Why is the Pallid Cuckoo declining in the Hunter Region, but relatively stable in Tasmania?

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A comparison of the status of the Pallid Cuckoo *Heteroscenes pallidus* in the Hunter Region and Tasmania using records from the BirdLife Australia database (Birdata) confirmed the species to be more abundant in Tasmania. In the Hunter Region a sustained decline in status was apparent over the last 20 years at both the regional scale and at individual locations. Over the corresponding period in Tasmania the evidence is ambiguous; increases apparent at the regional scale conflict with evidence of local declines.

In both regions the Pallid Cuckoo is a breeding visitor with more than 95% of records occurring between September and January.

Interpretation was based on the assumption that the Pallid Cuckoo has a very large home range supporting a large number of pairs of its brood host.

Pallid Cuckoo prefer dry open woodland, especially woodland edges. Excessive removal of tree cover and increases in the extent of dense moist understorey vegetation are detrimental. Recent changes in land use in the central Hunter Region near Paterson may have contributed to local decreases. The decreased presence of cuckoos may reflect issues with the status of its host species.

INTRODUCTION

The Pallid Cuckoo *Heteroscenes pallidus* occurs throughout Australia (Blakers *et al*. 1984; Barrett *et al*. 2003) but is primarily a breeding summer visitor in the southern part of its range, including the Hunter Region of NSW.

In the Hunter, where it is more frequently recorded in the west of the region, the Pallid Cuckoo is never numerous and there is evidence that its population status may be decreasing (Stuart 2018). On returning to south-east Tasmania in 2014 after 21 years in the Hunter Region, the contrast between the abundance of Pallid Cuckoo in the two areas was obvious. This paper compares the population status of the Pallid Cuckoo in the two regions, attempting to understand why there are fewer Pallid Cuckoo in the Hunter.

Examination of the literature on the Pallid Cuckoo highlights the complexity surrounding the apparently simple objectives outlined above. For instance, the HANZAB account of the Pallid Cuckoo (Higgins 1999: 665) summarises the movements as follows: "Migratory or partly migratory, but patterns of movement poorly understood, even though much information in the literature. Also described as nomadic or possibly resident". A further complication in evaluating the populations of cuckoos is the possibility that their status may be linked to that of their brood host. Again, the literature is vague with 55 host species being listed for the Pallid Cuckoo in HANZAB (Higgins 1999) and at least 80 host species mentioned in the First Atlas of Australian Birds (First Atlas) (Blakers *et al*. 1984). In the Hunter there is little information on host species with only one breeding record in the Annual Bird Report series (Stuart 1993 - 2018). That record involved a Yellow-faced Honeyeater *Caligavis chrysops* as host. In Tasmania the endemic Black-headed Honeyeater *Melithreptus affinis* and Strong-billed Honeyeater *M. validirostris* are both named as hosts (Higgins 1999).

A related species, the Common Cuckoo *Cuculus canorus* has a widespread breeding distribution in the northern hemisphere and has been well studied (Davies 2015). Findings from those studies provide insights into aspects of cuckoo behaviour important to the interpretation of local data. Again, ambiguity prevails; on the one hand cuckoos, particularly females, are secretive, seeking to avoid the attention of their brood hosts. On the other hand, they are highly vocal, since males and

females need to remain in contact as they seek hosts. It has been estimated that female Common Cuckoo may lay up to 25 eggs at two-day intervals and hence seek a similar number of hosts, usually of one species (Davies 2015). Consequently, they have large territories. For instance, in the UK the population density has been estimated to be four pairs in 100 km^2 (Gibbons *et al*. 1993), which could include pairs parasitising different host species. However, a number of males and females may be sharing the same home range and parasitising the same host species, as there is evidence that both males and females may have two or three different partners in one breeding season (Davies 2015). Recent satellite tracking studies in Scandinavia have indicated a breeding season home range of 130 km^2 (Williams *et al*. 2016*)*. A further complication is that the diets of the cuckoo and the host species may be different and the home range must provision both species. The Common Cuckoo (Davies 2015) and the Pallid Cuckoo (Higgins 1999) both predominantly feed on hairy caterpillars.

Seasonal distributions reported in the New Atlas of Australian Birds (New Atlas) (a 1999 – 2002 study) (Barrett *et al*. 2003) suggest that there is a population shift from south-east Australia in the breeding season, to north-west Australia in winter. Griffioen & Clarke (2002) provide support for this conclusion, suggesting that the Pallid Cuckoo is one of five species that migrate inland in an anti-clockwise circular pattern.

The Pallid Cuckoo favours open habitats with sparse understorey, inhabiting a range of lightly timbered country including open woodlands, shrublands, wooded grasslands and farmland (Higgins 1999). Insights into the habitat preferences in the Hunter Region are provided by studies in the forests of the Upper Hastings Valley north of the region where the Pallid Cuckoo was only found in dry open forest, preferring areas with dry understorey (Shields *et al.* 1985). Dry woodlands and open areas are also preferred in Tasmania (Ridpath & Moreau 1965). The importance of forest edges has been emphasised (Higgins 1999).

METHODS

Data source

The evaluation in this paper is based on the presence of Pallid Cuckoo in surveys submitted to Birdlife Australia's (BLA) Birdata archive between 1998 and 2019. Records for the Hunter Region and Tasmania for 1998-2019 were extracted in June 2019. Most Pallid Cuckoo records were submitted as one of three types of surveys:

2-ha surveys. This is BLA's preferred survey type and involves compiling species lists at 2-ha survey sites in a 20-minute period. This standardised procedure removes bias associated with variations in survey effort (i.e. time and area surveyed are fixed provided that observers exclude calls made outside the boundaries of their 2-ha survey site). Unfortunately, when a species is scarce, as in the case of the Pallid Cuckoo in the Hunter Region, this survey method may not provide sufficient records for meaningful population trends to be established.

500-m surveys involve recording the presence of species within an area of 500-m radius (*c.* 78.6 ha). The duration of the survey is variable. Most surveys are completed on the same day but some involve accumulating species lists over a period of one month. The increase in the area searched and the duration of these surveys usually leads to higher RRs, thus ameliorating the issue of insufficient records. However, the results may be subject to sampling bias associated with variations in the size of the area sampled (i.e. the actual area surveyed often is much smaller than the nominal 78.6 ha) and the duration of the survey. However, within 500-m survey data there are sub-sets of data where repeat surveys have been conducted at the same site in an identical manner by the same observer. These surveys were used to generate bias-free local trends for comparison with regional trends.

5-km surveys allow data collection over even larger areas (5-km radius) and the issues associated with potential survey effort bias in terms of variation in the area sampled and the duration of the surveys are further exacerbated. Again, there are sub-sets of data involving long-term repeat surveys that provide bias-free trends at a limited number of survey sites.

In the following analysis 500-m surveys were used as the default source of data for analysis because in the case of the Pallid Cuckoo it was deemed least compromised by issues such as data deficiency and bias. However, information from other survey types was used for confirmatory purposes and when it was considered more reliable.

Selection of sites for analysis

The Hunter Region and Tasmanian bird data records were searched to find survey sites monitored by the same person for at least five years that had sufficient Pallid Cuckoo records for temporal analysis. Most of the suitable sets involved either 5-km or 500-m surveys, where the duration of the survey was of the order of 3 hours. For short duration 500-m and 2-ha 20-minute surveys there were insufficient records and it was necessary to pool the results from local clusters of sites located in similar habitat in order to achieve sufficient statistical power.

Hunter Region

Three suitable long-term data sets in the central Hunter Region were identified (see details immediately below). Unfortunately, there were not any similar long-term data sets at sites in the western part of the Hunter Region where the Pallid Cuckoo is indicated to be more numerous (see maps in Stuart 2018) which could be used for comparative purposes. However, the area around Medhurst Bridge has been frequently visited since 1998 by a number of observers and their pooled data involving a combination of survey types was used.

Green Wattle Creek - Birdata Site ID 767161: 32.661°S 151.649°E; 500-m surveys of typically 200-min duration by M. Newman. Dry woodland with understorey recovering after cattle grazing ceased (Newman 2009; Newman & Cunningham 2018).

Black Rock – Birdata Site ID 97476: 32.568°S 151.649°E; 61 breeding season 5-km surveys of typically 150-min duration made by M. Newman in a lightly wooded area grazed by cattle (Newman 2014).

Balickera – Birdata Site ID 275801: 32.656°S 151.789°E; 500-m surveys conducted throughout the month by Jenny Musicka, survey duration unknown but typically longer than at other sites. There were no surveys in 2002/2003.

Medhurst Bridge – 32.514°S, 150.698°E – All Birdata for 2-ha 20-min, 500-m and 5-km surveys conducted within 20 km of Medhurst Bridge were pooled and evaluated as seven three-year data sets. Trends generated by this approach in which survey effort is variable, and many different observers contribute, is expected to be less reliable than the other data sets used for trend analysis. The habitat surrounding Medhurst Bridge was highly fragmented with extensive clearing of the valley floor for agricultural purposes. Remnant scrub and woodland were mainly restricted to creek lines and ridges.

Tasmania

Seven suitable data sets were identified in Tasmania, located in three regions of the state. At two sites, where 5-km surveys were used, there were sufficient records at the individual sites. At the other sites where 500-m and 2-ha 20-min surveys were used it was necessary to pool data across several sites.

Lake Llewellyn and Cuprona Road – Birdata Site IDs 449937 and 327214: 40.933°S, 145.567°E and 41.100°S, 145.983°E respectively. Two sites in north-west Tasmania approximately 30 km apart which were surveyed regularly for 21 years by Richard Ashby using 5-km surveys of approximately 240 minutes duration. There were no changes to the habitat at either site, other than those occurring naturally.

Woodsong – Birdata site IDs 22480, 405217, 640557 and 640708: 41.300°S, 148.117°E. A cluster of four 500-m survey sites in north-east Tasmania located in dry sclerophyll woodland with wet gullies. Breeding season surveys were made by Albert Nichols between 2009 and 2019. There were extensive fires in the surrounding area towards the end of this period, but no fires at the survey sites.

South Arm – 2-ha 20-minute and 500-m survey data for sites within a 5-km radius of Sandville (Birdata site ID 492918: 43.000°S 147.485°E) were pooled independently to provide separate trends for 2-ha 20-minute (12) and 500-m (3) sites. The 2-ha 20-minute sites were in dry sclerophyll woodland, fragmented by low-density residential development. Newman (2018) provides additional information on the habitat surrounding the Sandville survey sites. The 2-ha survey sets include both ridge and valley survey sites. The 500-m sites were located in an adjacent more lightly wooded area with large paddocks in the valleys.

Meehan Range – Birdata Site IDs 290076-77, 2960089 and 2960091-93: 42.840°S 147.397°E. Surveys were conducted at six 2-ha 20-minute survey sites located along a 4 km creekline transect in a gully through dry sclerophyll woodland (Newman 2018) at a location approximately 20 km north of the South Arm peninsula. Surveys were conducted most months between September 2014 and January 2019. The area was burnt in a wildfire in October 2006, eight years before the surveys commenced.

Analysis of data

Reporting Rates (RR), the ratio of the number of surveys in which the Pallid Cuckoo was recorded to the total number of surveys, expressed as a percentage, were used to compare the presence of Pallid Cuckoo in the two regions. The assumption that RRs are a measure of abundance is central to the interpretation of survey results reported in the following sections. The Chi Square test (χ^2) was used to test statistical differences in RRs (Fowler & Cohen 1994).

In both the Hunter Region and Tasmania >95% of Pallid Cuckoo records occurred between September and January, the nominal breeding season when Pallid Cuckoos are vocal (see Results section). Surveys outside of the nominal September to January breeding season were excluded in order to eliminate bias associated with annual variations in the proportion of surveys conducted in the breeding season. It is possible that birds were under-recorded outside the breeding season because they were less vocal.

Unless stated, no attempt was made to correct for the location bias caused by repeat surveys at the same location when determining regional scale trends. Similarly, no corrections were made for variations in the proportion of surveys conducted in areas outside the Pallid Cuckoo's core range (i.e. in unsuitable habitat).

RESULTS

Seasonal variation

Seasonal variations in the occurrence of the Pallid Cuckoo in the Hunter Region and Tasmania are compared in **Figure 1**. In both areas most of the records were in the period September to January (96.1% in the Hunter and 95.2% in Tasmania). Consequently, in temporal evaluations only surveys for these five months were used as discussed previously.

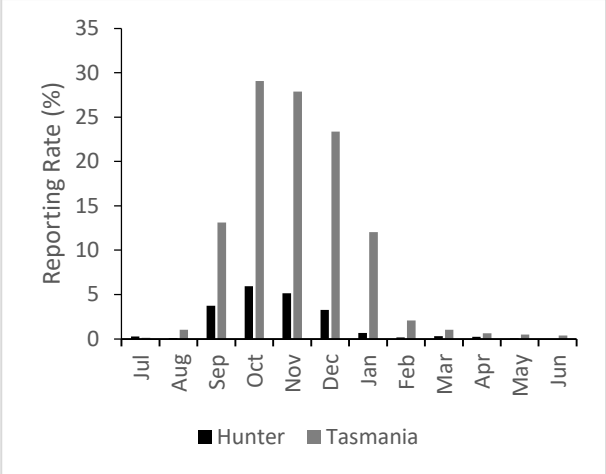

Figure 1. Monthly variations of the Reporting Rates of the Pallid Cuckoo in the Hunter Region and Tasmania for the 21 years between 1998/1999 and 2018/2019 (Birdata 500-m surveys: Hunter n = 15,926 surveys; Tasmania n = 12,790 surveys).

Regional trends

The annual RRs for the Pallid Cuckoo in the Hunter Region and Tasmania are compared in **Figure 2**. Throughout the 21-year period the Pallid Cuckoo was more frequently recorded in Tasmania than in the Hunter Region. In the Hunter, the RR decreased by 87%, or by 0.31%/annum assuming a linear trend, compared with an increase of 77% in Tasmania at a linear rate of 0.6%/annum. The increase in RR in Tasmania from 12.7% in 2008/2009 to 31.6% in 2009/2010 is partly, but not completely, explained by the commencement of an intensive 500-m survey campaign at one survey site, which contributed 21% of the Tasmania 500-m surveys during the second decade of the study period (unpublished results).

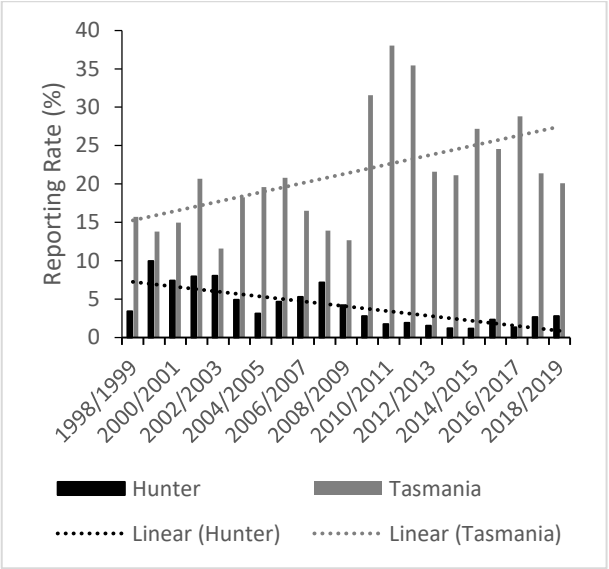

Figure 2. Comparison of temporal variations in the breeding season Reporting Rates of the Pallid Cuckoo in the Hunter Region and Tasmania (Birdata 500-m surveys).

Because the difference in the trajectories of the RR trends in the two regions was unexpected, confirmation was sought by comparing the RRs for the four-year periods at the start and end of the 20-year study of the study period (**Table 1**). The initial period, from 1998/1999 to 2001/2002 was during the data collection phase of the New Atlas of Australian Birds (Barrett *et al*. 2003). The second period 2015/2016 to 2018/2019 involved an increase in survey effort following promotion of Birdata in both regions. During both these periods the number of 2-ha and 500-m surveys was considerably higher than in the intervening years.

This analysis (**Table 1**) confirmed the finding that the RRs for the Pallid Cuckoo had decreased in the Hunter Region but had increased in Tasmania. Furthermore, this result was common to data generated by all three survey methods. In five of the six data sets the differences were highly significant statistically ($p < 0.01$) based on χ^2 tests.

In all six comparisons in **Table 1** the RRs for Tasmania were higher than for the Hunter Region. For example, in the period 1998/1999 to 2001/2002 the Tasmanian RR was 2.1 times that for the Hunter, but by the period 2015/2016 to 2018/2019 this difference had increased to 8.7 times (2-ha surveys). The differences for the other survey types were similar. All of the differences were highly significant $\chi^2 > 8$ for 1 df: $p < 0.01$.

Table 1. Comparison of the breeding season Reporting Rates of Pallid Cuckoo in the Hunter Region and Tasmania for two four-year periods using three types of Birdata survey method.

Survey type	**2-ha**	**2-ha**	**500-m**	**500-m**	**5-km**	**5-km**
Region	Hunter	Tasmania	Hunter	Tasmania	Hunter	Tasmania
1998/99 – 2001/02 RR (%)	3.8	6.8	7.5	14.6	11.0	35.1
2015/16 – 2018/19 RR (%)	1.2	10.6	2.2	19.7	3.7	41.9
Change in RR (%)	-61.5	56.0	-70.7	34.9	-66.5	19.3
$\chi 2$	8.5	8.9	59.6	15.2	14.6	3.7
Probability *p*	0.0035	0.0028	<0.0001	<0.0001	0.0001	0.0736
1999 – 2002 records	21	53	78	295	110	316
2015 – 2019 records	18	229	67	423	13	178
1999 – 2002 surveys	662	783	1040	2021	1003	900
2015 – 2019 surveys	1475	2164	3059	2164	354	425

As expected, RRs increased with the survey effort, being lowest in the 2-ha surveys and highest for the larger area longer duration surveys (e.g. in the Hunter Region for the period 1998/1999 to 2001/2002 the RR for 5-km area searches (11.0%) was 3.5 times higher than for 2-ha surveys (3.2%) (**Table 1**).

I also examined the results for individual sites to determine whether the trend apparent at the regional scale was replicated locally in unbiased data sets (i.e. surveys conducted in a consistent manner by the same observer).

Hunter sites

At Green Wattle Creek (**Figure 3**) the overall RR during the breeding season was 28.9% based on surveys at monthly intervals over an 18-year period commencing 1996/1997. Although the RR was higher in the first seven years (RR 42.9%), than in the subsequent 11 years (RR 20.0%) the difference was not statistically significant (χ^2 = 3.11 for 1 df: p = 0.077). The surveys, lasting approximately 200 min, were made in the morning and included four embedded 2-ha 20-min surveys. No Pallid Cuckoo were recorded at the 2-ha sites.

The Balickera surveys (**Figure 3**) involved observations accumulated throughout the month, and hence, are not directly comparable to those at Green Wattle Creek (200-min survey duration) because the observations were collected over a longer period and in a less consistent manner.

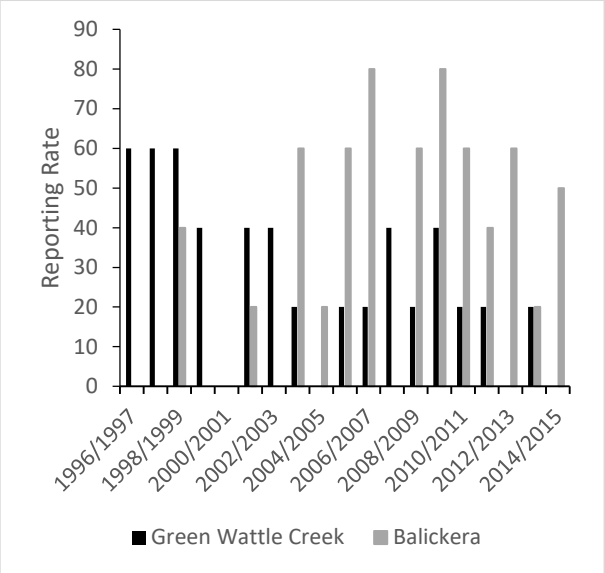

Figure 3. Variation in the breeding season Reporting Rates for Pallid Cuckoo at Green Wattle Creek and Balickera in the central Hunter Region (500-m surveys; zero bars reflect the absence of Pallid Cuckoo except for Balickera in 2002/2003 when there were no surveys). Balickera surveys by Jenny Musicka.

Surveys which I conducted at Black Rock Road near Martins Creek (**Figure 4**) between 1998 and 2014 (Newman 2014) provide another long-term data set, although annual survey effort was less consistent than at Green Wattle Creek. The overall RR was 23.3%, but as shown in **Figure 4**, the Pallid Cuckoo occurred more frequently in the three-year period 1999/2000 to 2001/2002 (RR 40.7%) than in the subsequent 12 seasons (RR 8.8%). This difference was statistically significant (χ^2 5.36 for 1 df: p 0.025).

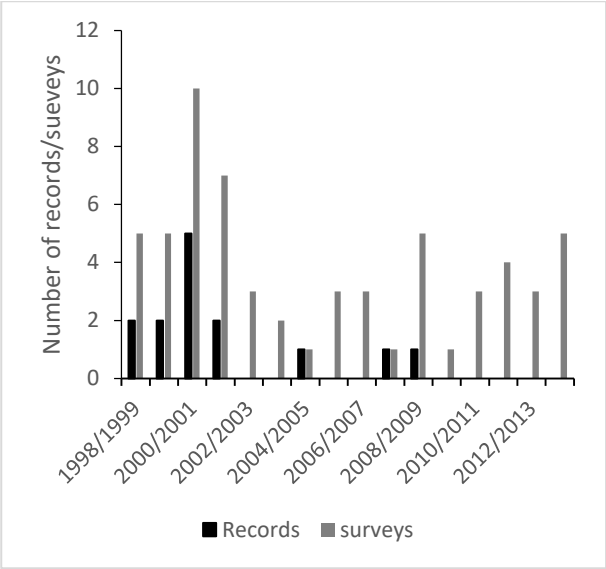

Figure 4. Pallid Cuckoo records from Birdata 5-km surveys conducted at Black Rock Road, Martins Creek in the central Hunter Region between 1998/1999 and 2013/2014.

The results for surveys conducted within 20 km of Medhurst Bridge in the west of the Hunter Region (**Figure 5**) suggest that with the exception of 2010-2013, when the number of surveys was low, the Pallid Cuckoo was less common post the 2003/2004 breeding season. However, an increase in the final three-year period is apparent.

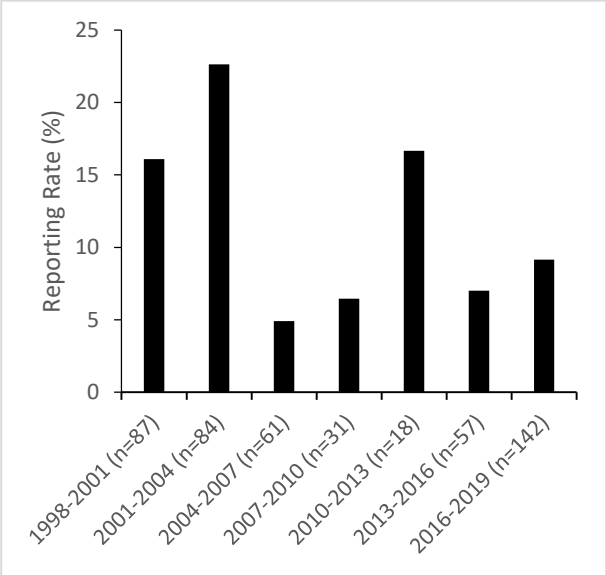

Figure 5. Variations in the breeding season Reporting Rates of Pallid Cuckoos for surveys conducted within a 20-km radius of Medhurst Bridge in the south-west of the Hunter Region. (Birdata 2-ha, 500-m and 5-km surveys pooled over three-year periods; n = the number of surveys).

Tasmania sites

The trends for two sites in north-west Tasmania are shown in **Figure 6**.

At Lake Llewellyn the overall RR rate was 59.7%. The linear trend line indicated a decrease of 13.5% in RR over the 20-year period, but the change was not statistically significant (p 0.59). At Cuprona Road the overall RR (58.8%) was similar, but in this instance the linear trend line, which indicated a 53.9% decrease from 81.2% to 37.4%, was statistically significant (p *0.011)*. There was a statistically significant correlation between the Lake Llewellyn and Cuprona Road data sets (p 0.031).

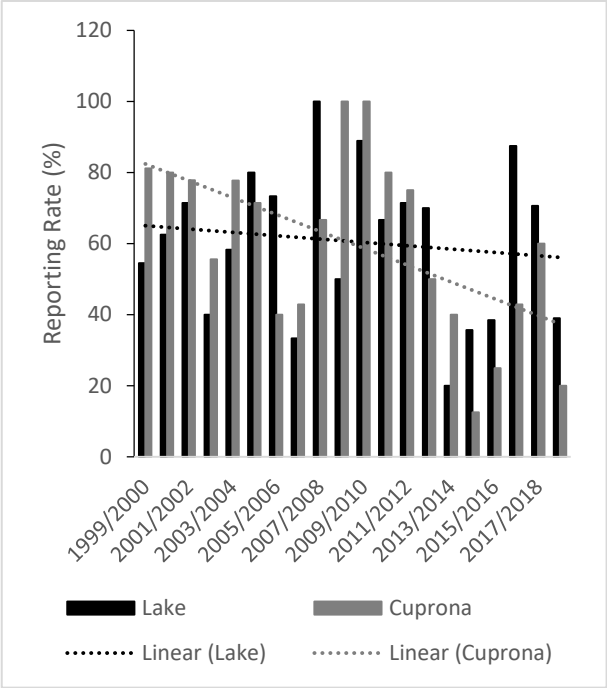

Figure 6. Variation in breeding season Reporting Rates of Pallid Cuckoos at two locations in north-west Tasmania (Birdata 5-km surveys of typically 240-min duration made by Richard Ashby: 232 and 136 surveys at Lake Llewellyn and Cuprona Road respectively).

At Woodsong there was compelling evidence of a decrease in the status of the Pallid Cuckoo for the decade commencing 2009/2010. The overall RR was 44.2% and the linear trend line indicated a statistically significant decrease (p 0.014) of 50.9% from a RR of 63.2% to 40.6%.

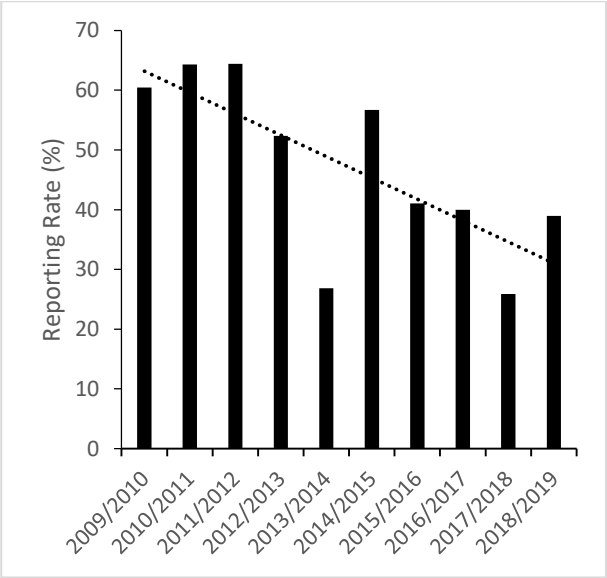

Figure 7. Variations in the breeding season Reporting Rates of the Pallid Cuckoos at Woodsong in north-east Tasmania (Birdata 500-m surveys of approximately 30 minutes duration conducted by Albert Nichols between September and January; 615 surveys).

The final data sets involve a five-year study on the South Arm peninsula near Hobart in south-east Tasmania (**Figure 8**). The overall RRs for the 2-ha and 500-m surveys were 32.0% and 54.1% respectively. Although the linear trends indicate the possibility of short-term decrease, they were not statistically significant.

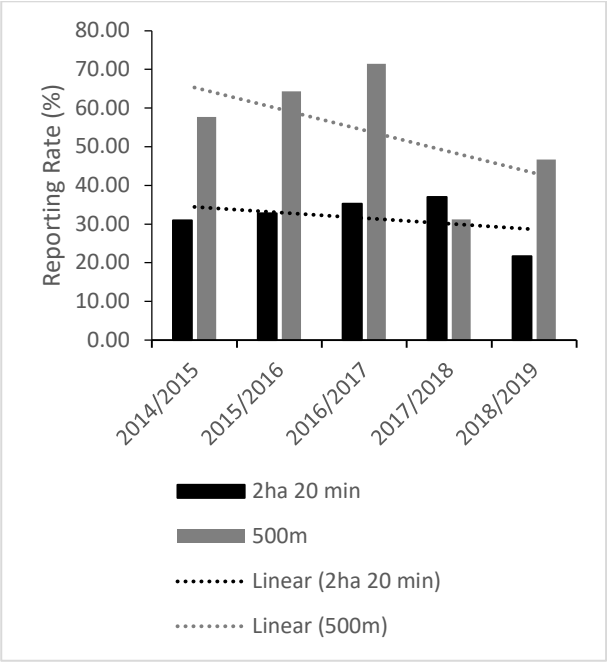

Figure 8. Breeding season Reporting Rates for the Pallid Cuckoo on the South Arm peninsula near Hobart in south-east Tasmania for monthly Birdata 2-ha 20-min (n = 317) and 500-m 45-min (n = 85) surveys made over a five-year period.

In contrast, in the Meehan Range, 20 km north of the South Arm peninsula, the overall RR for Pallid Cuckoos in a comparable set of 2-ha surveys over the same five-year period was 6.1%.

DISCUSSION

Effective use of Birdata records to establish comparative measures of bird populations and their trajectories requires a knowledge of both the behaviour of the target species and the manner in which the data were generated. In evaluating 20-year sets of citizen science data there is an inherent risk that changes in bird populations inferred from RR trends may in part relate to changes to the manner in which the data were collected. Data biases and measures taken to decrease them have been described earlier.

Timing of breeding season

The Pallid Cuckoo is a breeding season visitor to both the Hunter Region and Tasmania (Barrett *et al*. 2003) with most records in both regions occurring between September and January (**Figure 1**). The shape of the seasonal distributions suggests that the breeding season in the Hunter Region (32°S) is slightly earlier than in Tasmania (42°S), as would be expected given the latter region's more southerly latitude.

The seasonal variation of the RRs in **Figure 1** suggests that Pallid Cuckoo only spend about one third of their year in their southern breeding range. Most adults are thought to depart before the juveniles (Higgins 1999), but some remain and may assist the host to feed juveniles (Kikkawa & Dwyer 1962), in order to facilitate the transition from the food supplied by the host to the diet of independent Pallid Cuckoo (e.g. hairy caterpillars).

Reporting Rates are higher in Tasmania

During the breeding season RRs were higher in Tasmania than in the Hunter Region (**Figure 1**). This conclusion was found for all three survey types throughout the 21-year period of this study (**Table 1**) and these differences were highly significant statistically (p <0.01). Indeed, breeding season RRs in Tasmania are the highest in Australia (Barrett *et al*. 2003). The obvious conclusion is that the Pallid Cuckoo breeds more successfully at more southerly latitudes which may reflect on the quality of habitat for both the cuckoos and their hosts.

Regional trends

The statistically significant decline at the regional scale in the Hunter Region (**Figure 2** and **Table 1**) is supported by declines found in long-term studies at Green Wattle Creek (**Figure 3**) and Black Rock Road (**Figure 4**). Balickera, the third long-term data source in the central Hunter Region (**Figure 3**) provides evidence for the ongoing presence of Pallid Cuckoo at high RRs post-2002/2003 when the species had declined at the other sites. However, because the Balickera records were accumulated throughout the month they are not directly comparable with the other two data sets which involved surveys conducted during one day with duration of up to 240 minutes. When records are conducted over protracted periods, as at Balickera, the RRs of sparse species increase and it is not possible to detect changes in their status. Indeed, the RR levels do not even provide evidence that the Pallid Cuckoo was more common at Balickera than at the other two locations. Collectively, the records at these three survey sites, which are within a 10-km radius of each other in the central Hunter Region, indicate the persistent presence of Pallid Cuckoo at low RR levels, making it difficult to determine statistically reliable population trends. At Green Wattle Creek changes in the habitat to less-open woodland after cattle grazing ceased may have contributed to the observed decrease in RR (Newman & Cunningham 2018).

In contrast, the Tasmanian regional data (**Figure 2** and **Table 1**) indicates a statistically significant increase in the RR of the Pallid Cuckoo. However, long-term trends at individual survey sites (**Figures 6** and **7**) suggest that the Pallid Cuckoo population was either stable (Lake Llewellyn) or had declined (Cuprona Road and Woodsong). As there was no evidence of increases in RR at individual sites, it is concluded that the apparent increases at the regional scale probably were anomalous, a consequence of uncorrected survey bias. For instance, the period 1998 to 2002 involved data acquisition for the New Atlas with an emphasis on achieving widespread regional coverage (i.e. conducting surveys throughout the state). During the subsequent monitoring phase there was more emphasis on repeat surveys at a smaller number of sites (i.e. spatial coverage decreased). Woodsong (500-m surveys) and South Arm (2-ha and 500-m surveys) are examples of large subsets of data in the second decade of the study, conducted in habitat supporting Pallid Cuckoo at high RR levels. No correction was made for the increased proportion of Pallid Cuckoo records from these survey sites.

Similar biases almost certainly exist in the Hunter Region. As both the regional and individual site trends suggest a declining population trajectory, this provides a degree of confidence in the conclusion that the Pallid Cuckoo is declining in that region. Support for this conclusion is provided by the decreasing trend for NSW found by Cooper *et al*. (2016).

A comparison between the First Atlas and the New Atlas data suggested that a redistribution of Pallid Cuckoos had occurred between bioregions (Barrett *et al*. 2003). The statistically significant correlation between the increase in RR in Tasmania and the decrease in the Hunter Region is consistent with a population shift to more southerly latitudes. However, this evidence must be treated with caution in view of the issues with uncorrected bias in the Tasmanian regional trends. Nevertheless, Pallid Cuckoo populations have clearly been more resilient in Tasmania than in the Hunter Region during the last 20 years.

Local changes in Reporting Rates

Local changes in RR, either at individual survey sites (e.g. Green Wattle Creek in the Hunter Region; Lake Llewellyn in Tasmania), or locations (e.g. South Arm peninsula), might appear to provide our most reliable insights into changes in the status of the Pallid Cuckoo, but even these indicators need cautious interpretation.

If the breeding season home ranges of the Pallid Cuckoo are similar to the mean magnitude of 130 km^2 recently established for the Common Cuckoo in Scandinavia (Williams *et al*. 2016) they will be of similar magnitude or exceed the size of the Birdata 5-km survey method. However, during 5-km surveys the area actually sampled usually is relatively small (e.g. in the range 2.5 km^2 to 5 km^2 with a duration of approximately 240 minutes at the north-west Tasmanian survey sites). During surveys the probability of an observer encountering a Pallid Cuckoo moving around its home range, particularly males which call frequently, is increased by the duration of the survey and the area of habitat sampled. Hence, as demonstrated in **Table 1**, RRs are expected to be higher in 5-km surveys. The following discussion contrasts the results of long-term data sets involving similar types of surveys in the two regions.

The long-term Birdata 5-km surveys at Black Rock Road in the Hunter Region (**Figure 4**), and Lake Llewellyn and Cuprona Road in Tasmania (**Figure**

6) were conducted in a similar manner. Other than some clearing of roadside trees at Black Rock Road there was little habitat modification or change in land use at any of the sites. Thus, the differences in the magnitudes and trends of RRs at those sites reflect local differences in the occurrence of Pallid Cuckoo as opposed to survey methodology.

At Black Rock Road the RR for the Pallid Cuckoo was 40.7% for the period 1998/1999 to 2001/2002 when it was most regularly recorded (**Figure 4**). This was lower than at the sites in north-west Tasmania discussed above (**Figure 6**). This suggests that the home ranges of the Pallid Cuckoo were larger in the Hunter than in Tasmania and that habitat was less suitable, either in terms of providing sufficient brood hosts, or food for the adult cuckoos. The area surveyed at Black Rock Road involved land cleared for cattle grazing resulting in a landscape with highly fragmented remnant woodland. After 2001/2002 Pallid Cuckoo was seldom recorded. During this period the area was slowly developed for low-density residential dwellings and ongoing clearing of roadside trees and woodland occurred. This may have been detrimental as Pallid Cuckoos favour woodland edges in heterogeneous landscapes. Williams *et al*. (2016) suggest that the home range of the Common Cuckoo increases as woodland cover decreases. Although there was some evidence of a long-term decrease at one of the two north-west Tasmanian sites, overall the status of the Pallid Cuckoo was remarkably similar at the two sites with RRs of 59.7% and 58.8%. These were approximately 2.5 times higher than that at Black Rock Road. Short-term fluctuations in annual RRs at Lake Llewellyn and Cuprona Road were synchronous. The observed annual variations are consistent with the hypothesis that the Pallid Cuckoo has a home range larger than the areas surveyed at those locations. For instance, it is known that cuckoos avoid continual exploitation of hosts at the same location every year in order to prevent hosts from developing tactics which decrease the cuckoo's breeding success (Davies 2015). Hence, these short-term fluctuations in annual RRs may reflect changes in the Pallid Cuckoo's movements within its home range rather than an increase in the size of the home range and a decrease in abundance at the regional scale.

At Green Wattle Creek, which is approximately 10 km from Black Rock Road, the area surveyed (0.5 km^2) was smaller and the duration slightly longer (200 minutes). Initially RRs (42.9%) were similar to Black Rock Road, subsequently decreasing, but to a lesser extent (RR 20%) than at Black Rock Road (RR 9%, for the period post 2001/2002). At Green Wattle Creek the area surveyed was within lightly grazed continuous woodland with little understorey other than along creek lines. The Pallid Cuckoo records were exclusively outside the four embedded 2-ha survey sites which were located in areas of denser vegetation. The absence of the Pallid Cuckoo from the 2-ha survey sites is consistent with the species' preference for open woodland and forest edges (Shields *et al*. 1985). The area surrounding the Green Wattle Creek Reserve is a combination of land cleared for cattle grazing which was being progressively developed for acreage residential dwelling. The removal of cattle from the Green Wattle Creek woodland resulted in an increase in understorey vegetation, which is less suitable for Pallid Cuckoo (Shields *et al*. 1985). In addition, the continual removal of tree cover and increasing fragmentation of the landscape surrounding the Green Wattle Creek woodland would be expected to increase the home range of any Pallid Cuckoo frequenting the area.

Before European settlement the central Hunter Region landscape was probably dominated by forest with wet understorey and hence largely unsuitable for the Pallid Cuckoo. Forest clearing for agriculture provided a mosaic of open spaces favouring Pallid Cuckoo, which further benefitted when cattle grazed within woodland and removed understorey. However, during the past 20 years changes in the management of the landscape, including ongoing clearing of remnant woodland and removing cattle from State Forest and reserves, have contributed to regional scale changes in the vegetation structure which are unfavourable to the Pallid Cuckoo. Indeed, in NSW a passive parks management style, involving a philosophy of reversion to wilderness, may be detrimental to the status of some species, including the Pallid Cuckoo (see Newman & Cunningham 2018). Other factors such as drought may have contributed to the Pallid Cuckoo becoming less common, both directly, and indirectly through declines in their brood host populations. In the area surrounding Paterson in the central Hunter Region the Pallid Cuckoo is regularly present as evidenced by the records at Balickera (**Figure 3**). Collectively, records at these central Hunter sites are consistent with a scenario in which the breeding season home ranges of the Pallid Cuckoo have increased as conditions and habitat became less favourable. Consequently, Pallid Cuckoo now move more widely within their extended home range seeking brood hosts, food and places to roost. Hence, it is encountered less frequently by bird watchers.

The relatively high RR levels for the area around Medhurst Bridge for data involving a combination of survey types (**Figure 5**) provide tentative support for the view that the Pallid Cuckoo is more common in the western areas of the Hunter Region, particularly in the last decade. Unfortunately, there are no long-term data sets involving standardised data collection. While contemporary RRs may be higher than at survey sites in the central Hunter Region, they are well below those in Tasmania at sites where survey duration was similar (e.g. Woodsong - **Figure 7**, and South Arm - **Figure 8**). The increases apparent for the period 2016/2019 in **Figure 5** and noted elsewhere in the Hunter Region correspond to a period of drought in inland NSW. This suggests that the Hunter Region may act as a drought refuge for the Pallid Cuckoo. Evidence for periodic shifts in the distribution of the Pallid Cuckoo was identified in the comparison of the two national Atlases (Barrett *et al*. 2003). How displaced birds will be accommodated when moving to a region where resources already appear sub-optimal is an intriguing question. In addition, a cuckoo displaced from an inland to a coastal bioregion may have difficulty finding suitable brood hosts, because it is adapted to exploiting species which are either absent or scarce in the region to which it has moved.

The RRs for surveys of generally similar duration at Woodsong and South Arm in Tasmania were much higher than in the Medhurst Bridge area of the Hunter Region. At both Medhurst Bridge and Woodsong there were long-term decreases in RR. The statistically significant decade-long decrease at Woodsong commencing 2009/2010 (**Figure 7**) included an abnormally low RR of 26.9% in the 2013/2014 breeding season which was 44% lower than the linear trend line value and outside the 95% confidence interval. Various explanations are possible for this anomalous decrease including the previously mentioned strategy of cuckoos periodically using hosts from a different part of their home range in order to prevent their hosts becoming habituated to their presence (Davies 2015). Fires in the area surrounding Woodsong may have resulted in a loss of resources and caused the home range to increase, thus contributing to the long-term decrease in RR (i.e. as the home range increases cuckoos are recorded less frequently on a pro rata basis). For the above reasons the observed trends may be local and not necessarily representative of the regional situation.

The timing of the decrease at Medhurst Bridge (**Figure 5**) may be related to periods of drought in 2002 and 2006 that resulted in the decline of a number of bird species in that area (Tarrant 2008). In addition to decreasing the food available to adult Pallid Cuckoo, host species may have struggled to fulfil the voracious appetites of young cuckoos causing poor breeding success. Over a five-year period commencing 2014/2015 Pallid Cuckoo RRs were 32.0% and 58.3% for 2-ha (12 sites) and 500-m (3 sites) surveys conducted on the South Arm peninsula at monthly intervals during the breeding season. This corresponded to recording a Pallid Cuckoo on average at least once every 61 minutes in 2-ha surveys and every 77 minutes in 500-m surveys. These rates of occurrence were similar to Woodsong where a Pallid Cuckoo was recorded on average at least once every 68 minutes in 500-m surveys of similar duration. As very large data sets were involved the results provide a benchmark against which populations at other locations can be compared.

It is important to understand the features of these woodland areas in eastern Tasmania which provide suitable, perhaps optimal habitat for the Pallid Cuckoo. At South Arm the sites were in remnant woodland with a very open structure, particularly along ridge lines where there is minimal understorey. Small dams collecting run-off have increased water availability and this may have benefitted host species. Several instances of successful breeding were noted, involving Black-headed Honeyeater hosts feeding fledged young. The overall conclusion is that the home ranges of Pallid Cuckoo in the open dry woodland in eastern Tasmania are smaller than in the Hunter Region. Arguably this may be the bench-mark habitat for the species. Unfortunately, there are no comparable historical data that can be used to determine whether the contemporary South Arm population has increased recently; for instance, as a consequence of an influx of Pallid Cuckoo from the Australian mainland to Tasmania.

Selecting survey methods

In the above analysis it was advantageous to be able to draw on data from a range of survey types as outlined below.

The standardised 2-ha surveys provide the most reliable data provided that the cuckoos were frequently recorded as exemplified by the survey sets at South Arm and the Meehan Range in Tasmania. However, in the Hunter Region where the cuckoos were less common, 2-ha data sets contained insufficient observations for statistically meaningful conclusions to be drawn.

Birdata 500-m and 5-km surveys sample larger areas for extended periods of time and not surprisingly the Pallid Cuckoo was encountered more often in these surveys resulting in more records and higher RRs (**Table 1**). These surveys proved invaluable for the analyses in the Hunter Region during periods when the Pallid Cuckoo was scarce. The problem with these surveys in regional-scale assessments is that they involve variable survey effort (i.e. the duration of the survey and the area sampled within the nominal search area change between survey sites). However, repeat surveys under replicated conditions by the same observer involve constant survey effort and provide reliable trend data at individual locations. For detecting the Pallid Cuckoo, variation in survey duration appears more important than the size of the area searched and potentially provides a method of comparing surveys involving different survey effort. This possibility may be unique to the evaluation of species such as the Pallid Cuckoo where home ranges are much larger than the area surveyed.

When the Pallid Cuckoo is regularly present, long-duration surveys become insensitive to changes in status (e.g. Lake Llewellyn in NW Tasmania and Balickera). Variations in annual RR may be a consequence of local factors as opposed to changes in the status of the species at the landscape scale. When the Pallid Cuckoo is very uncommon, extremely long duration surveys, such as lists accumulated throughout the month at Balickera, provide evidence of the ongoing presence of the species in the area.

Intensive survey campaigns at single locations (e.g. South Arm and Woodsong) can skew the results of regional trends, for instance, by over-representing the dry open woodland habitat preferred by Pallid Cuckoo. This may have contributed to or even caused the apparent increase in the population status of the Pallid Cuckoo at regional scale in Tasmania (**Figure 1** and **Table 1**).

Breeding

As juvenile Pallid Cuckoos are very noisy when begging food from their brood host (the author's unpublished observations), it is surprising that there are so few breeding records in the Hunter Region (Stuart 1993–2018). This lack of breeding records is consistent with Pallid Cuckoo being a sparse species with large home ranges in the breeding season.

In dry woodland on the South Arm peninsula in Tasmania the RR for the Pallid Cuckoo was double that of its known host at that location, the Black-headed Honeyeater. In adjacent more open habitat, the RR for the Pallid Cuckoo was four times that of the Black-headed Honeyeater (M. Newman unpublished results). These results are consistent with the theory that the breeding season home range needs to include the habitat preferences of both the host (dry woodland) and the cuckoo (more open lightly timbered country). Although considerably less numerous, the extremely vocal and mobile Pallid Cuckoo has a higher detectability and hence a higher RR than its host.

CONCLUSIONS

The Pallid Cuckoo is a summer breeding visitor to both the Hunter Region of NSW and Tasmania. Most records are between September and January, when it is more vocal and easily detected.

Reporting Rates derived from survey records in the BirdLife Australia database (Birdata) suggest that the Pallid Cuckoo is more numerous in Tasmania than in the Hunter Region.

Evidence that the Pallid Cuckoo has declined in the Hunter Region during the last twenty years was found to be statistically significant. This conclusion at the regional scale is supported by local trends where surveys were conducted in a consistent manner by the same observer. The correspondence between the local and regional trends alleviated concerns that the regional trends might reflect changes in the style of data collection, rather than the status of the Pallid Cuckoo.

In Tasmania the regional-scale trends suggested that the Pallid Cuckoo has become more common. However, some local trends indicated that its RR was decreasing, although remaining at levels well in excess of those in the Hunter Region. The regional scale increases in Tasmania, although statistically significant, were, at least in part, a consequence of increases in the proportion of surveys conducted in the dry woodland habitat preferred by Pallid Cuckoo during the second decade of this study. Consequently, the conclusion that the species has increased regionally in Tasmania may be unsound and needs to be confirmed by more sophisticated analysis involving corrections for biases in survey effort across habitat types.

It is probable that during the breeding season the Pallid Cuckoo has large home ranges in which it seeks brood hosts as well as food and roost sites. Decreases in Pallid Cuckoo reporting rates may

reflect changes in the status of their brood-host species. There are few records of Pallid Cuckoo breeding in the Hunter Region, which is consistent with large home ranges and low RRs.

Pallid Cuckoo favour fragmented landscapes with high levels of open woodland cover, but without moist understorey vegetation. In the Paterson area of the central Hunter Region, ongoing clearing of remnant woodland and destocking of previously grazed woodland may have contributed to the Pallid Cuckoo's decline. Peak RRs in Tasmania were found in open dry sclerophyll where extensive tree cover had been retained in a fragmented landscape, supporting the above conclusion that the moister forest of the Hunter Region may provide less suitable habitat for the Pallid Cuckoo.

No conclusions were reached concerning the extent to which hotter drier breeding season conditions contribute to the differences in the abundance of Pallid Cuckoo between the two regions or to the decline in the Pallid Cuckoo's status in the Hunter Region.

The analysis presented in this paper benefitted from the availability of data generated by a range of survey methods. Long-term repeat surveys at individual locations provided valuable insights into the reliability of regional-scale trends as well as the habitat preferences and breeding season lifestyle of the cuckoos. However, local trends may not be representative of changes in status at the landscape scale.

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