Rehabilitating submerged macrophytes enhances survival of larval and juvenile fish

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1. Introduction

Submerged vegetation forms an important component of aquatic systems, but the effects of submerged macrophytes on ecosystem organisation, including changes in trophic structure, have not been well studied (Wigand et al. 2000). It is widely believed that there has been a loss of submerged and emergent macrophytes from lowland Australian rivers. Anecdotal information from residents, cross-referenced between sources to enhance its reliability, indicates that extensive stands of submerged and emergent macrophytes commonly occurred in the Lachlan River in the past (Roberts and Sainty 1996). Long-term inhabitants of communities on the Murray, Murrumbidgee and Darling Rivers provide similar descriptions of extensive macrophyte beds occurring prior to increased river regulation. It is likely that many of the smaller lowland rivers also had extensive growths of macrophytes but historical records are not available to assess this. The loss of macrophytes is attributed to increased turbidity, alterations in flow, and larger nutrient loads (Walker et al. 1994), all resulting from increased development within river catchments.

Macrophytes potentially increase the productivity of aquatic invertebrate populations by providing physical in-stream habitat and by increasing the supply of food through periphyton growth on their leaf surfaces. Invertebrates and sometimes periphyton can both be important food sources for larval and juvenile fish (King 2002), and macrophyte beds may also provide an important physical habitat for larval and juvenile fish. Some fish species also use aquatic macrophyte surfaces for egg attachment. These considerations led to the hypothesis that the loss of submerged macrophytes from river systems has impacted on fish populations by reducing the habitat and food sources available for the growth and survival of larval and juvenile stages.

Increased food resources may enhance fish populations if food shortages are critical at particular stages of their development. Measurements of river metabolism in the lowland reaches of the Murray River have indicated that this system is energy limited (Merrick and Oliver unpublished data). Phytoplankton provided the major part of the organic carbon metabolised within this river, but phytoplankton productivity was limited by the availability of light. Although coarse woody debris (snags) is an important component of

physical structure, its contribution to river productivity in turbid, lowland rivers is relatively small (Simon Treadwell pers comm). Benthic algal production in these rivers can also be small (Merrick and Oliver unpublished data), often being restricted by light penetration. In contrast, the surface area available for the growth of attached algae can be increased greatly by the presence of aquatic macrophytes. For example, typical beds of the submerged macrophyte *Vallisneria* have leaf surface areas of between 4 and 40 square metres for each square metre of substrate covered (Royle et al. 1991, Blanch et al. 1998). The increased surface area for growth of attached algae can lead to greatly enhanced primary production, providing a larger carrying capacity for macro- and micro-invertebrates with the potential to improve the food resources for larval, juvenile and adult fish.

It is difficult to establish and maintain populations of macrophytes, especially in systems where their paucity indicates that conditions are detrimental to growth. To circumvent this difficulty, it was proposed to use artificial macrophytes as surrogates to investigate biological responses to increased macrophyte densities. Artificial macrophytes of various shapes and sizes have been used in marine systems and in freshwater studies in other countries, but construction and application are still very much empirically determined, with little quantitative data available to guide design. Artificial macrophytes have not been extensively trialled in Australian freshwater systems and their application in this project was in part a "proof of concept" regarding their usefulness as surrogates for real macrophytes in experimental manipulations.

Vallisneria is a common and widely spread submerged macrophyte that is native to Australia. It is usually known as ribbon weed because of its ribbon-like leaves. Ribbon weed grows in a wide range of habitats from stationary to fast-flowing waters and is able to tolerate up to 1500 ppm total salts. The artificial macrophytes used in this project were designed to approximate the form of *Vallisneria* but this should not be interpreted to mean that the findings are restricted to this specific plant. The artificial macrophytes provide a means of creating a physical habitat and an enhanced site for production, and these characteristics are common to all submerged plants, although the degree will be influenced by morphometric features.

2. Objectives and Outcomes

The aim of this project was to demonstrate whether the re-establishment of submerged macrophytes in lowland rivers would improve the availability of nursery habitat and enhance the food resources to support larval and juvenile fish. The hypothesis to be tested is that the provision of macrophyte beds increases the occurrence of newly hatched fish by improving both food availability and habitat structure. Several specific objectives were identified to address the aim:

- Measure the change in primary productivity resulting from the installation of artificial macrophytes (AM).
- Measure the change in zooplankton and macro-invertebrates resulting from the installation of AM.

- Measure the abundance of larval and juvenile fish with and without AM.
- Assess if the provision of macrophyte beds increases the occurrence and persistence of larval and juvenile fish.
- Assess the major food sources used by the larval and juvenile fish during their development phase in the AM.
- Identify the influence of AM patch size on biological responses.

Information from these objectives should provide the following outcomes:

1. An improved understanding of the role that submerged macrophytes play in:
    - enhancing riverine primary production by providing a substrate for periphyton.
    - enhancing the biomass of zooplankton and macroinvertebrates by improving habitat structure and by increasing the food supply through growth of periphyton.
    - increasing the residence and survival of larval and juvenile fish by providing improved habitat structure and increased food supply
2. An assessment of the influence of AM patch size on the biological responses.
3. Information on the value of submerged macrophytes as nursery habitat for the growth and survival of larval and juvenile fish and the expected impact on fish populations.

The project was planned to span two growing seasons. In the first season an initial experiment was designed to determine if algae and invertebrates colonised the artificial macrophytes and if larval and juvenile fish used the artificial macrophytes. The influence of artificial microphyte patch size was also investigated. In the second season, spatial and temporal changes in the communities of aquatic organisms associated with the artificial macrophytes were investigated. Unfortunately, the late start of the project, due to circumstances beyond the control of the Project Team, severely curtailed the available time in the first season and only a small pilot experiment could be done.

3. Methodology

Locality:

A section of the Broken River near Benalla in northern Victoria (Figure 1) was used for the experimental manipulations. The Broken River is a tributary of the Goulburn River, which is itself a tributary of the Murray River. The Broken River is ca. 20-30 metres wide and contains sequences of pools (up to 3 m depth) and runs (<1 m depth) as well as still, shallow backwaters. The Broken River is mildly regulated through two impoundments, Lake Nillahcootie and Lake Mokoan. Summer discharge levels from these impoundments are fairly low however some water is released for irrigation purposes. Winter rainfall floods do occur in some years usually between August and October. The three sites were located on the Broken River between the weir at Benalla and the inflow channel from Lake Mokoan at Casey Weir (Figure 1). Two sites were accessed through the property "Morago", while the third was further downstream on the property "Mokoan Park". A distance of 0.5 km separated the Morago Upstream and Morago Downstream sites, while the site at Mokoan Park was a further 2 km downstream.

Populations of ten native and four introduced fish species are known to occur in the lowland region of the Broken River (Humphries and Lake 2000). Significant populations of the native species Murray cod (*Maccullochella peelii*), golden perch (*Macquaria ambigua*), Australian smelt (*Retropinna semoni*) and crimson-spotted rainbow fish (*Melanotaenia fluviatilis*) have been documented. The most common introduced species are carp (*Cyprinus carpio*) and mosquitofish (*Gambusia holbrooki*). Information on larval fish in the Broken River (Humphries et al. 2002) indicates that the young stages of different fish species appear at different times over the period September to April.

The historical extent of submerged macrophytes in the Broken River is unknown, as records do not exist. The river has undergone significant siltation and now has extensive areas of mobile sands as a result of human activities in the catchment. These changes are likely to have reduced the occurrence of submerged macrophytes, although natural patches of *Vallisneria* still occur intermittently throughout the river. Although the original extent of macrophytes is unknown, the Broken River was chosen as the experimental site because of its manageable size, the extensive range of native and introduced fish species available to investigate fish interactions with macrophytes, and the physical changes that have occurred as a result of catchment disturbance. The results from this river should be transferable to other rivers in the region that have experienced similar changes in flow and catchment impacts.

Artificial macrophyte units:

The artificial macrophyte units (AMU) were based on a design developed for portable artificial seagrass units (Kenyon et al. 1999) but modified for our purposes (see Photograph 1). The units consisted of a frame ca. 1.0 m x 1.0 m constructed from 40 mm. diameter PVC pipe. The frame was fitted with 20 cross bars of 25 mm diameter conduit held in place by two aluminium brackets that ran along the inside of two opposite sides of the frame. The artificial macrophytes were made of positively buoyant green 'Canvacon' plastic tarpaulin (Rheem Plastics) attached to the plastic cross-bars. For efficiency of construction and for added strength, 1 m^2 squares of the plastic tarpaulin were stacked in lots of 75 sheets and cut repeatedly with a band saw from two opposite sides, leaving a 10 cm strip uncut in the middle, to form two rows of blades each ca. 2 cm wide. Every third blade was removed to provide a more open structure to the artificial plants. Each sheet was then folded in half around a cross bar and attached to it. The form of the artificial macrophyte mimicked that of *Vallisneria* with 'leaf blades' 30-50 cm long and 1-2 cm wide. The density of the artificial plants was similar to natural stands of *Vallisneria* such that for each square metre of base there was ca. 25 m^2 of frond area. One hundred and thirty-five AMU's were manufactured for the project. The artificial macrophyte units can be deployed singly or aggregated in various combinations to investigate the influence of macrophyte patch size. Each artificial macrophyte unit was held in place on the river bed by attaching the PVC pipe frame to two star droppers positioned at the upstream and downstream corners. The artificial macrophyte units were deployed about one month prior to the first sampling to allow 'conditioning' of the materials and the development of periphyton populations on the blades.

Pilot experiment:
Eighteen artificial macrophyte units were installed in the Broken River in mid March 2001, arranged in two patch sizes (1 m^2 and 4 m^2). After 22 days to allow for conditioning and periphytic algal community development, three replicates of each unit size were sampled along with three river controls. The artificial macrophyte units were sampled three more times at intervals of 26, 21, and 37 days before being retrieved from the river in late June 2001. On each occasion six units and three river controls were sampled for algae, invertebrates and fish, except for the last occasion when only periphytic algae were sampled from all of the units due to the lateness in the season.

Main experiment design:
An upstream-downstream, block design model was developed in consultation with the project Scientific Advisory Committee. At three sites on the Broken River, a 60 m length of river (a reach) was divided into three 20 m lengths or blocks. In each of the three blocks, 15 AMUs were placed randomly within the zone of macrophyte growth as determined by light penetration and practical considerations of working depth and substratum flatness. Based on the findings of the pilot study, 1 m x 1 m AMU's were deployed. As the AMU fronds were 45 cm long, deployment was restricted to water depths between ca. 30 and 70 cm. In the upstream section of each of the three blocks, an area of several metres length was left devoid of AMU's and used for taking samples to act as "river controls". In general, controls were taken by randomly selecting and enclosing areas of the natural river habitat for sampling. On each field trip, three natural river control samples and three AMU's were sampled from each block of each reach. The design allowed for five sampling occasions without repeat sampling of the AMU's. Because control sections were positioned immediately upstream of each block they were also interspersed between blocks, a design that allowed for the comparison of AMU units, blocks and reaches.

The fifteen artificial macrophyte units covered ca. 5% of the river channel surface area in a block, but the area of the fronds was equivalent to ca. 125% of the surface area. This resulted in a significant increase in cover and a doubling of the surface area available for attachment (sediment plus fronds). If algal biomass, primary production, invertebrate biomass and larval and juvenile fish densities respond to changes in cover and surface area, then these manipulations should be large enough to cause measurable responses.

Sampling:
AMU's were picked at random from un-sampled units. AMU's and river control samples were sampled in the same way. The sampling procedure involved a hierarchy of several methods and was devised to avoid repeatedly sampling the AMU's for different organisms.

The AMU or river bottom was enclosed with a corral approximately 1 metre in height made of PVC pipe and covered on four sides with plastic sheet, leaving the top and bottom open. Once the enclosure was in place, the algae attached to the artificial macrophyte blades was sampled. Four blades on the AMU were selected at random, cut

off and rinsed by agitating in the water. Three of these were placed in 90% ethanol for chlorophyll analyses, while the fourth was preserved in Lugol's iodine for algal identification. The AMU was then released from the star droppers, inverted inside the enclosure and agitated vigorously for 10 seconds to disperse attached animals and loosely adherent algae. After removing the AMU the water within the enclosure was then sampled using several techniques.

Firstly, fish and macro-invertebrates were sampled using the Sweep Net Electrofishing (SNE) method described by King and Crook (2002). Briefly, a portable backpack electrofisher (Smith-Root Model 12), with standard braided wire cathode and 15 cm diameter anode, was modified by attaching a moulded plastic (HDPE) square frame (25 x 30 cm) to the bottom of the anode pole. A removable 250 µm mesh net was fastened to the frame using Velcro™ attachments; the net tapering to a removable collection jar (8.5 cm diameter).

The SNE method was carried out by sweeping for 30 s backwards and forwards through the enclosure, with an up-an-down action, so that the entire water column was included in the sample. Trials showed that the enclosed water was swept approximately four times during the 30 s period. Clogging of the 250 µm mesh net usually occurred before the completion of the 30 s sampling time, creating a bow wave which substantially reduced the effectiveness of collection. The influence of clogging on the capture of fish was tested on one sampling occasion in February. After taking the normal SNE sample, three successive 30 s sweeps of a 0.5 m diameter 500 µm net were made through the enclosed water.

The well-mixed water within the enclosure was then sub-sampled for micro-invertebrates using a bucket to remove 10 or 20 l and concentrating the sample through a 50 µm mesh net. Invertebrate and fish samples were preserved in 70% and 95% ethanol, respectively, immediately after collection.

Finally, water samples were collected for chlorophyll analyses and for identification of the algae that was associated with the artificial macrophytes or river bed and resuspended during sampling. Chorophyll-a concentrations were measured spectrophotometrically following extraction into boiling 90% ethanol. Chlorophyll in the algae attached to the blades was extracted directly into boiling ethanol after establishing that boiling the 'Canvacon' plastic did not contribute to the chlorophyll absorption maximum. Algal biomass measurements were standardized to the AMU unit for comparison purposes.

Fish and invertebrate samples were sorted using dissecting microscopes. Fish were identified using the taxonomic guides McDowall and Frankenberg, 1981 and McDowall, 1996, while zooplankton and macro-invertebrates were identified using standard taxonomic guides.

Light traps were used on one occasion to determine whether fish were present in the reaches in which the AMUs were deployed. This method has been extensively used in this river for catching the juvenile stages of fish (Humphries et al. 2002). At the Morago

Downstream and Morago Upstream sites in February, 6 light traps were placed randomly at each of three locations: along the edges of the river, amongst the AMUs and in river control stations. The light traps were lit with yellow 12 h Cyalume ® light sticks, set before dark and retrieved the next morning.

Five small natural beds of *Vallisneria* were also sampled for algae, invertebrates and fish in January 2002 at the Mokoan Park and Morago Upstream sites. A further 12 randomly selected natural *Vallisneria* beds and 12 river control stations located ca. 1 km upstream of the AMU sites were sampled for fish only, in early May 2002. Samples were taken in the same manner as described for the AMUs, except that the natural plants could not be removed before sampling.

Whole river primary production and community respiration rates were estimated from diel cycles in oxygen concentration measured using submersible oxygen probes fitted with data loggers (Yeokal Model 612). Metabolism measurements were made simultaneously upstream and downstream of the artificial microphyte units, on all fieldtrips. The metabolic activity of individual blades from the artificial macrophytes was examined on one occasion by incubating groups of three excised blades in sealed clear tubes of river water at the surface and measuring diel dissolved oxygen changes. Tubes of river water without blades were used as controls.

On one occasion, measurements of current velocities around all of the artificial macrophyte units were made using a current meter counter with a 50 mm propeller (Hydrological Services Model OSS PC1). This was done when the water levels were representative of most of the sampling period. Discharge rates in the experimental section of the Broken River for the sampling period, were obtained from Goulburn – Murray Water.

Samples collected:
Sampling was done every third week to cover the breeding times of the different fish species present. This resulted in a total of five trips where all groups of organisms were sampled and productivity measurements made. Each trip lasted 4 days and required 3-4 participants. Additional field trips were required for verification measurements and for maintenance of the AMU's. All samples were analysed for fish, algal chlorophyll and river metabolism measurements. However, because of the large amount of work involved in sorting and enumerating the invertebrates and algae, it was not possible to analyse all samples for these groups. Consequently three trips have been selected to demonstrate the patterns in community composition for these groups

Data analysis:
Algal biomass was compared between controls and AMU's, between sites and over time using ANOVA. Algal community composition was analysed by MDS ordination of Bray-Curtis dissimilarity values using log transformed abundance data, followed by ANOSIM and SIMPER (Primer Software). ANOVA was used to test for differences in the number of taxa and the density of animals between controls and AMU's, between sites and over

time for both zooplankton and macroinvertebrates. Samples from the natural *Vallisneria* patches could not be included in the above ANOVA's because of the limited sample numbers.

4. Results

Macrophyte deployment and siltation:
The macrophyte design was found to be robust and all units survived through the deployment period. However, a major problem did appear within a few weeks of installation when many of the artificial macrophyte units became so heavily silted that the plastic fronds no longer floated up freely into the water but were weighed down near the river bed. This significantly reduced the area in contact with open water, increased the average depth of the fronds and provided a covering of sediment that is likely to have influenced both the physical and chemical conditions within the AMU's. As a consequence of this severe siltation, all of the artificial macrophyte units deployed in the major experiment were lifted from the water, rinsed and then redeployed in mid February 2002. This was done after the completion of the major sampling effort and only algae were monitored after the washing.

Pilot Experiment (March – June 2001):
A larger algal biomass developed on the artificial macrophyte units than in the river controls (Figure 2). There was no consistent difference between the small ($1m^2$) and large ($4m^2$) patches in terms of the algal biomass attached to the blades. There was a large variation in the amount of algae attached to individual blades within an AMU, but the mean biomass was similar between artificial macrophyte units. There was an increase in the concentration of algae associated with AMU's over the experimental period which could be due to both sedimentation and growth (Figure 2). The algal community was composed primarily of diatoms of many genera, but especially the centric *Melosira* sp. and pennate *Fragilaria* sp.

Large numbers of micro- and macro-invertebrates (250µm size partition) were found associated with the artificial macrophyte units. The numerically dominant micro-invertebrates belonged to the Macrothricidae, Harpactacoida and Chydoridae with a total of 24 taxa recorded. The number of taxa was similar between the controls and the small and large AMU patches (Figure 3). However, the concentration of animals was significantly larger in the artificial macrophyte units than in the controls (2 to 6 times more), and significantly greater in the small AMU patches than in the large AMU patches (Figure 3). In contrast, a diverse macro-invertebrate community developed within the artificial macrophyte units with 25 families being represented compared with 17 in the controls. A comparison with natural *Vallisneria* sp. patches demonstrated that plant-chewing groups of the Mollusca and Lepidoptera were missing from the AMU's as might be expected with artificial vegetation. Eight of the 25 families found in the AMU's belonged to the Ephemeroptera, Plecoptera or Trichoptera, which indicated a balanced community structure. No larval or juvenile fish were caught during the pilot experiment. This was attributed to the deployment of the artificial macrophyte units very late in the growth season when fish spawning was virtually complete. The pilot experiment

demonstrated that the artificial macrophytes were readily colonized by algae and aquatic invertebrates and there was no influence of artificial macrophyte patch size on this colonization. It also provided opportunities to test the sampling procedures and as a result, the attachment of the AMU's was altered so that the units could be readily removed to ensure greater electrofishing efficiency.

Major experiment (October 2001 – April 2002)

Hydrology:

Estimates of the daily discharge upstream of Casey Weir where the artificial macrophytes were deployed are shown in Figure 4. These had to be derived using water balance calculations based on the measured daily discharge for the Broken River from Casey Weir, which includes the outflow from Lake Mokoan. Negative values are due to the mass balance calculations. Discharge through the artificial macrophyte reaches was at baseflow levels for most of the sampling period. From late February until late April, irrigation releases from Lake Nillahcootie replaced outflow from Lake Mokoan thereby increasing discharge through the artificial macrophytes (Figure 4).

Current velocities (mean +/-se) measured around the artificial macrophytes at the Mokoan Park site (0.20 +/- 0.015 m/s) were higher than those at the Morago Downstream (0.10+/-0.009 m/s) and Morago Upstream (0.13+/-0.008 m/s) sites.

Algae:

Algal Biomass

Figure 5 shows the algal biomass results during the sampling period. Algae were either attached to the artificial macrophyte blades ("AMU blade"), associated with the artificial macrophyte blades ("AMU associated"), associated with the river bed ("Control associated"), in the river water column ("River"), attached to the natural macrophyte blades ("Natural blade") or associated with the natural macrophyte blades ("Natural associated"), The biomass of algae associated with the artificial macrophytes was more than an order of magnitude greater ($P<0.001$) than the control associated algal biomass (Figure 5). There were significant ($P<0.001$) changes in AMU associated algal biomass with time across all three sites. The AMU associated algal biomass increased to a maximum in December or early January and then decreased to a minimum in late January before increasing again in February. The algal biomass attached to the AMU blades was also an order of magnitude less than the AMU associated algal biomass (Figure 5) and showed significant ($P = 0.002$) changes with time. AMU blade algal biomass showed an inverse response to AMU associated algal biomass at the two Morago sites in late January i.e. blade algae increased when the associated algae decreased. This may reflect an influence of shading although it did not occur at the Mokoan Park site where blade algal biomass decreased when associated algae decreased. However, throughout the sampling period the Mokoan Park site had a lower ($P<0.001$) associated algal biomass and a higher ($P = 0.013$) attached algal biomass than at the other two sites upstream. This may reflect the higher average water velocity at Mokoan Park.

In late January and February the algal biomass associated with natural *Vallisneria* sp. plants was less than that associated with the artificial macrophytes but was still greater than the associated algae in the river bed controls (Figure 4). In late January the natural *Vallisneria* sp. blades had an attached algal biomass similar to the artificial blades but in February there was less algae attached to the *Vallisneria* sp. blades than to the artificial blades.

The algal biomass in the river water was lower than the algal biomass in the river controls, which included material resuspended from the bed by sampling, and was an order of magnitude lower than the algal biomass associated with the artificial macrophytes (Figure 5). River algal biomass was highest in November and decreased to a minimum in late January before increasing again in February.

Algal Composition

A total of 46 algal taxa contributed significantly to the algal communities. Diatoms dominated in terms of both the number of taxa and in algal abundance, often representing over 90% of the algal cells present. Green algae contributed significantly to abundance on artificial blades from the Mokoan Park site. Blue-green algae (cyanobacteria) dominated algal abundance on half of the natural *Vallisneria* sp.blades sampled with diatoms dominating on the other half. In November the blade samples, associated samples and control samples all had similar numbers of algal taxa while in January the controls had fewer numbers of taxa than both blades and associated samples which had similar numbers of taxa but more than in November. River samples had the fewest numbers of taxa with only diatoms present. Artificial macrophytes and natural *Vallisneria* sp. had similar numbers of algal taxa associated with them but the artificial macrophytes had greater numbers of algal taxa attached to the blades than did the natural *Vallisneria* sp.

Community Analysis

MDS ordination of all data suggested that the algal community associated with the artificial macrophytes was positioned between the blade attached algae and the river bed control algal communities. Ordination of the artificial macrophyte blade and the natural *Vallisneria* sp. blade algal communities in January shows two distinct communities which are significantly different (ANOSIM P = 0.2%). The diatom taxa *Gyrosigma*, *Pinnularia*, *Suriella* and *Diploneis* were all absent from the natural *Vallisneria* sp blades and contributed more than 4% each to the overall difference between the communities while the cyanobacteria *Lyngbya* was absent from the artificial blades and contributed 3% to the overall difference.

Algal Metabolism

Whole river metabolic rates derived from diel dissolved oxygen changes are reported as gO/m3/d and are shown in Figure 6 as a mean for each site across time. There was no evidence of an increase in whole river gross production (GPP), community respiration (CR) or net production (NP) downstream of the artificial macrophytes compared to upstream, at any of the three sites. The Mokoan Park site had significantly ($P<0.05$)

lower GPP, CR and NP rates than the other two upstream sites throughout the season. Whole river GPP initially increased from October to December and then declined in late January at all three sites whereas CR remained high from October to December and then declined through to June (Figure 6). Net production in the experimental section of the Broken River was negative throughout the season at all three sites.

Diel changes in dissolved oxygen are shown in Figure 7 for clear tubes containing river water with or without artificial macrophyte blades. Both photosynthetic increases and respiration decreases could be measured for the communities attached to the blades on this occasion (Figure 7).

Zooplankton:

Number of taxa
The number of zooplankton taxa was not significantly different between the three sites although the number of taxa varied significantly ($P<0.001$) with time, showing an overall reduction from November to January (Figure 8). On average, the number of taxa in the controls was greater ($P<0.01$) than in the AMU's but this was largely due to differences in December, with numbers being quite similar at other times.

Density
At each site there were significantly ($P<0.001$) larger numbers of animals in the AMU's than the controls (Figure 9). Frequently zooplankton density in the AMU's was an order of magnitude larger than in the controls. The density of animals at the downstream site (Makoan Park) was significantly ($P<0.001$) less than at the other two sites which had similar concentrations. There was a significant ($P<0.001$) change with time in animal density. An initial increase in zooplankton abundance between November and December was followed by a substantial reduction in January. With a few exceptions, microcrustaceans dominated the AMU's and six taxon groups (one rotifer and 5 microcrustaceans) accounted for the significant differences between the AMU's and the river. The natural macrophyte samples could not be included in the ANOVA, but a comparison of the data (Figure 9) suggests that there was no substantial difference between natural macrophytes and the AMU's in either types or numbers of animals.

Macroinvertebrates:

As a result of the sampling procedure some zooplankton were captured in the macroinvertebrate samples, but they were excluded from this analysis to ensure that changes in the macroinvertebrates were identified.

Number of taxa
The numbers of macroinvertebrate taxa increased ($P<0.05$) in a downstream direction with slightly higher numbers at the Mokoan Park site compared to Morago Upstream (Figure 10). There was no significant difference in the number of macro-invertebrate taxa present over time or between the AMU's and controls. Although not included in the

ANOVA, there were more macroinvertebrate taxa present on the natural macrophytes than on either the AMU's or controls.

Density

The density of macroinvertebrates was similar across all three sites (Figure 11). As with the zooplankton, the density of macroinvertebrates was significantly ($P<0.001$) greater in the AMU's than in the controls, often 5 times higher. The macroinvertebrate density did not show the significant decline between December and January observed with the zooplankton at all sites.

Figure 11 shows that the dominant taxa in the AMU's were the chironomids, followed by the ecnomids (*Ecnomus pansus*), the caenids and *Micronecta* spp. (*M. annae* and *M. australiensis*). The controls showed a similar pattern except that the ecnomids were rare. *Ecnomus* is a net-spinner needing a stable substrate for attachment (i.e. plants, logs or rocks) with a covering of sediment.

A comparison of the AMU's with natural macrophytes showed differences in both the number of taxa and the abundance of macroinvertebtrates. The natural macrophytes had about 5 more taxa and a substantially higher concentration of animals, approximately double the number, than was observed in the AMU's. The higher animal concentration in the naturals was due to the presence of simuliids and baetids which accounted for nearly 50% of the abundance. The next four abundant taxa in the naturals were the same groups as dominated the AMU's, chironomids, ecnomids, caenids and *Micronecta*, and they were present in similar numbers to the AMU's. The additional presence of the simuliids and baetids on the natural plants was attributed to the reduced amount of sediment associated with them. The simuliids are filter feeders and do not tolerate excessive siltation, while baetids are detritivores that generally feed on substrate with minimal sediment covering. That sediment was having an influence on the community structure was further supported by the observation that caenids, which are mainly detritivores that live on sediment covered bark, rocks or plants, were more common in the AMU's and control sites.

The natural macrophytes contained large numbers of the limpet snail *Ferrissia petterdi* and the aquatic caterpillar Nymphulinae sp.8 which were both absent from the AMU and control samples. Their absence from these habitats can be explained by the dietary requirements of these two species. Both are plant herbivores with the caterpillar chewing and the limpet rasping the leaf tissue. The artificial plants and the open water do not provide this food material. The presence of siimulids, baetids, *Ferrissia* and Numphulinae on the natural plants but rarely on the AMU's, accounts for much of the difference in the number of taxa between these two habitats.

Fish:

Table 1 shows the electrofishing results. From 108 artificial macrophyte samples, only one fish was captured and this was a western carp gudgeon which is commonly found in

still, edge samples. In comparison, 45 fish were captured from control river samples. These were usually Australian smelt, which is a schooling, midwater species, not needing to be associated with physical structure. Some European or redfin perch juveniles were also captured in the control river samples; these also tend to prefer open water.

Table 1. Frequency of AMUs (out of 9) with fish, total abundance of fish and species collected from AMUs and river controls in November and December 2001 and on two occasions in January 2002. Hsp4 = *Hypseleotris* sp. 4, Pf = *Perca fluviatilis*, Rs = *Retropinna semoni*, Hsp = *Hypseleotris* sp.

Month	Site	AMU			River		
		Freq	Total abundance	Species	Freq	Total abundance	Species
November	Morago DS	0.11	1	Hk	0.44	4	Hsp4, Pf, Rs
	Morago US	0	0	0	0	0	-
	Mokoan Pk	0	0	0	0.22	9	Rs
December	Morago DS	0	0	0	0.11	2	Pf
	Morago US	0	0	0	0.44	16	Rs
	Mokoan Pk	0	0	0	0	0	-
January 1	Morago DS	0	0	0	0.11	1	Rs
	Morago US	0	0	0	0	0	-
	Mokoan Pk	0	0	0	0.22	2	Rs
January 2	Morago DS	0	0	0	0.22	4	Rs
	Morago US	0	0	0	0.22	5	Rs
	Mokoan Pk	0	0	0	0.22	2	Rs, Hsp.

Table 2 shows the light trapping results. No fish were caught in light traps in either the artificial macrophyte units or in the river control samples. However, light traps placed at the river edge did successfully capture fish at the two sites that were tested, 34 being caught at the Morago Downstream site and 12 at the Morago Upstream site. These numbers are typical of light trap sampling which has been done regularly in the Broken River over the last few years (Paul Humphries pers. comm.). Five species were collected,

with dominance by carp gudgeons and gambusia, both small adult species that tend to be near the river edge and often associated with cover, though not exclusively so.

Table 2. Frequency of light traps associated with AMUs, edge stations and river stations (out of 6) with fish, total abundance of fish and species collected in May 2002. Hsp4 = *Hypseleotris* sp. 4, Pf = *Perca fluviatilis*, Rs = *Retropinna semoni*, Hsp = *Hypseleotris* sp.

	AMUs			River			Edge		
	Freq	Total abun	Species	Freq	Total abun	Species	Freq	Total abun	Species
Morago downstream	0	0	0	0	0	0	0.67	34	Hsp (13), Hsp4 (2), Hsp5 (1), Gh (17), Mf (1)
Morago upstream	0	0	0	0	0	0	0.33	12	Hsp4 (1), Gh (5), Mf (6)

Of the six natural *Vallisneria* sp patches that were sampled in late January 2002, two at Mokoan Park contained fish. Three *H. klunzingeri* adults were collected from one of the patches and a juvenile *Gadopsis marmoratus* (river blackfish) was collected from the other. Of the 12 natural macrophyte patches sampled in May 2002, 5 contained fish and a total of 5 fish were collected. The species were: *G. marmoratus* a juvenile, and adults of *Galaxias olidus* (mountain galaxias), *Gambusia holbrooki*, and *Melanotaenia fluviatilis* (crimson-spotted rainbowfish). Of the 12 control river samples three contained fish, with a total of 4 fish collected. These were all adult *R. semoni.*

5. Discussion

Siltation

The artificial macrophyte units were deployed in shallow regions of the river between depths of 40 and 75cm, but where natural macrophytes did not occur, even though light conditions appeared suitable to support submerged plants. The absence of natural macrophytes has been related to a range of water quality issues, but the rapid siltation of the AMU's suggests that abrasion due to suspended particles carried by the water, and smothering by sediment may be a critical factor in their loss from these systems.

Algae

Algal biomass was high on both the AMU's and natural *Vallisneria* compared with river controls suggesting that they provided a substrate for enhanced algal production. Over the

period of sampling, the numbers of algal taxa were initially similar between controls, AMU's and naturals, but by the final sampling occasion the number of algal taxa on the AMU's and naturals had increased and were higher than the river controls. This further suggests that the development of the algal community on the AMU's was not simply deposition but due also to growth. The number of algal taxa found on the AMU's was comparable with that on *Vallisneria* sp.

Despite the large increase in algal biomass associated with the AMU's, there was no measurable change in whole river primary production. However, algae attached to the artificial blades were metabolically active and photosynthesized when placed in appropriate light conditions. This suggests that the lack of a measurable effect of photosynthesis downstream of the AMU's could have been due to the siltation and sinking of the artificial macrophytes thereby reducing the available light to levels insufficient for active photosynthesis. There is a possibility that gas exchange with the atmosphere was sufficiently fast that changes in oxygen concentration were rapidly lost upstream of the measuring probe. However the dissolved oxygen concentration in the Broken River was continuously undersaturated for most of the sampling period which does not support a rapid rate of gas exchange with the atmosphere.

Zooplankton

Both the composition of the zooplankton communities and the concentrations of animals in the AMU's are similar to river backwater communities where larval and juvenile fish are frequently found. The AMU's appear to provide habitat of sufficiently slow flows (<0.4m/s) that microcrustaceans are able to persist. The animal numbers in November and December were high enough to support fish recruitment, as it has been estimated that juvenile fish require about 500 animals per litre to sustain growth (Paul Humphries pers. comm.). The decrease in abundance in late January may have been due to the sedimentation of artificial macrophytes, thereby decreasing the potential surface area available for grazing. Alternatively a flow event in mid January may have washed out both the zooplankton and the associated algae from the artificial macrophyte units at all sites. The available discharge data is not reliable enough to accept or reject this possibility.

Macroinvertebrates

The macroinvertebrate communities associated with AMU's were similar in general to those associated with natural macrophytes, except for the large concentrations of simuliids and baetids that were found on the *Vallisneria* sp. Neither of these groups of organisms is likely to be a useful food source for larval fish as they are too large. Simuliids are not common in backwaters where juvenile fish are frequently found and so their absence from the AMU's is unlikely to have influenced their attractiveness. Baetids are found in backwaters, and it is possible that their absence may have influenced the usefulness of AMU's to juvenile fish. The community structure of the macroinvertebrates appeared to be altered by the high sediment load on the AMU's, and it is possible that this has also had an influence on juvenile fish. The high concentrations of macroinvertebrates associated with the AMU's suggest that they provide an enhanced environment for these organisms.

Fish

No significant numbers of larval or juvenile fish were caught in the AMU's or the natural macrophytes, especially when compared with those caught in light traps from the river edge. It would seem that the submerged macrophytes in the Broken River, artificial or natural, do not provide habitat that is extensively used by larval and juvenile fish. This is despite the observation that the food resources (algal, zooplankton and macroinvertebrates) associated with the macrophytes are substantial and, in the case of the invertebrates, comparable to those found in backwaters at the river edge where larval and juvenile fish are caught in highest numbers. Larval and juvenile fish did not take up residence in either the artificial macrophytes or real macrophytes under the conditions tested in the Broken River.

It was not possible within the scope of this project to assess whether the increased concentrations of organisms associated with AMU's and natural macrophytes provided a continual source of organisms to the river that might enhance the overall food supply for fish. This is an important aspect to assess, as indirect use of macrophyte-enhanced food supplies may make an important contribution to the support of fish populations.

6. Conclusions

Based on community composition and concentration data, the artificial macrophyte units provided reasonable surrogates for natural macrophytes, although some differences were evident, particularly amongst the macroinverbrate communities. A major problem with their deployment in the Broken River was the extraordinary rate of siltation, and in some cases burial, that occurred. This was difficult to overcome and perhaps indicates why the distribution of natural macrophytes is so limited in this river.

There are many provisos that must be kept in mind when assessing the outcomes of this project. These include: the very short period of investigation - essentially one season only; the large amount of technique development that was necessary to devise an acceptable sampling procedure; the relatively small number of samples that could be taken from natural macrophytes; the difficulty of sampling larval and juvenile fish in the macrophytes, the high sediment loads in the river water and the limited geographical location. However, it would appear from these results that larval and juvenile fish were not using the AMU's or the natural macrophyte that it most closely resembled (*Vallisneria*) for habitat. The artificial and natural macrophytes both enhanced the development of algal, zooplankton and macroinvertebrate communities and it is likely that these increase the food supplies available to support fish populations, provided that habitat requirements are met. However, it was not possible to demonstrate these links in this project.

Although these results are necessarily of a preliminary nature, if correct they have major implications for river management. The lack of use of these macrophytes by fish was unexpected and needs further clarification. A repeat of the experiment, but in a system less affected by suspended sediments, would provide an opportunity to explore the

impact of sediment loads on the organisms associated with macrophytes. If the plants remain more erect it is likely that they will offer improved habitat and this may enhance their usefulness. In clearer waters there may also be a greater opportunity to compare responses of AMU's with different forms of natural macrophytes.
As expected, the presence of macrophytes enhanced primary and secondary production but the fate of this material is unknown. The production by attached algae was not easily measured and this too was surprising and might have major implications for estimates of river metabolism that are based on measuring oxygen concentration changes in rivers. Again, this may be related to siltation of the macrophytes and a comparison with a system containing a reduced sediment load would be useful.

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