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Tide-excluded banked wetlands on the marine plains of northeastern Australia provide important habitat for migratory shorebirds, other threatened bird species and the Capricorn Yellow Chat

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ABSTRACT

Context. Banked systems that modify natural wetlands to enhance reliability of grass production for cattle are common along coastal Central Queensland. These are mostly positioned in the supratidal zone of extensive marine plains, leaving mangroves and saltmarsh with regular tidal influence intact. Perceived negative impacts on fisheries and carbon sequestration are frequently cited as reasons to remove banks and restore tidal influence, yet there is no specific evidence relating to the banked wetlands in this region. All ecosystem services provided by these systems need to be considered before decisions are made. **Aims.** This study aimed to evaluate the biodiversity values of marine plains with tide-exclusion banks. **Methods.** Five banked sites (39 000 ha) were compared to a single unbanked site of similar vegetation and tidal position with multiple counts of waterbirds (13–48/site) over several years. **Key results.** Banked sites collectively supported six threatened and 22 migratory species, including 17 migratory shorebirds, some with counts of international importance. All sites matched criteria used to define Ramsar wetlands. Banked sites had more waterbird species and a similar species richness of migratory shorebirds to the unbanked site. **Conclusions.** Given these wetlands support substantial numbers of migratory shorebirds and endangered species such as Capricorn Yellow Chat, as well as their importance to food production and improving water quality reaching reef ecosystems, any proposed 'restoration' of these areas to the previous tide-influenced state should be subject to impact assessment. **Implications.** Our study demonstrates that existing tide-excluded banked wetlands are beneficial for biodiversity and economic production, soundly justifying their retention.

Keywords: biodiversity, conservation, ecosystem services, Great Barrier Reef, migratory shorebirds, natural wetlands, sea level rise mitigation, threatened species, waterbirds.

Introduction

Tropical coastal wetlands on marine plains have been frequently banked to exclude or reduce tidal influence and thereby enhance freshwater grass productivity for cattle grazing (Middleton *et al.* 1996). Banks are mostly located in the supratidal zone (i.e. above the height of mean spring tide inundation), leaving mangroves and the majority of saltmarsh with regular tidal influence intact (Fig. 1*a*). The banking causes an increase in ponding of freshwater in the wet season, leading to an increased hydroperiod and area of inundation for wetland plant growth compared to the natural wetlands in the unbanked situation (Houston *et al.* 2013). Tide-exclusion banks range in size from long seawalls parallel to the coast, which totally exclude tides, to small earthen block banks in channels that permit highest spring tides to flow around them. In Australia, where salt levels allow, exotic ponded pasture species such as Para Grass (*Urochloa mutica*) are frequently introduced by graziers to enhance pasture production (Hyland 2002; WetlandInfo 2016). Banking potentially alters ecosystem processes such as carbon sequestration and connectivity of fish habitat, and may affect water quality to

Fig. 1. Two satellite images of banked marine plain wetland habitat showing (*a*) location of a typical bank in the supratidal area, the mangroves (dark green) and saltmarshes with regular tidal influence remain intact to the east of the bank (i.e. below the bank); the wetlands of interest to the study are highlighted by shading and lie between the bank and terrestrial uplands to the west of the marine plain and (*b*) an example of the intricate reticulated network of channels and playas present at some sites (Google Earth images: Maxar Technologies; CNES/Airbus).

downstream habitats (Negandhi *et al.* 2019; Waltham *et al.* 2019). Consequently, banked wetlands have been identified as targets for 'restoration' (i.e. bank removal) to reinstate those processes and services (Abbott *et al.* 2020). However, the value of altered wetlands for cattle production and as habitat for important fauna such as waterbirds needs to be considered before such restoration attempts should proceed (Waltham *et al.* 2019). Besides food production (i.e. fodder for cattle and nursery habitat for fisheries) and biodiversity and conservation benefits, banked marine plain wetlands also provide other valuable ecosystem services such as improving water quality by sediment retention and filtering of water by the plain's dense low vegetation, limiting negative impacts on the lagoon of the Great Barrier Reef (Sheaves *et al.* 2014; Waltham *et al.* 2019; Canning *et al.* 2021).

In eastern Australia, coastal marine plains formed approximately 8000 years ago, as rising seas created shallow coastal bays and drowned river valleys (Sloss *et al.* 2007). Slow infill with marine sediments created extensive, almost level plains, resulting in complex dense networks of wetlands including braided, sinuous channels and shallow broad depressions or playas (Fig. 1*b*). Residual salinity in the soil means they are largely treeless, with extensive areas of salt-tolerant native grasslands and sedge swamps above highest tide levels, and sedge wetland with samphire saltmarsh around the upper tidal level (Burgis 1974; Houston *et al.* 2013). Along the seaward margin they are bordered by mangroves and bare, hypersaline salt flats. Due to distinct wet and dry seasons, the wetlands above tidal influence normally vary from lush, flooded swamps in the wet season to totally dry plains late in the dry season. Typically, as the wetlands dry, the salinity changes from fresh to hypersaline, depending on location and wetland type (Houston 2013; Houston *et al.* 2013).

Although known to support high biodiversity of waterbirds including migratory shorebirds (Jaensch and Joyce 2006; Sheaves *et al.* 2014; Waltham *et al.* 2019; Canning *et al.* 2021), there is no comprehensive overview describing the habitat values of coastal banked wetlands to waterbirds and other wetland-dependent species. However, their importance as breeding habitat for Australian Painted-snipe (Jaensch *et al.* 2004; Black *et al.* 2010), egrets, Whiskered Tern and Red-necked Avocet (Jaensch *et al.* 2003, 2005) and threatened wetland-dependent species such as the Capricorn Yellow Chat (Houston *et al.* 2009, 2013) is documented. Inundation has been found to promote primary productivity of the wetlands and associated invertebrate abundance leading to conditions favouring nesting and breeding of these species (Houston 2013), while availability of inundated habitat in the late wet season (March–April) may be linked to use of these wetlands by Australian Painted-snipe when suitable habitat is less available elsewhere in eastern Australia (Black *et al.* 2010).

Restoration of banked wetlands by removal of banks has been proposed as a mechanism to enhance ecosystem services such as carbon sequestration and water quality and restore fisheries connectivity (Adame *et al.* 2019; Negandhi *et al.* 2019; Waltham *et al.* 2019). However, the existing ecosystem services also need careful consideration before such restoration proposals should proceed (Canning *et al.* 2021), including habitat values of banked wetlands for flora and fauna. For example, removal of banks is likely to be detrimental to wetland-dependent species that mainly occur in banked wetlands on marine plains, such as the Capricorn Yellow Chat (Houston *et al.* 2013). Some wetlands with tide-exclusion banks have been identified as internationally and/or nationally important for several species of migratory shorebird (Jaensch 2004; Melzer *et al.* 2008; Weller *et al.* 2020). Under Australian biodiversity legislation, any proposals recommending removal of tide-exclusion banks would have to consider impacts on conservation-listed species. Government legislation targeting threatened and migratory species at both the Federal [*Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)] and State [*Queensland Nature Conservation Act 1992* (NC Act)] levels, as well as specific legislation on migratory birds relating to international agreements such as CAMBA, JAMBA, RoKAMBA (respectively: the China–, Japan– and Republic of Korea–Australia Migratory Bird Agreements), and the Convention on Migratory Species would need to be considered. Special emphasis applies to migratory shorebirds since these are a Protected Matter under the EPBC Act 1999 and addressed by the Partnership for the East Asian–Australasian Flyway.

Waterbirds are widely regarded as indicators of health of wetland ecosystems, making them useful for long-term monitoring programs (Kingsford *et al.* 2017). Further, specific functional groups such as piscivorous waterbirds can be used as indicators of food availability (e.g. fish) (Kingsford *et al.* 2020).

In this study, the habitat value of several tide-excluded wetlands for migratory shorebirds, other waterbirds and wetland-dependent bird species is evaluated. To provide context, the study included an unbanked marine plain of similar origin and geomorphology. However, the focus of the paper is on providing information about the faunal values of the altered ecosystem so that these can be considered when 'restoration' developments are proposed. Attributes evaluated include presence of threatened species or migratory shorebirds, use as breeding habitat by waterbirds and other criteria relevant to determining whether the wetlands are of national and/or international importance. In addition, the relative contribution of piscivorous waterbirds such as cormorants, pelicans and terns to the overall waterbird assemblage is evaluated to provide context for understanding the importance (or not) of these modified ecosystems for fish.

Methods

Study area

The climate of the study area is classified as hot and seasonally wet–dry, but with relatively cool winters (Hutchinson *et al.* 2005). Average maximum temperatures are >30°C in summer and lowest in July (about 24°C); winter minima average 11–12°C. The wet season, during which average monthly rainfall is >100 mm, occurs mainly from December to March and accounts for >60% of the annual total (average 815 mm at Rockhampton 23.38°S, 150.48°E and 1100 mm at St Lawrence 22.35°S, 149.54°E); rainfall is least in June–September. However, the region is typified by highly variable rainfall, comparable with semi-arid Australia where rainfall is heavy in some years and much less in others (Bureau of Meteorology 2022). Annual pan evaporation rates are high, for example, around 2100 mm per year at Rockhampton (DES 2020).

The Capricorn Coast straddles the Tropic of Capricorn, encompassing the marine plains of coastal Central Queensland from 75 km south-east of Rockhampton at Curtis Island to St Lawrence approximately 150 km northwest. Marine plains in this region can be up to 15 km wide and have a gentle gradient (less than 1:100). They are characterised by a diverse array of wetland habitats including riverine, palustrine and lacustrine forms. These wetland types combine in an exceptionally complex mosaic pattern with freshwater, saline and transitional characteristics. Small claypan-like lakes may also be present. Freshwater is fed to the marine plains by direct rainfall and numerous local creek systems. Some of the smaller marine plains have limited freshwater inflow. Estuarine ecosystems with a macro-tidal regime abut the marine plains and, in some areas, support dense mangrove forest or shrubland, some of it on small islands.

Except for *Melaleuca* swamps on the landward margins and mangroves on the seaward edge, marine plains are treeless, due to residual salts in the soils impacting tree survival (Burgis 1974). Supratidal flats of salt-tolerant species such as Marine Couch *Sporobolus virginicus* and samphire (*Tecticornia pergranulata* and *T. indica*), plus some bare areas of salt flat, occupy the seaward margin of the marine plain wetlands. Marine Couch, with small patches of samphire and saltpan, also forms extensive grasslands across the plains on slightly higher ground where the habitat is not usually inundated by freshwater or tidal flows. Vegetation of wetlands where freshwater inundation dominates is characterised by tall sedges of two broad habitat types (Houston *et al.* 2013; Houston *et al.* 2020*a*). Where there is substantial salt influence, either from occasional high spring tides and/or high residual salt levels, the salt-tolerant club-rush *Schoenoplectus subulatus* occurs as extensive dense patches in shallow basins or fringing sinuous channels and deeper basins (Fig. 2*a*). Where freshwater influence is greatest, the sedges *Eleocharis dulcis* and *Cyperus alopecuroides* occupy the sinuous channels and are typically fringed by Water Couch *Paspalum distichum* (Fig. 2*b*). Landward of tide-exclusion banks, introduced ponded pasture species such as Para Grass may proliferate along wetland margins and in shallow depressions. Larger pools of open water (from 1 to 25 ha in size) are mostly less than 0.5 m deep and dry out rapidly after the wet season; whereas sinuous channels or ponds (5–20 m wide) may be up to 1.0 m deep when fully inundated, therefore persisting as water bodies well into the dry season.

Sites

The study focussed on areas of wetland on marine plains where tide had been excluded or its impact minimised by historical emplacement of banks. Sites for analysis of data from bird surveys were chosen accordingly. The banks fall

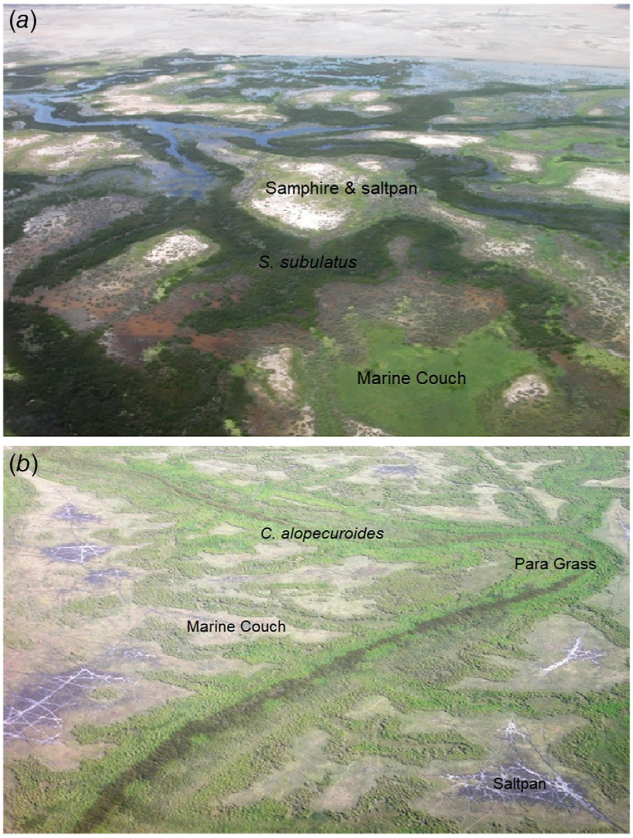

Fig. 2. (*a*) Oblique aerial photograph showing salt-tolerant wetland vegetation – *Schoenoplectus subulatus* in channels bordered by saltmarsh (samphire in saltpans and Marine Couch) and (*b*) fresher wetlands showing *Cyperus alopecuroides* in channels bordered by Para Grass, Water Couch and Marine Couch – note the cattle trails in the saltpans (Photos by Roger Jaensch).

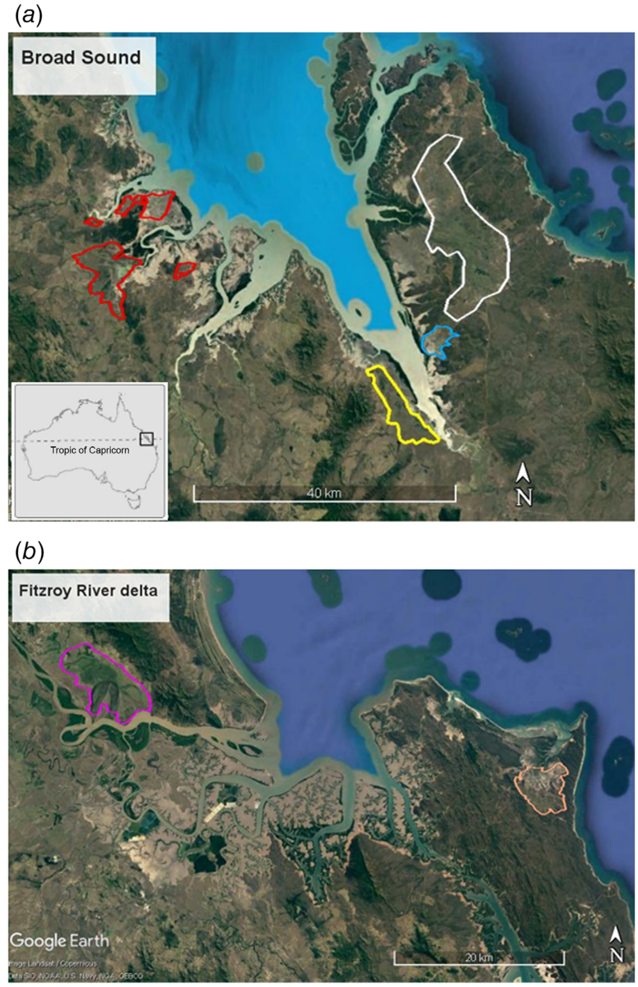

Fig. 3. Locality map showing (*a*) Broad Sound sites (inset shows the study site location, which encompasses both images) and (*b*) Fitzroy River delta sites (both images from Google Earth: Landsat/ Copernicus; Terrametrics; Data SIO NOAA, U.S. Navy, NGA, GEBCO). Polygons indicate the approximate marine plain area upstream of banks at each site (except at Curtis Island where the entire plain is shown). Red polygon, multiple banks at Upper West Broad Sound; yellow, Lower West Broad Sound; white, Torilla Plain; blue, Torilla South; and for the Fitzroy River delta sites – purple: Nankin Ck Plain, pink: Curtis Island Marine Plain.

into three categories: 'seawalls', which typically extend for several kilometres and are wide enough for a vehicle to pass along; 'low walls', which are similar but generally not high or wide enough for vehicular use (and therefore not as routinely maintained); and 'block banks' (also known as check banks), which are low banks placed across a channel, wide enough to stop or limit most flows of water. The aim of small block banks is to prevent or limit tidal ingress and to slow freshwater runoff, rather than to form extensive pools. In flood events, freshwater flows typically go around these small banks, allowing connectivity with the downstream estuarine or marine habitat at this stage; some tidal inflow may occur occasionally. In extreme flood events, water briefly covers most of the marine plain, irrespective of block banks.

Six sites (Fig. 3), five banked and one unbanked, were surveyed on at least 13 occasions between 2003 and 2020, with the majority of counts prior to 2015 except for the unbanked site at Curtis Island (Table 1, see Supplementary Material for full site descriptions). The unbanked site had similar vegetation and tidal position (supratidal to non-tidal) to the banked sites. Areas surveyed systematically did not include the habitats immediately downstream of banks such as tidal saltmarsh or mangroves, nor in most cases the *Melaleuca* woodlands on the landward margins. Nor were shorebirds using high tide roosts downstream of banked areas surveyed.

Surveys

Wetland sites were systematically surveyed by a team of experienced observers (two to four people) and waterbirds identified and counted. Wherever possible, total coverage of

Table 1. Description of wetland site characteristics including the area of marine plain influenced by banking.

Site	No. of surveys	Survey dates	Banked marine plain area (ha)[A]	Type of banks	Site description
Upper West Broad Sound (UWBS)	18	2006–2015	10 000	A mixture of low banks and seawalls, some block banks	A complex site comprising multiple separate plains and extending north from the Styx River to the southern bank of the St Lawrence River.
Lower West Broad Sound (LWBS)	13	2003–2020	4500	One long seawall	The bank at this site extends along the western side of the estuary of Herbert Creek in Broad Sound for approximately 14 km and the banked plain is up to 3 km across in places.
Torilla Plain (TP)	26	2003–2015	18 000	Mainly small block banks (a few low banks are also present)	This site occupies the Torilla Peninsula and has numerous creeks flowing onto it. The plain has a vast, extremely dense and complex network of channels, gutters, ponds and playas (Fig. 1*b*), providing a high total length of wetland edge habitat for waterbirds and other wetland-dependent species.
Torilla South (TS)	18	2003–2015	1500	Low banks	This site has low banks across the plain and includes a large *S. subulatus* swamp.
Nankin Ck Plain (NCP)	37	2005–2019	5000	One long seawall	This site is enclosed by a seawall of approximately 10 km that runs parallel to the Fitzroy River in the delta and includes a large oxbow.
Curtis Island Marine Plain (CIMP)	48	2009–2022	2500	Unbanked except for non-functional remnant	This site is a single area of marine plain on the northeastern end of Curtis Island that receives freshwater flow from several small seasonal creeks plus groundwater input from tall dune systems along its eastern edge.

[A]Large parts of each plain are directly affected by the banks (i.e. have tide excluded) but some landward parts have not been tidally impacted for hundreds of years (or more) and thus are unchanged hydrologically.

wetland habitats and total counts of all waterbirds present were attempted, rather than sampling and extrapolation. Larger sites such as Torilla Plain and Upper West Broad Sound were surveyed over several days. Waterbird data for a site were aggregated provided that the sub-sites were spatially separate and that counts were undertaken within a 3-day period (Weller *et al.* 2020) Most counts of larger sites were only partial due to the size of the wetlands. However, even the largest sites such as Torilla Plain and Upper West Broad Sound included some almost complete counts especially in relatively dry periods. In addition to counts, evidence of breeding such as nesting or presence of broods of dependent young was noted. Breeding records included species that foraged on the marine plain when rearing dependent young.

Waterbirds are broadly defined as all bird species that depend on wetlands for their survival, at least at some stage of their life cycle, consistent with the definition of waterbirds of the Ramsar Convention on Wetlands (Ramsar Resolution XI.8 Annex 2 2014) as being 'birds ecologically dependent on wetlands'. Thus, groups included ducks and allies, grebes, pelicans, cormorants and darters, herons, egrets, ibises and spoonbills, cranes, gallinules, rails and crakes, shorebirds, gulls and terns, several wetland-dependent raptors (White-bellied Sea Eagle, Swamp Harrier, Whistling Kite and Osprey) and wetland-dependent passerines (Eastern Yellow Wagtail, Australian Reed-Warbler, Little Grassbird, Zitting Cisticola and Capricorn Yellow Chat). The Zitting Cisticola has an unusual distribution in being found only on marine plains in Australia. Note that that, unlike waterbirds, wetland-dependent raptors and passerines were not necessarily counted systematically by all observers in all surveys so data from sites are not strictly comparable for these species.

Evaluating importance of wetlands

Migratory species listed under international agreements to which Australia is a party are identified as 'a matter of national environmental significance' (MNES) under the EPBC Act. In addition, the Act recognises nationally threatened species and ecological communities, along with wetlands of importance as listed under the Convention on Wetlands (Ramsar) as MNES. These species and their habitat are subject to the *EPBC Act Policy Statement 1.1 Significant Impact Guidelines – Matters of National Environmental Significance*. The EPBC Act also has specific legislation for migratory shorebirds and provides guidelines on how to evaluate impact levels outlined in *EPBC Act Policy Statement 3.21* (Commonwealth of Australia 2017). In all, 37 species of migratory shorebirds are included in these guidelines. This framework, in combination with state legislation (NC Act), was used to determine threatened and migratory waterbird species (hereafter referred to as MNES species).

The Ramsar Convention's Criteria for identifying Wetlands of International Importance (Ramsar Resolution XI.8 Annex 2 2014) are the most widely accepted and used criteria for identifying internationally important waterbird sites, including wetlands that are not being considered for Ramsar-listing.

Relevant criteria relate to wetlands supporting endangered species of waterbirds, fauna or flora at critical lifecycle stages such as waterbird breeding, counts of more than 20 000 waterbirds or more than 1% of the individuals in a population of one species or subspecies of a waterbird (criteria 2, 4, 5 and 6 respectively). The EPBC Act and associated regulations also provide a means to identify nationally important habitat for migratory shorebirds in Australia if it regularly supports: 0.1% of the flyway population of a single species of migratory shorebird, or 2000 migratory shorebirds, or 15 migratory shorebird species (Commonwealth of Australia 2017).

Population estimates for migratory shorebirds of the East Asian–Australasian Flyway (Hansen *et al.* 2022) were used to evaluate wetland status relating to designation of sites as wetlands of national or international significance. Estimates of Australian waterbird populations were sourced from an online database, Waterbird Population Estimates (WPE), hosted by Wetlands International (Wetlands International 2022). These estimates were used to evaluate the importance of wetland sites as habitat for waterbirds, including any non-shorebird migratory species listed by the EPBC Act. In addition, where available, estimates of the size of the population of wetland-dependent birds such as Capricorn Yellow Chat were included (Houston *et al.* 2018). Collectively, the six survey sites account for over 80% of the known population of this subspecies.

To align with Ramsar guidelines (Ramsar Resolution XI.8 Annex 2, clause 186), 'regular' use by migratory shorebirds was evaluated based on the most common species, Sharp-tailed Sandpiper. Only years in which two or more surveys were conducted in the migratory shorebird non-breeding season (i.e. September to May) were used. Maxima of each season's count were averaged where there were at least 5 years of consecutive data in which at least two surveys were undertaken and compared to nationally and internationally significant numbers to evaluate status of each wetland site. Four of the six sites qualified with this approach with another site having 3 consecutive years providing provisional data. The regularity of occurrence could not be evaluated at Lower West Broad Sound as surveys were infrequent.

Evaluation of banking

Species richness of waterbirds and migratory shorebirds were used to inform understanding of the broad effects of banking on biodiversity. Density of guilds was used to determine overall impacts of banks on waterbird feeding guild structure. Of particular interest was the piscivore group as an indicator of fish availability in the study sites and thus suitability of sites for tidal reconnection investments. Because some sites had multiple surveys in a year, maximum counts recorded in each year were used in analyses.

To evaluate guilds, the functional group approach of Kingsford *et al.* (2017) was followed, and waterbirds were placed into the following groups: Ducks, Herbivores, Large Waders, Piscivores and Small Waders (Table 2). To allow comparisons between sites to be made, abundance data were converted to density (numbers per km^2) based on banked marine plain area estimates in Table 1. Because the typical survey effort at complex sites (Upper and Lower West Broad Sound, and Torilla Plain) generally targeted only a portion of the banked wetland area, density estimates for these sites were adjusted accordingly (by 4/5ths and 2/3rds respectively).

Dunnett's test allows a statistical comparison of species richness where there are multiple comparisons between a single control (the unbanked site, CIMP) and treatment groups (i.e. the banked sites) (Lee and Lee 2018); and can be applied even where data are non-homogeneous (Gill 1977). This test was used to determine if there were statistically significant differences between species richness of waterbirds and migratory shorebirds at banked versus unbanked wetlands, and more specifically if there were differences between the density of piscivorous species.

Results

Overview

Overall, 91 species of waterbird or wetland-dependent bird were recorded from banked wetlands during the study (Table 2). This total included 83 waterbird species and eight other wetland-dependent species. Twenty-eight shorebird species were recorded. Sharp-tailed Sandpiper, Marsh Sandpiper, Common Greenshank, Red-necked Stint and Latham's Snipe were recorded from all six sites and Curlew Sandpiper from five sites, with Sharp-tailed Sandpiper the most abundant migratory shorebird. Of the 'resident' shorebirds, Pied Stilt was most numerous and found at all sites, along with Red-capped Plover, Black-fronted Dotterel, Red-kneed Dotterel and Masked Lapwing. Hundreds of shorebirds were frequently recorded at all sites with maximum counts of thousands at Torilla Plain, Upper West Broad Sound and Nankin Ck Plain.

Of the 91 species, 41 were confirmed as breeding on the marine plains, however, given the difficulty in finding evidence of breeding in secretive species such as crakes and rails, this is likely to be a minimum. Two MNES species were confirmed as breeding including the Endangered Australian Painted-snipe (Torilla Plain, twice; possibly also Upper West Broad Sound: Melzer *et al.* 2008, p. 277) and the Critically Endangered Capricorn Yellow Chat (all sites). Zitting Cisticola was another regular breeding wetland-dependent species. Species recorded breeding in nearly all sites were Magpie Goose, Black Swan, Grey Teal, Australasian Grebe, Purple Swamphen, Pied Stilt and Masked Lapwing. Waterbirds that typically breed in saline habitats such as Red-capped Plover were regularly observed breeding at several sites.

Table 2. Species list (see Appendix 1 in Supplementary Material for scientific names) and maximum numbers observed at each site.

Common name	Breed. status	Functional group	EPBC Act	NC Act	1% intl.	Sites					
						UWBS	LWBS	TP	TS	NCP	CIMP[A]
Ducks, geese and swans											
Magpie Goose[B]	Br	H			20 000	6215	6352	5716	96	300	0
Plumed Whistling-Duck[B]	Br	H			10 000	1989	65	3069	51	1500	200
Wandering Whistling-Duck[B]	Br	H			10 000	639	11	62	6	50	0
Freckled Duck		D			250	0	0	0	0	70	0
Black Swan	Br	H			10 000	217	328	347	310	202	92
Radjah Shelduck	Br	D			1000	34	24	30	7	138	5
Australian Wood Duck[B]	Br	D			10 000	20	52	191	8	714	5
Cotton Pygmy-goose[B]	Br	H			100	29	**128**	21	18	15	0
Green Pygmy-goose[B]		H			1000	2	0	1	0	0	0
Pacific Black Duck	Br	D			10 000	641	1540	776	150	2310	1811
Australasian Shoveler[B]	Br	D			1000	52	40	57	0	25	0
Grey Teal	Br	D			20 000	10 065	1380	3120	402	2340	1570
Chestnut Teal		D			1000	1	0	2	0	25	246
Pink-eared Duck		D			10 000	0	1	0	0	400	0
Hardhead	Br	D			10 000	282	95	505	4	200	12
Grebes											
Australasian Grebe[B]	Br	D			10 000	81	245	110	6	256	5
Great Crested Grebe	Br	P			250	1	6	0	0	0	0
Darter, cormorants and pelican											
Australasian Darter		P			1000	14	9	11	0	12	1
Little Pied Cormorant	Br	P			1000	55	43	27	2	208	4
Great Pied Cormorant		P			1000	0	0	2	0	10	2
Little Black Cormorant	Br	P			10 000	50	62	44	1	300	2
Great Cormorant		P			1000	0	1	1	4	2	0
Australian Pelican	Br	P			1400	1152	90	247	160	756	32
Herons, egrets, ibis, spoonbills and stork											
White-faced Heron	Br	LW			1000	112	30	213	14	97	44
Little Egret	Br	LW			1000	60	9	120	165	176	24
White-necked Heron[B]		LW			250	12	45	105	2	38	19
Pied Heron[B]		LW				0	0	2	0	0	0
Great Egret	Br	LW			1000	192	38	223	150	342	54
Intermediate Egret[B]	Br	LW			10 000	670	551	676	820	186	62
Cattle Egret[B]	Br	LW			10 000	1166	176	801	100	500	10
Striated Heron		LW				0	0	0	0	3	0
Nankeen Night-Heron[B]		LW			10 000	4	6	1	1	50	4
Australian Little Bittern[B]		LW			100	1	0	0	0	0	0
Black Bittern[B]		LW			1000	2	0	0	0	0	0
Glossy Ibis		LW	M		10 000	90	77	16	12	120	89
Australian White Ibis		LW			10 000	217	83	910	120	500	70
Straw-necked Ibis[B]		LW			10 000	1697	271	**15 300**	140	600	50
Royal Spoonbill	Br	LW			1000	681	150	559	7	**1002**	390

(*Continued on next page*)

Table 2. (*Continued*).

Common name	Breed. status	Functional group	EPBC Act	NC Act	1% intl.	Sites					
						UWBS	LWBS	TP	TS	NCP	CIMP[A]
Yellow-billed Spoonbill[B]		LW			250	13	5	16	3	36	20
Black-necked Stork	Br	LW			300	2	6	6	3	10	2
Brolga and gallinules											
Brolga	Br	LW			1000	220	124	195	8	16	167
Buff-banded Rail	Br	D				2	1	3	3	3	28
Pale-vented Bush-hen[B]		D				2	0	0	0	0	1
Baillon's Crake[B]		D				2	8	0	0	1	1
Australian Spotted Crake		D				0	0	0	1	2	1
Spotless Crake[B]		D				0	2	1	0	0	0
Purple Swamphen[B]	Br	H			1000	151	180	300	8	620	3
Dusky Moorhen[B]	Br	D			250	20	110	5	5	50	0
Black-tailed Native-hen[B]		H			10 000	6	0	0	0	20	0
Eurasian Coot	Br	H			10 000	255	900	235	0	900	0
Shorebirds											
Latham's Snipe[B,C]		SW	M		300	**32**	9	**203**	1	2	6
Swinhoe's Snipe[B,D]		SW	M		400	2	0	0	0	0	0
Black-tailed Godwit		SW	M		1600	**470**	6	58	1	0	0
Bar-tailed Godwit[E]		SW	V, M	V	3250	5	0	1	1	40	0
Little Curlew		SW	M		1100	0	1	5	0	0	0
Whimbrel		SW	M		650	1	0	0	0	30	1
Far Eastern Curlew		SW	CE, M	E	350	2	1	0	0	3	0
Marsh Sandpiper		SW	M		1300	**1656**	26	**330**	32	**493**	28
Common Greenshank		SW	M		1100	52	4	**212**	**256**	100	10
Common Sandpiper		SW	M		1900	0	0	0	0	1	0
Red-necked Stint		SW	M		4750	**2000**	12	10	420	100	147
Pectoral Sandpiper		SW	M		12 200	2	2	0	0	0	0
Sharp-tailed Sandpiper		SW	M		850	**3227**	**140**	**1276**	**280**	**1450**	**710**
Curlew Sandpiper		SW	CE, M	CE	900	**400**	15	**500**	0	2	17
Australian Painted-snipe[B]	Br	SW	E	E	20	3	0	6	0	0	0
Comb-crested Jacana[B]		SW			1000	16	15	1	6	24	0
Australian Pied Oystercatcher		SW			110	50	0	0	0	0	0
Pied Stilt	Br	SW			10 000	3236	126	1495	260	1180	816
Red-necked Avocet	Br	SW			1100	39	0	64	0	750	130
Pacific Golden Plover		SW	M		1200	46	0	4	7	0	12
Red-capped Plover	Br	SW			950	350	6	44	120	48	236
Lesser Sand Plover		SW	E, M	E	1800	0	0	2	0	0	61
Oriental Plover		SW	M		2300	0	0	0	0	1	0
Black-fronted Dotterel[B]		SW			250	12	7	22	2	32	1
Red-kneed Dotterel[B]	Br	SW			1000	10	19	25	59	40	59
Banded Lapwing[B]	Br	SW			1000	0	0	5	0	0	0
Masked Lapwing	Br	SW			10 000	99	60	197	20	473	125
Australian Pratincole		SW			1000	2	0	29	0	5	0

(*Continued on next page*)

Table 2. (*Continued*).

Common name	Breed. status	Functional group	EPBC Act	NC Act	1% intl.	Sites					
						UWBS	LWBS	TP	TS	NCP	CIMP[A]
Gulls and terns											
Silver Gull	Br	P			20 000	80	6	164	126	60	59
Gull-billed Tern[F]		P	M		1000	35	80	**1000**	6	150	32
Caspian Tern		P	M		1000	3	1	15	23	67	5
Whiskered Tern	Br	P			10 000	213	120	800	6	1000	24
White-winged Black Tern		P	M		10 000	1	0	600	0	0	22
Wetland dependent raptors											
Whistling Kite[B]						4	10	9	4	12	3
White-bellied Sea-Eagle	Br					5	4	5	3	5	2
Swamp Harrier						4	3	5	2	6	2
Wetland dependent passerines											
Yellow Chat	Br		CE	E	3	**12**	**81**	**557**[G]	**48**	**59**	**48**
Eastern Yellow Wagtail			M			1	0	0	0	0	0
Australian Reed-Warbler[B]						6	4	5	2	15	5
Little Grassbird	Br					2	7	2	1	6	20
Zitting Cisticola	Br					7	9	10	3	1	180
Species richness						**78**	**66**	**73**	**58**	**73**	**60**
Waterbird species richness						**70**	**59**	**66**	**51**	**66**	**53**

Numbers shown in bold indicate national significance (>0.1%) based on population estimates for the East Asian–Australasian (EAA) Flyway for migratory shorebirds (Hansen *et al.* 2022) and underline indicates numbers of international significance (>1% EAA Flyway for migratory shorebirds or >1% Australian population based on estimates from Wetlands International).

[A]The aggregated data for Curtis Island Marine Plain (Table 4) include four species that were found only at Curtis Island and not in the five banked sites and so were not shown in Table 2. These included two species of migratory shorebirds (Long-toed Stint and Grey Plover), Crested Tern and Osprey. All four species are listed as Migratory under the EPBC Act, occurred in low abundance and, with the exception of Osprey, were only observed on one occasion as single birds.

[B]Denotes species for which banking is likely to have promoted habitat by increasing freshwater-retention.

[C]A reduced national criterion is set for Latham's Snipe (18 instead of 30) as specified in *EPBC Act Policy Statement 3.21* (Commonwealth of Australia 2017).

[D]This species was identified as *Gallinago* sp. but is considered to be Swinhoe's Snipe *G. megala* based on notes taken at the time of observation by Roger Jaensch.

[E]Bar-tailed Godwit were identified only to species level, although it is likely that the birds in the study area were subspecies *baueri* as Bar-tailed Godwit arriving in Queensland from breeding grounds in the Northern Hemisphere are mostly this subspecies (Weller *et al.* 2020). This assumption was applied in categorising it as threatened (subspecies *baueri* is listed as Vulnerable under the EPBC Act).

[F]This taxon is now widely considered as two species (https://birdlife.org.au/conservation/science/taxonomy): the Australian Gull-billed Tern *Gelochelidon macrotarsa*, which breeds in the Central Queensland region and is common, and the Common Gull-billed Tern *G. nilotica* which breeds in Eurasia and occurs in northern Australia only in modest numbers. The project surveys did not distinguish them.

[G]This count included a large percentage of young birds.

Breed status: Br indicates species recorded breeding on at least one occasion. Functional group: D, Ducks; H, Herbivores; LW, Large Waders; P, Piscivores; SW Small Waders. EPBC Act and NC Act: V, Vulnerable; E, Endangered; CE, Critically Endangered; M, Migratory. 1% intl.: Refers to numbers for each species that must be exceeded for a site to be considered of international significance (>1% EAA Flyway for migratory shorebirds or > 1% Australian population based on estimates from Wetlands International).

Site abbreviations: UWBS, Upper West Broad Sound; LWBS, Lower West Broad Sound; TP, Torilla Plain; TS, Torilla South; NCP, Nankin Ck Plain; CIMP, Curtis Island Marine Plain.

Mixed flocks of hundreds of egrets (Great Egret, Intermediate Egret, Little Egret and Cattle Egret) regularly foraged on Torilla Plain and Torilla South during the breeding season and were observed nesting on a small mangrove island in Broad Sound near these two sites (Jaensch *et al.* 2005); also in mainland mangrove forest next to Newport Conservation Park in the Upper West Broad Sound (Melzer *et al.* 2008, p. 275), and in estuarine mangroves of the Fitzroy River opposite the Nankin Ck Plain (RJ pers. obs. from a light aircraft), confirming the importance of these marine plains as foraging habitat for breeding egrets.

In general, banked marine plains supported large numbers of typically freshwater-associated species including ducks, grebes, herons and allies, gallinules, shorebirds and plovers and some wetland-dependent species (Table 2), suggesting there is highly suitable habitat to support them. It is our collective experience that these species rarely feed in saltwater wetlands.

Matters of national environmental significance

A number of MNES species were identified including six threatened species (EPBC Act): Australian Painted-snipe, Bar-tailed Godwit, Far Eastern Curlew, Curlew Sandpiper, Lesser Sand Plover and Capricorn Yellow Chat, the latter being found at all six sites (Table 2). Twenty-two species were identified as migratory under the EPBC Act of which 17 were migratory shorebirds; the others being three tern species, Glossy Ibis and Eastern Yellow Wagtail (Table 2).

Abundance of waterbirds is used to identify internationally (and, for migratory shorebirds, also nationally) important habitat. Species present in numbers indicative of international importance (>1% of the population) included: Cotton Pygmy-goose, Straw-necked Ibis, Royal Spoonbill, Marsh Sandpiper, Sharp-tailed Sandpiper and Gull-billed Tern. Also, all sites recorded internationally significant numbers of the Capricorn Yellow Chat. An additional five species of migratory shorebird were present in nationally important numbers (i.e. >0.1% of the population): Common Greenshank, Black-tailed Godwit, Curlew Sandpiper, Latham's Snipe and Red-necked Stint.

Importance of the marine plains and their wetlands

All sites supported several MNES threatened species (Table 3). Two of the five banked wetlands recorded five: Torilla Plain and Upper West Broad Sound with a third site, Nankin Ck Plain, supporting four threatened species. These three sites also recorded many MNES migratory species – 15, 18 and 14 respectively, most of which were shorebirds (Table 4). Further, each of these three sites supported several migratory shorebird species that were present in numbers indicating national importance – 5, 6 and 2 respectively.

All sites met criteria under the Ramsar Convention, providing habitat for threatened species (criterion 2) and breeding habitat for wetland-dependent species (criterion 4) (Table 3). However, Torilla Plain was the only site to meet criterion 5 of the Ramsar agreement with 19 730 waterbirds recorded in March 2003 after a major inundation of the plain and this number would have exceeded the 20 000 threshold if all available wetland habitat had been surveyed (only about 90% was surveyed: Jaensch 2004). This site also recorded internationally significant numbers of Capricorn Yellow Chat, Straw-necked Ibis and Gull-billed Tern; the latter listed as Migratory under the EPBC Act.

In terms of migratory shorebirds, three sites met criterion 6 of the Ramsar Convention (Table 3). Numbers of Sharp-tailed Sandpiper exceeded 1% of the East Asian–Australasian Flyway population at Torilla Plain, Nankin Ck Plain and Upper West Broad Sound while the latter also held internationally significant numbers of Marsh Sandpiper.

All sites met additional criteria pertinent to defining wetlands with nationally important habitat and therefore MNES (Table 4). Torilla Plain (2012 in March 2008) and Upper West Broad Sound (7837 in March 2007) had more than 2000 migratory shorebirds on at least one occasion. In addition to the species listed previously regarding internationally important habitat, sites supporting migratory shorebirds present in nationally important numbers are

Table 3. Waterbird and wetland-dependent birds relevant to Ramsar criteria defining wetlands with internationally important habitat and nationally important habitat (see Table 1 for site names).

	UWBS	LWBS	TP	TS	NCP	CIMP
Ramsar criteria						
Criterion 2: The wetland supports vulnerable, endangered, or critically endangered species or threatened ecological communities.	BaTG, FEC, CS, APSn, CYC	FEC, CS, CYC	BaTG, CS, APSn, LSP, CYC	BaTG, CYC	BaTG, FEC, CS, CYC	CS, LSP, CYC
Breeding habitat for waterbirds based on Criterion 4: The wetland supports plant and/or animal species at a critical stage in their life cycles, or provides refuge during adverse conditions.	18 species	16 species	30 species	18 species	12 species	12 species
Criterion 5: The wetland regularly[A] supports 20 000 or more waterbirds.			Once in March 2003			
Criterion 6: The wetland regularly[A] supports 1% of the individuals in a population of one species or subspecies of waterbird.	MS, STS, CYC	CPGo, CYC	SNI, STS, GBT, CYC	CYC	RSb, STS, CYC	CYC
Nationally important habitat						
The wetland supports 0.1% of the individuals in a population of migratory shorebirds.	LSn, BlTG, MS, RNSt, STS, CS	STS	LSn, MS, CGs, STS, CS	CGs, STS	MS, STS	STS

[A]The requirement for regular usage is less stringent where bird surveys tend to be few and irregular (Ramsar Resolution XI.8 Annex 2, clause 188), as is common in Australia away from centres of population.

LSn, Latham's Snipe; BlTG, Black-tailed Godwit; BaTG, Bar-tailed Godwit; FEC, Far Eastern Curlew; CGs, Common Greenshank; MS, Marsh Sandpiper; CS, Curlew Sandpiper; RNSt, Red-necked Stint; STS, Sharp-tailed Sandpiper; APSn, Australian Painted Snipe; LSP, Lesser Sand Plover; CPGo, Cotton Pygmy-goose; SNI, Straw-necked Ibis; RSb, Royal Spoonbill; GBT, Gull-billed Tern; CYC, Capricorn Yellow Chat.

Table 4. Summary of pertinent statistics that relate to Australian biodiversity legislation applied to wetland-dependent birds including migratory shorebirds (see Table 1 for site names).

Parameters	UWBS	LWBS	TP	TS	NCP	CIMP	Total
Overview statistics							
Total species richness	78	66	73	58	73	64	91
Waterbird species richness	70	59	66	51	66	56	83
Statistics relevant to Australian biodiversity legislation							
No. of Threatened species (EPBC Act and/or NC Act) – also relevant to criterion 2 of the Ramsar convention							
Migratory shorebird species	3	2	3	1	3	2	4
Other waterbird or wetland-dependent species	2	1	2	1	1	1	2
TOTAL Threatened species	**5**	**3**	**5**	**2**	**4**	**3**	**6**
No. of Migratory species (EPBC Act)							
Migratory shorebird species	13	10	11	8	11	11	17
Other waterbird or wetland-dependent species	5	3	4	3	3	6	5
TOTAL Migratory species	**18**	**13**	**15**	**11**	**14**	**17**	**22**
Statistics relevant to defining wetlands as internationally important habitat (and therefore of national importance under the EPBC Act Policy Statement 3.21)							
Breeding waterbird species (criterion 4 of the Ramsar Convention)	18	16	30	18	12	12	41
More than 20 000 waterbirds in one count (criterion 5 of the Ramsar Convention)			1[A]				
No. of species present in internationally significant numbers (>1% of flyway or Australian population) (criterion 6 of the Ramsar Convention)							
Migratory shorebird species	2	0	1	0	1	0	2
Other waterbird or wetland-dependent species	1	2	3	1	2	1	5
TOTAL species present in internationally significant numbers (>1% of the flyway or Australian population)	**3**	**2**	**4**	**1**	**3**	**1**	**7**
Statistics relevant to defining wetlands as nationally important habitat for migratory shorebirds (EPBC Act Policy Statement 3.21)							
No. of surveys >2000 migratory shorebird counts	1		1				
No. of migratory shorebird species present in nationally significant numbers (>0.1% of the flyway population)	6	1	5	2	2	1	7

The Total does not include the four extra species observed at Curtis Island, but the Curtis Island counts do include those four extra species (see footnote, Table 2).
[A]The count was just under 20 000 (19 730) but some parts of the plain with similar habitat were unsurveyed (approximately 10%) so the count would have exceeded the 20 000 criterion.

listed in Table 3. These data refer only to non-tidal wetland habitat; intertidal habitat and roosting sites below the banks were not included in the study.

Evaluation of 'regular usage' based on Sharp-tailed Sandpiper showed that all sites with sufficient data (i.e. all except Lower West Broad Sound) regularly provided nationally important habitat for this species (see Supplementary Table S5). The average maxima of one site, Upper West Broad Sound, exceeded the level for habitat of international importance based on 3 years for which consecutive data were available.

Evaluation of banking

Four of the five tide-excluded sites averaged 30 or more species present each year and were significantly more diverse than the unbanked site, which averaged 19 species (Dunnett's Test, $P < 0.05$). Torilla South (17 species) had similar waterbird biodiversity to the unbanked site. However, tide-excluded sites had comparable species richness of migratory shorebirds (averaging three to six species each year) compared with four species at the unbanked site (Dunnett's Test, $P > 0.05$).

Piscivore abundance at tide-excluded sites ranged from ~3.2–7.3 per km^2, a relatively low proportion of the combined waterbird density, ~57–95 per km^2 (Fig. 4). In contrast, piscivore density at the only unbanked site was relatively lower at 1.0 per km^2. However, only one of the five banked sites, Nankin Ck Plain, had significantly greater piscivore density than the unbanked site (Dunnett's Test, $P < 0.05$). This was partly due to the high fluctuations in waterbird densities from year-to-year. Herbivorous waterbirds showed the same pattern as the piscivores, with the unbanked site the lowest, but only Lower West Broad Sound had significantly more herbivorous waterbirds than the unbanked site. Of the other guilds, densities in the unbanked site were generally intermediate compared to the tide-excluded sites, including small wading birds, the

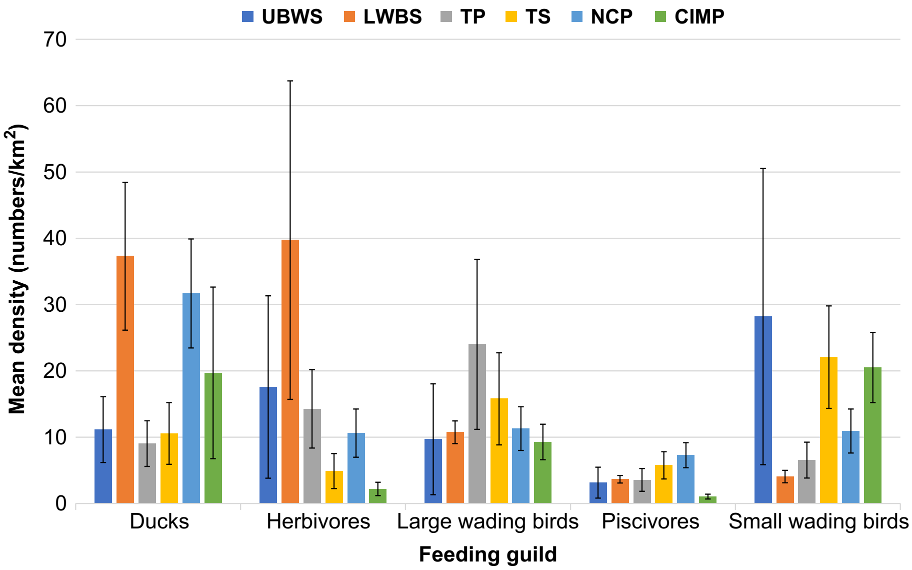

Fig. 4. Plot of the mean density (numbers/banked site area) of waterbird guilds based on the maximum count in each year at each site, error bars indicate ±1 s.e. (UWBS, Upper West Broad Sound; LWBS Lower West Broad Sound; TP Torilla Plain; TS Torilla South; NCP Nankin Ck Plain; CIMP Curtis Island Marine Plain).

group that includes the migratory shorebirds, and densities of the tide-excluded sites did not differ significantly from the control.

Discussion

All five banked wetland sites were found to have habitat values for waterbirds and wetland-dependent species covered by Australian biodiversity protection legislation. This was indicated by the regular occurrence of several species listed as Threatened, as well as numerous species listed as Migratory including migratory shorebirds which have special status under the EPBC Act. In addition, all sites met Ramsar and Australian guidelines defining wetlands as 'important habitats' under the EPBC Act. Internationally significant numbers of several species of migratory shorebirds were present at three of the five banked sites: Torilla Plain, Upper West Broad Sound and Nankin Ck Plain. These findings, reinforced by the importance of all sites to the Critically Endangered Capricorn Yellow Chat, show that any development proposals affecting these banked marine plains and tide-excluded wetlands in general, such as removal of banks, should be comprehensively assessed in the context of the EPBC Act. They show the importance of tide-excluded banked marine plain wetlands in providing ecosystem services (biodiversity and conservation values) and support the case for care and maintenance of the current banks as a means to mitigate sea level rise impacts (Houston *et al.* 2020*b*).

The levels of waterbird biodiversity and regular occurrence of nationally significant numbers of migratory shorebirds and waterbirds matched or exceeded levels in an unbanked marine plain wetland site. This suggests that banking *per se* is not detrimental to habitat values for a large variety of waterbird and migratory shorebird species including threatened wetland-dependent species such as Capricorn Yellow Chat and Australian Painted-snipe, and, in many cases, is advantageous.

The importance of tide-excluded wetlands to the Capricorn Yellow Chat has been previously identified; collectively accounting for over 80% of the known population with more than half at one site, Torilla Plain, and only two of 15 known sites were unbanked and in a natural state (Houston *et al.* 2013). It is very likely that the return of these banked sites to their natural state poses a risk to the survival of the Capricorn Yellow Chat. Climate change impacts and sea level rise have been identified as major threats to this species (Houston *et al.* 2013, 2020*b*) and breeding habitat on the unbanked marine plain at Curtis Island has already been lost to sea level rise, where salt-tolerant sedge swamps have become salt-encrusted basins. Curtis Island and other sites in the Fitzroy River delta have been identified as being vulnerable to loss in the medium term (the next 60 years) under current rates of sea level rise (Houston *et al.* 2020*b*). Sites in Broad Sound, while at slightly higher elevations, are still vulnerable to sea level rise and incremental intrusion. Alteration and loss of habitat will occur at all Capricorn Yellow Chat sites, irrespective of location, albeit at a slower rate in the Broad Sound area. Further, sites such as Torilla Plain, extend several kilometres inland and have a substantial capacity to provide suitable habitat with the retreating shoreline. However, others such as Torilla South, would be rapidly lost due to their small size. One site in particular stands out as a final refuge for the Capricorn Yellow Chat: Lower West Broad Sound is the highest above sea level and has the most substantial sea wall.

Removal of banks would also impact on waterbirds, particularly those dependent on freshwater influence. The variety and scale of waterbird breeding would be reduced. Many of the breeding ducks would be unlikely to raise their dependent young in saline wetlands. Because the structures increase the persistence of water on the marine plains, removal of these would lead to less waterbird use of the plains in the dry season. There would also be less habitat for migratory shorebird species that preferentially forage in non-tidal wetlands and/or pools in vegetated supratidal saltmarshes (Smith 1991). This includes species such as Sharp-tailed and Marsh Sandpipers that were present in internationally significant numbers.

Restoration of banked wetlands to tide-impacted regimes by removal of banks has been proposed as a mechanism to sequester carbon, improve water quality and restore fisheries values (Adame *et al.* 2019; Negandhi *et al.* 2019; Waltham *et al.* 2019). However, benefits are equivocal and no evidence was found of a decline in coastal fisheries in coastal northeastern Australia where banks are prevalent (Sheaves *et al.* 2014). Further, local climate such as rainfall patterns and wetland location (e.g. low or high in the tidal gradient) were found to influence ecosystem processes such as carbon sequestration (Negandhi *et al.* 2019), illustrating the need for site-specific studies to be carried out on the banked wetlands of these complex marine plain ecosystems before any decisions about 'restoration' are made (Sheaves *et al.* 2014). While there appears to be no specific studies of carbon sequestration in banked systems in Central Queensland, carbon sequestration in pastures has been shown to be greater where grass productivity is higher (Henry and McKenzie 2018). This implies that the relatively high grass production habitat provided by tide-excluded pastures, up to six times compared with unbanked habitat (Wildin and Chapman 1988; Middleton *et al.* 1996), would lead to greater carbon soil gains compared with unbanked supratidal habitat.

In this study, piscivorous waterbirds were used as bioindicators of the available levels of fish resources in the marine plain wetland habitat. All sites had relatively few piscivores compared to other functional groups. Very few piscivores were present at the unbanked site reflecting the lack of permanent pools and the shallowness (relatively brief inundation) of the seasonal wetlands (channels and basins) that occur naturally on these gently sloping plains. These findings, combined with the lack of permanent pools in either banked or unbanked wetlands on these marine plains, suggest that these sites generally have low fisheries potential. Pools in both banked and unbanked situations also become hypersaline as they dry (Houston *et al.* 2013, 2020*b*), further reducing their value for fish.

Connectivity allowing migration of diadromous fish into and out of permanent pools upstream of marine plain wetlands also needs consideration. However, block banks such as at Torilla Plain that are not much wider than the channel do not appear to be a barrier. These permit water to flow around them during wet season flows and large tidal events, thus providing connectivity between the upper floodplain and the sea (WetlandInfo 2016). Larger banks represent a barrier to fish migration under normal wet season flows but in flood events connectivity to the estuary may occur via other channels that flow around the wall (Department of Environment and Science 2022; Hyland 2002). In other situations, where fisheries potential of banked wetlands has been identified, rather than removing banks, other options such as fish ladders, culverts, flood gates or spillways (bywashes) to enhance floodplain connectivity could be sufficient to allow fish movements (Hyland 2002; WetlandInfo 2016; Waltham *et al.* 2019).

It is not possible to return these wetlands to their pre-banked state as mean sea levels have risen about 20 cm since most of the banks were constructed, so tides would incur far further across these almost level plains if banks were removed. Sea levels in the Central Queensland region were found to be increasing at a rate of 8 mm/annum, highlighting the importance of retaining existing banks to mitigate climate change impacts such as sea level rise, particularly for maintaining habitat of the Critically Endangered Capricorn Yellow Chat and associated shorebirds (Houston *et al.* 2020*b*; Peng *et al.* 2022). Block banks, due to their capacity to retain connectivity for fish, have been recommended as a management approach to protect marine plain habitat currently impacted by sea level rise such as at Curtis Island (Houston *et al.* 2013, 2020*b*).

When making management decisions about banked marine plain wetlands, given the array of competing interests, it is important to consider the full range of ecological, economic, and social values of these altered ecosystems, as well as legislated protection for fauna species. Prudent management would lead to optimal community outcomes by managing wetlands for a broad array of services (Waltham *et al.* 2019). This would also align with the 'wise use' concept of the Ramsar Convention (Ramsar Resolution XI.8 Annex 2 2014).

Conclusion

There is a lack of information on the value of tide-excluded banked wetlands and their effect on fish accessibility and carbon sequestration. However, indirect evidence, as shown in this study, indicates they have very significant importance for avifauna, as well as the previously identified ecosystem services associated with fodder production and reducing sediment and nutrient flows to the Great Barrier Reef. Any proposal to 'restore' these areas to the previous tide-influenced state should be stopped until there are appropriate studies to determine their status. Our study points to tide-excluded banked wetlands being advantageous to all parties and that the apparent conflict may be non-existent. Enhancement of existing banks should also be considered in strategies to mitigate sea level rise.

Supplementary material

Supplementary material is available online.

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Data availability. The data that support this study will be shared upon reasonable request to the corresponding author.

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