Protecting aquatic ecosystem health: are water quality objective realistic? Case studies from Queensland, Australia

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Pour la protection des écosystèmes aquatiques : les objectifs de qualité de l'eau sont-ils réalistes ? Études de cas du Queensland, Australie.

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RESUME

Beaucoup d'autorités de réglementation ont établi des objectifs ou des seuils de qualité de l'eau sur la base de concentrations nutritives pour sauvegarder la santé des écosystèmes aquatiques. Mais ces critères reflètent-ils avec précision l'état biologique et écologique ? Notre recherche s'est concentrée sur le comportement de zones humides artificielles destinée à l'amélioration de la qualité de l'eau et à la santé des écosystèmes. Dans cet article nous présentons des données sur la richesse d'espèces de macroinvertébrés de deux zones humides de traitement d'eaux d'égout et de deux zones humides de traitement des eaux pluviales. En dépit des concentrations en nutriments supérieures aux objectifs de qualité de l'eau, chacune des 4 zones humides abritait un assemblage divers des macroinvertébrés y compris des taxa sensibles. De notre étude nous avons conclu que les objectifs de qualité de l'eau peuvent être trop rigoureux et que les plantes aquatiques sont plus importantes pour la richesse de macroinvertébrés. Ainsi, les zones humides artificielles sont efficaces pour l'amélioration de qualité de l'eau et la biodiversité aquatique.

ABSTRACT

Many regulatory authorities set water quality objectives or thresholds based on nutrient concentrations to safeguard aquatic ecosystem health. But do these criteria adequately assess the biological and ecological status? Our research has been focussing on the performance of constructed wetlands for water quality improvement and ecosystem health. In this paper we present data on macroinvertebrate species richness from two wastewater treatment wetlands and two stormwater treatment wetlands. Despite nutrient concentrations exceeding water quality objectives all four wetlands supported a diverse assemblage of macroinvertebrates, including sensitive taxa. From our study we concluded that water quality objectives may be too stringent and that aquatic plants are more important for macroinvertebrate richness. Thus, constructed wetlands are effective for both water quality improvement and aquatic biodiversity.

KEYWORDS

Constructed wetlands, macroinvertebrates, nutrients, sewage effluent, stormwater, water quality.

1 INTRODUCTION

Municipal wastewater discharged from point sources such as sewage treatment plants or sewer overflows, as well as urban stormwater runoff and combined sewer overflows, contain a variety of potential pollutants that may cause detrimental effects to aquatic ecosystem health in the receiving waters. Suspended solids (sediment and organic particles) and soluble nutrients (ammonium, nitrate, nitrite, phosphate) can be particularly damaging to aquatic ecosystems if present in large quantities. Suspended solids increase water turbidity, which reduces light penetration and photosynthesis and, if there is a high proportion of organic particles, then biochemical oxygen demand (BOD) increases. Excessive nutrients cause algal blooms and eutrophication.

In the 1970's there was recognition of the need for legislation to assist in the protection and restoration of aquatic ecosystems by eliminating or reducing point source discharges from sewage treatment plants. Davis (1997) observed recovery of macrobenthic communities following improvements in sewage treatment providing habitat was not physically limiting. However, it wasn't until the 1990's that recognition was given to the need to control diffuse source pollution such as stormwater runoff and combined sewer overflows (CSO's) into receiving waters.

So, what are the threshold concentrations or loads of these pollutants to ecosystem health? Whilst excess organic matter and nutrients can be detrimental to aquatic ecosystem health, both are essential resources for ecosystem functions. Organic matter provides a food source for heterotrophic microorganisms and macroinvertebrates while nitrogen and phosphorus are vital for autotrophic microorganisms (phytoplankton, periphytic algae) and macrophytes, which in turn provide a food source for macroinvertebrates.

The concentrations, or loads of contaminants, reaching the receiving waters from sewage discharge or urban stormwater runoff depends on several variables. In the case of sewage discharge this will depend on the pre-treatment processes (primary, secondary, tertiary) - in particular tertiary treatment – Biological Nutrient Removal, waste stabilisation ponds, lagoons and wetlands, the population size (person equivalent) "catchment", and peak usage times. In the case of stormwater runoff this will depend on size of catchment, land use within catchment, extent of vegetated cover versus impervious areas, rainfall intensity and duration, time between rainfall events, flow pathways (drains versus natural channels, wetlands).

The municipal wastewater industry has had regulatory legislative requirements for water quality discharge for the past 30 years. As a point source discharge the quality of sewage effluent can easily be monitored. In Australia acceptable discharge standards for sewage effluent are 30mgL^{-1} Total Suspended Solids (TSS), 20mgL^{-1} BOD, 5-15mgL^{-1} Total Nitrogen (TN) and 2-10mgL^{-1} Total Phosphorus (TP). Though more recently treatment performance expectations are < 5mgL^{-1} TN and < 2mgL^{-1} TP.

It is only relatively recently that regulatory authorities in Australia have set "water quality objectives" for receiving waters (ANZECC, 1992; Qld Gov., 1997) (Table 1). These water quality objectives have been implemented in response to perceived environmental degradation using measures such as decreases in the biodiversity of aquatic flora and fauna and increases in number of algal and cyanobacterial blooms. Regulatory authorities continue to set these threshold water quality objectives for broad geographical regions.

Water Quality Guidelines	TN	NH_4-N	NOx-N	TP	PO_4-P	TSS
Queensland	0.5	0.02	0.06	0.05	0.02	6
Brisbane City Council	0.65	0.035	0.13	0.07	0.035	15

Table 1. Water Quality Guidelines (WQG) for Brisbane and Queensland, Australia (mgL^{-1})

As noted by the European Union Framework Directive on eutrophication (EC, 2003) "quality status" should be assessed on the basis of observed changes in biological factors in aquatic ecosystems, not simply on the basis of nutrient concentrations. However, regulatory authorities set water quality thresholds based on nutrient concentrations, but do these criteria adequately assess 'poor', 'moderate' or 'good' quality status in terms of ecological disturbance and aquatic health. In estimating the condition of a biological element the following parameters should be considered (Table 2, p10):

- Presence or absence of a species or group of species
- Overall richness or richness of a particular taxonomic group(s).
- Relative number of taxa in a particular taxonomic group
- Abundance or relative abundance of a particular species or groups of species.
- Overall diversity, or diversity within a particular taxonomic group

Ecosystem health can be a difficult concept to define, since it can incorporate a wide range of attributes including loss of an individual species, a reduction in community species richness or diversity, dominance of an individual species to complete ecosystem dysfunction. In our study we looked at macroinvertebrate species richness and their sensitivity to pollution in four constructed wetlands – two receiving stormwater (Golden Pond and Bridgewater Creek), and two receiving secondary treated sewage effluent (Cairns and Cooroy).

2 METHODS

2.1 Site Description

2.1.1 Stormwater Wetlands

The two stormwater wetlands are located in Brisbane, South-East Queensland, Australia. Both are retrofit structures located within existing residential areas (70% impervious area) (Table 2).

	Golden Pond (180ha catchment)		Bridgewater Creek (200ha catchment)	
	Wetland 1	Wetlands 2	Pond 1	Ponds 2-6
	water lilies, aquatic creepers, submerged pond weeds		emergent sedges and rushes	
Vegetation	10 sp.	7 sp.	3 sp. (littoral zone)	10 → 4 sp. (marsh zones)
% cover	80%	90%	1%	20 → 7%
Dimensions	80m x 15-20m	55m x 20m	30 x 34m	40-50m x 15-20m
Area	1550m^2	1100m^2	1000m^2	7000m^2
Depth	0.2 – 0.8m	0.5 – 1.2m	2m	0.2 - 1.5m

Table 2. Physical attributes of Golden Pond & Bridgewater Creek Wetlands

Golden Pond "Wetland System". Constructed in 1999 it consists of two contiguous wetlands. Both wetlands are dominated by floating-leaved emergent macrophytes: water lilies (*Nymphaea, Nymphoides*), aquatic creepers (*Ludwigia, Paspalum, Persicaria*), and submerged pond weeds (*Elodea, Ceratophyllum*) (Greenway and Polson, 2004).

Bridgewater Creek "Wetland System". Constructed in 2001, it consists of six inter-connected ponds. Pond 1 has a 2m littoral zone dominated by *Schoenoplectus validus*. Ponds 2 – 6 were designed with several macrophyte zones (ephemeral, shallow marsh, marsh and deep marsh), the dominant marsh species being *Juncus kraussii; S.validus, S.mucronatus, Bolboschoenus fluviatalis, Baumea rubiginosa* and *B.articulata*. However, macrophyte establishment was poor (Greenway *et al*. 2006;

Jenkins & Greenway 2007) resulting in only 20% cover in year 1 (2002); 13.5% cover in year 2 (2003) and 7.5% cover in year 3(2004) in the marsh zones.

Water quality during wet weather events and dry weather between 2001 – 2003 at Golden Pond and 2002 – 2004 at Bridgewater Creek is summarised in Table 3.

		TN	NO_x-N	NH_4-N	TP	PO_4-P	TSS
Golden Pond							
Wetland 1	Wet	1.22 ± 0.58	0.38 ± 0.28	0.09 ± 0.09	0.12 ± 0.05	0.06 ± 0.06	20 ± 8
	Dry	0.70 ± 0.33	0.58 ± 0.71	0.05 ± 0.05	0.08 ± 0.01	0.03 ± 0.03	6 ± 3
Wetland 2	Wet	0.94 ± 0.51	0.22 ± 0.16	0.07 ± 0.04	0.11 ± 0.06	0.06 ± 0.05	24 ± 12
	Dry	0.97 ± 0.50	0.25 ± 0.23	0.08 ± 0.09	0.14 ± 0.07	0.05 ± 0.08	13 ± 9
Bridgewater Creek							
Pond 1	Wet	1.45 ± 1.05	0.38 ± 0.40	0.10 ± 0.09	0.22 ± 0.09	0.12 ± 0.08	24 ± 16
	Dry	1.28 ± 0.45	0.12 ± 0.24	0.10 ± 0.09	0.22 ± 0.10	0.08 ± 0.06	10 ± 6
Pond 6	Wet	1.08 ± 0.36	0.07 ± 0.09	0.13 ± 0.15	0.19 ± 0.11	0.03 ± 0.02	22 ± 12
	Dry	1.04 ± 0.36	0.10 ± 0.14	0.11 ± 0.11	0.17 ± 0.07	0.02 ± 0.01	16 ± 8

Table 3. Water Quality Parameters for Bridgewater Creek and Golden Pond (mgL-1; $\overline{x}$ ± SD

2.1.2 Wastewater Treatment Wetlands

The wastewater treatment wetlands are located in Cairns, northern tropical Queensland and Cooroy (Noosa Shire), South-East Queensland. The Cairns Wetland was constructed in 1994 and consists of 3 linear channels, these were originally band planted with a diversity of species however, *Typha* spread rapidly and now dominates (Greenway *et al*., 2003). It receives secondary effluent after passing through an oxidation ditch and hence water quality is low in ammonia (Greenway and Woolley, 2001).

The Cooroy Wetland consists of 2 large linear wetlands built in 1995 and 1999. Each wetland consists of 3 large cells linked by pipes, each cell is separated by septa into sections producing a sinusoidal flow path. Cell 1 is shallow (20-40 cm) throughout. Cell 2 and Cell 3 each have a deep pond (1-2 m) in the first section (30 m length), the remainder is shallow. The wetland supports a diversity of plants (Greenway *et al*., 2003). The secondary effluent is treated by a trickling filter followed by alum dosing (to remove phosphate by precipitation), it then flows into an open water lagoon prior to release into the wetlands. (Table 4).

	Cairns	Cooroy
Vegetation	26 species; *Typha* dominant	38 species; diverse; sedges dominant
% cover	95%	70%
Area	2 x 300m^2 1 x 900m^2	2 x 7650m^2
Depth	0.4m	0.2 – 0.4m (marsh) 1 – 2m (pond)

Table 4 Comparison of physical attributes of the Cairns and Cooroy wastewater treatment wetlands.

Water quality data collected at Cairns and Cooroy wastewater treatment wetlands is summarised in Table 5.

	TN	NO_x-N	NH_4-N	TP	PO_4-P	TSS
Cairns						
In	6.1	5.0	0.5*	7.8	7.5	4.8
Out	1.6	<0.1	0.5	7.2	6.8	4.5
Cooroy						
In	25.0	8.0	12.5	0.02**	<0.01	10
Out	6.5	1.4	1.1	0.02	<0.01	6

* oxidation ditch pre-treatment for nitrification of NH_4 ** Alum dosing pre-treatment to remove PO_4

Table 5. Water Quality Parameters for Cairns and Cooroy

2.2 Aquatic Macroinvertebrates – Collection and Identification

Macroinvertebrate taxa were sampled at Golden Pond and Bridgewater Creek wetlands between 2001 and 2004 and at Cairns and Cooroy in 2001 and 2002.

Macroinvertebrates were collected from edge habitats (marsh areas < 1.5m deep) along the bank using a triangular framed, 250µm mesh dip net. Samples preserved in 70% alcohol and identified to family level for most orders, to sub-family for Chironomidae, or to the lowest taxonomic level possible and scored as present or absent at each site.

The macroinvertebrate data set was analysed to assess the ecological health of the wetland by using the three indices of ecological condition as used by the Ecological Health Monitoring Program (EHMP) in South-East Queensland (EHMP, 2006). The three indices calculated were for Invertebrate Family Richness; Plecoptera, Ephemeroptera and Trichoptera richness (PET); and Stream Invertebrate Grade Number – Average Level (SIGNAL) – using the SIGNAL-2 grades for invertebrate families (Chessman, 2003). Taxa were also grouped according to functional feeding groups (FFG) in order to establish if there was any pattern to their distribution and abundance.

3 RESULTS AND DISCUSSION

3.1 Water Quality

From Tables 3 and 5 it can be seen that both the stormwater wetland and wastewater treatment wetlands exceed many of the WQO. In the stormwater wetlands, Pond 6 and Wetland 2 show slightly better water quality than Pond 1 and Wetland 1 indicating improved treatment through the system. Nevertheless, nutrient concentrations and TSS in both wet and dry weather are highly variable. In the wastewater treatment wetlands influent nitrogen and phosphorus varied due to pretreatment. In Cairns most of the nitrogen was NOx-N, which was reduced to < $0.1 mgL^{-1}$ producing effluent of similar quality to the stormwater wetlands. However, phosphorus was high with little reduction in concentration. In Cooroy nitrogen was high in the influent with 50% NH_4-N and 32% NOx-N. Considerable reduction in both NH_4 and NOx-N occurred, but effluent concentrations still exceeded WQO. Virtually all phosphorus had been removed from the influent by alum dosing pre-treatment and there was no increase through the wetland, suggesting any phosphorus generated *in situ* was rapidly removed by ecosystem processes. TSS was low in the wastewater influent, with the outlet concentrations achieving WQO.

3.2 Macroinvertebrates

3.2.1 Species Richness and Pollution Sensitivity

Macroinvertebrate species richness showed an increase over the four years since construction at the Bridgewater Creek Wetland from 12 taxa to 84 taxa, with 28% of the families having a sensitivity grade > 5 (Table 6). Golden Pond Wetland maintained approximately 55 taxa, with 24% families having a sensitivity grade of >5.

	2001	2002	2003	2004
Worms & Leeches	3	6	9	8
Gastropods (water snails)	2	3	4	5
Crustaceans & Water Mites (ostracods, copepods)	1	5	4	14
Odonata (dragonflies & damselflies)	0	7	5	11
Mayflies & Caddisflies	1	2	2	2
Hemipterans (water bugs)	1	5	7	15
Dipterans (flies)	3	6	3	10
Coleopterans (water beetles)	1	6	8	19
Total Invertebrate Taxa	12	40	42	84

Table 6. Change in No. Macroinvertebrate taxa at Bridgewater Creek Wetland over time.

Macroinvertebrate species richness was also high in the Cooroy wastewater treatment wetland with a total of 81 taxa, with 20% of families having a sensitivity grade of >5. Sampling at Cairns was limited to 3 sampling events but still recorded 40 macroinvertebrate taxa (17% > 5 sensitivity grade) (Table 7).

Site	No. Macroinvertebrate Taxa	% Sensitive Families	SIGNAL2 Grade	No. EPT Families	% Predators
Golden Pond	55	24%	3.43	2	59%
Bridgewater Ck	84	28%	3.60	3	54%
Cairns	40	17%	3.00	1	50%
Cooroy	81	20%	3.30	4	51%

Table 7.No. Macroinvertebrate taxa, % pollution sensitive families, SIGNAL grade, No. EPT families and % no. predators at 4 constructed treatment wetlands

SIGNAL-2 grades of < 4.0 but with number of families > 20 indicate poor water quality or harsh physical conditions. Number of EPT families was lower than EHMP guidelines for lowland streams. Both of these grades are derived for running waters and many wetland species thrive in more slow flowing wetland waters where dissolved oxygen may be low and suspended solids high. Even so, the SIGNAL-2 grade and the number of EPT taxa equalled or bettered the number commonly found in streams in South-east Queensland (EHMP, 2006).

Both the stormwater wetlands and wastewater treatment wetlands maintained a diversity of macroinvertebrate taxa over time. Despite WQO not being met for stormwater treatment this did not limit the colonisation and establishment of a biodiverse aquatic ecosystem. Furthermore, the concentrations of pollutants in the wastewater treatment wetlands were considerably higher and yet still supported a high species richness of macroinvertebrates. Davis *et al*. (1993) showed that moderately eutrophic wetlands in Western Australia recorded the greatest number of macroinvertebrate species. Treatment wetlands provide diverse habitat and food sources for macroinvertebrate organisms.

The increasing number of taxa at Bridgewater Creek Wetland appeared to be more aligned with increasing macrophyte abundance and availability of food than to water quality (Figure 1). In a study of a constructed wetland in Ohio it was found that macrophyte habitats best explained patterns of macroinvertebrate species richness (Grubh & Mitsch, 2004) and in Western Australia it was found that salinised wetlands dominated by macrophytes supported a higher abundance and richness of macroinvertebrates taxa (Strehlow, 2005).

Rochfort *et al*. (2000) noted that sediment deposited by stormwater and CSO's would be more likely to impact stream benthic communities than water chemistry – the former being a more long term effect, the latter being only a short term effect due to the high variability in the water quality during storm events and short exposure times.

Sheeder and Evans (2004) compared water quality and ecosystem health in impaired and unimpaired watersheds in Pennsylvania and found concentration thresholds of 2.01 mgL-1 N and 0.07 mgL-1 P, whereas EPA concentrations were set at 0.5 mgL-1 N and 0.02 mgL-1 P. Furthermore, most unimpaired watersheds based on biological assessment did not meet EPA nutrient criteria. Sheeder and Evans point out that variability in climate and landscape characteristics between ecoregions will also affect the variability and causes of eutrophication suggesting that nutrient and sediment thresholds are localised.

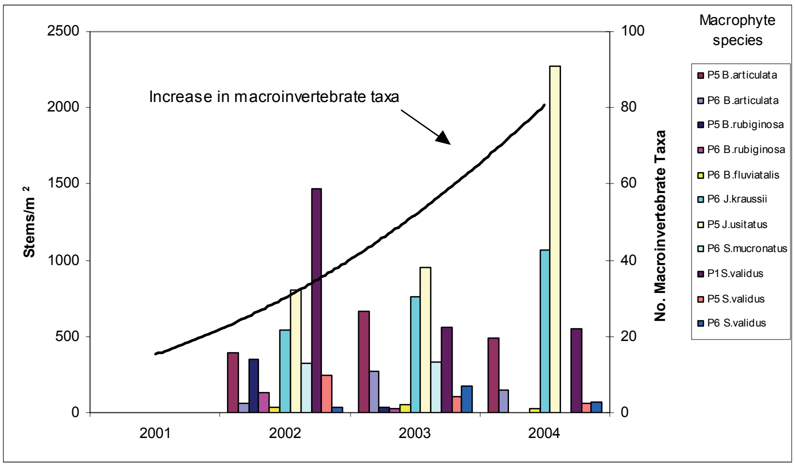

Figure 1. Increase in macroinvertebrate taxa (solid line) as macrophyte shoot/stem density increases over time at Bridgewater Creek Wetland.

3.2.2 Feeding group

More than half of the taxa collected at all sites could be classified as predators based on commonly used functional feeding groups (Cummins & Klug, 1979). Predators are often highly mobile (eg. stalking) and their strategies suit the slower flow of wetlands and ponds. Very few studies classifying macroinvertebrates by food type have been conducted in subtropical Australia. Tomanova (2006) found that in neotropical streams in South America most macroinvertebrates fed on fine detritus and that traditional feeding groups did not necessarily apply. Many of the predators found in our study were odonates, which are often graded in biotic indices as being more sensitive to pollution. It could be that habitat, provided by macrophytes, and feeding strategies were a much stronger indicator of the presence or absence of particular taxa than water quality, and that water quality is not a good predictor of macroinvertebrate biodiversity in treatment wetlands. Wetzel (2001) noted that the most effective wetland ecosystems are those possessing a maximum biodiversity of macrophytes.

4 CONCLUSION

This study has demonstrated that nutrient concentrations recommended in water quality guidelines may be too stringent. Exceeding guidelines did not limit macroinvertebrate species richness in the four constructed wetlands examined in this study. Macrophytes may be more important than water quality for determining macroinvertebrate associations because of the creation of habitats and food resources.

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