SHOREBIRD SURVEYS IN THE HUNTER ESTUARY OF NEW SOUTH WALES 1999-2021

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The Hunter Estuary in New South Wales, Australia, was surveyed monthly from April 1999 to March 2021. In this time, 46 shorebird species were recorded in the estuary including 33 species that migrate within the East Asian-Australasian Flyway (EAAF). Fifteen migratory species and eight non-migratory ones were recorded regularly; the other species were uncommon visitors or vagrants. Although the estuary continues to qualify for listing as an internationally significant site within the EAAF, the populations of most of the visiting migratory shorebirds have declined substantially. We compared the numbers present in the non-breeding and breeding seasons for three approximately equal time periods spanning the 22 years of surveys and found statistically significant differences. Although six species were formerly present in internationally significant numbers, currently only Sharp-tailed Sandpiper *Calidris acuminata* and the non-migratory Red-necked Avocet *Recurvirostra novaehollandiae* meet the criteria. Species in significant decline in the estuary include Far Eastern Curlew *Numenius madagascariensis*, Whimbrel *N. phaeopus*, Bar-tailed Godwit *Limosa lapponica*, Black-tailed Godwit *L. limosa*, Red Knot *Calidris canutus*, Curlew Sandpiper *C. ferruginea*, Marsh Sandpiper *Tringa stagnatilis*, and Common Greenshank *T. nebularia*. The populations of three migratory species have increased: Pacific Golden Plover *Pluvialis fulva*, Sharp-tailed Sandpiper and Grey-tailed Tattler *T. brevipes*. The Hunter Estuary now is an internationally significant site for Sharp-tailed Sandpiper, with at times more than 6% of the total population present. The populations of most of the regularly recorded non-migratory shorebird species were stable or had increased over 1999-2021. For example, the numbers of Masked Lapwing *Vanellus miles* have approximately doubled since around 2010. The estuary is very important for Red-necked Avocet, with 4-6% of the total population often present. There sometimes were nationally significant numbers of Pied Stilt *Himantopus leucocephalus* in the estuary. The possible reasons for population changes are discussed. Inland rainfall patterns (droughts and heavy rain) may have affected some species. Recent rehabilitation projects in the estuary have reinstated tidal flushing at former estuarine wetlands that has increased the amount of habitat for shorebirds. Targeted control of Grey Mangrove *Avicennia marina* incursions in the rehabilitated areas has helped create and maintain expanses of salt marsh habitat for foraging and roosting generalist species. Many of the EAAF migratory shorebirds with declining populations in the Hunter Estuary rely on Yellow Sea tidal mudflats during migration. Much of that ecosystem has been destroyed in recent decades, hence significantly affecting the populations of Yellow Sea-dependent species. However, the declines of those species in the Hunter Estuary seem to be larger, which suggests some local factors may also be involved. The main feeding area for those species is in Fullerton Cove, which has become contaminated with PFAS/PFOS, fire-fighting chemicals used for decades at the nearby Williamtown airport. It is speculated that chronic toxicity effects from the chemical contamination may be affecting the numbers and diversity of benthic organisms in Fullerton Cove, to the detriment of the populations of many coastal obligate shorebirds.

INTRODUCTION

In April 1999, members of the Hunter Bird Observers Club Inc. (HBOC) commenced monthly surveys of waterbirds in the Hunter Estuary of New South Wales (NSW). This report details the results and trends for shorebirds from 22 continuous years of monitoring up to and including March 2021.

Figure 1 shows the main roosting or foraging sites for shorebirds in the estuary (centred at 32º51' S 151º46' E). The single-most important area is Fullerton Cove, a large shallow embayment with a maximum depth of 2-3m at its centre and where, at low tide, large areas of mudflats are exposed (Weller *et al*. 2020). Many shorebirds feed in Fullerton Cove at low tide. As the tide rises most of those birds depart to roost at either the Kooragang Dykes or in the Stockton Sandspit/Fern Bay area. Some remain and roost on a narrow beach within the Cove. The three other important areas for shorebirds in the estuary are Ash Island, Hexham Swamp and Tomago Wetland. All three areas provide foraging and roosting habitat for shorebirds. The extent to which birds move from these sites to elsewhere, to forage or roost, is unknown.

The Hunter Estuary is recognised as the most important shorebird site in NSW. It regularly hosts many migratory species, involving thousands of individuals at times, and thus is considered both an internationally and nationally significant site in the East Asian-Australasian Flyway ("the Flyway", EAAF) (Weller *et al*. 2020). The estuary is considered internationally significant for Far Eastern Curlew *Numenius madagascariensis*, Red Knot *Calidris*

canutus and Sharp-tailed Sandpiper *C. acuminata*, and nationally significant for Bar-tailed Godwit *Limosa lapponica*, Curlew Sandpiper *C. ferruginea*, Pacific Golden Plover *Pluvialis fulva*, Black-tailed Godwit *L. limosa*, Marsh Sandpiper *Tringa stagnatilis*, Common Greenshank *T. nebularia*, Whimbrel *N. phaeopus*, Latham's Snipe *Gallinago hardwickii* and Double-banded Plover *Charadrius bicinctus* (Weller *et al*. 2020). It also frequently hosts thousands of Red-necked Avocets *Recurvirostra novaehollandiae* (Stuart 2017), as well as seven other non-migratory shorebirds.

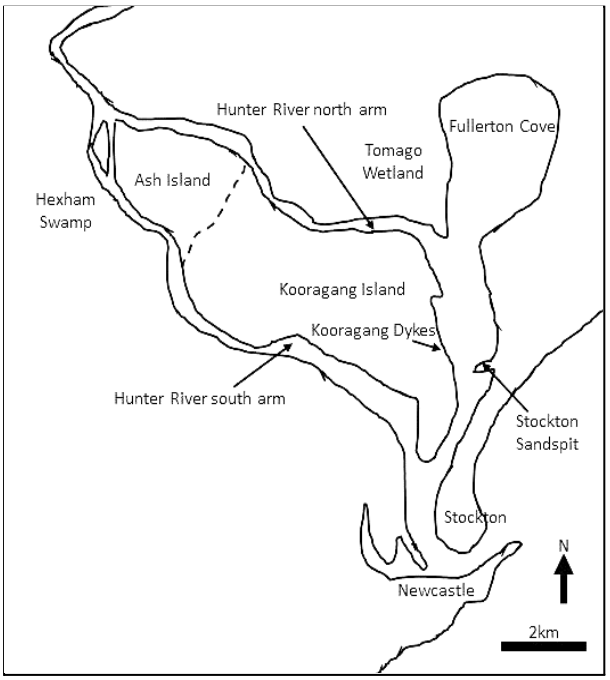


Figure 1. The Hunter Estuary in NSW with main shorebird foraging and roosting sites shown.

Recognition of the importance of the estuary to shorebirds and waterbirds led to the Kooragang Nature Reserve being gazetted in 1983 and designated as a Ramsar site in 1984. The Ramsar site was expanded in November 2002 to include the wetlands at Shortland (Brereton & Taylor-Wood 2010), now known as Hunter Wetlands Centre Australia. However, Ash Island (the name Ash Island is commonly used for the western section of Kooragang Island) and Hexham Swamp were not included in the Ramsar designation despite meeting Ramsar criteria.

In 2011, Kooragang Nature Reserve, Hexham Swamp and Ash Island were combined to form Hunter Wetlands National Park (Lindsey 2021; Hunter Wetlands National Park Plan of Management 2020). However, the most important shorebird sites on Ash Island were excluded from the National Park. Under NSW State Environmental Planning Policy (State Significant Precincts 2005), the site has been earmarked for an infrastructure corridor, which would bisect Ash Island. Currently, this land does not form part of the reserved area of park but is retained as Crown land and is held and managed by NPWS under Part 11 of the National Parks and Wildlife Act (Hunter Wetlands National Park Plan of Management 2020).

The estuary was also designated an Important Bird Area ("Hunter Estuary IBA") in 2010 (Dutson *et al.* 2009). IBAs have since been redesignated as Key Biodiversity Areas (KBAs) in order to extend the concept to non-avian threatened species (BirdLife Australia 2017).

Pre-1999 shorebird counts in the Hunter Estuary

The first documented systematic surveys for shorebirds in the Hunter Estuary occurred in 1967-1970 (Holmes 1970) and there were frequent surveys between 1969 and 1977 (Kendall & van Gessel 1972; van Gessel & Kendall 1972a; 1972b; 1974; 2015; Gosper 1981). The 1967-1977 surveys led to the initial recognition of the estuary's importance for shorebirds. Lane (1987) named the Hunter Estuary as a top-20 site Australia-wide for 14 shorebird species including twelve migratory ones. Smith (1991) nominated the Hunter Estuary as by far the most important shorebird site in NSW, based upon the maximum recorded counts.

After 1977, there were no further regular surveys of the estuary until 1982 when twice-yearly Australasian Wader Study Group (AWSG) counts began, spanning four years locally. However, there also were many opportunistic visits by birdwatchers to key shorebird sites in the estuary, particularly Stockton Sandspit, and it seems clear that high numbers of shorebirds persisted during those intervening years. That inference was confirmed from the annual summer and winter AWSG counts conducted between 1982 and 1985 (Stuart 2014a; 2014b).

After 1985 the survey effort in the Hunter Estuary became infrequent, except for the period 1994 -1997 when 6-10 surveys were carried out each year at key sites (Kingsford *et al*. 1998).

From the intermittent survey effort over 1982-1997, the estuary was rated as internationally important for six migratory shorebird species (Bamford *et al*. 2008 p 213).

History of shorebird habitat changes in the Hunter Estuary

Since European settlement, numerous changes have occurred to shorebird habitat in the estuary. Initially, most of the changes were detrimental for shorebirds. However, more recently various positive developments have partially restored some of the formerly lost habitat.

Lower estuary

Between 1801 and 1994, roosting and feeding sites were lost in the lower estuary, as a result of dredging and the amalgamation of islands aimed at improving passage for container ships and fishing vessels. The number of islands had been reduced from 20 to four, and shorelines where shorebirds could forage were more than halved, from 118 to 51 km. Eventually one large island was created, which became known as Kooragang Island (Kingsford & Ferster Levy 1997). The southern section of this island continues to be known as Kooragang Island. By 1928, 363.3 ha of river mudflats to the south of Fullerton Cove had been removed. As a result, Fullerton Cove became the main feeding area (Kingsford & Ferster Levy 1997). On the positive side, between 1966 and 1969, a breakwater, the Kooragang Dykes, was built (Kingsford & Ferster Levy 1997), using slag from the Newcastle steelworks. The site is now an important artificial roost for shorebirds. Over the decades the breakwater has gradually deteriorated; however, the damage is being addressed by NSW National Parks and Wildlife Service and Hunter Local Land Services through an ongoing maintenance program.

Kooragang Island

Despite ongoing industrial development, for several decades two sites on Kooragang Island continued to be important habitat for shorebirds particularly for small to medium-sized species. The Big Pond, a shallow, brackish wetland of approximately 45 ha was an important foraging site for Curlew Sandpiper, Marsh Sandpiper and Red-necked Stint *Calidris ruficollis* (Straw 1999). In 1993, a section of the wetland was reclaimed in order to extend a coal-loading terminal. This was followed by the suspension of tidal influence in 1996. The destruction of The Big Pond was completed in 2008, when the remaining vacant land became the site for a new coal-loading terminal. Altogether 16 species of migratory shorebirds had been recorded there (Straw 1999). The second site was Deep Pond, a shallow, non-tidal, largely freshwater pond where mudflats formed during drying periods. Eleven migratory shorebird species have been recorded there (Lindsey 2008). Deep Pond was bisected by a railway line constructed to service two coal-loading facilities during the mid-2000s creating Deep Pond North and Deep Pond South. Shorebirds still occur on Deep Pond North (Roderick 2015).

Ash Island, Hexham and Tomago

Flood mitigation schemes between the 1950s and 1970s and mosquito control initiatives, led to the installation of floodgates at creeks at Ash Island, Hexham Swamp and Tomago Wetland. The floodgates prevented tidal flushing and estuarine wetlands reverted to freshwater wetlands which were no longer able to support shorebirds in any substantial numbers. The planning and main initial rehabilitation activities for those three sites were driven by Hunter-Central Rivers Catchment Management Authority (now Hunter Local Land Services). Their Kooragang Wetland Rehabilitation Project (KWRP) commenced in the 1990s and initially was focussed mainly on Ash Island (one of the three sites targeted for rehabilitation). Reinstatement of tidal flushing was accomplished at Hexham Swamp between 2008-2013 and at Tomago Wetland between 2012-2015 (Lindsey 2021). A fourth project at Fish Fry Flats on Ash Island, the Newcastle Coal and Infrastructure Group (NCIG) Shorebird Compensatory Habitat Construction, commenced in 2016. Among the aims for these four projects was the restoration of estuarine wetland for the benefit of shorebirds through the reintroduction of tidal flow or partial tidal flow (Kooragang Wetland Rehabilitation Project 2010; Local Land Services Hunter 2016; Lindsey 2021; Reid 2019).

One way of achieving estuarine wetland was to promote the growth of salt marsh, often favoured by shorebirds, over that of Grey Mangrove *Avicennia marina*, a species which had been increasing throughout the estuary to the detriment of the former (Brereton & Taylor-Wood 2010; Clarke 2010; 2011; Straw 1999). Central to the NCIG project for example, was the removal of 17 ha of juvenile mangroves (Reid 2019). The control of weeds and mangrove incursion into salt marsh habitat has been an important local focus and has included an annual program to remove mangrove seedlings and weeds (Clarke 2020).

Stockton

Serious losses of shorebird habitat occurred as a consequence of the closure in 2001 of a primary sewage treatment plant at Stockton which destroyed an important roost site for Curlew Sandpiper, and changed conditions at a roost site near Stockton Bridge, which resulted in birds abandoning that site (Straw 1999).

A second component of KWRP was restoration work at Stockton Sandspit designed to bring shorebirds back to the site. Between 1966 and 1969 a sandspit had formed from dredge spoil deposited on the eastern shore of the river in preparation for the construction of the Stockton Bridge (Kingsford & Ferster Levy 1997). During the 1970s, thousands of shorebirds used the bare, shelly sand as a roost, but by the 1980s the site had become hemmed in by Grey Mangrove (Brereton & Taylor-Wood 2010) and overgrown with introduced weeds greatly reducing its value to shorebirds. The construction of a lagoon, the removal of weeds and mangroves fringing the site saw a

significant increase in numbers of shorebirds returning to the Sandspit (Svoboda 2017).

Major environmental incidents

Two major environmental incidents have occurred in the estuary. On 25 August 2010, 72,000 litres of fuel oil was accidentally discharged with ballast water into Newcastle Harbour from a coal ship. Although booms were placed in the South Channel of the Hunter River, oil was discovered on Stockton Sandspit two days later. Invertebrate animals on mudflats, in saltmarsh and mangroves and several Australian Pelicans *Pelecanus conspicillatus* were affected. Fortunately, there apparently were no long-term impacts (Rule of Law Education Centre 2021). A potentially more significant incident has resulted from the long-term use (over several decades) of firefighting foams at Williamtown airport to the north of Newcastle. That has resulted in substantial contamination of Fullerton Cove (Australian Department of Defence 2018). The fire-fighting group of chemicals includes a large variety of similarly-behaving products, such as per- and poly-fluoroalkyl substances (PFAS) and per- and poly-fluorooctyl sulphonates (PFOS). PFAS/PFOS chemicals have been shown to accumulate in the food chain (Taylor *et al*. 2018) and to have acute toxicity to benthic organisms (Simpson *et al*. 2021).

METHODS

Survey methodology

The estuary is divided into nine shorebird areas (BirdLife Australia 2021). Data were obtained from structured surveys, which commenced in April 1999. They were carried out monthly at high tide using a standard procedure involving multiple teams visiting high tide roost sites at Stockton Sandspit/Fern Bay/Stockton Channel, Fullerton Cove and Ash Island (Stuart *et al*. 2013). Simultaneous surveys at Hexham Swamp and Tomago Wetland commenced in 2013 and 2014 respectively, when those sites first began to host shorebirds (Stuart *et al*. 2013; Lindsey 2021). Simultaneous surveys at some other sites on Kooragang Island, the main one being the Deep Pond complex, commenced in September 2000. However, from 2014 these surveys took place the day before the other estuary surveys, because of access restrictions at what had become industrial sites (Roderick 2015). A document with detailed descriptions of the survey methodology is available (BirdLife Australia 2021).

Data management and data analysis

The data for each individually surveyed site from every survey were entered into BirdLife Australia's Birdata database (www.birdata.birdlife.org.au). Between 1999-2017, we also recorded the data in an MS Excel spreadsheet, updated monthly.

In March 2021 we downloaded the 1999-2021 Birdata records for the Hunter Estuary. However, it soon became apparent that the 1999-2017 records in the database had many errors. Primarily these involved duplicate records for the same site/s on the same day. From 2018 onwards, when it became easy for survey team leaders to enter data directly into Birdata, there appeared to be no more issues about data quality.

Accordingly, we expanded our original MS Excel spreadsheet by adding the downloaded 2018-2021 data to it. Where possible, we cross-checked the records against those published in other forums (e.g. the Hunter Region annual bird report series).

We used standard MS Excel graphing tools for our core analyses. We calculated annual rates of change of species abundance by analysing the slope of the linear trend line for that species. We divided the data into three-time intervals for closer analysis of any changes:

- Non-breeding season: data for the November to March period, spanning November 1999 to March 2006, November 2006 to March 2013, and November 2013 to March 2021.
- Breeding season: data for the May to August period, spanning May 1999 to August 2005, May 2006 to August 2013, and May 2014 to August 2020.

The three time periods we used to analyse the non-breeding and breeding season records were arbitrarily selected. However, they divided the data set into three approximately equal time intervals, each spanning 7-8 years of data.

To assess population changes over time, we compared the data sets for the above three time periods (NB comparing the non-breeding season data separately to the breeding season data). We compared time periods 1 and 2, and then separately compared time periods 2 and 3. We calculated p-values using two-tailed t-tests assuming unequal variance. With $p < 0.05$ we rated the differences in the two data sets as being statistically significant, and as highly significant with $p < 0.01$.

We excluded all data collected in surveys carried out in April, September and October from our general analyses, as we found that shorebird numbers had fluctuated markedly in these months. In particular, it was the time when migratory shorebirds were moving through on passage, and not necessarily staying for long in the estuary. However, we used the data for all months when considering the number of records and the maximum counts. For the Red Knot, which mainly was present on passage in spring, we also analysed the September-November records.

Table 1. Summary of the shorebirds recorded in the Hunter Estuary between April 1999 and March 2021

Species	Visitation status	Preferred habitat[@]	Number of records	Max.count	Population trend
Migratory shorebirds					
South Island Pied Oystercatcher[#] *Haematopus finschi*	Irregular	Coastal	1	1	Unknown
Grey Plover *Pluvialis squatarola*	Irregular	Coastal	6	1	Unknown
Pacific Golden Plover *Pluvialis fulva*	Regular	Generalist	191	522	Increasing
Double-banded Plover *Charadrius bicinctus*	Irregular	Generalist	22	60	Unknown
Lesser Sand Plover *Charadrius mongolus*	Irregular	Coastal	16	4	Unknown
Greater Sand Plover *Charadrius leschenaultii*	Irregular	Coastal	4[*]	2	Unknown
Oriental Plover[#] *Charadrius veredus*	Irregular	Generalist	1	10	Unknown
Whimbrel *Numenius phaeopus*	Regular	Coastal	227	185	Decreasing
Little Curlew[#] *Numenius minutus*	Irregular	Generalist	3	6	Unknown
Far Eastern Curlew *Numenius madagascariensis*	Regular	Coastal	260	617	Decreasing
Bar-tailed Godwit *Limosa lapponica*	Regular	Coastal	259	2019	Decreasing
Black-tailed Godwit *Limosa limosa*	Regular	Generalist	225	425	Decreasing
Ruddy Turnstone *Arenaria interpres*	Irregular	Coastal	35	6	Unknown
Great Knot *Calidris tenuirostris*	Regular	Coastal	108	90	Decreasing
Red Knot *Calidris canutus*	Regular	Coastal	150	1472	Decreasing
Ruff *Calidris pugnax*	Irregular	Generalist	1	1	Unknown
Broad-billed Sandpiper *Calidris falcinellus*	Irregular	Coastal	2[*]	1	Unknown
Sharp-tailed Sandpiper *Calidris acuminata*	Regular	Generalist	157	6408	Increasing
Curlew Sandpiper *Calidris ferruginea*	Regular	Generalist	180	812	Decreasing
Long-toed Stint *Calidris subminuta*	Irregular	Generalist	2[*]	1	Unknown
Red-necked Stint *Calidris ruficollis*	Regular	Generalist	148	144	Decreasing
Buff-breasted Sandpiper *Calidris subruficollis*	Irregular	–	1	1	Unknown
Pectoral Sandpiper *Calidris melanotos*	Irregular	–	6+[*]	1	Unknown
Latham's Snipe *Gallinago hardwickii*	Irregular	Generalist	32	22	Unknown
Terek Sandpiper *Xenus cinereus*	Regular	Coastal	133	68	Decreasing
Common Sandpiper *Actitis hypoleucos*	Regular	Generalist	87	6	Decreasing
Grey-tailed Tattler *Tringa brevipes*	Regular	Coastal	214	52	Increasing
Wandering Tattler *Tringa incana*	Irregular	Coastal	1	1	Unknown
Lesser Yellowlegs[#] *Tringa flavipes*	Irregular	–	2[*]	1	Unknown
Common Greenshank *Tringa nebularia*	Regular	Generalist	238	333	Decreasing
Wood Sandpiper *Tringa glareola*	Irregular	Generalist	3	1	Unknown
Marsh Sandpiper *Tringa stagnatilis*	Regular	Generalist	163	324	Decreasing
Oriental Pratincole[#] *Glareola maldivarum*	Irregular	Generalist	1	1	Unknown
Australian shorebirds					
Beach Stone-curlew *Esacus magnirostris*	Irregular	Coastal	1	1	Unknown
Australian Pied Oystercatcher *Haematopus longirostris*	Regular	Coastal	243	43	Prob. stable
Sooty Oystercatcher *Haematopus fuliginosa*	Regular	Coastal	127	22	Prob. stable
Banded Stilt *Cladorhynchus leucocephalus*	Irregular	Coastal	7	2	Unknown
Red-necked Avocet *Recurvirostra novaehollandiae*	Regular	Generalist	238	6753	Prob. stable
Pied Stilt *Himantopus leucocephalus*	Regular	Generalist	249	1576	Increasing
Red-capped Plover *Charadrius ruficapillus*	Regular	Coastal	208	158	Prob. stable
Black-fronted Dotterel *Elseyornis melanops*	Regular	Generalist	226	80	Increasing
Banded Lapwing *Vanellus tricolor*	Irregular	Generalist	1	1	Unknown
Masked Lapwing *Vanellus miles*	Regular	Generalist	263	364	Increasing
Red-kneed Dotterel *Erythrogonys cinctus*	Regular	Generalist	106	222	Increasing
Australian Painted-snipe *Rostratula australis*	Irregular	Generalist	1	1	Unknown
Australian Pratincole *Stiltia isabella*	Irregular	Generalist	1	1	Unknown

[#]Not recorded during a scheduled survey [*]Includes some records from non-survey days [@]Habitat preference assignments are based on Jackson *et al*. (2020)

Table 2. Data for shorebirds regularly present in the Hunter Estuary – the mean counts for November-March and May-August for three-time intervals and the linear trends (i.e. the average % change per annum over 22 years). Count data shown in **Bold** indicate where there is a statistically significant or highly significant difference to the data from the preceding time interval.

	November-March				**May-August**			
Species	1999-2006 mean	2006-2013 mean	2013-2021 mean	Linear trend 1999-2021	1999-2005 mean	2006-2013 mean	2014-2020 mean	Linear trend 1999-2020
Migratory shorebirds								
Pacific Golden Plover	69	**157**	**230**	+11.7%	0	1	5	-
Whimbrel	47	**22**	**32**	-1.3%	16	12	5	-3.8%
Far Eastern Curlew	383	**244**	**144**	-3.7%	110	**69**	**35**	-3.9%
Bar-tailed Godwit	1127	**859**	**579**	-2.9%	214	228	**125**	-2.5%
Black-tailed Godwit	179	**116**	**50**	-4.1%	8	**2**	1	-4.5%
Great Knot	8	3	1	-4.4%	1	0	0	-
Red Knot	38	15	10	-4.4%	3	1	0	-
Sharp-tailed Sandpiper	274	210	**1934**	>30%	0	0	9	-
Curlew Sandpiper	261	**125**	**87**	-4.5%	3	3	5	+2.0%
Red-necked Stint	44	**14**	29	-3.7%	5	2	1	-3.7%
Terek Sandpiper	23	9	3	-4.5%	0	0	0	-
Common Sandpiper	2	1	1	-	0	0	0	-
Grey-tailed Tattler	17	22	21	+1.5%	2	3	4	+4.5%
Common Greenshank	147	**82**	72	-3.4%	8	7	11	+1.9%
Marsh Sandpiper	85	**38**	31	-3.8%	9	**1**	**4**	-2.0%
Australian shorebirds								
Australian Pied Oystercatcher	8	8	7	0%	7	8	7	-
Sooty Oystercatcher	1	**5**	4	+4.5%	1	**4**	2	-
Red-necked Avocet	1471	993	1473	-0.1%	1918	1487	2245	+0.1%
Pied Stilt	374	**194**	**642**	+3.3%	395	**234**	**489**	+0.6%
Red-capped Plover	18	**10**	7	-2.5%	14	20	21	+5.3%
Black-fronted Dotterel	4	5	5	+2.3%	16	12	**29**	+8.2%
Masked Lapwing	77	80	**157**	+3.3%	43	47	**95**	+3.1%
Red-kneed Dotterel	2	8	17	+13.6%	17	5	25	+2.3%

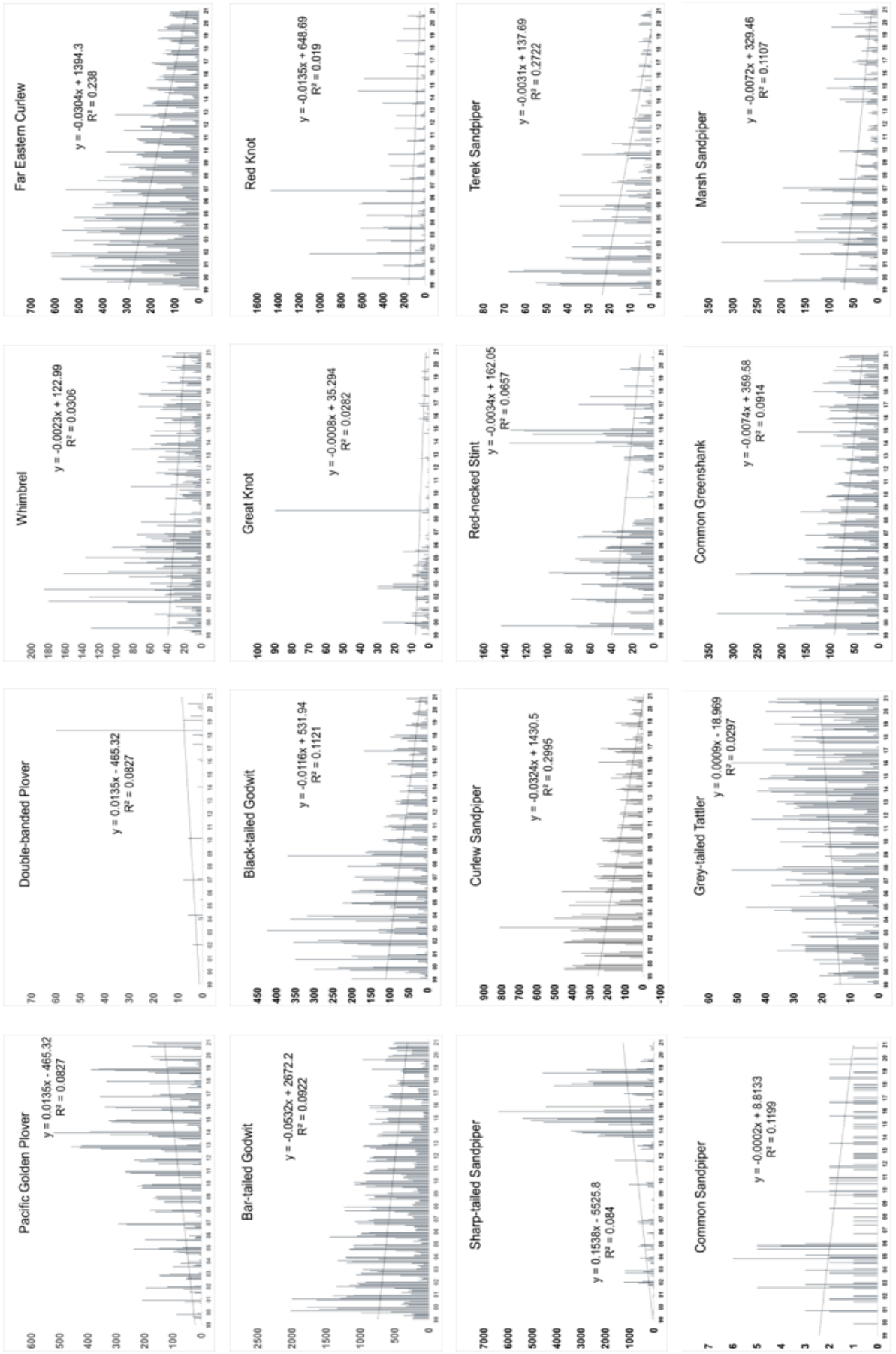


Figure 2. Monthly counts for the 16 most-frequently recorded migratory shorebirds in the Hunter Estuary, for April 1999 to March 2021 with trend lines and the related regression equation data, based on linear regression of all counts

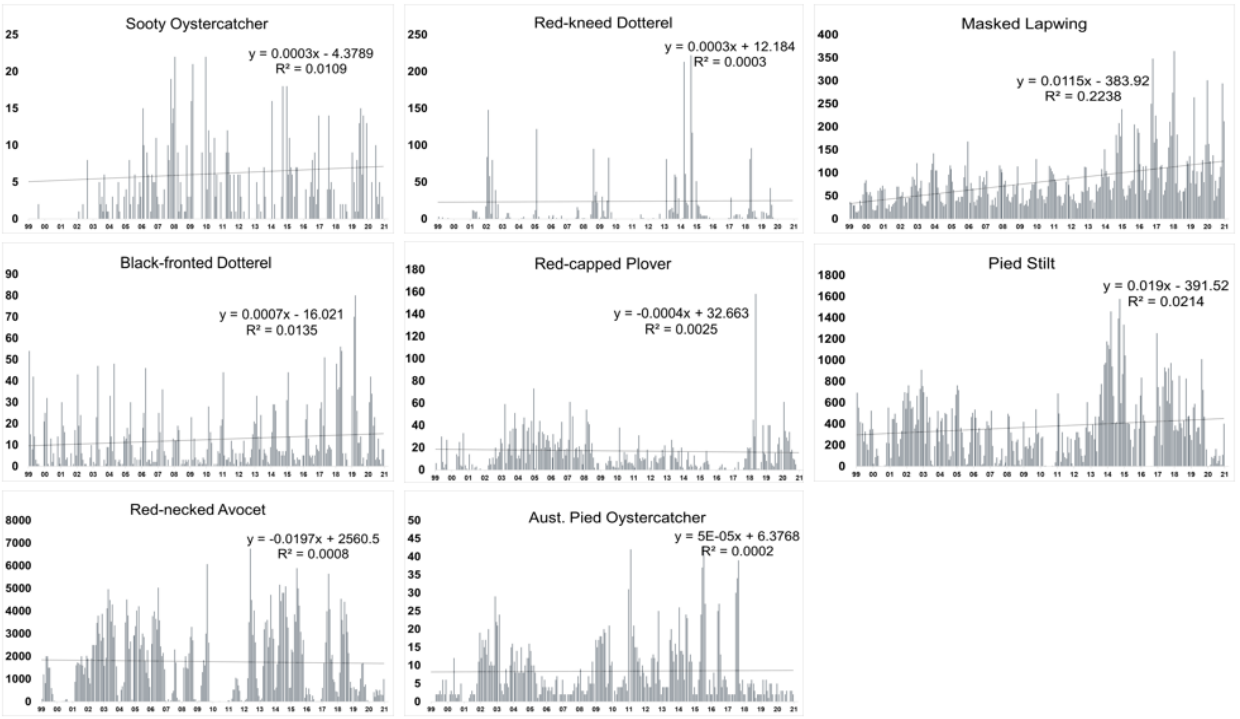


Figure 3. Monthly counts for the eight most-frequently recorded non-migratory shorebirds in the Hunter Estuary, for the period April 1999 to March 2021. Trend lines and the related regression equation data, based on linear regression of all counts, are presented to help guide the eye.

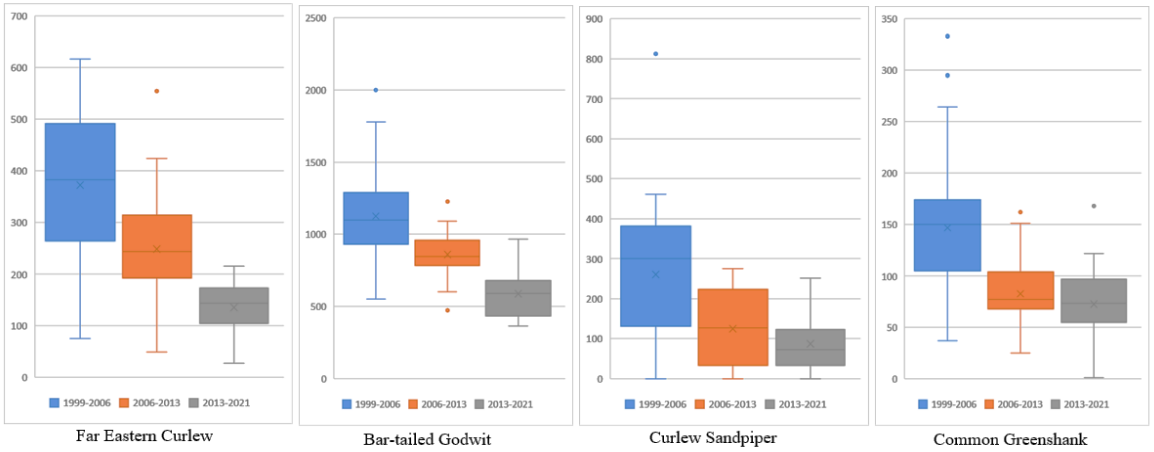


Figure 4. November-March survey results for four migratory shorebirds with declining numbers in the Hunter River Estuary. Means are represented as X and medians as horizontal lines, between the interquartile ranges (boxes), and 1.5*interquartile ranges (whiskers). Outlier values are presented individually (•).

RESULTS

Overview

Of the 264 possible surveys, the only one which did not take place was in June 2007 when none of the survey sites could be accessed after a series of East Coast Lows caused major local flooding and storm damage. In 10 other surveys, the Kooragang Dykes were not able to be surveyed because of mechanical or other operability problems with the boat (e.g. unsuitable weather, COVID-related access issues). In one survey, the Stockton Sandspit could not be accessed. On nine other occasions there were access problems at some other sites, mostly at the Tomago Wetland site.

For the 20 surveys that potentially resulted in an incomplete total count of shorebirds in the estuary, we mostly have still used the results in the analyses reported below. The exceptions involved the analyses of species, which were known to prefer to roost at the site that was not surveyed.

Fifteen migratory and eight non-migratory shorebirds were regularly recorded in the surveys (Table 1). The most commonly recorded species was Masked Lapwing *Vanellus miles*, which was present in every survey, while Common Sandpiper *Actitis hypoleucos* was the least common of the regular shorebirds, with 87 records.

In addition to the Masked Lapwing, five other species were each recorded in more than 90% of the surveys: Far Eastern Curlew, Bar-tailed Godwit, Australian Pied Oystercatcher *Haematopus longirostris,* Red-necked Avocet, Pied Stilt *Himantopus leucocephalus.* An additional 23 species were recorded as vagrants or were only occasionally present (Table 1). Three species were only briefly in the estuary and were not recorded on a scheduled survey date: South Island Pied Oystercatcher *H. finschi*, Oriental Plover *Charadrius veredus* and Little Curlew *N. minutus*. Most of the 23 species had only a small number of records; however Double-banded Plover *C. bicinctus*, Lesser Sand Plover *C. mongolus*, Ruddy Turnstone *Arenaria interpres* and Latham's Snipe each were recorded 16-35 times.

Thus, 46 shorebird species were recorded in the Hunter Estuary over 1999-2021 including 23 regular visitors (with 15 of those being migratory species) and 23 uncommon or vagrant species (with 18 being migratory species). Figures 2 and 3 illustrate monthly counts for the main migratory species and non-migratory species, respectively. Figure 2 also includes the results for Double-banded Plover, which had only 22 records but with a maximum count of 60 birds.

In Table 2 we summarise the trends for the 23 species which were regularly recorded in the estuary. Of the migratory shorebirds, 11 species have undergone declines in their non-breeding season populations while the numbers for three other species have increased. These trends were largely mirrored in the breeding season counts, although for Curlew Sandpiper and Common Greenshank there were modest increases. For the eight non-migratory shorebirds that were regularly present, many had increasing trends, while others had fluctuating, but overall stable or increasing populations. Red-capped Plover *Charadrius ruficapillus* was the only species with a decreasing population, with the mean counts dropping from 18 to 7 birds from November to March. However, their numbers increased in the May-August surveys.

Migratory shorebirds with declining populations

November-March counts for four of the species with declining populations illustrate the changes that have occurred for all 12 species (Figure 4). The plots for the other eight species in decline followed similar patterns. The differences in the two counts for any two time periods for ten of the species were found to be statistically significant ($p < 0.05$) and in many cases, highly significant ($p < 0.01$). The differences were not significant for the Common Sandpiper, which was only ever recorded in low numbers (the maximum count was of six birds, most counts were of one or two individuals). The differences for Red-necked Stint between 1999-2006 and 2006-2013 were highly significant. In general, its numbers further declined during 2013-2021; however, in 2014-2015 there was an influx, with 100+ birds often present and a peak count of 135 birds in March 2015. In the previous season, there also were 136 birds in March 2014. The influx raised the mean count for the overall period to 29 birds. If those records from the influx were excluded, the mean count for Red-necked Stint for 2013-2021 would have been 13 birds. That was not a statistically significant change from the 2006-2013 results.

Most migratory shorebirds were absent in the May-August period or present only in low numbers (Table 2). The exceptions were Whimbrel, Far Eastern Curlew and Bar-tailed Godwit. Although both of the latter species continued to be recorded regularly, there was clear evidence of their decline. The changes when comparing any two time periods were highly significant ($p < 0.01$). No statistically valid conclusions could be drawn from the Whimbrel data.

Small numbers of Red Knot spend their non-breeding season in the Hunter Estuary and very few in the breeding season. However, in spring there is a migration passage of birds primarily bound for New Zealand (Crawford & Herbert 2017*)*. Thus, the peak counts for Red Knot in the Hunter Estuary occur in the period September to November (Figure 5). There has been a substantial

decline in Red Knot numbers; however, the magnitude of the decline is exaggerated by unusually high counts occurring in September 2001 (1,100 birds) and October 2006 (1,472 birds).

Migratory shorebirds with rising populations

Three species had increasing populations over 1999-2021: Pacific Golden Plover, Sharp-tailed Sandpiper and Grey-tailed Tattler *Tringa brevipes*. The changes for Grey-tailed Tattler were not statistically significant. The changes for the other two species are summarised as box and whisker plots in Figure 6. They were found to be statistically highly significant. The Pacific Golden Plover population has been increasing steadily since regular monitoring began. However, the pattern for Sharp-tailed Sandpiper was different (Figure 2). Its numbers rose sharply in the 2013-2014 non-breeding season and remained high for the six years, up to and including the 2018-2019 non-breeding season.

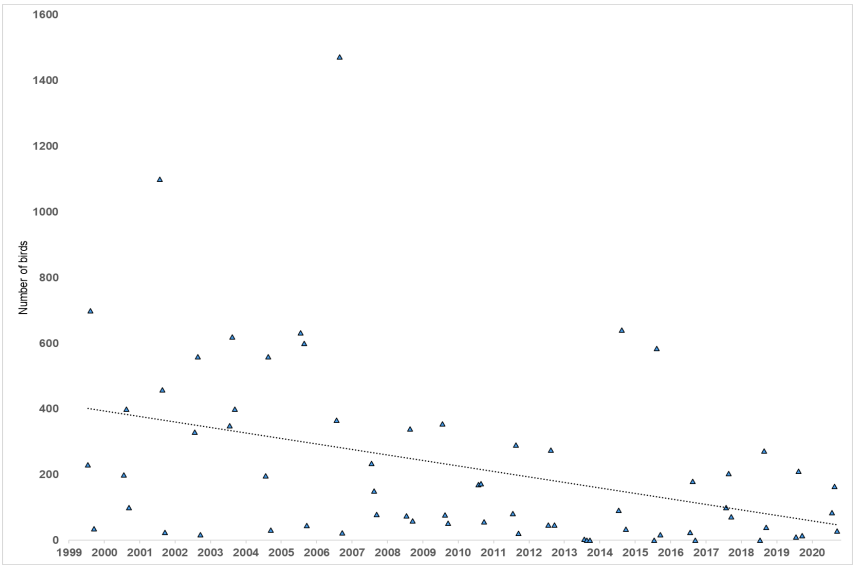
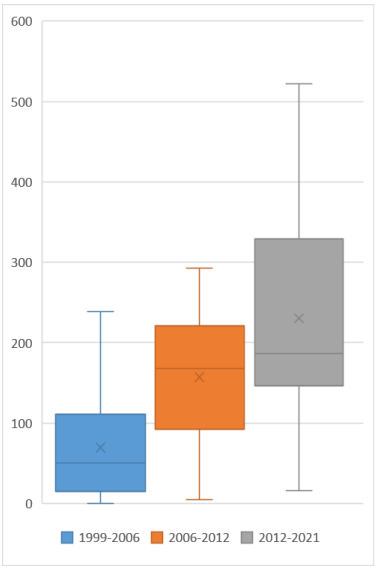


Figure 5. Annual monthly counts and linear trend line for Red Knot in September-November.

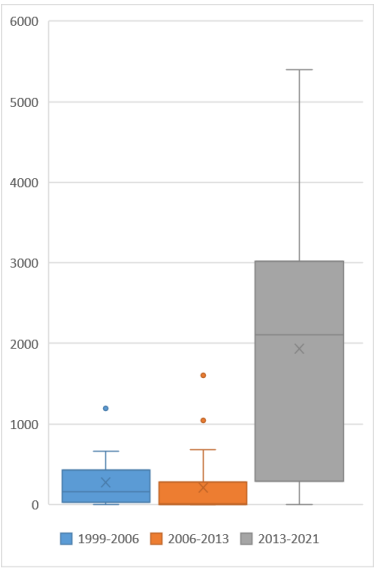
Non-migratory shorebirds

Large numbers of Red-necked Avocets often were present in the estuary. The peak count was of 6,753 birds in August 2012 and the mean counts mostly were of more than 1,000 birds. However, there also were many absences, for periods of several months and usually occurring in late summer and autumn although not in every year. Avocet behaviour in the estuary has changed somewhat. In the first *c* 15 years of surveying, and prior to that, the entire flock appeared to feed in Fullerton Cove each day and then roost at high tide on the Kooragang Dykes or at Stockton Sandspit. Since then, up to 1,000 birds have regularly been at Ash Island and appear to forage and roost there; also, there sometimes are birds (in fewer numbers) at Hexham Swamp and Tomago Wetland. The numbers of Pied Stilt also fluctuated considerably, ranging from a peak count of 1,576 birds in December 2014 to several times there being none found in the estuary. The absences of Red-necked Avocet and Pied Stilt did not correlate – sometimes both species were absent, but it was just as likely that only one of the species had left the estuary.

The most reliable site for Red-capped Plover was Stockton Sandspit, where 20+ birds often were recorded and there were many breeding records and attempts (in spring and summer). However, for the peak count of 158 birds in August 2018, 155 of those birds were at Tomago Wetland, where generally they were uncommon. In recent years there have been fewer Red-capped Plovers at Stockton Sandspit in the breeding season, and very few breeding attempts. In the non-breeding season, birds have begun to be distributed more widely in the estuary, for example on Ash Island.



Pacific Golden Plover



Sharp-tailed Sandpiper

Figure 6. November-March survey results for Pacific Golden Plover and Sharp-tailed Sandpiper.

The Masked Lapwing population initially was stable, albeit with seasonal changes. However, in recent years the population has approximately doubled. There were similar changes for Red-kneed Dotterel *Erythrogonys cinctus* and Black-fronted Dotterel *Elseyornis melanops* (for the latter, only in the May-August period). The trend for Red-kneed Dotterel was overshadowed by some large influxes, with counts of 100+ birds in May 2002, May 2005, June and November 2014 (the 2014 counts were of 200+ birds). All four of those counts were considerably above the mean. The 2002 and 2005 influxes occurred at Ash Island, and the 2014 events at Hexham Swamp.

DISCUSSION

International and national significance of the Hunter Estuary for shorebirds

The estuary's designation as a Ramsar site in 1984 was because it met the following criteria:

- Regularly supports 1% of the individuals in a population of one species or subspecies of waterfowl.
- Supports an appreciable number of rare, vulnerable or endangered species or subspecies of plant or animal.
- Is of special value for maintaining the genetic and ecological diversity of a region because of the quality and peculiarities of its fauna and flora.
- Is a particularly good example of a specific type of wetland community characteristic of its region.

The decline in populations of migratory shorebirds in the Hunter Estuary in general mirrors the trends observed elsewhere (e.g. Studds *et al*. 2017; Hansen 2011). However, some of the local declines have been steeper, such that the estuary is no longer internationally significant for several species, which previously it had been (based on Bamford *et al*. 2008). The estuary is no longer internationally significant for Latham's Snipe, Black-tailed Godwit, Bar-tailed Godwit or Curlew Sandpiper. It continues to be a nationally significant site for those species.

In a recent report, the estuary was listed as internationally significant for Far Eastern Curlew and Red Knot, based on 406 birds in February 2007 and 2,172 birds in October 2006, respectively (Weller *et al*. 2020). In 1999-2007, HBOC's surveys often recorded 500+ Far Eastern Curlew, but with substantial declines from then onwards. Surveys in the non-breeding season in 2020-2021 have recorded 100-150 birds i.e. around 0.3-0.5% of the total population. The 2006 Red Knot record of 2,172 birds (Spencer 2009; Weller *et al*. 2020) was not from an HBOC survey, but 1,472 birds had been present during a scheduled survey only a few days before and it is well-known that there is a transient population in spring when birds are on migration passage. However, since 2014 the peak count has been of 640 birds (in October 2014) and all of the counts since October 2015 have been of fewer than 300 birds. Those numbers represent around 0.3-0.5% of the total population. It has been 14-15 years since the Hunter Estuary hosted more than 1% of the populations of either Far Eastern Curlew or Red Knot.

Weller *et al*. (2020) also listed the estuary as internationally significant for Sharp-tailed Sandpiper. This is also the case based on our data, the peak counts of the 2013-2019 HBOC surveys often were of 3,000-5,000 birds, equivalent to 4-6% of the total population. The high numbers persisted for eight consecutive non-breeding seasons, from 2011/12 to 2018/19, with 1000+ birds being recorded each season (Stuart 2016; 2019).

The Hunter Estuary's importance for Red-necked Avocet is very clear. Since 1985 there have been records of more than 1% of the total population (estimated at 107,000 birds: Wetlands International 2021) in almost every year (Stuart 2017). There have only been three periods with prolonged absences of all or most birds: December 1999 – April 2001, January 2010 – May 2011 and February 2016 – March 2017. The peak count in August 2012 was approximately 6.5% of the total population. Also, for the Pied Stilt, there were several records of more than 1,000 birds over 2014-2019 with the peak count of 1,573 birds in December 2014. These records were 0.1-0.15% of the estimated total population (Wetlands International 2021).

The estuary's IBA nomination in 2010 included three shorebirds (Far Eastern Curlew, Sharp-tailed Sandpiper and Red-necked Avocet) and one waterfowl (Chestnut Teal *Anas castanea*) that were regularly present at more than 1% of their total populations. That is no longer the case for Far Eastern Curlew but the IBA continues to support significant numbers of all three other species.

Ramsar criteria continue to be met for the estuary although there have been changes in which species are present at levels of 1% or more of their total population. However, some of the Limits of Acceptable Change for the Ramsar site (Brereton & Taylor-Wood 2010) have been exceeded:

- *For any five consecutive years there will be no instance of all years recording a maximum summer annual count of migratory shorebirds of less than 5,000 birds*. 5,000+ migratory shorebirds were not recorded in any survey between April 1999 (when the surveys started) and October 2014 i.e. for more than 15 years. Between November 2014 and October 2018, there were several instances of more than 5,000 birds being recorded. However, there have been no further instances. It has been only when there have been substantial numbers of Sharp-tailed Sandpiper in the estuary that the target of 5,000+ birds has been met. If Sharp-tailed Sandpiper numbers are excluded from the reckoning, the highest total count of migratory shorebirds was 3,589 birds in December 1999. Since 2008, there have been only four instances where more than 2,000 migratory shorebirds were present (excluding Sharp-tailed Sandpipers).
- *For any five-year period, there will be no instance of all years recording a maximum summer annual count of eastern curlew* (sic) *for the Hunter River Estuary of less than 600 birds*. In 22 years of monthly surveys, there have been two records of 600+ Far Eastern Curlew. Both occurred in the 2001/02 non-breeding season and involved counts of 614-617 birds.

Winners and losers

The populations of seven species, including three migratory shorebird species, have increased over 1999-2021. For Pacific Golden Plover and Sharp-tailed Sandpiper the changes have been substantial. However, the populations of all twelve of the other regularly-visiting migratory shorebirds have decreased. In most cases the declines have been substantial and the differences in counts for three successive 7-8year periods were statistically significant or highly significant. For the most part, those declines have been a continuation of trends from the late 1980s onwards (Herbert 2007; Spencer 2009; Stuart 2014a; 2014b). For example, Lane (1987) reported 490 Far Eastern Curlew, 470 Black-tailed Godwit, 1,300 Bar-tailed Godwit; 560 Common Greenshank; 280 Marsh Sandpiper and 570 Curlew Sandpiper as average counts in the estuary for 1981-1985. Spencer (2009) showed that the declines for many of these species had been occurring since the 1980s. Between 1993 and 2009, the number of migratory shorebird species present in the estuary at >1% of their Australian populations decreased from 11 to five species and the number of migratory species present at >1% of their Flyway population decreased from five to two species (Spencer 2009). In 2009 the estuary was considered internationally significant for Far Eastern Curlew and Sharp-tailed Sandpiper (Spencer 2009).

Spencer (2009) assessed Pacific Golden Plover and Grey-tailed Tattler as in decline, however the evidence for Grey-tailed Tattler was not definitive. For Pacific Golden Plover, the average count was 410 birds in the 1980s (Lane 1987), similar to recent surveys. There also were many records of 500-800 birds in the 1970s and 1980s. However, in the 1990s the counts dwindled to 100-200 birds. This species has been making an encouraging local recovery in recent years, particularly given that the overall Australian population has decreased by 2.8% (Clemens *et al*. 2016). Grey-tailed Tattler has made a modest recovery in the Hunter Estuary in recent years (the mean counts have risen from 17 to 21-22 individuals). Importantly, it is no longer experiencing a continued decline in numbers.

Sharp-tailed Sandpiper was mainly only recorded in low numbers in the estuary until recently, although prior to that there were occasional brief influxes of more than 1% of the total population (Stuart 2016). The regular presence recently of many thousands of birds, over 2013-2019 in particular, is a significant change.

For migratory shorebirds with declining local populations, a crucial question is whether the local declines mirror the overall EAAF trends or whether there might be some local factors involved. Many migratory EAAF shorebirds have declining populations (e.g. Studds *et al*. 2017; Hansen 2011). However, the available evidence suggests that local declines for many species exceed their trends for the overall Flyway. Some indirect evidence is that the estuary no longer hosts internationally significant numbers of shorebirds, such as Bar-tailed Godwit, Black-tailed Godwit, Curlew Sandpiper Marsh Sandpiper and Common Greenshank. This change indicates that the local declines have exceeded the overall declines (i.e. if the population changes were uniform across the Flyway, the estuary would still be hosting internationally significant numbers of each of those species).

More direct evidence comes from a recent analysis of total Flyway populations (Clemens *et al*. 2016). The numbers of Bar-tailed Godwit, Black-tailed Godwit, Whimbrel and Curlew Sandpiper in the estuary have declined far more than in southern Australia, and the estuary had the highest decline of migratory shorebirds of all sites in Australia (Clemens *et al*. 2016). Again, this points to some local factors being involved.

Several non-migratory shorebirds have experienced population changes in the estuary. For Black-fronted Dotterel (in May-August) and Masked Lapwing there were statistically significant population increases, as discussed in the section *Effects of rehabilitation projects and inland conditions*.

Yellow-Sea dependency

Most of the migratory shorebirds that have undergone significant population declines in the Hunter Estuary have a high reliance on Yellow Sea tidal mudflats when they are on migration in the Flyway (Studds *et al*. 2017). Although Black-tailed Godwit was not mentioned as being Yellow Sea-dependent by Studds *et al*. (2017), we are assuming it to be, as more than 1% of the flyway population use Bohai Bay, north-western Yellow Sea as a staging area (Yang *et al.* 2011; Zhu *et al.* 2020). The area of tidal mudflats in the Yellow Sea has shrunk by more than 65% in recent decades and continues to shrink by more than 1% per year (Studds *et al*. 2017). Species with high reliance on the Yellow Sea during migration have declined at rates of up to 8% per year.

Yellow Sea habitat losses possibly account for the bulk of the population declines for migratory shorebirds in the Hunter Estuary. However, as discussed earlier the declines locally, in many cases, appear to have been larger.

Although some Sharp-tailed Sandpiper use Yellow Sea mudflats on migration, many of them do not (http://www.nzbirdsonline.org.nz/). According to geolocator data, Pacific Golden Plover migrate mainly through Japan and Pacific Islands (Johnson *et al*. 2012). This pattern was further confirmed when in 2016 a Pacific Golden Plover fitted with a Platform Terminal Transmitter (PTT) spent 13 days in Japan before flying to Alaska (Coleman & Bush 2020). Grey-tailed Tattlers mainly go via Japan and Taiwan (Branson *et al*. 2010). Thus, the three regularly visiting migratory species with increasing populations all have relatively low Yellow-Sea dependency.

Coastal specialist versus inland specialist/generalist species

Weller & Lee (2017) classified migratory shorebirds as being either coastal obligates, generalists, inland species or snipes, with generalists being species routinely found in both marine and freshwater habitats. Jackson *et al*. (2020) used a simpler classification scheme, categorising shorebirds as either coastal specialists or as inland specialists/generalists. Because Jackson *et al*. (2020) dealt with both non-migratory and migratory shorebird species we adopted their approach (Table 1). Three species which were recorded in the estuary over 1999-2021 were not categorised by Jackson *et al*.(2020): the locally uncommon Pectoral Sandpiper and two vagrants to the estuary – Lesser Yellowlegs and Buff-breasted Sandpiper.

In the Hunter Estuary, the majority of the coastal specialist shorebirds feed in Fullerton Cove at low tide and roost at high tide either at the Kooragang Dykes or at Stockton Sandspit.

The populations of most of the regularly recorded coastal specialist species are in decline in the Hunter Estuary. The exceptions are Red-capped Plover, Grey-tailed Tattler and the two oystercatchers. Those four species rarely forage in Fullerton Cove, preferring beaches and mangrove-dominated shorelines. To some extent the Red-capped Plover behaves as a generalist in the estuary as it also occurs regularly at Hexham Swamp and Ash Island. Red-capped Plover numbers in the estuary in the November-March have decreased, but their numbers in May-August have increased. These changes reflect improved management of the beaches in the Worimi Conservation Lands on Newcastle Bight, immediately to the north of Stockton (and stretching to Port Stephens). This has been to the advantage of beach-nesting shorebirds, such as Red-capped Plover and

Australian Pied Oystercatcher (Russell & George 2012; Newman & Lindsey 2014; Fraser & Lindsey 2018). It appears that the plovers now prefer to breed on the beaches rather than at Stockton Sandspit, hence are recorded in lower numbers in the estuary, while the increased numbers in the non-breeding season are an indicator of the improved breeding success.

In contrast to the coastal specialists, the populations of most generalist species have been stable or increasing. The main exceptions were Black-tailed Godwit, Red-necked Stint, Common Sandpiper, Common Greenshank (but which had an increasing population in the non-breeding season) and Marsh Sandpiper. Notably, they all are migratory species.

Common Sandpiper was classified in both articles as a generalist, but it behaves as a coastal specialist in the estuary, not ever having been recorded at Hexham Swamp or Tomago Wetland and only occasionally at Ash Island (at a roost site, not foraging). The behaviour of the Black-tailed Godwit is complex. Both Weller and Lee (2017) and Jackson *et al*. (2020) classified it as a generalist or inland specialist, but in the estuary, it forages in Fullerton Cove and roosts at the Kooragang Dykes or Stockton Sandspit from October to February, behaving like the coastal specialists. However, from late March until it departs to the breeding grounds in April, it moves to more brackish wetlands, primarily those on Ash/Kooragang Islands, where it both forages and roosts.

The inland / generalist species with increased populations in the estuary include two migratory species: Pacific Golden Plover and Sharp-tailed Sandpiper, and four non-migratory ones: Pied Stilt, Black-fronted Dotterel, Masked Lapwing and Red-kneed Dotterel. Pacific Golden Plovers seem to prefer to forage on mudflats around Stockton rather than in Fullerton Cove (Crawford & Herbert 2009). In recent years, a sub-population of them (involving up to 80 birds) have been foraging and roosting on Ash Island during the non-breeding season (AS pers. obs.). Sharp-tailed Sandpiper mainly were recorded at Hexham Swamp and Tomago Wetland, at times as many thousands of birds (Stuart 2016; 2019).

Effects of rehabilitation projects and inland conditions

The effects of rehabilitation projects are complex and outcomes will become clearer only in the long term. For some species there was a rapid response to wetlands with reinstated tidal flushing. The arrival of increased numbers of a species may however, also be linked to the condition of inland wetlands. Coastal annual bird abundance is generally higher when inland Australia is relatively hot and dry (Clemens *et al*. 2021).

Resident shorebirds

The rehabilitation projects at Tomago, Hexham Swamp and Ash Island resulted in positive outcomes for some shorebird species in providing an expansion in estuarine habitat. In Victoria and South Australia coastal wetland management was found to help mitigate shorebird declines (Clemens *et al*. 2016). Average numbers for Masked Lapwing, Pied Stilt and Red-kneed Dotterel for November-March almost doubled for 2013-2021 compared to the two previous time periods and there was also an increase over the winter period, May to August, though less substantial.

The effects of long-term inland droughts, such as the Millennium drought in 1996-2010 and the 2017-2019 drought Previous droughts - Climate may also have played a role in forcing shorebird species to the coast. For instance, the highest recorded number of Red-kneed Dotterel was 222 birds in 2014, which was then the warmest year on record in NSW with record-breaking temperatures inland and below average rainfall (New South Wales in 2014). During spring/summer 2013, 2014 and 2015 Red-kneed Dotterel bred successfully (Lindsey 2021) among the Samphire *Sarcornia quinqueflora* raising at least 10 chicks (more than one clutch) in one season at Tomago Wetland. Since February 2020, however, when widespread rain in the interior of the state again prevailed, there was only one record of 52 birds in the estuary in a freshwater wetland in March 2021 on a non-survey day (www.birdata.birdlife.org.au).

The overall population of Red-capped Plover is probably stable, but habitat preferences have changed according to local conditions. In the 2000s, Red-capped Plover became a common breeding species on Stockton Sandspit. As a result of ongoing maintenance work, it successfully bred every year from 2003 to 2010 on sandy, shelly ground with negligible vegetation. Vegetation increased gradually despite efforts to contain it. Breeding decreased and the last successful breeding event was 2015 and the last attempt was in 2017 (Clarke 2017). Since December 2017, Red-capped Plover has been breeding at Fish Fry Flats on Ash Island after extensive rehabilitation works were completed in December 2016. Before this date, there were no recorded sightings (Reid 2019). The maximum count of 54 in December 2019 (Birdata portal) at Fish Fry Flats was outside HBOC surveys. Overall numbers in the estuary decreased in the summer period perhaps because some birds flew to other areas such as Worimi Conservation Lands to breed. Vehicular access to dunes behind the beach front, where Red-capped Plover has been observed breeding has been curtailed and disturbance reduced accordingly (Worimi Conservation Lands Plan of Management 2015).

In 2002, Red-necked Avocet responded almost immediately to the removal of mangroves and other vegetation at Stockton Sandspit by choosing that site in preference to the hitherto-favoured Kooragang Dykes site, a kilometre away across the Hunter River. In response to disturbance at the Sandspit, the birds fly back across the river to the Dykes to roost. Differences between the two roost sites include proximity to tall vegetation, surface structure and microclimate. We speculate that Stockton Sandspit is preferred as it offers clear line of sight and cool, wet substrates. Cool, wet substrates have been found to be associated with diurnal roost choice (Rogers *et al.* 2006). During the diurnal low tide period, avocets fly from these roost sites to Fullerton Cove where they forage. Distance between these roost sites and foraging sites in Fullerton Cove does not seem to be a factor in the preferred choice of Stockton Sandspit as it is approximately one kilometre further from foraging sites than Kooragang Dykes. It has been found that foraging to roost distances often vary more than a kilometre in some migratory shorebird species (Jackson *et al*. 2017).

Migratory shorebirds

Although 14 migratory species initially visited rehabilitated sites after tidal flow was reintroduced, Sharp-tailed Sandpiper and Common Greenshank were the only species to return regularly in significant numbers to Tomago (Lindsey 2021). A similar pattern was noted at Hexham Swamp, the numbers of Sharp-tailed Sandpiper increased dramatically after reinstatement of tidal flows at Hexham Swamp and Tomago Wetland, with more than 5% of the population often present (Stuart 2016). Conversely, constant interruptions to tidal flow at Tomago combined with a long drought period led to their disappearance after 2018 (Lindsey 2021; Stuart 2016). Clemens *et al*. (2021) discuss the effects of changing wetland dynamics on migratory shorebirds. Temporary departures of Sharp-tailed Sandpiper were associated with heavy rainfall inland (Stuart 2016). This was reflected in the 2020/2021 non-breeding period when the maximum number observed was only 189 birds. Presumably this species was taking advantage of the temporary expansions of suitable habitat inland (Clemens *et al*. 2021). Salt marsh sites in the estuary are becoming well established which may also play a role in the decrease in numbers of Sharp-tailed Sandpiper, as this species seems to show a preference for salt marsh in transition rather than when it has been established for some time (Stuart 2016).

Tomago Wetland may be important as a winter site for Common Greenshank as some have been present there every winter since 2013 with a peak number of 38 in 2016 (Lindsey 2021). There is a small increase in the linear trend for the winter period May to August.

The significant increase in Pacific Golden Plover may be explained not only by the increase in salt marsh habitat but also by this species' use of a greater number of sites in the estuary compared with other species e.g. Kooragang Dykes, Stockton Sandspit, Stockton Channel and Ash Island. Roost sites may have been missed, as not all the available areas are monitored, e.g. at Tomago Wetland and Hexham Swamp. Also, Pacific Golden Plover are known to roost behind the dunes on Worimi Conservation Lands (Crawford & Herbert 2009).

Is the contamination of Fullerton Cove affecting its ability to provide prime feeding habitat?

The main reason for the Hunter Estuary to have hosted shorebirds in such high numbers for so many decades has been the rich feeding habitat available in Fullerton Cove. Nine migratory species have been recorded foraging in Fullerton Cove, the most numerous being larger-sized species, Bar-tailed Godwit, Black-tailed Godwit, Eastern Curlew and Whimbrel (Spencer 2009). The other five species occurred in small numbers. Red-necked Avocets also forage at Fullerton Cove (Spencer 2009) but, unlike the larger-sized migratory shorebirds, they do not probe into the mud to feed.

For several decades Fullerton Cove became increasingly contaminated by chemicals used in fire-fighting programs at the nearby Williamtown airport (Australian Department of Defence 2018). The fire-fighting group of chemicals includes a large variety of similarly behaving products, such as per- and poly-fluoroalkyl substances and per- and poly-fluorooctyl sulphonates. These two chemicals have been shown to be present in Fullerton Cove sediments (Australian Department of Defence 2018) and to accumulate in the food chain (Taylor *et al*. 2018).

The measured PFAS/PFOS levels in Fullerton Cove were found to be below the levels causing acute toxicity to benthic organisms (Simpson *et al*. 2021). However, in light of the magnitudes of the population declines for all the shorebirds that preferentially forage in Fullerton Cove, the possibility of chronic toxicity effects needs to be considered. There have been no studies about the potential chronic toxicity effects of PFAS/PFOS to benthic organisms and how the long-term PFAS/PFOS background concentrations might have affected benthic life and thus, the creatures that feed upon that benthic life. It seems telling that the most numerous migratory species that forage in Fullerton Cove are in decline, whereas the species that do not, mostly have been prospering. There is an urgent need for a comprehensive study of PFAS/PFOS distribution in Fullerton Cove and

how the contamination of Fullerton Cove by toxic chemicals is affecting benthic life and thus impacting on shorebird populations.

It could be argued that the population declines for the species that prefer to forage in Fullerton Cove are related to rising sea levels. A consequence of rising sea levels would be that less of the mudflats in Fullerton Cove were exposed and for shorter periods of time. However, rising sea levels are a global phenomenon and do not readily account for the more substantial declines that are occurring in Fullerton Cove.

CONCLUSIONS

For at least 50 years, the Hunter Estuary has been an important site for resident shorebirds and a significant international staging and destination site for migratory shorebirds. It has become an internationally significant site for Sharp-tailed Sandpiper, with many recent records of several thousand birds, representing 4-6% of the total population at times. However, with the exception of Pacific Golden Plover and Grey-tailed Tattler, the number of migratory shorebirds has decreased substantially in the past two decades, continuing the trends first established in the 1980s. In the non-breeding season fewer than 2,000 migratory shorebirds are now usually present, except when there are visiting Sharp-tailed Sandpipers. The estuary is no longer internationally significant for Latham's Snipe, Black-tailed Godwit, Bar-tailed Godwit or Curlew Sandpiper, although it continues to be nationally significant for those species. Also, it has been at least 14 years since the estuary has hosted more than 1% of the total populations of Far Eastern Curlew or Red Knot.

The estuary is important for Red-necked Avocet, with thousands of birds usually present, except when conditions inland are favourable for breeding. The peak count was almost 6.5% of the total population. There were also several records of more than 1,000 Pied Stilt.

For much of the 20th century, there were considerable losses of shorebird foraging and roosting habitat in the estuary because of industrial and agricultural development initiatives or for mosquito control. However, since the 1990s several positive developments have partially restored lost shorebird habitat. Those developments have favoured generalist shorebirds in particular, most species of which have experienced population growth in the past two decades.

The majority of migratory shorebird species with declining numbers in the Hunter Estuary rely on Yellow Sea tidal mudflats and adjacent saltpans during migration. Thus, local declines reflect overall Flyway trends of decreasing populations. However, for many species local declines exceed the overall Flyway declines. Those declining species mainly forage in Fullerton Cove, which has become contaminated by the fire-fighting chemicals used for decades at the nearby Williamtown Airport. There is an urgent need for a comprehensive study of chemical contamination in Fullerton Cove to assess whether benthic life has been affected thus impacting shorebird populations.

The local populations of Pacific Golden Plover and Sharp-tailed Sandpiper have increased significantly, and the Grey-tailed Tattler population also has risen. These three species have a lower dependency on the Yellow Sea during migration and, locally, a lower dependency on Fullerton Cove for foraging. Both of those points may be important factors for explaining the observed population rises.

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