Estuarine habitat change and its impact on shorebirds at Swan Bay, Port Stephens, NSW

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A small coastal wetland is located at Cockle Shell Point in the Gir-um-bit National Park, Swan Bay, in Port Stephens, NSW. It is a significant roost site, at times accommodating 25-50% of the shorebirds that use Port Stephens. An attempt to drain the site around 1985 caused tidal access to become regular. As a result, an open ephemeral lagoon became increasingly tidal, and surrounded by mangroves. Mangroves also replaced areas of saltmarsh and the area of open mud has been reduced. Rising sea level, possibly associated with climate change, has eroded the shoreline and eliminated a previous beach-front shorebird roost site.

Records sourced for the period from 1980 to 2023 revealed 20 species of migratory shorebirds and nine species of non-migratory shorebirds had used the area. However, many of the smaller species are no longer recorded, and the numbers of the larger birds have declined. In 2023 there were only eight migratory shorebird species and two non-migratory shorebird species using the site. The roosting behaviour of some species has also changed. The declining trend for five local shorebirds, Far Eastern Curlew *Numenius madagascariensis*, Whimbrel *N. phaeopus*, Bar-tailed Godwit *Limosa lapponica*, Grey-tailed Tattler *Tringa brevipes* and Red-capped Plover *Charadrius ruficapillus*, exceeds the national trend.

The study highlighted the importance of providing of artificial roosts and the need to maintain existing maritime infrastructure used by shorebirds for roosting, such as abandoned oyster leases, groynes, rock walls and wrecks. Careful planning and management of proposed changes to tidal regimes is essential to preserve coastal wetlands.

INTRODUCTION

Coastal and estuarine wetlands are vital to our marine life, avifauna and even our lifestyles and livelihoods. However, increasing coastal development and infrastructure has put many of these ecosystems in jeopardy.

The small Gir-um-bit National Park (NP) in Port Stephens hosts one of these wetlands (**Figure 1**). The National Park was established in 2007 and consists of a number of parcels of land located around the western shores of Port Stephens. It surrounds the settlement of Swan Bay and encompasses dry sclerophyll forests, wetlands and saltmarsh that provide key habitat for a variety of migratory and non-migratory shorebirds (Office of Environment and Heritage 2014). Many of these shorebirds are protected under the NSW *Biodiversity Conservation Act 2016* (BC Act) and/or the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The site hosting the wetland is south of the village of Swan Bay and was named Cockle Shell Point by Bartrim (1980).

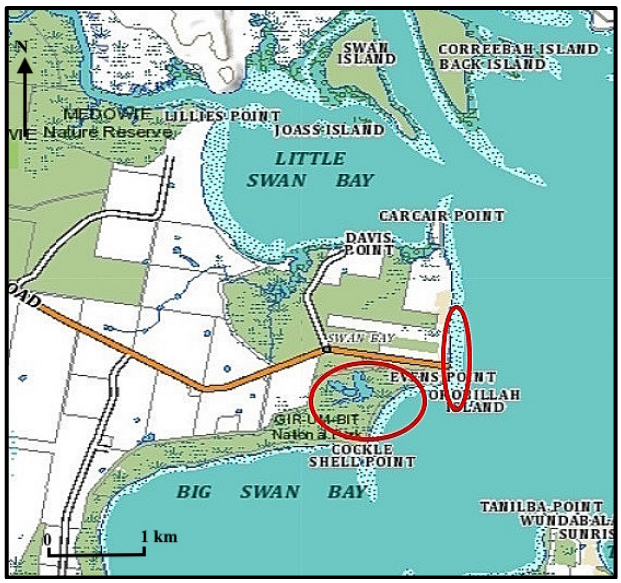

Figure 1. Location map, showing section of Gir-um-bit National Park, Swan Bay and two survey areas. (Image https://maps.six.nsw.gov.au/)

The Port Stephens estuary is recognised as the second most important site in NSW for shorebirds after the Hunter Estuary. Smith (1991) described it

as the most important site in NSW for Whimbrel *Numenius phaeopus* and one of the two most important sites for Far Eastern Curlew *Numenius madagascariensis*. He noted that both these species and the Pacific Golden Plover *Pluvialis fulva* had been recorded in Port Stephens in numbers exceeding 1% of the national population estimate. Stuart (2005) further confirmed its importance, documenting shorebird numbers that showed the estuary as internationally significant for Far Eastern Curlew and Australian Pied Oystercatcher *Haematopus longirostris,* and nationally significant for Bar-tailed Godwit *Limosa lapponica*, Whimbrel and Grey-tailed Tattler *Tringa brevipes*.

Swan Bay, including Cockle Shell Point, has been surveyed for birds since the early 1980s. Numerous reports have documented shorebird numbers and described roosting sites in Port Stephens (Bartrim 1980; Stuart 2004; Stuart 2005; Stuart 2010; Stuart 2011; Wooding & Stuart 2013; Wooding 2016; and Stuart 2020). Stuart (2004) estimated 25-50% of the total Port Stephens shorebird population roost there. However, over the past 40 years significant changes have occurred to the wetland. Considerable decline in shorebird numbers has accompanied these changes and many species are no longer recorded. This study documents changes to the Cockle Shell Point site and their impact on the most common shorebirds that use the site.

Current description of the site

The Cockle Shell Point site extends for around 2 km southwest from Swan Bay Road and Evens Point along the western shore of Big Swan Bay (**Figure 1**). The site is bordered to the north and west by casuarina woodland and heathland scrub. To the northeast around Evens Point, there is a small area of coastal woodland with a thick fringe of shoreline mangroves. To the southwest, the shoreline comprises a narrow shingle beach which is partially fringed by low mangroves. Two lagoons are located in the centre of the site, the largest of which is 300 m long and 80 m wide (**Figure 2**). Both are tidal and surrounded by mangroves (**Figure 3**). The substrate of the lagoons is soft black mud. Mangrove forest extends south and southwest from the lagoons to the shoreline. Tidal flows access the lagoons through this area and nearby drains.

Figure 2. Satellite image (2024) showing two lagoons surrounded by mangroves, surrounded by saltmarsh and mudflats, and narrow mangrove-lined beach at adjacent shoreline. Network of excavated drains evident. (Image Google Earth 2024)

The area surrounding the lagoons is mainly saltmarsh with occasional small patches of mud. Between the saltmarsh and the casuarina woodland, there are wide areas of mud with dead casuarinas. Areas of shallow open water are present between saltmarsh and mud. A series of tidal drains up to one metre deep are present to the east of the lagoons (**Figure 2**).

Figure 3. Lagoon at high tide surrounded by mangroves, view to west. Image N. Fraser, March 2024.

At high tide some areas of saltmarsh and mud become inundated. During periods of spring tides (>1.8m), the entire site is covered by 10-30 cm of water (**Figure 4, Figure 5**). At low tide, mudflats and sea grass are widely exposed along the Big Swan Bay shoreline, and from Evens Point out to Orobillah Island. Shorebirds and waterbirds forage on these mudflats. Remnant poles from abandoned oyster leases are located 200-300 m from the shoreline. At high tide, some shorebirds and waterbirds roost amongst saltmarsh while others roost offshore on oyster poles.

Figure 4. View to south towards mangrove covered Cockle Shell Point. Mangroves to east (left) define location of earlier shoreline. Current shoreline with saltmarsh and casuarina 20 m to west (right), at high tide. Image N. Fraser, March 2024.

Figure 5. High-tide survey at the Cockle Shell Point site. The surveyor is walking across submerged saltmarsh towards submerged shoreline. Black Swan ahead, view to southeast. Image S. Fleming, January 2024.

METHODS

Site changes

To assess the extent of habitat change, early aerial photographs were obtained from SIX Maps NSW (https://maps.six.nsw.gov.au) and compared with recent satellite imagery from Google Earth (https://www.google.com/). Habitat mapping was obtained from NSW Estuarine Habitat Maps (https://nsw-dpi.shinyapps.io/NSW_Estuarine_Habitat/) and compared with earlier aerial photography. Early published vegetation maps and accounts of the Swan Bay area (Bartrim 1980) were also reviewed.

Shorebird records

Records were extracted from five sources: BirdLife Australia Birdata portal (https://birdata.birdlife.org.au/home), Cornell Lab of Ornithology eBird Australia portal (https://ebird.org/australia/home), BioNet portal of the NSW Department of Planning and Environment (https://www.environment.nsw.gov.au/topics/animals-and-plants/biodiversity/nsw-bionet), old HBOC records (A. Stuart pers. comm.) and a resource study (Bartrim 1980).

Most Birdata records were from monthly high-tide surveys conducted from 2000-2023 by HBOC members and recorded as shorebird surveys or 500-m area searches. Data used were from land-based surveys only. Surveys of the northern part of the area covered the shoreline north from Evens Point to a rocky breakwater hosting the foundations of a former oyster farm and included roosts on nearby oyster leases. Surveys of the southern area within the Gir-um-bit National Park extended from Evens Point south to Cockle Shell Point and included nearby oyster leases and roosts on Orobillah Island (**Figure 1**). Birdata records included twice yearly surveys conducted by the Australasian Wader Study Group from 1982 to 1985. Bartrim (1980) conducted weekly surveys in 1978 and 1979. Records from eBird and BioNet were generally incidental.

Maximum annual counts for all shorebird species were charted using MS Excel.

RESULTS

Changes to the Cockle Shell Point site

An aerial photograph from 1976 showed the Cockle Shell Point site with a large open lagoon and a smaller lagoon to the west (**Figure 6**). Both lagoons appeared to be dry in the photograph, and to be fringed by saltmarsh. Surrounding areas to the east and west were mainly saltmarsh and mudflats.
Open woodland and heathland scrub surrounded the site to the north and west. A relatively wide, open beach along the adjacent shoreline extended northeast to southwest.

Bartrim (1980) produced a detailed vegetation map of the site as part of a resource study for the then-proposed Pipeclay Creek Nature Reserve. The map showed a single large lagoon surrounded by saltmarsh, which consisted of a mixture of Samphire *Salicornia quinqueflora* and Saltwater Couch *Sporobolus virginicus* interspersed with areas of mud. A large area of mud was present to the north of the lagoon. Grey Mangrove *Avicennia marina* shrubland existed southwest of the lagoon and extended to the shoreline. Small mangroves were scattered amongst the saltmarsh and along a small

western section of the lagoon. A northern fringing woodland was mapped as Swamp Oak *Casuarina glauca* and closed heathland scrub *Melaleuca nodosa* and included areas of dead casuarinas. A photograph taken at high tide showed the lagoon as an open water body surrounded by saltmarsh with nearby areas of mud (**Figure 7**). Bartrim (1980) stated that the entire wetland site became inundated by tides above 1.8 m.

Figure 6. Aerial photograph (1976) showing two open lagoons at wetland site surrounded by mudflats and a wide, open beach at adjacent shoreline. (Image https://portal.spatial.nsw.gov.au/portal/apps/webappviewer/).

Figure 7. A section of the lagoon at Cockle Shell Point at maximum capacity in 1980. View to west. Note saltmarsh around edges of lagoon, areas of bare mud nearby and no surrounding mangroves. Image G. Bartrim.

Bartrim (1980) described the lagoon as the most significant wetland in the then-proposed reserve owing to its use by shorebirds. The lagoon contained water most of the time, to a maximum depth of approximately 0.5 m, but dried up during prolonged dry spells. The water source was a mixture of high-tide inundation and freshwater runoff.

Adjacent tidal flats were described as the most significant area for shorebird foraging in the resource study (Bartrim 1980). At low tide, tidal flats were exposed for 100-200 m and hosted a 30 m wide mat of sea grass. Of the 13 shorebird species recorded by Bartrim (**Table 1**), 11 foraged on these flats, while Pied Stilt *Himantopus leucocephalus* foraged on the lagoon and Masked Lapwing *Vanellus miles* foraged on the saltmarsh and mud. Large shorebirds such as Far Eastern Curlew and Whimbrel foraged across all local tidal flats at low tide. Most smaller shorebirds such as Pacific Golden Plover, Red-capped Plover *Charadrius ruficapillus*, Double-banded Plover *Charadrius bicinctus*, Lesser Sand Plover *Charadrius mongolus* and Red-necked Stint *Calidris ruficollis* were restricted to the tidal flats around Cockle Shell Point. Bartrim attributed this to the substrate having a higher proportion of sand, making it relatively firm and supporting invertebrate fauna that were suitable prey for short-billed shorebirds. At high tide, most shorebirds roosted around the lagoon.

Aerial photography revealed a network of drains up to a metre deep that were excavated east of the lagoons between 1985 and 1986 (**Figure 2)**. Anecdotal reports state that this was done for agricultural purposes.

Estuarine habitat mapping by the NSW Department of Primary Industries documented vegetation changes since 1980. By 2004, the area of saltmarsh had expanded northwards, an area of mixed saltmarsh and mangrove extended southwest of the lagoons to the shoreline, and a narrow fringe of mangroves had developed along the western margin of the main lagoon. A small number of isolated mangroves were growing along the adjacent shoreline (**Figure 8A**). By 2017, the area of mangroves had increased to surround both lagoons, a large mangrove forest was present southwest of the lagoons, and a fringe of mangroves was present along most of the shoreline (**Figure 8B**).

A 2024 satellite image showed that mangrove forest had completely overgrown the area southwest of the lagoons (**Figure 6**). Saltmarsh west and east of the lagoon and along one of the drains was being overgrown with mangroves. The beach had narrowed to a thin strip behind a fringe of mangroves.

In summary, the observed macro-level changes to the site since 1976 owing to increasing salt-water inundation were as follows: the tidal prism across the site increased; casuarinas at the north of the site died; the two lagoons changed from ephemeral to tidal; the shoreline of the lagoons changed from open saltmarsh to mangroves; the substrate of the lagoons changed from silt to black mud; mangroves southwest of the lagoons became a forest and expanded into areas of adjacent saltmarsh;

Table 1. Shorebird species, numbers recorded and status, Cockle Shell Point (CSP) and other sites. Data extracted from Bartrim (1980).

Common name	Scientific Name	Records	Status	Location
Pied Stilt	*Himantopus leucocephalus*	2	Rare	CSP site only
Pacific Golden Plover	*Pluvialis fulva*	1 - 10	Common	CSP site only
Red-capped Plover	*Charadrius ruficapillus*	1 - 80	Common	CSP site only
Double-banded Plover	*Charadrius bicinctus*	1 - 150	Common	CSP site only
Lesser Sand Plover	*Charadrius mongolus*	1 - 150	Common	CSP site only
Greater Sand Plover	*Charadrius leschenaultii*	10 - 30	Rare	CSP site only
Masked Lapwing	*Vanellus miles*	1 - 4	Common	CSP + 11 other sites
Bar-tailed Godwit	*Limosa lapponica*	1 - 15	Common	CSP + 1 other
Whimbrel	*Numenius phaeopus*	1 - 60	Common	CSP + 10 other sites
Far Eastern Curlew	*Numenius madagascariensis*	2 - 400	Common	CSP + 10 other sites
Ruddy Turnstone	*Arenaria interpres*	1	Rare	CSP site only
Red-necked Stint	*Calidris ruficollis*	10 - 50	Common	CSP site only
Sharp-tailed Sandpiper	*Calidris acuminata*	2 - 15	Common	CSP + 3 other sites

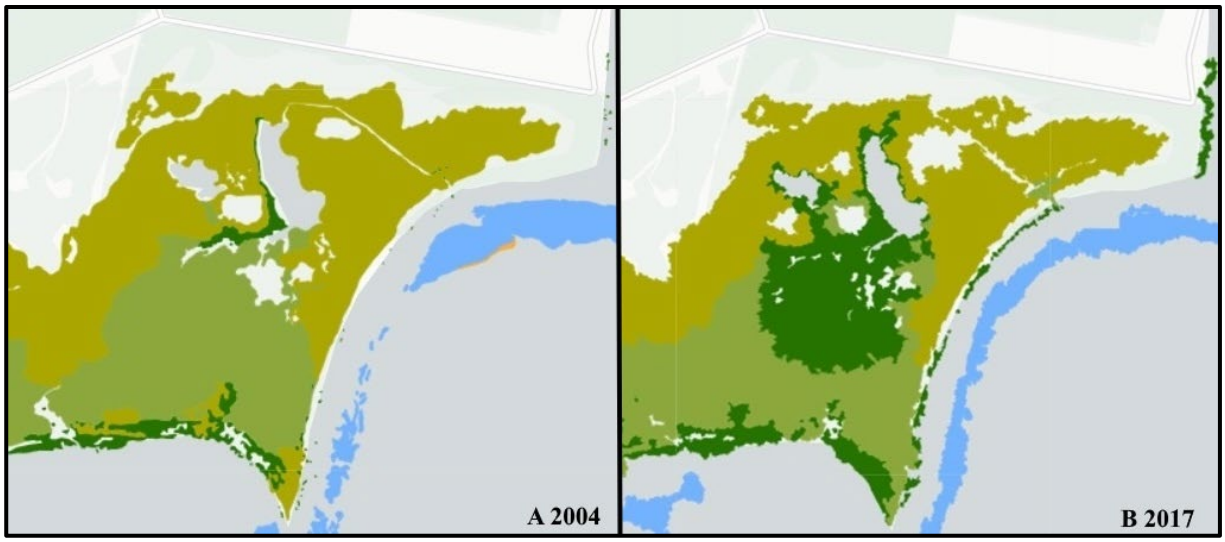

Figure 8A. Estuarine habitat mapping Cockle Shell Point 2004, NSW Dept. Primary Industries. (Colours: olive = saltmarsh; yellow-green = mangrove/saltmarsh; dark green = mangrove, blue = Zostera.)
Figure 8B. Estuarine habitat mapping Cockle Shell Point 2017, NSW Dept. Primary Industries.

saltmarsh expanded into areas of bare mud; the adjacent beach changed from relatively wide and open to narrow and fringed with mangroves.

Shorebird records

The number of surveys, their sources and survey time periods are summarised in **Table 2**. The earliest report (Bartrim 1980) identified 13 shorebird species using the site; 11 migratory and two non-migratory ones. Mostly, these species were restricted to the Cockle Shell Point site where they foraged on tidal flats and roosted around the lagoon. The species recorded by Bartrim, numbers observed, and locations are listed in **Table 1**.

Table 2. Data sources and records or surveys at Swan Bay, 1971-2023

Data source	Records or surveys	Years
Birdata records (incl. AWSG surveys)	332	1981-2023
eBird records	14	2021-2023
BioNet records	26	1982-2002
Old HBOC records	10	1971-1988
Bartrim resource study (1980)	55 approx.	1978-1979

Overall, 29 shorebird species have been recorded at the site since 1980, 20 of which are migratory and nine non-migratory. The total numbers of records, maximum counts, date last recorded, and conservation status are shown in **Table 3**. Thirteen of the species are listed as threatened under either

the BC Act or the EPBC Act. Eleven species have been recorded in only small numbers (ten birds or fewer) and nine of the smaller shorebird species have not been recorded for more than ten years.

Table 3. Numbers of records, maximum counts, last record, and conservation status for shorebird species, Swan Bay 1980-2023.

Common name	Scientific name	Records	Max. count	Last record	Threatened species
Australian Pied Oystercatcher	*Haematopus longirostris*	269	76	Dec-23	✓
Sooty Oystercatcher	*Haematopus fuliginosus*	152	38	Oct-23	✓
Pied Stilt	*Himantopus leucocephalus*	7	12	Jan-15	
Red-necked Avocet	*Recurvirostra novaehollandiae*	8	41	Jan-12	
Banded Stilt	*Cladorhynchus leucocephalus*	5	1	Jan-01	
Pacific Golden Plover	*Pluvialis fulva*	106	55	Dec-23	
Grey Plover	*Pluvialis squatarola*	1	1	Nov-13	✓
Red-capped Plover	*Charadrius ruficapillus*	159	70+	May-23	
Double-banded Plover	*Charadrius bicinctus*	93	55	Jul-23	
Lesser Sand Plover	*Charadrius mongolus*	32	150	Apr-17	✓
Greater Sand Plover	*Charadrius leschenaultii*	1	1	Sep-21	✓
Black-fronted Dotterel	*Elseyornis melanops*	1	1	Jun-01	
Red-kneed Dotterel	*Erythrogonys cinctus*	2	15	Jul-85	
Masked Lapwing	*Vanellus miles*	280	31	Dec-23	
Black-tailed Godwit	*Limosa limosa*	7	2	Sep-21	✓
Bar-tailed Godwit	*Limosa lapponica*	305	550+	Dec-23	
Whimbrel	*Numenius phaeopus*	204	260	Dec-23	
Far Eastern Curlew	*Numenius madagascariensis*	274	700+	Dec-23	✓
Terek Sandpiper	*Xenus cinereus*	2	1	Nov-81	✓
Common Sandpiper	*Actitis hypoleucos*	1	1	Nov-81	
Grey-tailed Tattler	*Tringa brevipes*	160	56	Nov-23	
Common Greenshank	*Tringa nebularia*	15	10	Jul-17	✓
Marsh Sandpiper	*Tringa stagnatalis*	2	2	Nov-09	
Ruddy Turnstone	*Arenaria interpres*	7	20	May-15	✓
Red Knot	*Calidris canutus*	18	12	Nov-18	✓
Red-necked Stint	*Calidris ruficollis*	81	150+	Nov-22	
Pectoral Sandpiper	*Calidris melanotos*	1	4	Dec-01	
Sharp-tailed Sandpiper	*Calidris acuminata*	34	261	Sep-21	✓
Curlew Sandpiper	*Calidris ferruginea*	10	7	Sep-14	✓

Shorebird numbers during 2000-2023

Systematic monthly surveys have been carried out since September 2000, allowing shorebird population trends to be analysed. The maximum annual number of shorebird species over this period was 17, in 2008. In 2023, only ten shorebird species were recorded, five migratory and five non-migratory. The decline in shorebird species numbers from 2000 to 2023 is illustrated in **Figure 9**. Charts showing maximum annual counts for nine migratory and one non-migratory species are presented in **Figure 10**. Most of those species were recorded until recently, however, Lesser Sand Plover has not been seen since 2016.

Six migratory species have been recorded over-wintering; Pacific Golden Plover, Bar-tailed Godwit, Whimbrel, Far Eastern Curlew, Grey-tailed Tattler and Sharp-tailed Sandpiper.

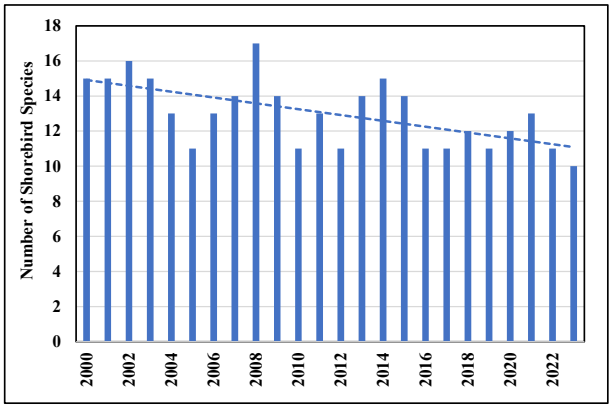

Figure 9. Number of shorebird species recorded annually at Swan Bay over 2000-2023, with linear trend line.

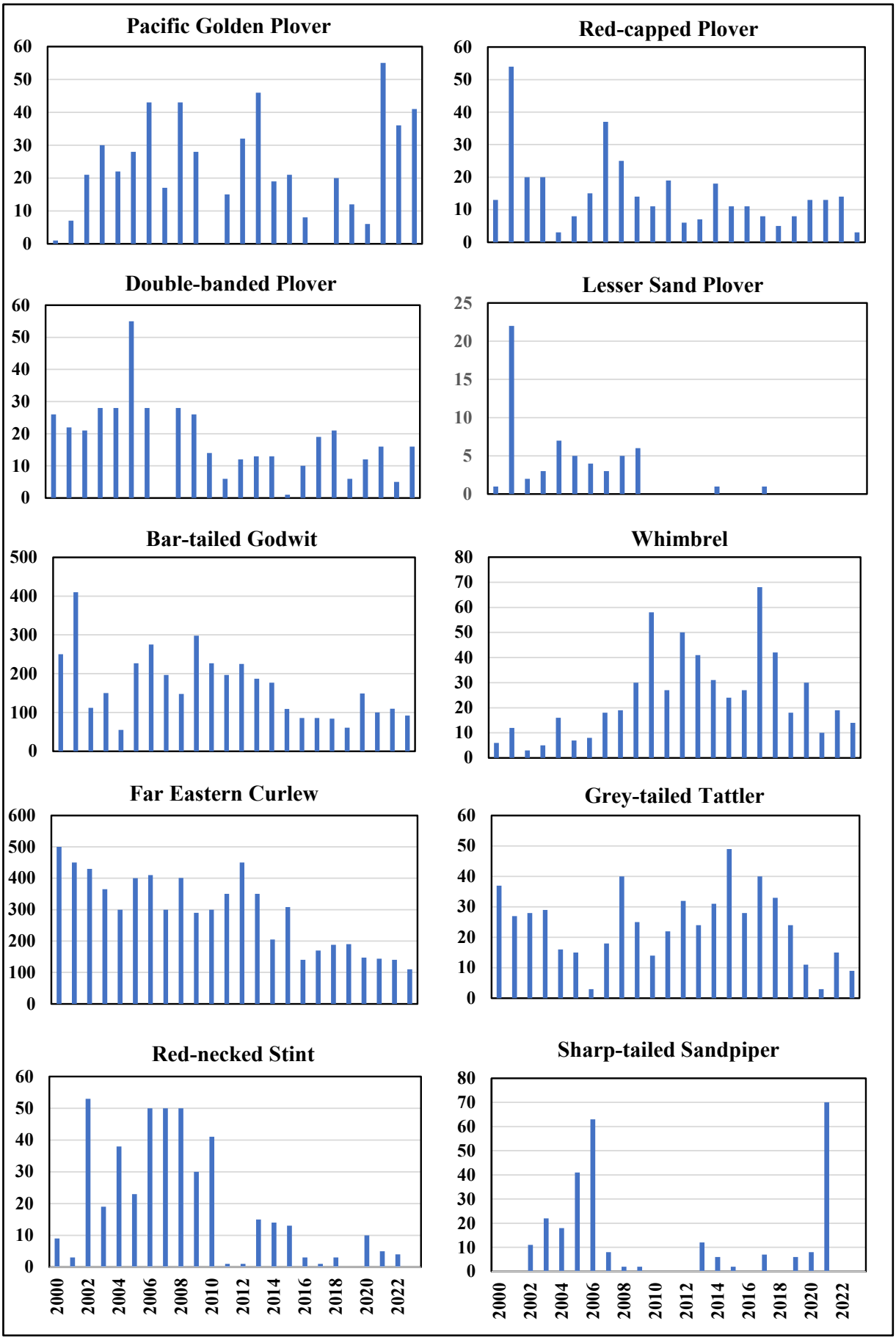

Figure 10. Maximum annual counts for selected species at Swan Bay over 2000-2023.

DISCUSSION

There are many reasons for the decline of migratory shorebird numbers across Australia. The main one however is the loss of habitat along the East Asian-Australasian Flyway (Hansen *et al*. 2016; Clemens *et al*. 2016). Non-migratory shorebirds which use inland habitats are declining while those using coastal habitat are stable (Clemens *et al*. 2016). The decline in numbers exhibited by species using the Cockle Shell Point site is a relatively small subset of a much larger picture. Nevertheless, numerous small local changes are cumulative and ultimately can result in larger national and global changes.

Stuart (2004) identified Port Stephens as the second-most important estuary for shorebirds in NSW, and Bartrim (1980) described the Gir-um-bit lagoon as the most significant wetland in the then-proposed nature reserve owing to its use by shorebirds. Of the 20 migratory shorebird species that have been recorded over 54 years at Swan Bay, only six were regularly observed in 2023: Pacific Golden Plover, Double-banded Plover, Bar-tailed Godwit, Whimbrel, Far Eastern Curlew and Grey-tailed Tattler.

Clemens *et al*. (2016) analysed continental-scale changes to the shorebird population in Australia including Port Stephens. They identified a significant continental-wide decline for Pacific Golden Plover and Sharp-tailed Sandpiper. No significant continental trends were identified for Whimbrel, Grey-tailed Tattler or Red-capped Plover. However, for Port Stephens, the authors identified a local trend for these five species as one or two standard deviations below the mean continental trend. This was also confirmed by Stuart (2020) who identified declining population trends for Far Eastern Curlew, Bar-tailed Godwit and Whimbrel in Port Stephens from boat-based shorebird surveys. An earlier study of Grey-tailed Tattler population in Port Stephens (Wooding and Stuart 2013) noted a decline since 1980 but suggested the population subsequently had stabilised. However, the current data indicate that the population has been in decline since 2015.

Although the records from Gir-um-bit NP are not necessarily representative of all of Port Stephens, the declining population trends identified in this study support the findings of Clemens *et al*. (2016) and Stuart (2020). The one possible exception is the Pacific Golden Plover whose local population trend fluctuates wildly (**Figure 10**).

Roost sites preferred by shorebirds are generally close to foraging habitats, in order to reduce energy expenditure, and provide an open, undisturbed area where birds can remain vigilant for predators (Rogers *et al*. 2006). While the decreasing use of the Cockle Shell Point saltmarsh roosting sites undoubtedly resulted in the local decline of shorebird numbers, it is impossible to distinguish definitively between decline in response to local factors and global factors. Additionally, some of the small shorebirds may have relocated permanently to more suitable sites within Port Stephens or elsewhere. Another factor impacting declining populations at the site may be mammalian predation. However, there have been no observations of these predators on the site, no dismembered bird carcasses and no predator tracks have been seen.

Broad generalisations can, however, be made relating habitat change to the declining numbers and the behaviour of some species. Because the site is relatively secluded, human disturbance is unlikely to be an important factor. Loss of suitable roosting sites at the lagoon and the beach has made the site unsuitable for small shorebirds including Lesser Sand Plover, Red-necked Stint and Sharp-tailed Sandpiper, and possibly Red Knot. Declining numbers of Red-capped Plover could be partially attributed to the loss of the beach and other areas of bare mud. While Pacific Golden Plover numbers fluctuate in Port Stephens, the local trend suggest numbers may be stable. Changes in roosting behaviour of Bar-tailed Godwit, which no longer roost amongst the samphire, may be attributed to mangrove growth removing the clear line-of-sight. Grey-tailed Tattler and Whimbrel do not use the lagoon and surrounding saltmarsh and therefore their decline cannot be attributed to site changes. The availability of suitable prey around the site for shorebird species has not been assessed as part of this study.

Human intervention

Construction of a series of drains east of the lagoons in 1985 or 1986 accelerated habitat change by allowing a larger tidal prism to access the site**.** The drains, combined with sea-level rise, have allowed more regular tidal flows to enter the large lagoon, altered the salinity and allowed mangroves to establish a fringe around the lagoon, removing the clear line-of-sight required by shorebirds. The substrate of the lagoon also changed to soft black mud. These conditions made the lagoon unsuitable for foraging or roosting by shorebirds. Mangroves also started to grow along the beach front, further

removing line-of-sight from the previous beach roost site. The essential nature of a clear line-of-sight in contributing to shorebirds' use of a roost site is well known (Jackson & Straw 2021) and has recently been demonstrated locally by Clarke (in prep.) as an essential component of the rehabilitation of Stockton Sandspit roost site in the Hunter Estuary. The detrimental impact of an increased tidal prism on important shorebird habitat through mangrove encroachment in the Hunter Estuary has been discussed by Herbert (2007).

The drains have continually widened over time, causing increased erosion. The increased tidal prism now inundates a wider area which has resulted in an expansion of saltmarsh and a reduction in the areas of bare mud. Small mangroves have started to encroach on the saltmarsh and along the drains. While Far Eastern Curlew, Pacific Golden Plover, and Double-banded Plover continue to roost amongst the saltmarsh, it is apparent that the area is becoming increasingly unsuitable for Red-capped Plovers due to the loss of clear, open areas of bare mud for foraging. This may also have contributed to the recent disappearance of Red-necked Stints.

Climate change

Sea-level rise and changes in wind patterns are two factors resulting from climate change that may be impacting shorebird habitat in the tide-dominated estuary of Port Stephens.

Sea-level rise for Port Stephens has been estimated to be 2.1 mm per year over the last half century (Coast Adapt 2017). This has resulted in an increased tidal prism with higher velocity flows entering the bay as larger tidal volumes are accommodated. Rising sea levels result in the inundation of low-lying areas, increased shoreline erosion, changes to seagrass distribution, altered estuarine tidal range and circulation patterns, and altered sediment transport regimes (Office of Environment and Heritage 2018). The increased inundation across the Cockle Shell Point site has resulted in the lagoon and some adjacent areas becoming tidal, the encroachment of mangroves into areas that were previously saltmarsh, and expansion of saltmarsh into areas that were previously bare mud. Thus, the lagoon has changed from an open ephemeral body inundated by only the highest tides, to a mangrove-fringed tidal body. This combined with the loss of a clear line-of-sight make it unsuitable for all shorebirds.

The Southern Annular Mode (SAM) is a global belt of low pressure in the southern hemisphere strongly associated with cold westerly winds. It has exhibited increasing periods in a positive phase across Australia since the early 1980s. Increased positive change in SAM has resulted in westerly winds associated with cold fronts tracking further southwards and allowing more frequent winds from the east (Hendon *et al*. 2007). In Swan Bay, increasing periods of easterly onshore airflow produce extended periods of onshore wind waves. These produce changes to hydrodynamic flows and littoral sediment transport along the shoreline resulting in increased erosion. This erosion is evidenced by the displacement of the fringing mangroves from the current shoreline. The mangroves, which originally propagated on the shoreline around 2004 (**Figure 8B**) are now around 20 m east of the current shoreline.

Wind pattern changes combined with higher sea levels have produced increased shoreline erosion. The shoreline has changed from a relatively wide, open beach to a narrow strip of westward retreating shingle. The high tide beachfront roost site formerly used by many small to medium sized shorebirds including Red-necked Stint, Curlew Sandpiper, Sharp-tailed Sandpiper, Red Knot and Bar-tailed Godwit, has been lost.

CONCLUSION

While availability of suitable foraging habitat is important for shorebirds, no less important is the availability of safe high-tide roost sites in proximity to the habitat. Due to the loss of clear line-of-sight, the previously ephemeral lagoon at Cockle Shell Point and the adjacent beach front are no longer suitable roost sites. The lagoon was once the most important roost site in the Swan Bay area. The main driver of on-site changes is an increased tidal prism which has facilitated encroachment by mangroves. Climate change is also having a detrimental impact on suitability of the site for shorebird roosting.

While the site no longer provides a suitable roost site for most smaller shorebirds, a reduced number of medium sized and larger shorebirds such as Far Eastern Curlew and Pacific Golden Plover continue to use the site. One small shorebird, the Double-banded Plover is present on site in the winter months. Bar-tailed Godwit, which previously roosted amongst the saltmarsh, now roost offshore on oyster leases. Eventually, the continuing encroachment of mangroves onto areas of saltmarsh will make the site unsuitable for all shorebirds. Remedial action to block the drain would prevent diurnal tidal access to the area east of the lagoons

and may prevent or delay mangrove encroachment of this area, as well as prevent onsite erosion.

How the additional impact of human intervention contributed to the change of the lagoon's character cannot be accurately measured, but the outcome provides some important lessons. Before manipulating existing tidal regimes, such as by installing drainage channels, a full understanding of anticipated tidal change is required in order to inform monitoring strategies and remedial works, and to ensure the maintenance and protection of preferred roost and foraging sites. A clear line-of-sight, particularly in coastal wetlands prone to mangrove encroachment, should be maintained. Future impacts of sea-level rise on coastal areas have been extensively researched and documented and should provide a sound basis for planning the protection of important shorebird roosts or dictate the provision of alternatives (Jackson *et al*. 2021).

While habitat change associated with climate change is inevitable, the provision of artificial roosts and the maintenance of existing maritime infrastructure such as abandoned oyster leases, groynes, rock walls and wrecks will assist shorebirds in the short to medium term.

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