FEATURE

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Lagoon of Islands, Tasmania: Ecosystem response to dam wall removal

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Lagoon of Islands was a rare wetland of high conservation value, supporting floating islands of vegetation before it was dammed to supply water for consumptive use downstream. After damming, water quality declined to such an extent that in 2013, the dam wall was removed and a wetland restoration project was commenced, resulting in immediate improvements in water quality and, within five years, regeneration of a plant community largely composed of dominant species of the original wetland.

Key words: *restoration, wetlands, alternative states, planned natural restoration.*

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Figure 1. View of south-eastern corner of Lagoon of Islands, showing this vegetation regrowth in foreground and the former location of the dam in the rear.

Introduction

Lagoon of Islands was a naturally occurring freshwater wetland recognised for its distinctive configuration of islands of vegetation (Fig. 1). The islands were formed by succession of terrestrial vegetation floating on a mat of rhizomatous sedges (Tyler 1976), unlike any other documented floating island system (Van Duzer 2004). It was dammed as a source of water for domestic use, irrigation and stock in 1964. The original wetland and its vegetation supported a diverse birdlife, including a migratory species, Latham's Snipe *(Gallinago hardwickki)* and several species which are now listed under State or Federal threatened species legislation (Australasian Bittern, *Botaurus poiciloptus;* Wedgetail Eagle, *Aquila audax;* Masked Owl, *Tyto novae-hollandiae*; and White-bellied Sea-eagle, *Haliaeetus leucogaster*) (Fletcher 1924).

Initially, the lake formed by the dam wall was effective for supplying water, but within 25 years (i.e. by 1989), the waterbody was eutrophic, with a monoculture of the green alga *Staurastrum excavatum* that could be seen in bloom by satellite (Maxwell 2007) (Fig. 2a). Subsequently, the maximum water level was lowered, allowing macrophytes in the lagoon to grow (Nazarov & Sanger 1992), but that provided short-lived relief. By the mid-2000s, Lagoon of Islands was again unfit for use as a water source. The poor water quality was driven by two factors. Firstly, there was internal loading of phosphorus (sourced primarily from the decaying remains of the plant community that was flooded when the dam wall was constructed, followed by wind-induced sediment resuspension). This was supplemented by additional phosphorus in sediments eroded from Ripple Canal which brought water from an adjacent catchment (Maxwell 2007). The resultant poor water quality meant the water from the lagoon was not suitable for irrigation, stock and domestic water supply (Fig. 2b).

Literature regarding restoration of eutrophic shallow lakes is dominated by treatment options focussed on nutrient reduction, biomanipulation or water level manipulation (e.g. Scheffer 1998, Coops and Hosper 2002, Jeppesen *et al* 2007, Jeppesen *et al* 2012, Hansen *et al* 2017). Removal of dams is not uncommon, especially in the northern hemisphere, but primarily these projects have been aimed at restoring connectivity in rivers. Conceptual models for restoration following ecosystem degradation (e.g. SERA 2017) and restoration of river connectivity following dam removal have been proposed (e.g. Robson *et al* 2011). However, there have been few dam removals aiming to restore a shallow wetland system such as this.

Restoration objective

The restoration aims to achieve an environmentally acceptable and self-sustaining condition at Lagoon of Islands. We aimed to restore a water regime similar to the original pre-dam hydrology to enable a self-sustaining shallow wetland system to re-establish.

The basis for restoration

The restoration of Lagoon of Islands adopted a process-based approach. The conceptual basis for the restoration can be distilled into three core elements: water regime, vegetation response and water quality improvement (Fig. 3).

Restoration has focussed on using hydrology to select a plant community in the lagoon that will stabilise the sediments and act as a nutrient sink. Vegetation communities respond to changes in the water regime, including changes in depth, flooding and drying frequency and duration (Casanova & Brock 2000). Water level had been recorded for 3.5 years prior to dam construction (Hydro Tasmania unpublished data), and it was identified that restoration of similar water levels would be the preferred water regime for Fine Twig-sedge (*Baumea arthrophylla*) (Rea & Ganf 1994), a key species in the original vegetation. The water level operating range of the dammed Lagoon of Islands was deeper and more stable than Fine Twig-sedge could tolerate, and the species was almost lost from the lagoon. It was anticipated that recovery of Fine Twig-sedge would occur if a more favourable water level were restored (Maxwell & Tyler 2006).

Seed bank persistence has been little explored in wetlands with extremes of wetting and drying (Brock 2011) and a study of the seed bank following 49 years of inundation in Lagoon of Islands showed limited viability (Visby 2014). However, the discovery of naturally regenerating Fine Twig-sedge suggested that viable propagules persisted (Maxwell & Tyler 2006).

Prior to inundation, Lagoon of Islands supported a high biomass of vegetation. Aiming to restore the ecosystem as near as possible to its pre-dam water regime offered the prospect that nutrient concentrations driven by internal loading will reduce as vegetation growth sequesters the nutrients in the lake and mitigates the effect of wind-induced sediment resuspension (both through binding sediments and disrupting the energy of any wind-induced waves).

Decommissioning the dam wall

In 2010, Ripple Canal (commissioned in 1984 to augment natural catchment inputs) was decommissioned to prevent further nutrient and inter-catchment water inputs to the lagoon. Decommissioning involved re-instating natural drainage lines in the catchment by removing earthen embankments. The dam at Lagoon of Islands was a clay-core earthen dam. It was decommissioned in 2013 by removing the material, and re-contouring the land in sympathy with the surrounding landscape (Fig. 4). Rip-rap from the dam wall was used to line the re-constructed outflow channel and to provide microhabitat for restoration of the dam footprint. Subsequent adjustment of the outflow channel was carried out in 2016, as described in the Results section below.

Methods for Assessing Change

Study site

Lagoon of Islands sits at an elevation of 758 m on the Central Plateau of Tasmania, Australia (Fig. 5), has a surface area of 8.99 km^2. It is surrounded by Jurassic dolerite, and the banks of the eastern shore are lined with quartzite sand. Glacial activity eroded the

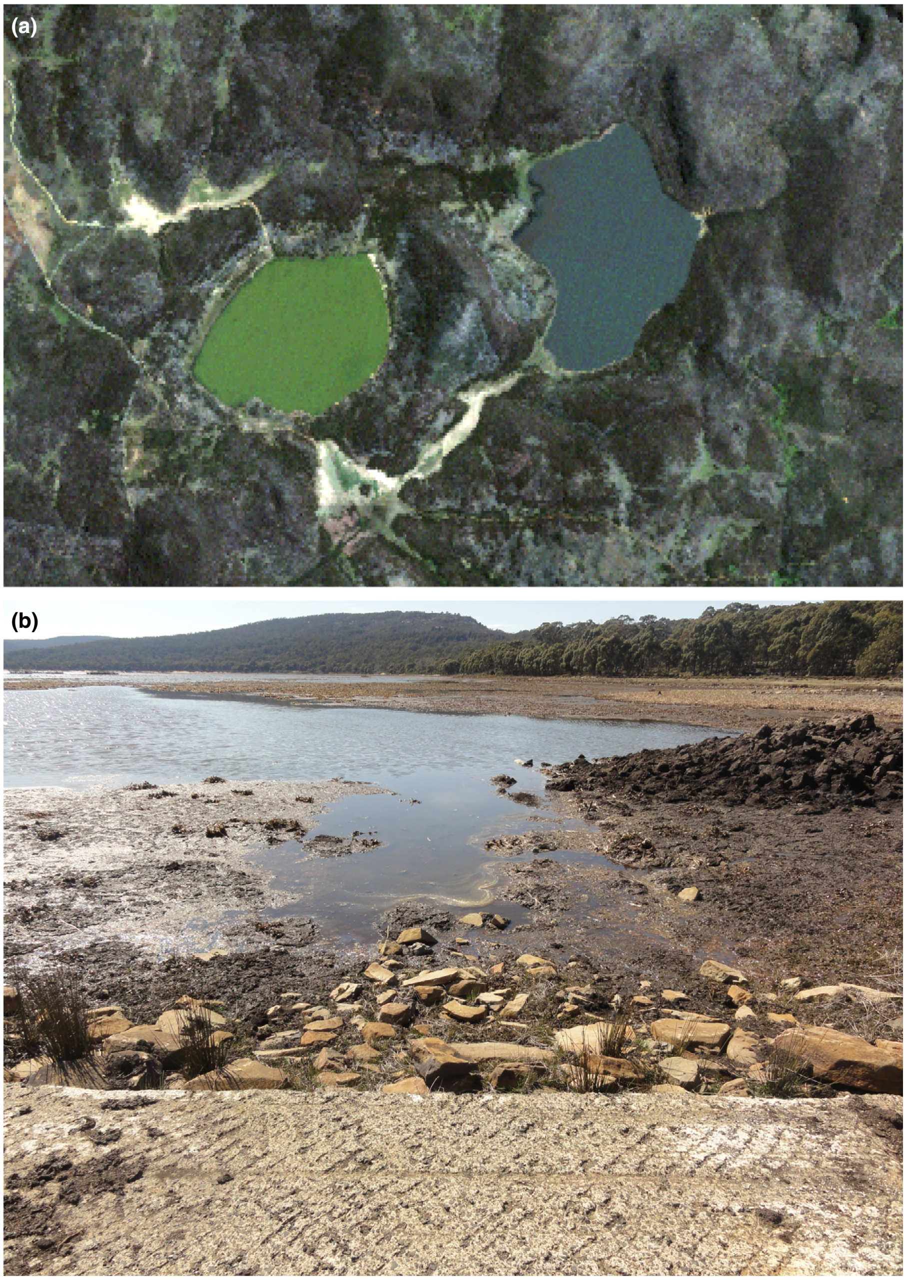

Figure 2. (a) Algal bloom (Staurastrum excavatum) in Lagoon of Islands, February 1988 © Landsat Imagery. (b) Water in Lagoon of Islands prior to decommissioning (2012).

dolerite cap and some of the underlying conglomerate/sandstone to form the depression basin in which Lagoon of Islands sits (Maxwell 2007).

Hydrology

Since dam decommissioning, water level was recorded in the south-east corner of the lagoon (as near as accessible to the deepest point) using an OTT Hydromet Radar Level Sensor attached to a Campbell Scientific CR850 data logger at 15-minute intervals. Prior to decommissioning, water level was recorded at the dam site at variable intervals between 15 November 1960 and 7 January 2013 (see method details). Rainfall was recorded approximately 500 m from the dam site from 1992–2008 and extended using SILO gridded rainfall for the grid cell covering that point (Queensland Government 1995-2019). Outflows from the lagoon are recorded 300 m downstream of the outlet from the lagoon currently using a Hydrological Services – AD375MAL absolute shaft encoder and W Campbell Scientific CR850 data logger; outflows have been recorded since 10 November 1960 using various instrumentation.

Pre-dam water level and outflow recording were used to develop an approximate pre-dam outflow curve. The water year (starting and ending at the approximate annual minimum water level) was defined as 1st April to 31st March.

Water quality

Water quality was monitored monthly or every second month between September 1989 and December 2019 with five sites monitored when the lagoon was dammed and three different sites monitored following removal of the dam. Turbidity was measured at all water quality sites in nephelometric units *in situ* using a Hach 2100 turbidity meter. Samples were analysed for total phosphorus, total nitrogen, chlorophyll a and algal composition by Analytical Services Tasmania (NATA accredited laboratory). Since dam decommissioning (April 2013), water quality monitoring has occurred monthly when water has been safely accessible for sampling in the lagoon. Details on monitoring site locations and sampling periods, analytical methods and detection limits are provided in the Appendix 1.

Vegetation monitoring

Quantitative vegetation monitoring commenced in January 2013 prior to removal of the dam wall. A total of 3 (10 m × 10 m) quadrats were established along each of 9 (30 m long) transects at five sites within the wetland (Fig. 6). Transects ran perpendicular from the shoreline to the middle

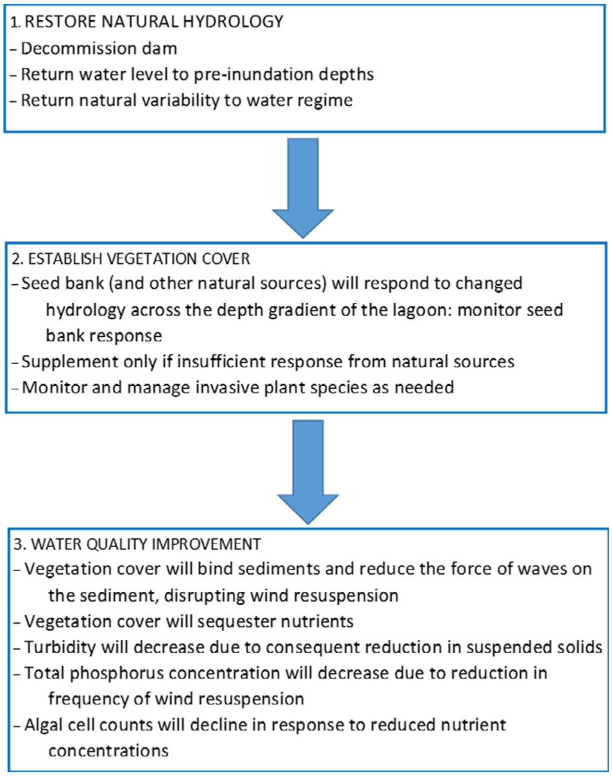

Figure 3. Conceptual basis for restoration of Lagoon of Islands.

Figure 4. Decommissioning the dam at Lagoon of Islands.

of the lagoon. Monitoring was conducted annually (over eight years from 2013 to 2019) in late summer and autumn for plant species cover and the assessment of ground conditions.

The transects were stratified by zones based on distance from the lagoon margin and water depth to capture the hydrological gradient within the lagoon to assess whether change was occurring uniformly across the lagoon or within particular vegetation types.

Two transects were established at some sites (Fig. 6), one at the edge (outer) and one towards the centre (inner) of the lagoon. The outer transects were established near the maximum water level of the lagoon prior to removal of the dam. The inner transects were an extension of the outer transect's direction, located closer to the centre of the lagoon. The distance of each inner transect from the shoreline was determined by accessibility as deeper sections of the lagoon can be unreachable due to deep mud depending on rainfall prior to monitoring. Only one transect was established at the Quarry site as it was a deeper area of the lagoon and generally cannot be accessed on foot because of the presence of deep mud.

The percentage cover of each individual species within each quadrat was estimated to the nearest per cent or recorded as less than 1 per cent or as a (+) when species are present but have negligible cover. Plant cover can exceed 100 per cent given different structural layers of plants present can overlap. Plant taxa were identified to species level where possible and the nomenclature for flora follows the current *Census of Tasmanian Vascular Plants* (Baker & de Salas, 2017).

The identification of immature plants is difficult, particularly with monocotyledons. Plant species from the genus *Juncus* are particularly difficult to identify when young and hybridisation often makes even mature plants difficult to key out. Therefore, *Juncus* spp. refers to multiple species of *Juncus* where keying out individual species was difficult.

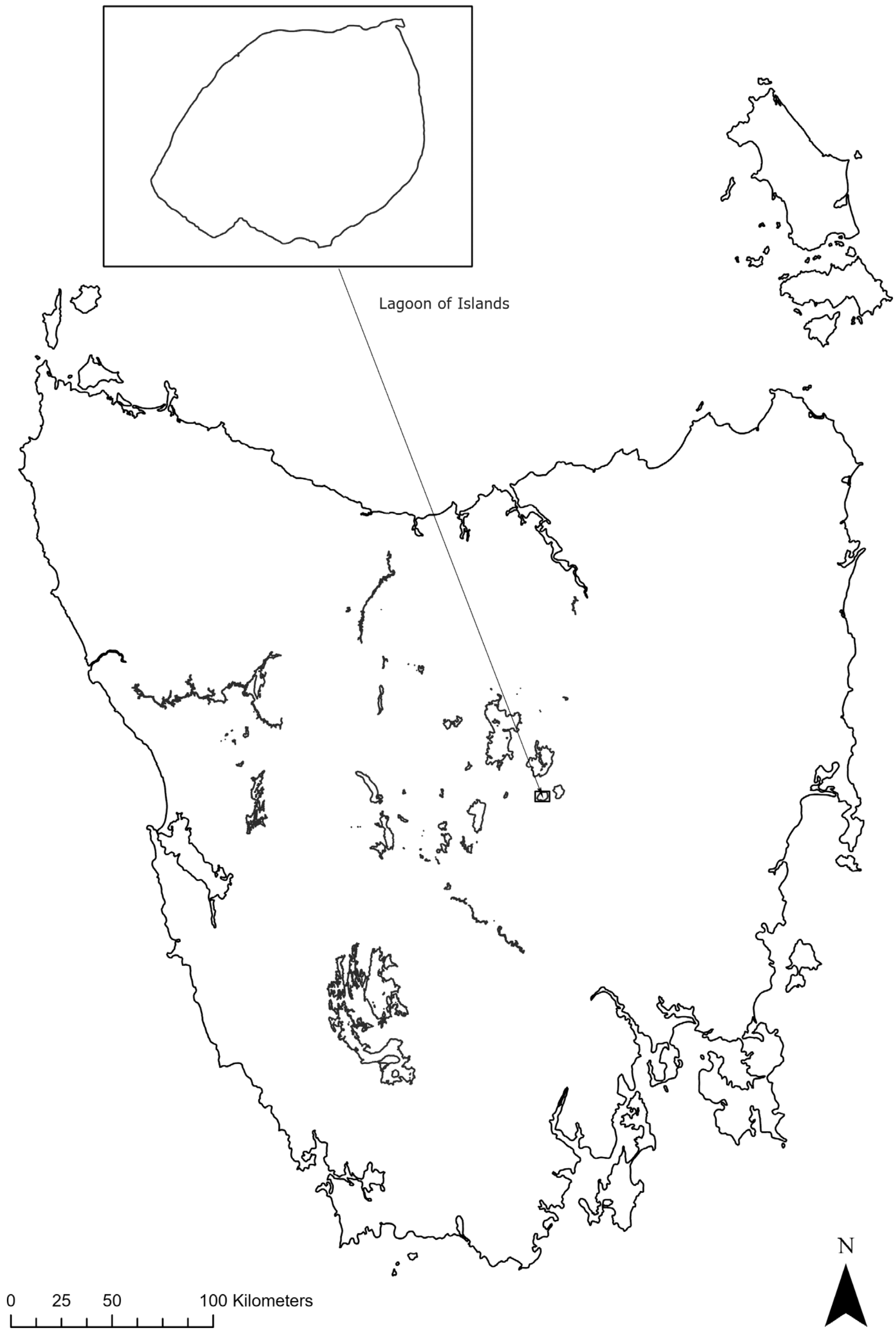

Figure 5. Location of Lagoon of Islands in Tasmania, Australia.

Recovery Results Over Time

Restoring the water level

Restoration of the wetland commenced in 2013 when the dam was decommissioned. Prior to decommissioning, the water level at Lagoon of Islands was operated between 758.34 m and 759.4 m (Fig. 7), with an annual pattern of filling during winter and spring and releasing over summer and autumn and some deviation due to climatic conditions. In the 2012/3 summer, water level was below 758.0m as the lagoon was drained to allow the dam to be decommissioned in 2013.

The lower water level in the lagoon following decommissioning of the dam is evident (Fig. 7). The operating range for the post-dam wetland is similar to that experienced before the dam was constructed, although the annual range has been smaller post-dam (based on limited pre-dam data) (Table 1).

Two of the post-dam water years had very low rainfall (approximately 10th percentile rainfall from 1924–2019) coinciding with seasonal drying and low maximum water levels. The level at which the surface was dry at the water level recorder changed between years.

Outflow adjustment

In the austral autumns of 2013, 2014, 2015 and 2016, the lagoon surface was dry at the water level recorder, although isolated pools remained in deeper areas of the lagoon, which is inconsistent with historical descriptions and anecdotal information (Tyler 1976, P Tyler Pers. Comm.). This suggested more water was flowing out from the lagoon annually following decommissioning than occurred prior to the dam installation, that is outflows were significantly higher at a given lake level compared with historical data (Fig. 8), which resulted in the drying of the lagoon sediments in the austral autumns of 2014, 2015 and 2016. This was attributed to the outflow channel being larger than had existing prior to construction of the dam wall, so the channel was adjusted to constrict outflows in May 2016. Since then the outflow has been slightly lower than historically for a given level, with outflow starting to flow approximately 0.25m higher than before the channel was adjusted.

Vegetation

Vegetation has re-established rapidly around the edge of Lagoon of Islands following the decommissioning of the dam wall, with four transects going from <10 per cent cover to

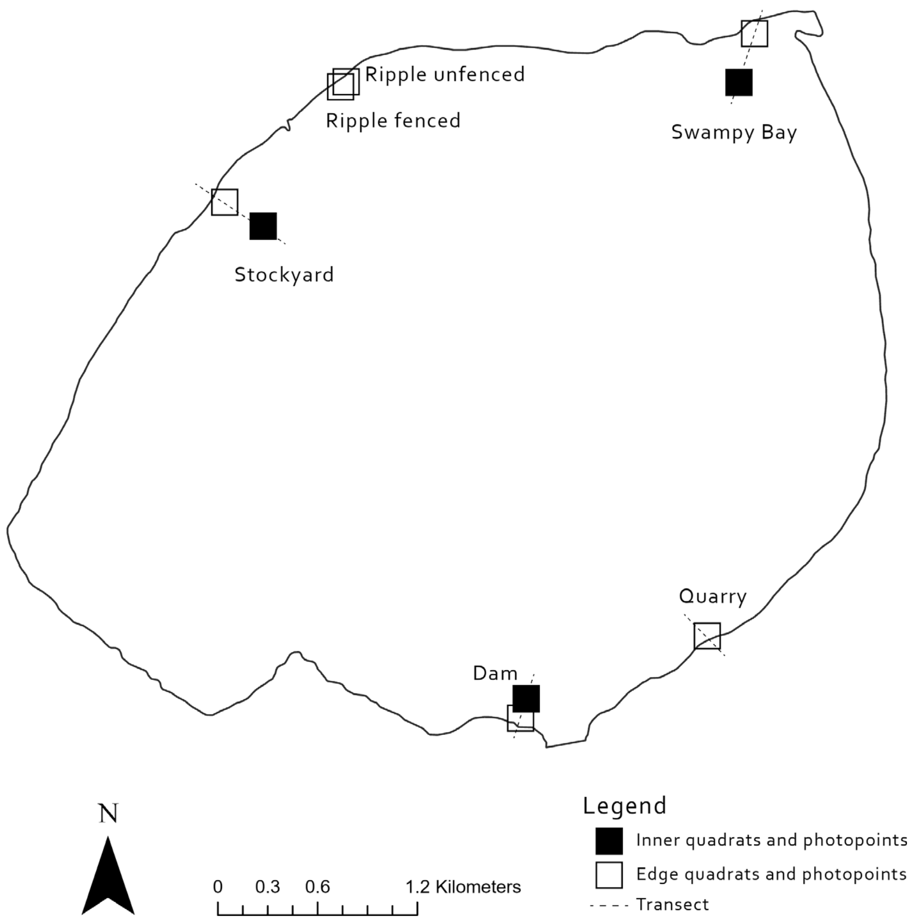

Figure 6. Vegetation monitoring locations within Lagoon of Islands.

>80 per cent cover within two years (Fig. 9, outer transects). The remaining two transects (Swampy Bay and the Quarry) have gradually increased in cover to >40 per cent cover over the five years since the dam wall was removed. The increased vegetation cover at these sites since the outflow was adjusted (2017, 2018 and 2019 monitoring) has been due to the growth of emergent amphibious species (species which prefer fluctuating water levels) (Brock & Casanova, 1997), particularly Common Spike-rush (*Eleocharis acuta*), Australian Lilaeopsis (*Lilaeopsis polyantha*) and Small River Buttercup (*Ranunculus amphitrichus*) at the edge sites and Bulbous Rush (*Juncus bulbosus*), Common Spike-rush and Water Ribbon (*Cycnogeton procerum*, formerly *Triglochin procera*) at the deeper site near the dam. Fine Twig-sedge (*Baumea arthrophylla*, reported as *Baumea rubiginosa* in Tyler 1976) was primarily responsible for increase in vegetation cover in the quadrats at greater depth along the transect (Q2 and Q3).

Since the adjustment of the outflow, the increase in vegetation cover in the inner transects (Fig. 10) has been achieved by the expansion of species such as Fine Twig-sedge at the expense of species such as Common Spike-rush and Small River Buttercup.

Sites subject to deeper inundation have seen a shift in the suite of species. Annual edge species such as Waterwort (*Elatine gratioloides*) and Australian Mudwort (*Limosella australis*) which accounted for most of the vegetation cover in 2017 have virtually disappeared and have been replaced by longer lived and taller species tolerating a higher water level/greater inundation period, for example Bulbous Rush, Fine Twig-sedge and Common spike-rush.

Invasive species

Small infestations of the weed Cumbungi (*Typha latifolia*) were identified in the lagoon, neighbouring farm dams and along Ripple Canal. Infestations of Cumbungi have been surveyed and treated for 4 years by removing, bagging and incinerating seed heads and treating foliage with herbicide. Infestations are now less than 50% of the population when treatment started and will be treated annually as required.

Infestations of Spear Thistle (*Cirsium vulgare*), Californian Thistle (*Cirsium arvense*) and Slender Thistle (*Carduus tenuiflorus*) were patchy but common within the edge zone and dry perimeter surrounding the lagoon. Great Mullein (*Verbascum thapsus*) infestations have occurred along the southern shoreline of the lagoon, in regions that historically were heavily disturbed including the dam site. All thistles and mulleins have been treated twice annually using herbicide application over 4 years. Infestations are now less than 10% of the population when treatment started and will be treated annually as required.

Water quality

No nutrient or algal data are available from Lagoon of Islands prior to dam construction. Between 2007 and 2009, water quality declined rapidly as insufficient inflows prevented flushing of the lagoon, with nutrient concentrations and turbidity increasing rapidly as a bloom of the cyanobacterium *Aphanothece sp.* became established in the lagoon (Fig. 11 and Appendix 1). The poor water quality persisted until the dam was decommissioned in 2013. An immediate improvement in water

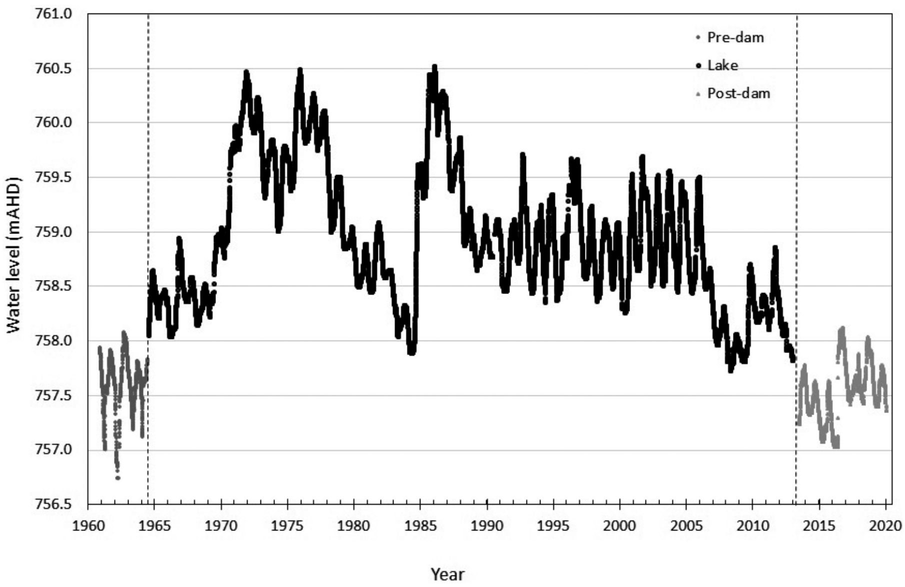

Figure 7. Water level at Lagoon of Islands, 1960–2019.

Table 1. Minimum, maximum and average water level in Lagoon of Islands, for the full data set, and pre-dam, during and post-dam

	All (mASL)	Pre-dam (mASL)	Lake (mASL)	Post-dam (mASL)
Minimum	756.75	756.75	757.73	757.03
Maximum	760.52	758.08	760.52	758.12
Average	758.71	757.62	758.94	757.54
Average annual range	0.8	1.06	0.8	0.64

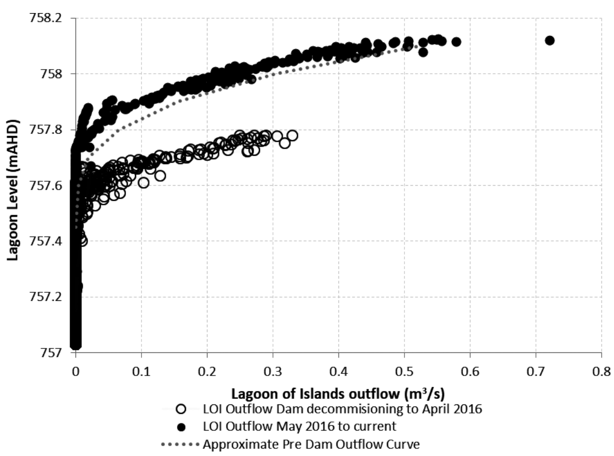

Figure 8. Observed water level to lagoon discharge at Lagoon of Islands for the period from dam decommissioning until outlet works were undertaken in May 2016 and from May 2016 to current, with the historic (pre-dam) relationship.

quality occurred upon re-filling of the lagoon following decommissioning (Table 2). Turbidity reduced fivefold and both minimum and average total phosphorus reduced by an order of magnitude.

For the first four years (2013–2016) following decommissioning of the dam, turbidity, total phosphorus and *Aphanothece* sp. concentrations were generally lowest at the start of the hydrological year and increased as the hydrological year progressed (Fig. 12 and Figure A2 in Appendix 1).

Discussion

Decommissioning and restoration of Lagoon of Islands provide a practical example of management intervention to provide more sustainable outcomes for a shallow wetland suffering from persistent poor water quality.

The process-based approach adopted for the restoration of Lagoon of Islands has so far been successful. The lowering of water level to maximum depths similar to those prior to inundation (step 1, Fig. 1) has facilitated an increase in vegetation growth (Step 2, Fig. 1). Drying of the sediments in 2013, 2014, 2015 and 2016 is likely to have had a significant impact on the vegetation community that established. Since removal of the dam, the vegetation cover has varied. In the first few years following dam removal, annual species dominated the vegetation in the lagoon. Common Blown-grass (*Lachnagrostis filiformis*) rapidly colonised the drying surface soils of the lagoon, moving from the edge inwards as the edges of the lagoon dried. Annuals such as Australian mudwort and Waterwort began colonising wetter areas where standing water was present for parts of the year. The cover of these annual species changed rapidly between years responding to the seasonal rainfall. Water Ribbon retreated from the edges of the lagoon to deeper, more permanent wet areas in the deeper pools as the lagoon dried out.

Perennial species such as Fine Twig-sedge, Common Spike-rush and *Juncus* sp. began to become more dominant across the lagoon three years following dam removal. Common Spike-rush, a short species, tended to be found in shallow areas at first. Fine Twig-sedge, growing up

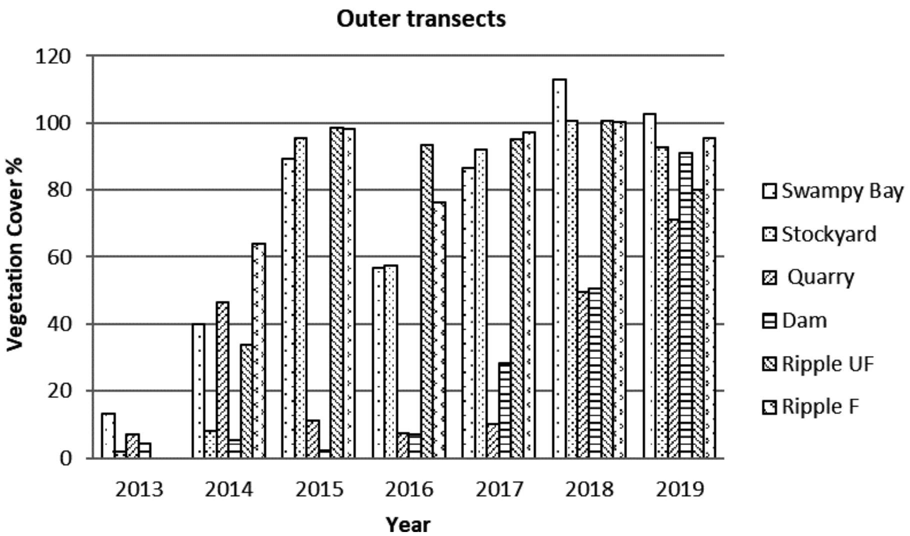

Figure 9. Vegetation cover in transects at the edge of Lagoon of Islands, 2013–2019. Ripple UF = unfenced site near Ripple Canal; Ripple F = fenced site near Ripple Canal.

to 1 m tall, steadily spread across the lagoon and often replaced Common Spike-rush as well as other species as it became dominant in deeper areas of the lagoon. As these perennial species continued to spread they displaced the annual species and occupied their previous niche, relegating the annual species to areas devoid of dense vegetation. Species that respond to water level by increasing their internode length (e.g. Small River Buttercup, Australian Lilaeopsis, Small-fruit Pond Weed (*Potamogeton cheesemanii*) and Water Milfoil (*Myriophyllum variifolium)* occupied similar habitats to the emergent species but at much lower cover.

Plant communities on the edge of wetlands become less diverse when the water level becomes deeper and less variable, for example as a result of damming (Brock and Casanova 1997). The corollary of this is that plant communities on the edges of wetlands will re-establish or become more diverse if natural variability is re-instated in an appropriate water regime (assuming there is sufficient seed and asexual propagules available). The results so far at Lagoon of Islands support this.

Fine Twig-sedge and Southern Bristlesedge (*Chorizandra australis*) were the key species in the pre-dam community (Tyler 1976) and both have returned to Lagoon of Islands following 49 years of inundation, although Southern Bristlesedge is only present in low abundance. This indicates that seeds and/or rhizomes were available for regeneration after decades of inundation. This offers an alternative to the more laborious, conventional approach of human intervention of planting or seed addition. The natural regeneration at Lagoon of Islands ensures that the plants that respond are suited to the water regime in specific area. In such an approach, human intervention is limited to weed management and plant or seed supplementation only where and when required, providing a sustainable, low-cost method for restoration of large areas.

The recovery of vegetation at Lagoon of Islands is continuing and further changes will be dependent on the future water regime with a variety of vegetation responding to the degree, depth and period of flooding in successive years.

The restoration at Lagoon of Islands has been successful in restoring water quality to a condition acceptable to downstream users (Step 3, Fig. 1). The parameters associated with eutrophication (total phosphorus, turbidity and the algal community and density) have all improved substantially following re-instatement of more natural hydrological patterns and subsequent establishment of vegetation.

The drying of the sediments of the lagoon prior to and post decommissioning of the dam resulted in a 're-set', with an immediate improvement in water quality (notably turbidity) as the lagoon re-filled

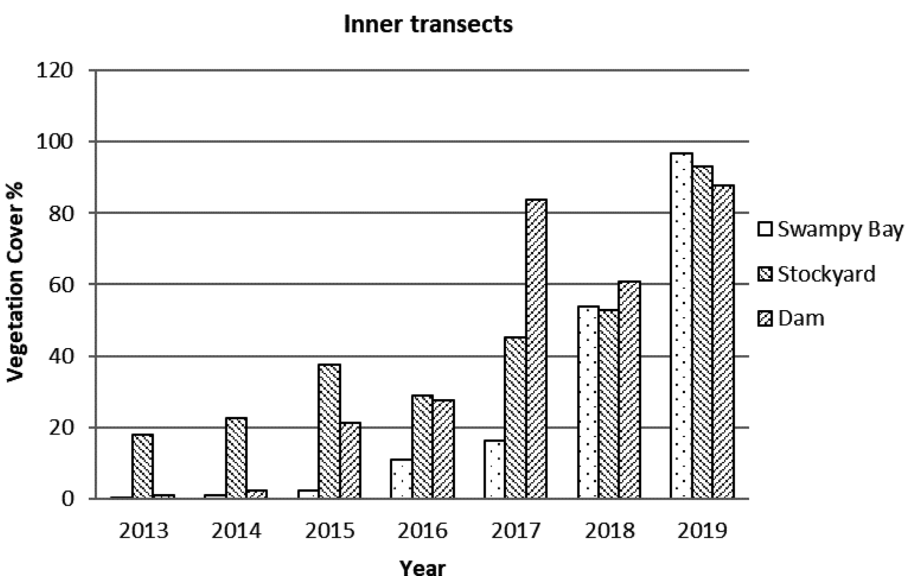

Figure 10. Vegetation cover of pooled quadrats in the inner lake transects.

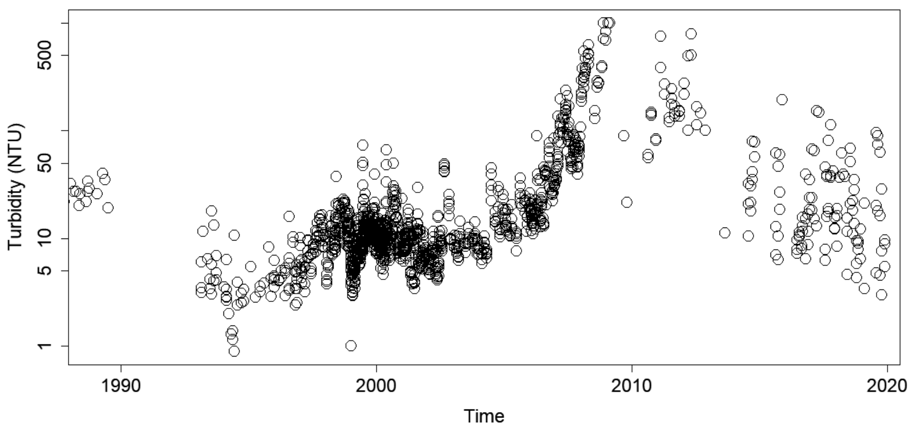

Figure 11. Time series plots of turbidity in Lagoon of Islands, September 1989 – December 2019.

Table 2. Minimum, maximum and averages for total phosphorus concentration and turbidity in Lagoon of Islands

	Total phosphorus (mg/L)			Turbidity (NTU)		
	Pre-dam removal		Post-dam removal	Pre-dam removal		Post-dam removal
	1989–2012	2006–2012	2013–2019	1989–2012	2006–2012	2013–2019
Min	0.001	0.042	0.020	0.89	11.0	2.99
Max	21	21.6	0.94	1000	1000	194
Median	0.032	0.210	0.08	10.8	67.1	17.7
Average	0.330	1.020	0.13	35.4	138	29.8
Count	374	114	112	1292	250	112

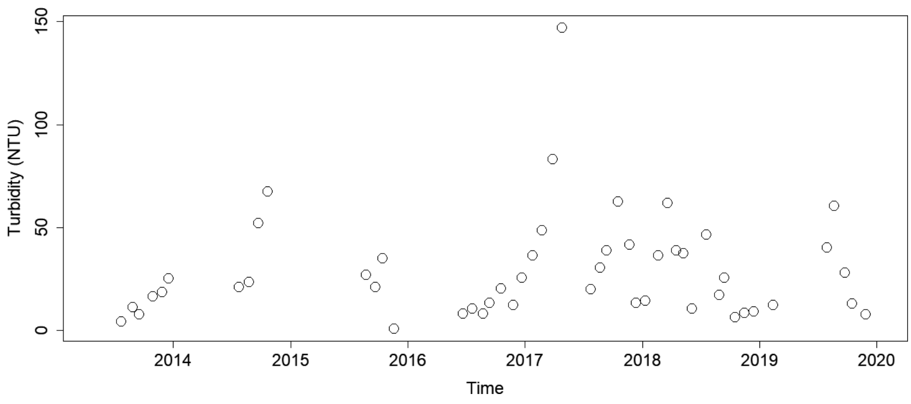

Figure 12. Time series plot turbidity in Lagoon of Islands since dam decommissioning.

to its new maximum water level, and possibly provided a germination cue for plants. The re-establishment of dense stands of vegetation has reduced the area of sediments available for wind-induced sediment resuspension. Shallow lake literature is dominated by discussion regarding alternative ecological states, but few papers offer practical solutions for managers of eutrophic lakes. Draining lakes to export nutrients from the lake and consolidate the sediments has been proposed (e.g. Scheffer 1998; Van der Wielen 2002). The improvements in water quality obtained upon re-wetting of the sediments in Lagoon of Islands suggest that temporary drying of the sediments may be a useful technique for restoring acceptable water where sediment types permit, and it is socially, economically and environmentally possible to do so.

The objective of the restoration project is to establish a healthy, self-sustaining wetland community in the lagoon. The results to date suggest Lagoon of Islands is well placed to achieve this objective. The process-based approach has resulted in a low-cost, sustainable pathway for the recovery: plant species and communities have re-established naturally, water quality continues to improve, observations suggest significant improvement in the diversity of fauna species using Lagoon of Islands as a refuge or for food. The approach adopted allows us to adaptively alter the outlet level in the future if needed to maintain key communities and processes into the future as the climate changes.

The conditions that led to the floating islands becoming established are not known. Consequently, re-establishing the floating islands is not a goal of the restoration. The authors hope that, by re-establishing the natural hydrological processes of the lagoon, the wetland has the best chance to re-establish as a self-sustaining, evolving wetland with or without islands of vegetation, with the capacity to adapt to climate change.

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algal community composition. Whispering Landscapes provided diligent and effective control of weed infestations to prevent them becoming dominant.

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