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Population trends of Silver Gulls *Chroicocephalus novaehollandiae* in breeding colonies in Port Jackson, Sydney

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Abstract. Silver Gulls *Chroicocephalus novaehollandiae* are a native species. They thrive in urban areas and can take advantage of new resources effectively. In the late 1980s, a breeding colony established itself in Port Jackson, Sydney. We look at how the size and location of this breeding population changed over time. We did a full count of all active nests in Port Jackson during peak breeding times in 2003, 2008, 2017 and 2018. The highest count of nesting pairs between 1988 and 1991 was 175. Then, in 2003, this number increased to 1,300 when gulls colonised Cockatoo Island for the first time. From 2003 to 2018, the breeding population size was relatively stable with counts 1,300 (2003), 1,070 (2008), 1,274 (2017) and 1,152 (2018). While the counts remained similar, the population spread out geographically. Silver Gulls were actively deterred from nesting during this period. This was unsuccessful at some sites, leading to gulls nesting over larger areas at lower densities. Land managers need to be mindful of the species' ecology and breeding timing, and how birds react to disturbances. Consideration needs to be given to adjacent land managers for the consequences of relocating birds when carrying out active management. Limiting access to food in dining areas and outdoor spaces, along with better food waste management near breeding colonies, will help reduce conflicts between humans and silver gulls.

Keywords: Silver Gull; urban ecology; colonial birds; Port Jackson; Sydney Harbour; *Larus novaehollandiae; Chroicocephalus novaehollandiae*

INTRODUCTION

Human activities have artificially increased the abundance of some species to superabundant status leading to potential human-wildlife conflicts (Feare 1991, Vidal *et al.* 1998). Knowing the population size of these species and its changes over time are key requirements to help understand how well mitigation measures work to lower numbers and if negative impacts are linked to population size.

In south-east Australia, Silver Gulls *Chroicocephalus novaehollandiae* have increased in abundance around human settlements (e.g., Sydney, Melbourne and Canberra) in the second half of the 20th Century. This increase has principally been a result of anthropogenic food resources and habitat modification (Auman *et al.* 2008, Auman *et al.* 2011, Smith 1992, Smith and Carlile 1993a, Temby 2004). In NSW, the main Silver Gull breeding colony is in the Five Islands Group (34.49°S, 150.93°E), near Port Kembla. In 1988, it accounted for ~70% of the coastal breeding activity in NSW (Smith, 1992, citing Lane, 1979). The Big Island colony is the largest in the Five Islands Group, covering 19 ha. It grew from a few pairs in the 1940s (Keast 1943) to about 51,500 breeding pairs by 1978 (Gibson 1979). In 1990, Smith and Carlile (1992) found that the colony had hit its carrying capacity. However, reasons why are not clear, the population dropped quickly to about 10,200 breeding pairs by 2015 (Carlile *et al.* 2017). Other NSW off-shore islands with significant colonies include Barunguba Montague Island Nature Reserve 36.25°S, 150.23°E (Fullagar 1973, 5,000–10,000 pairs; NPWS 1996, 2,000 breeding pairs) and Moon Island 33.09°S, 151.67°E (at least 1,000 nesting pairs; Gray and Gwynne 1974, Herbert 2008). In Victoria's Western Port Bay, Silver Gulls dropped in number from 1980 to 2008. This decrease may be linked to the closing of local rubbish tips (Loyn and Dennet 2008). Similar reductions are likely to be occurring with better waste management and reduced access to other food sources across Australia.

Silver Gulls bred in the Sydney region in low numbers in the early 1990s with a steady increase observed as human food waste products became increasingly available resources (Battam 1976a, b, Gibson 1976, 1979, Dalby *et al*. 1984, Smith 1992, Smith and Carlile 1992). From 1988 to 1991, researchers monitored a new breeding colony of Silver Gulls at Rozelle Bay in Port Jackson (33.85°S, 151.21°E). At its peak, the site had 175 nests annually (Smith and Carlile 1992). Additionally, a small colony of 20 nesting pairs was found 8.5 km to the west, in Homebush Bay on the Parramatta River. The Rozelle Bay colony has now expanded with multiple breeding locations within Port Jackson. Silver Gulls are now a conspicuous feature in Port Jackson and have been portrayed in popular culture as cartoon larrikins (Unkrich and Stanton 2003) and in the media as pests (Taouk 2021).

Port Jackson, in Sydney, is a major deep-water estuary. It sits at the heart of Australia's main city and brings important economic benefits (Banks, *et al.* 2016a, b, Taylor *et al*. 2004). Although the catchment is heavily urbanised (4.84 million residents in 2015), it is a major biodiversity hotspot (Banks, *et al.* 2016a, b, Johnston *et al.* 2015, Taylor *et al.* 2004). Johnson

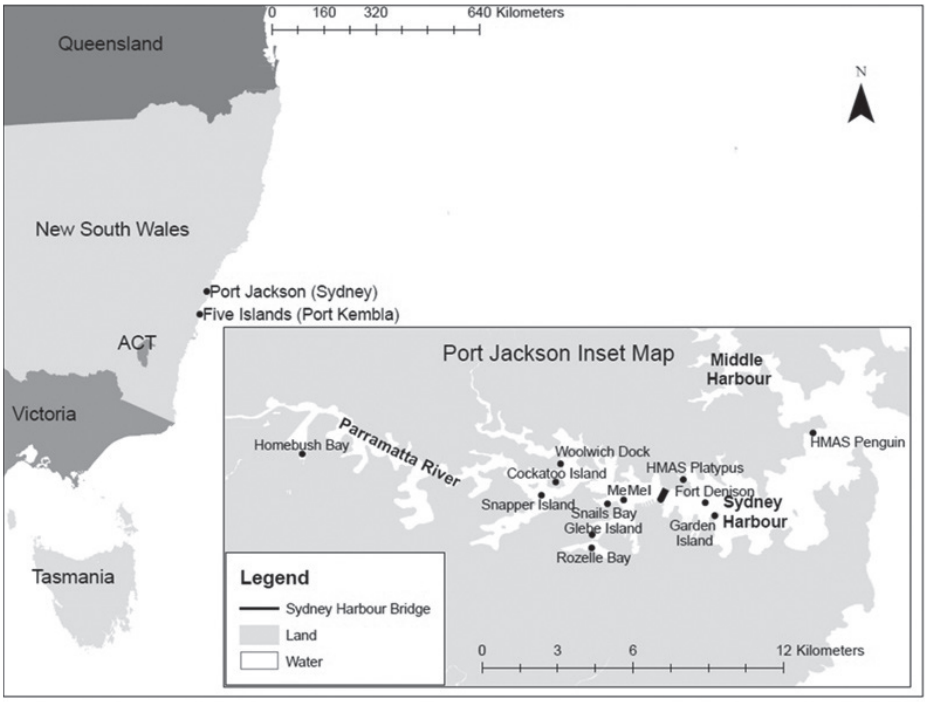

Figure 1. *Study area map showing locations of Port Jackson (Sydney), the study site and the Five Islands (Port Kembla), which contains a regionally significant breeding site for this species. The inset shows breeding locations (solid circles) within Port Jackson. The base map is from ABS (2016).*

et al. (2015) reviewed the published literature (on a broad range of estuarine studies) within our study area and found "an almost complete absence of substantial time series that constrains our capacity to identify trends, environmental thresholds or major drivers of biotic interactions". By documenting local population trends of Silver Gulls, an abundant mobile native species, we begin to address this deficiency.

This paper aims to document the Silver Gull breeding population in Port Jackson, not including the Homebush Bay site on the Parramatta River, from 2003 to 2018.

METHODS

Main breeding site descriptions

Port Jackson is a drowned river valley (Fig. 1), which contains eight islands (NPWS 2011). Silver Gull breeding activity occurs on Me-Mel (previously Goat Island; 6.5 ha) and Cockatoo Island (12.3 ha). Both islands have been modified to accommodate industrial uses and housing and have become tourist attractions in recent years. Vegetation on both islands is a mix of landscaped (including lawns) and native vegetation. There are no records of Silver Gull breeding on these islands before 2003 (NPWS 2011). Of the two islands, Cockatoo Island is a more established tourist attraction with an onsite eatery, camping facilities that necessitate nocturnal lighting (which allows an extended foraging period for Silver Gulls; Tarburton, 1991) and increases in food resources on the island. The Rozelle Bay breeding location was defined in 1989 by two barges (one having been moored here in 1985) and disused wharves and pylons (Smith and Carlile 1992). The removal of the barges sometime after 1992 resulted in the breeding sites concentrated on a secondary location on the redundant Glebe Island swing-bridge, associated wharves, pylons, nearby riprap (loose stone breakwaters) and structures bordering the mainland shore.

Silver Gull breeding sites in Port Jackson (Fig. 1) were recorded in a single day by visiting all known and likely nesting sites. These surveys aimed to count every nest during the peak of annual breeding in just one day. These counts were performed in 2003, 2008, 2017 and 2018. The counts reported include published observations from Smith and Carlile (1992) for 1988-1991. In 2003, there was a sudden rise in the number of Silver Gulls breeding in the study area and these surveys were initiated to quantify the population size and location in the study area. Additionally in 2008, all sites were surveyed throughout the year to better understand the timing of the peak breeding within a single year and any geographic variation.

Nesting success

Nesting success was documented in 2008 and 2018 at Me-Mel and Cockatoo Island, where nests were marked with uniquely numbered cattle ear tags. In 2008, all accessible nest contents were documented throughout the breeding season as often as possible (weekly or fortnightly). In 2008, land managers at both Me-Mel and Cockatoo Island were actively managing Silver Gull nests by removing vegetation, removing nests and oiling eggs. On Me-Mel, from 2006 to 2009, 30 X-shaped corrugated plastic nesting alcoves (300mm high, 600mm wide), each able to accomodate up to 4 nests, were pegged into cliff top unmown lawns to successfully encourage birds to nest in the this location. Disturbance was limited to weekly egg oiling in this area. In 2018, 50 nests were marked on Me-Mel and 124 on Cockatoo Island. Nests on Me-Mel were not disturbed and lawns left unmown by land managers (and visitor access was restricted at this time), while on Cockatoo Island, the management regime involved egg oiling, nest removal and routine vegetation management. Cockatoo Island management agreed to trial a fenced-off, no-intervention area for a season. Thirty-three nests were monitored in the fenced-off area and 91 nests were monitored in the area where eggs were oiled and accessible to the public. Most undisturbed nests (28 out of 33) were accidentally oiled the week before hatching and almost all birds abandoned nests, except for a few where chicks had already hatched. We instead then estimated nesting success on Cockatoo Island as a coarse estimate. We did this by counting the total nests and noting the number of Class 3 birds (variably aged chicks up to 35 days old with pin tail feathers obvious) seen during each visit (as defined by Smith and Carlile 1992). As birds remain in Class 3 for up to seven days, class 3 birds recorded on different visits would not be double counted and could be summed to estimate a total number of fledged birds. We used the fledging rate recorded from Me-Mel to make a coarse estimate of nesting success on Cockatoo Island.

At Me-Mel and Cockatoo Island, nests were located and marked on 21 Aug 2018 and revisited on 15 Sept, 25 Sept, 11 Oct and 17 Oct. On each occasion, the nest contents were recorded and aged following, Smith and Carlile (1992). Nests were deemed successful when the young reached six weeks (Class 3 of Smith and Carlile, 1992). At this age survivorship is high and individuals become mobile, making their link to specific nests no longer feasible. Nesting success and fledging success definitions follow Smith and Carlile (1992) and are;

(1) the proportion of clutches fledging young (i.e. surviving to 21 days or more) of the total clutches (nesting success), and

(2) the number of young fledging (i.e. surviving to 21 days) as a proportion of the number of eggs laid (fledging success).

Nesting density was also estimated at Me-Mel (2017 and 2018) and Cockatoo Island (2003, 2017 and 2018) by accurately drawing a polygon around high-resolution aerial photographs and calculating the number of nests contained within this area as nest per m^2. Additional *ad hoc* surveillance for new colonies occurred during other non-gull-related boating activities on Sydney Harbour. We also report the number of breeding pairs on Big Island (part of the Five Island Group, see Fig. 1) collected in 2018 using the methods outlined in Carlile *et al*. (2017) as a context for trends in the regional population.

Port Jackson - estimating the number of breeding pairs

To allow inter-annual comparisons and assess long-term trends, counts of active nests were undertaken on a single day during the peak of the breeding season (typically September). A single survey is cost-effective but has some limitations compared with continuous monitoring of nests or marked birds for the duration of the breeding period and is likely to underestimate the total number of breeding pairs. This is due to the capacity for Silver Gulls to nest more than once in a season if nesting attempts fail (double brooding with fledging success has not been recorded in the study region) and asynchronous breeding timing between nearby locations (Smith *et al.* 1992, Woehler *et al.* 2014). As breeding timing is variable in this species, we used the following criteria to determine the most representative census period.

(1) The colony size at Me-Mel had apparently peaked with very few nests being established and the spatial extent of the colony no longer growing. This was assessed multiple times a week by a staff member who lived on the island. At Me-Mel we observed that birds usually arrive and commence nesting within a two-week period. As the incubation period is 24 days, and chicks move through predictable development classes before fledging (Smith and Carlile 1992, there is a window of a few weeks after this peak in which the numbers are relatively stable, and observers were able to determine active nests.

(2) The colony size at Cockatoo Island had apparently peaked based on information from Cockatoo Island staff and observations of the number of birds present on this island when members of the author team passed this island on a boat multiple times a week. During the study, nesting usually commenced first at Cockatoo Island and usually started within a week at Me-Mel. These two colonies were consistently the largest colonies in the study area.

All known Port Jackson breeding sites (Fig. 1) were surveyed and active nests counted during single visits to estimate the total breeding population. Accessible nests were surveyed on foot, while inaccessible sites (e.g., cliffs) were observed with binoculars from land or from a boat. Peak breeding counts occurred on 30 Sep. 2003, 23 Sep. 2008, 22 Aug. 2014, 12 Sep. 2017 and 13 Sep. 2018. Individual locations were visited within these years and in the years where a full survey was not conducted. The date of peak breeding was informed by reports from land managers and our direct observations in the lead-up to the breeding peak. The breeding peak was not necessarily synchronised across all sites, and the date selected best represented the peak breeding timing at two main colonies.

Data analyses and *visualisations*

The study area map (Fig. 1) was created with ArcGIS 10.4 (ESRI, 2014), based on the GDA 1994 datum and the base map is from ABS (2016), with all sites mentioned in this paper labelled. The maps in the Appendix share the same datum and data source as Figure 1 and were created using packages within the Tidyverse (Wickham *et al.* 2019). The annual peak number of nests (Fig. 2b) was displayed using a stacked bar chart (Wickham *et al*. 2019) for each year for which data was available (1991, 2003, 2008, 2017, 2018). For Big Island annual counts, a linear model was fitted (R Core Team 2021; R 3.6.3) with 95% confidence intervals (Wickham *et al.* 2019). In 2008, repeat counts across the study area were available for the entire calendar year. These counts were displayed as an area plot (Wickham *et al*. 2019) to illustrate the temporal patterns among sites throughout the year.

RESULTS

Trends in breeding activity over time and the history of colony establishment

Overview

The annual counts for Port Jackson and Big Island are shown in Figure 2. The number of breeding pairs on Big Island decreased over the previous three decades (F-statistic: 20.14, p-value: 0.001; updated from Carlile *et. al* 2017).

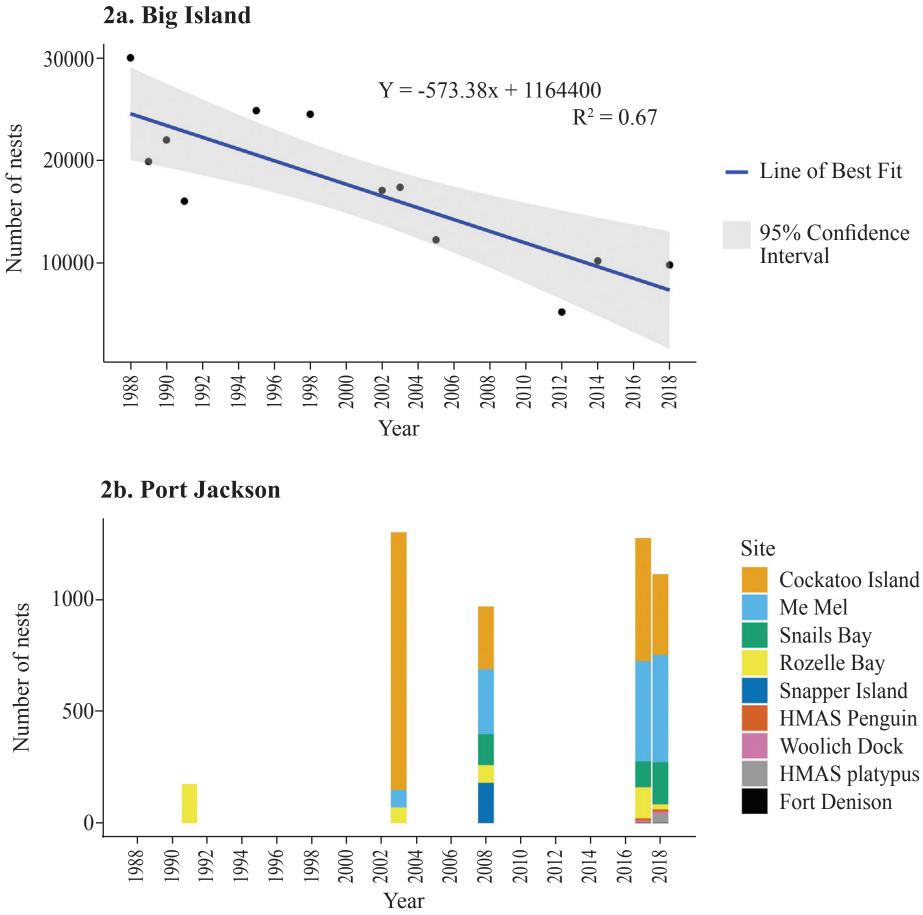

Figure 2. *Comparison of trends in number of breeding pairs at peak breeding time between Big Island (Fig. 2a) and Port Jackson (Fig. 2b). In Port Jackson, the number of nests increased in 2003 with the colonisation of Cockatoo Island, then remained relatively stable, while on Big Island numbers decreased. Linear regression ($r^2 = 0.67$, $n = 12$, 10df, $p < 0.01$, significant).*

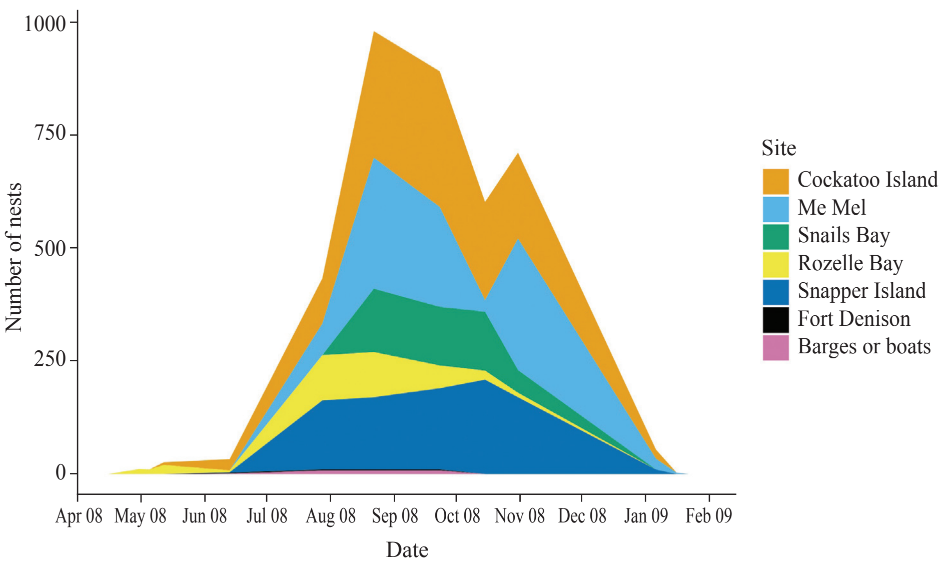

Figure 3. *The bimodal pattern of breeding observed in in Port Jackson based on detailed monitoring in 2008.*

Table 1

Summary table of breeding parameters at different sites between 2003 and 2018.

Site	Year	Disturbance regime	Density	Nesting success (n)	Fledging success	Nests monitored (eggs monitored)	Mean Clutch size (n)	Birds Fledged/ nest
Me-Mel	2008	High (Egg oiling and destruction)	0.007 nests/m^2	3.1-4.2%	-	197 (362) at breeding peak (62 nests inaccessible)	1.6 (43) destruction zone, 1.9 (154) oiling zone. With oiling zone 1.9 (49) in alcoves, 1.4 (47) not in alcoves	Estimated at 1.5-2
Me-Mel	2018	Low	Main colony 0.65 nests/m^2, with peak density 1.3 nests/m^2 in a 33 m^2 area, rocky apron (222 m^2) 0.22 nests/m^2	56% (50) for all nests monitored, 60% (45) in the dense cliff top nesting area (in which nesting commenced first) and 20% (5) in lower density nesting area, where nesting commenced one week later	32.5% (n=123)	50 (123)	2.4 in successful nests (28) and unsuccessful nests (22)	1.4 birds fledged from successful nests, 0.8 birds fledged per nests for all nest monitored
Cockatoo Island	2003	High (nesting ceased due to disturbance)	1.1 nests/m^2			Not recorded		
Cockatoo Island	2008	High (oiling and destruction)	0.06 nests/m^2	Coarse estimate of 11% for each breeding pair (pairs made multiple attempts to breed, success per attempt much lower)		Not recorded		
Cockatoo Island	2018	High (oiling and destruction)	Low, upper areas 0.006 nests/m^2 , lower area 0.004 nests/m^2 , peak density 0.18 nests/m^2 (100 nests in 535 m^2	Variable based on disturbance. 0% in oiled nests, ~10% for the colony, coarse estimate	Not recorded	136 (254)	1.9 (136)	Not recorded

In 2008, more intensive monitoring occurred (every 2-3 weeks) and the number of breeding pairs in Port Jackson in this period is shown in Figure 3. In 2008, an early peak in August/September was followed by a later November peak, although the locations of breeding differed throughout the year. Active colony management to reduce or deter extended breeding by egg oiling and nest destruction was performed by land managers on Cockatoo Island, Snapper Island and Me-Mel. In years where active colony management did not occur on Me-Mel (2017 and 2018), the second peak was not observed.

Location of breeding

In the early 2000s, Silver Gulls were nesting on Cockatoo Island and by September 2003 an apparent substantial increase had occurred with numbers estimated at ~1,150 pairs, breeding in two discreet areas. Elsewhere in Port Jackson there were smaller breeding sites with 80 breeding pairs nesting at Me-Mel, 70 at Rozelle Bay and a small uncounted number at Garden Island. The apparent sudden expansion of the colony on Cockatoo Island resulted in management actions in 2004. These breeding birds were successfully, but temporally, dissuaded from nesting on Cockatoo Island using dog patrols, netting of habitat and other deterrents. The displaced birds began nesting in greater numbers on Me-Mel (250 breeding pairs in May 2004, reduced to 90 pairs in July 2004) and elsewhere in the harbour (NPWS 2011). After 2003, birds reliably returned to nest at both Cockatoo Island, Me-Mel, Rozelle Bay sites (Old Glebe Island Bridge and nearby seawalls and moored boats) and hulks and large concrete moorings in Snails Bay.

Snapper Island (0.36 ha) had occasional nesting activity, with nesting recorded in 2007 (at least 80 nests), 2008 (209 nests at its peak) and again in 2018 (approximately 80 nests appeared late in the season after the peak). Garden Island had a small number of birds breeding sometime between 2003 and 2007; however, birds have not attempted to nest in this location since. Riprap (loose stone breakwaters) at Glebe Island terminal had a large colony for a short period before birds were moved on (October 2012, 363 nests, see Dolejska et al. 2016). Smaller colonies in Port Jackson also include Middle Harbour (on hulks near Northbridge baths, 2011-2012, 2 nests) and Fort Denison (1-4 nests every year since mid-2000s). More recently, colonies have established on mainland locations including Woolwich dock (~10 nests, 2017), HMAS Penguin (~10 nests, 2017) and HMAS Platypus (40 nests, 2018). In 2016, a low number of birds were recorded nesting under the Pyrmont Bridge, although bird spikes were installed in this location and no nesting occurred subsequently during the period of observations. The location of breeding each year is mapped in Appendix 1.

Nesting success, density and impact of disturbance

Nesting density was negatively influenced by the level of disturbance, with high-disturbance sites having lower nesting density (Table 1). Nesting success was also reduced with disturbance, with egg oiling rendering all treated eggs unviable.

On Me-Mel, the management regime was different between 2008 (when active management was occurring) to 2018, when a low disturbance approach was taken. Nesting success on Me-Mel in 2018 was 56% and fledging success 32.5%, with 1.4 birds per nest fledged from successful nests (n = 33). Clutch size was 2.4 and a total of 123 eggs were monitored in 50 nests. Nesting density on Me-Mel was 0.65 nests/m^2, with a peak density 1.3 nests/m^2 in a 33 m^2 area. In 2008, nesting success (3.1-4.2%), clutch size (1.5 -2) and nesting density (0.007 nests/m^2) on Me-Mel was much lower than in 2018, due to active management of accessible nests, with only inaccessible cliff-based nests fledging young.

On Cockatoo Island similar management regimes were in place in 2008 and 2018 and nesting densities (2008, 0.6 nests/m^2; 2018, 0.004-0.006 nest/m^2) clutch sizes (2008 not recorded; 2018, 1.9), and nesting success (2008, ~11%; 2018,~10%) were similar between these two periods. In 2003, the nesting density was initially higher (1.1 nests/m^2) before active management commenced. Nesting success on Cockatoo Island in 2018 in monitored nests was 0% (n = 91) in oiled nests. Most (28 out of 33) of the nests designed to be excluded from the oiling program were accidentally oiled in the few days before hatching was predicted. This led to all nests being abandoned in this area in the following week. Based on a total count of Class 3 birds observed, and assuming 1.4 birds fledge per nest (as was the case on Me-Mel), the total number of nests present (n=360), it was estimated that ~10% of nests present in the period monitored on Cockatoo Island were successful in 2018. These successful nests were the cliff-based or otherwise inaccessible nests, which were not oiled. Nesting density (2018) on Cockatoo Island was 0.006 nests/m^2 (on the elevated parts of the island) and 0.003 nests/m^2 on the flatter low-elevation area. Clutch size was 1.9 (n = 33) in the undisturbed nest area and 2.0 for oiled nests (n= 91). Birds maintained nests for longer than usual when eggs were oiled; 27% of nests were maintained for over 35 days, with the longest maintained for 57 days.

DISCUSSION

Population trends

Since the first records of Silver Gull breeding colonies in Port Jackson (1989-1991), the population has remained stable after 2003. It has fluctuated between 945 and 1320 breeding pairs, with only small yearly changes from 2003 to 2018. In contrast, the much larger Big Island population, off Port Kembla, has decreased from the late 1980s to 2018 (Carlile et al. 2017; Fig. 2). Similar declines occurred further south on Montague Island. Nest numbers decreased from 5,000-10,000 in 1973 to around 1,500-2,000 in the late 2000s (Dolejska et al. 2016, Fullagar 1973). It is not clear if the apparently stable Port Jackson population is maintained by maturing young hatched from within Port Jackson or is acting as a sink for these other, larger decreasing populations. Monitoring of both the Port Jackson and the regional populations is desirable to inform the ongoing management of this species.

The figures presented here provide baseline data for investigations of the link between these populations and to determine any future population changes. Although the total counts have remained similar between 2003 and 2018, colony sizes at individual sites around Port Jackson have varied. The number of nesting pairs has increased on Me-Mel, decreased on Cockatoo Island and remained about the same on old Glebe Island Bridge (until a large section of the bridge collapsed in 2018; this colony is now smaller), while other sites (e.g., Snails Bay) vary in size based on the number of infrequently used objects (moored hulks, concrete mooring structures, disused wharves and timber structures, floating stages or other structures) and the level of disturbance. Cockatoo Island (42% of nests in 2018) and Me-Mel (32% of nests in 2018) have been consistent sites of breeding with nesting occurring every year since 2003. These two sites have contained a large proportion of all breeding activity every year.

Breeding timing

Human food appears to have allowed almost year-round breeding in Port Jackson, which indicates this population is likely accessing a separate food web compared with non-urban populations (Auman *et al.* 2011). Outside of the main spring breeding period, small numbers of active nests are present year-round on abandoned moored boats or disused maritime structures. Larger breeding events outside the typical period occasionally are aseasonal with disturbance extending the nesting period in some locations. Active management to limit nesting extended the end point of breeding. Birds continued to nest until January or February on sites that were intensively managed (Cockatoo Island, Me-Mel 2006-2009) compared to sites that were left unmanaged (Me-Mel 2010-2018), where nesting occurs in a single peak and nesting ceases in October. While breeding is year-round, most nesting in Port Jackson occurs within defined breeding peaks. Outside these peaks, nesting is usually restricted to a low number of birds breeding on hulks (in Rozelle Bay and Snails Bay) and the Glebe Island Bridge (the breeding success of these aseasonal breeders has not been assessed at any site). Aseasonal breeding may also be the result of birds that failed to breed in the previous year and are in suitable body condition.

At Rozelle Bay, Smith and Carlile (1992) found breeding numbers peaking in April, with another larger peak, in late July-early August at a time when the main breeding colony at Big Island commences nesting. At this time, the only other breeding site in Port Jackson was the small colony at Homebush Bay. In the current study, the first (April) peak was not observed in 2008. April breeding has only been recorded twice on Me-Mel, in 2003 and 2006, although is occasionally observed at sites with low disturbance (hulks and disused structures).

There are several sites with irregular breeding. A colony of ~1,500 adults (~363 nests) bred at Glebe Island Terminal (White Bay) in October 2012, but not in other years (Dolejska *et al.* 2016). This is estimated to represent about 30% of the peak breeding population in a typical year. Significant other temporary colonies have also been observed on Snapper Island in 2007, 2008 (and estimated 19.5% of total breeding in that year) and 2018. Birds breeding on hulks or long-term moorings are only able to do so when boats are present and left untended for extended periods of time. These sites provided 9% (2017) and 16 % (2018) of the Port Jackson estimated breeding population. In other years, these breeding sites may not have been available, so birds dispersed to other sites.

At the start of the peak breeding season, typically between May and July, the early breeding pairs preferentially selected sites with low disturbance (e.g., mooring dolphins or hulks). After these low-disturbance nesting sites fill, birds typically colonised Cockatoo Island and then Me-Mel. The earlier arrival on Cockatoo Island compared with Me-Mel may be because it is a larger island and accessibility to food resources improved by night-time lighting. Alternatively, it may be a legacy of historical breeding at this location, being the first island location where substantial numbers of nesting pairs were recorded breeding. Ottaway *et al*. (1988) found a small percentage of birds showed a high fidelity to breeding sites, while over half eventually bred at non-natal breeding sites.

Colony management

A comparison of land management approaches and visitation patterns between Me-Mel (which was largely unmanaged and had very low public use at the time) and Cockatoo Island (which was actively managed by oiling eggs and removing nests and has very high levels of public visitation) gives insights into the impact of disturbance on breeding Silver Gulls. Specifically in this case study, disturbance decreases clutch size, nesting success and colony density. Disturbance also prolongs the nesting period, as many birds renest if the first nesting attempt was unsuccessful. Previous studies (Smith and Carlile 1993b) found that egg pricking and habitat modification reduced nesting success and lowered nesting density. This matches our findings. While egg pricking did not increase incubation time, in this study we found egg oiling did. A previous study (Skira and Wapstra 1990) found that both management of reproductive output and lethal control alone were not able to reduce population sizes and suggested limiting access to human food sources is the only likely method to reduce population size. Another study (Kentish 1994) found that at a local-scale revegetation can render the habitat unsuitable for nesting and at a local scale landscaping can be used to exclude gulls from nesting.

While disturbance may limit the reproductive output of a colony, and population control is often the goal of urban gull management, the cost is birds' nesting for a prolonged period of time over larger areas. These trade-offs need to be carefully considered when designing plans to manage gull colonies.

CONCLUSIONS AND RECOMMENDATIONS

Increased food availability has likely led to the establishment of a permanent breeding population in Port Jackson, which has remained relatively stable after the initial establishment period. This stability is noteworthy as the regional population is decreasing. Food supplementation has likely contributed to an altered seasonality of breeding, with urban colonies of Silver Gulls breeding successfully almost year-round in Rozelle Bay (Smith and Carlile 1992). Smith and Carlile (1992) found that breeding timing and duration varied between Big Island and Rozelle Bay, and this study agreed with those findings. While Smith and Carlile (1992) found nesting success was higher in the less crowded satellite population in Rozelle Bay compared with Big Island, more recently the breeding on Big Island has seen the reverse with high breeding success at lower densities (Carlile *et al.* 2017). At Port Jackson, the ability of birds to move between nesting locations if one becomes temporarily unsuitable or permanently unavailable, along with low nesting densities (and likely higher breeding success) and a year-round supply of food, may explain the stability of this population.

Silver Gulls have proven to be an adaptable, resilient, and successful urban breeding native species. While improvements in food waste management will ultimately reduce waste available to gulls, other sources of human food may continue to be available, for instance from outdoor dining areas and humans' innate need for connection with wild animals, leading to free feeding despite education of its deleterious impacts. Food availability needs to be strictly managed within tourist precincts (both in waste receptacles and unfinished diners' meals) near gull breeding colonies to avoid disease transmission (Cummins *et al.* 2020) and wildlife conflict and to limit food resources.

Breeding gulls at accessible island locations within Port Jackson provide a unique and currently unutilised opportunity as a tourist attraction and an educational tool on a species that can withstand human disturbance (compared with less resilient species e.g., penguins, Ellenberg *et al*. 2007). Strategic education could be used to increase public awareness of bird ecology, waste management, and environmental issues if interpretive signage and infrastructure was developed and installed that allows low disturbance viewing of a nesting colony of Silver Gulls. There are also opportunities for citizen science projects using marked birds to help gather information on movements of Silver Gulls in the region (Davis *et al.* 2017) or to document reproductive ecology at established sites monitored by web cams (Debus *et al.* 2014, Harrington *et al.* 2013).

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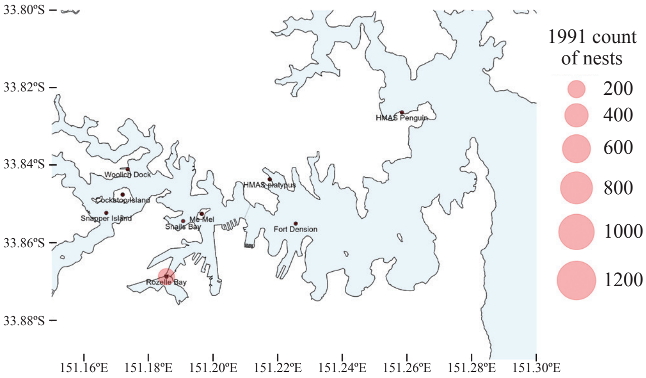
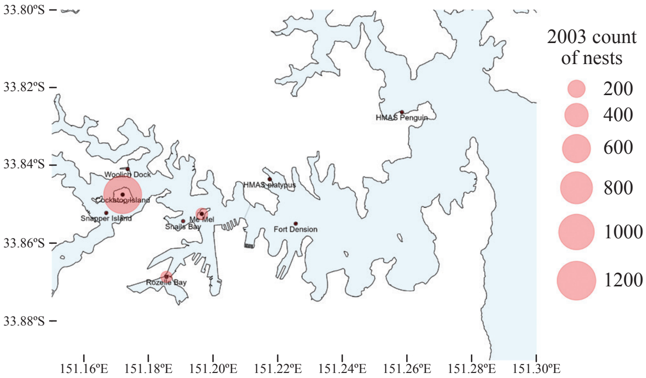
APPENDIX 1

Location of Silver Gull nesting locations in 1991, 2003, 2008, 2008, 2017, 2018 for the peak breeding counts reported in Figure 2b within the Port Jackson study area.

1a. Silver Gull Nest Counts – 1991

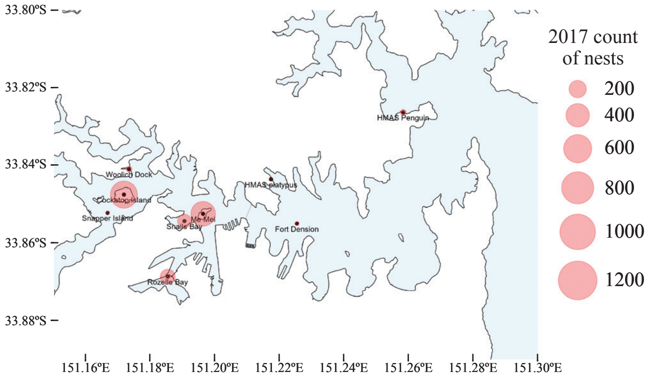


1b. Silver Gull Nest Counts – 2003



1c. Silver Gull Nest Counts – 2008

1d. Silver Gull Nest Counts – 2017



1e. Silver Gull Nest Counts – 2018