia, and the only one on upland streams. Prior to this survey, information about the distribution of in-stream vegetation in the ACT came from herbarium records, photographs in citizen science platforms, and descriptions of fish habitat. These are valuable, but have limitations and biases (Daru et al 2018, Mesaglio et al 2023, Schmidt-Lebuhn et al 2013). With herbarium specimens, for example, collections rarely offer a contemporary picture, and the ACT is no exception: since 2000, there have been no collections of three species in this survey, *Myriophyllum variifolium*, *Potamogeton ochreatus*, *Isotoma fluviatilis* (Australasian Virtual Herbarium, accessed June 2023). With photographic records, there is a bias towards species with attractive flowers or that are readily accessible, for example found in shallow water, or on stream margins, rather than in deep water. This bias is nicely exemplified in Canberra Nature Map which has 27 records for the white-flowered *Montia australasica* but only 2 for the aquatic trailing sedge *Isolepis fluitans* (accessed June 2023). Fish habitat descriptions for the ACT are not contemporary but date from 30 years ago when multiple sites were visited in the Cotter, Tidbinbilla, Naas-Gudgenby and Paddy's Rivers between 1988 and 1994 (summarised in Roberts 2021, Appendix 3).

Plant Communities

The six in-stream plant communities recognised by numerical classification were structurally diverse, being dominated or characterised by plants of different forms: submerged macrophytes (the *Myriophyllum community*), floating-leaf macrophytes (*Callitriche* community), mat-forming amphibious plants (*Hydrocotyle*) and erect to decumbent amphibious plants (*Myosotis*, *Veronica* and *Gratiola* communities). The seven species of submerged macrophytes (Table 3) tended to co-occur, so formed just one plant community. Western ACT thus has a lower diversity of submerged macrophytes than the lower altitude sub-tropical Mary River in south-east Queensland, where Mackay et al (2003) recorded 13 submerged taxa (this included two genera of charophytes) and four communities.

Some geographic patterns are evident in the distribution of these six communities (Figure 14) suggesting that macro-scale factors are important as well as site-scale factors described above (Table 5). The *Callitriche* community was concentrated in the north-west, the *Myriophyllum* community in the extreme south, and the four amphibious communities (*Myosotis*, *Veronica*, *Gratiola* and *Hydrocotyle*) were in-between. The *Myosotis* community appears to be clustered in the central area but was actually distributed more widely: in the plot, some sites are partly obscured by *Callitriche* and *Veronica* communities.

These patterns roughly correspond to sub-catchments. The *Callitriche* community was concentrated in Condor and Pierces sub-catchments (5 and 3 sites out of 9 *Callitriche* community sites), the *Myriophyllum* community was concentrated in Naas and Gudgenby sub-catchments (13 and 3 sites out of 17), and the two occurrences of *Hydrocotyle* community were both in the Gibraltar sub-catchment. In contrast, *Veronica*, *Gratiola* and *Myosotis* communities occurred across several sub-catchments, and were generally absent from survey sites in the Naas sub-catchment. There is some resemblance between the pattern for summer-autumn 2022 and that recorded in fish habitat descriptions of 1986-1992, which show that 30 years ago sites in the Naas and

Gudgenby sub-catchments were richer in macrophytes than sites in the Tidbinbilla and Cotter sub-catchment (Appendix 3 in Roberts 2021).

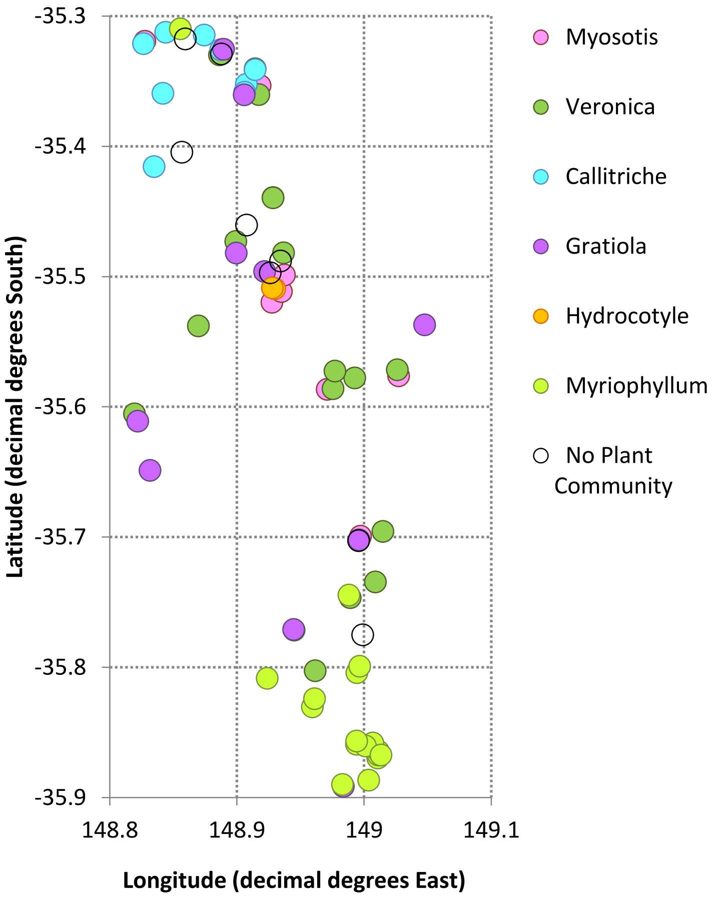


Figure 14: Distribution of plant communities in the study area

Distribution of plant communities at 72 study sites in western ACT. Some sites are obscured, because the software overlays similar co-ordinates without attempting to jitter them apart. The outlier in the *Myriophyllum* community is just visible in extreme north of the study area. Sites labelled No Plant Community are where no vascular plants were recorded.

Geomorphic reach could not be established by modelling (Section 2.3) but was relevant to community distribution at the site-scale, as shown below (Table 16). The cross-tabulation is set out following the conceptualisation of Buffington and Montgomery (2021), with geomorphic reaches arranged along an energy gradient from colluvium (where particles and sediment are transport limited) to bedrock (where particles and sediment are supply limited).

River plant distribution is known to be strongly influenced by fluvial geomorphology and hydraulics (Chessman et al 2006, Gurnell et al 2010), and hence it was expected that plant communities would be associated with particular reaches. This expectation was broadly sustained, but the association was not as tight as expected. None of the communities was exclusively associated with any one reach type, and instead the association is somewhat diffuse. *Veronica* and *Callitriche* communities mostly occur in pool-riffle and step-pool reaches; the *Myriophyllum* community mostly occurs in pool-riffle and plane-bed reaches; amphibious dicot communities, *Veronica* and *Gratiola,* are the only ones recorded in cascades. Cascades are high energy sites defined as "chaotic arrangement of boulder-sized material and continuous macro-scale turbulence" (Buffington and Montgomery 2021), conditions which are not generally suitable for plant establishment and growth. It was evident that plants in cascades were restricted to low-energy micro-sites, such as along channel margins and in backwaters. The occurrence of the *Myriophyllum* community in a bedrock reach was anomalous but was due to sand filling in a small tributary. A series of stepped rock pools had accumulated sand and silt deposits and so supported *Myriophyllum variifolium* in pools, and *Hydrocotyle rivularis* at the lips of pools (Table 16).

Environmental events in the few years prior to the survey are likely to have modified the distributions of some, if not all, species and hence also modify community composition. Probably because of the small sample size, the reach-community association was not strong in this survey, but did show that geomorphic reach would be useful for structuring ecological surveys, whether of river plants or other river biota. A geomorphic reach is effectively a synthesis of multiple physical characteristics, so using reach by-passes the need for detailed site descriptions. The development of a hierarchical geomorphic classification for rivers in the ACT would greatly assist design and analysis of surveys and monitoring.

Table 16: Occurrence of plant communities in geomorphic reaches

Table shows the number of sites per plant community per geomorphic reach. Geomorphic reach types are arranged on a gradient of sediment dynamics, from transport limited (Colluvium) to supply limited (bedrock). For completeness, 'Sand obscured' sites are included. The last row refers to the survey, so includes 8 sites with no plant community present.

	Colluv-ium	Braided	Pool-Riffle	Plane-Bed	Step-Pool	Cascade	Bed-rock	Sand Obscured	Total
Myosotis			1	2	4			1	8
Veronica			6	1	5	3		3	18
Callitriche			5		4				9
Gratiola			1	2	1	3		3	10
Hydrocotyle	1			1					2
Myriophyllum		2	6	8			1		17
Sum of communities	1	2	19	14	14	6	1	7	64
Sites per reach type	1	2	20	14	19	7	2	7	72

The *Myriophyllum* Community

The *Myriophyllum* community was distinctive amongst the six plant communities for its high cover and high species richness. Descriptions of submerged macrophyte communities elsewhere in Australia persistently comment on cover being low and variable (Mackay et al 2003, Hughes 1988, Paice et al 2017). It was also distinctive in that its character species *Myriophyllum variifolium* has been shown to be associated with good geomorphic condition (Chessman et al 2006).

This community was found in a distinctive type of landscape, in streams flowing through relatively wide, higher altitude valleys, specifically in Naas and Grassy Creeks (Section 3.3), and through particular vegetation types. According to ACT vegetation mapping, 8 of its 17 sites were in community r2 "*Fen Sedge – Small River Buttercup – Common Reed aquatic herbfield of waterways*" and 5 were in community u118 "*Black Sallee grass-herb woodland in drainage depression and moist valley flats*". The *Myriophyllum* community was likely more widely distributed within the study area (and may even have occurred in different landscapes) prior to recent extreme environmental conditions. Persons with long experienced of fish sampling in the western ACT advised that dense beds of milfoil used to occur in the Upper and Lower Cotter River (Mark Lintermans, University of Canberra, pers. comm., Lisa Evans, ACT Government, pers. comm.). The occurrence of sparse trailing stems, stripped of leaves, in streams near the Gudgenby homestead (pers. obs. March 2023) suggests the community also occurred in this valley. Within the ACT, it appears to be restricted to higher altitude rivers. Herbarium records show that the milfoil occurring in rivers at lower altitudes, such as Paddy's, Murrumbidgee and Gudgenby Rivers, is a different species, *Myriophyllum verrucosum*.

It is not known why the *Myriophyllum* community persisted at sites in the Naas and Grassy Creek valleys, despite these creeks undoubtedly having experienced high flows (high enough to deposit sand on Boboyan road, pers. obs.). One possibility is that the combination of incised channel and grassland fringe allowed flood waters to spill laterally, rather than being concentrated in-channel, which dissipates the stream energy. A second possibility is that Cotter River flows have greater energy and scour potential; and a third possibility is that the macrophyte beds in the Cotter River were abraded by the large quantities of sand that moved through during the floods. Certainly in summer-autumn 2022, there were no beds of *Myriophyllum* or any other macrophyte at the two sites surveyed in the Upper Cotter. As the Cotter River recovers from scouring and sand-infilling, the *Myriophyllum* community may re-establish, and descriptions in this report may prove useful in assessing recovery. Two monitoring projects are already underway in the Cotter (recovery of fish habitat – Mark Lintermans; condition of fish habitat – Matt Beitzel): these track macrophyte abundance as cover but not species composition.

The *Myriophyllum* community described here is likely to be part of a plant community associated with upland streams, and found in treeless areas of the ACT and the Australian Alps (Helman and Gilmour 1985, McDougall and Walsh 2007) and the Upper Murrumbidgee catchment (Armstrong et al 2013). This has been named "*Carex gaudichaudiana – Ranunculus amphitrichus – Phragmites australis aquatic herbfield of waterways in the Australian Alps and the South Eastern Highlands bioregions*" (Armstrong et al 2013). Its characteristic species include four macrophytes that were also part of the *Myriophyllum* community: *Lilaeopsis polyantha*, *Montia australasica*, *Myriophyllum variifolium* and *Ranunculus amphitrichus*. Its habitat corresponds well with where *Myriophyllum* community occurred (Table 5): open and treeless so little shaded, in permanent and intermittent streams (Grassy Creek is specifically mentioned), on gentle slopes (range 0 to 1) at moderate elevations (range 978 to 1065 m asl), and with relatively few exotic species which are mostly amphibious species such as *Myosotis laxa var caespitosa* (Armstrong et al 2013). This re-enforces that the *Myriophyllum* community is, and has been, more widespread than recorded in this survey.

The *Myriophyllum* community in the ACT differs in species composition and richness from the *Myriophyllum* group in south-eastern Queensland, as described by Mackay et al (2003). Both are characterised by *Myriophyllum variifolium*, but the Mary River group has only two other submerged macrophytes (*Myriophyllum verrucosum*, *Potamogeton crispus*) compared with five for the ACT *Myriophyllum* community. No other descriptions of *Myriophyllum variifolium* stream communities are known.

Based on general ecological understanding of submerged macrophytes, the biggest threats to this community are likely to be environmental disturbances (both natural and anthropogenic) and feral animals. Floods, and disturbance sequences such as fire then floods, can mean scouring flows, sand abrasion and sand-infilling. Floods cannot be prevented but damage to the *Myriophyllum* community can be minimised by catchment and bank protection, and careful attention to placement and design of infrastructure. Hard hooved animals trampling and foraging along streams can cause bank erosion, changes in hydrology, and sedimentation. The loss of in-stream vegetation such as the *Myriophyllum* community would be problematic because so little is known about its refuges, sources and dispersal distances of propagules, or how to encourage re-establishment at a landscape-scale.

4.2 Growth form Assemblages

The distribution of the eight BET assemblages across survey sites is shown below (Figure 15). As with the six plant communities, geographic patterns are evident in some of these, specifically the High Mixed and Moderate Floating-leaf assemblages. This suggests that – in addition to the site-scale factors described above (Section 3.5) - macro-scale (regional and landscape) factors influenced their distribution. The High Mixed assemblage occurred in southern sites, a pattern similar to the *Myriophyllum* community: the Moderate Floating-leaf assemblage occurred in the north-east only, similar to the *Callitriche* community. Sites with Low Moss were clustered towards the centre of the study area; sites with Moderate Filamentous Algae were distributed widely. The other assemblages had too few sites to be interpreted as a geographic pattern.

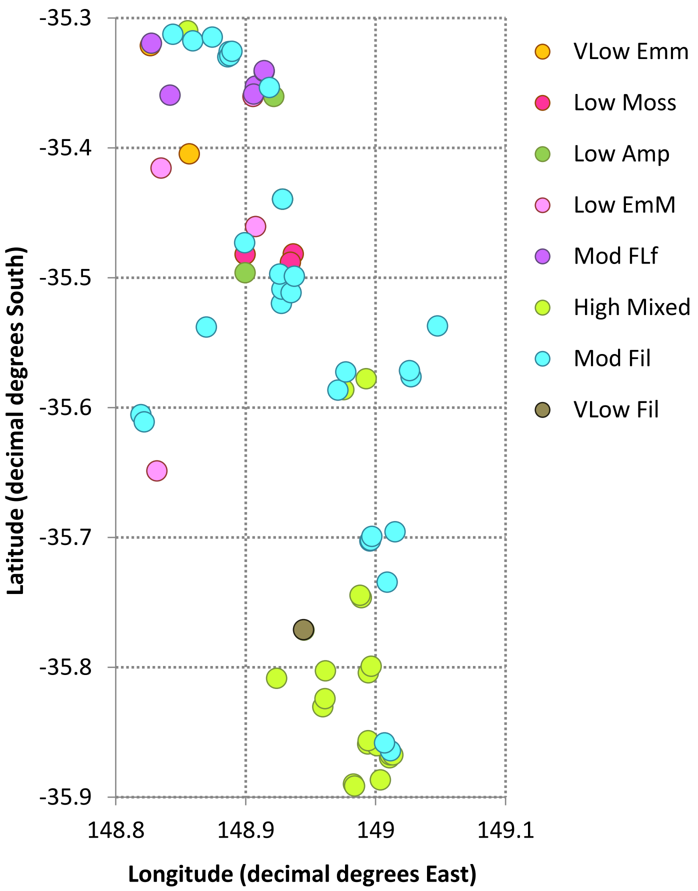


Figure 15: Distribution of BET assemblages in the study area

In the plot, some sites are obscured, as the software overlays co-ordinates without jittering them apart. The site excluded from the classification analysis would (if included) be hidden under the cluster of pale blue Moderate Filamentous Algae sites at 35.5 degrees South.

As with the plant communities, these geographic patterns for assemblages correspond with sub-catchments: four of the 6 sites in Moderate Floating-leaf assemblage were in Pierces Creek sub-catchment, and 12 of the 23 High Mixed sites were in Naas sub-catchment. Sites of the Moderate Filamentous Algae assemblage occurred in all nine sub-catchments but were most frequent in Condor Creek and Gudgenby sub-catchments (with 7 and 6 sites respectively).

Assemblages were not strongly associated with geomorphic reach, as shown in the cross-tabulation below (Table 17), with a few exceptions. The High Mixed assemblage occurred in all types of geomorphic reach, but was concentrated in pool-riffle and plane-bed reaches, and under-represented in step-pool reaches. The Moderate Filamentous Algae assemblage was strongly represented in step-pool and pool-riffle reaches, and to a lesser extent in cascades. Step-pool reaches had a low occurrence of macrophyte assemblages (such as High Mixed and Moderate Floating-leaf), and a high occurrence of low abundance and filamentous algae assemblages (11 sites were Moderate Filamentous Algae).

Table 17: Occurrence of BET assemblages in geomorphic reaches

Table shows the number of sites per assemblage (rows) per geomorphic reach (column). Geomorphic reach types are arranged on a gradient from left to right, of sediment dynamics, from transport limited (colluvium) to supply limited (bedrock). For completeness, 'Sand obscured' sites are included. The last row refers to the survey, so includes 1 site with no assemblage present.

Abbreviations for BET assemblages are as given or Table 11.

	Collu-vium	Braided	Pool-Riffle	Plane-Bed	Step-Pool	Cascade	Bed-rock	Sand Obscured	Total
VLow Fil								1	1
VLow EmM			1		1				2
Low Moss					2	1			3
Low Amp					1			1	2
Low EmM			1	2	1				4
Mod FLf			4	1	1				6
High Mixed	1	2	7	7	1	2	1	2	23
Mod Fil			7	4	11	4	1	3	30
Sum of assemblages	1	2	20	14	18	7	2	7	71
Sites per reach type	1	2	20	14	19	7	2	7	72

The use of an array of growth forms, as with BET in this survey, is unusual in stream and river vegetation studies, which are mostly species-based. The few studies that have used or incorporated growth forms are generally restricted to just a few (submerged, floating-leaf, emergent macrophytes) with charophytes (Mackay et al 2003). Plants such as mosses, charophytes and filamentous algae tend to be studied separately (eg Entwistle 1990, Suren 1996), as if a separate part of the stream ecosystem. The few instances of using multiple growth forms, or mix of species and growth forms, have been mostly to address functional questions: an investigation into using macrophytes as biomonitoring tools in Far North Queensland expanded the conventional definition of macrophyte to include "charophytes, mosses, pteridophytes, and non-woody angiosperms" (Mackay et al 2010); a study of the effect of wet season floods on primary production in a Queensland river considered micro-algae, macro-algae and submerged macrophytes (Townsend et al 2017); and in the UK, five growth forms (called morphotypes) were associated with physical conditions and stream power of stream reaches (Gurnell et al 2010).

Surveys that use growth forms or include growth forms as well as species of vascular plants report on high energy, high altitude, fast flowing sites (eg Manolaki and Papastergiadou 2013), so have greater coverage of a stream network. In Far North Queensland, Mackay et al (2010) found that bryophytes were more abundant in upper stream reaches; in the UK, Gurnell et al (2010) found that mosses were most abundant in high energy streams with coarse sediments. In this survey, growth forms were present at all 72 sites whereas the sample size was 64 sites if only vascular plants were considered.

Assemblages and Plant Communities

Assemblages characterised by submerged or floating-leaf macrophytes (High Mixed and Moderate Floating-Leaf) were broadly similar (ie characterised by same growth forms) to plant communities such as *Myriophyllum* and *Callitriche* communities respectively. This raised the possibility of plant communities in the survey corresponding with BET assemblages.

However, cross-tabulation showed that overall, correspondence was variable (Table 18). Examples of low correspondence were that sites in the *Veronica* community occurred in four assemblages, and sites in the *Gratiola* community occurred in six assemblages. Examples of high correspondence were the *Myosotis* and *Myriophyllum* communities, with 7 of the 8 *Myosotis* sites in the Moderate Filamentous Algae assemblage, and 15 of the 17 *Myriophyllum* sites in the High-Mixed assemblage (highlighted in Table 18 below). These instances of high correspondence were uni-directional, meaning they applied from community to assemblage but not in reverse. *Myosotis* community accounted for only 23% of all Moderate Filamentous Algae sites, and *Myriophyllum* community accounted for only 65% of High Mixed sites.

In summary, there was no perfect match between any assemblage and plant community. There was overlap, but this was limited to the few assemblages and plant communities that were macrophyte-based.

Table 18: Assemblages and plant communities - cross tabulation of sites

Cross-tabulation of plant communities (rows) and assemblages (columns) showing the number of sites in common. Excluded means sites were not included in the classification analysis. See text for explanation of highlighted text.

Abbreviations for BET assemblages are as given for Table 11.

	VLow Fil	VLow EmM	Low Moss	Low Amp	Low EmM	Mod FLf	High Mixed	Mod Fil	Excluded	Total
Myosotis						1		7		***8***
Veronica			1	1		1	6	9		***18***
Callitriche		1			1	4		3		***9***
Gratiola	1		1	1	2		1	4		***10***
Hydrocotyle							1	1		***2***
Myriophyllum							15	2		***17***
Excluded		1	1		1			4	1	***8***
Total	***1***	***2***	***3***	***2***	***4***	***6***	***23***	***30***	***1***	***72***

The two approaches (VIS and BET) used different units of vegetation (species versus growth forms), targeted different species and groups (VIS had only submerged, floating-leaf and amphibious dicot species, BET had those as well as emergent macrophytes, charophytes, mosses, filamentous algae, gelatinous blobs, liverworts) and used differing measures of abundance (categorical versus meristic data), so provided different information about in-stream vegetation. The VIS approach had finer resolution regarding vegetation (24 species versus 9 growth forms) whereas the BET approach had greater resolution concerning abundance (meristic versus categorical data) and recorded greater ecological diversity. The BET approach gave greater coverage: all sites in this survey had one or more BET present. Most of the eight sites with no VIS were in the Moderate Filamentous Algae assemblage.

The dual approach (species and growth form) was easy to use in the field and found to be efficient in terms of time and effort, but increased data processing and interpretation, without a commensurate boost in information. The species-based approach (VIS) is closer to the needs of conservation management, making it the preferred approach. Two refinements are suggested for the sampling protocol. The first is to record VIS species per quadrat, rather than per site, but retain the simple abundance categories of Absent, Present and

Dominant: quadrat information would then be combined to describe species abundance per site. This would give finer resolution to species abundance, but without requiring cover estimates per species. The second is to expand the range of plants beyond VIS, and include selected growth forms, the obvious candidates being charophytes and possibly filamentous algae. The growth-form approach (BET) is more suited when working on stream condition or in-stream habitats. If using the BET approach, it would be sensible to partition amphibious dicots into two growth forms: one being semi-erect, cushiony plants, typically on stream margins and the other being stoloniferous forms, typically trailing in flowing water or mat-forming when stranded. In addition, a possible refinement could be to record filamentous algae and gelatinous blobs as different growth forms according to where attached, limiting to epiphytic, epixylic and epilithic.

4.3 Plant-Environment Relationships

Selection of Environmental Variables

Environmental variables used to analyse species-environment relationships for macrophytes typically range from resources that directly affect plant growth or abundance (eg Manolaki and Papastergiadou 2013, Kaijser et al 2021), to habitat descriptions, to catchment and regional scale factors such as climate (Gillard et al 2020), longitudinal connectivity (Demars and Harper 2005), and stream condition (Chessman et al 2006). Recent studies in Europe have utilised data sets that have been built up through national or continental-scale monitoring programs. These have multiple sites and span several years, making the analyses quite powerful. Gillard et al (2020) used plant and environmental variables from 300 sites in Finland that had been monitored for 6 years; and Kaijser et al (2022) considered 62 species from 1896 sites across 22 European countries. Where there is no program for monitoring macrophytes and no data sets, as in Australia, then generating the data is the first step in a project. This constrains the data to a short temporal window, typically within a single year, as for this survey and also for Chessman et al (2006) and Chessman and Royal (2010). It also constrains the geographic coverage and the number of sites surveyed, thus sample size in Australian studies is much smaller, being 41 and 85 sites respectively for Chessman et al (2006) and Chessman and Royal (2010).

The number of environmental variables analysed depends on purpose of the study and the level of resourcing, and is known to range from 9 (Kaijser et al 2022) to over 30 (Mackay et al 2010). Reporting and interpreting multiple variables can be clumsy, hence it is common practice to group them into broad categories or reduce the number by combining several into a complex factor such as an environmental gradient using PCA (eg Chessman and Royal 2010, Demars and Harper 2005).

For varied reasons, this study did not use as wide a range of environmental variables as other Australian studies (Chessman and Royal 2010, Mackay et al 2003, Hughes 1988). Hydrological variables such as flow history could not be included because survey sites were distant from or outside the stream gauging network; nor was it feasible, within the time and resources available, to make on-site hydrological or hydraulic measurements, other than stream wetted width and thalweg. Variables expected to be invariant through the study area such as land use were not included. All sites except one were on land managed for nature conservation with no livestock present (the one exception was an easement through grazing land, and this was fenced to exclude stock). Being managed for nature conservation is not equivalent to being in pristine condition, as the landscape of the western ACT carries legacies from earlier land uses such as pastoralism, dwellings and pine forestry. The possibility of damage by feral animals (deer, pigs, horses) was accommodated by making an observational check as part of the field protocol (Appendix 1), however, no impact from animals, native or feral, was noted at survey sites.

Water quality was not included, partly because the project was not resourced for chemical analyses, and partly because much of the study area is a water supply area, so streams were assumed to be of good quality and free of pollutants. A small area in the extreme north (the Jeir Hill HGL) has moderate in-stream salinity (ACTmapi, downloaded 25 November 2021) but this was not expected to be influential due to the diluting effect of high flows in the preceding 18 months. Turbidity was addressed by subjectively rating each site: all sites were rated “clear” (benthos clearly visible) except for two rated “not clear” (benthos visible but not clearly) and one was tannin-coloured. With such little variation evident, water clarity was considered unlikely to discriminate between sites, so was not included in analyses.

The 17 environmental variables used in analyses were at the same spatial scale and limited to five categories (Table 2, Figure 5): stream size (wetted width, thalweg depth), landscape setting (altitude, slope of stream), shading of water surface (overhead by trees and shrubs, laterally by banks and marginal vegetation), substrate composition (seven particle size classes, and organic matter) and disturbance (evidence of fire or flood, sand in-filling). Regional-scale influences were not addressed as analysis of multi-level categorical factors proved problematic (Section 2.5).

Species Profiles

The individuality of species-environment associations is repeatedly emphasised (eg Kaijser et al 2022), and was evident here, despite the sample size being smaller than aspired to, and despite the relatively small spatial and temporal scale, and the limited range of environmental variables used. The nine species differed from each other in the number of associations that were significant (from 0 to 5 site characteristics), the effect of each site characteristic (positive or negative or not significant), and type of variable (whether size, setting, shading, substrate, or disturbance) (Table 7). Collectively, significant and non-significant associations describe a species-environment relationship, here referred to as a profile.

Some species had profiles consistent with existing knowledge. *Veronica anagallis-aquatica* was the only species positively associated with disturbance indicators and one of only two species with seedlings and young plants (Table 10): together these showed a capacity to colonise and establish following erosion and deposition, and so consistent with being recognised as a coloniser (Riis et al 2004), adapted to low-resource - intermediate disturbances (Riis and Biggs 2001), and associated with poor geomorphic condition (Chessman et al 2006). Similarly, *Callitriche stagnalis* was the only species positively associated with coarse substrate (cobbles), which parallels findings from Germany that substrate coarseness was the most important environmental variable for this species (Kaijser et al 2022).

Other species had profiles that were not strongly consistent with existing knowledge. The profile for *Myriophyllum variifolium* in this survey was broadly similar to its profile in north-eastern NSW except in relation to land use: in north-eastern NSW, it was positively associated with sites subject to grazing pressure (Chessman and Royal 2010). In this survey, the profile for *Gratiola peruviana* suggested it was a stream generalist with broad rather than specific in-channel habitat requirements, yet in north-eastern New South Wales it had a complex relationship with multiple environmental variables including water quality (Chessman and Royal 2010).

Not surprisingly, species that co-occurred (for example, were in the same plant community) had similar profiles, differing only in one or two site characteristics. Two species of submerged macrophytes in the *Myriophyllum* plant community, *Montia australasica* and *Myriophyllum variifolium* had three identical associations (positive for altitude and mud & silt, negative for slope) and two that differed: depth (negative for *Montia australasica*, positive for *Myriophyllum variifolium*) and sand (negative for *Myriophyllum variifolium,* not significant for *Montia australasica)*.

In general species profiles are shaped by the range of environmental variables tested and their temporal context. The profiles of some species in this survey would probably shift if the study area had been larger or more geographically diverse, or if water quality had been included. This becomes evident when comparing profiles from this study with those from north-eastern New South Wales (Chessman and Royal 2010). The NSW study had 85 sites, in coastal and inland catchments (a larger and more diverse area than the ACT), covered a range of land uses, and had an altitudinal range from sea-level to 1500m AHD. In the ACT study, *Gratiola peruviana* and *Veronica anagallis-aquatica* had no significant associations with site characteristics, other than disturbance, but in north-eastern New South Wales, water quality was important for both species, and in different ways. *Gratiola peruviana* was negatively associated with alkalinity, pH and EC and positively with filterable oxidised nitrogen, filterable phosphorus, and turbidity, whereas *Veronica anagallis-aquatica* was positively associated with alkalinity, pH and EC, and nutrients were not significant (Chessman and Royal 2010).

This emphasises that the profiles established in this survey - not just for species, but also for growth forms, plant communities, assemblages, and richness - are specific to prevailing conditions, which in the summer-autumn 2022 was post-wildfire and post-floods. The profiles are conservative for species negatively affected by scouring and deposition, such as *Myriophyllum variifolium* and would be also for *Isoetes muelleri*. In the case of *Myriophyllum variifolium*, its profile would change if it was counted as present at sites on the Cotter River (where it previously occurred) as these are higher, wider and have different substrates.

Most Important Variables

Knowing which site characteristics are the most important in determining distribution can help make surveys more efficient and informative, and assist with management of species or communities. Techniques for establishing importance are detailed and elaborate: for example Kaijser et al (2022) used Random Forest Models followed by corrections for bias. A simpler approach is used here. It counts across all species profiles and recognises the variable (site characteristic) with the highest number of significant associations as the most important (Table 19).

The two site characteristics with the highest number of associations were altitude (in setting category) and mud & silt (substrate composition), with 7 and 6 respectively, and were largely to entirely positive. The importance of mud & silt was expected, as fine substrates are widely recognised as influencing distribution of macrophytes (eg Riis and Biggs 2003, Kaijser et al 2022). They provide nutrient resources for growth and are less subject to flow disturbances. Causality is not clear for altitude, which is a proxy variable. Interpretation of altitude varies, depending on the altitudinal range surveyed. In a survey ranging from 0 to 1280 m AHD (Chessman and Royal 2010), it was interpreted as a climate or temperature gradient but in a survey with vertical range of only 160 m, it was treated as a proxy for certain combinations of substrate, slope, stream size, and discharge (Mackay et al 2003). This ACT survey ranged from 587 to 1306 m AHD so altitude could be interpreted as climate, but is more likely to be a proxy for geographic location of set of site characteristics.

The minor importance of overhead shade in the ACT survey was unexpected, as riparian shading reduces macrophyte abundance (Bunn et al 1998). This finding is possibly an inadvertent consequence of post bushfire conditions at the time of the survey, with little variation in the sample. Most sites were little shaded (Table 2, Figure 2), and only 3 sites had more than 50% of water surface shaded by tree or shrub canopy. However, shade was also of minor importance in the study on German rivers (Kaijser et al 2022). This study did not include water quality variables but this may not have constrained the findings, as nutrients and related variables (P-PO_4, pH, TN) were of only minor importance in predicting species occurrence in German rivers (Kaijser et al 2022), and in northern New South Wales had no influence on aquatic species (ie macrophytes), only on amphibious species (Chessman and Royal 2010).

Table 19: Site characteristics – relative importance for species occurrence

Table shows how the number of species that were significantly associated with each site characteristics by category, broken down into the number of positive and negative associations.

		Species		
	SITE CHARACTERISTICS	Total Number (max=9)	Number Positive	Number Negative
STREAM SIZE	Wetted width (m)	1	1	0
	Thalweg depth (cm)	2	2	1
SETTING	Altitude (m AHD)	7	6	1
	Slope	3	0	3
SHADING	Shade - overhead	1	0	1
	Shade - bank	2	1	1
SUBSTRATE	Bedrock%	0	0	0
	Boulders%	0	0	0
	Cobbles%	2	1	1
	Pebbles%	1	1	0
	Granules%	0	0	0
	Sand%	3	1	2
	Mud & Silt%	6	6	0
	Organic Matter%	0	0	0
DISTURBANCE	Sand filled	2	1	1
	Evidence - Fire	0	0	0
	Evidence - Flood	0	0	0

Due to their small samples sizes, importance was not determined for plant communities, individual BET, BET assemblages or species richness, but if these are aggregated then the findings are similar (Table 20): altitude, with 8 significant associations, was the most important, with substrate characteristics (mud & silt, cobbles) and slope of secondary importance, each with 5 significant associations.

Table 20: Site characteristics – relative importance, generally

Table shows how many plant communities, BET, BET assemblages and species richness were significantly associated with each of 17 site characteristics, and the total for each site characteristics aggregated across the four plant responses.

		Occurr-ence	Abund-ance	Occurr-ence	Occurr-ence	
	SITE CHARACTERISTICS	Plant commun-ities (n=5)	BET (n=2)	BET assem-blages (n=3)	Species richness (n=1)	Total Number
STREAM SIZE	Wetted width (m)	1	0	0	0	**1**
	Thalweg depth (cm)	0	1	0	0	**1**
SETTING	Altitude (m AHD)	2	3	2	1	**8**
	Slope	2	1	1	1	**5**
SHADING	Shade - overhead	0	2	0	0	**2**
	Shade - bank	1	0	1	0	**2**
SUBSTRATE	Bedrock%	0	0	0	0	**0**
	Boulders%	1	0	0	1	**2**
	Cobbles%	1	1	2	1	**5**
	Pebbles%	1	1	1	0	**3**
	Granules%	0	0	0	0	**0**
	Sand%	2	1	0	0	**3**
	Mud & Silt%	1	2	1	1	**5**
	Organic Matter%	1	0	1	1	**3**
DISTURBANCE	Sand filled	1	1	0	1	**3**
	Evidence - Fire	0	1	0	0	**1**
	Evidence - Flood	0	0	0	0	**0**

4.4 Disturbances

Context for this Study

Heat waves, fire, floods, and drought that re-structure stream ecosystems (Leigh et al 2014) can impact riverine macrophytes through heat and water stress, desiccation, up-rooting, sand abrasion, and even burial. Riverine macrophytes re-establish from root-stock or rhizome, if these still present and still viable after a disturbance, or from propagules, *in situ* or brought in. For riverine macrophytes, propagules are vegetative fragments dispersing downstream (Boedeltje et al 2003) rather than seeds. Establishment from fragments is favoured by low flows (Riis 2008).

Disturbance studies are mostly opportunistic or retrospective utilising historic data, an example being effects of drought on wetland plants (Wassens et al 2017). One of the few studies with 'before' as well as after disturbance data is a 28-month study of flow disturbance on riverine vegetation by Hughes (1990). Findings were synthesised into a model (Figure 8 in Hughes 1990), setting out how vegetation cover and species richness respond to discharge (low and stable v pulses) and timing (winter or summer). A conclusion from this study was that the development of plant communities following disturbance was governed by stochastic processes, which lead to the speculation that considerable lapse of time, perhaps up to 15 years, would be needed for communities and seasonal patterns to fully develop (Hughes 1990). In-stream vegetation re-establishes gradually in a temporal sequence determined by opportunity, propagules and species-specific requirements, and by the magnitude (intensity or duration) of preceding disturbance (eg Wassens et al 2017). The sequence in a tropical river scoured by unusually large Wet Season floods was benthic filamentous algae, then charophytes, and finally vascular plants (Townsend et al 2017).

These disturbances preceding this survey were followed by months of sustained high flows (Figure 1), conditions unsuitable for re-growth or establishment of new plants. Thus the environmental relationships and profiles described here may be specific to one stage in a dynamic sequence.

Sand-infilling

In-filling of streams by sand or other debris is a legacy of fire and heavy rainfall but was not the only such legacy observed during the survey. Also noticed were: infilling by cobbles, as seen at Burke Creek and adjacent Cotter River; moderate scouring of the central area of the stream bed leaving 'cleaned' stones in centre and retaining macrophytes along the margins, as was evident along Naas Creek between the broad valley and Mt Clear campground; severe scouring, as seen at several places on the Cotter River, notably at Bushrangers Creek crossing, where meadows of *Isoetes muelleri* had been nearly completely lost, leaving small patches of fine to organic sediments in protected micro-areas along stream margins or on the downstream side of boulders. Large growths of filamentous algae that were evident at several sites may have been a post-fire response to nutrient flushes combined with increased light, resulting from loss of riparian canopies.

Sand-infilling is generally a transient physical issue (Smith et al 2011), with sand being gradually exported to a site further downstream, thus in-filling duration and rate of recovery are dependent on flows of sufficient energy which in turn may be driven by rainfall patterns. Parts of the upper Cotter River are already recovering. Two years previously, at Cotter Flats the river channel was so sand-filled that there was only 10 cm of water flowing over the top (Matt Beitzel, pers. comm. 16 Feb 2022) whereas in March 2022, the stream bed was still sand-covered filled but not as deeply and had water 70 cm deep. Recovery of riverine macrophytes that were growing in fine organic sediments will depend on such depositional features being re-formed. This could take decades, as it will be driven by flow regimes, and requires low-flow conditions to allow the accumulation of sediment and organic matter, and opportunities for plant growth. Stream recovery thus has multiple paths to complete, and at differing time-scales.

Of the three indicators of environmental disturbance (evidence of flood, evidence of fire, and sand in-filling) sand-infilling was the most important for in-stream vegetation (Tables 19 and 20): it had five significant associations, compared with only one for fire, and none for flood. These five associations affected various vegetation measures: species occurrence (*Hydrocotyle rivularis*, *Veronica anagallis-aquatica*), plant community (*Veronica* community), richness of submerged and floating-leaf species, and abundance of Submerged BET. All were negative except the two involving *Veronica*, an exotic species. The importance of one type of disturbance (sand and sand-infilling) does not signify that fire and flood had no effect on in-stream vegetation, only that the spatial patterns evident in summer-autumn 2022 show little relationship to disturbances that happened some 1-2 years earlier.

Environmental Legacy

European settlement is another kind of environmental disturbance and naturalised plant species are part of the environmental legacy that European settlement has left on landscapes in Australia. In any landscape, naturalised species have 'arrived' through diverse human agency such as inadvertent introductions (eg contamination, adherence), deliberate introductions (eg plantings), and careless introductions (eg weed and aquarium dumping). They have also arrived unassisted, by dispersal.

The occurrence of Watercress *Nasturtium officinale* at a site on Condor Creek at Blundells Flat was not surprising, as this is a food plant and the Blundell homestead had a productive garden (Butz 2009). Although this was the only 'garden' plant recorded in the survey, other 'garden' species occur nearby, such as the amphibious dicots Musk Monkey-flower *Erythranthe moschata* and Garden Mint *Mentha spicata*. What was surprising, however, was the occurrence of abundant Watercress *Nasturtium officinale* on a small tributary to Grassy Creek.

These seven naturalised species have differing strategies for persistence, which are clearly effective. Most macrophytes regenerate from fragments rather than from seed, such as *Ranunculus trichophyllus*, however some such as Marsh Purslane *Ludwigia palustris* are prolific seeders. Its seeds are readily transported in river flow: a hydrochory study in northern Victoria found that this species was the single biggest contributor to the annual seed load being transported downstream (Greet et al 2012b). Seed production is prolific for *Callitriche stagnalis* (Philbrick et al 1998) however no flowering plants were observed in the study area (Table 9).

4.5 Synthesis

This survey established that, in summer-autumn 2022, there were six plant communities in streams of the western ACT. Two of these were characterised by macrophyte species, which were the principal interest for this project (Sections 1.2 and 1.3), and the other four by amphibious dicots. The two macrophyte communities had well-defined distribution patterns, with the *Myriophyllum* community mainly in wide grassy valleys of the southern ACT, and the *Callitriche* community mainly in shallow cobble streams in disturbed and modified catchments in the north-west ACT.

The *Myriophyllum* community was notable for its form (trailing stems, over 1 m long), for its generally high abundance (typically, the submerged macrophytes and stoloniferous amphibious dicots filled the stream channel: see front cover, Photo 2, and Photo 4). The High Mixed assemblage, with similarities to the *Myriophyllum* community and 15 sites in common (Table 21), had high ecological diversity, with up to 8 growth forms, including the gelatinous blobs epiphytic on *Myriophyllum variifolium*). Beds of submerged macrophytes modify stream hydraulics and hydrology, affect water chemistry, trap sediments, and contribute organic carbon (Champion and Tanner 2000, Clarke 2002) and so influence a stream ecosystem and its functioning. Streams with abundant macrophytes have higher rates of primary production and ecosystem respiration (Alnoee et al 2021), and beds of submerged macrophytes such as *Myriophyllum simulans/variifolium* (identification was not resolved) support more macroinvertebrates than beds of emergent macrophytes (Humphries 1996). The streams where this *Myriophyllum* community occurs are a distinctive type of aquatic system, and as such are likely to support a distinctive suite of stream fauna. From a conservation perspective, an important step is to confirm the ecological distinctiveness of these streams, understand their role as a habitat, establish their longitudinal extent within the ACT and occurrence in adjacent New South Wales, and build knowledge practical for management on resilience, regeneration and recovery.

This study found empirical evidence of relationships between geomorphic reach and in-stream vegetation, both plant community and BET assemblage. The strong association between macrophyte species and geomorphic characteristics (Chessman et al 2006, Gurnell et al 2010) means stream geomorphology can be used to structure and design studies of riverine biota. The development of this 2022 survey would have been facilitated, and the application of its findings would have been extended more widely if a reach-based classification of streams and rivers had been in place for the ACT. Such a classification would be a framework not only for survey design and reporting, and for monitoring, but would inform planning, management and conservation.

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6 Appendices

Appendix1. Data collection sheet for In-channel macrophytes project of Western ACT. Summer-Autumn 2022

TRIP:	STREAM:			SITE:		DATE	
SITE PHOTO and NOTES	Time: Where:		Channel Unit(s):				
REACH Comment on Reach Length							
TYPE	**Bedrock**	**Cascade**	**Pool-Riffle**	**Step-Pool**	**Plane-Bed**	**Dune-Riffle**	**Braided**
SUBSTRATE (% site, viewed in planform)	**Bedrock**	**Boulders (>256 mm)**	**Cobbles (64-256)**	**Pebbles (16-64)**		**Types OM present**	**Fallen tree or shrub**
	Granules (4-16 mm)	**SAND (< 4 mm)**	**Mud Silts**	**OM**		**Branch** **Twig**	**Bark** **Root**
WATER	Clear	Tannin-rich	Not Clear	Turbid	**FLOW RATE**		
BANK	Vertical	Steep	Gentle	Non-exist	**Bank Ht Material**		
SUB-SAMPLE (quadrats)							
	Q_1	**Q_2**	**Q_3**	**Q-4**	**Q-5**		
WIDTH (m) of wetted perimeter)	**W_1**	**W_2**	**W_3**	**W_4**	**W_5**		
						MEAN =	
THALWEG DEPTH (cm)	**D_1**	**D_2**	**D_3**	**D_4**	**D_5**		
						MEAN =	
SHADING: Direct Overhead Shading of Water Surface of Reach (Extent / Density							
Tree & Shrub Extent							
Density							
Extent X Density =						**MEAN =**	
Banks & BVeg (cm)							
As %						**MEAN =**	
RIVER PLANTS – ABUNDANCE as Cover (in water)							
SubM						**MEAN =**	
Fl-Leaf						**MEAN =**	
Amphib						**MEAN =**	
Moss						**MEAN =**	
Fil Algae						**MEAN =**	
Blobs & Nostoc						**MEAN =**	
EmM						**MEAN =**	
Liverwort						**MEAN =**	
CharoFF						**MEAN =**	

Data collection sheet page 2

SPECIES (rooted in wetted perimeter): **PER SITE:** **1: DOMinant (cover >=30%)**	SUBM	
	FLOAT	
	AMPHIB	
2: PHENology per species	EmM (optional)	
ADJACENT WOODY VEGETATION	No Trees Dead Trees Re-sprouting & Epi Eucalypts Acacia Casuarina Other Native Trees Pinus Salix Non-native Trees	No Shrubs Dead Shrubs Native Shrubs Regenerating Native Shrubs Blackberry
PAST DISTURBANCE (evidence of)	**recent FIRE** Can't see – ground cover too thick/tall: ADJACENT to channel: COG charcoal on ground YES NO BLB Burnt logs/branches YES NO BB Burnt boles YES NO BS Burnt shrubs YES NO IN CHANNEL: CIC charcoal in channel YES NO BF black fines YES NO	**recent FLOOD High Flow** Can't see – ground cover too thick/tall: ADJACENT to channel: Flood debris FD_PER debris perched YES NO FD_GR debris on ground YES NO SS Sand splays YES NO LJ Log Jams across creek YES NO FV Flattened veg YES NO IN CHANNEL: SIF Sand in-filling channel YES NO ERB Eroded banks YES NO
ANIMAL or PEOPLE IMPACT	None obvious Specify:	

NOTES

SITE and quadrats:

Homogenous stream reach 20+ m long, longer if stream >5m wide. Within that, five quadrats. Quadrat is a belt across stream, from wetted edge to wetted edge, and 2 m wide and 2-3 m apart (small streams) or else 3 m wide and 3-4 m apart (larger streams >5m).

FLOW: observations consider 'energy' also velocity.

Fast = too fast for Observer to get in and be confident about maintaining footing (not sampled).

Moderate PLUS: becoming marginal for working in (waders flattened against legs: current strong enough to make balance uncertain.

Moderate: flowing vigorously, but OK to work in.

Gentle = slow, should be audible.

Trickling = barely detectable.

DIMENSIONS refer to wetted perimeter.

Width is ‘typical’ for the quadrat: depth is deepest part of thalweg in quadrat.

ABUNDANCE (% cover) refers to BET incl plants rooted in wetted perimeter being sampled. If Terrestrial present, then is ignored, as their cover is of no consequence.

Appendix 2: Site Details

Details for Study Sites, from left to right: Site Number, Date Sampled, Site Name, Co-ordinates (South then East), Code name (as used in analyses), VIS Plant communities, and BET assemblages.

Site Number	Date Sampled	Site Name	South	East	Code Name	VIS plant community	BET assemblage
MF001	12 Jan 2022	Reedy Ck on Brandy Flat FT	35.69576	149.01495	RBFFT	Veronica	Moderate Filamentous Algae
MF002	12 Jan 2022	Dry Ck on Brandy Flat FT	35.73453	149.0089	DBFFT	Veronica	Moderate Filamentous Algae
MF003	13 Jan 2022	Gibraltar Ck at Woods Reserve	35.48176	148.93666	GBWOO	Veronica	Low Mosses
MF004	13 Jan 2022	Gibraltar Ck above Falls	35.48804	148.93443	GBABF	*No Plant Community*	Low Mosses
MF005	13 Jan 2022	Billy Billy Ck off forest track	35.49621	148.92178	BBCOF	Gratiola	Low Amphibious Dicots
MF006	17 Jan 2022	Tributary to Gibraltar Ck	35.51986	148.92755	GBTR2	Myosotis	Moderate Filamentous Algae
MF007	20 Jan 2022	Stream DS Corin Wetland	35.50931	148.92979	UDSCO	Hydrocotyle	High Mixed
MF008	20 Jan 2022	Gibraltar Ck UP Corin Rd	35.50875	148.92801	GBUPC	Hydrocotyle	Moderate Filamentous Algae
MF009	20 Jan 2022	Kangaroo Ck off Corin Rd	35.53796	148.86975	KOFCO	Veronica	Moderate Filamentous Algae
MF010	21 Jan 2022	Tidbinbilla R Upper Ring Rd Crossing	35.48194	148.89957	TIURX	Gratiola	Low Mosses
MF011	21 Jan 2022	Ashbrook Ck Upper Ring Rd Crossing	35.47302	148.89925	ASURX	Veronica	Moderate Filamentous Algae
MF012	21 Jan 2022	Mountain Ck Upper Ring Rd Crossing	35.46053	148.90769	MOURX	*No Plant Community*	Low Emergent Macrophytes
MF013	23 Jan 2022	Gibraltar Ck at forest track	35.49717	148.9263	GBAFT	*No Plant Community*	Moderate Filamentous Algae
MF014	24 Jan 2022	Little Dry Ck at Yerrabi Track	35.80421	148.99439	LDAYT	Myriophyllum	High Mixed
MF015	24 Jan 2022	Hospital Ck DS of ford	35.74649	148.98912	HODSF	Veronica	High Mixed
MF016	26 Jan 2022	Honeysuckle Ck on Tank service trail	35.58615	148.97562	HCTST	Veronica	High Mixed
MF017	26 Jan 2022	Honeysuckle Ck off Orroral Ridge Trail	35.58657	148.97111	HCORR	Myosotis	Moderate Filamentous Algae
MF018	26 Jan 2022	Honeysuckle Ck DS Apollo Wetland	35.57782	148.99278	HCDAW	Veronica	High Mixed
MF019	27 Jan 2022	Honeysuckle Ck at New Bridge	35.57255	148.9771	HCNBB	Veronica	Moderate Filamentous Algae
MF020	27 Jan 2022	Honeysuckle Ck at ford Mt Tennent FT	35.57621	149.02731	HCFMT	Myosotis	Moderate Filamentous Algae
MF021	27 Jan 2022	Tributary to Booroomba Ck	35.57159	149.0262	BOOTR	Veronica	Moderate Filamentous Algae
MF022	28 Jan 2022	Grassy Ck UPS Naas Valley FT	35.86975	149.01088	GCUNV	Myriophyllum	High Mixed
MF023	28 Jan 2022	Grassy Ck DS Naas Valley FT	35.86746	149.01127	GCDNV	Myriophyllum	High Mixed
MF024	1 Feb 2022	Tidbinbilla R at Webbs	35.43943	148.92844	TIAWE	Veronica	Moderate Filamentous Algae

Site Number	Date Sampled	Site Name	South	East	Code Name	VIS plant community	BET assemblage
MF025	1 Feb 2022	Tributary to Tidbinbilla R at Webbs	35.43958	148.92848	TITRW	Veronica	High Mixed
MF026	3 Feb 2022	Condor Ck DS Currie Rd ford	35.32131	148.82664	CNCRF	Callitriche	Very Low Emergent Macrophytes
MF027	3 Feb 2022	Wombat Ck at trail crossing	35.30979	148.85545	WOATX	Myriophyllum	High Mixed
MF028	5 Feb 2022	Grassy Ck UPS Boboyan Rd	35.89001	148.98302	GCUBO	Myriophyllum	High Mixed
MF029	5 Feb 2022	Grassy Ck DS Boboyan Rd	35.89148	148.98383	GCDBO	Gratiola	High Mixed
MF030	10 Feb 2022	Cribbs Ck	35.6054	148.81954	CRIBB	Veronica	Moderate Filamentous Algae
MF031	10 Feb 2022	Cotter R at Lick Hole Track	35.61102	148.82197	COLHT	Gratiola	Moderate Filamentous Algae
MF032	11 Feb 2022	Alpine WT nr Cypress Look Out	35.53708	149.0477	ALPCL	Gratiola	Moderate Filamentous Algae
MF033	14 Feb 2022	Tributary to Naas Ck	35.85909	148.994	NATR2	Myriophyllum	High Mixed
MF034	14 Feb 2022	Naas C at Mt Clear Campground	35.86434	149.0114	NAMCC	Myriophyllum	Moderate Filamentous Algae
MF035	14 Feb 2022	Naas Ck DS Boboyan Rd	35.85818	149.00688	NADBO	Myriophyllum	Moderate Filamentous Algae
MF036	16 Feb 2022	Cotter R at Cotter Flats	35.64882	148.83176	COCOF	Gratiola	Low Emergent Macrophytes
MF037	19 Feb 2022	Dry Ck on East West Rd	35.35342	148.91835	DRCEW	Myosotis	Moderate Filamentous Algae
MF038	19 Feb 2022	Pierces Ck on East West Rd	35.35246	148.90752	PICEW	Callitriche	Moderate Floating-leaf
MF039	21 Feb 2022	Burke Ck	35.40459	148.85671	BURKE	*No Plant Community*	Very Low Emergent Macrophytes
MF040	21 Feb 2022	Cotter R at Bushrangers Ck	35.41558	148.83489	COABU	Callitriche	Low Emergent Macrophytes
MF041	23 Feb 2022	Condor Ck DS old ford	35.3125	148.84407	CNDOF	Callitriche	Moderate Filamentous Algae
MF042	23 Feb 2022	Condor Ck at Picnic table	35.31761	148.85942	CNAPT	*No Plant Community*	Moderate Filamentous Algae
MF043	24 Feb 2022	Condor Ck at Warks Rd	35.31469	148.87431	CNAWA	Callitriche	Moderate Filamentous Algae
MF044	13 Mar 2022	Dry Ck	35.36036	148.91724	DRYCK	Veronica	Low Amphibious Dicots
MF045	13 Mar 2022	Pierces Ck	35.36048	148.90578	PIERC	Gratiola	Low Emergent Macrophytes
MF046	13 Mar 2022	Pierces Ck at Crossing	35.35851	148.90614	PIERX	Callitriche	Moderate Floating-leaf
MF047	17 Mar 2022	Bogong Ck	35.77105	148.94464	BOGON	Gratiola	Very Low Filamentous Algae
MF048	17 Mar 2022	Tributary to Bogong Ck	35.77145	148.94502	BOGTR	Veronica	High Mixed
MF049	17 Mar 2022	Breakfast Ck DS Old Boboyan Rd	35.80271	148.96153	BCOBO	Veronica	High Mixed
MF050	19 Mar 2022	Tributary to Nursery Ck	35.70284	148.9957	NURT1	*No Plant Community*	Moderate Filamentous Algae
MF051	19 Mar 2022	Tributary to Nursery Ck	35.7022	148.99611	NURT2	Gratiola	Moderate Filamentous Algae
MF052	19 Mar 2022	Nursery Ck	35.69929	148.99724	NURSY	Myosotis	Moderate Filamentous Algae
MF053	21 Mar 2022	Lees Ck upper	35.3594	148.84186	LEECU	Callitriche	Moderate Floating-leaf

Site Number	Date Sampled	Site Name	South	East	Code Name	VIS plant community	BET assemblage
MF054	21 Mar 2022	Lees Ck lower	35.32981	148.88638	LEECL	Veronica	Moderate Filamentous Algae
MF055	23 Mar 2022	Naas Ck DS Old Boboyan Rd	35.83048	148.95944	NAOBO	Myriophyllum	High Mixed
MF056	23 Mar 2022	Naas Ck in western valley	35.80854	148.92387	NATOV	Myriophyllum	High Mixed
MF057	25 Mar 2022	Naas Ck in eastern valley	35.86041	149.00125	NAEVA	Myriophyllum	High Mixed
MF058	25 Mar 2022	Naas Ck near Mt Clear turn-off	35.85663	148.99432	NANMC	Myriophyllum	High Mixed
MF059	30 Mar 2022	Little Dry Ck	35.7992	148.99667	LIDRM	Myriophyllum	High Mixed
MF060	30 Mar 2022	Little Dry Ck UPS rapids	35.77517	148.99896	LIDRU	*No Plant Community*	*No BET assemblage*
MF061	1 Apr 2022	Pierces Ck UPS Vanitys Crossing Rd	35.34118	148.91432	PIEWA	Callitriche	Moderate Floating-leaf
MF062	1 Apr 2022	Pierces Ck above Vanitys Crossing Rd	35.34054	148.91435	PIEAX	Veronica	Moderate Floating-leaf
MF063	3 Apr 2022	Condor Ck at Bullock Paddock Rd	35.32582	148.88733	CNABP	Callitriche	Moderate Filamentous Algae
MF064	3 Apr 2022	Condor Ck DS confluence Lees Ck	35.32913	148.88785	CNDLC	*No Plant Community*	Moderate Filamentous Algae
MF065	4 Apr 2022	Hospital Ck at Gudgenby Cottage	35.74465	148.98811	HOGUC	Myriophyllum	High Mixed
MF066	6 Apr 2022	Condor Ck at Padovans Crossing	35.3256	148.88948	CNPAX	Gratiola	Moderate Filamentous Algae
MF067	11 Apr 2022	Condor Creek beside Condor wetland	35.31936	148.82759	CNBWE	Myosotis	Moderate Floating-leaf
MF068	13 Apr 2022	Tributary to Naas Ck	35.82415	148.96117	NATR1	Myriophyllum	High Mixed
MF069	13 Apr 2022	Grassy Ck above confluence Naas Ck	35.86746	149.01331	GCUNC	Myriophyllum	High Mixed
MF070	13 Apr 2022	Tributary to Grassy Ck	35.88672	149.00368	GRTRI	Myriophyllum	High Mixed
MF071	17 Apr 2022	Punchbowl Ck	35.51157	148.93503	PUNCH	Myosotis	Moderate Filamentous Algae
MF072	18 Apr 2022	Tributary to Gibraltar Ck	35.49881	148.93749	GBTR1	Myosotis	Moderate Filamentous Algae