Survival, movements and breeding success of Bush Stone-curlews *Burhinus grallarius* in the Moreton Bay Region, Queensland

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Abstract

The survival, movements and breeding success of Bush stone-curlews on Coochiemudlo Island in Moreton Bay, Queensland, was studied from 2007 to 2019 through monthly counts and observations of leg-flagged birds. In addition, annual counts organised by Redland City Council have been conducted since 1997. The population on the island increased from 1997 to 2007 and has since remained relatively stable at between 171 and 216 birds. Most movements were within Coochiemudlo Island but there was evidence of movements of birds to other islands in Moreton Bay and to and from adjacent mainland sites. Of 324 potential breeding events, 179 (55%) either failed to hatch any young or lost all hatched young prior to independence. The number of birds reared to fledging was high (1.04 per breeding attempt) when compared to that of mainland sites. The high productivity and evidence of movements away from the island suggest that these birds could be an important source of recruitment for less successful mainland populations. Based on resightings of leg-flagged resident birds, mean apparent annual adult survival rate was 92.91%. A comparable study at a mainland site would allow a demographic comparison with our study, providing a better understanding of factors influencing populations in eastern and southern Australia.

Introduction

The Bush Stone-curlew *Burhinus grallarius* occurs primarily in coastal and sub-coastal regions of Australia (Barrett *et al.* 2003). Although the species is reported to be in decline over much of its range, particularly in southern Australia (Gates & Paton 2005), populations in northern Australia are probably stable (Marchant & Higgins 1996; Garnett & Crowley 2000). The decline across much of southern Australia has been related to a range of factors including land clearing and disturbance (Webster & Baker-Gabb 1994), predation by introduced predators (Johnson & Baker-Gabb 1994; Baltais 2006), and vehicles, at least in areas near large human populations (DECC 2006).

The species normally lays two eggs (Marchant & Higgins 1996), and frequently makes and multiple breeding attempts each year as mortality shortly after hatching is common (Garnett 1985). In Victoria, from 52 eggs, only 17 offspring survived for more than four weeks (Johnson & Baker-Gabb 1994) and in Brisbane a study of six nesting pairs found that only five offspring reached independence (Wilson 1989). Protected areas and islands often have higher productivity, thought to be linked to reduced predator impacts (Gates & Patton 2005; Johnson & Baker-Gabb 1994; Cannard & Milton 2012).

Bush Stone-curlews are apparently capable of living up to 30 years (Baltais 2006). However, the oldest known banded bird was recaptured only 15 years and 3 months after being banded, and was alive when released (ABBBS 2021). The species is sedentary, breeding birds holding territory while breeding and dispersing only locally during the non-breeding season (Marchant & Higgins 1993). The mean distance travelled by recaptured or recovered birds was only 5 km from their original banding site although one individual was recorded moving 104 km (ABBBS 2021). Using radio-tracking, Gates (2001) established that most breeding birds maintained a home range of 26–64 ha, but non-breeding birds appeared to range more widely, with one individual located 8 km from its original capture location on Kangaroo Island.

Encompassing a large area of southern Moreton Bay in southeast Queensland, Redland Shire has a up to 150 breeding pairs of Bush Stone-curlews (Baltais 2006). This may be up to 1% of the Australian population, estimated at 10,000–15,000 individuals (Birdlife International 2020). However, even in this region of high abundance, there are large areas of seemingly suitable habitat on the mainland with fewer than expected or no birds, thus highlighting the vulnerable nature of this species (Baltais 2006).

In this paper we present long-term demographic data on Bush Stone-curlews inhabiting the islands of Moreton Bay, primarily Coochiemudlo Island. We provide estimates of the population size and adult survival rates in the region, and details of the frequency and distance of local movements, and breeding success. We also consider the role of such island populations as source populations for less secure mainland populations where productivity and survival may be markedly lower.

Methods

Counting and catching

Since 1997, Redland City Council has organised an annual count of the Bush Stone-curlew population on Coochiemudlo Island, in southern Moreton Bay, in February. The count is undertaken just before dusk when the birds are most active. Teams of volunteers are allocated fixed areas of the island to search so that the count can be completed as quickly as possible, reducing the potential for double counting of mobile individuals or groups.

Since May 2009, the Queensland Wader Study Group has supplemented these annual counts by conducting monthly counts of the birds on the island. These have been done with a smaller group of volunteers, surveying the island between dawn and midday by bicycle, ensuring that all streets and open areas are checked for birds. This different approach has been adopted due to the difficulties of organising a large team of volunteers to survey the island every month.

Additional visits to the island were made periodically between January 2009 and December 2019 to catch and band birds for monitoring. Birds were caught in mist nets set flush to the ground between trees and houses. Teams of people surrounded birds and slowly walked them into the nets. Birds were removed from the nets and placed in a calico bag before being banded. Each captured bird was fitted with an Australian Bird and Bat Banding Scheme (ABBBS) metal band on the left tarsus and a green, individually engraved leg flag on the right tibia (Plate 1). The green leg flag code could be read using binoculars and enabled multiple resightings of banded birds to be collected without the need to recapture the bird.

Plate 1. Bush Stone-curlew, leg flag APM, caught and banded (#101-42773) on 3 May 2021 on Coochiemudlo Island (Jon Coleman)

Captured birds were aged using known plumage characters (Marchant & Higgins 1996), and their body mass recorded to the nearest gram. In addition, the total head length, tarsus and wing length were measured to the nearest 0.1 mm following the methods described in Lowe (1989).

Re-sightings and monitoring breeding success

Resightings of leg-flagged birds were made during monthly and annual counts with adhoc sightings provided by members of the public, mainly at locations away from Coochiemudlo Island. Recovery reports from the ABBBS were also received for birds found dead or injured during the period of the study. Where possible, additional information for each resighting was recorded, including if the bird was paired, if it was found breeding and if the breeding attempt was successful, how many young were hatched and reared.

Additionally, some birds were banded at locations away from Coochiemudlo Island. Occasional visits were made during the period of the study to other islands and mainland sites to band birds and to look for leg-flagged individuals dispersing from Coochiemudlo Island. The areas visited and the sites at which birds were banded are shown in Figure 1.

Breeding attempts were recorded by direct observation of banded and un-banded pairs on the monthly visits. The incubation period of the species is 25-28 days and young remain with their parents for up to 71 days (Marchant & Higgins 1996). The duration of the breeding attempt, along with input from residents on the island, allowed breeding pairs and their fates to be tracked over multiple monthly visits. For each pair, the number of eggs laid, the number of young hatched and the number of young reared to fledging was recorded where possible. The date of each breeding event was also recorded to establish the duration of the breeding season in each year of the study. (Fig 1)

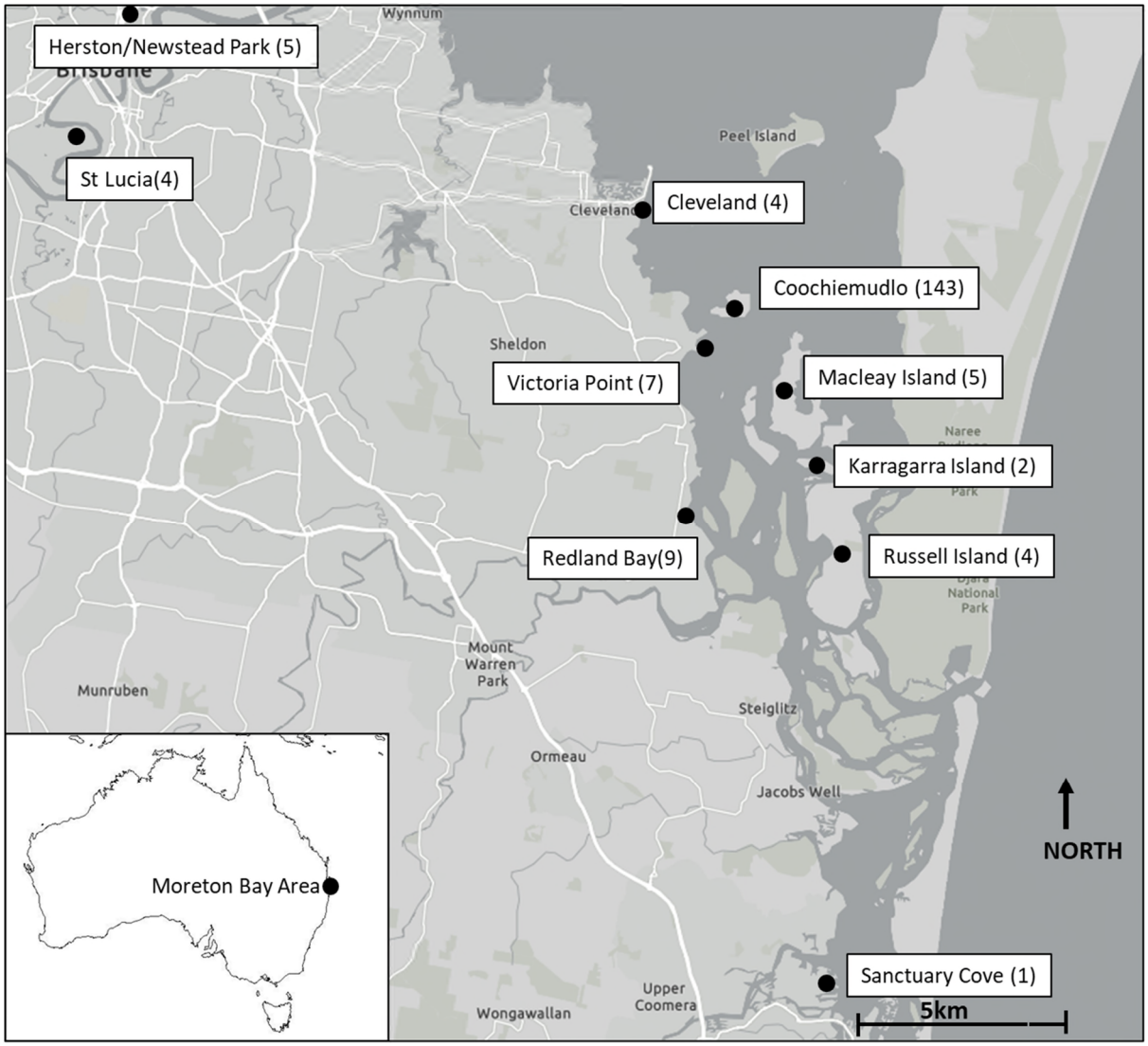

Figure 1. Locations at which Bush Stone-curlews were banded in Moreton Bay from September 2008 to December 2019.

Statistical analysis and estimation of apparent mean adult survival rates

Apparent annual survival rates were estimated for birds banded as adults in 2008 and 2009 combined, on Coochiemudlo Island using a live recaptures only model (Seber 1970), employing MARK survival estimation software v9.0 (White and Burnham 1999). Multiple re-encounters (recaptures and re-sightings) in any calendar year were combined to provide a single annual encounter event rather than using each monthly visit and encounter as a discrete encounter event.

Four basic survival models were tested, with the following assumptions:
Model 1: Φ(t)P(t) survival rate and recapture probability time-dependent;
Model 2: Φ(t)P(.) survival rate time-dependent and recapture probability constant;
Model 3: Φ(.)P(t) survival rate constant and recapture probability time-dependent; and
Model 4: Φ(.)P(.) both parameters constant.

In these models, Φ represents the apparent survival rate and P, the calculated recapture probability, with the symbol (t) used to represent a time-dependent value and (.) a constant value over time.

The best fit models were selected on the basis of the lowest value of Akaike's Information Criterion (AIC) being the model that best represents the observed data (Akaike 1973). A Goodness of Fit (GOF) estimation was used to assess the model fit to the data. Where GOF could not be applied due to low sample sizes the models were recalculated using the actual calculated ĉ value rather than the model value for comparison, using the alternative method to GOF described in Cooch & White (2015).

To correct for the potential inclusion of juveniles, birds within their first year of life that had attained adult plumage, survival rates were calculated again using a Time since Marking Model (TSM). Eight models were tested using this method to assess whether juveniles had been inadvertently included in the cohort samples and if so, to calculate more accurate mean adult survival rates (Cooch & White 2015):

Model 1: Φ(M2-,/.)P(.) two TSM classes for survival, both constant through time, recapture probability constant;
Model 2: Φ(M2-./t)P(.) two TSM classes for survival, first class (juveniles) constant, second class (adults) time dependent, recapture probability constant;
Model 3: Φ(M2-./.)P(t) two TSM classes for survival, both constant through time, recapture probability time dependent;
Model 4: Φ(M2-t/.)P(.) two TSM classes for survival, first class (juveniles) time dependent, second class (adults) constant, recapture probability constant;
Model 5: Φ(M2-./t)P(t) two TSM classes for survival, first class (juveniles) constant, second class (adults) time dependent, recapture probability time dependent;
Model 6: Φ(M2-t/t)P(.) two TSM classes for survival, both time dependent, recapture probability constant;
Model 7: Φ(M2-t/.)P(t) two TSM classes for survival, first class (juveniles) time dependent, second class (adults) constant, recapture probability time dependent; and
Model 8: Φ(M2-t/t)P(t) two TSM classes for survival, both time dependent, recapture probability time dependent.

Results

Population of Bush Stone-curlews on Coochiemudlo Island

The annual Redland City Council-led counts of Bush Stone-curlews on Coochiemudlo Island showed an overall significant linear increase in the number of birds since 1997 ($r=0.87$, $df=21$, $p<0.0001$) (Fig. 2) with a slope estimate of 49.23 (standard error, ± 0.97). The lowest count of 37 birds was made in 1997 and the highest count of 216 was made in 2018, although in 2019 only 171 birds were recorded. The most rapid increase occurred over that 13-year period between 1997 and 2009 when numbers more than quadrupled. Between 2009 and 2019 numbers have fluctuated between 171 and 216 birds, with no significant trend ($r=0.06$, $df=9$, $p=0.84$).

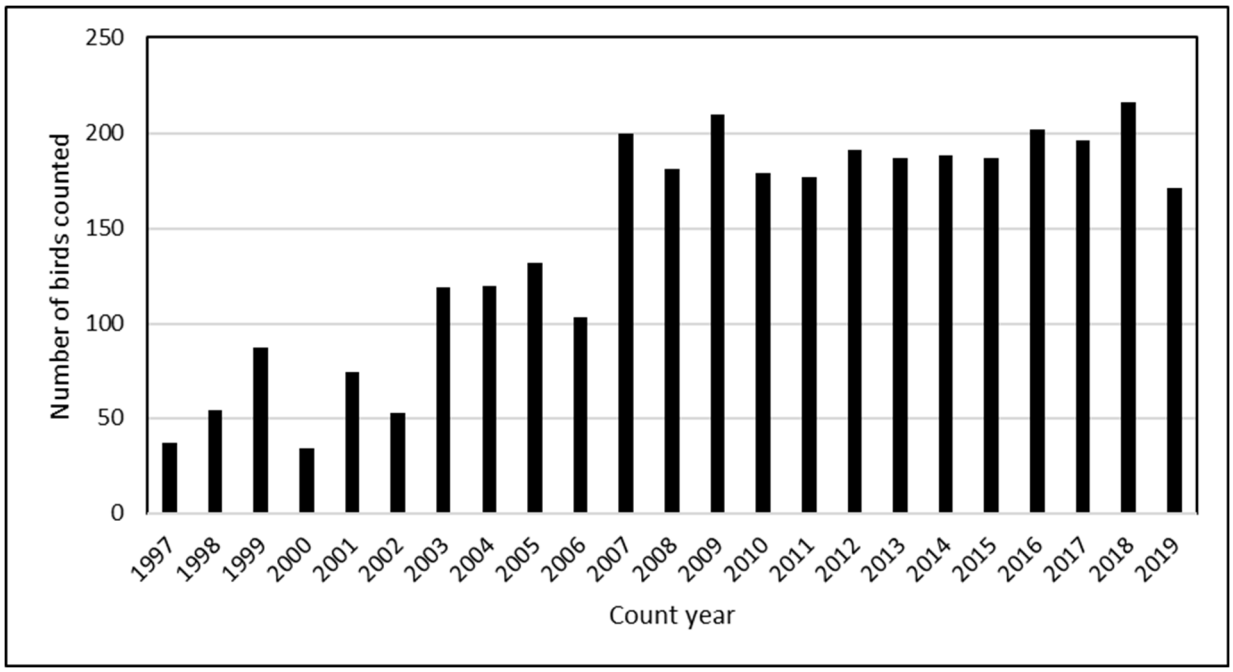

Figure 2. Annual February counts of Bush Stone-curlews on Coochiemudlo Island between 1997 and 2019, collected by Redland City Council.

Monthly counts conducted since May 2009 (Fig.3) show an increase in numbers over time ($r=0.37$, $df=111$. $P<0.001$), contrasting with the annual February count data, in which there is no apparent trend in numbers between 2009 and 2019. Mean monthly counts varied throughout the year (Fig. 4), with the highest mean counts in July and the lowest in October. However, these differences were not statistically significant (ANOVA $F=1.42$, $df=11,101$, $P=0.18$).

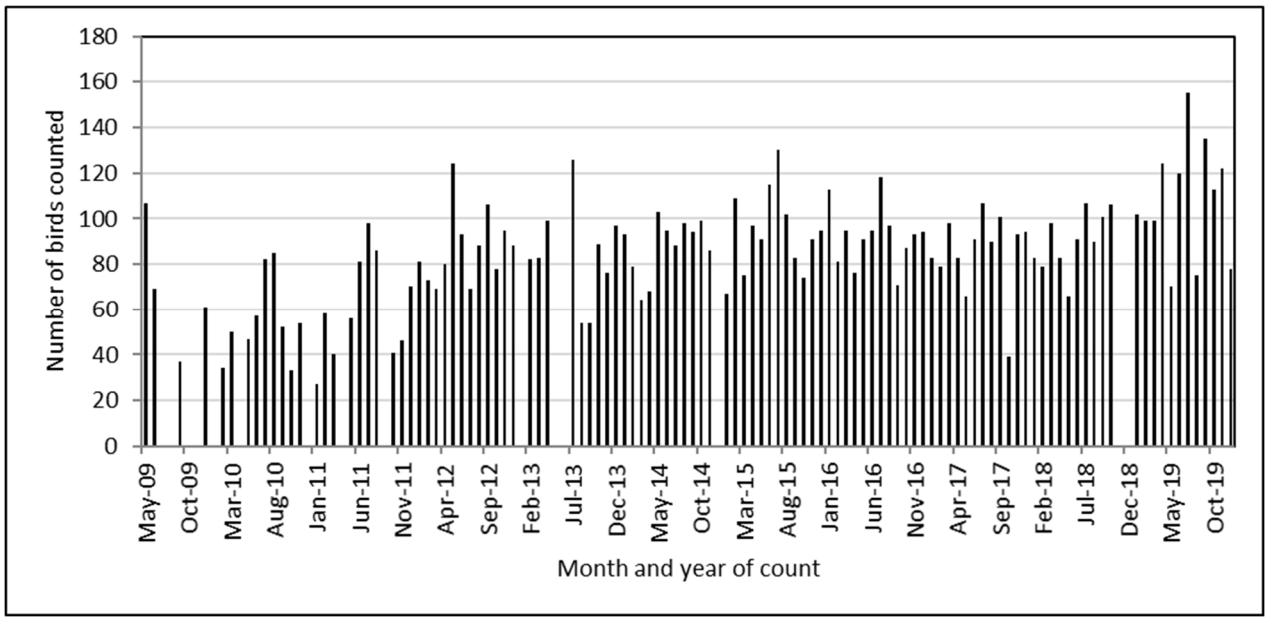

Figure 3. Monthly counts of Bush Stone-curlews on Coochiemudlo Island from May 2009 to December 2019.

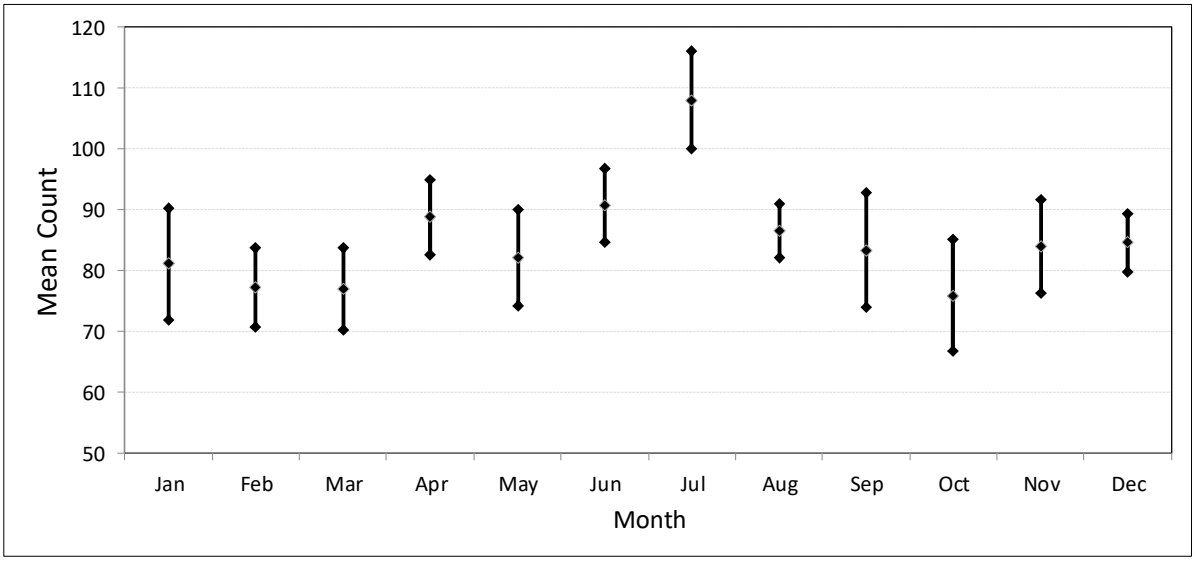

Figure 4. Mean monthly counts of Bush Stone Curlews on Coochiemudlo Island from May 2009 to December 2019 (bars represent standard errors from the mean).

Movements in the Moreton Bay area

From 7 September 2008 to 31 December 2019, a total of 184 Bush Stone-curlews were banded at 12 sites in the Moreton Bay and Brisbane region. The majority (143) were banded on Coochiemudlo Island. Figure 1 shows the locations used in this study and the number of birds banded at each location.

Over the period of the study a total of 1,035 re-sightings of leg-flagged birds were recorded. Of the 143 individuals banded on Coochiemudlo Island, 23 (16.1%) were not seen again, while 103 (72.0%) were resighted one or more times on Coochiemudlo Island only, and 17 (11.9%) were resighted at locations away from Coochiemudlo Island. Eleven of the movements (64.7%) were between Coochiemudlo Island and Victoria Point, the nearest mainland point from the island. Of these seven individuals either returned to Coochiemudlo Island or moved between Coochiemudlo Island and Victoria point two or more times.

Of the 41 birds banded at locations away from Coochiemudlo Island, 22 (53.7%) were not seen again, 11 (26.8%) were resighted one or more times but only at the banding location and 8 (19.5%) birds were recorded moving to a new location. Again, most movements were local inter-island movements, or movements between islands and the mainland. The longest movement was of a bird banded in Brisbane and resighted on Coochiemudlo Island, a movement of 32 km. All movements away from the banding site are shown in Figure 5.

Of the 25 individuals recorded moving away from their banding location, eight (32%) were banded as juveniles. The remaining birds were banded as adult birds suggesting that both juvenile and adult birds disperse to new locations. Although the status of most birds at sites away from Coochiemudlo Island was not recorded, four were found dead and three birds dispersing from Coochiemudlo Island were recorded on territories with mates.

Figure 5. All recorded movements of Bush Stone-culews away from their banding locations

Breeding success on Coochiemudlo Island

From January 2008 to December 2019 a total of 324 potential breeding events were recorded. Of these, 179 (55.3%) either failed to hatch any young or lost each of their young prior to independence. This latter category accounted for ten (3.1%) of all breeding attempts, indicating that once hatched, pairs usually rear at least one nestling to independence. Of the 179 failed nesting attempts, there was evidence of a second breeding attempt in ten cases (5.6%).

Breeding occurred between July and January, with most records of birds on nests or with newly hatched young from August to October (Fig. 6). Of the 324 potential breeding events, 93 (28.7%) successfully resulted in chicks (Plate 2) being reared to independence. Of the 93 successful nesting attempts, there were four occasions (4.30%) where pairs immediately re-nested once offspring had been reared to independence. The remaining 52 (16.05%) potential breeding events involved pairs that were recorded on a territory but the outcome for that season was unknown with birds either not recorded again or breeding and the outcome of that breeding attempt remaining unknown. The cause of breeding failure was recorded on four occasions. Laughing Kookaburras *Dacelo novaeguineae* took eggs from two nests and a nestling from another, and one 3-week old juvenile was also run over by vehicle.

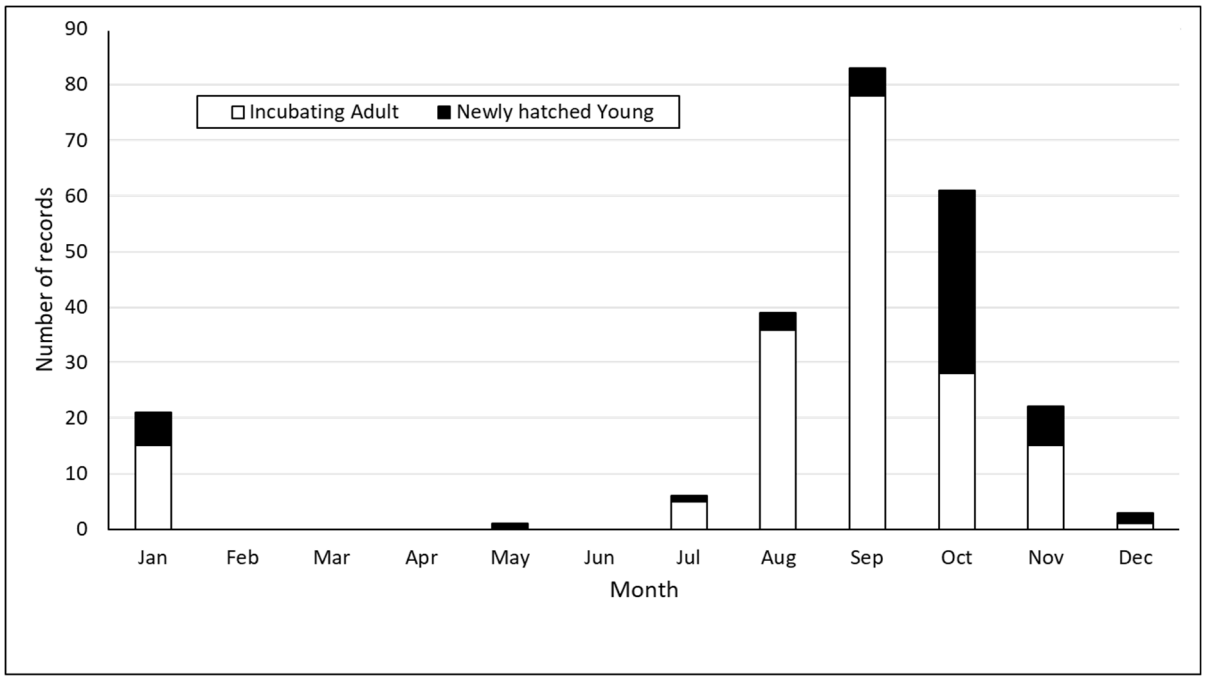

Figure 6. Records of Bush Stone-curlew pairs on Coochiemudlo Island recorded on nests (open bars) and pairs with newly hatched young (black bars) aggregated by month for the period 2008 to 2019.

Plate 2. Bush Stone-curlew (unbanded) and hatchling in Brisbane City Botanic Gardens, 3 November 2007 (Jon Coleman)

Analysing all breeding attempts in which the outcome was known, successful or otherwise, the mean number of nestlings produced per breeding attempt over the 12 years between 2008 and 2019 was 1.42 (± 0.04), and the number of young reared to independence was 1.04 (± 0.06). . The mean number of hatchlings per breeding attempt varied significantly between years (ANOVA, F=2.42, df=11,180, P=0.01), from the lowest value of 0.83 (± 0.22) in 2011 to the highest value of 1.71 (± 0.25) in 2017 (Fig. 7). The mean number of young reared per breeding pair also varied significantly between years (ANOVA F=2.42, df=11,180, P=0.02), (Fig. 8) but the differences between years were still significant from the lowest value of 0.5 (± 0.2) in 2018 to the highest value of 1.5 (± 0.5) in 2017.

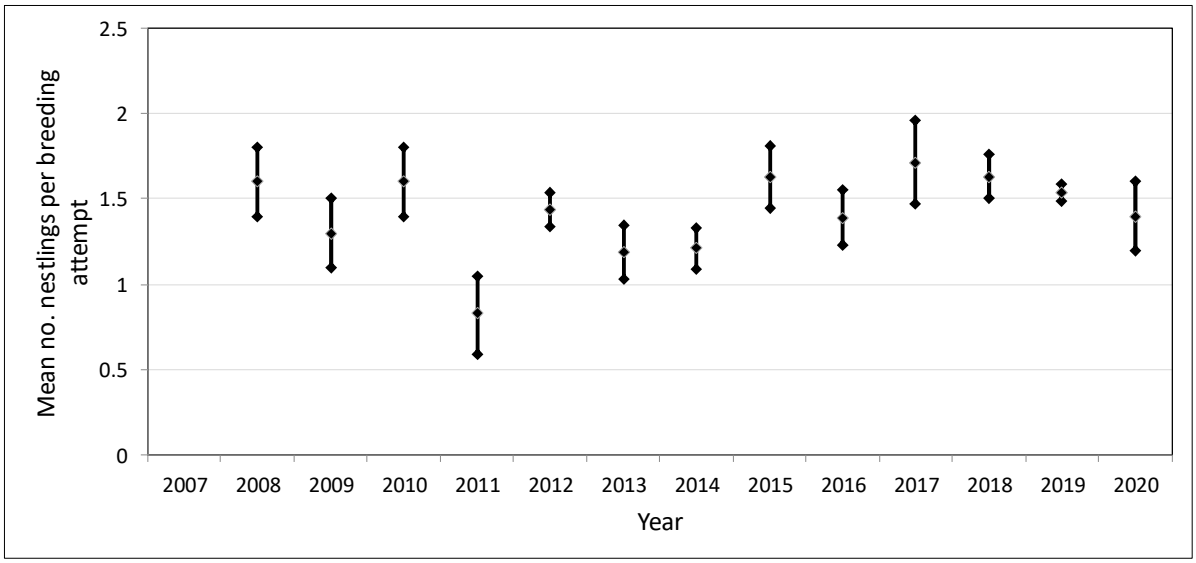

Figure 7. Mean young hatched per breeding attempt on Coochiemudlo Island in each year of the study (bars represent standard error from the mean).

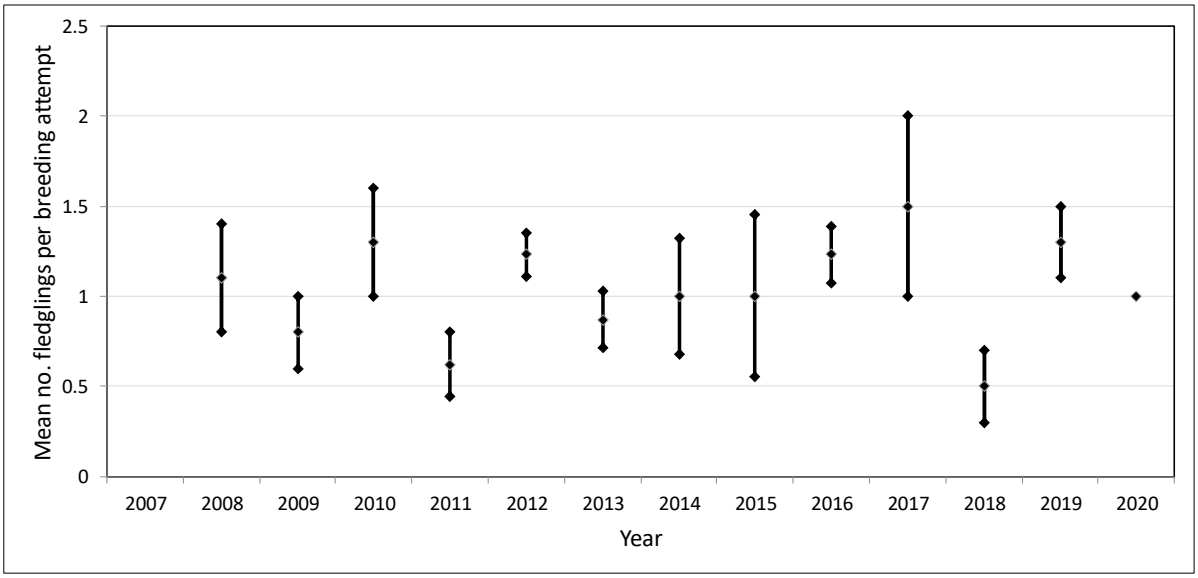

Figure 8. Mean young reared per breeding attempt on Coochiemudlo Island in each year of the study (bars represent standard error from the mean)

Longevity and survival rates

The earliest birds banded in this study were banded in November 2008 (n=21) and January 2009 (n=38), with a further 29 birds banded between May and November 2009. For the 16 birds banded as adults in the 2008 cohort, four (25.0%) were resighted in 2019, 11 years after banding. For the 47 adult birds banded in the 2009 cohort, 17 (36.2%) were resighted in 2019, 10 years after banding. Longevity records from both cohorts thus indicate that the species could survive in the wild well beyond the tenure of this study.

Mean apparent adult survival rates were calculated for the 2008 and 2009 cohorts combined using the time-dependent live recaptures model. For the combined sampling cohort the most appropriate model assumed a constant survival and time-dependent recapture probability (Table 1). The apparent adult annual survival rate for this cohort was calculated to be 88.6% (± 0.02%) with resighting probabilities varying from 19.3% to 43.6%.

Insufficient data were available to test the model fit to the data using a Goodness of Fit test so the calculated actual median ĉ value of 2.31 for each cohort was used to recalculate corrected models rather than using the default ĉ value. The results of the corrected models confirmed the model selections as appropriate and the best fit to the data, in which the QAIC values for the selected models were still the lowest observed. Based on lowest AIC and number of model variables, we selected a TSM model with time-dependent juvenile survival, constant adult survival and time-dependent recapture probability. The revised mean adult survival rate for the combined 2008 and 2009 cohort was 92.9% (± 1.8%).

Table 1. Standard Cormack Jolly-Seber Live Recapture models used to analyse survival rates of Bush Stone-curlews banded as adults on Coochiemudlo Island in 2008 and 2009. The selected model is shown in bold.

Model	AIC_c	ΔAIC_c	Model likelihood	No. parameters	Deviance
Φ(t)P(t)	480.20	0.00	0.17	19	147.45
Φ(t)P(.)	526.25	49.61	0	11	213.25
Φ(.)P(t)	**476.63**	**19.22**	**0**	**11**	**163.65**
Φ(.)P(.)	535.54	58.91	0	2	531.46

The cause of death for banded birds on Coochiemudlo Island was rarely recorded during the study period. However, ABBBS records and reports from residents indicate that impact with vehicles caused the death of four adult banded birds on Coochiemudlo Island and two adults at nearby Victoria Point. The cause of death of three other adult banded birds involved fishing line injuries, in one case due to ingestion of the fishing hook and line.

Numbers of Bush Stone-curlews on Coochiemudlo Island

The Bush Stone-curlew has declined across much of its southern range (Garnett & Crowley 2000; Gates & Paton 2005). Three major events are believed to be responsible for this decline (Robinson 1998) with the first associated with land clearing during European settlement,

followed by further declines in the 1950's with changes in agriculture practises and the introduction of the Red Fox *Vulpes vulpes.* A removal of bounties on foxes in Victoria in the 1980's has further impacted Bush Stone-curlew populations in south eastern Australia. This decline contrasts with the increase in abundance on Coochiemudlo Island which has led to a plateaued population level in recent years.

Foxes are known to still predate the species in the southern Australia (Johnson & Baker-Gabb 1994). Experiments have demonstrated that Bush Stone-curlew productivity is significantly better if ground predators are excluded (Gates & Paton 2005). Coochiemudlo Island is very likely fox free and, despite being heavily populated, is still suitable for Bush Stone-curlew habitation as urban development, and patterns of associated land clearing, is thought to have created conditions favourable to the species (Cannard & Milton 2012). The lack of predators and abundance of suitable habitat are therefore likely to explain the population increase seen on Coochiemudlo Island. The recent plateauing of numbers recorded may be an indication that the island has approached maximum carrying capacity but further work on territory sizes and available habitat would be required to quantify this.

Movements in the Moreton Bay area

The high numbers of birds banded and only recorded within the confines of Coochiemudlo Island is not surprising and is consistent with results from other studies. For example, Gates (2001) identified that resident breeding Bush Stone-curlews typically ranged within a 26 to 64-ha range but two other groups, more mobile breeders and non-breeding birds, ranged more widely. A 70-ha home range for this species was calculated for birds in Victoria (Johnson & Baker-Gabb 1994), with 95 ha calculated as the usual home range in northern Queensland (Wilson 1989). All these calculated home ranges fall well within the surface area of Coochiemudlo Island, estimated at 500 ha, so a large sedentary population on the island could be expected.

Gates (2001) noted in the more mobile Bush Stone-curlew cohorts' evidence of some of birds dispersing to new locations. The movement data from Coochiemudlo Island and adjacent areas suggests this may also be the case in our study with movements away from the island recorded. While most recorded movements were between Coochiemudlo Island and Victoria Point, the nearest mainland site, there were other movements to mainland sites further away and a number of examples of inter-island movements. This involved both juveniles and adult birds dispersing and although the status of these birds was rarely recorded, several were known to have established territories in those locations. This may suggest that Coochiemudlo Island may be a source population for other islands and the local mainland in that part of Moreton Bay.

Breeding success on Coochiemudlo Island

The breeding season in this population was from July to January, similar to the breeding season recorded in South Australia (Schodde & Mason 1980) and in northern Queensland (Marchant & Higgins 1996). This seems to coincide with the wettest times of the year in those areas and with a diet primarily consisting of insects and other invertebrates (Marchant & Higgins 1996) this presumably aligns chick rearing with periods of increased food supply arising from wetter conditions. Some breeding pairs on Coochiemudlo Island nested more than once in a season,

particularly if the first clutch or brood were lost. Other populations of the species are known to rapidly replace clutches (Wilson 1989; Marchant & Higgins 1996).

The number of fledglings produced per breeding attempt on the island (1.04) appears high when compared to a local mainland study which recorded only 0.8 nestlings fledglings per breeding attempt (Anderson 1991). This may reflect a lack of predators and more suitable habitat on Coochiemudlo Island when compared to mainland sites, such as in Victoria (Johnson & Baker-Gabb 1994) where fledging rates are also low. These differences in breeding productivity suggest that Moreton Bay island populations may be an important source of recruitment for mainland populations.

Longevity and survival rates on Coochiemudlo Island

The Bush Stone-curlew is known to be long-lived with the oldest birds in this study being at least 11 years old and still resighted regularly. The high adult survival rate calculated at 94.47% supports the recorded longevity in this species and suggests the species can live well beyond what has been recorded to date in this study. Green *et al.* (1997) recorded a mean annual adult survival rate of only 83% in the European Stone-curlew *Burhinus oedicnemus* which although lower, likely reflects the migratory nature of this species when compared to Bush Stone-curlew which are resident. Establishing a comparative study at a mainland location to compare breeding success and survival rates in this species would be beneficial in understanding the factors influencing Bush Stone-curlew numbers in Eastern and Southern Australia.

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