2023

Shorebird Populations on the Wollongong Open Coastline: An Evaluation of Occurrence Records, Species Richness and Key Threats

Emily Baonza
University of Wollongong

Shorebird Populations on the Wollongong Open Coastline: An Evaluation of Occurrence Records, Species Richness and Key Threats

Abstract

Shorebirds consistently serve as indicator species for measuring the extent of environmental change. As a consequence of the rapid shift in global climatic conditions and anthropogenic interference, long-term trends in shorebird populations demonstrate an alarming decline. Focusing in on the open coastline of Wollongong, NSW, there is a lack of up-to-date, comprehensive ecological information of shorebirds for use in the Wollongong City Council's (WCC) upcoming Coastal Management Plan (CMP). This thesis aims to source the available occurrence records from citizen science databases eBird and Birdlife Australia, as well as the BioNet Atlas database to produce an inventory of shorebirds within the Wollongong LGA and open coastline. Field studies of dog visitation are conducted to quantify the efficacy of dog access zones within the Wollongong LGA, coupled with human visitation data to examine these key threats to shorebirds alongside the growing human population. Additionally, an assessment of the potential for citizen science data to be incorporated into the WCC's CMP is explored. The key findings suggest that there is a wide diversity of 40 species of shorebird present in the LGA's record with variable degrees of spatial and temporal extent, and 18 species recorded on the coastline, correlated strongly with user effort and spatial accessibility. Field studies of dog visitation concluded that off-leash and no-dog access zones are reflected in the counts of dogs on these beaches, but that timedon leash zones have a high rate of non-compliant behaviours with a leashing rate of 33%. A combination of physical protective measures, like fencing and mesh caging, in conjunction with signage indicating both the location of beach-nesting shorebird nests and the severe impact of off-leash dogs, an increase in nest count and chick survival can be achieved. Further, through the integration of citizen science data using model-based analysis specifically designed for citizen science, expert involvement for quality control, and engagement with the birding community through incentive, training and birdwatching event organisation, a wider scope of ecological surveying of shorebirds in the Wollongong LGA's CMP can be effectively achieved. By compiling available ecological data, assessing threats, and proposing strategies for citizen science integration, this study contributes a foundational insight for the conservation and management of shorebirds within the WCC's CMP.

Degree Type

Thesis

Degree Name

Bachelor of Environmental Science (Honours)

Department

School of Earth, Atmospheric and Life Sciences

Advisor(s)

Bethany Hoye

Keywords

Shorebirds, Wollongong, Ornithology, Coastal Management, Conservation

Shorebird Populations on the Wollongong Open Coastline: An Evaluation of Occurrence Records, Species Richness and Key Threats

Emily Baonza

School of Earth, Atmospheric and Life Sciences

University of Wollongong

October 2023

Submitted in fulfilment of the requirements for the degree of

Bachelor of Environmental Science (Honours)

In the School of Earth, Atmospheric and Life Sciences, Faculty of Science, Medicine, and Health.

The information in this thesis is entirely the result of investigations conducted by the author, unless otherwise acknowledged, and has not been submitted in part, or otherwise, for any other degree or qualification.

[redacted]

Emily Baonza

Abstract

Shorebirds consistently serve as indicator species for measuring the extent of environmental change. As a consequence of the rapid shift in global climatic conditions and anthropogenic interference, long-term trends in shorebird populations demonstrate an alarming decline. Focusing in on the open coastline of Wollongong, NSW, there is a lack of up-to-date, comprehensive ecological information of shorebirds for use in the Wollongong City Council's (WCC) upcoming Coastal Management Plan (CMP). This thesis aims to source the available occurrence records from citizen science databases eBird and Birdlife Australia, as well as the BioNet Atlas database to produce an inventory of shorebirds within the Wollongong LGA and open coastline. Field studies of dog visitation are conducted to quantify the efficacy of dog access zones within the Wollongong LGA, coupled with human visitation data to examine these key threats to shorebirds alongside the growing human population. Additionally, an assessment of the potential for citizen science data to be incorporated into the WCC's CMP is explored. The key findings suggest that there is a wide diversity of 40 species of shorebird present in the LGA's record with variable degrees of spatial and temporal extent, and 18 species recorded on the coastline, correlated strongly with user effort and spatial accessibility. Field studies of dog visitation concluded that off-leash and no-dog access zones are reflected in the counts of dogs on these beaches, but that timed-on leash zones have a high rate of non-compliant behaviours with a leashing rate of 33%. A combination of physical protective measures, like fencing and mesh caging, in conjunction with signage indicating both the location of beach-nesting shorebird nests and the severe impact of off-leash dogs, an increase in nest count and chick survival can be achieved. Further, through the integration of citizen science data using model-based analysis specifically designed for citizen science, expert involvement for quality control, and engagement with the birding community through incentive, training and birdwatching event organisation, a wider scope of ecological surveying of shorebirds in the Wollongong LGA's CMP can be effectively achieved. By compiling available ecological data, assessing threats, and proposing strategies for citizen science integration, this study contributes a foundational insight for the conservation and management of shorebirds within the WCC's CMP.

Table of Contents

List of Figures

List of Tables

Abbreviations

ALA	Atlas of Living Australia
AWSG	Australasian Wader Studies Group
CAMBA	China-Australia Migratory Bird Agreement
CMP	Coastal Management Plan
CZMP	Coastal Zone Management Plan
EAAF	East Asian-Australasian Flyway
EEC	Endangered Ecological Communities
EPBC Act	Environmental Protection and Biodiversity Act
GBIF	Global Biodiversity Information Facility
JAMBA	Japan – Australia Migratory Bird Agreement
LGA	Local Government Area
NPWS	National Parks and Wildlife Services
ROKAMBA	Republic of Korea – Australia Migratory Bird Agreement
SCSRP	South Coast Shorebird Recovery Program
UOW	University of Wollongong
WCC	Wollongong City Council

Acknowledgement

I would like to extend a most sincere thank you to my academic supervisor, Bethany Hoye; without whose guidance I would not have succeeded in this thesis. Her expertise and dedication to her Honours students is inspiring, and it is with her encouragement and expertise that I present this thesis.

I would also like to thank my industry supervisor, Martine Fraser of the Wollongong City Council; whose encouragement, expert knowledge and opinion enabled me to deliver a purposeful thesis. I would like to extend this thank you to the team of experienced Environmental Officers who provided invaluable advice and access to data that guided this thesis; I hope that it represents your countless hours of hard work well.

Additionally, I would like to thank Kristy Blackburn and Kerrylee Rogers of the University of Wollongong, for their infinite support and encouragement. I would personally like to express my gratitude for their belief in my abilities and for pushing me to continue when I wasn't certain I could.

Lastly, I would like to thank my friends and family, and most importantly, my partner Nicholas. Without your support throughout this thesis and my entire academic career, I would not be where I am today.

"There is symbolic as well as actual beauty in the migration of the birds. There is something infinitely healing in the repeated refrains of nature – the assurance that dawn comes after night, and spring after winter."

- *Rachel Carson, "Silent Spring"*

1 Introduction

On the coastline of Wollongong, an assemblage of marine, coastal and wetland habitats support a diverse ecological array. These habitats include pristine sandy beaches, rock platforms, offshore islands, intertidal wetlands, and coastal lagoons. Amidst this ecological framework are the shorebirds, an order of bird that wades through shallow waters to forage. They are categorized as shorebirds by a set of taxonomic similarities but are extensively diverse both in morphology and in life history. Most species of shorebird are migratory, and cross remarkable annual distances to reach breeding and feeding grounds, in sync with seasonal patterns that bring about ideal ecological conditions for their survival (Colwell 2010). Their close association with the world's wetland and coastal habitats, their sensitivity to ecological change, and their widespread presence and diversity, makes shorebirds a key indicator group for monitoring the direction of long-term environmental change in these habitats (Wormworth & Şekercioğlu 2011). It is for this reason that this thesis aims to address the presence of shorebirds along the coastline of Wollongong, examine the threatening processes that impact them, and identify conservational strategies for their future management.

The Wollongong City Council (WCC) has within its borders approximately 60km of open coastline from Garie Beach in the North to Windang Beach and Lake Illawarra in the South, and includes 27 beaches separated by cliffs, rock platforms and headlands (Graham et al. 2023). Creeks and small lagoons cut through the coastline intermittently, as does marine infrastructure. To manage this coastline, the WCC implemented the Wollongong Coastal Zone Management Plan (CZMP) in 2017, which served the purpose of identifying coastal hazards, analyzing their likelihood and associated consequences, and evaluating the current circumstances surrounding each. The identified hazards included beach erosion, shoreline recession, coastal inundation, cliff instability and geotechnical hazards, coastal entrance instability, erosion due to stormwater outlets and drainage lines, and sand drift (Haines 2017). Through this plan, the coastal processes and interactions, and the coastal values and features on this coastline were extensively catalogued. This included an investigation and mapping of Wollongong's Endangered Ecological Communities (EEC). This plan, in conjunction with the 2014 Dune Management Plan and the 2005/2007 Estuary Management Plans, have guided a series of targeted projects along the coastline that are now completed (Graham et al. 2023).

As new research into coastal management develops, the requirements of governments and councils to implement updated strategies and guiding frameworks is imminent. Thus, the WCC has prepared a five-stage development program for a new Coastal Management Plan (CMP). This plan seeks to reassess the coastal hazards impacting the Wollongong coastline and update the scope of the hazard studies previously undertaken in the CZMP, as well as assess new hazards that have increased in severity. Stage 1 of the plan is titled 'Identify the scope of a CMP' and was completed in March of 2023. The key issues identified in this document included outdated data for shorebirds, rock platforms, estuaries, coastal dunes, water quality, and EEC mapping, as well as all the same coastal hazards identified in the CZMP. Each of these issues have a counterpart study recommendation within the scoping report to be undertaken in Stage 2: 'Determine risks, vulnerabilities and opportunities.' The specific recommendation for an ecological study of shorebirds was detailed as follows: 'Shorebird baseline inventory and threats assessment.'

- 'The assessment should include systematic field studies of both sandy and rocky habitats. The assessment report would provide information on shorebird species occurrence, abundance, use of habitat, key threats, and conservation management requirements. Recommendations for future monitoring should also be included.' (Graham et al. 2023, p. 154)

This project was proposed to the University of Wollongong as an Honours research project to address, in part, the recommendation for an ecological study of shorebird occurrence, abundance, key threats and conservation management requirements. The following aims and objectives were outlined and agreed upon as an outline for the completion of this thesis.

2.9 Aims and Objectives

The aim of this thesis is to source occurrence records for shorebirds that are present within the Wollongong LGA to address, in part, the recommendations cited in the Stage 1 Scoping Report of the WCC's CMP. These records are sourced from three databases: eBird, Birdlife Australia and BioNet Atlas, dated between 1970-2023. This thesis also aims to address the concerns of rising population density within the LGA, and the associated implications to shorebird habitat.

The primary objectives are to:

a) Identify the assemblage of shorebird species that are present in the LGA, the spatial distribution of the species occurrence records, and which beaches within the LGA they are observed. In addition, establish a basis for conservation priority by calculating species biodiversity on each beach.
b) Examine the geographical patterns of domestic dog visitation and human visitation, to evaluate the overlap between shorebird habitat, domestic dog usage and human population intensity.
c) Evaluate the potential for occurrence data sourced from citizen science databases to be integrated into the development of the CMP for the Wollongong LGA.

1.2 Thesis Structure

This thesis is segmented into 6 sections. 1: Abstract, 2: Overview of the thesis topic, project background, aims and objectives, 3: Literature review covering an introduction and background to shorebird ecology, threats to shorebirds, international treaties and strategies in Australia, successful case studies, and an introduction to citizen science, 4: Methods covering data sourcing, fieldwork and analysis, 5: Results presenting findings broken down into the two spatial resolutions of Wollongong LGA as a whole, and the open coastline only, followed by an analysis of the citizen science databases used, 6: Discussion of findings, a detailed interpretation, comparison with existing literature, and future recommendations, and 7: Conclusion of thesis.

2 Literature Review

Key Threats to Shorebirds, International Conservation Efforts, and the Use of Citizen Science as a Tool for Future Research

2.1 Introduction

Shorebird populations are declining globally, with growing concern for migratory shorebirds on the East Asian-Australian Flyway (Hansen et al. 2015; Nebel et al. 2008; Piersma et al. 2016; Sutherland et al. 2012). In Australia, long-term trends suggest that migratory shorebird populations have declined by 73% and residential shorebirds have declined by 81% between 1983-2006 (Nebel et al. 2008). Although there is extensive research that documents these long-term trends, there are gaps in our comprehensive understanding of the major anthropogenic stressors impacting shorebird populations and their wetland habitats (Belo et al. 2023; Sutherland et al. 2012). Additionally, the precise nature of these threats and how significant each is to shorebird populations is not fully understood (Martín et al. 2015). To inform conservation strategies, a more intricate understanding of the threats faced by shorebird populations is vital (Szabo et al. 2016). In addition to their role as shorebird habitats, wetlands and open coastlines are an invaluable asset to humans beyond industry and development (Howard et al. 2014). They provide a source of food, leisure and wellness to local populations and are integrated into the cultural heritage of many global communities. To begin, an investigation of the fundamental habitat requirements of shorebirds and the interactions between shorebirds and other species in wetland and coastal ecosystems is addressed as a foundational element to future research.

This literature review will identify and synthesize the existing research on the threats that impact shorebirds and their habitats both globally and within an Australian context. Additionally, an evaluation of the implications to population size, distribution, and abundance investigated in scientific literature will be outlined. Finally, an overview of the existing research in the Wollongong LGA and other important East Coast sites will be evaluated to provide context to the following research project. Additionally, the global and localized policies and legislation that govern shorebird protection will be examined. This synthesis will then guide a critical evaluation of citizen science as a tool for estimating and monitoring these aspects of shorebird populations, by first building a comprehensive understanding of the current strategies for assessing citizen science data thus far. Furthermore, this review will explore avenues in which citizen science data can be incorporated into the traditional scientific method in future research. In concluding this literature review, a deeper insight into the current understanding of shorebird ecology and conservation efforts will be gained.

2.2 Introduction to Shorebirds

Shorebirds, which fall under the order *Charadriiformes,* encompass 390 species from 19 families distributed among the three suborders of waders (Nebel et al.), gulls (Pichler & Hartig) and auks (Alcae) (Kratter 2005). The taxonomic classification of shorebirds has been historically disputed, and a consensus regarding the lower taxonomic levels within the *Charadriiform* order is lacking in ornithological literature (Černý & Natale 2021; Livezey 2010; Livezey & Zusi 2007). This stems from disagreements in the fossil record and evolutionary timeline of shorebirds (Černý & Natale 2021), as shorebirds do not come from a single monophyletic group; meaning that they do not share a singular common ancestor (Gochfeld et al. 1984). However, the generally accepted physical characteristics shared by *Charadriiformes* are 'long legs, pointed beaks, and long pointed wings' (Beach Chair Scientist 2012). Families like cranes (Gruiformes) have been controversially related to shorebirds in literature, due to their proximity in lifestyle and morphology, but are traditionally classified separately. These adjacent orders are referred to as 'allies' of shorebirds in literature (Livezey & Zusi 2007; Mayr 2011). Regardless of these discrepancies in classification, the morphological diversity and ecological specialization in shorebirds are widely accepted in ornithology (Mayr 2011).

As suggested by the common name *Shorebird,* most species in this order live and forage in and near where the land meets a body of water. As such, shorebirds have a largely species-specific diet, primarily consisting of invertebrates, such as the molluscs, insects, and gastropods that populate their environment, as well as available plant matter (Quaintenne et al. 2010; Schreiber & Burger 2002; Tsipoura & Burger 1999). Some species have specialized morphological adaptations that allow them to break into shells, like the triangular bill of oystercatcher (*Haematopus)*(Beach Chair Scientist 2012), while some feature an enlarged gizzard to ingest this benthic prey whole, like the red knot (*Calidris canutus islandica)* (Quaintenne et al. 2010). Shorebird forage behaviours include plunging their bills into the wetland sediment, and probing beneath the surface for prey, as well as plucking prey directly from the water column (Schreiber & Burger 2002). The caloric intake of shorebirds fluctuates throughout the year; during the non-breeding season, shorebirds forage to replenish their daily energy demand and accumulate energy stores in preparation for the beginning of the breeding season (Saint-Béat et al. 2013). During the breeding season, when migrating species of shorebird migrate to their breeding grounds, stop-over habitats provide the necessary caloric intake to sustain flight over large distances (Schreiber & Burger 2002).

The habitats of shorebirds have a species-dependent range that crosses a variety of coastal and wetland environments such as estuaries, tidal mudflats, grasslands, ocean beaches and rocky coastlines (Ma et al. 2013; Schreiber & Burger 2002). Wetlands and open coastlines play a critical role in supporting the nutritional needs, nesting requirements, and predatory refuge for many shorebirds throughout their seasonal cycles (Colwell 2010; Saint-Béat et al. 2013; Schreiber & Burger 2002). Habitat selection for shorebirds is thought to be based upon factors that optimize the odds of survival for eggs, chicks and adults (Cunningham et al. 2016). As such, nesting systems vary across shorebird species, but site selection for reproductive success ultimately favours habitats that reduce predation risk, sustain caloric intake for both adults and young and have suitable climate conditions for chick rearing (Cunningham et al. 2016). Given the extensive span of flyways used by migratory shorebird species, these flyways must contain an adequate array of wetland and coastal habitats to facilitate all of these key functions during each seasonal cycle (Duan & Yu 2022). Global wetlands, however, have declined both in extent and quality in recent decades, and the diminishing of these vital habitats is well documented in the literature. Similarly concerning, open coastlines have faced extensive area losses over the previous decades, among other damaging threats to be discussed in detail (Quaintenne et al. 2010; Schreiber & Burger 2002; Tsipoura & Burger 1999).

Shorebirds undertake long-distance migration along eight global flyways, including the East Asian-Australasian Flyway (EAAF) (Colwell 2010; East Asian-Australasian Flyway Partnership). The EAAF extends from the Russian Far East and Alaska, down through East and South-East Asia, and ends in Australia and New Zealand; it is the longest flyway in the world at 25,000km. The EAAF supports approximately 2 million birds on their migratory flight each year and is a key focal point in conservational efforts (East Asian-Australasian Flyway Partnership ; Szabo et al. 2016). It contains the highest number of threatened species, as well as a range of significant wetland types (Clemens et al. 2016; Szabo et al. 2016). These wetlands are largely categorised as intertidal, and range between saltmarshes, mudflats, and mangrove forests. Additionally, a geomorphologically diverse expanse of coastal environments including sandy beaches, rock platforms and pools exists alongside threatened wetlands. Intertidal zones are limited in total area across global coastlines, leaving their occupants particularly susceptible to decline if and when these areas become threatened (Hansen et al. 2015).

Among the many key wetland types that populate the EAAF, the saltmarsh and mudflat support a large diversity of benthic prey species amongst an abundance of marsh grasses and rushes for shelter and predatory refuge. The intertidal nature of saltmarshes and mudflats allows for these ecosystems to support such a diverse array of species by facilitating a unique and rich nutrient cycle (Howard et al. 2014). They are significant for their terrestrial drainage, carbon sequestering and water filtration capacity, and their ability to adapt to rising sea levels and increased storm events by protecting coastlines from degradation (Bell-James 2022; Mitsch & Gosselink 2015). Each of the outlined wetland types holds ecological value and services but with variable use to shorebirds specifically. For example, mangrove forests protect coastlines from degradation with dense root systems and absorb energy from severe storm events, but are rarely supportive of the nutritional, nesting, or protective requirements of shorebirds. Irrespective of their value, efforts to restore mangrove forests have inadvertently threatened highly important saltmarshes and other intertidal zones inhabited by shorebirds, as will be discussed in subsequent sections (Choi et al. 2022). Hence, striking a balance between wetland conservation and shorebird conservation by understanding the ecological value of each wetland type is vital.

The life history of shorebirds has been extensively linked to the seasonal cycles of wetland ecosystems like saltmarshes, particularly for long-distance migratory shorebirds (Smith et al. 2020). One such species is the eastern Willet, whose arrival to their breeding sites in the saltmarshes from Georgia to Maine is synchronous with the 'green wave' that occurs in the spring, as is true for the majority of migratory shorebirds (Smith et al. 2020). Another notable example of this relationship is observed between the Red Knot and their primary prey, as the spawning of horseshoe crabs in Delaware Bay coincides with the arrival of thousands of Red Knots on their migratory route along several North American flyways (Tsipoura & Burger 1999). A common shortfall of many studies that focus on habitats for shorebirds fail to recognize stopover habitats as critical to survival and thus are significantly underrepresented in conservation (Sheehy et al. 2011). Understanding these ecological dynamics between the species within the wetlands of the globe is critical for future shorebird conservation (Melville et al. 2016; Wang et al. 2020; Yi et al. 2022).

In contrast, open coastlines offer a geomorphologically diverse environment that differs from the intertidal wetlands discussed. Sandy and gravel beaches, rock platforms, tidal pools and reefs host ecosystems that support a large variety of shorebird species and their prey throughout their life cycles (Sims et al. 2013). For example, tidal pool ecosystems are generally made up of pits of various depths that form on rock platforms, and can host a diversity of molluscs, crustaceans, and seaweed, among other sea life; all of which attract many shorebird species, such as the Sooty Oystercatcher (*Haematopus fuliginosus)*. Unsheltered coastlines, particularly sandy beaches, are susceptible to erosion and inundation by sea level rise and storm events, which threaten dune volume and cause beach migration (Coastal Environment Pty Ltd 2012). Human development restricts response processes to these events, further exacerbating this threat. As a result, birds that nest in the substrate of beaches, like the endangered Piping Plover (*Charadrius melodus*) of the Atlantic flyway and the vulnerable Hooded Plover (*Thinornis rubricollis*) of the EAAF, are susceptible to nesting failure. Further on, a more in-depth discussion of the threats faced by beach and rocky shoreline-dwelling shorebird species will be addressed.

2.3 Threats to Shorebirds

Observed across many avian orders, there are accelerating trends of international decline in population and species range (Szabo et al. 2016). With this understanding, a large pool of research has recognised that trends in shorebird populations are strongly correlated to changes in environmental factors, making shorebirds an excellent indicator of environmental health (Bonney & Dickinson 2017; Hochachka et al. 2021; Lee et al. 2023; Mathot et al. 2018; Sutherland et al. 2012). Shifts in the frequency and severity of regional climate change, sea level rise, and disaster events, both naturally occurring and those aggravated by human activity, are strong contributing factors to shorebird decline. Similarly, anthropogenic stressors like agricultural intensification, infrastructure development and pollution are also contributing to habitat loss (Mitsch & Gosselink 2015).

Linked in response to these shifts, trends in shorebird populations, as well as seabirds and forest birds, have been rapidly declining since the 1980s (Hansen et al. 2015; Szabo et al. 2016). A leading synthesis of the current and potential threats to migratory shorebirds by William J. Sutherland et al. was published in 2012 and has been cited hundreds of times in successive research. It identifies 45 major threats, including emerging threats like microplastics and infectious diseases, to establish a complete horizon scanning of the interconnection between environmental changes and decline in shorebird populations (Sutherland et al. 2012). The threats discussed in this review are guided by Sutherlands' comprehensive synthesis of threats and are built upon using focused research papers on each major threat, with specific emphasis on habitat loss, predation, human development, and pollution.

2.3.1 Climate Change

The timing and duration of climate variation heavily influence the biosphere, altering the breeding and migration cycles of shorebirds, as well as impacting the dynamics between peak prey availability and time of arrival for migrating shorebirds (Anderson et al. 2023; Kwon et al. 2018; Ma et al. 2022; McKinnon et al. 2012; Sutherland et al. 2012). This is of particular concern to migratory birds in the Arctic region, where snowmelt timing impacts vegetation availability and animal activity to a higher degree than in other regions of the world (Kwon et al. 2018; Sutherland et al. 2012). Additionally, evidence has shown that warmer temperatures in the Arctic have already altered the reproductive success and spatial range of Arctic nesting shorebird species (Kwon et al. 2018; McKinnon et al. 2012; Zhu et al. 2022). These may be behavioural changes, like the misalignment of egg-laying with optimum food availability, altering prey species to adapt to local availability, shifting habitats due to area loss or food availability decline, and adjusting to human presence and infrastructure (Kwon et al. 2018; Ryeland et al. 2021; St Clair et al. 2010). For example, the Red Knot of the Eastern Atlantic Flyway is commonly researched, as their prey relationship with the declining horseshoe crab allows researchers to observe their adaptability to alternative invertebrate prey (Ersoy et al. 2022; Heller et al. 2022; Tsipoura & Burger 1999). Although the advance in egg-laying timing is alarming and has been observed in a variety of species, the implications of this phenomenon are not yet fully understood (Kwon et al. 2018; McKinnon et al. 2012).

In a more widespread context, climate change is the most severe stressor contributing to sea-level rise, as mean global temperatures continue to destabilize with the persistent emission of greenhouse gases by humans. Moreover, this threat is expected to escalate in severity in the coming decades (Sims et al. 2013; Sutherland et al. 2012) and has the potential to severely alter wetlands and open coastlines. Sea-level rise will also cause devastation to coastal human communities (Geselbracht et al. 2015) such as the many that exist in Australia and across hundreds of Indo-Pacific islands (Iwamura et al. 2013; Sims et al. 2013). Specifically, a rise in sea level increases the potential wave energy of storm surges, inundation severity, and beach recession (erosion) Considering these circumstances, many coastal ecosystems have demonstrated a potential to adapt to sea level and mean temperature rise, such as the mangrove forest in tropical regions of the globe. The expansion of mangrove forests into tidal mudflats and saltmarshes is accelerating due to increased temperatures and mangrove resilience to saline soil, both supporting their overall growth and spread (Choi et al. 2022; Howard et al. 2014; Sutherland et al. 2012). Although shorebirds use mangrove forests for shelter and foraging while wintering in tropical regions of the world, their expansion into other critical wetland types in Australia, New Zealand and South Asia is a major issue for conservation (Choi et al. 2022). Conversely, human developments like seawalls, ship ports and inlet jetties lack this capacity and are predicted to create conservation problems as humans attempt to adapt (Geselbracht et al. 2015; Sims et al. 2013). On the east coast of Australia, many of the impacts of sea-level rise and climate change are already measurable, with increased frequency of flooding and storm events, severe coastal erosion on hundreds of beaches, and other damages amounting to millions of dollars in recovery efforts. Cliff recession and instability caused by sea-level rise are also a growing concern on this coastline and across Australia, where settlements are at risk of collapse (Haines 2017). Climate change is undoubtedly influencing the distribution and overall population trends of shorebirds and their habitats, as well as exacerbating the severity of a variety of other threats that are equally disruptive to the ecology of shorebirds (Anderson et al. 2023; Iwamura et al. 2013).

2.3.2 Habitat Loss

Habitat loss is a multifaceted and widely prevalent issue, with hundreds of causalities that are challenging to decipher, catalogue, and manage. Reclamation of coastal wetlands like mudflats and saltmarshes is one of the major contributors to shorebird habitat loss globally (Wang et al. 2020). As a result of human activity, a 2016 assessment of the 'Australian state of the environment' found that saltmarshes, mangrove forests and seagrasses are all in poor condition and currently declining in Australia (Clark & Johnson 2017). Agricultural intensification is the most common purpose of land reclamation and impacts shorebirds for reasons beyond the total area lost. The primary method of land reclamation is through the drainage of wetlands to prepare them for agricultural development. These lands are then predominantly used to produce grass, which then dries the soil and reduces invertebrate prey availability and foraging opportunities for many shorebirds. This strategy has increased in popularity in highly productive rice farms in Japan, where many shorebirds had previously relied on traditionally flooded rice fields as staging sites (Sutherland et al. 2012). Similarly, domestic livestock has been introduced to reclaimed lands, where they have severely reduced vegetation cover by intense grazing and trampling of land that shorebirds rely on for breeding and foraging (Sutherland et al. 2012). These kinds of intense land management strategies have been linked to the drastic reduction of shorebird populations, like the European Golden Plover and the Marbled Godwit (Sutherland et al. 2012).

Internationally, China has a substantial wetland area of approximately 13% of its total landmass (Meng et al. 2017). Thus, China holds a large expanse of critical habitats for shorebirds along their migratory route along the EAAF (Melville et al. 2016). These wetland habitats are experiencing area losses to land reclamation for four major purposes: 'sea salt production, agricultural farming, the construction of industrial development zones, and the development of tourist and other large infrastructures' (Jackson et al. 2021; Meng et al. 2017; Sutherland et al. 2012; Wang et al. 2020; Yi et al. 2022). This loss was calculated to span 11162.89km between 1979 and 2014 (Meng et al. 2017). Land claiming in China has increased exponentially due to its rapid socio-economic development (Melville et al. 2016; Sutherland et al. 2012), where 37% of intertidal zones in China have been reclaimed (Sutherland et al. 2012). Many studies quantify the decline of wetlands in China, and how this correlates with shorebird decline (Piersma et al. 2016); however, more work into precise mapping of the network of key sites along the Chinese coastline is necessary to assess the threats specific to this area of the EAAF (Jackson et al. 2021; Wang et al. 2020; Yi et al. 2022).

There are a number of significant sites on the Chinese coastline, including the Yellow River Delta, a habitat of incredible importance to shorebirds that use the EAAF, as are many sites along the Yellow Sea coastline of China. Unfortunately, the delta has been extensively altered by development, such as urbanization, industrial activity, and infrastructure projects like dams, resulting in a severely reduced sediment load since the 1950s (Jackson et al. 2021; Melville et al. 2016). Sediment load is a vital element in retaining the health of wetlands, as it carries nutrients and prevents area loss and coastal erosion due to sea-level rise (Sutherland et al. 2012; Yi et al. 2022). Additionally, dams reduce the seasonal floodwater that inundates river environments, reducing the total area of wetland available to shorebirds. This has impacted the deltas' function as a key stopover habitat for endangered species like the Eurasian oystercatcher (Melville et al. 2016), where limited intertidal zones are now available. Declines in Whimbrels (*Numenius phaeopus)* and Wrybills (*Anarhynchus frontalis)* have also been attributed to a reduction in river-inundated wetlands (Sutherland et al. 2012). However, more research on shorebirds' response to sediment load reduction and river management infrastructure is needed to understand this threat (Sutherland et al. 2012). A large-scale example of the impact of industrialisation in China was brought about due to the availability of brine and salt deposits across the Chinese coastline. China has the largest salt production industry in the world with a history dating back hundreds of years (Chiang 1976), and in the present day, China fulfils this demand by evaporating vast reservoirs of seawater in the sun. This is one of the leading purposes of wetland reclaiming in China, also called sea enclosing (Meng et al. 2017). Salt marshes are, by natural association, converted into salt reservoirs for this purpose.

In addition to agriculture and industry, the loss of key wetland habitats like tidal flats and saltmarshes has been attributed to the prevalence of introduced species, like smooth cordgrass (*Spartina alterniflora*) (Sutherland et al. 2012). These species have been introduced to mitigate intense flooding, and yet have significantly altered the ecological structure of these wetland habitats in the process (Sutherland et al. 2012). One way that invasive species disrupt wetland vegetation is by outcompeting native species, leading to the biological homogenization of wetland habitats. Studies have shown that in the cast of *S. alterniflora,* long-term invasion significantly disrupts soil organic carbon and nitrogen, impacting all trophic levels of wetland ecosystems (Yang et al. 2016). The spread of invasive grasses has already been attributed to the decline of Dunlin in Britain and wintering shorebirds in China within population studies (Sutherland et al. 2012).

Open coastline environments, including sandy beaches, dunes, rock platforms, and headlands as well as estuaries and offshore islands are also globally impacted by habitat disturbance (Iwamura et al. 2013; Koh et al. 2018; Sims et al. 2013). The Australian coastline is made up largely of beaches (49.1%)(Short & Woodroffe 2008), segmented by cliffs and rocky headlands. In addition to what has been discussed regarding coastal erosion, inundation, and increased storm and wave severity from sea-level rise and climate change, other factors contribute to the area loss of these key habitats (Coastal Environment Pty Ltd 2012). Focusing on the local context of the Wollongong Coastline, this region of the East Coast of Australia experiences periodic and severe storm and flooding events that cause extensive beach recession (Coastal Environment Pty Ltd 2012). In addition, longstanding industrial developments and ever-increasing urbanization pose complex threats to the natural environment in this region (Jafari et al. 2020). The majority of shorebird habitat in this LGA consists of sandy beaches, dunes, rock platforms, offshore islands, cliff faces and headlands. Wetlands do exist in the LGA and across Illawarra, however, the total area has decreased by more than 41% since European settlement due to land reclaiming (Wollongong City Council 2011). Each of these landforms is managed by the WCC and is used extensively by the human population for leisure, recreation, and as a food source. Human visitation and occupation as a threat to shorebird habitats in Wollongong is explored further in later sections. In addition, the WCC manages Lake Illawarra in partnership with the Shellharbour Council. Lake Illawarra is a 35km2 tidal lake that supports a diverse ecosystem and is highly significant to the Dharawal people as a source of cultural heritage. Lake Illawarra is permanently open to the ocean due to the construction of training groynes in 2007 and has undergone extensive development along its interior shoreline. Similar structures have been erected across the Wollongong coastline, such as the training walls at Thirroul, Bellambi, and Port Kembla beaches. The WCC's current coastal management strategies are to be discussed in subsequent sections.

The loss of coastal and riparian vegetation in Wollongong has been a focal point of conservation for the WCC. Coastal vegetation, particularly species that cover the foredunes of many sandy beaches, protects the beach from severe erosion during storm events with root systems that trap and stabilise sediment. In Wollongong, coastal management strategies have involved altering the composition of vegetation communities on coastal foredunes, including the removal of species that grow tall to increase ocean views, clearing to provide entrance paths, and the construction of walkways and retaining walls (Doyle & Woodroffe 2023). More recently, the WCC published the 'Wollongong City Beach Dune Vegetation Site Plan 2018' regarding the dune vegetation management of City Beach, which aimed to remove vegetation that obscured the site line to the Surf Lifesaver

Club. Further back in time, a 2014 re-profiling of the Woonona foredunes and the removal of vegetation was carried out in response to public grievances regarding sightlines. Gangaiya, Beardsmore & Miskiewicz' (2017) publication that monitored Woonona beach following the reprofiling concluded that the reduction in volume during periods of higher wave energy was greater for the reprofiled portion of foredune than other parts of the beach that were not reprofiled, demonstrating the potential impact of these coastal management strategies (Gangaiya et al. 2017). As a result of coastal infrastructure and the potential impacts of previous coastal management strategies, the geomorphological processes responsible for forming and adapting dunes to environmental change have been restricted (Doyle & Woodroffe 2023), posing a threat to sandy beach habitats and the fauna that they support. In summary, the EAAF is facing several conservational challenges, primarily comprised of the factors contributing to habitat loss. Addressing these threats and their trickle-down effects on shorebirds by expanding research prospects, policy advocacy, and international collaboration will ultimately yield a more comprehensive approach to safeguarding these endangered habitats and their diverse inhabitants.

2.3.3 Domestic Dogs and Predation

There are many ways that humans interact with their environment in everyday life, without the intention of causing direct harm. Bringing their domestic dogs to sandy beaches for activities and enrichment is part of popular culture in many places where dog ownership is common (Cortés et al. 2021; Guinness et al. 2020), yet is one such interaction that impacts the environment more intensely than is suspected by dog owners. This pastime has the potential to adversely impact shorebird species that use the beach for nesting and foraging due to predation pressure from domestic dogs (Baudains & Lloyd 2007; Rutter 2016; Williams et al. 2009). Studies of direct threats to shorebirds by dogs have found that dogs chase and prey upon shorebirds at all life stages and cause temporary nest abandonment, resulting in the death of eggs (Battisti et al. 2022; Gómez-Serrano 2021; Rutter 2016). Similar studies have found that humans accompanied by dogs are twice as likely to cause birds to flee; particularly with shorebirds that use sandy beaches (Cortés et al. 2021; Gómez-Serrano 2021; Rutter 2016; Williams et al. 2009). These threats are heightened when the dogs are off-leash (Gómez-Serrano 2021). Additionally, the rate of disease spread is heightened by the increased microbial load of dog faeces on beaches, threatening the entire ecosystem of sandy beaches (Rutter 2016). The threat of domestic dogs to shorebirds has been reported globally, and is a factor in the 'landscape of fear' concerns regarding wildlife (Rutter 2016), described as the perceived increase in predation risk within the habitat of a given population, even when many activities are not an explicit threat to their lives (Yasue 2006). As a result, evidence suggests that shorebirds may select nesting and foraging sites that avoid the presence of domestic dogs, which may expose them to other unfavourable pressures like reduced food availability and other forms of predation (Rutter 2016). Additionally, dog presence at key migratory stopover sites makes shorebirds particularly vulnerable, as individuals are less likely to refuel efficiently and may suffer from exhaustion (Rutter 2016).

Other predator species, primarily domesticated or introduced species like feral cats and foxes, are observed to threaten shorebirds in a similar capacity (St Clair et al. 2010; Wijewardhana et al. 2022).

Feral cats (*Felis catus*) and red foxes (*Vulpes vulpes*) pose unique obstacles to conservation that differ from domestic dogs, as these individuals are generally untethered to a culpable human owner and are introduced species in much of the globe. Under positive circumstances, these two species effectively control rodent populations like mice and rabbits and contribute to the natural selection mechanisms of the ecosystem. However, feral cats are globally recognised threats to a large array of vulnerable wildlife, including ground-nesting shorebirds like the Double-banded Plover (*Charadrius bicinctus)* in New Zealand (St Clair et al. 2010). Effective controls like trapping and removal are most popular for conservation efforts on island ecosystems and have proven to aid in nest survival rates of the monitored ground-nesting bird, the critically endangered St Helena Plover (*Charadrius sanctaehelenae*) of the St Helena volcanic island (Oppel et al. 2014). Oppel et al. (2014) noted an increase in rodent populations following feral cat removal, as have similar studies (Cypher et al. 2017; Rendall et al. 2021). Red foxes pose almost identical threats to wildlife, including many species of vulnerable and endangered shorebirds world life; an extensive amount of literature is dedicated to monitoring fox predation of the near-threatened Piping Plover (*Charadrius melodus)* (Black et al. 2023; Doherty & Heath 2011; Stantial et al. 2020). Fox and feral cat controls have been implemented throughout Australia to aid in shorebird conservation, however, there is minimal literature that follows the impact of their control (Totterman 2021; Wijewardhana et al. 2022). Due to the complex interaction between introduced predator and prey species, approaches to their control are evolving and require improved modelling to optimize the recovery of endangered endemic species (Rendall et al. 2021).

Despite the evidence that demonstrates the impacts of domestic dogs on sandy beaches, there are sociological obstacles that make restricting their beach access challenging (Rutter 2016; Williams et al. 2009), namely the rights of their owners to exploit the natural environments around them. The abundance of dogs is invariably related to the presence of humans, the density of urbanized areas and the proximity of residences to sandy beaches (Cortés et al. 2021). In Australia, this issue is particularly prevalent in coastal management, as more than 85% of the population lives in relative proximity to the coast, and the cultural significance of beach-related activities is engrained (Guinness et al. 2020), in conjunction with a high rate of dog ownership. However, the perspectives of dog owners regarding how their pets influence the natural environment, as well as the rights of dogs to access certain activities, vary geographically and are likely related to culture (Guinness et al. 2020; Williams et al. 2009). Understanding the perceptions of the public in regulating beach usage is a major part of conservation efforts, where growing populations on the NSW coastline will continue to put pressure on the habitats most frequented by shorebirds during their migration and breeding seasons. Further, understanding the relationship between dog abundance and human presence may aid in coastal management, by introducing regulations that consider both the needs of the public and the protection of wildlife from domestic dogs (Guinness et al. 2020; Williams et al. 2009).

Regardless of the inherent challenges that restricting dog access entails, evidence shows that these restrictions can effectively reduce the local impact of domestic dogs (Rutter 2016; Williams et al. 2009). The WCC has implemented a stringent plan for the restriction of dogs on sandy beaches and rock platforms, as well as in parklands. The 'Dogs on Beaches and Parks – Council Policy' summary implemented in July of 2019 outlines the intentions of the WCC to support the conservation and enhancement of the natural environment, as well as to emphasize the individual responsibilities of dog owners to respect access regulations while providing adequate leisure spaces for them (Wollongong City Council 2019). The dominant strategy to achieve these goals is the zoning of each publicly accessible beach and parkland into red, orange, and green zones, each corresponding to a level of restriction. Red indicates no dog access and includes all patrolled beaches, coastal platforms and rock pools, and wildlife protection areas. Orange indicates a timed on-leash period for all listed beaches; these times are before 9:00 am and after 6:00 pm between September and April, and before 9:00 am and after 4:00 pm outside of these months. Having on-leash-only zones serves the purpose of providing areas of leisure for dog owners while reducing the risk of aggression events towards people and conserving wildlife and flora (Wollongong City Council 2019). Green zones represent the unrestricted off-leash access of dogs onto the specified beaches and parks to meet the needs of the large population of dog owners. To promote the acknowledgement of these zones, signage and appropriate waste facilities have been installed where possible (Wollongong City Council 2019). This compartmentalization of the natural environment within the WCC LGA aims to balance both the human population's needs and the needs of wildlife (Wollongong City Council 2019). Although there are many considerations in developing this plan and deciding zoning, predominantly pleasing a variety of opinions upheld by the public, the protection of wildlife and the natural environment from domestic dogs is certainly present.

2.3.4 Human Visitation

Human inhabitants within proximity to global coastlines pose a unique host of problems for the local ecosystem. Throughout history, the coastlines have drawn human populations for the agricultural, commercial, and climatic richness. This has led to the extensive transformation of natural coastlines to accommodate human populations, disturbing the otherwise expected rates of geomorphological change (Hapke et al. 2013). As a result, these coastal transformations in the shared environment between shorebirds and humans has endangered shorebirds throughout their life cycle (Baudains & Lloyd 2007; Glover et al. 2011; Mengak & Dayer 2020; Webber et al. 2013). In Australia, a frequently studied species is the endangered Far Eastern Curlew; this species resides in Australia for half of the year during their non-breeding season and is observed to pinpoint prevalent threats to their conservation (Finn & Catterall 2023; Morrick et al. 2022; Zharikov & Skilleter 2003). One such study identified land modification as a key threat within Australia, by comparing two different populations; one from the northwestern coastline, which experienced less human disturbance and one from the southeastern coastline, which experienced intense land modification and steeper population decline (Morrick et al. 2022).

Direct disturbance to the breeding habitats of shorebirds occurs in the form of noise, like music and crowds, waste, and nest trampling by walkers and joggers, in addition to the impacts of domestic dogs discussed in previous sections. Each of these disturbances contributes to what is termed a 'landscape of fear'. As a result, shorebirds may deviate from their natural behaviours, putting them at risk of other threats (Mengak & Dayer 2020). For example, breeding individuals may pass over otherwise suitable environments for less favourable ones for nesting if they recognise a high density of human visitation (Palacios et al. 2022; Webber et al. 2013). In addition to breeding shorebirds, foraging patterns may also be disturbed throughout the life of shorebirds; a matter of particular importance at key stopover sites during migration (Webber et al. 2013). Disturbances to foraging impacts energy storage and may cause seasonal carryover of reduced survival rates (Mengak & Dayer 2020). Further, the impact of disturbances can be observed in behavioural responses, such as the time it takes for an individual to return to a foraging site after fleeing (Yasue 2006), and fewer individuals observed at high-density beaches (Palacios et al. 2022). However, given the general acceptance that each of the discussed disturbances are threatening to shorebirds, there is a relatively small pool of research dedicated to how their responses to disturbance impact reproductive success (Baudains & Lloyd 2007).

2.3.5 Pollution

Pollution caused by human activity, whether it be chemical contamination or the accumulation of debris, poses a threat to the delicate wetland ecosystems inhabited by shorebirds (Connor & Thomas 2003; Ma et al. 2022; Tang et al. 2015). Atmospheric pollutants also pose a significant threat to coastal wetlands, as the natural processes that occur in these ecosystems lead to the absorption of pollutants from the atmosphere, through respiration and particulate capturing (Connor & Thomas 2003). However, there are gaps in this field of research; specifically, the precise impact of pollutants during each life stage, as well as the long-term impacts of pollutants on their wetland habitats (Ma et al. 2022). This is reflected in the low number of studies conducted in key global flyways, particularly on the EAAF (Ma et al. 2022). However, limited studies on key regions like the Yellow Sea show that it is threatened by heavy metal contamination from nearby coastal cities. The most common heavy metals of concern are 'mercury, cadmium, lead and arsenic' along with an increased concentration of 'inorganic nitrogen and phosphorus' (Tang et al. 2015). Influxes of strong pollutants have adversely impacted the food chain of migratory shorebirds, due to the decline in marine prey species. Within Australia, similar concerns of heavy metal and debris pollutants, with a strong emphasis on pesticide pollutants, have been reflected in the number of studies of wetland habitats and the impacts of these pollutants (Connor & Thomas 2003; Pettigrove et al. 2023).

Pesticides are used in Australia in urban areas at higher concentrations than any commercial usage, including agriculture (Pettigrove et al. 2023). This not only poses a risk to human health but leaches into a variety of aquatic environments from hard-surface runoff and sewerage (Ma et al. 2022; Pettigrove et al. 2023). In addition, plastic waste, and the impact that it has on global oceans and waterways is an ongoing conservational issue that impacts shorebirds through accidental ingestion and entanglement (Flemming et al. 2022; Mylius et al. 2023; Rossi et al. 2019). Species that forage near or in the ocean and those that forage by plucking prey out of their environment are particularly susceptible to ingestion. Flemming et al.'s (2022) study of the plastic ingestion risk of shorebirds identified Oystercatchers (Haematopus) as particularly vulnerable to plastic ingestion, including the endangered Pied Oystercatcher of the Australian continent. Pollution is an anthropogenic threat to shorebirds that has the potential to critically endanger global aquatic habitats and their shorebird inhabitancy (Connor & Thomas 2003; Flemming et al. 2022; Mylius et al. 2023; Pettigrove et al. 2023; Tang et al. 2015). Therefore, furthering research to fill gaps in this area of conservation is imperative for effectively mitigating this threat.

Narrowing down to the Wollongong LGA, industrialization, increased urbanization, and stormwater runoff events have led to the contamination of the soil, ocean, and waterways across Wollongong. Heavy metal contamination is a pollutant of concern in the LGA, as the dominant industries of Wollongong are coal mining and metal production. These industries, particularly metal smelting, release harmful atmospheric particulate and liquid discharge in Port Kembla and Lake Illawarra (Jafari et al. 2020). Sampling of the soil around the Port Kembla industrial area was recorded in 1973 (Beavington 1973) to be 21 times greater than regional controls, and again in 2020 (Jafari et al. 2020) to exceed the ANZECC and ARMCANZ accepted trace range (Jafari et al. 2020). Heavy metal contamination, as discussed, has the potential to impact the local food chain in the Wollongong LGA, particularly in the biologically diverse Lake Illawarra. To tackle heavy metal contamination, the WCC has worked through a contamination plan in partnership with the NSW Environmental Protection Authority and the NSW Department of Health

Another major concern for this region is the impact of stormwater runoff during major storming events, although there is little to no peer-reviewed scientific literature on this region for this concern, attributed in part to a lack of data available for flooding events (Iqbal et al. 2023). There are two available theses on the impact of stormwater runoff in the Wollongong LGA, many alerts of beach contamination after such events, and stormwater management plans produced by the WCC. The intensity of stormwater runoff during and following extreme rainfall is exacerbated by bitumen roads, concrete pathways and other pavement that cannot absorb excess water. Although roadways, pathways and open spaces can act as 'major system flows' because they are constructed with water escape routes, the capacity for drainage systems to handle sudden and high precipitation can overload the network. As a result, stormwater runoff overflows, carrying pollutants like debris and chemical/biological contaminants into soil, through waterways and into the ocean, leading to the death of shorebirds and their prey (Brudler et al. 2019; Ma et al. 2022; Navedo et al. 2021). For shorebirds, the consequences of stormwater contamination can be severe, with largely undocumented impacts (Ma et al. 2022). Ma et al.'s (2022) 'review of contaminant levels and their effect on shorebirds' found that there is only 1 Australasian study of the impacts of contamination and that others are based primarily on the American flyway (Ma et al. 2022). Ultimately, the global threats that impact shorebirds are heavily complex, and continued research into this field is a fundamental necessity for creating and implementing effective mitigation strategies against the global decline of shorebirds.

2.4 International Treaties and Strategies in Australia

The political discourse surrounding biodiversity monitoring is a complex issue of public perception, policy-making, advocacy surrounding environmental protection, and governmental obligations to protect biodiversity across the globe. The Australian Government has entered three international treaties that address the conservation of migratory birds across borders: the Japan – Australia Migratory Bird Agreement (JAMBA), the China – Australia Migratory Bird Agreement (CAMBA) and the Republic of Korea – Australia Migratory Bird Agreement (ROKAMBA) (*Australian Treaty Series 1981 No 6* 1981). These agreements outline the responsibilities of each government in minimizing harm to migratory bird habitats along the EAAF routes that fall within their respective territories. Moreover, the treaties emphasize the need for the signed governments to implement additional protective measures that are aimed at preserving species with the conservation status of vulnerable, endangered or at risk of extinction (*Australian Treaty Series 1981 No 6* 1981). These measures include the ongoing identification and preservation of key stopover sites between the two countries, controlling the hunting and illegal trading of listed species, funding scientific research into the ecological understanding of shorebirds, and encouraging outreach programs for public awareness and participation in conservation efforts. These treaties also contain a list of recognized species, to provide clear identification for targeted species-level conservation, as well as to provide a reference point for ongoing monitoring of population trends within research. Australia is also a signatory of the Ramsar Convention on Wetlands, which designates and protects wetlands of international importance. By entering these international commitments, the Australian Government recognizes the importance of preserving migratory bird populations and their key habitats and highlights their dedication to long-term conservation efforts.

Within Australian borders, the *Environmental Protection and Biodiversity Conservation Act 1999* (EPBC Act) protects ecologically significant habitats within Australia like coastal wetlands and promotes the conservation of threatened species and communities. The EPBC Act also enacts the Ramsar Convention within federal legislation. Within NSW, the *Biodiversity Conservation Act 2016* lists all the species of animals that are currently critically endangered, endangered, or vulnerable, including the 22 species of shorebirds that fall under these conservation statuses. These species are also protected under the *Threatened Species Conservation Act 1995,* the *National Parks and Wildlife Act 1974,* and the *Environmental Planning and Assessment Act 1979.* Each of these pieces of legislation collectively protects shorebirds and their environment, by ensuring the protection of critical habitats, facilitating conservation agreements on private land, requiring biodiversity offsets for development impacts, issuing conservation orders, supporting research and monitoring, and enabling recovery actions.

Each state government provides a framework for the development of CMP's, described with some variation in the name and the precise guidelines. LGAs that require this kind of conservational plan for the management of coastal environments are guided by the state's specific framework. For NSW, this framework is provided under the *Coastal Zone Management Act 2016* which outlines 13 objectives that aim to achieve the effective management of coastal ecosystems, along with the *State Environmental Planning Policy (Hazard and Resilience) 2021* and the NSW Coastal Management Manual Part A &B. The CMP for the WCC is currently under development and involves a 5-stage plan, and will include the management of all coastal zones within the Wollongong LGA, excluding Port Kembla and Lake Illawarra (Graham et al. 2023). Lake Illawarra, due to its ecological significance and morphology, will be managed under a separate CMP from the rest of the Wollongong coastline. Currently, the CMP is set for implementation between 2024-2025. Stage 1, completed in March of 2023, aimed to identify the scope of the CMP, and included the recommendation of a 'shorebird baseline inventory of threats' for an ecological study in stage 2 among 6 key study recommendations (Graham et al. 2023). Once completed, the CMP will succeed the current Wollongong Coastal Zone Management Plan (CZMP) developed in 2017, with the incorporation of newer research and the scoping studies undertaken in stages 1 and 2.

In addition to the CMP in development, the WCC has developed a series of documents that inform and guide the decision-making process regarding environmental planning and protection. Specifically, these documents serve to outline the preservation of the natural ecosystems within Wollongong LGA. They emphasize the conservation of coastal, estuarine, and riparian environments that sustain shorebirds and other important species for biodiversity. Among these documents is the 'Illawarra Biodiversity Strategy Vol.2', which provides a comprehensive framework that outlines the federal and state legislation and policies that govern the WCC's actions towards biodiversity conservation (Wollongong City Council 2011). To make effective recommendations, understanding the scope of the current efforts being made by the WCC to maintain the sustainability of the natural environment is critical. Like any governing body, the council operates within the bounds of the current sociopolitical climate, and recognizing these constraints is vital in reaching an effective balance in the decision-making process. The WCC consistently consults with residents, indigenous communities, environmental organizations, and planning professionals throughout their decision-making processes for the protection of the environment, to ensure that the decisions benefit all stakeholders.

2.5 Successful Case Studies in Conservation

Government policy and regulation have their place in conservation and are often an avenue for the public to become aware of ecological decline. Alongside these efforts are hundreds of conservational projects that have slowed or reversed the steep population decline of shorebirds and their key prey items. Several case studies in the literature highlight the importance of advancing monitoring efforts, implementing predator management, recovering key prey species, and enhancing habitat management to significantly improve the survival rates of shorebirds throughout each life stage (Dinsmore et al. 2014; Watts et al. 2012). These studies focus on the species-specific challenges faced by shorebirds and their ecosystems, while also providing insight into the efficacy of the implemented strategies for future projects to consider. Within Australia, there are programs dedicated to the monitoring and recovery of shorebirds like the South Coast Shorebird Recovery Program (SCSRP) and the Australasian Wader Studies Group (AWSG), as well as government organisations like the NSW National Parks and Wildlife Services (NPWS). Each of these groups has worked to report extensive long-term data from shorebird monitoring, population recovery and protective programs.

Internationally, there are highly successful programs that have recovered threatened populations of shorebirds and their prey items. The Western Snowy Plover, listed as threatened in key areas of the United States, migrates within the Pacific Flyway that spans from Arctic tundra to the wetlands of South America and nests on sandy beaches of California (Colwell et al. 2005; Dinsmore et al. 2014; Watts et al. 2012). This species is the subject of several management programs on the Californian coast, like the Ventura Audubon Society Shorebird Recovery Program, where the removal of invasive grasses, lethal predator management for red foxes, coyotes, and crows, and using mesh wire as protective fencing for nests has tripled the number of breeding adults for species recovery (Colwell et al. 2005; Dinsmore et al. 2014; Watts et al. 2012). Captive breeding and rearing have also been implemented for endangered species, with generally successful results in species like the Snowy Plover (Neuman et al. 2013; Quinn 1989), the Piping Plover (Roche et al. 2008), and the Killdeer (Powell & Cuthbert 1993), although some studies suggest that in-situ protection of eggs is more successful than removal (Claassen et al. 2014). Also based in the US, the Horseshoe Crab Recovery Coalition has partnered with 45 wildlife advocacy groups to campaign for stricter protections for this keystone species (Horseshoe Crab Recovery Coalition 2023). As discussed, the peak timing and abundance of prey species at key foraging sites are also critical in supporting shorebird populations (Heller et al. 2022). Red knots are reliant on horseshoe crabs that have declined in abundance due to overharvesting at major stopover sites for Red Knots like Delaware Bay, USA (Smith et al. 2022; Tsipoura & Burger 1999). As a result of restrictions on the harvesting of horseshoe crabs, the successful stabilization of their population has been documented. Further, studies of the program have predicted that stronger management strategies could enable both harvesting and population recovery to pre-1990 size (Karpanty et al. 2011; Niles et al. 2009; Smith et al. 2022).

Finally, the SCSRP in NSW, Australia has made tremendous progress with the recovery and protection of the endangered Pied Oystercatcher (*Haematopus longirostris*), critically endangered Hooded Plover (*Thinornis rubricollis*) and endangered Little Tern (*Sternula albifrons*). Their priority is educating the public about the impact of domestic dogs on beach-nesting species, like nest abandonment due to disturbance and the importance of leashing your dog. Part of this program is the installation of beach signage in foraging and nesting areas, as well as the erection of predator protections like electric fencing and mesh caging around nests in partnership with the NPWS, volunteers and the Shoalhaven Council (SCSRP 2019b). Through extensive monitoring, each of these measures has proven to increase counts of eggs, chicks, and fledglings for each of their focus species. Moreover, they have raised public awareness and a more complex understanding of the threats to these species has been recognised for their future conservation (SCSRP 2019a). In addition to the efforts of the SCSRP, the AWSG publishes the findings of their many monitoring programs in their Journal 'Stilt' biannually inclusive of papers and report, as well as produce a quarterly newsletter called 'Tattler' in their mission to promote the conservation of wader species in the Australasian region (AWSG 2017c). They are a group affiliated with Birdlife Australia and coordinate the large biannual counts and leg bandings of shorebirds at 23 sites within the EAAF, including the Chinese coastline in partnership with Wetlands International – China (AWSG 2017b). Further, they are a keen advocacy group for the conservation of wetlands through policy implementation and coordination with government organisations and are promoters of further ecological studies into shorebirds (AWSG 2017a). It's important to note that monitoring efforts and recovery program strategies are continuously evolving, and as such, their contribution to the conservation of shorebirds should be subject to ongoing scrutiny to ensure the best possible outcomes.

2.6 Citizen Science: Background, Extent and Limitations

Citizen science is the active involvement of the public in organized scientific surveying efforts, where individuals without formal training or educational background in the field contribute their time and resources towards data collection (Bonney & Dickinson 2017). Including data collected from citizen scientists into research is relatively new and broadens the opportunities available within established science (Hochachka et al. 2021; Sullivan et al. 2009), alleviating limitations that many researchers face including the time and funding that can be dedicated to a given research project. In addition, there is growing recognition by scientific organisations around the world that a need for large-scale synthesis of data, both spatially and temporally, is required to overcome the current conservation crisis (Hochachka et al. 2021). Meanwhile, the inclusion of citizen science into research expands the pool of data available, and challenges like geographical location and long-term monitoring can be effectively mitigated (Hochachka et al. 2021; Leitão et al. 2011; Watts et al. 2012).

In the field of Ornithology, citizen scientists with a special interest in birds offer a unique perspective and contribute significantly to the ecological knowledge base of birds and their habitats. Additionally, the perspective of Avian enthusiasts is often that the evolutionary, biogeographical, and behavioural ecology of shorebirds amongst other bird orders makes them an 'alluring subject' of intrigue in addition to the many ecological roles that their order plays in coastal ecology (Colwell 2010). It is heavily explored in the literature that birds, with their striking morphological diversity and intriguing behaviours and vocalizations, have accumulated a significant historical presence in human observations of the natural world (Callaghan et al. 2021; Hochachka et al. 2021; Sullivan et al. 2009). As a result, the historical accumulation of bird data coupled with the growing network of community-based observation platforms makes birds an ideal candidate for analysing the potential role of citizen science data (Hochachka et al. 2021; Sullivan et al. 2009). In addition to the special interests of citizen scientists and conventional scientists alike, the gratification of contributing to large-scale scientific exploration is also regarded as a key motivator in why citizen scientists volunteer their time, effort and resources to data collection (Sullivan et al. 2009).

There is substantial growth in the awareness of and engagement with the monitoring and conservation efforts of threatened species, both within the birding community and the wider public. Recognition of this interest has led to the development of several avenues for learning about and recording occurrence data online (Hochachka et al. 2021). Access to a smartphone or desktop computer allows birders to upload photos, occurrence coordinates and checklist information into their database of choice, based on their level of expertise and dedication to their data collection. In addition, these platforms offer a wealth of knowledge and training that can grow the skills of citizen scientists, helping to improving the quality and accuracy of their observations (Hochachka et al. 2021). As such, each database is varied in the kind and reliability of information that is shared, and so a data category can be used to describe each database. The terms structured, semi-structured and unstructured are used in literature to distinguish between the public databases based on the surveying technique that the collector uses to obtain their data. In terms of the accessibility of data, many of these databases will also restrict access to records of threatened species to prevent malicious use of this information, so that they can be accessed only by legitimate third parties.

eBird was developed collaboratively by the Cornell Lab of Ornithology and the National Audubon Society in 2002. It's founding purpose was primarily to harness the unique expertise of birders around the world and the data that they collect (eBird). eBird hosts the largest citizen-collected database publicly available, and provides a documented insight into 'bird distribution, abundance, habitat use, and trends' (eBird). eBird hosts a publicly accessible domain where birders can record and share their observations of bird occurrence (eBird ; Hochachka et al. 2021). It operates as a semi-structured database, where the observer selects a checklist protocol based on the kind of surveying undertaken. These protocols can describe the observer's movement, such as stationary or travelling, and can also indicate location, like their 'pelagic' protocol, for surveys taken more than 2 miles offshore (Callaghan & Gawlik 2015). 44 protocols are designed to best suit the nature of the data and the environment that the observer is surveying (eBird). It is then published by the observer and vetted by an approval process before it is uploaded onto the eBird database. Millions of observations pass through this vetting process and are entered into the database each year (Hochachka et al. 2021). Ultimately, this data can be used for visualizing spatial distribution changes, monitoring species range, and detecting temporal changes in migration; all accessible through the online platform (Hochachka et al. 2021). EBird data for Australian occurrence records is accessed via download services provided by the Global Biodiversity Information Facility (*What is GBIF?*). The GBIF keeps species occurrence records by drawing upon a network of databases. eBird is the largest database available through the GBIF and it is free to access. All appropriate Digital Object Identifier (DOI) citations are recorded for each species to identify the unique database downloaded through the GBIF (*What is GBIF?*).

Similar to eBird is the Birdlife Australia database, a semi-structured database and a partner of the Birdlife International global partnership. Birdlife Australia and eBird have a data collaboration agreement to aid in conservation efforts for the monitoring programs that draw from these databases. Alternatively, there are several unstructured databases that require only an image and location to record occurrence data, like iNaturalist. iNaturalist is not specific to birds and is used to record all members of the animal, plant, and fungi kingdoms. More accessible to a wider range of observers, the database has grown its user base substantially over recent years (Callaghan et al. 2021); particularly during the 2020-2022 lockdowns (Hochachka et al. 2021). Each of the abovementioned databases is also publicly accessible for download on the GBIF platform. These open-access databases are few among hundreds of programs, events and other data collaborations that have contributed to the synthesis of long-term bird population trends (Sullivan et al. 2009).

Understanding the scientific validity of citizen science data and the effect that it may have on the traditional scientific method of research is critical during this time of its rapid expansion worldwide. Among many aspects of validating scientific findings, the completeness of a dataset is fundamental in demonstrating reliable, consistent, and repeatable results. Several publications assess the surveying completeness and the research applicability of these major citizen science databases. One such study conducted in 2020 examined the survey completeness of eBird database contributions between 2002-2018 (Frank A. La & Somveille 2020) and determined the global regions where completeness was the highest. Australia achieved average completeness of 55-74%, with the highest values occurring during spring migration and a steady increase in completeness across temporal and spatial scales between 2004-2018 (Frank A. La & Somveille 2020). In addition, the impacts of spatial and temporal resolution on survey completeness were significant; whereby completeness summarized by day averaged 55%, and 72% if summarized by month (Frank A. La & Somveille 2020). Therefore, the role of spatial and temporal resolution in determining completeness is a notable element for further research (Callaghan et al. 2021; Frank A. La & Somveille 2020; Hochachka et al. 2021; Sullivan et al. 2009).

As discussed, there are many avenues that citizen scientists can utilize for data collection, depending on their location, access to equipment and possession of technology for sharing their surveying. With this understanding, several obstacles become clear. Most significantly, the geographical distribution of birding efforts from citizen scientists is globally unequal (Hochachka et al. 2021; Husby et al. 2021). Several factors contribute to this, including access to educational resources, human density, and geographical accessibility issues (Husby et al. 2021). In addition, there is a strong potential bias in sampling, caused by challenges like species being disproportionately detected based on their colouration or evasive behaviour (Callaghan et al. 2021), inconsistent protocols for sampling, and preferences for recording rare species (Leitão et al. 2011; Manu & Cresswell 2007). Further, a large proportion of citizen science data is opportunistic, which can spatially and temporally skew data (Jacobs & Zipf 2017). With this is the misidentification of species due to a lack of experience or expert opinion (Husby et al. 2021; Manu & Cresswell 2007), as many of these platforms do not have a minimum level of skill. Therefore, the checklists that are submitted are always open to incorrect reporting (Hochachka et al. 2021). In turn, these databases have the potential to produce skewed models of species distribution, among the many other applications of citizen science data (Leitão et al. 2011).

The works of Dr. Corey T. Callaghan include a heavy focus on understanding the direct and indirect implications of incorporating citizen science data into traditional scientific methods, by analysing its applicability to a wide range of ecological research. This area of research has included measuring the recovery of bird species after disaster events by investigating the patterns of citizen science occurrence records post-2019-2020 mega-fires in Australia (Lee et al. 2023), testing the robustness of citizen science data by modelling the efforts required to determine species diversity for conservation (Callaghan et al. 2022; Callaghan & Gawlik 2015), and identifying potential biases in bird occurrence data and how these may be quantified and corrected when used in further research (Callaghan et al. 2021). Each of these specific areas of investigation is a significant factor in understanding citizen science, and each is an opportunity for further research. Expanding the applicability of citizen science more widely into conventional research will allow challenges like time, funding, data size and participation to be alleviated. The rise of this network of community-based databases continues to provide vast amounts of occurrence data on birds and their environments and has the potential to tackle many of these issues. However, forming a deeper understanding of the associated limitations of this data and the observers that capture it is a critical obstacle (Sullivan et al. 2009).

2.7 Conclusion

This literature review has synthesized the taxonomy, key morphological features and overall ecology of shorebirds that have shaped their place as a key sentinel species for monitoring the progression of global environmental change (Wormworth & Şekercioğlu 2011; Zockler 2005). Their essential role as predators of a wide range of species (Heller et al. 2022; Karpanty et al. 2011; Quaintenne et al. 2010), and in turn their place as prey in the food web of coastal ecosystems (Aharon-Rotman et al. 2015; Watts et al. 2012), in addition to their widespread annual migration, makes their conservation an undertaking of significance (Choi et al. 2022; Szabo et al. 2016). By researching their species-specific diet, habitat requirements, and migration patterns, a foundation has been established for an in-depth discussion of the threats that they face and the literature that supports these concerns (Colwell 2010; Finn & Catterall 2023). Although several major threats impact shorebirds across the globe (Sutherland et al. 2012), key threats like climate change, habitat loss, predation by domesticated dogs and other mammalian species, human visitation and population increase, and pollution are some of the most prolific concerns of the WCC's conservation of shorebirds, and so have been the primary focus of this review of threats (Sutherland et al. 2012; Wollongong City Council 2011). Overall, this literature review has effectively demonstrated the significance of shorebirds, the causes of their steep global decline, and the profound urgency of conserving them.

To further this literature review, a discussion of the current international conservation efforts and the socio-political challenges of implementing stronger regulations and policies has been undertaken. Intergovernmental cooperation has been at the forefront of shorebird conservation, a conservational necessity given their cross-country migration patterns in all regions of the world. These regulations and policies have covered implementing poaching regulations, enlisting coastal habitats as protected, and identifying key threatened species. Australia's obligation to conserve shorebirds has been strengthened through the three key international treaties: the Japan – Australia Migratory Bird Agreement (JAMBA), the China – Australia Migratory Bird Agreement (CAMBA) and the Republic of Korea – Australia Migratory Bird Agreement (ROKAMBA) (*Australian Treaty Series 1981 No 6* 1981), and these obligations have trickled through to the federal, state and local governments throughout Australia. The WCC has been involved in upholding biodiversity conservation for decades and continues to implement updated coastal management strategies, most significantly the CMP that will replace the existing CZMP under the guidance of a federal and state framework.

However, despite the significant advancement in the conservation of shorebirds internationally, gaps in our understanding of shorebirds and their responses to threats and, in turn, specific mitigation and recovery strategies, are yet to be understood. For example, the impact of specific pollutants on different species, their life stages and their food availability remain a topic of concern, as does the long-term influence of pollutants on their habitats (Ma et al. 2022). Further, climate change is an ever evolving and complex issue that requires extensive long-term research to understand the implications for shorebirds (Anderson et al. 2023; Nebel et al. 2008; Wang et al. 2020). Considering the challenges that prevent these knowledge gaps from being effectively addressed, an introduction and in-depth appraisal of citizen science has been conducted in this literature review. Citizen science, with an appreciation for its unique limitations and challenges, has great potential to alleviate a lack of geographical coverage, support public advocacy of conservation, enable access to millions of species occurrence records, and overcome scientific research obstacles like funding, study longevity, and exponentially increase sample size and representation with enough user effort (Callaghan & Gawlik 2015; Hansen et al. 2022; Jacobs & Zipf 2017; Lee et al. 2023; Wijewardhana et al. 2022).

This literature review serves the purpose of informing the thesis to follow, which aims to address the lack of shorebird occurrence data to support the upcoming Coastal Management Program (CMP) of the WCC, by sourcing foundational occurrence records collected by citizen science databases, producing preliminary biodiversity calculations for all shorebirds, and introducing recommendations based on these findings for continued data collection. Currently, the WCC primarily sources occurrence records from BioNet, with relatively low spatial resolution. Additionally, there is a lack of targeted understanding of the potential threats that impact shorebirds and the coastal wetland environments present in the LGA. This results in several challenges in forming effective conservation management strategies, and impedes the council's ability to understand shorebirds' abundance, diversity, and distribution within the Wollongong LGA. By establishing the relevance of shorebird studies in a global context, the stage can be set for advanced localized studies in this region. The research design of this thesis seeks to examine each of these potential gaps in the upcoming CMP, by first developing key research questions that address shorebird occurrence across both the entire LGA and the coastline alone, the frequency of domestic dogs on beaches and the potential influence of dog access zones, and the validity of citizen science within this context. Quantitative measurements of domestic dog visitation and the presence of shorebird species in 9 study sites within the LGA are coupled with human visitation data sourced from the WCC in partnership with Place Intelligence to strengthen the recommendations to follow. Further, this research journey is only the beginning of an advancement into understanding these avian sentinels and their complex relationship with wetland environments, both within the Wollongong LGA and across the globe.

3 Methods

3.1 Selection of Shorebird Species

A shortlist of species expected to be present in the Wollongong LGA was compiled using the Shorebird Identification Booklet produced by Birdlife Australia (Davies & Bailey 2020). Each species was then input into the Atlis of Living Australia (ALA) to determine whether any observations have been made within the Wollongong region from its 208 bird databases. Further consultation with 'Birds of the world' (*Birds of the World* 2022) and the Australian Faunal Directory (ABRS 2020) validated the expected presence of each species in the study area. Information such as conservation status, habitat type, migratory status, establishment, and breeding region was compiled using the above resources as well as Birdlife International (BirdLife International 2023), Animalia (Animalia 2023) and the Australian Bird Study Association (Hardy 2014). A shortlist of 49 shorebird species was produced for this thesis (Appendix A).

3.2 Data Sourcing – Citizen Science Databases

Global Biodiversity Information Facility: The objective of obtaining occurrence records was to produce a dataset sourced from well established, expansive, and accessible domains. The Global Biodiversity Information Facility (GBIF) is an internationally recognized and government funded database that employs data standardization to compile species occurrence records, making them accessible through a public platform. To facilitate the sourcing of occurrence records from multiple databases, GBIF provides a standard file type (Tab-delimited CSV) to download. CSV files hold simple datasets and are easily imported to a variety of programs for data analysis, including Excel. In the case of avian data, the largest contributors include eBird, Birdlife Australia, and NSW . These contributors collectively contribute over 123,000,000 bird occurrence records globally, with approximately 9,000,000 recorded within Australia. Using the following filters, the data for Australia was obtained - scientific name, basis of record (occurrence), year (1970-2023), database (eBird, NSW BioNet Atlas, Birdlife Australia), and country (Australia).

eBird: A users will select 1 of the 44 protocols to perform their survey and upload it onto their eBird account. The survey will be vetted using both a computerized filter and one verified approver. It will then be added to the eBird Basic Dataset. eBird data can be obtained by requesting access to the eBird Basic Dataset using an eBird account and is downloadable once approved as a text file. Alternatively, this data can be obtained using the GBIF. Data for this thesis was downloaded using the latter, to efficiently obtain eBird data using the standardized formatting that GBIF provides.

NSW BioNet Atlas: a database managed by the NSW Department of Planning and Environment that stores data obtained through their associated biodiversity management programs, and is a culmination of 5 data collections: BioNet Atlas, BioNet Vegetation Classification, BioNet Web Services, SEED (Sharing and Enabling Environmental Data) (The SEED Initiative), and the Trees Near Me NSW app and website (NSW Department of Planning and Environment 2023). These collections are a source of data for the Department of Planning and Environment to perform research and make decisions regarding the management of biodiversity in NSW. BioNet atlas is contributed to largely by 'ecological consultants, research scientists, and others' including 'Forests NSW, the Australian Museum and the Australian Bird and Bat Banding Scheme' with smaller contributions by the public (NSW Department of Planning and Environment 2023a). Users or organizations will upload their surveys by electing the appropriate protocol, which will be vetted and uploaded to the respective database. This data is accessible through the environment.nsw.gov.au website, by registering as a user or applying for a data license. This data was also made accessible on the GBIF in 2013, where the NSW Department of Planning, Industry and Environment published 13,500,000 NSW BioNet Atlas occurrence records onto the GBIF database. Likewise, the data for this thesis was obtained through GBIF for efficiency and to obtain a standardized CSV file format. The WCC primarily uses the BioNet database to source ecological data for the creation of environmental management strategies and other relevant threat mitigation plans. This data has been labelled as potentially outdated for use in complex ecological studies.

Birdlife Australia: a partner of Birdlife International and was established in 2012 with the mantra 'Save birds. Save life'. However, Birdlife Australia's history spans more than a century and is a culmination of the Royal Australasian Ornithologist's Union and the Bird Observers Club (Birdlife Australia). It currently promotes several bird recovery programs, including the beach-nesting bird recovery program with specific emphasis for the recovery and ongoing protection of the hooded plover, and has hosted hundreds of outreach programs to educate and recruit the public. Birdlife Australia sources surveys from its userbase in the same fashion as eBird, whereby users will create an account and select the survey type that they are performing. They may also select a 'program' if they are participating in a larger community survey, like 'birds in backyards'. This is then run through a computerized vetting system before being uploaded to the 'Birdata Database'. Birdlife Australia upheld a data sharing agreement with the GBIF until 2021 and are seeking to renew this agreement to share data between 2021-2023. Birdlife data that was not sourced from the GBIF because it was recorded after 2021 was obtained via email request to birdata@birdlife.org.au, who extracted all bird data from the Wollongong LGA and sent it as a .csv file. This observational data was combined with all the other data obtained through the GBIF.

3.2.1 Coordinate Filtering and GIS Data

A boundary shapefile for all NSW LGA's and NSW boundary was obtained from Peclet Technology (*NSW Local Government Area spatial boundaries (polygons)* 2022) (Figure 3.1). Using the SEED database, polygons representing wetland extent from a 2010 mapping project were added (Figure 3.1) (State Government of NSW and Department of Planning and Environment 2010). Using ArcMap, all occurrence records in the region were added as a feature class to the workspace and the points that were outside of the LGA boundaries were excluded. The points remaining were exported back into an xls. file for later data analysis. For density mapping of this data, the kernel density tool in ArcMap, a point-based density tool for hot-spot mapping, was employed.

To isolate the coastal records only, a boundary shapefile for the coastal zones of the Wollongong LGA was obtained through the WCC's GIS team (Figure 3.1). This shapefile was created during the zoning of dog access on beaches and parks and is compartmentalized into each zone using polygon feature classes. There are 54 polygons in this shapefile that correspond to an area of dog access, and points outside of these polygons were excluded. This process produced two complete Excel sheets of species observations: one for the Wollongong LGA, and one for the coastline only.

In addition to the geographical splitting of the occurrence records, records were split into the timeframes 1970-2009 and 2010-2023, as well as monthly. Splitting between migratory, residential, and individual species as well as records by username was also performed. Excel was used to create several visual data presentations using this categorized occurrence data.

3.3 Surveying Design

3.3.1 Study Sites

Nine sandy beaches were selected within the Wollongong LGA, grouped within three geographical clusters. These beaches are Coledale, Sharkys, Thirroul (Cluster 1), Towradgi, Fairy Meadow, North Wollongong (Cluster 2), MM, Fisherman's, and Port Kembla (Cluster 3), from North to South as displayed on Figure 3.1. Each cluster contained one of each dog zone: off-leash, timed on-leash and no dogs. Each site was visited 8 times, 4 in the morning and 4 in the afternoon, across 4 weekdays and 4 weekends. Achieving this took 8 weeks between the 27th of May and the 15th of July 2023.

Study Site Locations Marked Across Wollongong

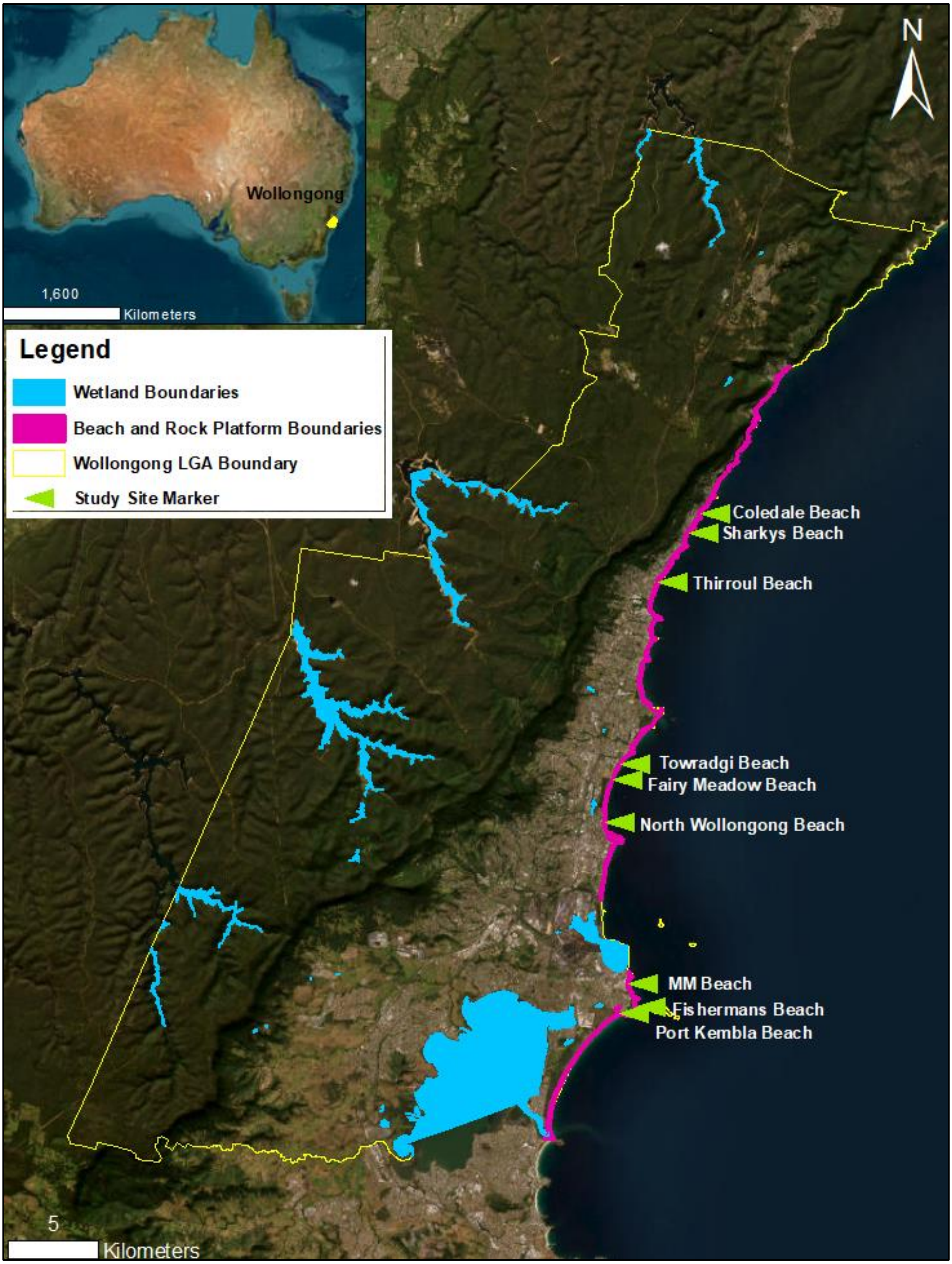


Figure 3.1: Map of each site marked the Wollongong coastline (green marking). Wollongong LGA boundary (yellow), coastal boundaries (magenta) and wetland polygon (blue) displayed.

3.3.2 Domestic Dogs

Each count was performed during a 15-minute timed visit, between the hours of 7:00am-9:00am and 3:00pm-5:00pm, whereby all dogs currently on the beach and any dogs that entered the beach during this period were counted. This was the agreed upon time to maximize the validity of dog counts, as these are popular walking times. Observations were always taken in the same stationary location each visit, at the central point of each beach towards the surf line for maximum visibility of the sand and dunes. Observer positioning was either based on Google Earth satellite imagery or map signage posted at each beach for zone boarders, as depicted in Figure 3.2. The use of binoculars was employed where individual Figures on the beach were not easily distinguished due to the length of the beach, like Thirroul Beach and Fairy Meadow Beach.

Each beach had specific borders that varied what constituted the beach, generally determined using either a bordering retaining wall or the vegetation line. Making this distinction was to ensure that owners without the intention of using the beach for off- or on-leash activity were excluded, and so any passers-by dogs were not counted. For example, the top of the retaining wall at Thirroul Beach is also a walking path where dogs walked with their owners but may not enter the beach. At Sharky's Beach, owners and their on-leash dogs were observed walking through the grass above the beach, without entering the sandy portion. Dogs were still counted whether their owner also entered the sand or just observed from the border. Whether the dogs were off- or on-leash was also noted.

Observation Points for Dog Counts

Figure 3.2: The location on each site where observations for dog counts were taken, as well as the location of parking and the entry point onto each site. Dog icon colour denotes dog access of each beach as either off-leash (green), timed on-leash (orange) and no dogs (red).

3.3.3 Bird Species Presence

The surveying method for shorebird presence is based on a recommended technique by the National Parks Association of NSW (Carlton). This method involves marking a 500m line on each beach (Figure 3.4), beginning at one end. This line is broken into 5 points, approximately 100m apart; the diagram of this transect design is shown in Figure 3.3. Surveying was taken at each mark for 3 minutes each. Every observable species within sight was recorded at the species level. The purpose of this survey was not to take individual counts of the population present during the survey, but to record that each species is present on the beach as part of the overall habitat, and so recording the same individual twice was not a problem.

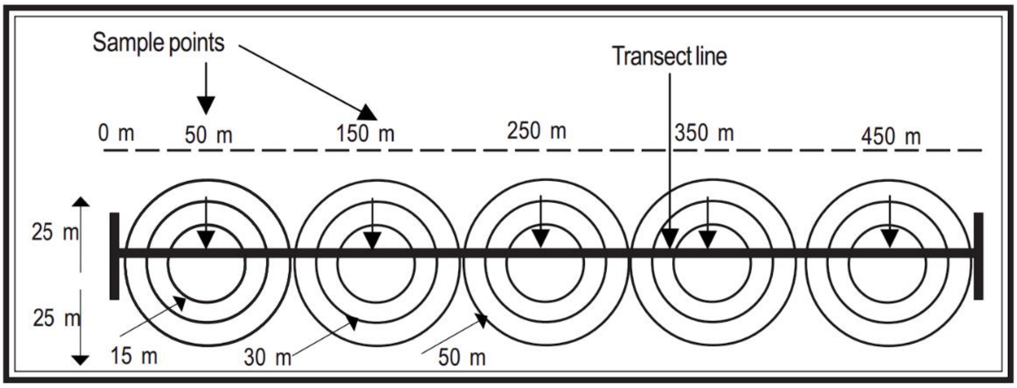


Figure 3.3: The transect design used for bird observations extracted from the National Parks Association of NSW's community biodiversity survey manual, under subsection 'setting up your transect', pg. 2, 'Figure 2: laying out the bullseye targets on a 500 meter transection' (Carlton).

Due to time and equipment restrictions, a transect line was not set up with pegs and markers for each beach. Instead, a digital line was drawn using the google earth app's path function to mark the transect line. This line was used to produce Figure 3.4, where the yellow line of the path tool is replaced with a bold red path line for visibility. This method of tracking transect paths during surveying is supported in the guidelines for detecting birds listed as threatened under the *Environment Protection and Biodiversity Conservation Act 1999* (Magrath et al. 2008). Studies of the approximate measurement accuracy of the google earth path tool suggests that off-road measurements of 300m+ may have a margin of error of 2.75% (Harrington et al. 2017), and so the measurements taken for these transects should be considered guidelines for bird observations, not precise measurements. Both dog counts and bird species presence were recorded during each site visit.

Figure 3.4: Transect line for recording bird presence at each of the 9 beaches observed.

3.4 Ethical Considerations and Quality Control

The surveying design for bird and dog observations underwent ethical approval by the affiliated animal ethics committee of UOW. The application included a description of the above surveying design and was restricted to observation only. This meant that no direct disturbance of individuals was necessary for data collection, and due to the season (winter), no risk of shorebird nest disturbance on sandy beaches was present. I have completed the ComPass Animal Welfare Training program hosted by the University of Adelaide to ensure that an adhesion to the standard code of ethics for working with wildlife was upheld during the length of this thesis. Although no physical contact or disturbance was made to any of the subjects of the field observations, this training is a key component of seeking ethics approval from the relevant animal ethics committee. Approval for field observation was granted on the 4th of May 2023.

3.5 Calculating Biodiversity

A statistical analysis of the shorebird diversity of all beaches in the Wollongong LGA that contains records will be performed by calculating the Simpsons Index (D) (Figure 3.4). The Simpsons Index is a value between 0-1, 0 representing no recognizable diversity and 1 representing complete biodiversity. This statistical tool was chosen to further describe the nature of these shorebird communities within the constraints of the occurrence records. The purpose of this analysis is to identify the beaches, rock platforms or coastal pools that may demonstrate higher shorebird species diversity, with consideration for the species richness and evenness present in the occurrence records. Polygons with fewer than 40 occurrence records were not part of this analysis, to prevent this biodiversity indexing from being skewed due to small sample sizing.

$$D = 1 - \left(\frac{\sum n(n-1)}{N(N-1)} \right)$$

D = Simpsons Index Value

n = number of individuals of each species

N= total number of individuals at each location

Figure 3.4: 'Finite' Simpsons index equation for small sample sizes.

3.6 Overlap of Threats and Occurrence Records

The purpose of this section is to assess the overlap between shorebird occurrence records, human visitation records and domestic dog counts to establish a baseline for further research into the severity of these impacts. Maps of the 9 study sites that dogs and shorebirds were observed during the fieldwork component are the focal point of this assessment. In addition, a statistical analysis of the dog visitation counts will be undertaken with the following research question in hand. This section aims to test whether the dog visitation data is reflective of the dog access zoning of each study site. To test whether there is a statistically significant difference between each dog access zone, a Wilcoxon rank-sum test (Mann-Whitney U Test) will be employed. This nonparametric test was chosen as the data is non-normally distributed, the sample size is small, and each sample group is independent. This test will be performed using R Studio software with a significance level of 0.05. P-values below <0.05 indicate a statistically significant difference between the two groups; >0.05 indicates that there is not enough evidence to reject the null hypothesis.

The human visitation data is sourced using Place Intelligence, a company focused on cloud-based location services. The WCC is mapping the patterns in human visitation to public spaces within the LGA, including beaches and parks between 2019-2022. These maps and statistical summaries are accessed using the online Geodata Studio interface. The visitation data is collected by gathering the GPS data from smartphones carried by visitors to each location and includes the time, date, and whether the visitor came from within or outside of the LGA. The human visitation summary data for each of the study sites has been individually downloaded (Appendix B). For the results, the visitation data for the 9 study sites will be examined. The 9 study sites are the only sites that human visitation data will be examined in order to draw parallels to the dog visitation data collected for the same 9 sites.

3.7 Analysis of Citizen Science Databases

The purpose of this section is to compare the volume of data contributed by each database and address any notable variation in the species that are represented in each database. This comparison will involve calculating the proportion that each database each species. Estimates of user efforts will be established using the number of eBird users and their associated contributions within the LGA. Each of these data summaries will be used to assess whether citizen science databases have the potential to be incorporated into traditional research, and in turn the upcoming CMP for the WCC.

4 Results

4.1 Shorebirds in the Wollongong LGA

After completing the data sourcing and filtering component of obtaining the occurrence records, 35,529 records were produced between 1970-2021 for the 49 shortlisted species (Figure 4.3). The GBIF did not have data sharing agreements with the relevant databases to source beyond 2021, and so 2022-2023 data was sourced directly from Birdlife Australia. This data is limited and does not encompass the full extent of data collected for these years by citizen scientists. All records between 1970-2023 are largely concentrated around the open coastline and Lake Illawarra in the Wollongong LGA, with high concentration at Bellambi Park and the beaches of Woonona, Bulli, Sandon Point, and McCauley beach. Towards the South, Port Kembla Lookout (Hill 60) and the nearby beaches of MM and City beach contain high record counts(Figure 4.1, A). There are also inland coorindates that exhibit a high concentration of records, the densest of which is centred at the Wollongong Botanic Gardens. At Lake Illawarra, the Windang inlet, Duck Creek catchment, and Hooka Point park exhibit high concentrations of occurrence records. This area is adjacent to the Korrongulla Wetlands, to the right of lake Illawarra in the Windang Peninsula. In the mapping only between 2010-2023, Puckey's Estate Nature Reserve features a high concentration of records. This heritage site features marshland and rainforests, and includes Puckey's Lagoon and Puckey's Boardwalk (Figure 4.1, B). Additionally, Bellambi Park, Port Kembla Lookout and their surrounding beaches are concentrated areas, with concentration at the same lookout locations on the shoreline of Lake Illawarra. Records between 1970-2009 demonstrate fewer concentrated areas, with the highest centred at Windang inlet and Lake Illawarra with more spare records along the coastline, as displayed in Figure 4.1 (C).

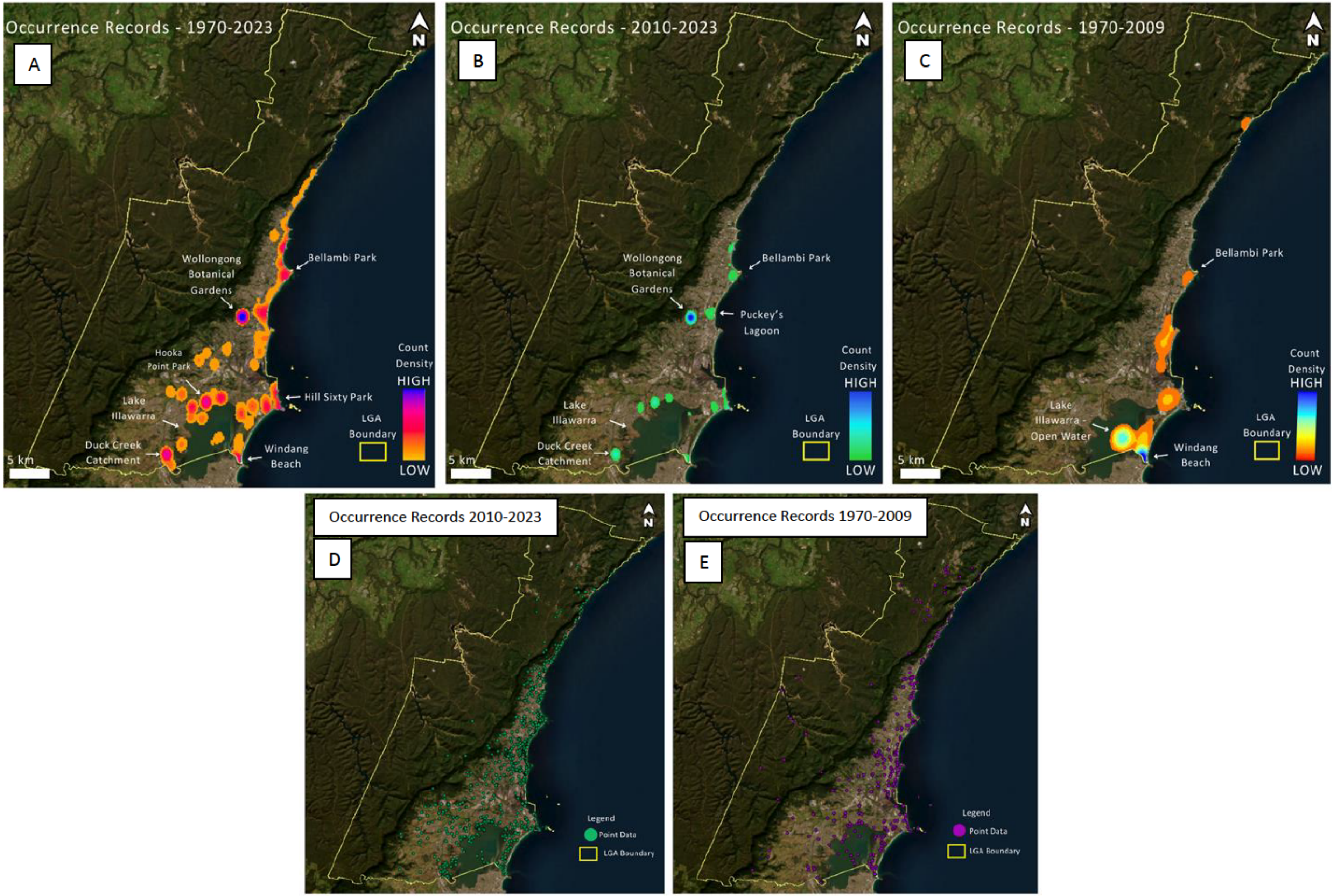


Figure 4.1: Mapping of the Wollongong LGA with density display for all the records (A), present records between 2010-2023 (B) and historical records between 1970-2009 (C). The present and historical records (D and E respectively) are also plotted as points on the same Wollongong LGA map.

4.1.1 Species Present

Of the 49 species shortlisted for this study, 9 (18%) are not represented with an occurrence record in the Wollongong LGA between the years 1970 and 2023 (53 years). These species are the Banded Stilt *(Cladorhynchus leucocephalus),* Banded Lapwing *(Vanellus tricolor)*, Wandering Tattler *(Tringa incana)*, Pectoral Sandpiper (Calidris melanotos), Terek Sandpiper *(Xenus cinereus)*, Broad-billed Sandpiper *(Limicola falcinellus)*, Wood Sandpiper *(Tringa glareola),* Ruff *(Philomachus pugnax)*, and the Comb-crested Jacana *(Irediparra gallinacean),* as denoted by transparency in Figure 4.3.

Silver Gulls *(Chroicocephalus novaehollandiae)* contribute 61.7% of counts, followed by 20.7% Masked Lapwing *(Vanellus miles).* After these species is the vulnerable Sooty Oystercatcher *(Haematopus fuliginosus)* at 4.8%, the Kelp Gull *(Larus dominicanus)* at 2.9%, the Bar-Tailed Godwit *(Limosa lapponica)* at 1.5%, and the Latham's Snipe *(Gallinago hardwickii)* at 1.1%, with the remaining 35 species representing >1.0% of the LGA occurrence record.

4.1.2 Migratory vs. Residential Species

Of the 49 species shortlisted, 20 are residential and breed within Australia, and 29 are migratory and breed outside of Australia in Figure. Due to the proportion of Silver Gulls in the record, a third representation excluding this species is displayed in Figure 4.2. This demonstrates that Silver Gulls are the only species that have been uploaded between February and August. Migratory shorebirds are present from springtime to the end of summer in Australia depending on the species, and these records align generally with their expected presence in Australia during spring, but not in summer.

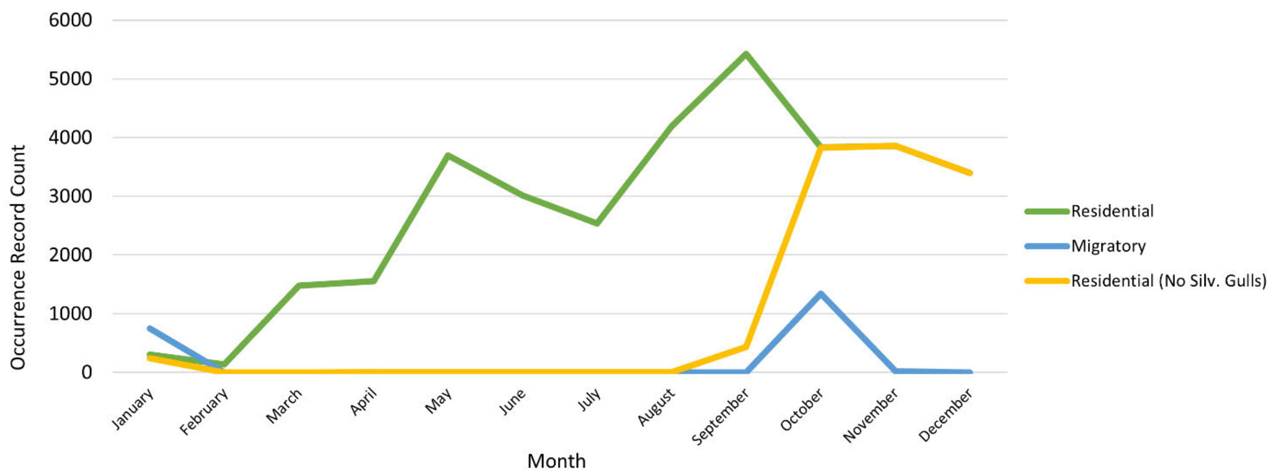


Figure 4.2: Line graph to represent the Migratory vs Residential Species count of occurrence records.

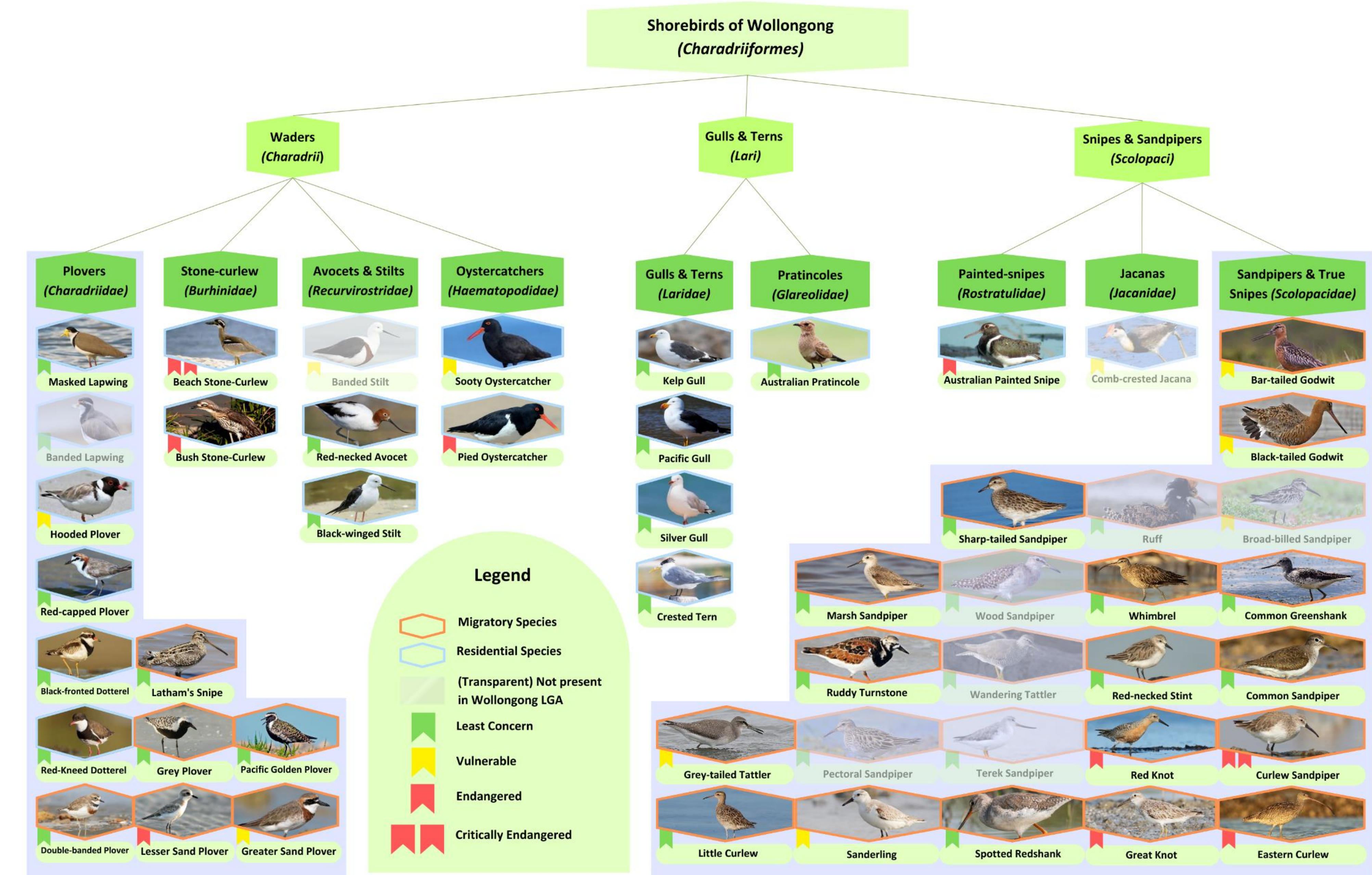


Figure 4.3: Tree graph for the shorebirds observed in Wollongong from 1970 – 2023 reported to BioNet Atlas, eBird or Birdlife Australia. Migratory species are outlined in orange, residential species are outlined in blue. Flag color is reflective of the conservation status of each species: least concern (green), vulnerable (yellow), endangered (red), and critically endangered (double red) (Menkhorst et al. 2019). Transparency represents zero occurrence records in all of the Wollongong LGA.

4.1.3 Annual and Decadal Records

Trends in annual records indicate that Silver Gull records make up the entire record between February-August, and reduce to 0 records between October to December (Figure 4.4). All other shorebird species are recorded between September-January. The submission of records by month has changed over time, where all data for March and April was submitted between 1971-2014, and no data for these months has been submitted since then. Conversely, data was not submitted for June-August and December until 2015 (Figure 4.5).

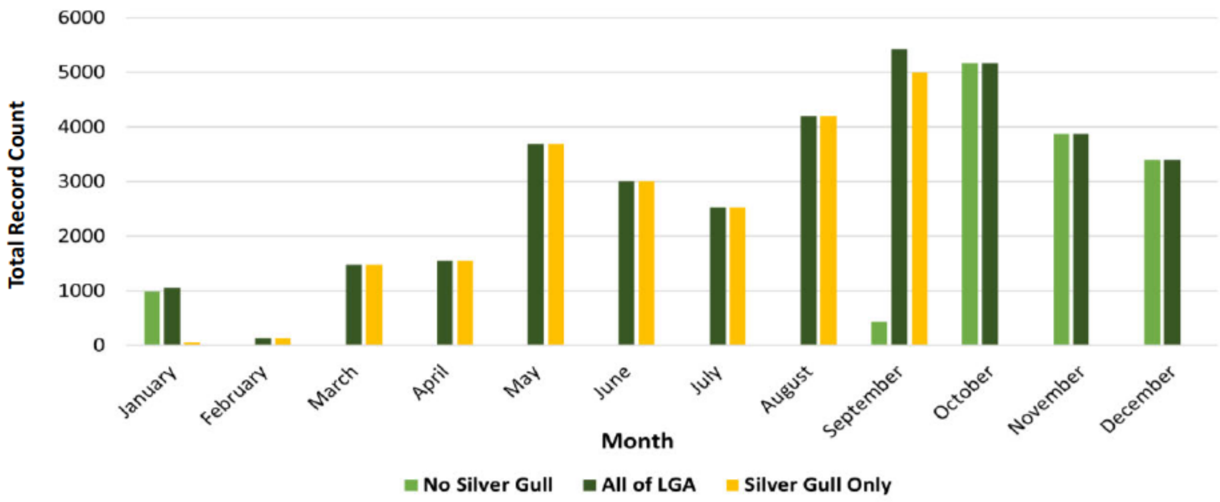


Figure 4.4: Count of records for each month of the year between 1970-2023, seperated by All Occurrence (dark green), No Silver Gulls (light green), and Silver Gull Only (yellow).

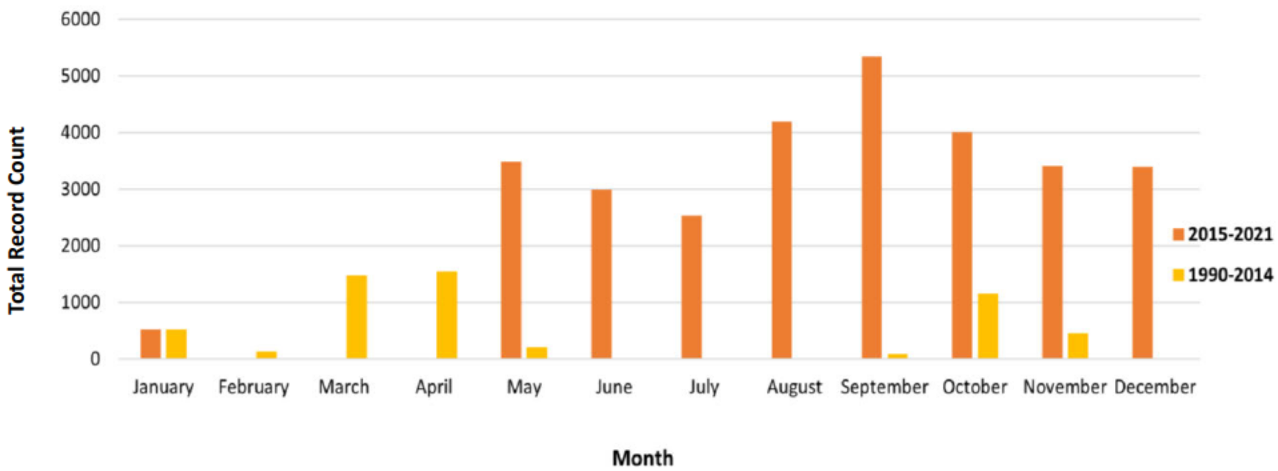


Figure 4.5: Count of records for each month of the year, separated into pre- and post-2014 records. Occurrence records from 1990-2015 wihtin the Wollongong LGA.

Few and sparce records were obtained between 1970-2009. In March of 1990, a large amount of silver gull records were recorded and later published to BioNet Atlas, representing a spike for this year in the overall records. Other than this spike, the incline in the number of records submitted annually began to climb in 2010 (221) and increasing exponentially until 2018 (5279), with a slight dropoff between 2019 (4507) -2020 (3983) and increasing again in 2021 (5011). Additional records are present between 2022-2023, however, they do not respresent all of the databases (Figure 4.6).

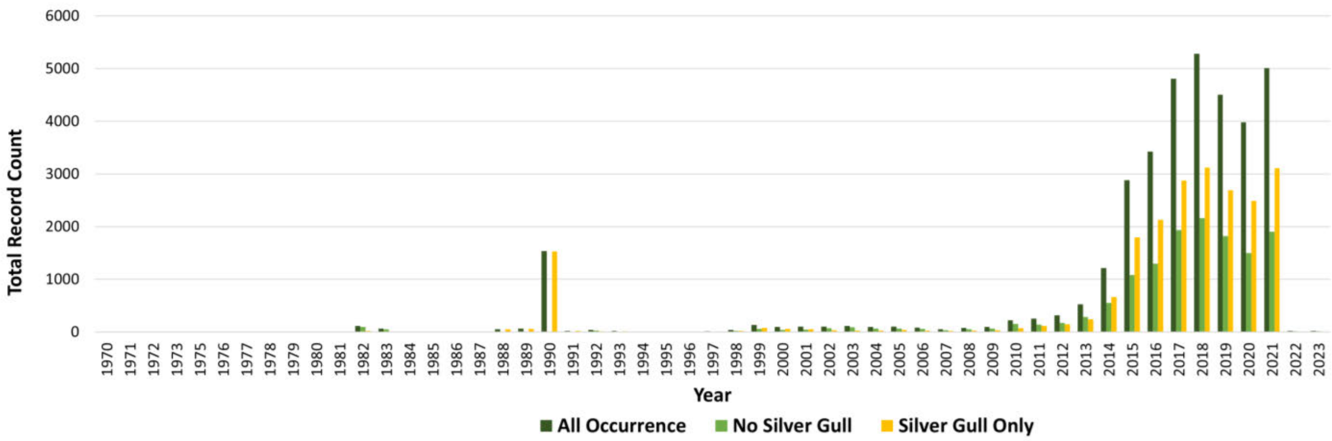


Figure 4.6: Count of records each year between 1970-2023, seperated by All Occurrence (light green) and No Silver Gull (dark green).

4.1.4 Vulnerable and Endangered Species

Species	*Record Note*
Australian Painted Snipe *(Rostratula australis)*	There is only 1 occurrence record; it is on the south-western shore of Lake Illawarra, 2km south of Duck Creek on the 28th of October 2011.
Australian Pied Oystercatcher *(Haematopus longirostris)*	280 records, with a scatter of 18 records across the coastline between 2001-2021, and the remaining concentration around Lake Illawarra (88) and Windang (175). All records occurred in October.
Bar-tailed Godwit *(Limosa lapponica)*	515 records, 498 of which are around Lake Illawarra and Windang between 1982-2023. There is a cluster of 12 records at Bellambi Park observed between 2000-2021 and several scattered elsewhere across the LGA. All records have occurred in October. Across the LGA, an increase in 2013 and high spike in 2017 followed by a low year in 2019 occurred.
Beach Stone-Curlew *(Esacus magnirostris)*	7 records, 6 of which are in Windang and Windang Park in October of 2012-2014. 1 record from 1998 placed an individual 1km inland of Thirroul Beach.
Black-tailed Godwit *(Limosa limosa):*	4 records, 1 at Puckey's Beach in 2014, 1 on Windang Beach in 2004, and 2 in Lake Illawarra in 2002 and 2019. All records occurred in October.
Bush Stone-Curlew *(Burhinus grallarius)*	On the 13th of January 2021, 4 records were submitted by 4 different users to the eBird database either side of Cabbage Tree Creek, Fairy Meadow. No other records exist for the Wollongong LGA.
Curlew Sandpiper *(Calidris ferruginea)*	17 records, 16 of which are across Lake Illawarra and Windang. Custers of 5 in 1982, 3 in 1983 4 in 2003, with scattered records up to 2018. All records took place in January.
Eastern Curlew *(Numenius madagascariensis)*	265 records, concentrated around Lake Illawarra and Windang between 1982-2021, with 4 records on the rock platforms of Port Kembla in 2014 and 2016. All records have occurred in October. A small number of records accumulated between 1982-2014, spiked in 2017 and dropped in 2019 with steady recovery.
Great Knot *(Calidris tenuirostris)*	7 records, 6 of which are across Lake Illawarra and Windang between 2001-2003, and 2 in 2017. 1 record was uploaded to the eBird database at Coledale Beach in 2019. All records took place in January.
Greater Sand Plover *(Charadrius leschenaultia)*	3 records, all in Windang. 1 in January 2009 and 2 on the 25th of January 2011 by 2 different users of eBird.
Grey-Tailed Tattler *(Tringa brevipes)*	32 records, 28 of which are concentrated around Lake Illawarra (13) and Windang (15) between 1982 and 2020. 1 other record at Woonona Point in 2013 and 3 other records 1.2km inland of Wollongong Beach in 2003, 2005, and 2006 by the same eBird user.
Hooded Plover *(Thinornis rubricollis)*	5 records scattered across the LGA, 1 on Wollongong Beach at the Wollongong Golf Course in 1986, 1 in Bulli Park in 2011, 1 in Elizabeth Park Bellambi in 2012, and 2 in Port Kembla Harbor in 2011 and 2012. All records occurred in October.
Lesser Sand Plover *(Charadrius mongolus)*	7 records, all in Windang, between 2003-2005, and then 2011-2012. All records took place in January.
Red Knot *(Calidris canutus)*	20 records, 19 of which are across Lake Illawarra and Windang. 5 records were submitted in 1982, followed by scattered records between 1990 and 2010 with a cluster of 7 records in 2017. All records took place in January.
Sanderling *(Calidris alba)*	6 records, 2 at Bellambi Beach on the 12th and 13th of January 2013, and the other 4 across Windang Park in January of 2004 2005, 2010 and 2013.
Sooty Oystercatcher *(Haematopus fuliginosus)*	There are 1671 records spread across the coastlines of the LGA, with dense clusters on the rock platforms of Port Kembla, Flagstaff Hill, Bellambi, and Sandon Point between 1990-2023. Across the LGA, records steadily rose from 2009 and spiked in 2021.

Table 4.1: Records of vulnerable and endangered species and their associated geographical locations within the Wollongong LGA.

4.2 Shorebirds on the Beaches and Rock Platforms in the Wollongong LGA.

On the beaches and rock platforms of the Wollongong LGA, there are 18 species that appear in the occurrence records. Of the 49 shortlisted species, 18 have been observed on the coastline between 1970-2023. Silver Gulls retain most of the record at 57%. Of these species, 4 are either vulnerable (Sooty Oystercatcher, Grey-tailed Tattler and Sandering) or Endangered (Australian Pied Oystercatcher), and they account for 15.6% of the record, 15.3% of which is contributed by the Sooty Oystercatcher. Of the 54 polygons used to identify the dog zoning of each coastal area, 33 of them contain at least 1 occurrence record. There is no clear pattern of occurrence records from North to South, and no clear trends between the types of coastal areas. Of the 9 study sites in this thesis, 8 contain occurrence records: Coledale, Sharkys, Thirroul, Towradgi, Fairy Meadow, North Wollongong, MM and Fisherman's (Figure 4.7). There are no records for Port Kembla Beach. Port Kembla beach makes up only a small portion of the coastal compartment, while Perkins Beach borders Port Kembla and contains approximately 300 records. Perkins boarders Windang Beach on the south side, which represents the southernmost beach in the LGA and is connected to the Windang Inlet to Lake Illawarra.

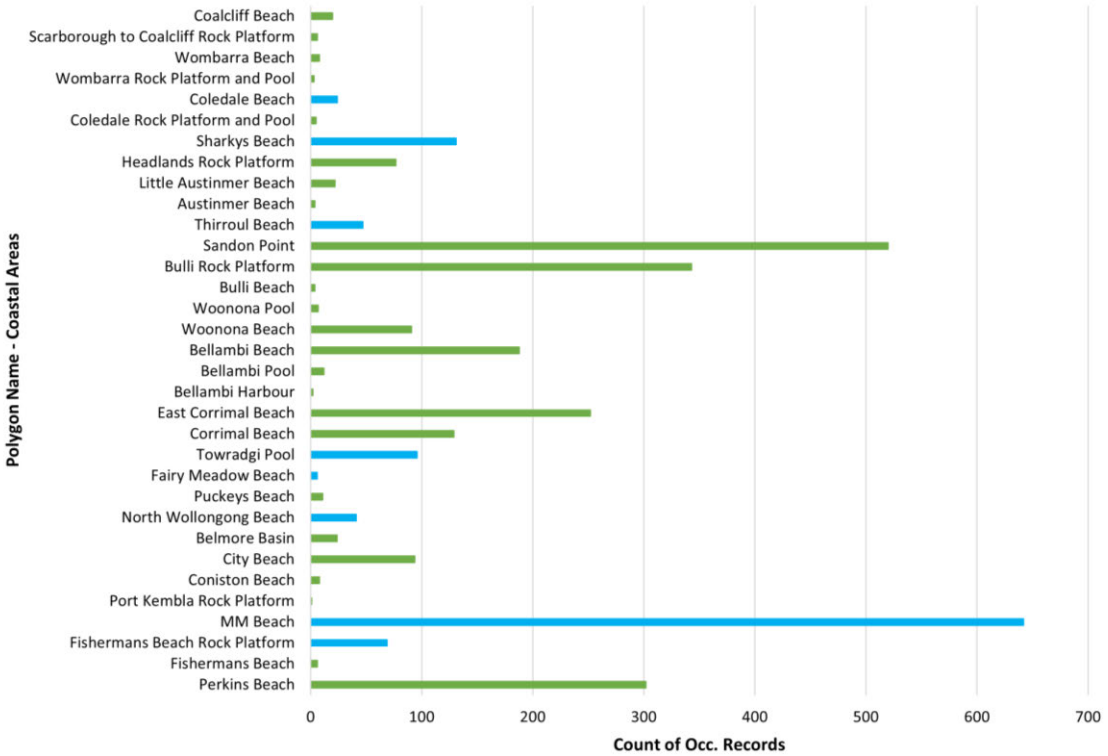


Figure 4.7: Shorebird observations between 1970-2023 sourced from BioNet Atlas, eBird and Birdlife Australia from Northmost (Coal cliff Beach) to Southmost (Perkins Beach) beaches that contain records. Blue bars denote sites that were also observed through field studies in 2023, green bars denote all other beaches, rock platforms and tidal pools from occurrence records.

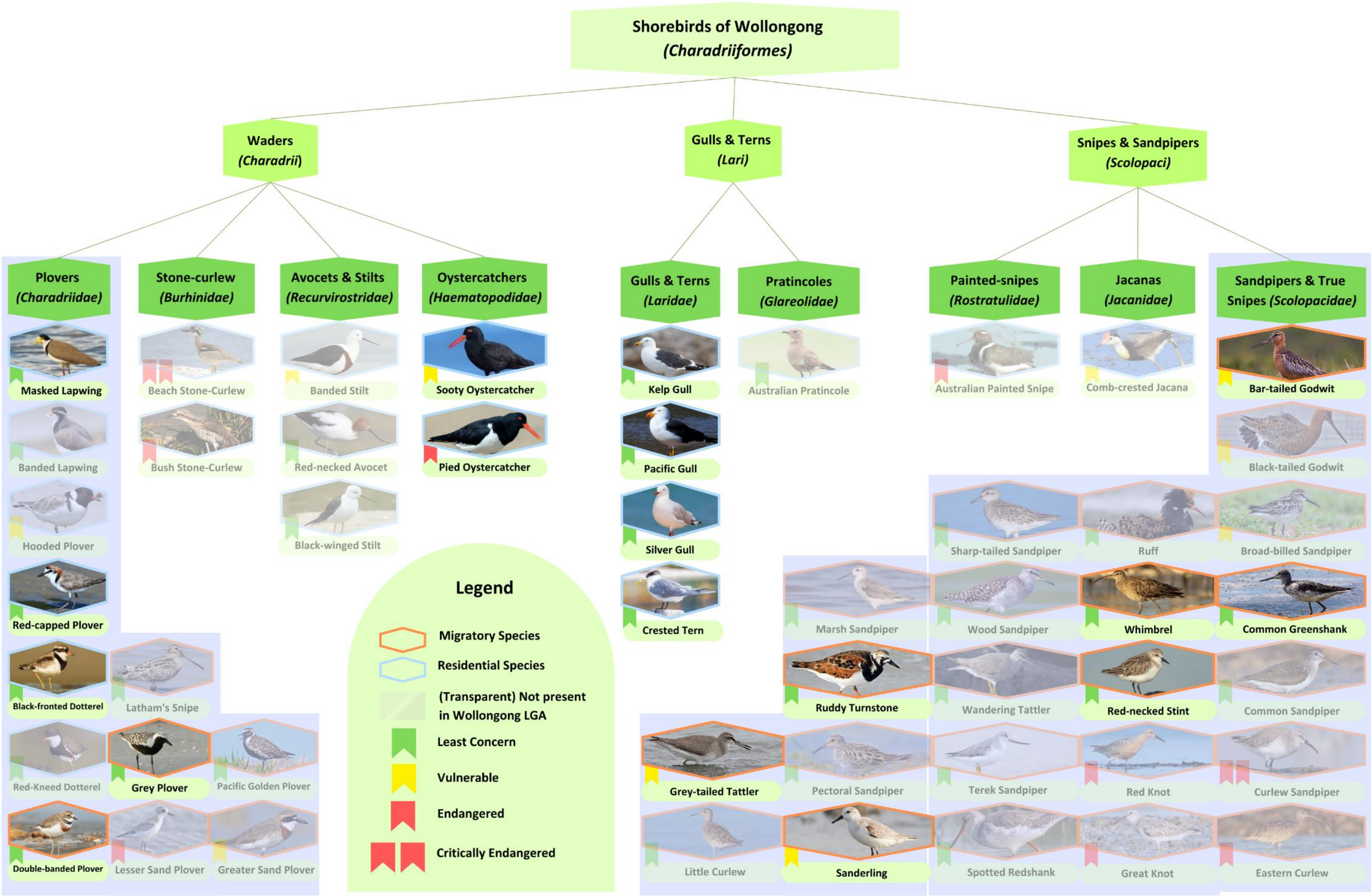


Figure 4.8: Tree graph for the shorebirds observed in Wollongong from 1970 – 2023 reported to BioNet Atlas, eBird or Birdlife Australia. Migratory species are outlined in orange, residential species are outlined in blue. Flag color is reflective of the conservation status of each species: least concern (Smith et al.), vulnerable (yellow), endangered (red), and critically endangered (double red) (Menkhorst et al. 2019). Transparency represents zero occurrence records on the beaches and rock platforms of the Wollongong LGA.

4.2.1 Fieldwork Results for Shorebirds

During the series of total 15 minute observation periods, 5 species of shorebird were observed across all beaches. A total of 72 visits were conducted across the 9 sites. Port Kembla was the only site where all 5 species were observed, and Fairy Meadow was the least diverse site with only silver gulls observed. Figure 4.9 represents the percentage of visits that each species was observed at each site. In the course of field observations, several bird species exhibited distinct patterns of presence and occurrence across the surveyed sites. Silver Gulls, for instance, were reliably recorded at all sites, with a remarkable 100% presence during every visit to Coledale, MM, North Wollongong, Sharkys, and Thirroul. Meanwhile, Sooty Oystercatchers, while observed at 7 out of 9 sites, displayed an average presence of 36% across all visits. Notably, they were most frequently spotted on the northern rock platform at North Wollongong Beach (87.5% of visits) and Coledale (62.5%), conspicuously absent from Fairy Meadow and Thirroul, the only sites lacking a rock platform within the 500m transect or its immediate vicinity. Additionally, Masked Lapwings made appearances at Coledale, North Wollongong, Port Kembla, and Thirroul, accounting for 32.5% of visits, with their highest frequency of observation occurring at Sharky's (50%). Crested Terns, on the other hand, were a common sight at Coledale beach (75% of visits), primarily on the southern rock platform, but their presence was scarce or non-existent at other sites, save for one recorded visit at Port Kembla. Lastly, Kelp Gulls were rarely observed, making just two appearances—once at Port Kembla and once at Thirroul.

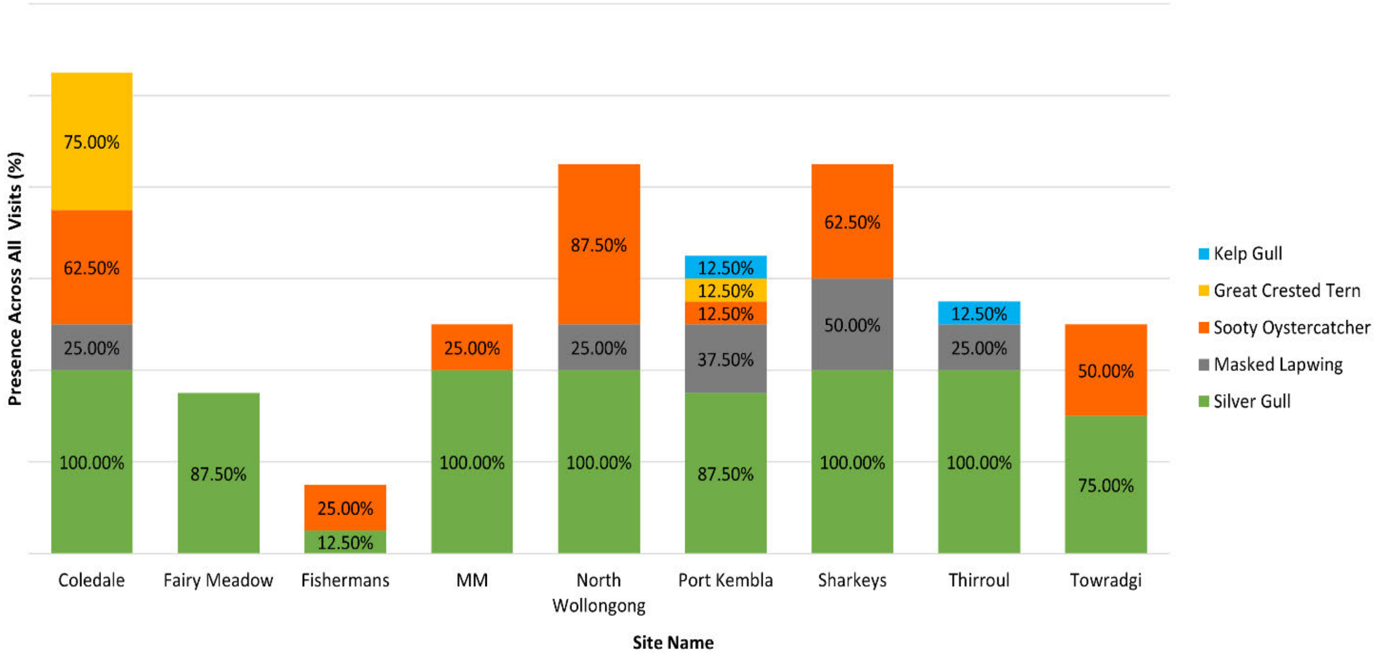


Figure 4.9: Species of shorebird observed during field study in Winter of 2023 and the percentage of visits that they were present between May-July of 2023. Percentage value equates to the percentage of visits each species was observed at each site.

The observations made here are unsubstantiated by the occurrence records, as none of these species have previously been reported in the occurrence record during this the time period of the field study. The only species documented in the record during the time that this fieldwork was conducted (May-July) are Silver Gulls, even as the 4 other species of shorebird appeared consistently throughout field observation.

4.2.2 Calculating Biodiversity

Based on the occurrence records, Perkins Beach is the most biodiverse beach in the Wollongong LGA with a Simpsons Index of 0.74. It holds the highest species richness in the record (14 species), followed by Bellambi (11 species). Beaches like Sharkys and Sandon, although relatively low in species richness (5 and 6), the even proportion of counts per species brings their Simpsons index up. Beaches with relatively low Simpsons' indexes are as such due to either a high proportion of Silver Gulls in the record, low species richness, or both. East Corrimal Beach has a relatively high number of records and high species richness (8 species), however, a disproportion amount of these records is Silver Gulls; lowering the Simpson Index (Figure 4.10).

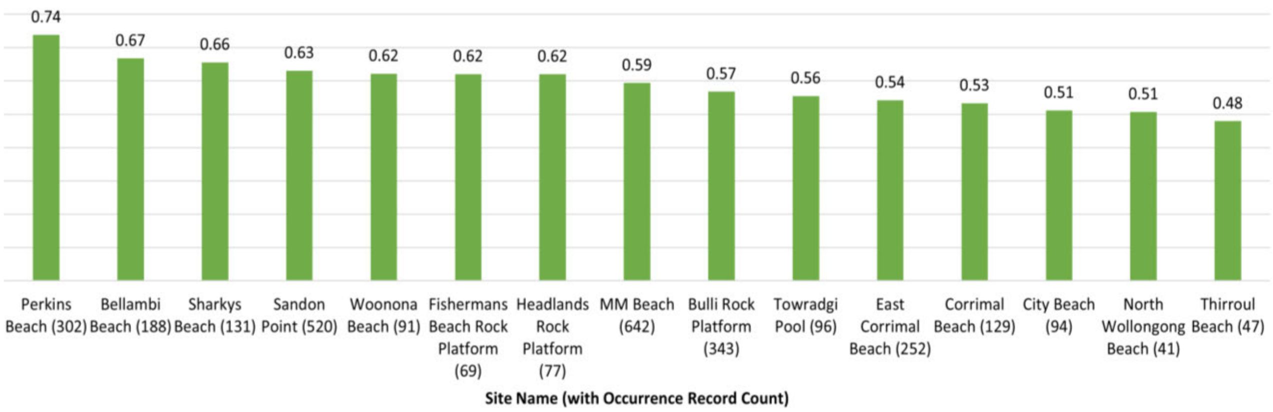


Figure 4.10: Simpsons Index Value of each beach within the LGA with more than 40 occurrence records between 1970-2023. The count of records is displayed next to the beach name in brackets.

4.2.3 Domestic Dogs – Field Results

Overall, Off-leash beaches demonstrated the highest average dog count at each site, followed by timed-off leash and no dog zones. Between the times of 7:00am-9:00am and 3:00pm-5:00pm, the following average dog counts were observed on each study site. On off-leash beaches, mornings and evenings were precisely equal in the average dog count per period. Field data demonstrates a broad variation in the distribution of dog visitation data between each beach. This is exaggerated further between the dog access zones, with no comparable median, indicating a possible statistically significant difference between each dog zone to be further tested.

The analysis of off-leash zones reveals distinctive patterns among the surveyed sites. Sharkys (7 dogs/15min), MM (4.9 dogs/15min) and Fairy Meadow (4.5 dogs/15min) demonstrate the highest overall spread in the distribution of data. These sites, particularly Sharkys and MM, had a higher variability and were overall less predictable in the count of dogs per visit. Fairy Meadow demonstrates a more normally distributed dataset and is the only site where the data is spread in this way. When compiled (Figure 4.11, B), the off-leash zone has an overall high distribution of data and is slightly positively skewed, with no outliers. 4% of dogs were still on-leash during their activities.

Thirroul (1.88 dogs/15min), Fisherman's (1.88 dogs/15min), and Towradgi (0.63 dogs/15min) demonstrate a slightly smaller distribution, with the first quartiles (Q1) of Fisherman's and Towradgi plotted against the x-axis due to the prevalence of zero (absent) dog counts in the data. Notably, all the box plots within this zone display a negative skewness. When aggregated and visualized in the timed on-leash plot (Figure 4.11, B), a similar pattern emerges, with Q1 plotted on the x-axis and a more normally distributed spread. It's noteworthy that only 33% of the observed dogs remained on-leash for the entire observation period.

The assessment of no-dog zones reveals specific data patterns. North Wollongong (0.25 dogs/15min) and Port Kembla (0.25 dogs/15min) present data with an identical spread, featuring median scores of 0 (absent) plotted against the x-axis. On these beaches, the highest count of observed dogs was merely 1. In contrast, Coledale (0.38 dogs/15min) exhibits a unique pattern with no plotting and a single outlier, stemming from a dataset comprising exclusively 0 (absent) counts with the exception of a single count of 3. When combined into the zone plot (Figure 4.11, B), any data points above 0 (absent) are considered outliers, resulting in no visible plot for this particular zone.

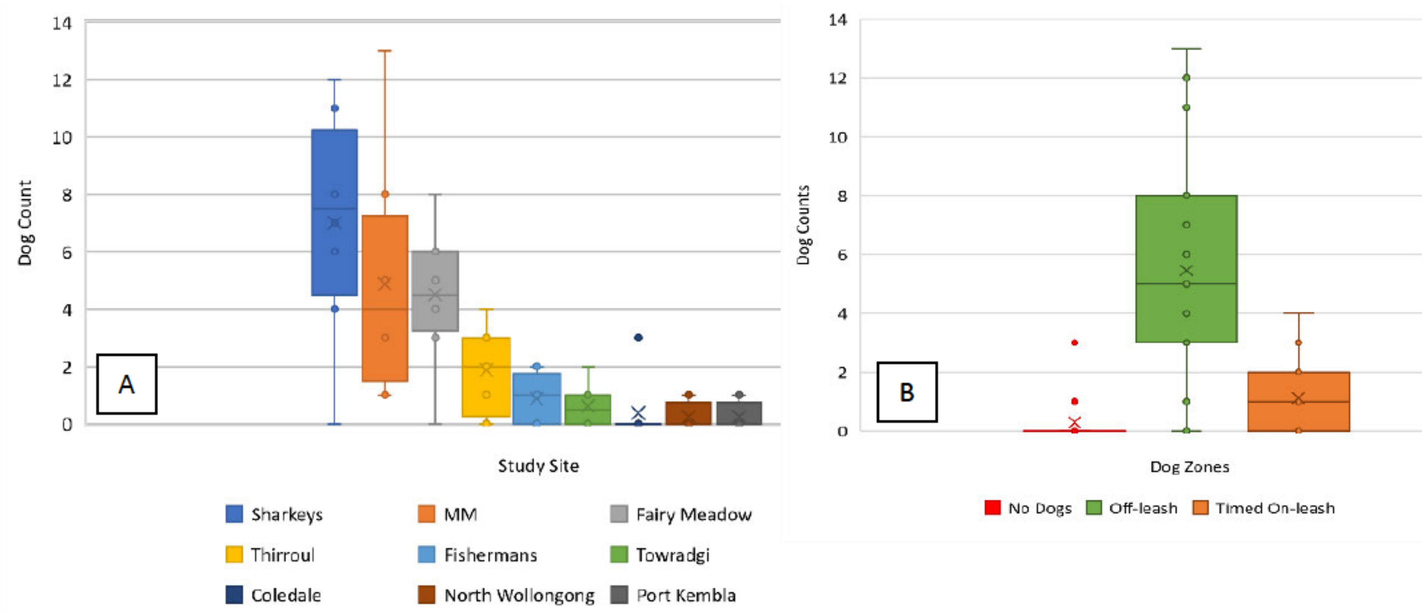


Figure 4.11: Box and whisker plots of the dog counts from field study in Winter of 2023 at each of the 9 study sites (A) and of each dog access zone (B). Sharky's, MM and Fairy Meadow (A) are off-leash beaches (B), Thirroul, Fishermans and Towradgi (A) are timed on-leash beaches (B), and Coledale, North Wollongong and Port Kembnla (A) are no-dog beaches (B).

Results of the Wilcoxon rank-sum test when sites are compared indicate that there are no statistically significant differences between each site with the same dog access zone, with mixed results between sites of different dog access zones (table 4.2). Results between off-leash (Smith et al.) and any other dog zone demonstrate a statistically significant difference. However, results between no dogs (red) and timed on-leash (orange) are mixed, and there is not enough of a statistically significant difference between no dogs and timed off-leash beaches to make a conclusive distinction.

	Coledale	*Fairy Meadow*	*Fisherman's*	*MM*	*North Wollongong*	*Port Kembla*	*Sharkys*
Fairy Meadow	0.014						
Fisherman's	0.159	0.020					
MM	0.014	0.856	0.021				
North Wollongong	0.741	0.014	0.159	0.014			
Port Kembla	0.741	0.014	0.159	0.014	1.000		
Sharkys	0.014	0.159	0.020	0.332	0.014	0.014	
Thirroul	0.057	0.042	0.212	0.132	0.042	0.042	0.025
Towradgi	0.287	0.019	0.643	0.016	0.343	0.343	0.019

Table 4.2: Wilcoxon rank-sum test output in R Studio, table caption 'Pairwise comparisons using Wilcoxon rank sum test with continuity correction' between each of the 9 study sites. Color of cell denotes off-leash (green), timed on-leash (orange), no dogs (red), p-value >0.05 (yellow), and p-value <0.05 (blue).

When counts for each site are combined by their corresponding dog access zone, there is a strong statistically significant difference between each zone (table 4.3). Although the value between timed on-leash and no dogs is the highest, it is well within the significance level of 0.05. In comparing the total found of dogs observed during the field study and the total number of occurrence records at each site, there is no observable correlation between the two datasets (Figure 4.12).

	No Dogs	*Off-leash*
Off-leash	1.8e-7	
Timed On-leash	0.0025	8.2e-06

Table 4.3: Wilcoxon rank-sum test output in R Studio using Wilcoxon rank sum test between each dog access zone.

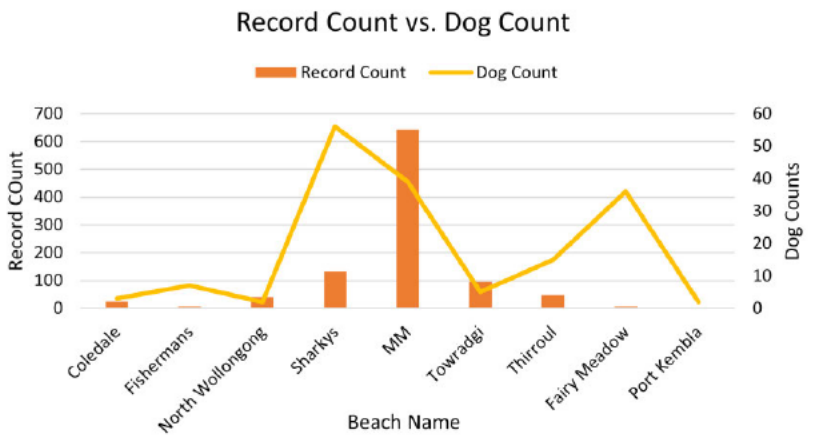


Figure 4.12: Combination graph between the count of record and count of dogs for each of the 9 study sites.

4.2.4 Human Visitation

Overall, beach usage is highest at the beach entrance points, as shown in yellow in Figure 4.13's heat maps. Usage is lowest towards and on headlands and rock platforms. This is evident at Coledale, Fisherman's, and MM, all of which have prominent rock platforms and headlands enclosing the beach (Figure 4.13). Beaches that are bordered by other beaches like Fairy Meadow, or beaches with a larger stretch of beach like Thirroul better evidence a concentration at the entrance points to each beach.

Human Visitation to Each Site

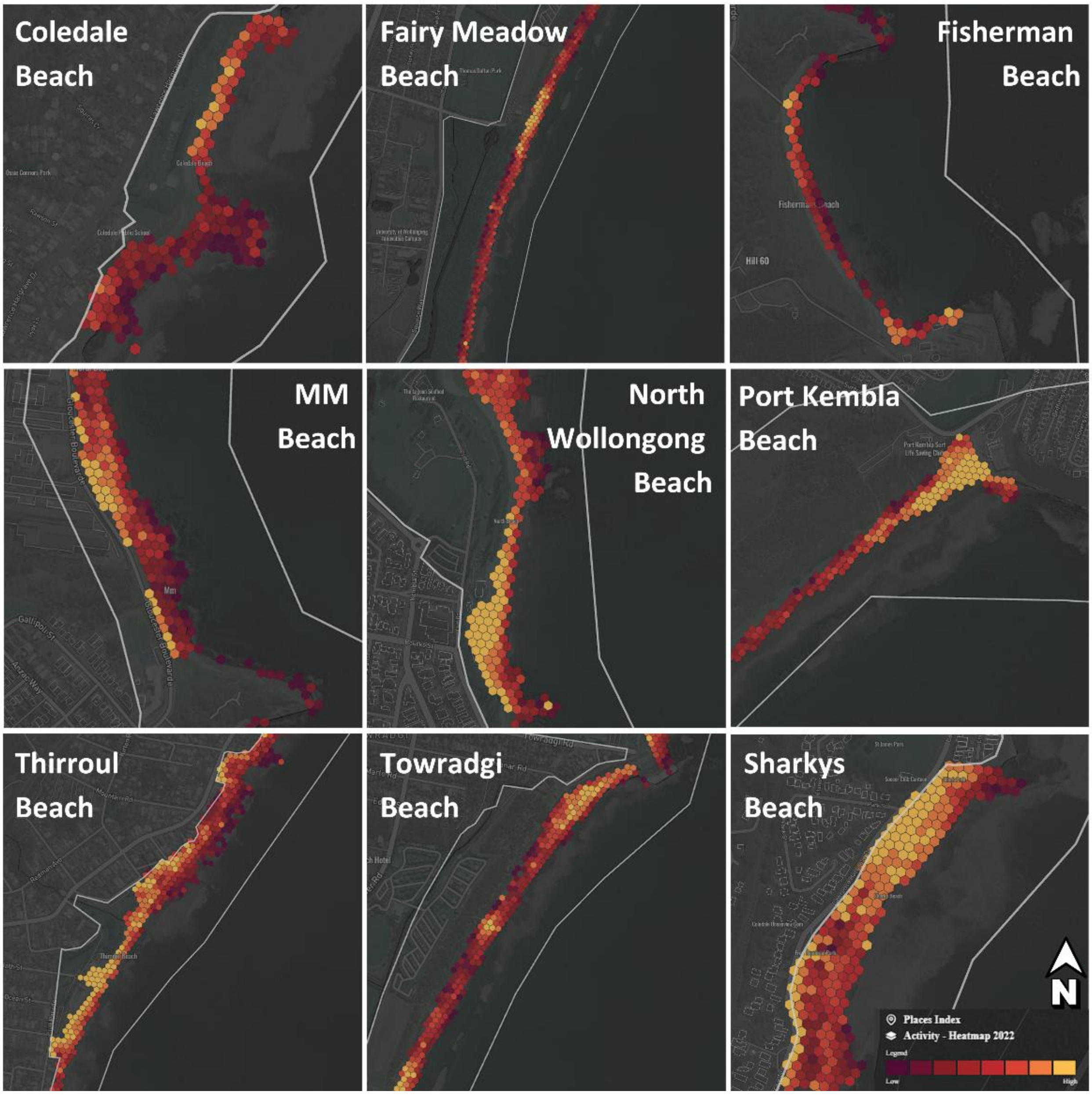


Figure 4.13: Heap maps of human visitation data sourced from the Place Intellegence Geodata Studio.

The percentage of total usage for each of the 9 beaches is summarized by rank in Figure 4.14 below, and their individual statistical summaries from Place Intelligence are arranged in Appendix B. The three most popular beaches among the 9 are Thirroul, Port Kembla and North Wollongong. Each has a more even spread of visitation throughout the week, with Sunday at the highest proportion of visitation (between 17-25%). Sunday is also the most popular day for Towradgi (28%), MM (17%) and Fisherman's (30%). Coledale is the only beach with the highest day on a weekday: Thursday (21%). Fairy Meadow and Sharky's highest day is Saturday (27%, 16% respectively). Each beach experiences contrasting monthly fluctuation in visitation throughout the year; Sharky's is unique across the study sites and is most visitation through the summer months of December – February, while beaches like Fairy Meadow, North Wollongong, Fisherman's, Port Kembla, Towradgi and MM have a generally even distribution of visitation across each month, all with a steep influx in April. Coledale shows an increase in February-March and a low in Winter and November-December, while Thirroul trends highest in Autumn and Spring, with lows in Winter and Summer.

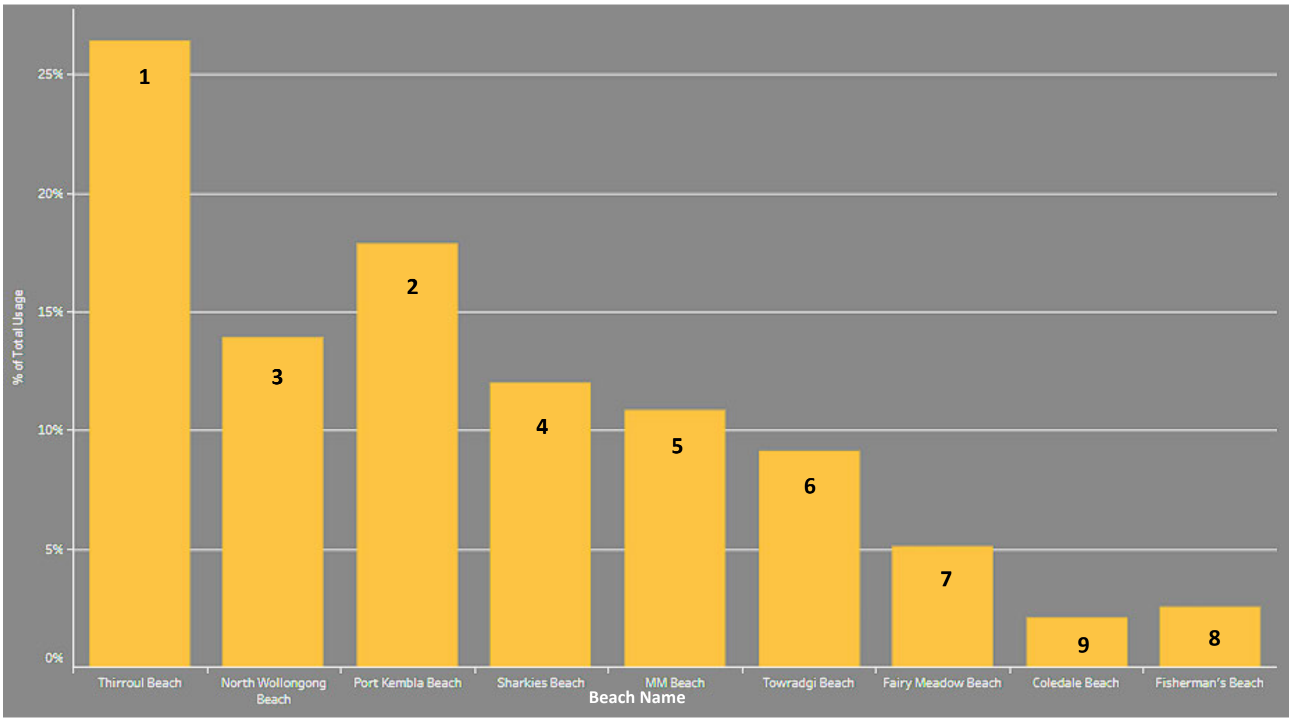


Figure 4.14: Each of the study sites and their percentage of overall beach usage in 2022. Number between 1-9 indicates rank from highest (1) to lowest (9) percentage of usage. Derived from place intelligence interface.

Across all of Wollongong's beaches, Sunday is still the most popular day of the week (17%), as evidenced in Figure 4.15 (B). The busiest time of day picks up between 9:00am-5:00pm, with the highest visitation between 12:00pm-1:00pm. The year is generally evenly spread between the months with an influx in April and a decrease in December across all beaches of the LGA. Comparing all beaches in the LGA, South Wollongong Beach has the highest annual visitation and accounts for 13% of total beach visitation across Wollongong, followed by Belmore Basin/Brighton Beach, and then Thirroul Beach (Figure 4.16).

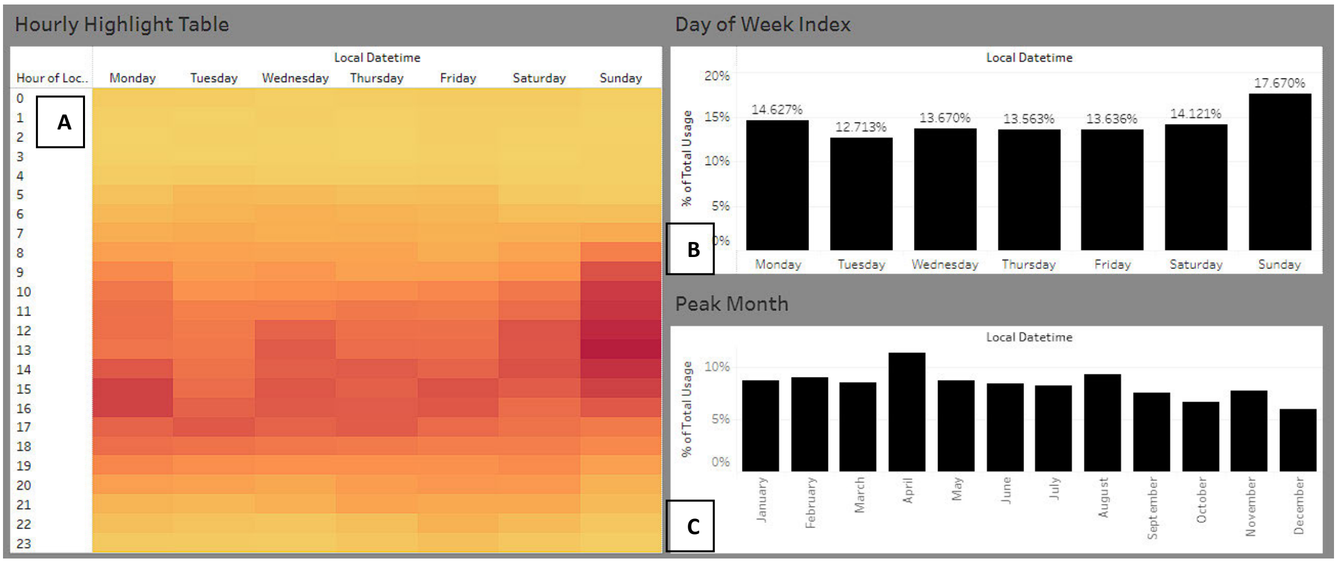


Figure 4.15: Heatmap of visitation throughout the day by hour (A), throughout the week by day (B), and the year by month (C) for all beaches in the Wollongong LGA. Red denotes highest visitation and yellow denotes lowest visitation. Derived from place intelligence interface.

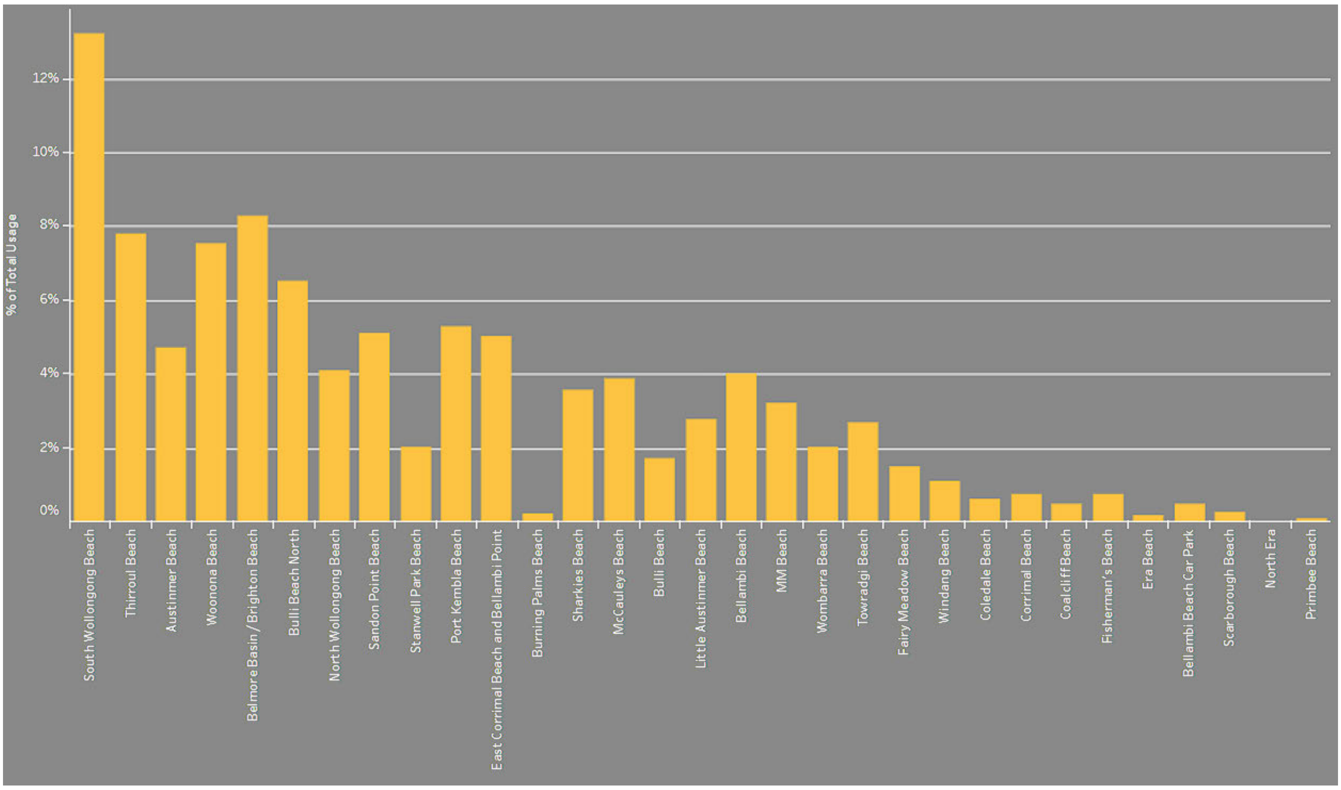


Figure 4.16: Bar graph of each beach in the Wollongong LGA and their respective proportion of beach usage. Derived from place intelligence interface for 2022.

4.3 Citizen Science Databases

Of all records, represented in Figure 4.17, eBird is the highest contributing database with 31,399 records across the LGA. This is followed by BioNet Atlas at 3217 records and Birdlife Australia with 912 records. To consider only the beaches within the LGA, eBird contributes 3052 records, BioNet Atlas contribute 83 and Birdlife Australia contributes 60. As a percentage, eBird contributes 88.4% of the records in the LGA, and 95.5% of the records on beaches within the LGA.

The historical records are contributed entirely by NSW BioNet Atlas before 1998, who then contribute 17.5% of the record along with Birdlife Australia at 53.1%, then eBird at 29.4% between 1998-2009. Between 2010-2023, eBird contribute 95.7% of records in the LGA, followed by BioNet at 3.2% and Birdlife at 1.0%.

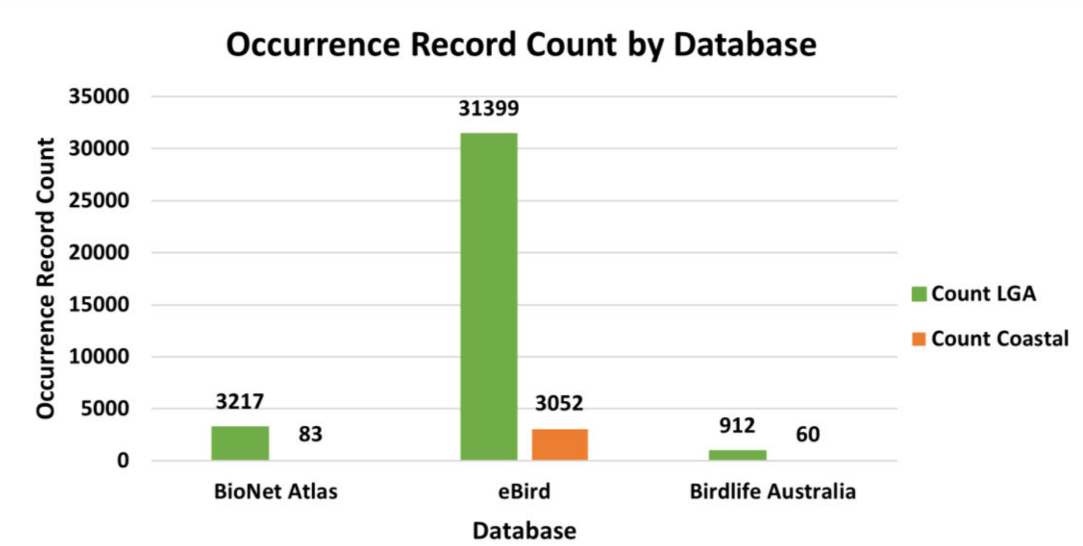


Figure 4.17: The proportion of occurrence records within the Wollongong LGA contributed by each database between 1970-2023 from eBird, NSW BioNet Atlas and Birdlife Australia.

4.3.1 eBird vs. BioNet Atlas Species Representation

The proportion of species with the conservation status 'least concerned' appears evenly between the two databases. For Silver Gulls, the species with the highest record count, the proportion of records between each database is approxmiately 50/50 (Figure 4.18). Overall, eBird contributes a higher proportion of data for vulnerable and endangered species within the database. They contribute all of the available data for the endangered Lesser Sand Plover, Bush-stone Curlew and Great Knot, and the vulnerable Black-tailed Godwit, Great Sand Plover, Australian Painted Snipe, and Banded Stilt. Conversely, BioNet Atlas contributes all the available data for the vulnerable Crested Tern and Hooded Plover. This data is represented in Figure 4.19. The occurrence data between these two databases differs temporaly, where the majority of BioNet Atlas data is contributed pre-2010, and eBird post-2010.

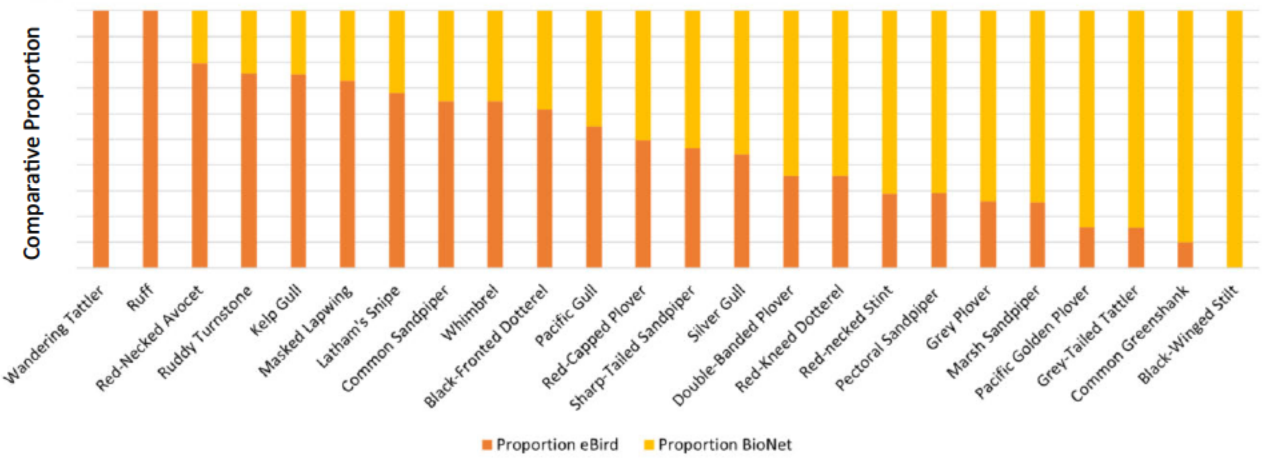


Figure 4.18: Occurrence records for the Wollongong LGA between 1970-2023 between eBird and BioNet Atlas. Species in this graph have the conservation status of 'least concern'.

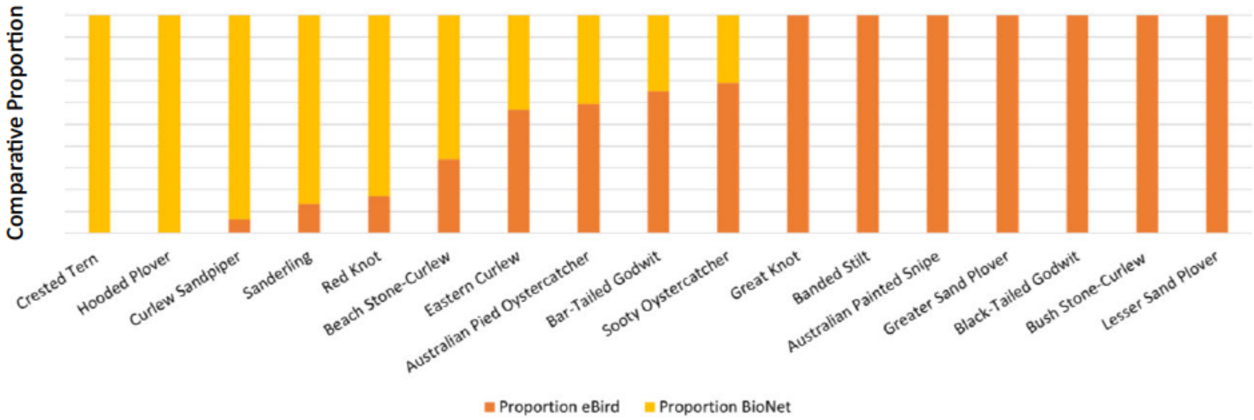


Figure 4.19: Occurrence records for the Wollongong LGA between 1970-2023 between eBird and BioNet Atlas. Species in this graph have the conservation status of 'vulnerable', 'endangered' or 'critically endangered' – refer to 'Shorebirds of Wollongong' for conservation status.

4.3.2 Observer Efforts on the eBird Database.

There are 527 users that have submitted at least 1 survey within the Wollongong LGA. 14 of those users have contributed 99% of the observation records for all beaches (Figure 4.21) between 1970-2023. The observer with the highest contributions (obsr450380) contributed 670 records of 12 shorebird species between 2012-2021 (9 years) at 14 different beaches across the LGA. MM Beach has the highest record count of the 54 coastal polygons with 643 records. 87% of these records are contributed by 3 users only (Figure 4.20).

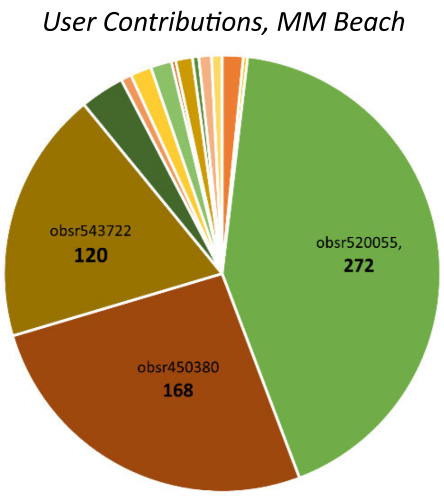


Figure 4.20: Pie chart of the proportion of records contributed by each user on MM beach, Wollongong.

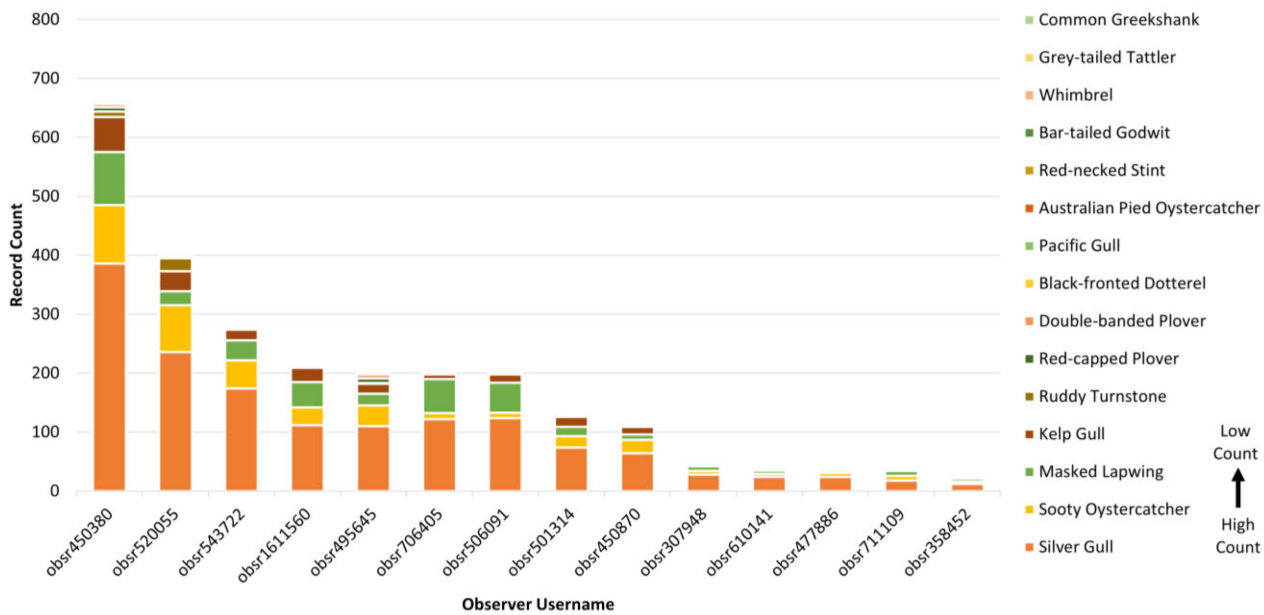


Figure 4.21: User Efforts and the proportion of counts towards each species record. Legend is ordered from highest species count (bottom) to lowest species count (top). Graph includes 14 users, who contribute 99% of the records.

5 Discussion

5.1 Baseline Inventory of Shorebirds in Wollongong

In this discussion section, a comprehensive presentation and analysis of the research findings and their implications will lay a base for conservational recommendations to the WCC, and for future ecological studies of shorebirds in this region. The primary aim of this thesis was to source the available occurrence records for shorebird species that are present on the Wollongong LGA's open coastline, aligning with the recommendation of the Stage 1 Scoping Study for the WCC's CMP. This was prompted by concerns of outdated data and a lack of ecological studies in Wollongong, which led to a recommendation to produce an inventory of shorebird species and their associated threats. To accomplish this, all occurrence records from eBird, Birdlife Australia and BioNet Atlas were accessed through the GBIF website for the Wollongong LGA between 1970-2023. Two spatial scales were used to inventory which species have been recorded and where they are being observed: the Wollongong LGA as a whole, and the coastline from Garie Beach in the north to Windang Beach and Lake Illawarra in the south of the LGA. By examining the broad trends and patterns across the LGA, a more comprehensive ecological context can fill the gaps in surveying across the coastline.

This thesis was structured around 3 key objectives: a) identify the assemblage of shorebird species that are present in the LGA, the extent of occurrence records for each species, and pinpoint the beaches where these species are mostly observed, b) to investigate the overlap between shorebird habitat within the Wollongong LGA with domestic dogs and human visitation as key threats, and c) to evaluate the occurrence records sourced from citizen science databases to discuss the potential for their integration into assisting the development of management actions for the WCC Open Coastline CMP. Finally, each of the key research findings will aid in supporting a set of conservational management recommendations that incorporate the density of occurrence records, the extend of dog and human visitation patterns, and future projects for obtaining shorebird occurrence data through citizen science efforts.

The occurrence records of shorebirds from the citizen science databases provided a moderate degree of insight into the objectives outlined in this thesis, as illustrated by the following summary of species distribution within the LGA. Of the 49 species shortlisted, 40 species had 1 or more record in the Wollongong LGA (figure 4.3). Of these records, Silver Gulls and Masked Lapwings comprised the majority (82.4%). The records were concentrated in or near areas of shorebird habitat along the open coastline and Lake Illawarra, with hotspots including Bellambi Park, Port Kembla and Hill 60 Lookout, Puckey's Lagoon, Windang Peninsula and inland at the Wollongong Botanic Gardens (figure 4.1). Cumulative annual occurrence records for residential species did not demonstrate the expected trend of year-round presence, and were instead only recorded in October through January; the exception of this is the Silver Gull, which was observed all year-round excluding February (figure 4.2). However, observations taken during the field between June-August demonstrate that at least 5 species of residential shorebird are present during this time. Migratory species records exist only in October and January and are not represented consistently in the expected months (September-March). Records exist for 15 of the 19 threatened species, primarily located around Lake Illawarra, Windang, and Perkins beach, or scattered along the coastline and inland close to creeks. The threatened Sooty Oystercatcher, Bar-tailed Godwit, and Eastern Curlew stood out with over 200 records each, spiking between 2017-2018, followed by a drop in 2019 and a gradual increase, especially for the Sooty Oystercatcher with an increase from 221-329 records from 2020-2021 (table 4.1).

The spatial distribution of occurrence records is strongly correlated with landforms of significance for shorebirds, drawing birdwatchers in. For instance, the Wollongong Botanic Gardens hosts a birdwatching tour on the 1st Thursday of each month with a guide from Illawarra Birders and is a popularly recommended location for birdwatching in Wollongong among birdwatchers on social media. While the Wollongong Botanic Garden supports a diverse range of species, it is particularly appealing to birdwatchers, resulting in the highest user count within Wollongong. Its proximity to UOW may also be a key contributing factor, utilized as a teaching tool for university students and other levels of school alike. Similarly, Bellambi Park shares features that appeal to birdwatchers, including an accessible walking loop across Bellambi Lagoon Nature Reserve. Just south of Bellambi Park is Puckey's Estate Nature Park, another location with a notable record count, featuring an accessible nature walk and public amenities. Consequently, areas with a better opportunity for birdwatchers to capture occurrence records tend towards a higher concentration of records. Therefore, evidence suggests that the accumulation of a location-specific inventory of species with higher completeness is most probably tied with the accessibility of the location to birdwatchers (Jacobs & Zipf 2017). In contrast, locations like Greenhouse Park, situated north of Tom Thumb Lagoon and containing wetlands, lack accessible routes or amenities and have yet to accumulate many occurrence records. As this park undergoes a Remedial Action Plan from 2023-2025, there exists an opportunity to encourage the birdwatching community to explore and survey this area.

On beaches and rock platforms of the Wollongong LGA, 18 out of the 49 shortlisted species for this analysis were observed (figure 4.8). Of the 54 polygons used to distinguish coastal boundaries, 33 contained at least 1 occurrence record (figure 4.7), with no clear geographical trend. Comparing the 9 study sites observed during field surveying with the citizen science data, only Port Kembla had no occurrence records. The zoning of Port Kembla is, however, comparatively small and is bordered by Perkins Beach, which has >300 records. For the annual occurrence records, the field observations revealed a discrepancy in species presence from June to August. During 72 visits to the 9 study sites, we observed four residential shorebird species (Sooty Oystercatcher, Masked Lapwing, Great Crested Tern, and Kelp Gull) that were not documented in the occurrence records for the same period. In terms of biodiversity, Perkins Beach is the most diverse polygon in the Wollongong LGA according to its Simpson's Index value of 0.74. It held both the highest species richness in the record with 14 different species, and a more even count of records between species. Bellambi followed closely behind with 11 recorded species. Sharkys and Sandon Point beaches, while relatively low in species richness (5 and 6 species, respectively), had higher Simpson's Index values due to a more proportioned record count between species. Beaches like Thirroul and North Wollongong had lower Simpson's Index values due to their remarkably high proportion of Silver Gull records, a limited range of species, or a combination of both factors.

In addressing the lack of consistent annual records for residential shorebird species, it is difficult to conclusively summate any one reason. Other studies of citizen science databases have also identified this seasonal decrease in occurrence records (Jacobs & Zipf 2017). The field studies conclude that, at the very least, a small group of 5 shorebird species can be found on the coastline during the winter months, and the occurrence records may improve if the registered Wollongong users for eBird and Birdlife Australia begin to deliberately survey sandy beaches and rock platforms during the winter months. There are, however, temporal trends in the occurrence records that are highly likely to be related to annual events, like the October diversification of records. The spike in observations in October of all species other than the Silver Gull can be directly attributed to the active involvement of the birdwatching community. These events are the 'Aussie Bird Count' held by Birdlife Australia, and eBird's event known as 'October Big Day'. Each year, these events strategically align with the arrival of 2 million migratory shorebirds in Australia. Both databases promote these events extensively throughout the year to encourage new and experienced birdwatchers to participate. From an annual trends' perspective, the growth of the eBird and Birdlife Australia userbases has increase the number of occurrence records submitted each year, lifting off in 2014 and growing substantially. As the database grows, so too does the spatial resolution of these yearly counts across the Wollongong LGA and across Australia.

Of course, factors other than user efforts have impacted the annual occurrence records for the Wollongong LGA. Examining the balance between user efforts and actual shifts in the assemblage of shorebirds in Wollongong requires a complex understanding of both anthropogenic and ecologically significant events that impact the long-term records. Over recent years, particularly between 2019-2020, there has been a decline in annual record counts that may be due to two major anthropogenic events. These events were the 2019-2020 Black Summer Wildfires that devastated a range of ecologically significant communities across Australia, and the 2020-2021 Covid-19 pandemic public health orders and restrictions. These events are important to understand to make the appropriate corrections to the data for future use by WCC.

The black summer wildfires began to escalate at unprecedented rates in August 2019, and resulted in a death and displacement estimate of over 3 billion animals, including 180 million birds. The birdwatching community faced reduced surveying opportunity as Australia-wide governments advised that these fires posed a public health risk due to poor air quality and urged the public to remain indoors. The impacts to birds were both the direct fatalities by fire and smoke in affected areas, and the loss of breeding and feeding grounds across the East and South Coast, although the precise impact on shorebirds and their habitats is currently unstudied in Australia. A study of eBird occurrence records before and after the Black Summer fires indicated a shift in the number of records for certain species (Lee et al. 2023), and eBird Australia released a statement estimating that bushfires and drought will continue to threaten birds and their habitats as climate change increases in severity (Tulloch 2020). Similarly, findings from Hochachka et al. (2021) found that changes in eBird user behaviour occurred during the 2020-2021 Covid-19 pandemic, and that the representation of species found in wetlands dropped during this time, while species found in human-dominated areas increased in representation. The stay-at-home order imposed in NSW was in effect from March of 2020 and extended until May, which included periods of restricting non-essential travel and gatherings, limited outdoor exercise, or travelling far from the residence. In June and July, stay-at-home orders were imposed for Wollongong among other East-Coast regions and included the closure of campgrounds and some beaches to reduce the spread. May through to October saw the easing of restrictions, with continued precautionary public health orders into 2021.

All research comes with its set of limitations, and it is essential to acknowledge them to maintain the integrity and credibility of these findings. The Australian Eastern coastline is documented to contain many key stopover and breeding locations for migratory and residential species of shorebirds. Indeed, the presence of shorebirds on the Wollongong coastline is an expected part of the coastal ecosystem, particularly with the presence of sandy beaches, rock platforms, offshore islands, and other wetland types. However, the availability of shorebird data through citizen science resources or BioNet Atlas is quantitatively limited for many of the species researched during this project. Due to this limitation, species-specific recommendations for their conservation are unlikely to be effective based on the data presented in the following results section alone. The extent of the data presents several analytical challenges for effectively determining an accurate distribution and abundance model, or a detailed baseline inventory for shorebirds in the LGA. Having access to 50 years of occurrence records between the 3 databases has produced a record for 40 species of shorebird in the LGA, and 18 species specifically for application to the CMP for the open coastline. Conversely, there is an overall absence of completeness in surveying across the coastline, where only 33 of the 54 coastal polygons contain a record. Through examining the distribution of occurrence records across the LGA, observing areas of high or low record concentration is likely a testament to user effort and opportunistic surveying, not an accurate distribution of species. In addition to the spatial biases demonstrated in the records, large temporal variations are present in the decadal and annual trends in shorebird records. With these limitations in hand, an in-depth discussion of the best practices suggested when incorporating citizen science data into ecological studies will be laid out in subsequent sections.

5.2 Threats to Shorebirds in Wollongong

Having established an understanding of the current shorebird species present in the Wollongong LGA, their distribution patterns, and the influence of various factors on occurrence records, the focus is shifted towards the critical aspects of their conservation. In this context, a discussion of two of the key threats that shorebirds face on the Wollongong coastline is undertaken. This project observed the spatial patterns of dog visitation and human visitation to assess the potential overlap with the occurrence records and expected shorebird habitat. In addressing the objective of an analysing whether dog zoning is an effective tool for eliminating dogs on no-dog beaches, a comparison between the sites individually and their respective dog zone allocations was performed. Overall, off-leash beaches yielded a zone average of 5.5 dogs/15 minutes, timed on-leash yielded 1.4 dogs/15 minutes, and no-dogs yielded 0.7 dogs/15 minutes. At least 1 dog was counted at every site. Although the comparison between individual sites was inconclusive, there is a statistically significant difference between the zones. Leashing compliance for on-leash beaches was followed for only 33% of dogs observed, and on the other hand, off-leash beaches still had 4% of dogs on-leash. Between occurrence record and dog count overlap, there is no observable correlation (figure 4.12).

For human visitation, the spatial patterns were generally consistent across the 9 study sites and included a decreased concentration towards rock platforms and headlands, and an increased concentration fanned around beach entrance points and towards the shoreline. Across the LGA, Sunday is the most popular day to visit a beach in Wollongong, and between 12:00pm-1:00pm is the most popular time. Coledale deviates from this weekly norm, where Thursday is the most popular day. Visitation throughout the year is generally steady, with a spike in April and a low in December. Each beach in Wollongong may vary from this overall trend, with some minor deviation from beach to beach, but of the 9 study sites, each loosely follows this weekly and annual trend. Of the 9 study sites, Thirroul is the most popular beach, followed by Port Kembla throughout the year. Across all of Wollongong, South Wollongong Beach is the most popular beach.

According to WCCs 'Dogs on Beaches and Park Council Policy', Council aims to balance both the needs of the dog owning community by providing off-leash and timed on-leash zones and protecting wildlife by allocating dog-free recreation areas. The field data analysis demonstrates that implementing detailed and informative physical signage (as depicted in Figure 5.1) and online information on WCC's website plays a crucial role in reducing non-compliant domestic dogs' presence on no-dog beaches. This impact is shown at Port Kembla, North Wollongong, and Coledale. Additionally, our examination of occurrence records for the Sooty Oystercatcher suggests that the installation of informative signage (as shown in Figure 5.1) may have contributed to an increase in observation submissions. Signage includes their conservation status, rock platform habitats, and dog control requests. In the 2020-2021 period, records surged from 221 to 329, surpassing the increases in submission counts for other commonly reported species like the Bar-tailed Godwit or Eastern Curlew during the same years. While there were isolated instances of dogs on each of these beaches, they were treated as outliers within the overall dataset. However, the presence of dogs in no-dog zones during the field study should be included in future field studies of dog occurrence, as they may represent a more significant issue for other no-dog beaches in Wollongong. Regardless, this finding partially resolves the analysis of whether dog zoning is reflective of actual dog visitation counts, concluding that for no-dog beaches, zoning is effective.

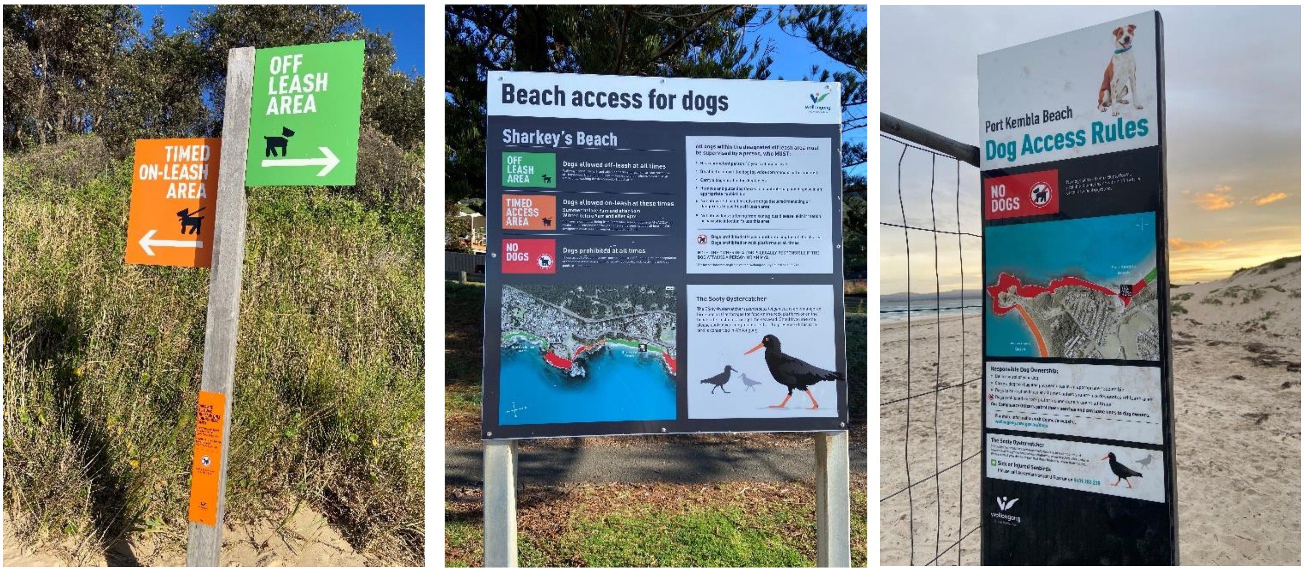


Figure 5.1: Signage that indicates dog zone boundaries at Sharky's Beach (left), detailed beach signage for dog zones across Sharky's rock platforms and adjacent beach compartment (middle), and detailed beach signage for Port Kembla beach and adjoining Perkin's Beach zone boundaries (right).

However, it's important to note that timed on-leash zones did not receive adequate compliance from the public. At timed on-leash beaches like Towradgi, Thirroul, and Fisherman's, only 33% of observed dogs were on-leash, limiting the ability to definitively conclude that dog zoning is effective tool for controlling dogs, or that actual usage reflects the dog access zone allocation. This pattern of non-compliance for on-leash regulations has been observed in similar field studies conducted by Williams et al. (2009) in Victoria, Australia and Bowes et al. (2017) in Pacific Rim National Park in British Columbia, Canada. Both studies found that increased awareness of a dog's threat to wildlife and the perceived social normality of leashing dogs may have an impact on the attitudinal barriers that enable the public to disregard on-leash regulations. They also recognized the challenge of distributing funds for direct enforcement efforts and suggested a more confrontational approach to educating the public about the potential harm domestic dogs can cause to shorebird eggs, chicks, and adults.

The ability to compare the visitation of dogs and the visitation of humans across the 9 sites is limited for the available data examined throughout this thesis, however, similar studies such as Cortes et al.'s (2021) study of dog presence on sandy beaches in Southern Chile found a positive correlation between increased human population and increased dog presence on beaches. Additionally, Gomez-Serrano's (2021) study of human versus dog disturbance on tourist beaches in the Mediterranean found that dune-nesting plovers were twice as likely to flee in response to dogs than they were for humans. Dogs unaccompanied by humans caused plovers to flee 100% of the time. Although each of these studies produced findings outside of the scope of this thesis, the Wollongong LGA has an increasingly urbanized coastline with a high rate of dog ownership. In addition, the lifestyle of the population of Wollongong influences the dynamics of beach visitation in comparison to other regions that studies have been conducted, including the large community of surfers that use Wollongong beaches all year-round. Thus, the lack of field studies dedicated to quantifying the impacts of dogs on beaches is alarmingly scarce for the Wollongong LGA, and although rock platforms are protected under the dog access regulations of WCC, dune systems are not. To address this gap in our understanding, conducting comprehensive annual dog counts, along with concurrent human visitor counts, could offer a path to correlating the WCC's human visitation study with quantifiable dog frequencies as the population of the WCC continues to grow.

Regarding the limitations of the dog surveying, there are a few key limitations to be considered in future studies. This small-scale field study was conducted during the winter months of 2023, when temperatures during 7:00am-9:00am are between 7-9 degrees Celsius, and 15-17 degrees Celsius between 3:00pm-5:00pm. The days are shorter, and the sun is set before the standard business closure of 5:00pm. Additionally, daytime walking outside of the observed hours for this field study are more comfortable for dogs and their owners. These variations have an unknown impact on dog visitation, although a general assumption of dog owner culture would dictate that a walking regime may pick up in the morning and evening when the daytime temperature is more extreme, or the days are longer in the spring and summer months. For these reasons, this field study is temporally limited for the Wollongong LGA's high dog ownership statistics and should be seen as a guideline for future surveying of dog visitation.

5.3 Summary of Conservational Recommendations

Through a culmination of record counts, species diversity analysis, off-leash dog zone allocation, and geographical proximity to Lake Illawarra and Korrongulla Wetlands within the Windang Peninsula, these findings recommend that Perkin's Beach be considered a priority site for the implementation of additional protective measures for shorebird. Further, this beach and region was identified as possessing high ecological value in the Wollongong Dune Management Strategy, stating that several shorebird species have been observed 'and would be expected to fossick and roost above the high water line amongst the spinifex dune vegetation' (Coastal Environment Pty Ltd 2012, p. 128). Although the CMP for Lake Illawarra encompasses much of the Windang Peninsula, including the channel between Windang beach and Windang Island, as well as all of the shores of Lake Illawarra, a specific program for Perkin's Beach would equally benefit the diversity of shorebird species observed in this region. Temporary seasonal bans of dog access to Perkins beach is a solution recommended in studies of the impact of recreational activities to shorebird habitat in Moreton Bay Marine Park in Queensland (Stigner et al. 2016), and again in Bowes et al. (2017) study of dog walking compliance behaviours, and has been put into effect in the Auckland LGA, New Zealand to protect shorebird nests. Other key sites include Puckey's Estate and Bellambi Park, both of which are recommended locations for scouting studies for nest protection measures during the spring and summer months.

In conjunction, the use of clear signage and 'predator exclusion caging' to protect nests from domestic dog, fox and cat predation as well as accidental human disturbance can be implemented, as has been done with successful outcomes by the SCSRP in figure 5.2 (SCSRP 2019a). Battisti et al.'s (2022) study tested cage use for the conservation of Kentish Plover and Little Ringed Plover nests on the Tyrrhenian coast of Italy used false eggs and nests with and without cages, and found that the their use greatly increases the hatching success. Recruiting dedicated citizen scientists for a monitoring program in Wollongong is possible; the SCSRP has over 100 volunteers that erect temporary nest caging, deposit sandbags at nesting sites to protect from inundation, take surveys to scout for nesting sites, and participate in public outreach. As of right now, there are hundreds of registered eBird and Birdlife Australia users that have submitted surveys for the Wollongong LGA on their own time. The Shoalhaven City Council, working with the SCSRP, the NPWS, and community volunteers, has successfully increased the count of nests of threatened species like the Hooded Dotterel and Little Tern over recent years by implementing these measures of protection (Shoalhaven City Council 2023).

Figure 5.2: Photographs of the conservational strategies used by the SCSRP: erection of signage to indicate nesting areas (right), and wire caging to prevent predation of shorebird nests (left).

There are several key species that are a focal point of the SCSRP that WCC should consider hosting species-specific ecological studies for. These species are the Hooded Plover, Little Tern, Pied Oystercatcher, Sooty Oystercatcher and Beach-stone Curlew. Due to the Five Island Nature Reserve, a breeding ground for both the Sooty and Pied Oystercatcher, these two species maintain a higher count of occurrence records along the coastline. However, the Hooded Plover has not been seen as a vagrant since 2012, and there are no records of Little Terns in Wollongong although a breeding subspecies of Eastern Little Tern have been observed along the East Coast. Similarly, a Beach-stone Curlew has not been observed in Wollongong since 2014, although surveyed several times in Windang previously. To scope whether any of these species continue to nest in Wollongong, a scouting study is recommended for Windang and Perkin's dune systems, where they have been observed previously. As outlines in the 'Best practices guideline: managing threatened beach-nesting shorebirds' (Department of Environment and Climate Change NSW 2008), the implementation of a monitoring program begins with the identification of key sites. To summarise, the following strategies and recommended actions are outlined in table 5.1.

Strategy	*Locations*	*Recommended Action*	*Desired Outcome*	*Sources*
Dog Control Signage	Timed on-leash and off-leash beaches, especially Perkins, Sharkys and MM.	Erect educational signage warning owners of their dog's impact to shorebird eggs, chicks, and adult mortality, particularly during spring and summer.	Increase leashing compliance on timed on-leash beaches and increase controls on off-leash beaches.	(Bowes et al. 2017) (Department of Environment and Climate Change NSW 2008)
Dog Visitation Surveying on Beaches	All beaches of the LGA.	Counting dog visitation concurrently to human visitation over an annual period and across each dog access zone.	Predict the impact of dogs on beaches as the population grows.	(Cortés et al. 2021)
Scouting Study for Nesting Locations	Priority beaches are Windang, Perkins, Puckey's Estate and Bellambi Park.	During the spring and summer months, surveying should be conducted to locate shorebird nesting locations across the LGA.	Uncover areas for the physical erection of nest protection measures.	(Department of Environment and Climate Change NSW 2008)
Seasonal Dog and Human Bans for Nesting Areas	Beaches that allow dogs with nesting sites identified in scouting study.	Temporary dog bans on beaches with high populations of both breeding and nesting migratory and residential shorebirds.	Increased eggs and chick survival rates for both threatened and near-threatened species.	(Stigner et al. 2016)
Nesting Signage and Predator Protection	Beaches with nesting sites identified in scouting study.	Erect fencing, wire caging, and informational signage to protect nests from dogs, cats, and foxes, as well as trampling from humans.	Increased eggs and chick survival rates for both threatened and near-threatened species.	(Schoenleber et al. 2022) (Dinsmore et al. 2014) (Black et al. 2023)

Table 5.1 Summary of recommendation for conservation strategies, to be implemented as part of the shorebird component of the WCC's CMP.

In summary of the research outcomes that addressed objective a) and b), insight into the spatial and temporal patterns that BioNet, eBird and Birdlife Australia combine to produce have provided a foundation to understand the ecology of shorebirds in the Wollongong LGA. The findings emphasize the pressing need for further, strategic ecological studies of shorebirds in areas of low survey concentration, and of broader studies into the dynamics between dog visitation, human visitation and shorebird habitat overlap. Preliminary field studies of dog visitation have indicated that the current no-dog zone regulations on certain beaches through signage and public awareness is an effective tool for keeping these zones dog free, but that more must be done to improve the compliance of timed on-leash dog zones. To enhance management policies on allowing dogs on beaches, the findings and conservation recommendations from this study can be integrated by taking proactive measures, such as installing informative signage, implementing fencing, and using protective cages. Additionally, conducting regular and current ecological surveys will enable the WCC to incorporate supplementary data effectively, as sourced from citizen science databases, in a way that ensures ecological accuracy and relevance in the management of shorebirds within the Wollongong LGA.

5.4 Applicability of Citizen Science Databases in Wollongong

The integration of citizen science data into conservation efforts of shorebirds represents an approach that capitalizes on the influence of engaged community members to contribute valuable insights and observations within Wollongong. To summarize the findings of the analysis between each citizen science database and BioNet Atlas, eBird succeeds in terms of the sheer volume of occurrence records it contributes, accounting for 88.4% of the data in the Wollongong LGA and 95.5% along the coastline. Although this has changed over time, and while BioNet Atlas is an invaluable source of ecological surveying dating before 2010, eBird has quickly taken over and grown exponentially in comparison to BioNet Atlas. In addition to its record volume, eBird also demonstrates a slightly higher representation of threatened species and includes records not available on BioNet Atlas for nine species in Wollongong. While BioNet Atlas exclusively holds records for 3 species absent from eBird, it falls short in terms of species diversity and record completeness. Moreover, eBird provides a user-specific breakdown in its datasets, allowing us to analyse the number and frequency of survey uploads by contributors within the LGA. Although Wollongong has a large eBird userbase, consisting of 527 individuals who have submitted at least one survey, it's evident that the majority of data is contributed by a select group of dedicated birdwatchers. However, the potential for an expansion of citizen science in Wollongong is within reach.

Since the inception of widely available citizen science databases, there have been a selection of dedicated research papers for assessing their applicability and accuracy, as well as critiquing the associated challenges and biases to work through overcoming them. The major issues are the opportunistic nature of citizen surveying, the misrecognition of species, the underrepresentation of elusive species such as nocturnal species or underappreciated taxa like invertebrates, and the overrepresentation of animal groups with hobbyist followings, such as birds (Mesaglio et al. 2023). Other issues in interpreting the data include disturbances to human activity, such as the Covid-19 pandemic or the unprecedented fires of 2019-2020. Fortunately, many of the issues associated with citizen science, such as incorrect identification and ecological inconsistencies (species outside of range, number of individuals counted), go through complex computerized vetted, as well as validation from experts in the field on both eBird and Birdlife Australia. Based on the specific findings from the available citizen science data within the Wollongong LGA, there are several possibilities and recommendations for their integration into the ecological studies to be undertaken as part of WCC's Open Coast CMP. The following recommendations, as listed in table 5.2, are based on the findings of several research papers that assess the validity, considerations, completeness, and completeness of citizen science data.

To conclude, both eBird and Birdlife Australia present a fantastic opportunity for extensive occurrence data to be integrated into WCC's ecological surveying of shorebirds as an action with the Open Coast CMP. By implementing the recommendations listed (table 5.2), WCC can foster a growing citizen science community within the LGA that will continue to improve the spatial and temporal variations in the current shorebird occurrence records, through education, training, and community engagement. Further, by integrating the specific modelling approaches in adapting citizen science data, WCC can broaden the scope of future ecological surveying within Wollongong across a range of threatened species and ecosystems.

Strategy	*Recommended Action*	*Sources*
GIS Review Team	eBird provides visualization tools that demonstrate the distribution and relative abundance of any given region that has been sufficiently surveyed. Using developed services like these minimises the groundwork required to use raw occurrence data. eBird also has opportunities for organizations to collaborate through data sharing, which can further the accessibility of protected data not available to the public, i.e. protected species occurrence.	(Sullivan et al. 2009) (eBird)
Model Based Analysis	Specific modelling tools, like the nonparametric Bagged Decision Tree that aids in quantifying sampling variation as a function of user effort, distance travelled, and time spent, to account for biases in sampling variation and make accurate prediction of distribution and relevant abundance. Other extrapolation-base modelling tools can be used for small sample sizes or uneven survey distribution.	(Sullivan et al. 2009) (Callaghan et al. 2022) (Frank A. La & Somveille 2020) (Hertzog et al. 2021)
Expert Involvement	eBird and Birdlife Australia both recruit experts in the field of ornithology to validate data. By locating and recruiting local experts through incentive programs, knowledge of both the geographical context of the region and the birds that reside there can improve the quality of data.	(Mesaglio et al. 2023) (Sullivan et al. 2009)
Quality Controls	Identify species within the databases that have a sample size sufficient for accurately representing species-specific distribution patterns at the minimum required spatial and temporal scales. An 'extrinsic completeness assessment' can be performed if sufficiently complete ecological surveying is taken, after which citizen science data can be contrasted to assess for it's relative completeness. To validate the vast amounts of eBird and Birdlife Australia obtained during October, small-scale subsampling efforts by professional surveyors can be implemented to validate the results of citizen science counts.	(Mesaglio et al. 2023) (Jacobs & Zipf 2017)
Training and Education	Host workshops with birdwatching groups like Illawarra Birders to improve the interest in and identification of shorebirds, and improved data collection technique. This form of training can also be extended to the documentation of invasive species and other ecological issues.	(Mesaglio et al. 2023) (Starr et al. 2014) (Feldman et al. 2018)
Community Engagement	Host events specifically for the surveying of shorebirds throughout an annual cycle, i.e. once a month. For example, the 'Rusty Blackbird Blitz' was an event created to increase reports for the endangered Rusty Blackbird and resulted in thousands of user participation on the eBird platform. The 'gamification' of surveying by means of a simple achievement-based reward system is an effective way to get school-ages children involved with largescale surveying efforts. ANSTO has a program to engage school aged children years 3-6 through incursion programs and competitions.	(Sullivan et al. 2009) (Callaghan et al. 2022) (Feldman et al. 2018) (ANSTO 2022)

Table 5.2: Summary of recommendations for the integration of citizen science data into the management of shorebirds by WCC and for future monitoring.

7 Conclusion

Shorebirds are invariably a key indicator species for global environmental change, and continued localized ecological studies of these species is imperative to their conservation and management. The presence of shorebird species along the coastline of Wollongong and within the broader LGA is connected to expanding human population. This thesis aimed to produce a baseline inventory of shorebirds by sourcing the occurrence records within this region and scope the presence, richness, and spatial distribution of their populations. Findings suggest that in the years between 1970-2010, scarce surveying was recorded for the occurrence of shorebirds, and that the introduction of citizen science databases between 2014-2021 vastly improved the extent of records for this region. Moreover, the findings suggest that current spatial distribution of occurrence records across the coastline is tied, in a significant way, to the efforts and accessibility of birdwatchers. Through the culmination of biodiversity calculation, proximity to Lake Illawarra, the ecological value of the dune systems present, and its status as an off-leash beach, Perkins Beach is the recommended location for implementing additional nest protection measures. Most importantly, that there are records available for at least 40 species of shorebird, 18 of which are threatened species, with which can be integrated into the conservation and monitoring objectives of the WCC's CMP.

Additionally, this thesis aimed to quantify two major threats that impact shorebirds within the Wollongong LGA to lay a foundation for further research into their conservation and management. For the field study of domestic dog visitation, findings suggest that the current zoning controls for dog access are affective on off-leash and no-dog beaches, but that a reconsideration of timed on-leash regulation and efficacy is required to improve compliance. In a broader context, field studies of the dynamics between domestic dogs and the beaches across any given LGA can provide these kinds of insights, to effectively address issues of non-compliance from dog owners. An examination of the human visitation data concluded that visitation is concentrated at entrance points and close to the shoreline, and scarcer at rock platforms and headlands. Additionally, that annual visitation records are consistent throughout the year, potentially tied with the coastal lifestyle and surfing community within Wollongong.

The recommendations that are produced by this thesis are centred around adapting the practises of successful shorebird recovery programs like the SCSRP, who have increased the clutch size and chick survival of threatened species like the Little Tern, Hooded Plover, Sooty Oystercatcher and Pied Oystercatcher in recent years. These recommendations include the erection of signage targeted at dog owners to inform of the potential impacts of off-leash dogs on beaches, as well as signage and fencing to protect nesting areas from accidental human trampling. Additional erection of wire caging to prevent nest predation by dogs, foxes and cats in conjunction with dedicated scouting studies of shorebird habitats for nesting locations. Further ecological surveying that quantifies dog visitation across an annual cycle to understand the dynamics between human and dog visitation will aid in managing this threat as the population continues to grow. Each of these recommendations are applicable to the WCC's CMP regarding future planning of shorebird conservation and monitoring on the coastlines of Wollongong.

Furthermore, the examination of the occurrence records sourced from the citizen science databases eBird, and Birdlife Australia was undertaken to recommend their integration into the ecological surveying conducted by the WCC for the CMP. Based on the findings regarding both the examination of citizen science databases and the comparisons between eBird and Birdlife Australia, the integration of citizen science data into the ecological studies conducted for the CMP are highly recommended, aided by the existing research that assesses the validity and completeness of citizen science data. Integrating citizen science data can enhance the precision and scope of ecological surveys, while overcoming challenges of funding and spatial restraints using the collaborative efforts of engaged community members and scientific experts. Citizen science holds the potential to create a more comprehensive and effective approach to environmental conservation within Wollongong, and with the open and direct engagement of the WCC with the birdwatching community, through training and education opportunities, the growth and extent of these databases has the potential to become an invaluable tool to the WCC and its CMP. This thesis is intended to provide a foundation for the WCC's proactive involvement in the wider context of global shorebird monitoring and conservation efforts. By providing a preliminary baseline inventory of shorebird species, addressing the extend of the records, and producing preliminary field studies of the threats to shorebirds in the Wollongong LGA, gaps in the current records can be addressed.

8 References

ABRS 2020, *Australian Faunal Directory (AFD)*, Australian Biological Resources Study, Canberra, 15th March 2023.

Aharon-Rotman, Y, Soloviev, M, Minton, C, Tomkovich, P, Hassell, C & Klaassen, M 2015, 'Loss of periodicity in breeding success of waders links to changes in lemming cycles in Arctic ecosystems', *Oikos*, vol. 124, no. 7, pp. 861-70.

Anderson, CM, Fahrig, L, Rausch, J, Martin, JL, Daufresne, T & Smith, PA 2023, 'Climate-related range shifts in Arctic-breeding shorebirds', *Ecology and evolution*, vol. 13, no. 2, pp. e9797-n/a.

Animalia 2023, *Birds*, viewed 15th March 2023, <https://animalia.bio/birds>.

ANSTO 2022, *Shorebird Compeititon 2022*, viewed 5th October 2023, <https://www.ansto.gov.au/education/primary/competitions/shorebirds-competition-2022>.

Australian Treaty Series 1981 No 6, 1981, (Cth).

AWSG 2017a, *About the AWSG*, viewed 25th September 2023, <https://awsg.org.au/>.

—— 2017b, *Field Activities*, viewed 25th September 2023, <https://awsg.org.au/about-us/field-activities/>.

—— 2017c, *Publications*, viewed 25th September 2023, <https://awsg.org.au/publications/>.

Battisti, C, Perchinelli, M, Luiselli, L, Dendi, D & Vanadia, S 2022, 'Cages Mitigate Predation on Eggs of Threatened Shorebirds: A Manipulative-Control Study', *Conservation*, vol. 2, no. 3, pp. 450-6.

Baudains, TP & Lloyd, P 2007, 'Habituation and habitat changes can moderate the impacts of human disturbance on shorebird breeding performance', *Animal conservation*, vol. 10, no. 3, pp. 400-7.

Beach Chair Scientist 2012, *Comparing seabirds, shorebirds, and wading birds*, viewed 27th June 2023, <https://beachchairscientist.wordpress.com/2012/05/23/comparing-seabirds-shorebirds-and-wading-birds/>.

Beavington, F 1973, 'Contamination of soil with zinc, copper, lead, and cadmium in the Wollongong city area', *Australian journal of soil research*, vol. 11, no. 1, pp. 27-31.

Bell-James, J 2022, 'Overcoming legal barriers to coastal wetland restoration: lessons from Australia's Blue Carbon methodology', *Restoration ecology*.

Belo, JR, Dias, MP, Jara, J, Almeida, A, Morais, F, Silva, C, Valadeiro, J & Alves, JA 2023, 'Synchronous Declines of Wintering Waders and High-Tide Roost Area in a Temperate Estuary: Results of a 10-Year Monitoring Programme', *Waterbirds*, vol. 45, no. 2, pp. 141-9, 9.

Birdlife Australia *Who we are - History*, viewed 16/08/2023, <https://birdlife.org.au/about/history/#:~:text=Taking%20bird%20conservation%20into%20the,'>.

BirdLife International 2023, *Data Zone*, 15th March 2023, http://datazone.birdlife.org/species/search.

Birds of the World 2022, viewed 28th August 2023, <https://birdsoftheworld.org/bow/home>.

Black, KM, Karpanty, SM, Robinson, SG, Bellman, HA, Walker, KM, Catlin, DH & Fraser, JD 2023, 'Using GPS location data to assess red fox responses to predator exclosure setup and hatching at shorebird nests', *Wildlife Society bulletin (2011)*, vol. 47, no. 2, p. n/a.

Bonney, R & Dickinson, JL 2017, 'Overview of Citizen Science', in Cornell University Press, Ithaca, NY, pp. 15-26.

Bowes, M, Keller, P, Rollins, R & Gifford, R 2017, 'The Effect of Ambivalence on On-Leash Dog Walking Compliance Behavior in Parks and Protected Areas', *Journal of park and recreation administration*, vol. 35, no. 3, pp. 81-93.

Brudler, S, Rygaard, M, Arnbjerg-Nielsen, K, Hauschild, MZ, Ammitsøe, C & Vezzaro, L 2019, 'Pollution levels of stormwater discharges and resulting environmental impacts', *The Science of the total environment*, vol. 663, pp. 754-63.

Callaghan, CT, Bowler, DE, Blowes, SA, Chase, JM, Lyons, MB & Pereira, HM 2022, 'Quantifying effort needed to estimate species diversity from citizen science data', *Ecosphere (Washington, D.C)*, vol. 13, no. 4, p. n/a.

Callaghan, CT & Gawlik, DE 2015, 'Efficacy of eBird data as an aid in conservation planning and monitoring', *Journal of field ornithology*, vol. 86, no. 4, pp. 298-304.

Callaghan, CT, Poore, AGB, Hofmann, M, Roberts, CJ & Pereira, HM 2021, 'Large-bodied birds are over-represented in unstructured citizen science data', *Scientific reports*, vol. 11, no. 1, pp. 19073-.

NP Association *Community Biodiversity Survey Manual - Bird Survey Methods*, by Carlton, C.

Černý, D & Natale, R 2021, *Comprehensive taxon sampling and vetted fossils help clarify the time tree of shorebirds (Aves, Charadriiformes)*, Cold Spring Harbor Laboratory Press, Cold Spring Harbor.

Choi, CY, Xiao, H, Jia, M, Jackson, MV, Lai, YC, Murray, NJ, Gibson, L & Fuller, RA 2022, 'An emerging coastal wetland management dilemma between mangrove expansion and shorebird conservation', *Conservation biology*, vol. 36, no. 5, p. n/a.

Clark, GF & Johnson, EL 2017, *Australia state of the environment 2016*, Canberra.

Clemens, R, Rogers, DI, Hansen, BD, Gosbell, K, Minton, CDT, Straw, P, Bamford, M, Woehler, EJ, Milton, DA, Weston, MA, Venables, B, Wellet, D, Hassell, C, Rutherford, B, Onton, K, Herrod, A, Studds, CE, Choi, C-Y, Dhanjal-Adams, KL, Murray, NJ, Skilleter, GA & Fuller, RA 2016, 'Continental-scale decreases in shorebird populations in Australia', *Emu*, vol. 116, no. 2, pp. 119-35.

Coastal Environment Pty Ltd 2012, *Wollongong Coastal Erosion Emergency Action Sub Plan*, BMT WBM Pty Ltd.

Coastal Management Act, 2016, NSW Legislation, Australia.

Colwell, MA 2010, *Shorebird ecology, conservation, and management*, University of California Press, Berkeley.

Colwell, MA, Millett, CB, Meyer, JJ, Hall, JN, Hurley, SJ, McAllister, SE, Transou, AN & LeValley, RR 2005, 'Snowy Plover reproductive success in beach and river habitats', *Journal of field ornithology*, vol. 76, no. 4, pp. 373-82.

Connor, SE & Thomas, I 2003, 'Sediments as archives of industrialisation: Evidence of atmospheric pollution in coastal wetlands of southern Sydney, Australia', *Water, air, and soil pollution*, vol. 149, no. 1-4, pp. 189-210.

Cortés, EI, Navedo, JG & Silva-Rodríguez, EA 2021, 'Widespread Presence of Domestic Dogs on Sandy Beaches of Southern Chile', *Animals (Basel)*, vol. 11, no. 1, p. 161.

Cunningham, JA, Kesler, DC & Lanctot, RB 2016, 'Habitat and social factors influence nest-site selection in Arctic-breeding shorebirds', *The Auk*, vol. 133, no. 3, pp. 364-77.

Cypher, BL, Kelly, EC, Ferrara, FJ, Drost, CA, Westall, TL & Hudgens, BR 2017, 'Diet patterns of island foxes on San Nicolas Island relative to feral cat removal', *Pacific conservation biology*, vol. 23, no. 2, p. 180.

Davies, J & Bailey, L 2020, 'The Shorebird Identification Booklet', in L Kidd, D Weller, M Ferenczi, S Klose & L Rhodes (eds), 3rd edn, Birdlife Australia

Department of Environment, Land, Water and Planning.

Department of Environment and Climate Change NSW 2008, *Best Practice Guidelines: Managing threatened beach-nesting shorebirds.* .

Dinsmore, SJ, Lauten, DJ, Castelein, KA, Gaines, EP & Stern, MA 2014, 'Predator exclosures, predator removal, and habitat improvement increase nest success of Snowy Plovers in Oregon, USA', *The Condor (Los Angeles, Calif.)*, vol. 116, no. 4, pp. 619-28.

Doherty, PJ & Heath, JA 2011, 'Factors Affecting Piping Plover Hatching Success on Long Island, New York', *The Journal of wildlife management*, vol. 75, no. 1, pp. 109-15.

Doyle, TB & Woodroffe, CD 2023, 'Modified foredune eco-morphology in southeast Australia', *Ocean & coastal management*, vol. 240, p. 106640.

Duan, H & Yu, X 2022, 'Linking landscape characteristics to shorebird habitat quality changes in a key stopover site along the East Asian–Australasian Flyway migratory route', *Ecological indicators*, vol. 144, p. 109490.

East Asian-Australasian Flyway Partnership *What is a Flyway?*, viewed 19th April 2023, <https://www.eaaflyway.net/the-flyway/>.

eBird *About eBird*, <https://ebird.org/about>.

—— *About eBird*, viewed 1st August 2023, <https://ebird.org/about>.

—— *eBird Basic Dataset*, 1.14 edn, eBird, Ithaca, New York.

Environmental Planning and Assessment Act, 1979, Australia.

Environmental Protection and Biodiversity Conservation Act, 1999, Australia.
Ersoy, S, Beardsworth, CE, Dekinga, A, van der Meer, MTJ, Piersma, T, Groothuis, TGG & Bijleveld, AI 2022, ‘Exploration speed in captivity predicts foraging tactics and diet in free-living red knots’, *The Journal of animal ecology*, vol. 91, no. 2, pp. 356-66.
Feldman, RE, Žemaitė, I & Miller-Rushing, AJ 2018, ‘How training citizen scientists affects the accuracy and precision of phenological data’, *International journal of biometeorology*, vol. 62, no. 8, pp. 1421-35.
Finn, PG & Catterall, CP 2023, ‘Towards an efficient indicator of habitat quality for Eastern Curlews on their intertidal feeding areas’, *Australasian journal of environmental management*, vol. 30, no. 1, pp. 26-47.
Flemming, SA, Lanctot, RB, Price, C, Mallory, ML, Kühn, S, Drever, MC, Barry, T & Provencher, JF 2022, ‘Shorebirds ingest plastics too: what we know, what we do not know, and what we should do next’, *Environmental Reviews*, vol. 30, no. 4, pp. 537-51.
Frank A. La, S & Somveille, M 2020, ‘Survey completeness of a global citizen-science database of bird occurrence’, *Ecography (Copenhagen)*, vol. 43, no. 1, pp. 34-43.
Gangaiya, P, Beardsmore, A & Miskiewicz, T 2017, ‘Morphological changes following vegetation removal and foredune re-profiling at Woonona Beach, New South Wales, Australia’, *Ocean & coastal management*, vol. 146, pp. 15-25.
Geselbracht, LL, Freeman, K, Birch, AP, Brenner, J & Gordon, DR 2015, ‘Modeled Sea Level Rise Impacts on Coastal Ecosystems at Six Major Estuaries on Florida's Gulf Coast: Implications for Adaptation Planning’, *PloS one*, vol. 10, no. 7, pp. e0132079-e.
Glover, HK, Weston, MA, Maguire, GS, Miller, KK & Christie, BA 2011, ‘Towards ecologically meaningful and socially acceptable buffers: Response distances of shorebirds in Victoria, Australia, to human disturbance’, *Landscape and urban planning*, vol. 103, no. 3, pp. 326-34.
Gochfeld, M, Burger, J & Jehl, JR 1984, ‘The Classification of the Shorebirds of the World’, in J Burger & BL Olla (eds), *Shorebirds: Breeding Behavior and Populations*, Springer US, Boston, MA, pp. 1-15.
Gómez-Serrano, MÁ 2021, ‘Four-legged foes: dogs disturb nesting plovers more than people do on tourist beaches’, *Ibis (London, England)*, vol. 163, no. 2, pp. 338-52.
Graham, E, Wainwright, D & Nevell, E 2023, *Wollongong Scoping Study*, Wollongong.
Guinness, SJ, Maguire, GS, Miller, KK & Weston, MA 2020, ‘My dog, my beach! Attitudes towards dog management on Victorian beaches’, *Australasian journal of environmental management*, vol. 27, no. 3, pp. 329-42.
Haines, P 2017, *Wollongong Coastal Zone Management Plan: Implementation Action Plan*, Wollongong.
Hansen, BD, Menkhorst, P, Moloney, P & Loyn, RH 2015, ‘Long-term declines in multiple waterbird species in a tidal embayment, south-east Australia’, *Austral ecology*, vol. 40, no. 5, pp. 515-27.
Hansen, BD, Rogers, DI, Watkins, D, Weller, DR, Clemens, RS, Newman, M, Woehler, EJ, Mundkur, T & Fuller, RA 2022, ‘Generating population estimates for migratory shorebird species in the world’s largest flyway’, *Ibis (London, England)*, vol. 164, no. 3, pp. 735-49.
Hapke, CJ, Kratzmann, MG & Himmelstoss, EA 2013, ‘Geomorphic and human influence on large-scale coastal change’, *Geomorphology (Amsterdam)*, vol. 199, pp. 160-70.
Hardy, JW 2014, *Bird in the Hand (2nd Edition) - Australia*, viewed 21st March 2023, <https://absa.asn.au/bird-in-the-hand-2nd-edition/>.
Harrington, S, Teitelman, J, Rummel, E, Morse, B, Chen, P, Eisentraut, D & McDonough, D 2017, ‘Validating Google Earth Pro as a Scientific Utility for Use in Accident Reconstruction’, *SAE International journal of transportation safety*, vol. 5, no. 2, pp. 135-66.
Heller, EL, Karpanty, SM, Cohen, JB, Catlin, DH, Ritter, SJ, Truitt, BR & Fraser, JD 2022, ‘Factors that affect migratory Western Atlantic red knots (Calidris canutus rufa) and their prey during spring staging on Virginia’s barrier islands’, *PloS one*, vol. 17, no. 7, pp. e0270224-e.
Hertzog, LR, Frank, C, Klimek, S, Röder, N, Böhner, HGS & Kamp, J 2021, ‘Model-based integration of citizen science data from disparate sources increases the precision of bird population trends’, *Diversity & distributions*, vol. 27, no. 6, pp. 1106-19.

Hochachka, WM, Alonso, H, Gutiérrez-Expósito, C, Miller, E & Johnston, A 2021, ‘Regional variation in the impacts of the COVID-19 pandemic on the quantity and quality of data collected by the project eBird’, *Biological conservation*, vol. 254, pp. 108974-.

Horseshoe Crab Recovery Coalition 2023, *Help Save the American Horseshoe Crab*, viewed 25th September 2023, <https://hscrabrecovery.org/>.

Howard, J, Hoyt, S, Isensee, K, Pidgeon, E & Telszewski, M 2014, *Coastal Blue Carbon: Methods for assessing carbon stocks and emissions factors in mangroves, tidal salt marshes, and seagrass meadows.*, Conservation International, Intergovernmental Oceanographic Commission of UNESCO, International Union for Conservation of Nature., Arlington, Virginia, USA.

Husby, M, Hoset, KS & Butler, S 2021, ‘Non-random sampling along rural–urban gradients may reduce reliability of multi-species farmland bird indicators and their trends’, *Ibis (London, England)*, vol. 163, no. 2, pp. 579-92.

Iqbal, U, Barthelemy, J, Perez, P, Cooper, J & Li, W 2023, ‘A Scaled Physical Model Study of Culvert Blockage Exploring Complex Relationships Between Influential Factors’, *Australian journal of water resources*, vol. 27, no. 1, pp. 191-204.

Iwamura, T, Possingham, HP, Chadès, I, Minton, C, Murray, NJ, Rogers, DI, Treml, EA & Fuller, RA 2013, ‘Migratory connectivity magnifies the consequences of habitat loss from sea-level rise for shorebird populations’, *Proceedings of the Royal Society. B, Biological sciences*, vol. 280, no. 1761, pp. 20130325-.

Jacobs, C & Zipf, A 2017, ‘Completeness of citizen science biodiversity data from a volunteered geographic information perspective’, *Geo-spatial information science*, vol. 20, no. 1, pp. 3-13.

Jafari, Y, Jones, BG, Pacheco, JC & Umoru, S 2020, ‘Trace element soil contamination from smelters in the Illawarra region, New South Wales, Australia’, *Environmental earth sciences*, vol. 79, no. 15.

Karpanty, SM, Cohen, J, Fraser, JD & Berkson, J 2011, ‘Sufficiency of horseshoe crab eggs for red knots during spring migration stopover in Delaware Bay USA: Shorebirds and Horseshoe Crab Eggs’, *The Journal of wildlife management*, vol. 75, no. 5, pp. 984-94.

Koh, HL, Teh, SY, Kh’ng, XY & Raja Barizan, RS 2018, ‘MANGROVE FORESTS: PROTECTION AGAINST AND RESILIENCE TO COASTAL DISTURBANCES’, *Journal of tropical forest science*, vol. 30, no. 5, pp. 446-60.

Kratter, AW 2005, ‘The Howard and Moore Complete Checklist of the Birds of the World’, *The Auk*, vol. 122, no. 2, pp. 712-4.

Kwon, E, English, WB, Weiser, EL, Franks, SE, Hodkinson, DJ, Lank, DB & Sandercock, BK 2018, ‘Delayed egg-laying and shortened incubation duration of Arctic-breeding shorebirds coincide with climate cooling’, *Ecology and evolution*, vol. 8, no. 2, pp. 1339-51.

Lee, JS, Callaghan, CT & Cornwell, WK 2023, ‘Using citizen science to measure recolonisation of birds after the Australian 2019–2020 mega-fires’, *Austral ecology*, vol. 48, no. 1, pp. 31-40.

Leitão, PJ, Moreira, F & Osborne, PE 2011, ‘Effects of geographical data sampling bias on habitat models of species distributions: a case study with steppe birds in southern Portugal’, *International journal of geographical information science : IJGIS*, vol. 25, no. 3, pp. 439-54.

Livezey, BC 2010, ‘Phylogenetics of modern shorebirds (Charadriiformes) based on phenotypic evidence: analysis and discussion’, *Zoological journal of the Linnean Society*, vol. 160, no. 3, pp. 567-618.

Livezey, BC & Zusi, RL 2007, ‘Higher-order phylogeny of modern birds (Theropoda, Aves: Neornithes) based on comparative anatomy. II. Analysis and discussion’, *Zoological journal of the Linnean Society*, vol. 149, no. 1, pp. 1-95.

Ma, Y, Choi, C-Y, Thomas, A & Gibson, L 2022, ‘Review of contaminant levels and effects in shorebirds: Knowledge gaps and conservation priorities’, *Ecotoxicology and environmental safety*, vol. 242, pp. 113868-.

Ma, Z, Hua, N, Peng, H, Choi, C, Battley, PF, Zhou, Q, Chen, Y, Ma, Q, Jia, N, Xue, W, Bai, Q, Wu, W, Feng, X & Tang, C 2013, ‘Differentiating between stopover and staging sites: functions of the southern and northern Yellow Sea for long-distance migratory shorebirds’, *Journal of avian biology*, vol. 44, no. 5, pp. 504-12.

Magrath, M, Weston, M, Olsen, P & Antos, M 2008, *Survey guidelines for Australia's threatened birds: Guidelines for detecting birds listed as threatened under the Environment Protection and Biodiversity Conservation Act 1999*.

Manu, S & Cresswell, WRL 2007, 'Addressing sampling bias in counting forest birds: a West African case study', *Ostrich*, vol. 78, no. 2, pp. 281-6.

Martín, B, Delgado, S, de la Cruz, A, Tirado, S & Ferrer, M 2015, 'Effects of human presence on the long-term trends of migrant and resident shorebirds: evidence of local population declines: Human presence and shorebird population declines', *Animal conservation*, vol. 18, no. 1, pp. 73-81.

Mathot, KJ, Piersma, T & Elner, RW 2018, 'Shorebirds as Integrators and Indicators of Mudflat Ecology', in PG Beninger (ed.), *Mudflat Ecology*, Springer International Publishing, Cham, pp. 309-38.

Mayr, G 2011, 'The phylogeny of charadriiform birds (shorebirds and allies) - reassessing the conflict between morphology and molecules', *Zoological journal of the Linnean Society*, vol. 161, no. 4, pp. 916-34.

McKinnon, L, Picotin, M, Bolduc, E, Juillet, C & Bêty, J 2012, 'Timing of breeding, peak food availability, and effects of mismatch on chick growth in birds nesting in the High Arctic', *Canadian journal of zoology*, vol. 90, no. 8, pp. 961-71.

Melville, DS, Chen, Y & Ma, Z 2016, 'Shorebirds along the Yellow Sea coast of China face an uncertain future – a review of threats', *Emu*, vol. 116, no. 2, pp. 100-10.

Mengak, L & Dayer, AA 2020, 'Defining Human Disturbance to Shorebirds Using Manager and Scientist Input', *Environmental management (New York)*, vol. 65, no. 1, pp. 62-73.

Menkhorst, P, Rogers, D, Clarke, R, Davies, J, Marsack, P & Franklin, K 2019, *The Australian Bird Guide*, CSIRO.

Mesaglio, T, Callaghan, CT, Samonte, F, Gorta, SBZ & Cornwell, WK 2023, 'Recognition and completeness: two key metrics for judging the utility of citizen science data', *Frontiers in ecology and the environment*, vol. 21, no. 4, pp. 167-74.

Mitsch, WJ & Gosselink, JG 2015, *Wetlands*, Fifth edition. edn, Wiley, Hoboken, New Jersey.

Mylius, KA, Lavers, JL, Woehler, EJ, Rodemann, T, Keys, BC & Rivers-Auty, J 2023, 'Foraging strategy influences the quantity of ingested micro- and nanoplastics in shorebirds', *Environmental pollution (1987)*, vol. 319, pp. 120844-.

National Parks and Wildlife Act, 1974, Australia.

Navedo, JG, Araya, V & Verdugo, C 2021, 'Upraising a silent pollution: Antibiotic resistance at coastal environments and transference to long-distance migratory shorebirds', *The Science of the total environment*, vol. 777, p. 146004.

Nebel, S, Porter, JL & Kingsford, RT 2008, 'Long-term trends of shorebird populations in eastern Australia and impacts of freshwater extraction', *Biological conservation*, vol. 141, no. 4, pp. 971-80.

Niles, LJ, Bart, J, Sitters, HP, Dey, AD, Clark, KE, Atkinson, PW, Baker, AJ, Bennett, KA, Kalasz, KS, Clark, NA, Clark, J, Gillings, S, Gates, AS, GonzÁlez, PM, Hernandez, DE, Minton, CDT, Morrison, RIG, Porter, RR, Ken Ross, R & Veitch, CR 2009, 'Effects of Horseshoe Crab Harvest in Delaware Bay on Red Knots: Are Harvest Restrictions Working?', *Bioscience*, vol. 59, no. 2, pp. 153-64.

NSW Coastal Management Manual 2018, Office of Environment and Heritage, Sydney.

NSW Department of Planning and Environment 2023, *NSW BioNet*, viewed 22nd August 2023, <https://www.environment.nsw.gov.au/topics/animals-and-plants/biodiversity/nsw-bionet>.

NSW Local Government Area spatial boundaries (polygons), 2022, Peclet Technology, NSW.

Oppel, S, Burns, F, Vickery, J, George, K, Ellick, G, Leo, D, Hillman, JC & Fuller, R 2014, 'Habitat-specific effectiveness of feral cat control for the conservation of an endemic ground-nesting bird species', *The Journal of applied ecology*, vol. 51, no. 5, pp. 1246-54.

Palacios, E, Vargas, J, Fernández, G & Reiter, ME 2022, 'Impact of human disturbance on the abundance of non-breeding shorebirds in a subtropical wetland', *Biotropica*, vol. 54, no. 5, pp. 1160-9.

Pettigrove, V, Hassell, K, Kellar, C, Long, S, MacMahon, D, Myers, J, Nguyen, H & Walpitagama, M 2023, 'Catchment sourcing urban pesticide pollution using constructed wetlands in Melbourne, Australia', *The Science of the total environment*, vol. 863, p. 160556.

Pichler, M & Hartig, F 2021, ‘A new joint species distribution model for faster and more accurate inference of species associations from big community data’, *Methods in ecology and evolution*, vol. 12, no. 11, pp. 2159-73.
Piersma, T, Lok, T, Chen, Y, Hassell, CJ, Yang, HY, Boyle, A, Slaymaker, M, Chan, YC, Melville, DS, Zhang, ZW, Ma, Z & Fuller, R 2016, ‘Simultaneous declines in summer survival of three shorebird species signals a flyway at risk’, *The Journal of applied ecology*, vol. 53, no. 2, pp. 479-90.
Quaintenne, G, van Gils, JA, Bocher, P, Dekinga, A & Piersma, T 2010, ‘Diet selection in a molluscivore shorebird across Western Europe: does it show short- or long-term intake rate-maximization’, *The Journal of animal ecology*, vol. 79, no. 1, pp. 53-62.
Rendall, AR, Sutherland, DR, Baker, CM, Raymond, B, Cooke, R & White, JG 2021, ‘Managing ecosystems in a sea of uncertainty: invasive species management and assisted colonizations’, *Ecological applications*, vol. 31, no. 4, pp. e02306-n/a.
Rossi, LC, Scherer, AL & Petry, MV 2019, ‘First record of debris ingestion by the shorebird American Oystercatcher (Haematopus palliatus) on the Southern coast of Brazil’, *Marine pollution bulletin*, vol. 138, pp. 235-40.
Rutter, JE 2016, ‘Bird Friendly Beaches: Evaluating dog and human interactions with Great Lakes piping plovers (Charadrius melodus) and other shorebirds’, ProQuest Dissertations Publishing.
Saint-Béat, B, Dupuy, C, Bocher, P, Chalumeau, J, De Crignis, M, Fontaine, C, Guizien, K, Lavaud, J, Lefebvre, S, Montanié, H, Mouget, J-L, Orvain, F, Pascal, P-Y, Quaintenne, G, Radenac, G, Richard, P, Robin, F, Vézina, AF & Niquil, N 2013, ‘Key Features of Intertidal Food Webs That Support Migratory Shorebirds’, *PloS one*, vol. 8, no. 10, pp. e76739-e.
Schoenleber, C, D'Antonio, A & Hall, TE 2022, ‘Are signs enough? Using normative and narrative messaging to protect the western snowy plover (Charadrius nivosus) in coastal Oregon’, *Journal for nature conservation*, vol. 69, p. 126251.
Schreiber, EA & Burger, J 2002, *Biology of marine birds*, CRC marine biology series, CRC Press, Boca Raton, Fla.
SCSRP 2019a, *Achievements*, viewed 25th September 2023, <https://www.southcoastshorebirds.com.au/our-achievements/>.
—— 2019b, *Program Background*, viewed 25th September 2023, <https://www.southcoastshorebirds.com.au/about/>.
Sheehy, J, Taylor, CM & Norris, DR 2011, ‘The importance of stopover habitat for developing effective conservation strategies for migratory animals’, *Journal of ornithology*, vol. 152, no. Suppl 1, pp. 161-8.
Shoalhaven City Council 2023, ‘Help protect our threatened shorebirds’.
Short, AD & Woodroffe, CD 2008, *The coast of Australia*, Cambridge University Press, Port Melbourne, Vic.
Sims, SA, Seavey, JR & Curtin, CG 2013, ‘Room to move? Threatened shorebird habitat in the path of sea level rise—dynamic beaches, multiple users, and mixed ownership: a case study from Rhode Island, USA’, *Journal of coastal conservation*, vol. 17, no. 3, pp. 339-50.
Smith, JAM, Dey, A, Williams, K, Diehl, T, Feigin, S & Niles, LJ 2022, ‘Horseshoe crab egg availability for shorebirds in Delaware Bay: Dramatic reduction after unregulated horseshoe crab harvest and limited recovery after 20 years of management’, *Aquatic conservation*, vol. 32, no. 12, pp. 1913-25.
Smith, JAM, Regan, K, Cooper, NW, Johnson, L, Olson, E, Green, A, Tash, J, Evers, DC & Marra, PP 2020, ‘A green wave of saltmarsh productivity predicts the timing of the annual cycle in a long-distance migratory shorebird’, *Scientific reports*, vol. 10, no. 1, pp. 20658-.
St Clair, JJH, García-Peña, GE, Woods, RW & Székely, T 2010, ‘Presence of mammalian predators decreases tolerance to human disturbance in a breeding shorebird’, *Behavioral ecology*, vol. 21, no. 6, pp. 1285-92.
Stantial, ML, Cohen, JB, Darrah, AJ, Farrell, S & Maslo, B 2020, ‘Red Fox Use of Landscapes with Nesting Shorebirds’, *The Journal of wildlife management*, vol. 84, no. 8, pp. 1536-47.
Starr, J, Schweik, CM, Bush, N, Fletcher, L, Finn, J, Fish, J & Bargeron, CT 2014, ‘Lights, camera…citizen science: assessing the effectiveness of smartphone-based video training in invasive plant identification’, *PloS one*, vol. 9, no. 11, pp. e111433-e.

State Environmental Planning Policy (Hazard and Resilience), 2021, Australia, https://legislation.nsw.gov.au/view/html/inforce/current/epi-2021-0730.

State Government of NSW and Department of Planning and Environment 2010, *NSW Wetlands*, The Sharing and Enabling Environmental Data Portal, [https://datasets.seed.nsw.gov.au/dataset/36c734bd-1c9c-40b9-966a-0ad0f7500a09].

Stigner, MG, Beyer, HL, Klein, CJ & Fuller, RA 2016, 'Reconciling recreational use and conservation values in a coastal protected area', *The Journal of applied ecology*, vol. 53, no. 4, pp. 1206-14.

Sullivan, BL, Wood, CL, Iliff, MJ, Bonney, RE, Fink, D & Kelling, S 2009, 'eBird: A citizen-based bird observation network in the biological sciences', *Biological conservation*, vol. 142, no. 10, pp. 2282-92.

Sutherland, WJ, Alves, JA, Amano, T, Chang, CH, Davidson, NC, Max Finlayson, C, Gill, JA, Gill Jr, RE, González, PM, Gunnarsson, TG, Kleijn, D, Spray, CJ, Székely, T & Thompson, DBA 2012, 'A horizon scanning assessment of current and potential future threats to migratory shorebirds', *Ibis (London, England)*, vol. 154, no. 4, pp. 663-79.

Szabo, JK, Choi, C-Y, Clemens, RS & Hansen, B 2016, 'Conservation without borders – solutions to declines of migratory shorebirds in the East Asian–Australasian Flyway', *Emu*, vol. 116, no. 2, pp. 215-21.

Tang, Z, Huang, Q, Nie, Z & Yang, Y 2015, 'Pollution threatens migratory shorebirds', *Science (American Association for the Advancement of Science)*, vol. 350, no. 6265, pp. 1176-7.

The SEED Initiative *SEED the change: Growing knowledge with NSW environmental data*, viewed 22nd August 2023, <https://www.seed.nsw.gov.au/>.

Threatened Species Conservation Act, 1995, Australia.

Totterman, S 2021, *Taking fright: the decline of Australian Pied Oystercatchers Haematopus longirostris at South Ballina Beach, New South Wales*, Cold Spring Harbor Laboratory Press, Cold Spring Harbor.

Tsipoura, N & Burger, J 1999, 'Shorebird Diet during Spring Migration Stopover on Delaware Bay', *The Condor (Los Angeles, Calif.)*, vol. 101, no. 3, pp. 635-44.

Wang, Z, Li, N, Gao, S & An, S 2020, 'Response of wintering waterbird diversity to reclamation history and post-reclamation habitat along Yellow Sea coast', *Integrative zoology*, vol. 15, no. 6, pp. 595-602.

Watts, CM, Cao, J, Panza, C, Dugaw, C, Colwell, M & Burroughs, EA 2012, 'MODELING THE EFFECTS OF PREDATOR EXCLOSURES ON A WESTERN SNOWY PLOVER POPULATION', *Natural resource modeling*, vol. 25, no. 3, pp. 529-47.

Webber, AF, Heath, JA & Fischer, RA 2013, 'Human disturbance and stage-specific habitat requirements influence snowy plover site occupancy during the breeding season', *Ecology and evolution*, vol. 3, no. 4, pp. 853-63.

What is GBIF? , Global Biodiversity Information Facility, viewed 11th April 2023, <https://www.gbif.org/what-is-gbif>.

Wijewardhana, UA, Jayawardana, M & Meyer, D 2022, 'Modelling the recovery of resident shorebirds following a fox eradication program using citizen science data', *Ecological informatics*, vol. 72, p. 101854.

Williams, KJH, Weston, MA, Henry, S & Maguire, GS 2009, 'Birds and Beaches, Dogs and Leashes: Dog Owners' Sense of Obligation to Leash Dogs on Beaches in Victoria, Australia', *Human dimensions of wildlife*, vol. 14, no. 2, pp. 89-101.

2011, *Illawarra Biodiversity Strategy*, by Wollongong City Council vol. 2.

2019, *Dogs on Beaches and Parks, Council Policy*, by Wollongong City Council.

Wormworth, J & Şekercioğlu, Caa 2011, *Winged sentinels : birds and climate change*, Cambridge University Press, Cambridge.

Yang, W, An, S, Zhao, H, Xu, L, Qiao, Y & Cheng, X 2016, 'Impacts of Spartina alterniflora invasion on soil organic carbon and nitrogen pools sizes, stability, and turnover in a coastal salt marsh of eastern China', *Ecological engineering*, vol. 86, pp. 174-82.

Yasue, M 2006, 'Environmental factors and spatial scale influence shorebirds' responses to human disturbance', *Biological conservation*, vol. 128, no. 1, pp. 47-54.

Yi, Y, Wang, X, Liu, Q, Zhang, J & Yi, Q 2022, 'Influence of Water–Sediment Regulation Scheme on Accretion and Erosion in a River Delta: a Case Study of the Yellow River Delta, China', *Estuaries and Coasts*, vol. 45, no. 7, pp. 1879-87.

Zhu, B-R, Verhoeven, M, Velasco Saragoni, N, Sanchez Aguilar, L, Zhang, Z & Piersma, T 2022, 'Current breeding distributions and predicted range shifts under climate change in two subspecies of Black-tailed Godwits in Asia', *Global change biology*, vol. 28, no. 18, pp. 5416-26.

Zockler, C 2005, 'Migratory bird species as indicators for the state of the environment', *Biodiversity (Nepean)*, vol. 6, no. 3, pp. 7-13.

Appendices

Appendix A: Shorebird Species Shortlist for Wollongong LGA

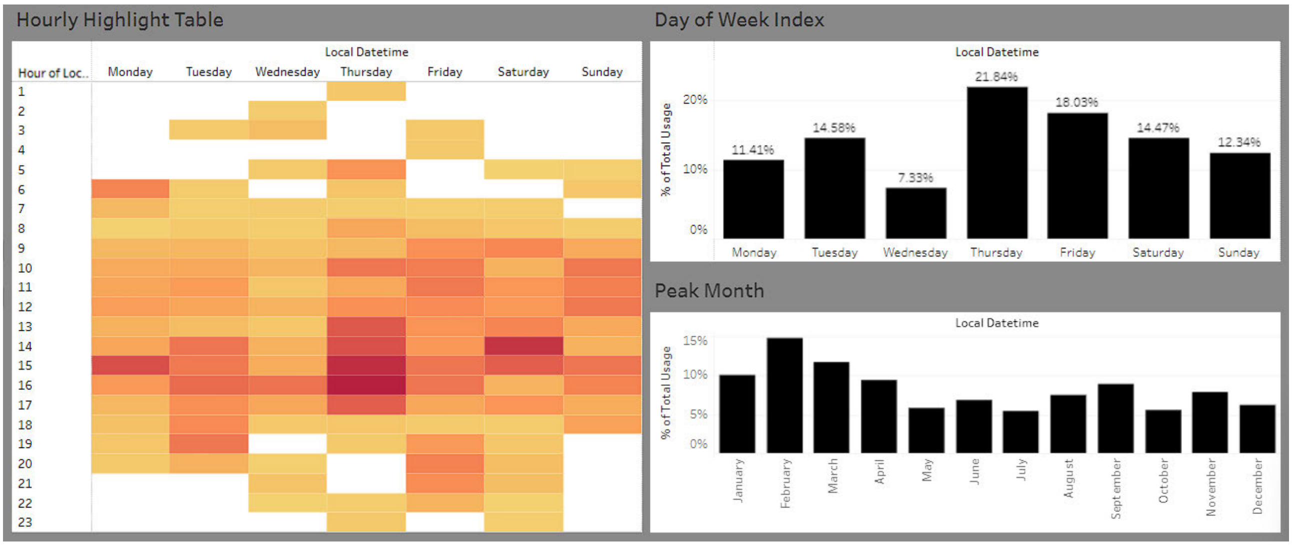
Shorebird Occurance in the Illawara

Common Name	Scientific Name	Habitat Type	Observed in SA	Migratory	Estbalishment	Conservation Status	Breeding Area	Wingspan (cm)	Length (cm)	Weight (g)
Australian Painted Snipe	*Rostratula australis*	Shallow freshwater swamps	Yes	Yes	Breeding	Endangered	Australia	50-54	24-30	125-130
Australian Pied Oystercatcher	*Haematopus longirostris*	Coastal mudflats, Sandy intertidal zones	Yes	Within Aus	Breeding	Endangered	Australia	72-91	39-50	410-775
Australian Pratincole	*Stiltia isabella*	Open and barren grasslands and gibber plains	Yes	Within Aus	Breeding	Least Concern	Australia	50-60	19-24	55-75
Banded Lapwing	*Vanellus tricolor*	Open short grassands, semi-arid rangelands	Yes	No	Breeding	Least Concern	Australia	61-67	25-29	150-200
Banded Stilt	*Cladorhynchus leucocephalus*	Saline lakes and saltpans	Yes	Within Aus	Breeding	Vulnerable	Australia	55-68	45-53	220-260
Bar-Tailed Godwit	*Limosa lapponica*	Coastal mudflats, Sandy intertidal zones	Yes	Yes	Non-Breeding	Vulnerable	N of Scandinavia, Russia and NW Alaska	62-75	37-39	250-450
Beach Stone-Curlew	*Esacus magnirostris*	Beaches, Mudflats, Small islands and reefs	Yes	No	Breeding	Critically Endangered	Australia	1100	55-57	1000
Black-Fronted Dotterel	*Elseyornis melanops*	Dry margins of freshwater wetlands, Farm dams	Yes	No	Breeding	Least Concern	Australia	11-12	16-18	26-39
Black-Tailed Godwit	*Limosa limosa*	Coastal mudflats, Sandy intertidal zones, Inland saline and freshwater marshes	Yes	Yes	Non-Breeding	Vulnerable	Northern Hemisphere	63-75	40-44	200-300
Black-Winged Stilt	*Himantopus himantopus*	Saline and freshwater wetlands, Coastal intertidal zones	Yes	Yes	Breeding	Least Concern	Australia	71-83	33-36	115-200
Broad-Billed Sandpiper	*Limicola falcinellus*	Coastal intertidal zones	Yes	Yes	Non-Breeding	Vulnerable	N Europe , Scandinavia and W Siberia	34-37	16-18	40
Bush Stone-Curlew	*Burhinus grallarius*	Woodlands	Yes	Within Aus	Breeding	Endangered	Australia	55-60	50-58	625-670
Comb-Crested Jacana	*Irediparra gallinacea*	Tropical freshwater wetlands	Yes	No	Breeding	Vulnerable	Australia	39-46	20-27	68-150
Common Greenshank	*Tringa nebularia*	Coastal mudflats, Inland saline and freshwater marshes	Yes	Yes	Non-Breeding	Least Concern	Northern Hemisphere	30-35	55-65	155-210
Common Sandpiper	*Actitis hypoleucos*	Margins of coastal or inland wetlands	Yes	Yes	Non-Breeding	Least Concern	Eurasia	32-35	18-20	41-56
Crested Tern	*Thalasseus bergii*	Coastlines and tropical island habitats	Yes	Within Aus	Breeding	Least Concern	Australia	90-115	40-50	275-370
Curlew Sandpiper	*Calidris ferruginea*	Coastal intertidal zones, Inland saline and freshwater marshes	Yes	Yes	Non-Breeding	Critically Endangered	Siberia	38-41	18-23	44-117
Double-Banded Plover	*Charadrius bicinctus*	Coastal mudflats, Sandy intertidal zones, Bare margins of inland and coastal wetlands, Wet pastures	Yes	Yes	Non-Breeding	Least Concern	New Zealand	37-42	18-21	47-76
Eastern Curlew	*Numenius madagascariensis*	Coastal mudflats, Sandy intertidal zones	Yes	Yes	Non-Breeding	Endangered	China and Russia	97-110	53-66	390-1350
Great Knot	*Calidris tenuirostris*	Coastal mudflats, Sandy intertidal zones	Yes	Yes	Non-Breeding	Endangered	Russia, Korea and China	56-66	26-28	115-261
Greater Sand Plover	*Charadrius leschenaultii*	Coastal mudflats, Sandy intertidal zones	Yes	Yes	Non-Breeding	Vulnerable	Central Asia	44-60	20-25	55-121
Grey Plover	*Pluvialis squatarola*	Coastal mudflats, Sandy intertidal zones	Yes	Yes	Non-Breeding	Least Concern	Tundra, Northern Hemisphere	71-83	27-30	190-280
Grey-Tailed Tattler	*Tringa brevipes*	Coastal mudflats, Sandy intertidal zones	Yes	Yes	Non-Breeding	Vulnerable	Siberia	60-65	23-27	80-162
Hooded Plover	*Thinornis rubricollis*	Sandy ocean beaches, Open edges of salt lakes in Western Australia	Yes	No	Breeding	Vulnerable	Australia	23-44	19-23	79-110
Kelp Gull	*Larus dominicanus*	Sheltered coast, bays, inlets and estauries, beaches, and island reefs	Yes	No	Breeding	Least Concern	Australia	128-142	54-65	540-1390
Latham's Snipe	*Gallinago hardwickii*	Shallow freshwater swamps	Yes	Yes	Non-Breeding	Least Concern	Japan, E Russia	50-54	29-33	150-230
Lesser Sand Plover	*Charadrius mongolus*	Coastal mudflats, Sandy intertidal zones	Yes	Yes	Non-Breeding	Endangered	Central Asia, W India, SW Asia, E and SE Africa	45-58	18-21	56-71
Little Curlew	*Numenius minutus*	Floodplains, Short dry grassland	Yes	Yes	Non-Breeding	Least Concern	Siberia	68-71	28-31	175
Marsh Sandpiper	*Tringa stagnatilis*	Coastal intertidal zones, Inland saline and freshwater marshes	Yes	Yes	Non-Breeding	Least Concern	E Europe, S Siveria and N China	40-45	22-26	70
Masked Lapwing	*Vanellus miles*	Short-grassed habitats, Wetland edges, Modified urban environments.	Yes	No	Breeding	Least Concern	Australia	75-85	30-37	191-412
Pacific Golden Plover	*Pluvialis fulva*	Coastal mudflats, Sandy intertidal zones, Roost in short saltmarsh, harb fields or short-grassed pastures	Yes	Yes	Non-Breeding	Least Concern	N Siberia, Russia	44-60	23-26	120-175
Pacific Gull	*Larus pacificus*	Sandy or rocky coasts and sandy beaches	Yes	No	Breeding	Least Concern	Australia	137-157	58-66	900-1180
Pectoral Sandpiper	*Calidris melanotos*	Saline and freshwater marshes	Yes	Yes	Non-Breeding	Least Concern	N Russia and N America	37-45	19-24	60-85
Red Knot	*Calidris canutus*	Coastal mudflats, Sandy intertidal zones	Yes	Yes	Non-Breeding	Endangered	High Arctic	45-54	23-25	120
Red-Capped Plover	*Charadrius ruficapillus*	Sandy beaches, Bare margins of inland and coastal wetlands	Yes	No	Breeding	Least Concern	Australia	27-34	14-16	35-37
Red-Kneed Dotterel	*Erythrogonys cinctus*	Margins of inland freshwater wetlands including temporary shallows after rain	Yes	Within Aus	Breeding	Least Concern	Australia	33-38	17-20	40-55
Red-Necked Avocet	*Recurvirostra novaehollandiae*	Saline lakes and saltpans, Freshwater wetlands, Coastal intertidal zones	Yes	Within Aus	Breeding	Least Concern	Australia	75	43-45	310
Red-necked Stint	*Calidris ruficollis*	Coastal intertidal zones, Inland saline and freshwater marshes	Yes	Yes	Non-Breeding	Least Concern	Siberia and W Alaska	29-33	13-16	25
Ruddy Turnstone	*Arenaria interpres*	Rock platforms and reefs, Sandy and cobble beaches	Yes	Yes	Non-Breeding	Least Concern	Northern Hemisphere	50-57	22-24	85-150
Ruff	*Philomachus pugnax*	wetlands surrounded by dense vegetation including grass, sedges, saltmarsh and reeds.	Yes	Yes	Non-Breeding	Least Concern	N Russia, NW Kazakhstan	54-60	20-32	110-180
Sanderling	*Calidris alba*	Sandy ocean beaches, Sandbars, Mudflats	Yes	Yes	Non-Breeding	Vulnerable	Tundra in Greenland, Canada and Siberia	35-39	18-20	33-85
Sharp-Tailed Sandpiper	*Calidris acuminata*	Coastal intertidal zones, Inland saline and freshwater marshes	Yes	Yes	Non-Breeding	Least Concern	N Siberia, Russia	36-43	17-22	65
Silver Gull	*Chroicocephalus novaehollandiae*	Beaches, Harbours, man-made environments like parks and gardens.	Yes	Within Aus	Breeding	Least Concern	Australia	91-96	40-45	260-350
Sooty Oystercatcher	*Haematopus fuliginosus*	Coastal mudflats, Sandy intertidal zones	Yes	No	Breeding	Vulnerable	Australia	72-91	42-52	819-980
Spotted Redshank	*Tringa erythropus*	Breed in arctic bogs and swamps, occur in varied wetland habitats	Yes	Yes	Non-Breeding	Least Concern	N Arctic	61-67	29-31	121-205
Terek Sandpiper	*Xenus cinereus*	Coastal intertidal zones	Yes	Yes	Non-Breeding	Least Concern	N Russia, Finland, Siberia and the Arctic Tundra	57-59	22-25	60-78
Wandering Tattler	*Tringa incana*	Rocky coasts and reefs	Yes	Yes	Non-Breeding	Least Concern	Russia, Alaska, British Colombia	50-55	26-30	60-169
Whimbrel	*Numenius phaeopus*	Coastal mudflats, Sandy intertidal zones	Yes	Yes	Non-Breeding	Least Concern	Northern Hemisphere	76-89	40-45	350
Wood Sandpiper	*Tringa glareola*	Shallow freshwater marshes with abundant aquatic vegetation	Yes	Yes	Non-Breeding	Least Concern	Northern Hemisphere	56-57	19-23	55-62

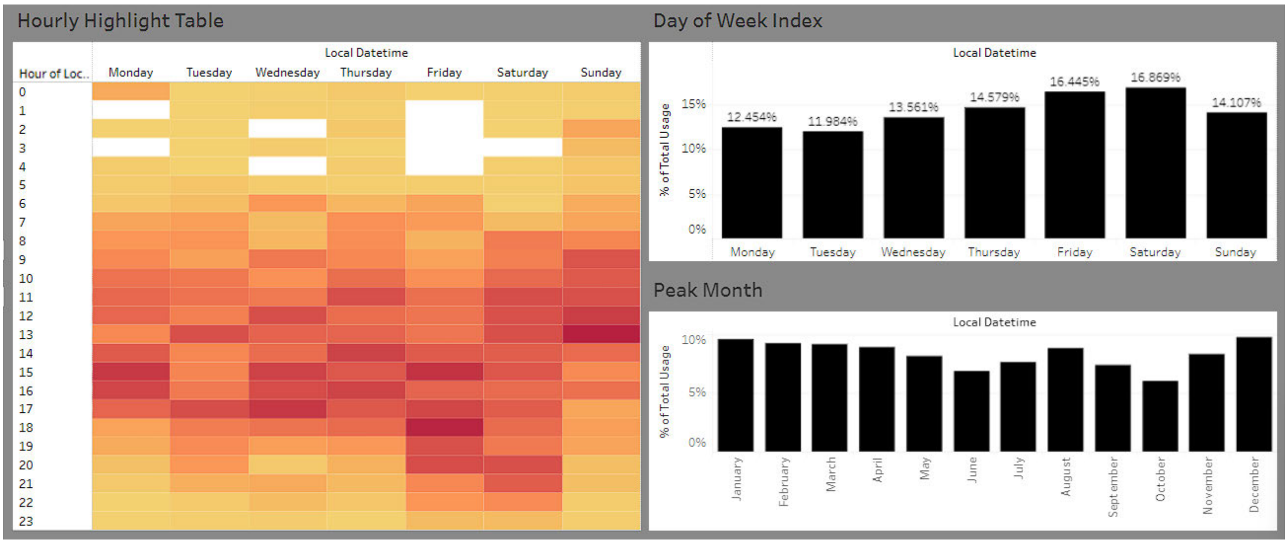
Appendix B: Visitation Data for Each Study Site (2022).

Red, orange, yellow and white heatmap indicates the highest (red) and lowest (white) concentration of human visitation at each site. The top right bar graphs indicate the proportion of usage per day throughout the week for each study site, averaged across the year. The bottom right graph indicates the proportion of usage per month throughout the year for each study site. All graphs derived from place intelligence.

Coledale Beach

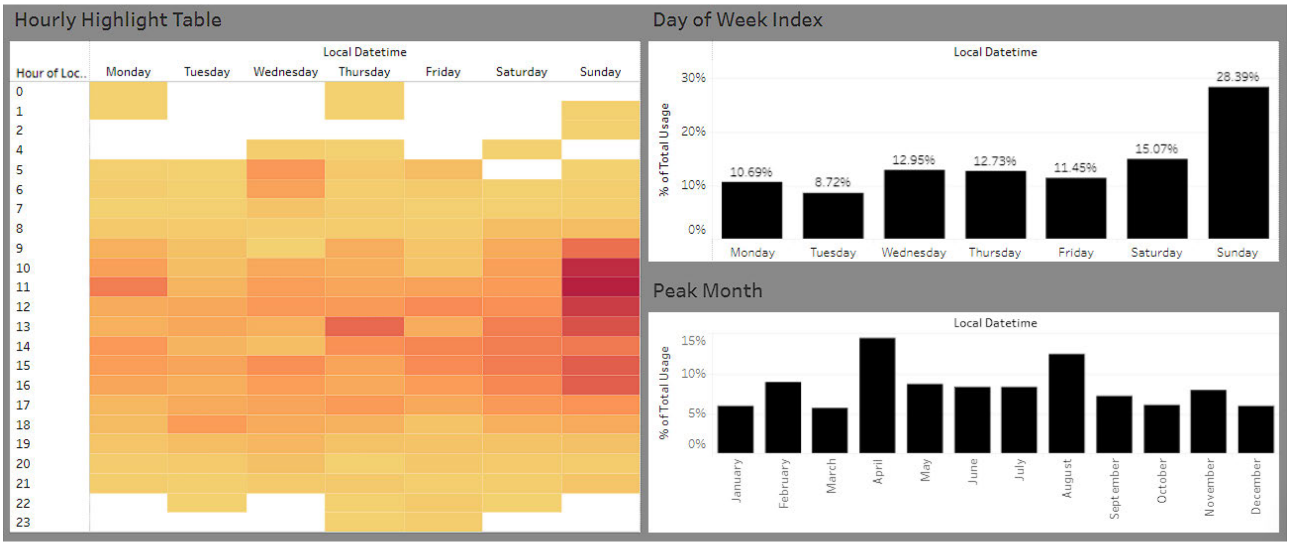


Sharkys Beach

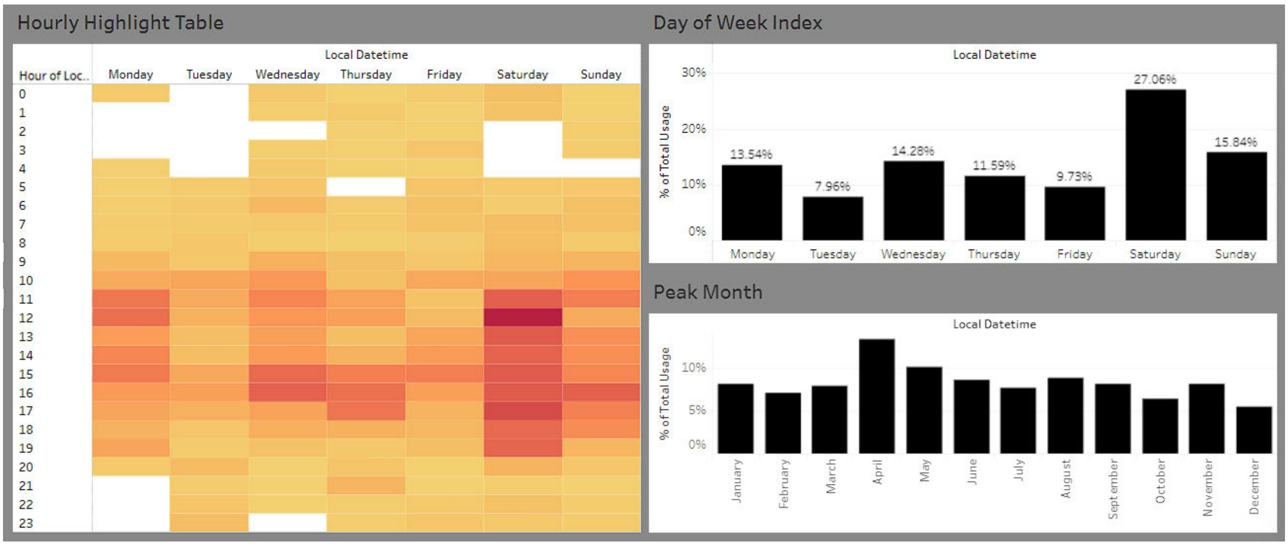


Thirroul Beach

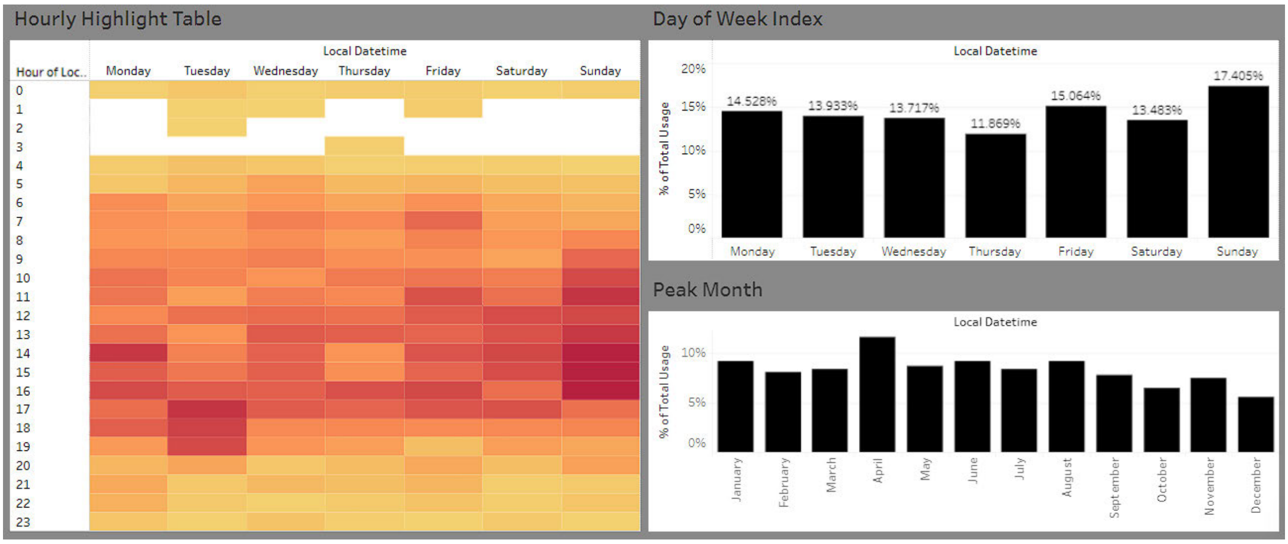
Towradgi Beach



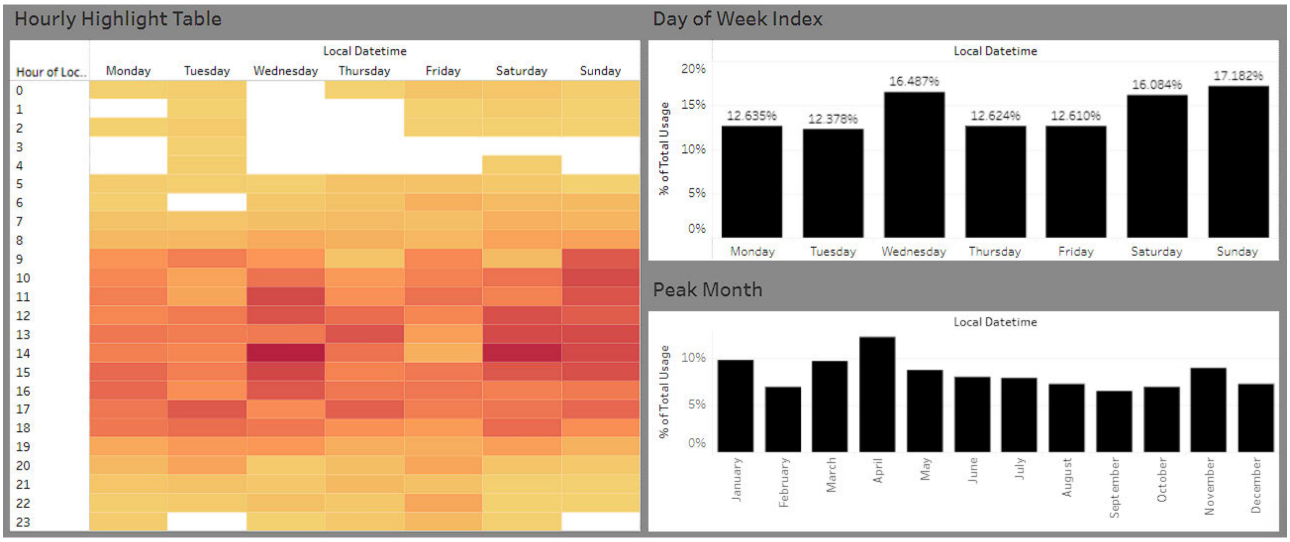
Fairy Meadow Beach



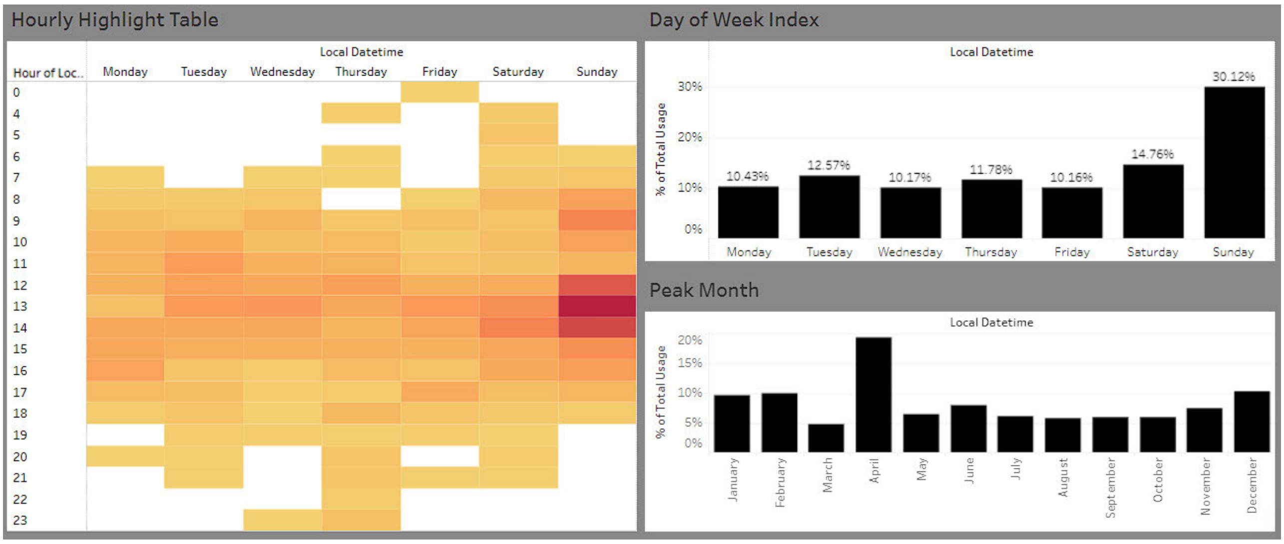
North Wollongong Beach



MM Beach



Fisherman's Beach



Port Kembla Beach