

Changes in shorebird use of the Maroochy River estuary, Sunshine Coast, Queensland over 25 years

Penn Lloyd^{1,2}, Peter V. Driscoll² and Simone Bosshard³

¹Biodiversity Assessment and Management Pty Ltd, P.O. Box 1376, Cleveland, Queensland 4163, Australia

²Queensland Wader Study Group, Brisbane, Queensland, Australia

³Sunshine Coast Council, Locked Bag 72, Sunshine Coast Mail Centre, Queensland 4560, Australia

Email: penn@baamecology.com

Received: 21 January 2024

Accepted: 11 March 2024

The lower Maroochy River estuary is surrounded by densely populated areas of Maroochydhore, a rapidly growing population centre on the Sunshine Coast in south-east Queensland, Australia. To inform management of shorebirds, we conducted surveys of shorebird use of the estuary over three seasons 2020/21 to 2022/23 and reviewed long-term monitoring data of the Queensland Wader Study Group to analyse long-term trends in shorebird numbers in relation to the changes in the estuary. The approximately 87 ha of tidal flats in the lower estuary supported an average of 114.4 ± 39.4 (maximum of 173) migratory shorebirds and an average of 9.9 ± 5.1 (maximum of 16) resident shorebirds at low tide during eight summer-season surveys in 2020/21 to 2022/23. Only two of five known roost sites were used by shorebirds during seven high tide surveys in 2020/21 to 2022/23, with 40 to 109 migratory shorebirds and 2 to 12 resident shorebirds present. Since 1997, roosting abundance has declined significantly for four species, increased significantly for two species, with two species showing no trend. Declines were at least partly related to increased human disturbance that caused the abandonment of a previously preferred roost site. Since 2011, abundance at low tide has declined significantly for four species, with four species showing no trend.

Keywords: Conservation, disturbance, East Asian–Australasian Flyway, shorebirds

INTRODUCTION

The lower Maroochy River estuary is surrounded by densely populated areas of Maroochydhore, a rapidly growing population centre on the Sunshine Coast in south-east Queensland, Australia. The southern bank of the estuary is heavily urbanised whereas the northern bank is mostly fringed with mangrove forest. Two vegetated sand islands (Channel Island and Goat Island) occur within the centre of the estuary close to the mouth; they effectively appear as one island and are hereafter referred to as Goat Island (Fig. 1). The mouth of the estuary was historically very mobile, with the entrance shifting both to the north and south of Pincushion Island, a rock outcrop on the coastline (BMT WBM 2012). Prior to 1999, the estuary opened to the Pacific Ocean to the north of Pincushion Island, but during the early 1990's the southern channel in the estuary became dominant and erosive pressure resulted in a breakthrough of the entrance south of Pincushion Island in 1999 and a subsequent build-up of sand over the old entrance along the North Shore (Fig. 2; BMT WBM 2012). This configuration of the entrance has maintained to the present day following the construction of geotextile groynes and seawalls to stabilise the southern bank and protect the assets of a caravan park south of the mouth.

During storms over the period 2009 to 2011, the sandy beach and frontal dune of Maroochydhore Beach that runs south of the estuary mouth was severely eroded, causing the beach to lower and erode much of the dune buffer, exposing coffee rock, damaging beach access structures and threatening inland infrastructure (BMT WBM 2012). To reverse this degradation to the amenity of the beach and assets with high economic and social values, a plan was developed to nourish the beach with

approximately 350,000 m³ of sand over four years dredged from the lower reaches of the estuary using a small cutter/suction dredge to pump loose unconsolidated sand directly by pipeline to the beach nourishment area (BMT WBM 2012). Guided by a Shoreline Erosion Management Plan (Sunshine Coast Council 2014), sand on Maroochydhore Beach is now replenished approximately every two years. Since the start of the dredging program in 2013, approximately 650,000 m³ of sand has been dredged from the lower Maroochy River over the past ten years. To minimise potential impacts on migratory shorebirds and their habitat, dredging activities are temporally and spatially restricted. No dredging is allowed between October and April (the months when most migratory shorebirds are present) apart from six weeks in February and March. If dredging is conducted in February–March, sand extraction is restricted to the deeper sub-tidal and highly dynamic area near Cotton Tree Beach, and a temporary shorebird refuge area is created on the Maroochy North Shore throughout the period of dredging. The refuge area covers approximately 20 ha of the southern extent of the North Shore that is most suitable for shorebird roosting, is delineated using exclusion zone fencing and signage, and operates during dredging work hours on weekdays, 7am–5pm.

Volunteer members of the Queensland Wader Study Group, a special interest, citizen-science group of the Queensland Ornithological Society Incorporated, have monitored shorebird use of the lower Maroochy River estuary at regular intervals since 1997 as part of a broader programme of monitoring shorebird populations across Queensland (Milton and Driscoll 2006). A large proportion of Australia's shorebird species are migratory, spending their non-breeding season (the Austral summer) in Australia and migrating up to 13,000 km north along the East

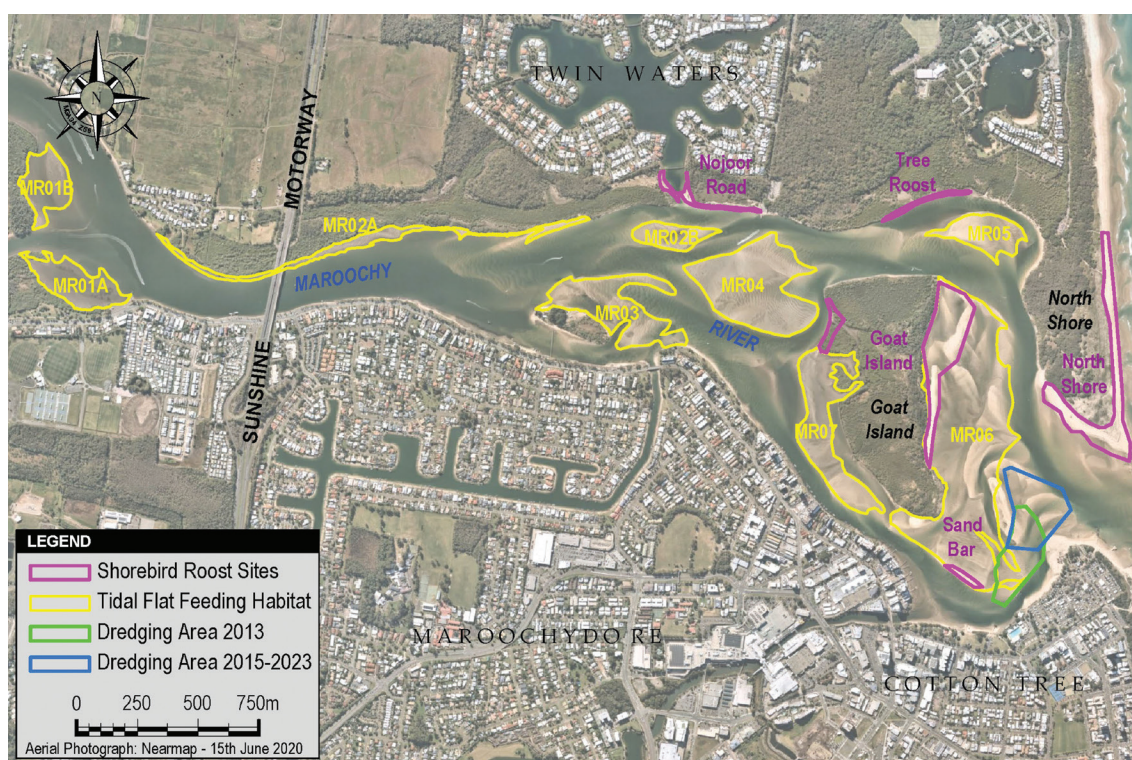


Figure 1. Locations of tidal flat shorebird feeding habitat areas and roost sites on the lower Maroochy River.



Figure 2. Changes in the configuration of the Maroochy River entrance channel 1996-2023. Contains imagery © State of Queensland 2023, © 2023 Google and © 2023 Airbus.

Asian–Australasian Flyway to breeding grounds in central to northern Asia and western Alaska (most species, Bamford *et al.* 2008) or south to New Zealand (Double-banded Plover, Pierce 1999) (see Table 4 for scientific names for all species). On their non-breeding grounds in Australia, coastal migratory shorebirds have a daily activity pattern driven largely by the tidal cycle, roosting in flocks at sites above the high-water mark at high tide and moving to tidal flat feeding areas once they become exposed as the water recedes through the low-tide phase of the tide cycle (Colwell 2010). In 2019, the Sunshine Coast Council local government started implementing a Shorebird Conservation Action Plan (Sunshine Coast Council 2019) that aims to raise awareness and educate the public around shorebirds, to manage and protect shorebird habitat and to provide management solutions for shorebird conservation. To better understand shorebird use of the Maroochy River estuary to inform the management of shorebirds, the Sunshine Coast Council contracted Biodiversity Assessment and Management Pty Ltd to undertake shorebird surveys over three seasons 2019/20 to 2022/23 and review and analyse the existing long-term dataset of the Queensland Wader Study Group. This paper presents the results of this assessment and documents the spatial use of the Maroochy River estuary by shorebirds for feeding at low tide and roosting at high tide and long-term trends in shorebird numbers in relation to the changes in the estuary over the duration of monitoring.

METHODS

The authors conducted nine surveys at high tide and nine surveys at low tide over the months November to March in the 2020/21 to 2022/23 shorebird seasons. These surveys were performed from a small, motorised boat, which facilitated rapid access to all parts of the estuary. Surveys for shorebirds feeding on tidal flats were conducted as close to the time of low tide as practicable and at a maximum of no more than two hours either side of low tide. Tidal flats between the Maroochy River/Eudlo Creek confluence and the estuary mouth were divided into seven survey areas (Fig. 1). Similarly, surveys for shorebirds roosting at high tide were conducted as close to the time of high tide as practicable and at a maximum of no more than two hours either side of high tide. High tide surveys involved traversing the estuary by boat searching all exposed sand banks and fringing mangrove trees for roosting shorebirds. Shorebirds were identified and counted using a combination of high quality 10x40 binoculars (on the boat) and a high-powered spotting telescope mounted on a secure tripod (when coming ashore on sand banks).

Surveys by volunteer members of the Queensland Wader Study Group have been conducted at regular (typically monthly) intervals over the past 25 years 1997 to 2023. Shorebirds were typically surveyed over a 4-hour period using spotting telescopes mounted on tripods from a network of vantage points on the northern and southern shorelines that gave clear views over either tidal flats or roost sites, with occasional surveys conducted by boat or kayak. All available Queensland Wader Study Group data were reviewed. Surveys that did not fall within two hours either side of high tide or low tide were excluded from analysis. A previous analysis of seasonal variation in the abundance of migratory shorebirds in south-east Queensland (Lloyd *et al.* 2022) has shown that the total numbers of migratory shorebirds are relatively stable over the period 1 October to 15 March (summer, non-breeding season)

and 1 May to 31 August (winter, breeding season), outside the peak periods of northward and southward migration. To examine long-term trends among migratory shorebirds, relevant surveys were attributed to one of the above two seasonal periods or were otherwise excluded from analysis. To examine long-term trends among resident shorebirds, surveys in all months of the year were included after exploratory data analysis found no seasonal variation among resident species counts.

Tests for temporal trends in shorebird count numbers at any site were conducted using a generalised linear model fitted to a Poisson distribution for count data in R (R Core Team 2023). Analyses were conducted separately for data at high tide and low tide due to the limited overlap in count data across years. Averages are presented ± 1 standard deviation (SD).

RESULTS

Shorebird use of tidal flat feeding habitat at low tide

The approximately 87 ha of tidal flats along the lower Maroochy River supported an average of 114.4 ± 39.4 (maximum of 173) migratory shorebirds and an average of 9.9 ± 5.1 (maximum of 16) resident shorebirds at low tide during the eight summer-season surveys conducted by the authors in 2020/21 and 2022/23 (Table 1). Four migratory shorebird species dominated the counts: Pacific Golden Plover, Whimbrel, Bar-tailed Godwit and Far Eastern Curlew. The most important tidal flat area for foraging migratory shorebirds was MR06 on the eastern side of Goat Island (Fig. 1), which supported an average of 65.9 ± 36.8 (maximum of 115) migratory shorebirds at low tide (Table 1). Other important tidal flats were MR04 and MR07, both on the western side of Channel and Goat islands.

Combining the Queensland Wader Study Group data and survey data from this study, five migratory shorebird species (Pacific Golden Plover, Whimbrel, Bar-tailed Godwit, Far Eastern Curlew, Grey-tailed Tattler) and two resident shorebird species (Pied Oystercatcher, Red-capped Plover) dominated the low tide counts (Table 2). A total of 14 migratory shorebird species and six resident shorebird species have been recorded feeding at low tide through the summer period, whereas a total of six migratory shorebird species and seven resident shorebird species have been recorded feeding at low tide through the winter period (Table 2).

The Queensland Wader Study Group started monitoring shorebirds at low tide from the 2011 shorebird year (Fig. 3). Over the period 2011 to 2022 there was a significant decline in the total migratory shorebird count at low tide during both the summer ($\chi^2 = -58.43$, $P < 0.001$) and winter ($\chi^2 = -14.78$, $P < 0.001$) periods (Fig. 3). Exploratory data analysis showed no seasonal trends in the counts of resident shorebird species. Among the most commonly recorded individual species, abundance at low tide since 2011 declined significantly for four species (Fig. 4): Pacific Golden Plover ($\chi^2 = -100.16$, $P < 0.001$), Grey-tailed Tattler ($\chi^2 = -42.43$, $P < 0.001$), Double-banded Plover ($\chi^2 = -4.16$, $P = 0.041$) and Red-capped Plover ($\chi^2 = -73.48$, $P < 0.001$), whereas there was no significant trend for Bar-tailed Godwit ($\chi^2 = 1.36$, $P = 0.24$), Far Eastern Curlew ($\chi^2 = -0.68$, $P = 0.41$), Whimbrel ($\chi^2 = 1.87$, $P = 0.17$) and Australian Pied Oystercatcher ($\chi^2 = -0.05$, $P = 0.82$).

Table 1

Average (± 1 SD) shorebird counts across seven tidal flat sectors in the lower Maroochy River, with maximum counts in brackets, from eight summer-season surveys in 2020/21 and 2022/23. The maximum counts in the total migratory and total resident rows/columns represent the maximum count on any survey of all species combined.

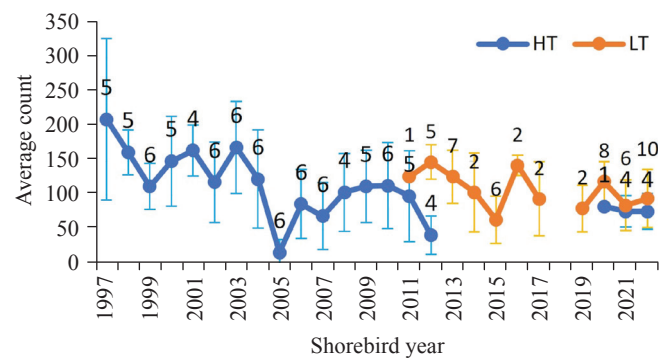
Tidal flat area	MR1 9.4 ha	MR2 6.5 ha	MR3 8.5 ha	MR4 13.4 ha	MR5 4.0 ha	MR6 35.9 ha	MR7 9.3 ha	Total 86.9 ha
Bar-tailed Godwit		0.6 \pm 1.2 (3)	0.4 \pm 1.1 (3)	8.8 \pm 7.6 (23)	0.1 \pm 0.4 (1)	3.9 \pm 4.4 (13)	2.8 \pm 3.2 (8)	16.5 \pm 10.5 (35)
Whimbrel	0.4 \pm 0.7 (2)	0.8 \pm 0.7 (2)	0.6 \pm 1.1 (3)	6.9 \pm 2.7 (11)	0.5 \pm 1.1 (3)	29.8 \pm 17.8 (72)	4.4 \pm 3.6 (9)	43.3 \pm 18.2 (82)
Far Eastern Curlew		0.5 \pm 1.1 (3)	0.1 \pm 0.4 (1)	1.0 \pm 1.1 (3)	0.1 \pm 0.4 (1)	4.0 \pm 2.1 (8)	1.1 \pm 1.0 (2)	6.9 \pm 3.3 (13)
Great Knot						0.3 \pm 0.7 (2)		0.3 \pm 0.7 (2)
Greater Sand Plover				0.3 \pm 0.7 (2)				0.3 \pm 0.7 (2)
Grey-tailed Tattler					0.6 \pm 1.8 (5)		0.1 \pm 0.4 (1)	0.8 \pm 1.8 (5)
Pacific Golden Plover	0.1 \pm 0.4 (1)	0.8 \pm 2.1 (6)	0.1 \pm 0.4 (1)	8.3 \pm 11.5 (33)	5.8 \pm 14.7 (42)	28.0 \pm 30.0 (76)	3.5 \pm 6.5 (14)	46.5 \pm 37.7 (111)
Total migratory	0.5 \pm 0.9 (2)	2.6 \pm 2.3 (6)	1.3 \pm 1.8 (5)	25.1 \pm 12.3 (42)	7.1 \pm 16.2 (47)	65.9 \pm 36.8 (115)	11.9 \pm 10.5 (27)	114.4 \pm 39.4 (173)
Australian Pied Oystercatcher	0.5 \pm 0.9 (2)		0.3 \pm 0.7 (2)	0.3 \pm 0.7 (2)		1.8 \pm 1.7 (5)	2.5 \pm 1.7 (5)	5.3 \pm 2.4 (10)
Masked Lapwing	1.0 \pm 1.4 (3)					0.5 \pm 0.9 (2)		1.5 \pm 2.1 (5)
Red-capped Plover					0.5 \pm 1.4 (4)	2.5 \pm 3.7 (11)		3.0 \pm 3.9 (11)
Beach Stone-Curlew						0.1 \pm 0.4 (1)		0.1 \pm 0.4 (1)
Total resident	1.5 \pm 1.7 (4)		0.3 \pm 0.7 (2)	0.3 \pm 0.7 (2)	0.5 \pm 1.4 (4)	4.9 \pm 4.5 (13)	2.5 \pm 1.7 (5)	9.9 \pm 5.1 (16)

Table 2

Average count per survey at low tide and high tide of migratory shorebirds during each of the summer (October to mid-March) and winter (May to August) periods and of resident shorebirds throughout the year, based on Queensland Wader Study Group data and this study over the period 1997-2023.

	Summer		Winter	
	Low tide	High tide	Low tide	High tide
Migratory shorebirds				
Pacific Golden Plover	49.4	37.67	0.16	2.64
Whimbrel	31.96	13.62	4.18	1.64
Bar-tailed Godwit	13.92	31.38	0.52	5.64
Grey-tailed Tattler	5.29	3.71	0.63	0.33
Far Eastern Curlew	5.18	3.87	1.31	1.57
Double-banded Plover	0.49		4.75	11.05
Red-necked Stint	0.40	3.97		0.81
Sharp-tailed Sandpiper	0.26			
Greater Sand Plover	0.18	1.29		0.38
Lesser Sand Plover	0.12	0.34		0.60
Common Greenshank	0.09	0.04		
Great Knot	0.07	0.20		0.24
Ruddy Turnstone	0.02	0.21		0.05
Wandering Tattler	0.02	0.04		
Black-tailed Godwit		1.39		
Terek Sandpiper		0.22		0.31
Curlew Sandpiper		0.15		
Sanderling		0.02		
Red Knot				0.14
Resident shorebirds (throughout year)				
Australian Pied Oystercatcher	4.59	2.39		
Red-capped Plover	2.51	16.96		
Masked Lapwing	1.31	0.70		
Beach Stone-curlew	1.22	0.11		
Pied Stilt	0.26	0.39		
Sooty Oystercatcher	0.09	0.20		
Black-fronted Dotterel		0.06		

Migratory shorebirds (summer)



Migratory shorebirds (winter)

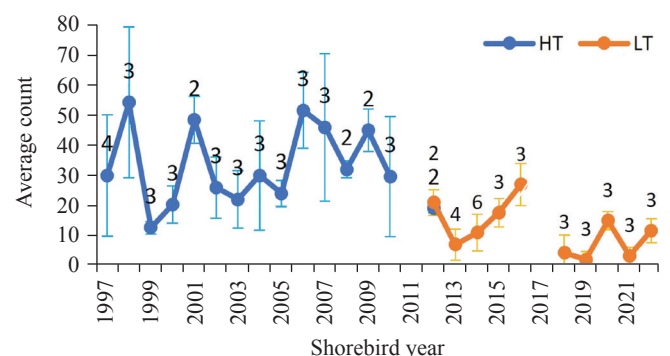


Figure 3. Average (± 1 standard deviation) total migratory shorebirds recorded roosting at high tide (HT) and feeding at low tide (LT) in the lower Maroochy River each summer (October to mid-March) and winter (May to August) season based on Queensland Wader Study Group data and this study. Number of counts each year shown above each point.

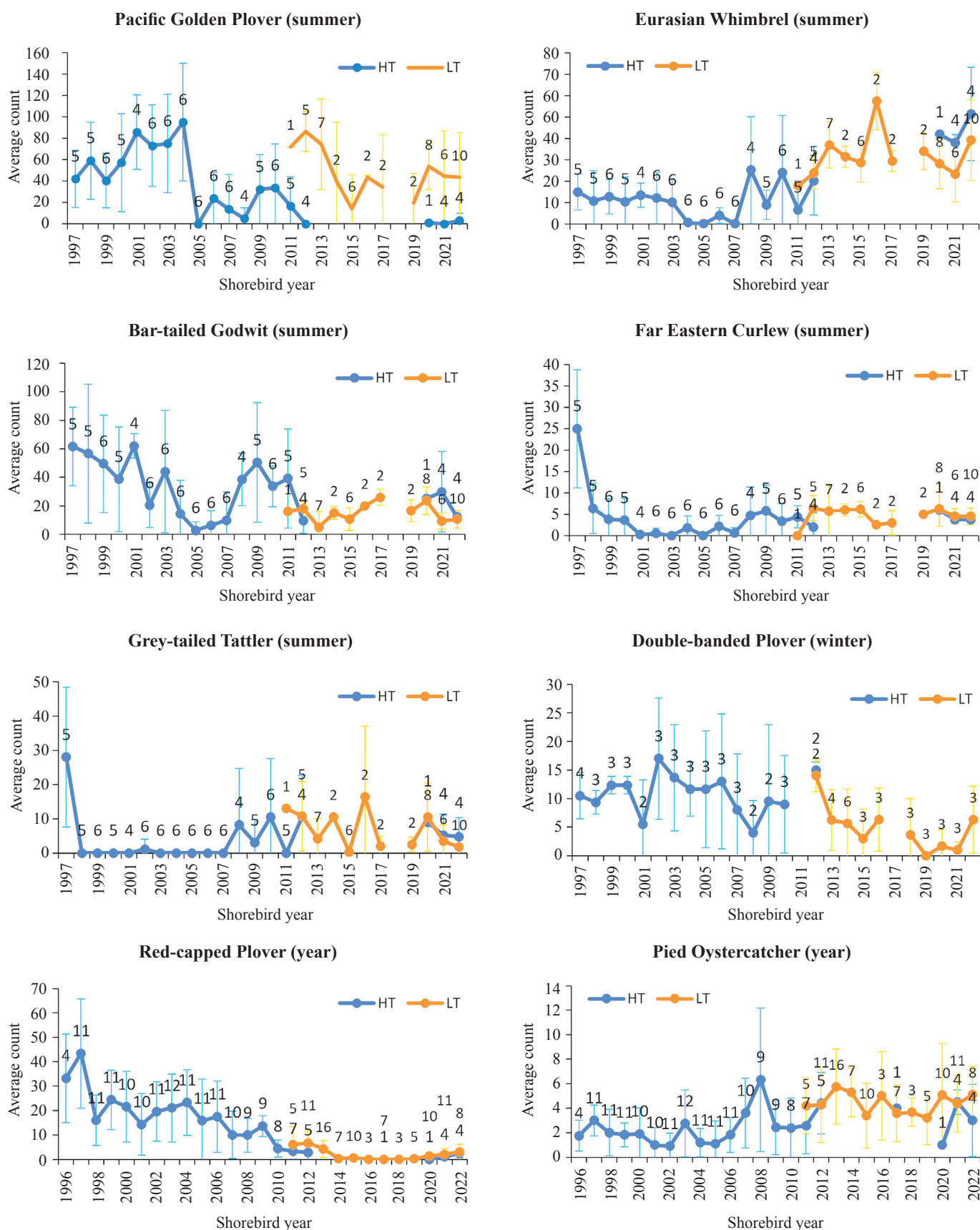


Figure 4. Average (± 1 standard deviation) total count of different shorebird species recorded roosting at high tide (HT) and feeding at low tide the lower Maroochy River each summer (October to mid-March), winter (May to August) or throughout the year based on Queensland Wader Study Group data and this study. Number of counts each year shown above each point.

Table 3

Summary of the total numbers of shorebird species and other waterbirds roosting at the Goat Island roost site in the lower Maroochy River during summer high tide surveys in 2020/21 (1 survey), 2021/22 (4 surveys) and 2022/23 (4 surveys).

Common name	12/11/2020	7/12/2021	19/1/2022	27/1/2022	7/2/2022	2/11/2022	7/12/2022	19/1/2023	20/2/2023
Far Eastern Curlew	6	5	4	3	3	3	4	4	4
Eurasian Whimbrel	42	17	34	43	39	22	63	72	49
Bar-tailed Godwit	25	25	71	12	11	11	12	13	13
Pacific Golden Plover	1								13
Red-necked Stint	1					4			
Grey-tailed Tattler		11			10			11	
Beach Stone-curlew	1							1	
Australian Pied Oystercatcher	1	3	5	5	5	3		7	2
Sooty Oystercatcher			2						
Red-capped Plover				4		4	2	4	
Masked Lapwing		2							
Total migratory shorebirds	75	58	109	58	63	40	79	100	79
Total resident shorebirds	2	5	7	9	5	7	2	12	2
Total other waterbirds	41	18	124	75	46	1	982	1842	2

Table 4

Summary of the percentage of high tide surveys (within 2 hours either side of high tide) in all months of the year that shorebirds have been recorded roosting at each of the four main roost sites on the lower Maroochy River 1997-2022.

Roost site				Goat Island	Nojoor Road	North Shore	Sand bar
Total number of high tide surveys (1997 to 2022, all months)				147	163	163	165
Common name	Scientific name	EPBC*	NCA*				
Far Eastern Curlew	<i>Numenius madagascariensis</i>	M, CE	E	19%	10%	16%	20%
Whimbrel	<i>Numenius phaeopus</i>	M	S	27%	9%	36%	16%
Bar-tailed Godwit	<i>Limosa lapponica baueri</i>	M, V	V	24%	8%	33%	25%
Black-tailed Godwit	<i>Limosa limosa</i>	M	S	1%		1%	1%
Pacific Golden Plover	<i>Pluvialis fulva</i>	M	S	10%	1%	45%	7%
Greater Sand Plover	<i>Charadrius leschenaultii</i>	M, V	V			11%	1%
Lesser Sand Plover	<i>Charadrius mongolus</i>	M, E	E		1%	14%	
Double-banded Plover	<i>Charadrius bicinctus</i>	M	S	1%		22%	4%
Ruddy Turnstone	<i>Arenaria interpres</i>	M	S		1%	7%	1%
Sharp-tailed Sandpiper	<i>Calidris acuminata</i>	M	S	1%		1%	
Sanderling	<i>Calidris alba</i>	M	S			1%	
Red Knot	<i>Calidris canutus</i>	M, E	E				1%
Broad-billed Sandpiper	<i>Calidris falcinellus</i>	M	S			1%	
Curlew Sandpiper	<i>Calidris ferruginea</i>	M, CE	E			6%	
Red-necked Stint	<i>Calidris ruficollis</i>	M	S	1%	2%	34%	1%
Great Knot	<i>Calidris tenuirostris</i>	M, CE	E	1%		6%	2%
Grey-tailed Tattler	<i>Tringa brevipes</i>	M	S	9%	3%	6%	1%
Wandering Tattler	<i>Tringa incana</i>	M	S			3%	
Common Greenshank	<i>Tringa nebularia</i>	M	S	1%	1%		
Terek Sandpiper	<i>Xenus cinereus</i>	M	S	1%		4%	
Beach Stone-curlew	<i>Esacus magnirostris</i>		V	3%	1%	2%	
Sooty Oystercatcher	<i>Haematopus fuliginosus</i>		LC	1%		5%	3%
Australian Pied Oystercatcher	<i>Haematopus longirostris</i>		LC	46%	16%	21%	30%
Pied Stilt	<i>Himantopus leucocephalus</i>		LC	3%	6%		1%
Masked Lapwing	<i>Vanellus miles</i>		LC	2%	13%	4%	1%
Red-capped Plover	<i>Charadrius ruficapillus</i>		LC	2%	3%	81%	17%
Black-fronted Dotterel	<i>Elseya melanops</i>		LC		1%		1%

* Status under the Commonwealth Environment Protection and Biodiversity Conservation Act 1999 (EPBC) or Queensland Nature Conservation Act 1992 (NCA): CE = critically endangered; E = endangered; LC = least concern; M = migratory; S = special least concern (migratory); V = vulnerable.

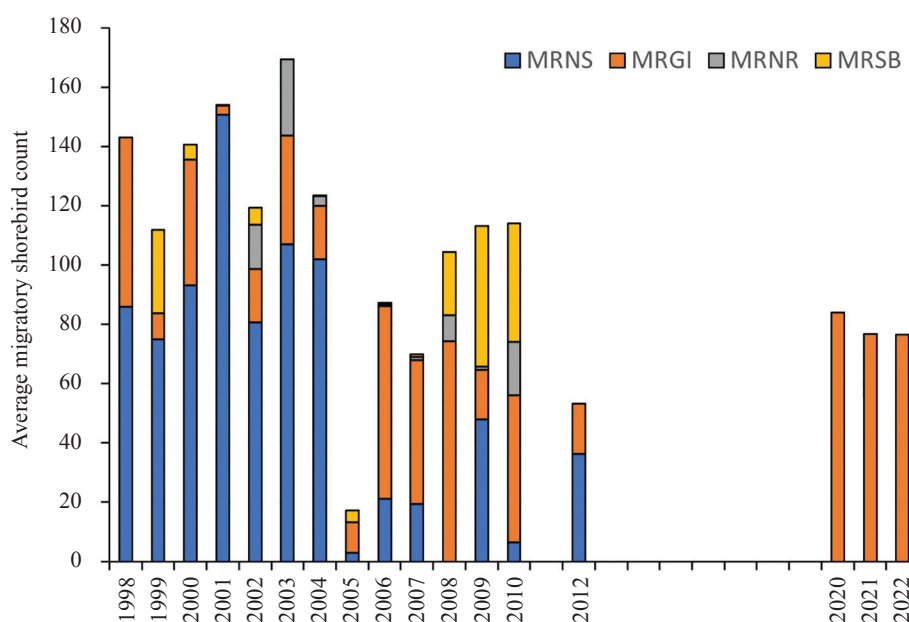


Figure 5. Average annual summer-season (October to mid-March) count of migratory shorebirds at high tide (within 2 hrs either side of high tide) at each of four roost sites in the lower Maroochy River since 1998 based on Queensland Wader Study Group data and this study. MRNS = North Shore; MRGI = Goat Island; MRNR = Nojoor Road; MRSB = Sandbank.

Shorebird use of roost sites at high tide

Five main roost sites used by shorebirds and other waterbirds occur in the lower Maroochy River (Fig. 1): Goat Island (comprising a sand bank and beach on the eastern side of Channel and Goat islands and fringing mangroves on the northern to north-western edges); Nojoor Road; the North Shore sandy beach; a sand bar; and a mangrove tree roost on the northern shoreline. During seven high tide surveys conducted by the authors through the summer periods of 2020/21 to 2022/23, roosting was observed only on Goat Island and the mangrove tree roost. Goat Island was the most important roost, where between 40 and 109 migratory shorebirds and between 2 and 12 resident shorebirds roosted on the sandbank on the eastern edge of the island (Table 3). The mangrove tree roost was used on only three occasions, with a flock of 9 Grey-tailed Tattler on 9/11/2020, a flock of 19 Whimbrel on 7/12/2021 and a flock of 8 Grey-tailed Tattler on 7/12/2022. The other waterbirds roosting on Goat Island were mostly Silver Gull *Chroicocephalus novaehollandiae* and several species of tern, the latter occasionally in large numbers.

On 2/11/2022, observations were made of shorebird movements between low tide and high tide as the tide rose to cover the tidal flats. A large flock of 75 Pacific Golden Plovers that had been feeding on tidal flat sites MR05 and MR04 gathered on MR05 as the tide rose. At approximately 4.5 hours before high tide, most of the flock (about 60) flew up and left the Maroochy River heading in the direction of 32 degrees north; the remainder left about 15 minutes later in a more northerly direction. In the hour before high tide, mowed grass areas around the Novotel Resort and the southern end of the airport runway, as well as the beach front were checked to see if the birds had moved there to roost; however, no Pacific Golden Plovers were observed at those locations.

Four of the Maroochy River roost sites (Goat Island, Nojoor Road, North Shore and sand bar) were regularly monitored by the Queensland Wader Study Group from 1997 to 2012. The locations of the roost sites at the mouth of the Maroochy River have changed over time due to the dynamic nature of the sand bars at the river mouth. A total of 20 migratory shorebird species and seven resident shorebird species have been recorded roosting at high tide at roost sites on the lower Maroochy River, with the North Shore, Goat Island and the sand bar being most frequently used (Table 4). The North Shore was the most important migratory shorebird roost site in the lower Maroochy River area up until 2004 (Fig. 5). Thereafter, Goat Island became more increasingly used by shorebirds for roosting. The Queensland Wader Study Group discontinued monitoring of roost sites on the lower Maroochy River after 2012 due to increasing levels of disturbance affecting the counts; disturbance in the form of people walking with dog's off-leash became particularly frequent along the sandy beach on the North Shore (L. Cross, Queensland Wader Study Group, personal communication).

Since 1997, abundance at roost sites at high tide through the summer period has declined significantly for Pacific Golden Plover ($\chi^2 = -1086.4$, $P < 0.001$), Bar-tailed Godwit ($\chi^2 = -217.22$, $P < 0.001$), Far Eastern Curlew ($\chi^2 = -44.20$, $P < 0.001$) and Red-capped Plover ($\chi^2 = -781.69$, $P < 0.001$), but increased significantly for Whimbrel ($\chi^2 = 391.8$, $P < 0.001$) and Australian Pied Oystercatcher ($\chi^2 = 19.55$, $P < 0.001$), whereas there has been no trend for Grey-tailed Tattler ($\chi^2 = 0.25$, $P = 0.62$) and Double-banded Plover ($\chi^2 < 0.01$, $P = 1$) (Fig. 4).

Disturbance

Shorebird roost sites and tidal flat feeding habitat areas in the lower Maroochy River are subject to multiple sources of disturbance to roosting or feeding shorebirds, including people

Table 5

Table 5. Percentage of surveys in which people, dogs, boats or jetskis were recorded as potential or actual sources of disturbance to roosting or feeding birds at sites in the lower Maroochy River based on Queensland Wader Study Group data over the period 1997-2022.

Site	Surveys	People	Dogs	Boats	Jetskis
Goat Island (MRGI)	299	45%	18%	33%	14%
Nojoor Rd (MRNR)	304	55%	27%	27%	22%
North shore (MRNS)	303	72%	64%	36%	29%
Sandbank (MRSB)	312	45%	30%	29%	14%

using the area for recreation, dogs being walked on and off-leash, and various watercraft. Queensland Wader Study Group survey data on disturbance are not captured in a format that allows examination of temporal trends in disturbance with sufficient rigour. However, the data do allow comparison of the relative frequency of different sources of potential or actual disturbance between sites. These data show that the North Shore has experienced the highest disturbance pressure, particularly from people and dogs walking along the shoreline at all tides (Table 5). During the surveys conducted by the authors over the three seasons 2020/21 to 2022/23, there was a constant presence of people walking with dogs, often off-leash along the North Shore. During the low tide surveys, people were observed disembarking from boats on the Goat Island tidal flats on several occasions, occasionally with dogs running off-leash, and also crossing the shallow channel from the southern mainland to walk along the tidal flats, inadvertently disturbing foraging shorebirds.

DISCUSSION

The approximately 87 ha of tidal flats along the lower Maroochy River provide important foraging habitat at low tide for a variety of migratory shorebirds, particularly Pacific Golden Plover, Whimbrel, Bar-tailed Godwit and Far Eastern Curlew. In the few years in which shorebirds were surveyed at both low tide and at roost sites at high tide, the total number of migratory shorebirds recorded foraging at low tide generally exceeded the number recorded roosting at high tide (Fig. 3), suggesting that some birds that feed in the lower Maroochy River estuary at low tide do not roost within the estuary at high tide. This was particularly the case for Pacific Golden Plover; while the most abundant species at low tide, few birds have been recorded roosting at roost sites within the estuary at high tide since 2011 (Fig. 4). Furthermore, flocks of Pacific Golden Plover were observed leaving the estuary to fly north once the rising tide covered the tidal flats. Yet, there is no known regularly used shorebird roost site within at least 15 km north and south of the Maroochy River mouth. A potential roost site for Pacific Golden Plover north of the Maroochy River mouth is Mudjimba Island, a small (1.3 ha), infrequently visited island located 1 km offshore and 3.5 km north of the Maroochy River mouth. The long-term monitoring data show that an average of up to 80 to 100 Pacific Golden Plover used to roost within the estuary, but there has been a significant decline in the number roosting since 2004, to the point where very few birds now roost in the estuary (Fig. 4). Plovers including Pacific Golden Plover and Red-capped Plover most frequently roosted along the sandy beach of the North Shore, Table 4). Since 2004, the use of the

North Shore for roosting has decreased significantly (Fig. 5), most likely due to an increase in disturbance from people using the beach for recreation, including walking dogs off-leash, to the point that no birds have been recorded roosting on the North Shore over the past three years. Similarly, increased human use of the sandy beaches north and south of the Maroochy River mouth as the area has become more developed is the likely cause of the significant decline in Red-capped Plover (Fig. 4), a resident shorebird that nests in foredune and saltmarsh habitats. However, the substantial reduction in the extent of open sand on the North Shore spit as much of it became colonised by vegetation following the changed configuration of the entrance to south of Pincushion Island (Fig. 2) may also have played a role in the declining use of the North Shore by plovers.

The significant decline in the abundance of Bar-tailed Godwit and Far Eastern Curlew roosting in the lower Maroochy River estuary since 1997 (Fig. 4) may reflect either a reduction in the suitability of the area for these species and/or a background population decline of the East Asian-Australasian flyway populations of these two species. The flyway population of Bar-tailed Godwit has decreased 32.4% over 29 years (1.4% per year) (Threatened Species Scientific Committee 2016) and the flyway population of Far Eastern Curlew has decreased 66.8% over 20 years (5.8% per year) and 81.4 % over 30 years (Threatened Species Scientific Committee 2015), largely due to the extensive loss of tidal flat habitats at key staging sites in the Yellow Sea in south-east Asia that the species are dependent on during their migration (Studds *et al.* 2017). However, there has been no significant decline in the abundance of either of these species foraging at low tide in the lower Maroochy River estuary since 2011 (Fig. 4), which might suggest a halt in the decline of these species over the most recent decade.

The significant increase in Whimbrel roosting within the lower Maroochy River estuary is largely attributable to larger counts in the past three years (Fig. 4). Whimbrel roost either on land or in mature mangrove trees fringing estuary channels. Their habit of roosting in often dispersed aggregations in mangrove trees, which are widespread in eastern Australian estuaries, including in the lower Maroochy River estuary, means that the overall abundance of this species at high tide may often be underestimated by monitoring surveys that typically focus on larger, land-based roost sites. Nonetheless, the apparent increase in birds roosting on the sandbank on the eastern side of Goat Island in recent years, where they may be subject to regular disturbance, suggests that these birds may have moved there from unrecorded mangrove roost sites elsewhere in the estuary.

Assessing whether the dredging of sand close to the mouth of the estuary for beach replenishment has had an impact on migratory shorebird abundance at low tide is complicated by the significant declines that many species experienced prior to the dredging works. Of the four species that have experienced significant declines in the numbers feeding in the estuary at low tide since 2011, namely Pacific Golden Plover, Grey-tailed Tattler, Double-banded Plover and Red-capped Plover, two species (Pacific Golden Plover and Red-capped Plover) experienced significant declines in the number of roosting birds prior to 2011 (Fig. 4). Thus, there is no unequivocal evidence to suggest an impact of dredging on shorebird abundance at low tide. The restriction of the dredging to a localised area at the estuary entrance, where the sandy sediments are highly dynamic, has ensured minimal overlap with the tidal flat areas used by shorebirds for feeding at low tide, particularly since 2015 (Fig. 1). Further, the cutter-suction dredge is largely immobile and therefore likely to cause minimal disturbance to shorebirds feeding nearby. Consequently, minimal impact on shorebirds is expected. The residence times of sediment in the estuary have been estimated to be less than 30 years, indicating relatively low sediment accumulation rates (Douglas *et al.* 2009). However, when the Maroochy River entrance relocated to the south of Pincushion Island in 1999, a large quantity of sand from the beach and dune system connecting to Pincushion Island, moved into the entrance, where it had largely remained and been reworked by the prevailing coastal and estuarine processes prior to dredging (BMT WBM 2012).

The abandonment of the North Shore as a roost site means that roosting birds have fewer roosting options now in the lower Maroochy River estuary than in the past. The increasing reliance of migratory shorebirds on Goat Island as the only remaining shoreline roost site on higher tides highlights the importance of limiting disturbance to this roost site as a priority for the conservation and management of shorebirds in the lower Maroochy River estuary. The Goat Island and nearby sand bar roost sites enjoy a moderate level of protection from disturbance by being accessible at high tide only by watercraft due to the deeper water channels running either side of the island. Nonetheless, boaters and paddle-boarders, sometimes with pets on board do regularly come ashore at Goat Island, and dogs are often allowed to run off-leash in these instances despite it being part of the Maroochy River Conservation Park where dogs are not allowed. These disturbance pressures are expected to continue to increase as the population of the region continues to grow. Research has shown that off-leash dogs in particular cause severe disturbance to shorebirds, reducing their use of important habitats (Dhanjal-Adams *et al.* 2016) and are a key threat to migratory shorebirds in Moreton Bay (Fuller *et al.* 2021).

The Sunshine Coast Council has responsibility for managing disturbance to migratory shorebirds in the lower Maroochy River estuary, except on Goat Island, which is part of the Maroochy River Conservation Park and managed by the Queensland Parks and Wildlife Service. Implementation of one or more of the following approaches is recommended for reducing disturbance to feeding and roosting shorebirds:

- Site-specific information signage to raise awareness of the presence of shorebirds in the area and the importance of the key habitat areas for shorebirds, particularly migratory shorebirds (Antos *et al.* 2006, Williams *et al.* 2009);
 - Other approaches to raising public awareness of how the migration and feeding ecology of shorebirds are impacted by disturbances to try to change public awareness of, and attitudes towards disturbing shorebirds, particularly among dog-owners that exercise their dogs along foreshore areas (Antos *et al.* 2006, Williams *et al.* 2009);
 - Planning to ensure suitable dog-walking facilities such as dog-off leash areas are situated in locations convenient and attractive to the public but separated from important shorebird foreshore habitats (Stigner *et al.* 2016);
 - Planning to limit access to important feeding or roosting areas by people and/or dogs (Weston *et al.* 2012, Stigner *et al.* 2016); and
 - Effective enforcement of access restrictions and dog on-leash areas, given that compliance to access restrictions or on-leash laws is strongly dependent on the extent of enforcement (Dhanjal-Adams *et al.* 2016, Stigner *et al.* 2016).
- Trying to ensure all dogs are kept on-leash in foreshore areas may be impractical where walking dogs off-leash has already become a pervasive activity; in such situations, designating foreshore dog off-leash areas in places where shorebird foraging abundance is relatively low and recreational demand is relatively high could result in reduced overall disturbance to migratory shorebirds if there is also more effective enforcement of access restrictions or on-leash laws in important shorebird areas (Stigner *et al.* 2016, Fuller *et al.* 2021). The sandy beach on the North Shore is an easily accessible area with high recreational amenity that has become popular for walking dogs off leash over many years. Thus, it would be challenging to protect a portion of the North Shore on the northern bank of the estuary mouth to restore this area as a shorebird roost site. A more effective use of management resources may be to focus management on increasing public awareness and providing greater protection to the Goat Island roost site.
- Over the past several years, Sunshine Coast Council has worked to increase public awareness of shorebirds through: (1) an information page on Council's website with links to four short videos on the shorebirds and other waterbirds of the Sunshine Coast, a shorebird identification guide, a map of the important tidal flat feeding habitats, best places to view shorebirds and recent shorebird sightings (Sunshine Coast Council 2023a); (2) funding local artists to paint large murals of various shorebird species including interpretive signage on public toilet blocks, including at the North Shore Road parking lot and the access point to the North Shore (Sunshine Coast Council 2023b); (3) holding education pop-ups together with Council's Responsible Pet Ownership Team to educate the community about shorebirds and disturbance by dogs; (4) holding regular talks for community groups and at events such as the Nambour Garden Expo; (5) ongoing social media campaigns and media releases throughout summer; (6) having a shorebird stall with information and kids' activities at various events; (7) a shorebird art exhibition (Shorebirds – What is their Future?) in January 2023 (Sunshine Coast Council 2023c); and (8) temporary local signage. These management interventions are expected to be continued.

ACKNOWLEDGMENTS

The 2019–2023 surveys reported in this paper were commissioned and paid for by Sunshine Coast Council to inform the ongoing management of migratory shorebirds as an action under the Sunshine Coast Shorebird Action Plan. Survey activities were undertaken in accordance with Scientific Purposes permit WA0024832. Additional long-term count data used in this publication were supplied by the Queensland Wader Study Group (a special interest group of the Queensland Ornithological Society Incorporated). The Queensland Wader Study Group is not liable for any potential errors in the count data or for any misuse or misinterpretation of the count data. While every care was taken to ensure the accuracy of the data reported in this paper, Sunshine Coast Council makes no representations or warranties about its accuracy, reliability, completeness or suitability for any particular purpose and disclaims all responsibility and all liability (including without limitation, liability in negligence) for all expenses, losses, damages (including indirect or consequential damage) and costs that might be incurred as a result of the data being inaccurate or incomplete in any way and for any reason. The views expressed in this paper remain those of the authors, who were entirely responsible for the design and implementation of the survey programme and analysis of data, and do not imply endorsement by Sunshine Coast Council or the Queensland Wader Study Group. Fig. 1 was produced by Michael Page of Michael Page Designs and includes material © Nearmap. We gratefully thank the many Queensland Wader Study Group volunteers who contributed data to the long-term monitoring programme, particularly Jill Chamberlain, Jill Denning, Robyn and David Leslie, Shirley Rooke, Barbara Dickson, Judith Hewett, Judith Coles, Gillie Matthew, Jan Bedwell, Cliff and Peg Whiteoak and Judy Caughley, and Phil Straw and Walter Boles for comments that improved the manuscript.

REFERENCES

- Antos, M. J., Weston, M. A. and Priest, B. (2006). Factors influencing awareness of community-based shorebird conservation projects in Australia. *Applied Environmental Education and Communication* **5**: 63–72.
- Bamford, M. J., D. G. Watkins, W. Bancroft, and G. Tischler (2008). *Migratory shorebirds of the East Asian-Australasian Flyway; Population Estimates and important Sites*. Wetlands International, Oceania.
- BMT WBM Pty Ltd (2012). *Maroochy Beach Nourishment Feasibility Report*. Report prepared for Sunshine Coast Regional Council, 27 March 2012.
- Colwell, M. A. (2010). *Shorebird Ecology, Conservation and Management*. University of California Press, London.
- Dhanjal-Adams, K. L., Mustin, K., Possingham, H. P. and Fuller, R. A. (2016). Optimizing disturbance management for wildlife protection: the enforcement allocation problem. *Journal of Applied Ecology* **53**: 1215–1224.
- Douglas, G., Caitcheon, G. and Palmer, M. (2009). Sediment source identification and residence times in the Maroochy River estuary, southeast Queensland, Australia. *Environmental Geology* **57**: 629–639.
- Fuller, R. A., Clemens, R. S., Woodworth, B. K., Moffitt, D. and Simmons, B. A. (2021). *Managing Threats to Migratory Shorebirds in Moreton Bay*. A report to Healthy Land and Water. University of Queensland, Brisbane.
- Lloyd, P., Driscoll, P. V. and Coleman, J. T. (2022). *Port of Brisbane shorebird monitoring annual report 2021/22*. Report prepared by the Queensland Wader Study Group for Port of Brisbane Pty Ltd, October 2022.
- Milton, D. and Driscoll, P. (2007). An assessment of shorebird monitoring in Queensland by the Queensland Wader Study Group. *Stilt* **50**: 242–248.
- Pierce, R. (1999). Regional patterns of migration in the Banded Dotterel (*Charadrius bicinctus bicinctus*). *Notornis* **46**: 101–122.
- R Core Team (2023.) *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria. URL <https://www.R-project.org/>.
- Stigner, M. G., Beyer, H. L., Klein, C. J. and Fuller R. A. (2016). Reconciling recreational use and conservation values in a coastal protected area. *Journal of Applied Ecology* **53**: 1206–1214.
- Studds, C. E., Kendall, B. E., Murray, N. J. *et al.* (2017). Rapid population decline in migratory shorebirds relying on Yellow Sea tidal mudflats as stopover sites. *Nature Communications* **8**:14895, DOI: 10.1038/ncomms14895.
- Sunshine Coast Council (2014). Shoreline Erosion Management Plan <https://www.sunshinecoast.qld.gov.au/Environment/Rivers-and-Coast/Coastal-Management/Shoreline-Erosion-Management-Plan>
- Sunshine Coast Council (2019). *Shorebird Conservation Action Plan*. https://assets-au-scc.kc-usercontent.com/330b87ea-148b-3ecf-9857-698f2086fe8d/dd95852a-046c-405c-b67f-d873efe889af/Shorebird%20Conservation%20Action%20Plan_July%202020.pdf
- Sunshine Coast Council (2023a). Shorebird protection: <https://www.sunshinecoast.qld.gov.au/environment/native-animals/shorebird-protection>
- Sunshine Coast Council (2023b). Shorebird murals: <https://www.sunshinecoast.qld.gov.au/Environment/Education-Resources-and-Events/Environment-Resources-and-Publications/Coast-and-Marine/Shorebird-murals>
- Sunshine Coast Council (2023c). Shorebirds – What is their Future?: <https://oursc.com.au/council-news/shorebirds-what-is-their-future>
- Threatened Species Scientific Committee (2015). Approved Conservation Advice for *Numenius madagascariensis* (Eastern Curlew). Department of the Environment, Canberra. Available from: <http://www.environment.gov.au/biodiversity/threatened/species/pubs/847-conservation-advice.pdf>.
- Threatened Species Scientific Committee (2016). Approved Conservation Advice for *Limosa lapponica baueri* (Bar-tailed godwit (western Alaskan)). Canberra: Department of the Environment. Available from: <http://www.environment.gov.au/biodiversity/threatened/species/pubs/86380-conservation-advice-05052016.pdf>.
- Weston, M. A., Dodge, F., Bunce, A., Nimmo, D. G. and Miller, K. K. (2012). Do temporary beach closures assist in the conservation of breeding shorebirds on recreational beaches? *Pacific Conservation Biology* **18**: 47–55.
- Williams, K. J. H., Weston, M. A., Henry, S. and Maguire, G. S. (2009). Birds and beaches, dogs and leashes: dog owners' sense of obligation to leash dogs on beaches in Victoria, Australia. *Human Dimensions of Wildlife* **14**: 89–101.