Drivers affecting the aquatic biodiversity and the ecological value of water storages on irrigation properties: a conceptual model

Susan Lutton
Centre for Riverine Landscapes, Griffith University, PO Box 1176, Goondiwindi, QLD 4390
E-mail: Susan.Lutton@student.griffith.edu.au, luttonsusan@hotmail.com
Phone: 07 4671 4650, Fax: 07 4671 4858, Mobile: 0427 771857

Abstract
Floodplains along river systems of the northern Murray-Darling Basin contain a diversity of wetland habitats, maintained through highly variable patterns of flood inundation. However, in catchments such as the Border Rivers, the development of irrigation farms on floodplain areas and subsequent flow regulation has reduced the extent and frequency of floods and led to a decrease in the distribution of wetlands. Due to the flow variability of the system, irrigators use on-farm water storages to store water until required for irrigation. With the decline in natural wetlands, these water storages may now represent a key form of artificial aquatic habitat within the Border Rivers. A conceptual model was developed to explore the drivers affecting the biodiversity of on-farm storages. It is believed that ring tanks with a greater selection of habitat types and more complex morphology will support a more abundant and diverse animal community. Potential management options to improve storage biodiversity include adding coarse woody debris to the banks, planting aquatic vegetation and limiting recycled tailwater to only one storage on the property.

Keywords: biodiversity, Border Rivers catchment, irrigation, modelling, on-farm water storages, wetlands

1. Introduction
Wetlands are an important part of floodplain ecosystems across semi-arid regions of Australia. In a flood event these wetlands are connected with the main river channel and, following floodwater recession, remain behind as isolated ecosystems. During the in between dry periods permanent wetlands provide vital refuge for aquatic plants and animals (Shiel, 1995; Walker *et al.*, 1997) and when flooding occurs, may provide an important source for colonisation of temporary waterbodies (Nielson *et al.*, 1999) and the adjacent river channel.

In the northern Murray-Darling Basin, water resource development has led to many natural wetlands contracting in size (DWR, 1995) or disappearing altogether (Kingsford, 1999). Along the Macintyre River, there is evidence that the growth of irrigation and river regulation has had significant implications for patterns of floodplain inundation, both by reducing the magnitude of flow events and the flooding frequency of certain channels (Southwell, 2002; Thoms *et al*., in press:a). Regulation of Whalen Creek, an anabranch of the Macintyre that supplies water to numerous wetlands and billabongs, has reduced flows to this creek by between 30-70% (Kingsford, 1999). With this decline in natural wetlands, artificial waterbodies (on-farm water storages) on the floodplain may now represent a key form of aquatic habitat.

There has been little investigation into the ecological value of on-farm storages in Australia to fish and macroinvertebrate populations. Jarman and Montgomery (2002) investigated the use of on-farm wetlands and storages by waterbirds in the Lower Gwydir Valley and Bowmer *et al.* (1994) considered the potential of irrigation drains to be used as wetlands. Brooks (1995) looked at the macroinvertebrate community structure in irrigation channels in the Gwydir Valley but concentrated on possible relationships between pesticide concentrations and macroinvertebrate communities and made no comparisons with natural wetlands. In other parts of the world artificial wetlands have been recognised as a possible alternative habitat. In the US for example, Knutson *et al.* (2004) found that constructed farm ponds may help sustain amphibian populations in landscapes where natural wetland habitat is rare.

There is the potential that, if properly managed, on-farm water storages in the northern Murray-Darling Basin may represent alternative habitats and refugia for fish and macroinvertebrates in the region. Effective management to maximise the ecological value of these on-farm storages will require an understanding of the processes at work in nearby natural wetlands and the factors affecting fish and macroinvertebrate populations. The present study aims to investigate these factors and identify possible drivers of population structure in on-farm storages. The findings will be used to outline management options to add to the Best Management Practices (BMP) manual for the cotton industry and will also have transferable applications to farmers wishing to use their on-farm storages for aquaculture purposes.

2. Study Area

The present study was undertaken in the Border Rivers catchment of north west New South Wales and southern Queensland. The first broadacre flood irrigation of cotton in the catchment occurred in the late 1970s and today this industry is of major economic importance, employing a large (approximately 2,500) number of people (BRFF, 1999). Broadacre irrigation is one of the main users of water within the catchment, extracting an average of 40% of the total Border Rivers inflows (BRFF, 2002). Summer rainfall patterns dominate the region, with 55% of the annual rainfall occurring from November to March. However, annual median rainfalls vary considerably. For example, records from Boggabilla show that annual rainfalls have ranged from a low of 174 mm in 1902 to a high of 1,041 mm in 1950 (DWR, 1995). Due to this variability, irrigators use large on-farm storages to store water pumped from rivers during regulated and unregulated flows, collect rainfall runoff and receive recycled tailwater. In 2002, on-farm storages across the catchment had a total capacity of approximately 459,000 ML (B. McCollum, pers. comm.).

There are many significant wetlands in the Border Rivers, particularly downstream of Boggabilla where the majority of broadacre irrigation occurs. These wetlands include lagoons or water holes in flood channels, such as the Telephone/Malgarai, Rainbow, Maynes and Boobera lagoons, Whalan Creek and the Morella Watercourse (DWR, 1995). There are also numerous anabranch channels and associated billabongs along the Macintyre River channel itself (Southwell, 2002). The larger lagoons have naturally high commence-to-flow levels and generally contain some permanent water.

3. Typical On-farm Storages

A large number of constructed on-farm storages occur in the Border Rivers catchment, built to overcome the problem of an unreliable natural water supply. Water stored in these on-farm storages is mainly used for the irrigation of row crops, particularly of cotton. Site visits were carried out to survey characteristics of 100 of these storages and interviews with landholders provided information about management practices, storage dimensions and water sources. A two-way cluster analysis of the water source and morphological data found that the majority could be placed in one group (Table 1). This group comprised storages containing water sourced from allocated flows, unallocated flows and overland flows and also recycled tailwater. Site visits revealed that the majority had little or no vegetation growing on the embankment and aquatic vegetation was also rare. The banks were devoid of snags and substrate was generally a fine, clay sediment. As most of the storages in the catchment were in this group, it was these characteristics that were used to construct a conceptual model of the factors driving the biodiversity of on-farm water storages in the region (Fig 1). These are hereafter referred to as 'typical storages'.

Table 1: Mean values for characteristics of typical on-farm water storages in the Border Rivers catchment

	Age (Years)	Height (m)	Area (Ha)	Perimeter (km)	Capacity (ML)	Distance from source (km)*
Mean	9.05	4.66	38.44	2.51	1553.24	2.71
SE	0.888	0.114	2.287	0.076	98.75	0.353

*Distance from source = distance to river from which flows are pumped

4. Conceptual Model – regulation of biodiversity between wetlands and storages

4.1 Riparian vegetation

The majority of on-farm storages visited had little or no vegetation on the embankment. Many property holders use broad-spectrum herbicides to kill any vegetation that emerges on the embankment or regularly grade the top of the embankment while others use selective herbicides to kill broad leaf species but allowing grasses to grow. The reasoning behind this is to prevent damage to the wall of the embankment from growing roots, which may cause leaks in the storage. In contrast natural wetlands have a multi-layered band of vegetation along their edge (Lovett *et al.*, 2003). The importance of linkages between the riparian zone and the aquatic ecosystem has been well documented (Bunn, 1993; Pusey and Arthington, 2003; Schulze and Walker, 1997). Riparian vegetation adds organic carbon to the aquatic food web in the

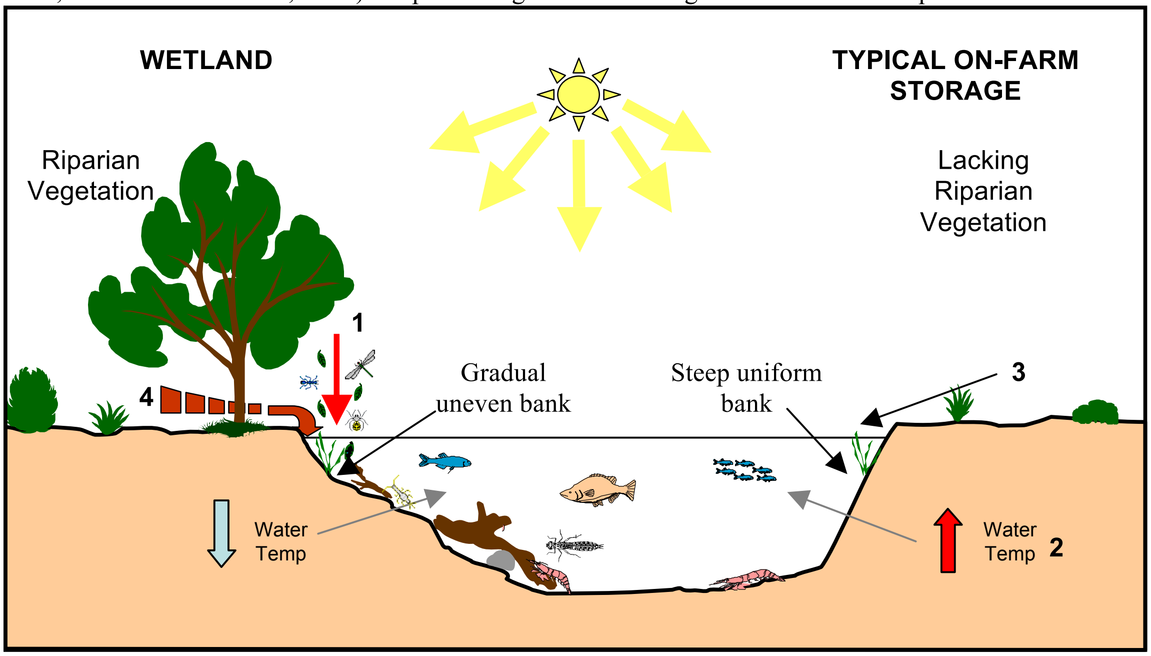

Fig 1: Conceptual model comparing potential drivers affecting biodiversity between natural wetlands and on-farm water storages. 1. Inputs of leaf litter and terrestrial invertebrates. 2. Rise in water temperature due to lack of shading. 3. No source of logs and branches. 4. Filtration of sediments and nutrients.

form of litter (e.g. leaves, bark, fruit: Bunn *et al*., 1998; Schulze and Walker, 1997).

Native vegetation provides inputs of leaf litter all year round, with a slight peak around late summer, providing a continuous food source for macroinvertebrates (Read and Barmuta, 1999). Terrestrial invertebrates falling from riparian vegetation also add energy and nutrients to the aquatic food web (Bunn *et al*., 1998). The lack of riparian vegetation on constructed storages will lead to a reduction in the amount of energy and nutrients from leaves and terrestrial invertebrates available to the aquatic food webs therein. As well as leaf litter, branches and whole trees may fall into the water, providing important habitat for fish, plants and macroinvertebrates (Bunn, 1993; Bunn *et* al., 1998; Sheldon and Walker, 1998). The general absence of trees on storage embankments means that there is no source of coarse or large woody debris. This was apparent from site visits, with the majority of storages being devoid of snags on their banks.

Riparian vegetation also provides shading during the day, moderating fluctuations in water temperature. Where riparian vegetation is absent, water temperatures are likely to rise affecting the balance of algal and aquatic plant communities and their contribution to energy production (Arthington, 1995). This also results in a shift in aquatic production dominated by microalgae such as diatoms to larger, less palatable species such as green algae and macrophytes (Bunn *et al.*, 1999). In natural wetlands, riparian vegetation also acts as a buffer, filtering sediments and nutrients before they reach the water. The importance of this to on-farm storages is likely to be minimal as typical storages are raised above the ground and, therefore, the only run-off will be off the top of the embankment itself.

4.2 Morphology

The morphology of aquatic ecosystems such as surface area, volume, perimeter, depth and channel complexity is thought to affect the overall health of the ecosystem. Thoms *et al.* (in press:b) found that in dryland rivers, increased channel complexity increased the surface area available for organic matter to provide a food source and the amount of habitat for lower order aquatic organisms. Morphological differences between natural wetlands and the more uniform on-farm storages could lead to differences in species composition, diversity and abundance.

Benthic algae have been found to be extremely important contributors to waterhole (Fellows *et al.*, 2003) and lake (Hecky and Hesslein, 1995) food webs. In dryland river waterholes, as found in the Border Rivers, the water is very turbid restricting the photosynthesis of benthic algae to a narrow photic zone around the bank. The steeper the slope of the bank, the smaller the width of this photic zone (Fellows *et al.*, 2003). If the slope of on-farm water storages is steeper than in natural wetlands it is likely that rates of primary production will be reduced. Keast and Harker (1977) also found that fish biomass and, to a lesser extent, benthic invertebrate biomass was concentrated towards the margins of a lake up to a depth of 2.5 m. Fish distribution has also been associated with lake morphological characteristics. Jackson and Harvey (1993) found that large, deep lakes differed from shallow lakes in their fish species diversity. Olden *et al.* (2001) stated that surface area, volume and shoreline perimeter were positively correlated with habitat diversity which in turn affects species diversity (Jackson *et al.*, 2001). Unfortunately evaporation from storages can be a significant loss to irrigation farms and property holders will be aiming to reduce the amount of surface area to minimise these losses.

4.3 Habitat availability and substrate type

The amount and type of habitat available is often considered as a primary limiting factor in population and community recovery in degraded ecosystems (Bond and Lake, 2003). The availability of habitat is believed to be important to fish and macroinvertebrate communities for a number of reasons. Habitat can provide shelter from the elements and refuge from predators while providing suitable spawning sites for certain species and in some cases can also be a source of food. Both species abundance and diversity have shown positive correlations with the abundance of coarse woody debris (CWD) (Benke *et al.*, 1984) with CWD providing a refuge from predation for epibenthic fish and invertebrates (Everett and Ruiz, 1993). Fish abundance has been found to increase when CWD has been added to streams (House and Boehne, 1985). The complexity of the habitat available has also been observed to be positively correlated with the number of macroinvertebrate species present. Addition of grooves to artificial snags increased the number of macroinvertebrate species associated with them (O'Connor, 1990).

The presence of hard substrate matter has been found to increase the number of benthic diatom species found in dryland river waterholes with species numbers double that found on soft substrates (McGregor, 2003). The lack of hard substrates in on-farm storages could affect the amount of organic carbon available to their aquatic food webs. Several studies have also found that substrate characteristics are a major factor in determining the structure of freshwater macroinvertebrate communities (Faith and Norris, 1989; Richards *et al.*, 1993; Richards and Host, 1994). Although it is possible that response to substrate will depend on the species (Richards *et al.*, 1993), in general, high proportions of fine substrate were found to reduce species richness (Richards and Host, 1994). However, these studies were carried out in either streams or rivers. In lakes, ponds and ditches, which are more comparable to storages, the habitat preference of macroinvertebrates has been found to be influenced chiefly by the vegetation where there was a definite relation between vegetation and the distribution of macroinvertebrates (Scheffer *et al.*, 1984). As the majority of storages had very little or no aquatic vegetation, it is likely that substrate composition will still be an important factor in determining macroinvertebrate species composition.

4.4 Source of water

The source of the water used to fill storages is likely to have implications for biodiversity and water quality. Floodplain wetlands are filled during overland flows when water runs across the land after rainfall, either before it enters a watercourse or after it leaves a watercourse as floodwater or after it rises to the surface naturally from underground. In contrast, storages can also be filled using tailwater and water pumped from the river during regulated and unregulated flows.

When fields are irrigated, any excess water is collected in the tail drain and known as tailwater. Tailwater is then recycled back to the storage dam or supply channel where it can be used for further irrigations. As the water travels along the crop rows it is likely to pick up chemical residues from recent spraying, either in solution or adsorbed onto soil particles. Endosulfan is the most well known pesticide in the cotton industry but is only one of many used throughout the season. Brooks (1995) investigated two cotton properties in NSW and found that levels of endosulfan in the water column were always above the 1992 ANZECC trigger value for 99% of ecosystem protection of 0.1 μg/L (ANZECC, 1992). However, concentrations were generally lowest in the storage dams compared with the irrigation channels. This study was also carried out before guidelines were introduced for the 1999/00 cotton season to limit endosulfan use. Other potential contaminants include herbicides, other insecticides, defoliators, wetting agents, conditioners and fertilisers. Some of these are likely to reduce algae in storages which are an important base of food-webs in dryland river catchments.

Water accessed during unregulated and regulated flows is usually pumped from the river either directly into the storage or via a supply channel. Any fish or macroinvertebrates in the pumped water pass through at least one pump before entering the storage. Due to their size it is more likely that fish will be injured or killed as they go through the pump, although numbers of fish do survive this process and become established in the storage. These include carp, bony bream, spangled perch and yellowbelly (S. Lutton, unpublished data). There are a number of fish screens which can be used to prevent the movement of fish into irrigation offtakes, although they are uncommon in Australia (Blackley, 2003).

4.5 Stock access

Livestock watering and grazing are known to have detrimental effects on natural wetlands. Jansen and Healey (2003) found that grazing stock reduced the quality and availability of aquatic vegetation. This led to a decrease in the abundance and diversity of frog communities in Australian floodplain wetlands due to changes in habitat quality. Breakdown of banks by cattle trampling has led to increased erosion along streambanks and subsequent effects on water quality (Trimble, 1994). Godwin and Miner (1996) found that offstream watering can reduce water quality impacts from manure which is a source of bacteria, nitrogen and phosphorous. A number of property holders allowed livestock to access the storages on their property and this may be having an effect on the already limited vegetation and on water quality.

5. Discussion

Storages differ intrinsically from natural wetlands by their constructed nature and lack many of the attributes that native species have become adapted to, such as coarse woody debris, riparian vegetation and macrophytes. These differences are likely to result in on-farm storages having a lower biodiversity of fish and macroinvertebrates than natural wetlands. However, storages represent a significant proportion of the floodplain aquatic habitat in the Border Rivers catchment and changes could be made to utilise this more effectively.

Altering the morphology of existing storages would most likely be impractical and cost prohibitive, although could be addressed during the design and construction of new storages. Planting large riparian vegetation may lead to damage to the embankment and storage walls and is not likely to be undertaken by many property holders. However, there are a variety of different management options that could be put into place relatively easily. Planting aquatic vegetation is one option that could be implemented to improve the biodiversity value of on-farm storages by providing habitat and a food source. Coarse woody debris could also be added to the inner banks of the storage to provide a hard substrate and further habitat. It is possible that the presence of chemicals in tailwater may be having a detrimental affect on aquatic species. On properties where there is more than one storage, tailwater returns could be limited to only one to reduce chemical contamination of the remaining storages. To prevent damage to the bank and any vegetation present, property holders should restrict the access of livestock to the storage.

The benefits of implementing these management options not only include improving the aquatic biodiversity of the storage but increasing habitat availability for mobile fauna such as waterbirds, and boosting the potential for aquaculture production. In order to test the predictions of this conceptual model an aquatic sampling programme comparing storages of different characteristics and natural wetlands is required. Once management options are undertaken, ongoing monitoring to record any changes in biodiversity will be essential.

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