Who’s who of palm cockatoos: Evaluating non-invasive techniques for identification of individual palm cockatoos (*Probosciger aterrimus*)

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Declaration

I declare that the research in this thesis is my own original work and that I took the principal role in the data collection, analysis, and writing up of the work presented here. While I completed this thesis in collaboration with my supervisors, Rob Heinsohn and Naomi Langmore, in all cases I was the leading researcher. This work has not been submitted for the award of any other degree, and it does not contain any material published or written by another person.

Signed,

Christina N. Zdenek
16 May 2012
Acknowledgements

This research posed considerable challenges at every stage. First and foremost, I want to thank my two supervisors, Rob Heinsohn and Naomi Langmore, for remaining positive and helpful through the good, the bad, and the ugly. It was a pleasure to work with them.

I want to thank my parents, Betty and Gene, and my siblings for staying with me in support (mentally and monetarily). My oldest brother, Chad, helped me logistically prepare for my first season, including driving up the east coast of Australia with me to get to my field site, and he even was my first field assistant. My sister, Jennifer, and her parter/significant-other gave me an office (with a window- very important) in their home for me to write up, not to mention a huge veggie-and-locally-native-plant garden that kept me sane and physically active during countless long-hour days in front of the computer. Eric, my other brother, was the one who inspired me to study abroad (in England) and later turned my eyes to prestigious, merit-based scholarships. (This is how I came to apply for the Fulbright Fellowship and later won the award to do this research). And my other brother, Jason, taught me many virtuous lessons growing up that helped lead me on this path.

Here’s a short list of those integral in aiding my Fulbright application process: Rebecca Harris (UC, Irvine Scholarships program), Barry Nerhus (conservation mate), Jessica and Riley Pratt (late night coffee shop), my family (reviewing countless documents and email drafts), and reference letter writers: Peter Bryant, Susan King, Michael Cumski, and Kathleen Treseder.

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namely Lyndell Wilson, guided all my visa application processes and transition into the Australian culture.

And here’s a toast to those who researched palm cockatoos before me, namely Daryn Storch and Steve Murphy. If they had as hard of a time as I did in researching this difficult (though still beautiful) species, my hat goes off to them. The life-history information they acquired before me steered my daily movements and thoughts out bush, as I searched day in and day out for palm cockatoos and their nests. (And Daryn, I wish we would have met earlier.)

Whether because they were my officemates and had no choice or because they are truly giving people, nonetheless, Karen Stagoll, Kara Youngentob, Pia Lentini, Nikki Munro, and Juliana Lazzari were colleagues of mine who provided the day-to-day, little-by-little help with Excel and EndNote issues, grant-writing, formatting, project marketing, and piles of admin. forms. Karen Stagoll, in particular, also helped with editing my public (non-scientific) articles and gave me on-site uni support when I was out bush (in the field). Mike Hutchinson provided a sound sounding-board and countless friendly smiles.

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Regarding Chapter 4 (Photo-identification): Dean Portelli (field assistant) and George Gornacz (amateur photographer and wildlife enthusiast) took the photos I used to evaluate this technique. Silas Goodlet gladly put in a great deal of effort to supply photographs that yielded a presumed four to five individuals photographed. I also used one photo each from Brett Backhouse (Adelaide Zoo) and Brett and Kathy Hinz (Moreton Telegraph Station, Cape York Peninsula). I’d like to thank Brett and Kathy for posting an up-close headshot of their local palm cockatoo on their notice board because the unique facial features of this bird gave
me the idea for the photo-ID portion of this study. Appreciation goes to Dean Portelli for exciting discussions that helped steer the early stages of the photo-ID part of this study.

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*Ethical Note:* Permission for this study was sought and received from the traditional landowners of the Uutaalnganu, Kanthanampu, and Kuuku Ya’u language groups. This work was approved by the QLD Dept. Of Environment and Resource Management (permit No.: WITK06171009) and received approval from the ANU Animal Ethics Committee (Protocol No. C.RE.62.09).

Luminous mushroom (*Mycena sp.*) in the day (left) and night (right) on a fallen log in the rainforest. Seen while I was spotlighting at night for fun at my field site. Photo by: George Gornacz.
General Abstract

Knowledge of individual identity within populations is often essential for obtaining a detailed understanding of the ecology and conservation requirements of species. Palm cockatoos (*Probosciger aterrimus*) are extremely difficult to catch and are susceptible to over-stress. As such, a non-invasive alternative to traditional capture techniques is highly needed. This thesis primarily investigates vocal individuality as a non-invasive technique for this species.

First, I developed a naming system for palm cockatoo vocalisations to organise and verbally described them all. I used advanced sound recording equipment and sound analysis technology to quantify call parameters, such as multiple temporal, energy (amplitude), and frequency measurements on the spectrogram. Using this data, I performed multivariate analysis to classify distinct syllables and determine the number of discrete syllables in their vocal repertoire (27).

In this process, I found that palm cockatoos have an unusually large vocal repertoire for a parrot (Psittaciformes) and that they enhance vocal complexity by combining multiple syllables to create longer and more varied vocalisations. Although most syllables (19/27) in the repertoire were used in this manner, this vocal technique occurred exclusively in two behavioural contexts: display and call-exchange with intruders. The process of combining vocal units to form more complex vocalizations is analogous to the formation of songs in many passerines. Further, the contexts in which palm cockatoos produce complex calls appear to be the same as the main contexts in which passerines sing. I propose that these similarities might have evolved through convergent evolution to facilitate territorial defence in both palm cockatoos and many passerines.
I then showed that palm cockatoos are individually distinctive in their call structure for three discrete call types: 85.6% of calls, or 137 out of 160, were assigned to the correct individual. However, a small sample of five birds recorded over several months, together with three birds recorded over one year, suggests a lack of vocal stability within individuals over time. For this reason, as well as due to various logistical aspects, I recommend against using the call-dependent (comparing same call types across individuals) vocal individuality technique for this species. Call-independent techniques were beyond the scope of this study but may be more appropriate.

I also provide preliminary evaluation of the photo-identification technique for identifying individual palm cockatoos. Using up-close facial profile photographs of a presumed 13 individuals, I illustrate and provide unique and descriptive terminology for various facial features (namely on the beak) of this species that can probably be used to identify individuals. Four presumed individuals were photographed over several days and appear to be re-identifiable using this technique. I encourage further work be done on developing the photo-ID technique for this species.

Juvenile Spotted Cuscus (*Spilocuscus maculatus*) by my study site. Photo by: Christina Zdenek.
Table of Contents

Declaration ........................................................................................................................................ 2

Acknowledgements .......................................................................................................................... 3

General Abstract ............................................................................................................................ 6

Chapter One – General Introduction ............................................................................................. 11

Chapter Two – The large and complex vocal repertoire of palm cockatoos (*Probosciger aterrimus*) on Cape York Peninsula ......................................................................................... 41

Chapter Three – Vocal individuality of palm cockatoos (*Probosciger aterrimus*) on Cape York Peninsula ......................................................................................................................... 64

Chapter Four – Preliminary evaluation of photo-identification of individual palm cockatoos (*Probosciger aterrimus*) ............................................................................................................. 89

Chapter Five – General Discussion ................................................................................................ 108

Appendix One – Verbal description of all recorded palm cockatoo vocalisations ......................... 118

A nesting pair of palm cockatoos. Female on left; male on right. Photo by: Martin Willis (at CNZ’s study site).
Preface

Conducting this research not only gave me the opportunity to add to the knowledge of palm cockatoo biology and move my conservation biology career forward, but it also allowed me to convey the conservation message to the local peoples and kids of my study site region (see photo below), hopefully helping to ensure the long-term survival of palm cockatoos in Australia.

This thesis would never have even been possible without the leap of faith from my supervisor, Rob Heinsohn. While still an ocean apart and despite having never previously met, Rob welcomingly took me in during the long Fulbright application process. It turns out our gut-instincts were spon-on and we became a great team. Thanks for being my friend, Rob.

For interest’s sake, parts of this thesis were written in all of the following places: far north Queensland (my field site), a remote farm 160km from my field site, San Diego, Laguna Beach, three different houses in L.A, the passenger seat of multiple cars, several airports, overnight buses and five different hostels in Peru, the Peruvian Amazonian rainforest, and a lazy-boy couch during recovery from an incapacitating basketball injury. Needless to say, it is great to be done.

And for anyone planning on studying palm cockatoos in the future, I highly recommend getting all the helpful tips you can from previous researchers (Daryn Storch, Steve Murphy, myself, and my supervisor, Rob Heinsohn) because palm cockatoos are an extremely difficult system to work with on multiple levels.
Lastly, if you plan on printing out this thesis, I recommend printing pages 97 and 99 in colour for best viewing. And if possible, please use recycled paper and print double-sided. Cheers!

The kids of Lockhart State School and I pretend to be palm cockatoos. Once in 2009 and once in 2010, I gave talks to five school classes at the one school near my field site.
Chapter One

General Introduction

A male palm cockatoo performs a drumming display on a piped tree near Lockhart River. Photo title: “I…don’t want to work…I just want to bang on the drum all day!” Photo by: George Gornacz (at CNZ’s study site).
Despite the popularity of parrots as pets, and ironically partly because of this, Psittaciformes (parrots and cockatoos) are among the most threatened groups of birds worldwide (Snyder et al., 2000). In 2000, 29% of all Psittacine species worldwide were at some risk to extinction (Snyder et al., 2000). Four years later, this percentage increased to 34.6% (Birdlife International, 2004), and in 2011, 39%, or 139 out of 355 extant Psittacine species worldwide, are at some risk to extinction (Birdlife International, 2011). While this increasingly grim situation is primarily due to habitat loss and poaching for the pet trade (with a lower extent due to local hunting of some species), these problems are also compounded in the larger species by extremely slow reproductive rates.

**Identifying individuals**

Knowing the identity of individuals within populations is often essential for a detailed understanding of the ecology and conservation of the species, particularly for species with slow life-history strategies, like large parrots. If individuals can be tracked from one year to the next, data such as nest turn-over rate, survival, nest site-fidelity, and recruitment can be acquired and used for population viability analyses. Further, behavioural studies require individual identification for most forms of data collection (e.g. focal watches, playback experiments), and uncovering animal behaviour that is interesting to the general public (e.g. the discovery of tool-making and tool-use in chimpanzees by Jane Goodall in 1960) can also lead to greater protection of habitat and funding to preserve iconic species (Goodall, 1990).

**Traditional techniques for identifying individuals**

Individual animals usually need to be marked to enable their individual identification. This usually involves capturing an individual (as a chick or an adult), adding an individually distinctive marker (e.g. a uniquely numbered leg-band or a combination of coloured bands), and either viewing this number from a distance or capturing the individual at a later date.
Although this technique can provide life-history and behavioural data that is useful for conservation and management strategies, it can involve negative public perception (Mellor et al., 2004) and multiple considerable welfare issues for the study species. Although unintended negative impacts to marked individuals are likely to be species-specific, they can include: 1) direct costs of the capture and handling process (Nimon et al., 1995), possibly leading to a decreased immune response due to stress, 2) an altered sex-ratio of offspring (Moorhouse and Macdonald, 2005), 3) loss of subsequent reproductive success (Saraux et al., 2011), as well as 4) increased predation (Saunders, 1988) and 5) mortality rates (Castelli and Trost, 1996; Saraux et al., 2011) of marked individuals.

Beyond welfare issues, the habitat and/or behaviour of some species severely hinder or even preclude the capture process. For example, the cryptic nature of some bird species, like rails (Gruiformes) that live amongst thick, tall reeds in wetlands, precludes the usefulness of coloured leg-bands to re-identify individuals from a distance. The same problem occurs with nocturnal birds (e.g. Strigiformes). Furthermore, some species are very difficult to catch (e.g. Black-throated Divers *Gavia arctica*, Gilbert et al., 1994; palm cockatoos *Probosciger aterrimus*, pers. comm., R. Heinsohn). A combination of public perception, as well as welfare and logistical issues, elicits a great need for a non-invasive method to identify individuals.

With birds, non-invasive identification of individual birds can be achieved by vocal individuality (e.g. Peake et al., 1998), photo-identification (e.g. Gilkinson et al., 2006), and or genetic tagging (e.g. Rudnick et al., 2008). These are discussed independently below.

**Vocal individuality**

Individual features of vocalisations can be quantified with sound analysis software to provide a non-invasive alternative to capture and marking, called vocal individuality (hereafter, VI). Individual differences in vocalisations have been identified as a feature of multiple non-human taxa, including birds (see Table 1.1), frogs (Bee and Gerhardt, 2001, Feng et al., 2009,
Friedl and Klump, 2002), canids (Darden et al., 2003), primates (Jones et al., 1993), bats (Melendez and Feng, 2010), bears (Charlton et al., 2009), and deer (Briefer et al., 2010). Early stages in the development of VI involved printing spectrograms (visual representation of sounds) and using volunteers to group similar-looking calls (e.g. Saunders, 1983). Advances in sound analysis programs now allow for comparable, semi-automatic measurements to be calculated on various features of the call, such as frequency, amplitude, and temporal values. Advances in quality recorders and microphones, combined with their increasing affordability, has made recording animal vocalisations more practical than ever before.

VI was first pioneered on the European bittern (*Botaurus stellaris*) (Gilbert et al., 1994). The reedbed wetland that this species inhabits renders conventional banding techniques unhelpful because bands are rarely seen through the dense vegetation. The species had been declining, with only 20 known males left in Britain, and conventional banding techniques proved relatively unhelpful because of the difficulty in capturing the birds. Plus, re-sightings were rare due to the dense reedbeds in the wetlands this species inhabits. To address these issues, the far-travelling, relatively simple and repetitive yodel call—termed ‘boom’—of males was recorded and both qualitatively and quantitatively analysed for individual identification. Qualitative analysis of distinctiveness was based on 20 naive observers that were given two spectrograms from each of the 12 bitterns and coupled similar-looking spectrograms together. Quantitative analysis of distinctiveness was based on a step-wise discriminant function of six measures of time and frequency of the males’ calls. To assess the population size over time, these calls were then compared to calls in the same territories the following year. Fixed territories were used to gauge the vocal stability between years, and one bird was radio-tagged to provide independent confirmation that between-year boom similarities indicated the same individual. Overall, although boom constancy between different study sites proved
problematic, this study showed that 1) VI may be effective for species where conventional techniques to identify individuals are unfeasible; 2) an independent means (e.g. radio-tag) of identifying a sub-set of individuals within the study can substantiate vocal interpretations; and 3) the factors that influence the feasibility of using individually-distinctive vocalizations as a census tool will likely differ between species.

Since VI was first pioneered, multiple applications have been used. These include improving census estimates of Corncrakes *Crex crex* by 20-30% (Peake and McGregor, 2001), estimating of bird population density (Dawson and Efford, 2009), and determining annual adult survival and population change for male great bitterns (Gilbert et al., 2002). Although numerous species have shown vocal individuality (Table 1.1), relatively very few have applied this technique (Table 1.2). The reason for this disparity is likely two-fold: 1) VI is still a relatively new technique, and 2) the applicability of the vocal individuality technique is limited to certain species. For example, data collection can be relatively quick and easy for species that give dozens of repetitive calls in succession within a short time period, such as ‘chattering’ raptors (Falconiformes) (e.g. Eakle et al., 1989), ‘hooting’ owls (Strigiformes) (e.g. Lengagne, 2001; Rognan et al., 2009), or ‘booming’ bitterns (Ciconiiformes) (e.g. Gilbert et al., 2002). In contrast, for species that have large vocal repertoires (e.g. songbirds), collecting enough calls of the same call-type to compare between individuals can be time-consuming or even impossible.

Another limitation is that some species are not vocally stable over time (i.e. their call parameters change). As such, for avian and non-avian species alike, it is of critical importance to have an independent means of identifying individuals (e.g. radio-tags or leg bands) for at least a sub-set of individuals. This allows for the corroboration of interpretations based on vocal data so as to determine whether calls are consistent within and between years.
for individuals. Such assessment is required to determine the efficacy of using the VI technique over time for a species, and this is especially important for long-term studies. With regards to non-avian species, a four-year long study on seven individual Wied's black tufted-ear marmosets (Primate; *Callithrix kuhli*) revealed a 91.7% accuracy of identification but less than a 50% accuracy on average in re-identification of individuals (Jorgensen and French, 1998). The lack of consistency found in the vocalisations of this species renders long-term VI studies unhelpful for this species. Likewise, the vocalisations of 42 male European treefrogs (*Hyla arborea*)—individually marked and identified by toe-clipping—changed according to water temperature (Friedl and Klump, 2002). Furthermore, Briefer et al. (2010) found both age-and rank-related changes to groans of individual male fallow deer (*Dama dama*) (14 and 10 individuals, respectively; previously marked for other studies).

With regards to avian species, although not widely reported, vocal stability can be lacking and must be assessed prior to long-term VI studies. To address potential lack of vocal stability in a species, a sub-set of captive or marked individuals are often used as a proxy for gauging the vocal stability of wild individuals (Jones et al., 1993; Lengagne, 2001). When male loons (*Gavia immer*) change their territories, they change their vocalisations in a way that increases the difference between the new resident's yodel and that of the previous resident (Walcott et al., 2006). Likewise, bald eagles (*Haliaeetus leucocephalus*) could not be re-identified between years, despite having 83-100% classification rate by their calls within a given year (Eakle et al., 1989). Ellis (2008) found a significant decrease in individual assignment accuracies of calls from 12 out of 13 female white-throated magpie-jays (*Calocitta formosa*) across two seasons. In contrast, vocal stability was present in six radio-tagged and banded male great bitterns (*Botaurus stellaris*), confirming that the birds were vocally stable enough to identify between years (Gilbert et al., 2002). Hence, without confirmation of vocal stability of individuals within a species, newly recorded calls at a later
date may be incorrectly attributed to the wrong individual, thereby making one individual appear as two. As such, assessing the level of individual vocal stability is a crucial prerequisite of long-term monitoring of species via the VI technique.

**Photo-identification**

Using photographs to identify individuals based on distinctive physical features is called photo-identification. Photo-identification (photo-ID, hereafter) is a widely used non-invasive technique to identify individual animals (e.g. Ardovini et al., 2007; Buray et al., 2009; Kelly, 2001; Petersen, 1972; Sherley et al., 2010). It has been systematically used in studies of cetaceans (whales and dolphins) for nearly 30 years (for review see Wursig and Jefferson, 1990), providing information about movement patterns, site-fidelity, group-dynamics, and population size. Individual morphological differences of cetaceans, as well as other marine animals, such as sharks, seals, sea otters, and octopus, have been found in unique pigment patterns on the fin and body (Buray et al., 2009; Cunningham, 2009; Karczmarski and Cockcroft, 1998; Gope and Kehtarnavaz, 2007; Huffard et al., 2008, Kehtarnavaz et al., 2003; Rosso et al., 2008, Van Tienhoven et al., 2007), nicks on the trailing edge of fins (Araabi et al., 2000; Ciano and Huele, 2001; Currey et al., 2008; Gope et al., 2005; Huele and De Haes, 1998; Kniest et al., 2009) and/or scarring pattern on the skin surface (Currey et al., 2008; Gilkinson et al., 2006).

Besides marine animals, many land vertebrates also have individual morphological differences, such as colour patterns on snake head scales (e.g. broad-headed snake *Hoplocephalus bungaroides*, pers. comm., R. Goldingay), scutes patterns on turtle carapaces (Schofield et al., 2008), zebra stripes (Petersen, 1972), bat fur colour pattern (e.g. Grey-headed flying fox *Pteropus poliocephalus*, pers. comm., V. Jones), dot pattern on cheetah skin (Kelly, 2001), elephant ear scars (Ardovini et al., 2007), and rhinoceros horn shape and
size, as well as ear markings (e.g. black rhino *Diceros bicornis*, Patton and Jones, 2008). Opportunistic identification of individual birds can sometimes occur using individualistic feather moulting pattern, but this provides only a short-term means of identification. Long-term identification over years can sometimes be based on individually distinctive colour patterns of some species (e.g. yellow-headed amazon *Amazona ochrocephala oratrix*). One large rainforest parrot, called red-and-green macaw (*Ara chloroptera*), in south-Western Peru is naturally individually ‘marked’ by unique patterns of red feather-lines across their otherwise white featherless cheek, as well as marks and irregularities on the large upper mandible (Munn, 1992). In combination with regular bird counts at clay licks, photo-ID was successfully used to generate population density estimates in this species (Munn, 1992).

Photo-identification of animals is often now assisted by various computer programs, which help quantify individually distinctive features, as well as match query images to a library of photos. The most widely used computer programs either digitally define an edge (Araabi et al., 2000; e.g. flipper of a seal, Gope et al., 2005; Huele and De Haes, 1998; e.g. dorsal fin of a dolphin, Kehtarnavaz et al., 2003,) or detect colour patches (Cunningham, 2009; Gope and Kehtarnavaz, 2007; Hillman et al., 2002; Kehtarnavaz et al., 2003; Rosso et al., 2008, Sherley et al., 2010; Van Tienhoven et al., 2007) for automatic comparison of individuals. Less often used are computer programs that detect superficial scar patterns (Gilkinson et al., 2006; Currey et al., 2008).

**Genetic tagging**

Genetic tagging is the identification of individuals by genetic markers (Peakall et al., 2005). This technique has been applied to several species of birds (e.g. capercaillie grouse (*Tetrao urogallus*), Jacob et al., 2010; eastern imperial eagles (*Aquila heliaca*), Rudnick et al., 2008) as a non-invasive alternative to traditional marking methods. For example, Rudnick et al.
(2008) used naturally shed feathers from non-breeding eastern imperial eagles (*Aquila heliaca*) to successfully identified 308 ± 8 individuals. Compared to the limited sample sizes from previous wing-tagging or telemetry studies, this study was able to determine population size, natal origin, and patterns of roost usage. In addition to feathers, Jacob et al. (2010) also used faeces samples at leks (communal male display areas) from capercaillie grouse (*Tetrao urogallus*) to identify individuals. In this study, the genetic tagging technique was less biased than field surveys and therefore better suited to determine management actions for that dramatically declining species (Jacob et al., 2010).

Genetic tagging by use of feathers in the nest was successfully used to determine nest fidelity of 310 *Eclectus* parrots (*Eclectus roratus*) (Heinsohn et al., 2007). In addition, a PhD student, G. Olah, is currently comparing feathers from nest hollows and communal clay licks for macaws in southeastern Peru to determine dispersal of individuals (pers. comm., G. Olah). I did not attempt to use genetic tagging as a non-invasive identification technique for palm cockatoos because feathers and faeces are rarely encountered on the ground, and I did not climb nests to retrieve them.

*The study species*

The primary aim of this research was to establish a non-invasive technique to ‘mark’ and identify individual palm cockatoos in the wild. Palm cockatoos are an elusive, iconic species of parrot that is restricted to Cape York Peninsula (far north Queensland, Australia), as well as lowland New Guinea and some offshore islands (Higgins, 1999). Out of 21 species of cockatoos (Cacatuidae) worldwide, palm cockatoos are the heaviest (650-1000g) and one of the longest (Forshaw, 2010; Juniper and Parr, 1998). In Australia, they are a largely monogamous, non-flocking species that nest in vertical piped (hollowed) trees in woodland adjacent to rainforest (Murphy et al., 2003). Females have both a low rate of attempted
reproduction and low reproductive success. Individuals attempt to breed every 2.2 years on average, as determined from monitoring of 11 nests over three years. As determined from 41 breeding attempts at 28 active nests, the success rate of fledglings per egg was found to be one of the lowest breeding success rates known of any parrot (23%; second only to the Eclectus parrot), with 62% of failed breeding attempts likely caused predators such as varanids (Varanus sp.), large rodents (e.g. Uromys caudimaculatus), black butcherbirds (Cracticus quoyii), and by Australia’s longest snake, the scrub python (Morelia kinghorni) (Murphy, 2003). However, their infrequent breeding attempts give them the lowest rate of reproduction for any parrot.

Data from 20 different eggs revealed that incubation takes 30-32 days, and data from three nests revealed that chicks take 65-79 days to fledge (Murphy et al., 2003). Pairs have high nest-site fidelity, with one pair recorded to nest in the same hollow three years apart, and nesting occurs mostly in Eucalyptus tetrodonta and Corymbia clarksoniona trees (Murphy et al., 2003). Their breeding season is protracted (July-May), with egg-laying dates occurring as long as eight months apart (Murphy et al., 2003). Pairs maintain multiple nest hollows during the breeding season, with males displaying (see below) on multiple hollows, especially during June, corresponding with the beginning of the ‘dry season’ (June-Dec) (Murphy et al., 2003).

Unique among non-human species

Palm cockatoos are unique among non-human species in their manufacture of sound-tools. Males perform remarkable ‘drumming’ displays, whereby they beat a stick, which they fashion from a live tree branch, on the edge of a hollow (“drumming,” Wood 1984). This constitutes a rare case of both tool-use and tool-making in a non-foraging context and appears
to occur in only one population (Wood, 1984) and to be absent in the New Guinea population, as well as the west coast population on Cape York Peninsula.

*Territoriality and importance of nesting hollows*

Although not yet proven by playback-studies, palm cockatoos appear to exhibit year-round territoriality. For example, male palm cockatoos defend multiple tree hollows, and displays (which may have a territorial function) have been observed in all months of the year (Murphy et al., 2003). In defence of nesting hollows, strong intra-specific competition seems apparent. Murphy et al. (2003) describes two occasions where rival male palm cockatoos visited nests containing incubating resident males. Males invariably incubate during the day, while females do so at night (Murphy et al., 2003), and this may be because males are the larger sex and have larger mandibles to better defend the nest during the day. Furthermore, even though males may display at up to four display hollows, these may not be suitable for nesting. For example, out of 12 tree and hollow measures, Murphy et al. (2003) found two to be significantly different between nest and display hollows: nest hollows were slightly off vertical and occurred in live trees, rather than dead ones. Also limiting the availability of nesting trees is inter-specific competition for nesting hollows with sulphur-crested cockatoos (*Cacatua galerita*), as indicated by direct behavioural conflicts (Heinsohn et al., 2003), some of which have led to a change of nest ownership from palm cockatoos to sulphur-crested cockatoos (Heinsohn et al., 2003; pers. obs.). One driver for year-round territoriality may be a combination of a protracted breeding season (from late July to early May) and the substantial amount of energy required to construct the nesting platform (in piped trees). These platforms can be up to 2m deep above the bottom of the hollow and consist of long (20-30cm), thick (>10mm) sticks, presumably allowing for rain, excreta, and feather sheaths to be drained (Murphy et al., 2003). These platforms may take hundreds of hours to construct. Egg-laying dates of different pairs can be six or eight
months apart, and incubation and chick-rearing time can be 95-111 days, so year-round
defence of hollows may be necessary to ensure nests are not usurped. Besides nesting
hollows being a valuable resource, they may also be a very rare resource and increasingly so
(see Threats section).

Threats

There are two main threats facing palm cockatoos in Australia: changed fire ecology and
mining. With regards to the former, aboriginals on Cape York Peninsula no longer live on the
land as they used to, and this is likely the reason for the changed fire ecology of the region.
As a result of fire exclusion, for example, encroachment of rainforest into the woodland has
occurred at my field site (Russell-Smith et al., 2004), thereby precluding the recruitment of
woodland tree species in the area that are used for nesting by palm cockatoos. Indeed, visual
inspection of World War II aerial photographs of the region from 1947 confirms the loss of
multiple woodland pockets that used to occur throughout the rainforest. At the other extreme,
intense wildfires (i.e. hot and fast-moving) do occur on Cape York Peninsula in the late dry
season (Sept.-Nov.), in particular during years when early, dry-season fires (which are often
not as hot and burn less area) do not occur. In this scenario, the late dry-season the grass (fuel
load) is abundant and cured, leading to fires that result in lower tree survival compared to
low-intensity fires (Williams et al., 1999). In addition, the formation of piped nesting hollows
depends on termites (and fungi) to eat out the middle of the tree, but, as was shown in
Western Australia, successive years of intense fires may decrease termite (Isoptera)
populations (Abenspergtraun and Milewski, 1995), thereby potentially hindering the creation
of palm cockatoo nesting hollows.

‘Strip-mining’ is a process whereby all vegetation and trees are removed from often vast
areas of land for the purpose of excavating materials from the earth. This economically-
driven activity has occurred on the west coast of Cape York Peninsula since 1957 and still continues today. The total amount of land on Cape York Peninsula that is covered by bauxite mine lease and/or exploration lease totals 744,258 hectares, or 81.8% of the total area of Eucalyptus tetrodonta tall woodland (where palm cockatoos breed) on Cape York Peninsula (S. Gould, PhD thesis, 2010). Although no research has directly looked into the impact these mines have on palm cockatoos (Forshaw, 1964), this destructive activity has likely reduced their feeding and breeding habitat substantially over the decades. Furthermore, rehabilitation of vegetation after the strip-mining activity on Cape York Peninsula supports a lower diversity of bird species than remnant habitat (S. Gould, PhD thesis, 2010).

Palm cockatoos in New Guinea have been less studied than those in northern Australia, but it has been shown that the rate they are harvested for food is likely unsustainable (~40% of nestlings taken by local people in one region) (Heinsohn et al., 2009; Igag, 2002). Furthermore, hunters often chop down whole trees to reach the nestlings, thereby reducing the number of suitable hollows for palm cockatoos and other hollow-nesting species (Heinsohn et al., 2009).

Conservation status

At the state-level (Queensland), palm cockatoos are listed as ‘Near Threatened’ because the population is likely to be small but is ‘under no immediate threat’ (Garnett and Crowley, 2000). Internationally, they are a CITES Appendix I species, meaning international trade is banned, and under the IUCN they are listed as ‘Least Concern’ (http://www.iucnredlist.org), even though neither population size nor structure (e.g. number of breeding pairs) has been quantified. Recent studies suggest that palm cockatoos in Australia may be in decline due to changed fire ecology (e.g. Russell-Smith et al., 2004), low reproductive success (Murphy et
al., 2003, Heinsohn et al., 2009), and loss of habitat due to strip-mining for bauxite on Cape York Peninsula, Australia (S. Gould, PhD thesis, 2010).

Via population viability analyses, Heinsohn et al. (2009) demonstrated two main important points: 1) in New Guinea, where nestlings are taken for food by local people, the reported current rate of 40% of nestlings taken is not sustainable, and 2) the population on the east coast of Australia, encompassing the Iron-McIllWraith Ranges, is likely to be in decline. This study also stressed that further research on unknown demographic parameters, particularly nest site fidelity, age at first reproduction, and mortality rates of juveniles and adults, is urgently needed to understand the viability of the meta-population of palm cockatoos on Cape York Peninsula. These demographic parameters require identification of individuals, and as with any species that employs a slow-life history strategy (reproducing slowly over the course of a long life), identifying and monitoring individuals over time is particularly important for assessing their conservation status.

Study area

I conducted my field research for this thesis in Iron Range National Park and surrounding freehold aboriginal lands in the Lockhart River region on Cape York Peninsula (far north QLD, 12° 47’S, 143° 18’E) (Figure 1.1). This tropical region is characterised by two main climatic seasons, with the majority of the annual rainfall of 2.1 m (Bureau of Meteorology) occurring during the wet season (Jan.-April) and annual fires occurring in the dry season (May-Dec.). The study area contains a mosaic of multiple habitat-types, with often a distinct edge between the rainforest and savanna woodland. While rainforest is widespread in the study area, it covers only 5.6% of Cape York Peninsula’s total land area (Cofinas and Creighton, 2001). Cape York Peninsula is unique in Australia in that it provides a living historical link with that of New Guinea, sharing many of its species that are otherwise not
present elsewhere in Australia (e.g. Green python *Morelia viridis*, Cuscus *spp.* (Phalanger family), Magnificent riflebird *Ptiloris magnificus*).

I sought and received permission for my studies from the traditional owners of the *Uutaalnganu, Kanthanampu*, and *Kuuku Ya’u* language groups. People of these language groups in the Lockhart River aboriginal community, just south of Iron Range NP, have a profound reverence for palm cockatoos. For example, whereas Sulphur-crested cockatoos *Cacatua galerita* are taken for food, palm cockatoos are left alone because they are seen as devilish. Through communication with members of the community, I learned that this notion is due to the red colouring of their featherless cheek and occasional night-time calling behaviour.
Figure 1.1. Study area: Iron Range National Park and Lockhart River region (12° 47’S, 143° 18’E), Cape York Peninsula, Australia.
Thesis aims and structure

In this thesis, I aim to assess the efficacy of two non-invasive methods to identify individual palm cockatoos, thereby providing a viable technique for censusing and monitoring palm cockatoos for conservation research.

In Chapters 2 and 3, I investigate whether palm cockatoo vocalizations can be used to identify individuals. The first stage of this process is to catalogue the vocal repertoire of palm cockatoos (Appendix 1) and determine which call types are the most widely and frequently used. This process led to the unexpected discovery that palm cockatoos possess a large and complex vocal repertoire, which is in many ways analogous to the song repertoire of songbirds (Chapter 2). In Chapter 3, I gauge the efficacy of the vocal individuality technique to identify individual wild palm cockatoos, based on individually distinctive differences in call structure among individuals and the extent of vocal stability in the call structure over time.

Chapter 4 gives preliminary data for another non-invasive identification technique, photo-identification. This was not one of the original aims of my thesis, but was identified as a possibility following observations of distinctive bill features during the course of field observations. Therefore, this chapter provides a preliminary exploration of the potential of this technique rather than a rigorous analysis.

Finally, Chapter 5 reviews the major findings of the thesis, and suggests directions for future research.

Because each chapter is designed as a stand-alone manuscript for scientific publication, I included a thorough introduction and relevant literature review for each chapter, and some material may occur in multiple chapters. Although I have completed this thesis in collaboration with my supervisors, Rob Heinsohn and Naomi Langmore, who have
contributed valuable ideas and constructive assistance with analysis, in all cases I was the leading researcher.
Table 1.1. Summary of vocal individuality and vocal stability studies on birds*

<table>
<thead>
<tr>
<th>Study</th>
<th>Species</th>
<th># of individuals</th>
<th>Marked Individuals</th>
<th>Study Type</th>
<th>Reason for study</th>
<th>Classifier</th>
<th>VI accuracy</th>
<th>VS accuracy</th>
</tr>
</thead>
</table>
| **Caprimulgiformes** (Nightjars, frogmouths, and allies)  
(This order contains 1.2% of the world’s bird species**) |
| Jones & Smith 1997 | Marbled frogmouth *Podargus ocellatus* | 8 males; 5 females | Only one pair was marked | VI | Little known about species; difficult to see, but often heard | DFA | 87% (males); 94.4% (females) | --- |
| **Charadriiformes** (Shorebirds, gulls, and allies)  
(This order contains 3.7% of the world’s bird species) |
| Beightol & Samuel 1973 | American woodcock *Scolopax minor* | 36 males | yes | VI, VS (1 bird) | To allow further study of site fidelity, local movements, and census | Hoteling Principal Component Technique (VI), Student’s t-test (VS) | 83% | yes (p<0.05 b/w years) |
| Hoodless *et al.* 2008 | Woodcock *Scolopax rusticola* | 39 males | No (but based on known home-range territories) | validation of a survey method | Cryptic and secretive | DFA, then PCA | 95% | --- |
| **Ciconiiformes** (Long-legged wading birds: storks, herons, ibises, spoonbills)  
(This order contains 1.2% of the world’s bird species) |
<p>| Gilbert &amp; McGregor 1994 | European bittern <em>Botaurus stellaris</em>, (not disclosed) | yes (only 1 Bittern); no, but same territories | VI, VS (bitterns only) | Cryptic; difficult to capture and thought to be sensitive to | DFA (bitterns) &amp; naïve observers | 98.8%; 100% | 60% (for 3 of the birds), 5% (for 4 of the birds) | --- |</p>
<table>
<thead>
<tr>
<th><strong>Species</strong></th>
<th><strong>Scientific Name</strong></th>
<th><strong>Sex</strong></th>
<th><strong>Tagging</strong></th>
<th><strong>Years Studied</strong></th>
<th><strong>Notes</strong></th>
<th><strong>Methods</strong></th>
<th><strong>Accuracy (%)</strong></th>
<th><strong>Results</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Black-throated diver</td>
<td><em>Gavia arctica</em></td>
<td></td>
<td></td>
<td>(divers)</td>
<td>human disturbance; (both) leg bands rarely seen</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Puglisi &amp; Adamo 2004</td>
<td>Great bitterns <em>Boutaratus stellaris</em></td>
<td>18 males</td>
<td>yes (radio-tagged)</td>
<td>VI, VS</td>
<td>To determine if individually distinctive features of calls remained stable over time for later censusing of this elusive species</td>
<td>Nested ANOVA &amp; DFA</td>
<td>91.2%</td>
<td>not stable…showing significant variations among different dates within individuals</td>
</tr>
<tr>
<td>Policht et al. 2009</td>
<td>Rufous-headed hornbill <em>Aceros waldeni</em>, Visayan Hornbill <em>Penelopides panini panini</em></td>
<td>9, 5</td>
<td>yes (captive)</td>
<td>VI</td>
<td>For future life history studies and improve census data</td>
<td>DFA</td>
<td>89%, 90%</td>
<td>---</td>
</tr>
<tr>
<td>Eakle et al. 1989</td>
<td>Bald eagles <em>Haliaeetus leucocephalus</em></td>
<td>11 pairs</td>
<td>yes (captive)</td>
<td>VI, VS, site-fidelity</td>
<td>Trial for using the technique in the field</td>
<td>DFA &amp; paired t-test</td>
<td>83-100%</td>
<td>two attempts at re-identifying individuals were unsuccessful</td>
</tr>
</tbody>
</table>

**Coraciiformes** (Rollers, kingfishers, and allies)
(This order contains 2.2% of the world’s bird species)

**Falconiformes** (Raptors)
(This order contains 3.1% of the world’s bird species)
**Gruiformes** (Diverse terrestrial and marsh birds)
(This order contains 2.2% of the world’s bird species)

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Species</th>
<th>Year(s)</th>
<th>Monitoring</th>
<th>DFA &amp; ANN</th>
<th>Technique</th>
<th>Accuracy</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peake <em>et al.</em> 1998</td>
<td>Corncrake <em>Crex crex</em></td>
<td>16 (1993); 46 (1994); 3 (VS)</td>
<td>yes</td>
<td>VI, VS</td>
<td>To test efficacy of using VI to provide monitoring info on a species that is endangered, secretive, highly vocal, and rarely seen</td>
<td>DFA (VI); combined DFA of Euclidean distances (VS)</td>
<td>&gt;80%; 100% (using fine scale on wave-form)</td>
</tr>
</tbody>
</table>

**Passerines** (Perching birds, songbirds, passerines)
(This order contains 59.3% of the world’s bird species)

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Species</th>
<th>Year(s)</th>
<th>Monitoring</th>
<th>DFA &amp; ANN</th>
<th>Technique</th>
<th>Accuracy</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ellis 2008</td>
<td>White-throated magpie-jays <em>Calocitta formosa</em></td>
<td>17</td>
<td>yes (banded or unique facial plumage)</td>
<td>VI, VS</td>
<td>Determine usefulness of VI studies by gauging vocal stability over time.</td>
<td>DFA (VI); Mantel test (VS)</td>
<td>51%</td>
</tr>
<tr>
<td>Fernandez-Juricic <em>et al.</em> 2009</td>
<td>Southwestern willow flycatcher <em>Empidonax traillii extimus</em></td>
<td>18 (only 6 for VS)</td>
<td>yes (leg-bands)</td>
<td>VI, VS, and VR</td>
<td>Endangered; address monitoring challenges (dense habitat, short breeding season, migration behaviour)</td>
<td>DFA &amp; ANN; (ANOVA for VS)</td>
<td>75.75% (coarse); 86.27% (fine-scale); ANN: 80.7</td>
</tr>
<tr>
<td>Reference</td>
<td>Species Description/Details</td>
<td>Number of Individuals</td>
<td>Call Type</td>
<td>Experiment Details</td>
<td>Methodology / Analysis</td>
<td>Accuracy Range</td>
<td></td>
</tr>
<tr>
<td>------------------------</td>
<td>-----------------------------------------------------------------------------------------------</td>
<td>-----------------------</td>
<td>-----------</td>
<td>-----------------------------------------------------------------------------------</td>
<td>-------------------------</td>
<td>-----------------</td>
<td></td>
</tr>
<tr>
<td>Fox et al. 2008</td>
<td>Willie wagtails <em>Rhipidura leucophrys</em>, singing honeyeaters <em>Lichenostomus virescens</em>, and common canaries <em>Serinus canaria</em></td>
<td>7 individuals from each species</td>
<td>Yes (canaries-captive); not disclosed (other two species)</td>
<td>To trial VI comparing different call-types between individuals, rather than the same.</td>
<td>MFCCs fed into an ANN</td>
<td>69.3-97.1%</td>
<td></td>
</tr>
<tr>
<td>Fitzsimmons et al. 2008</td>
<td>Screaming piha <em>Lipaugus vociferans</em></td>
<td>26 males</td>
<td>No (but confident identification based on male territories)</td>
<td>To understand vocal learning in a sub-oscine species</td>
<td>SPCC + DFA + ANOVAs (on coefficients of variance)</td>
<td>92.3% (DFA)</td>
<td></td>
</tr>
<tr>
<td>Sharp &amp; Hatchwell 2005</td>
<td>Long-tailed tits <em>Aegithalos caudatus</em></td>
<td>63-90 pairs</td>
<td>Yes</td>
<td>Investigate a theory</td>
<td>DFA &amp; SPCC</td>
<td>47.6% (churr call) 76.2% ('tripple' call)</td>
<td></td>
</tr>
<tr>
<td>Trawicki &amp; Johnson 2005</td>
<td>Norwegian ortolan bunting <em>Emberiza hortulana</em></td>
<td>150 males</td>
<td>Yes (leg-bands)</td>
<td>For better habitat management and species survival plan; to aid remote and automated censusing methods for many different species</td>
<td>HMM using MFCCs</td>
<td>76.2-98.7%, depending on number of speakers</td>
<td></td>
</tr>
<tr>
<td><strong>Phoenicopteriformes</strong> (Flamingos)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(This order contains 0.1% of the world’s bird species)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mathevon 1996</td>
<td>Greater flamingo <em>Phoenicopterus ruber</em></td>
<td>5</td>
<td>yes (captive)</td>
<td>VI</td>
<td>To see which call parameters flamingos use to identify one another in a large colony</td>
<td>PCA</td>
<td>clear separation of individuals' in PCA</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Psittaciformes</strong> (Parrots, macaws, lories, cockatoos)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(This order contains 3.8% of the world’s bird species)</td>
<td></td>
</tr>
<tr>
<td>Saunders 1983</td>
<td>Short-billed white-tailed black cockatoo <em>Calyptrorhynchus funereus latirostris</em> Carnaby</td>
</tr>
</tbody>
</table>

| Zdenek 2011, this thesis | Palm cockatoo *Probosciger aterrimus* | 4-7 | no (but nest and display hollows used as proxies for ID) | VI, VS (preliminary analysis only) | For future life history studies; species may be in decline | DFA (VI); DFA and Mann-Whitney U-test (VS) | 81.3% (averaged for three different call types) | some call parameters stable over time, some not |

<table>
<thead>
<tr>
<th><strong>Strigiformes</strong> (Owls, barn owls)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(This order contains 1.9% of the world’s bird species)</td>
<td></td>
</tr>
<tr>
<td>Hill &amp; Lill 1998</td>
<td>Christmas Island hawk-owl <em>Ninox natalis</em></td>
</tr>
<tr>
<td>Author</td>
<td>Species</td>
</tr>
<tr>
<td>---------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>Lengagne 2001</td>
<td>Eagle owl</td>
</tr>
<tr>
<td>Rognan et al. 2008</td>
<td>Great grey owl</td>
</tr>
</tbody>
</table>

*This table is not exhaustive.

**Based on 9,702 species of birds in the world grouped into 30 different orders (Gill, 2007)


--- means not assessed
### Table 1.2. Bird studies that applied the VI technique

<table>
<thead>
<tr>
<th>Study</th>
<th>Species</th>
<th># of Individuals</th>
<th>Marked Individuals?</th>
<th>Span of study</th>
<th>Statistic used</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dawson &amp; Efford 2009</td>
<td><em>Seiurus aurocapilla</em></td>
<td>estimated 11-13 males</td>
<td>no</td>
<td>two months during each of four years</td>
<td>SECR analysis</td>
<td>A successful attempt at acoustic monitoring of a bird population; was more precise than mist-netting, required less fieldwork, and did not expose birds to stress of capture</td>
</tr>
<tr>
<td>Eakle et al. 1989</td>
<td><em>Haliaeetus leucocephalus</em></td>
<td>11 pairs (6 birds for VS)</td>
<td>yes (captive)</td>
<td>3 years</td>
<td>DFA &amp; paired t-test</td>
<td>A failed attempt to determine site-fidelity</td>
</tr>
<tr>
<td>Gilbert et al. 2002</td>
<td><em>Botaurus stellaris</em></td>
<td>7</td>
<td>yes (four for VS)</td>
<td>9yrs (2yrs for VS)</td>
<td>DFA, Euclidean distances</td>
<td>The first successful use of VI for censusing bird populations. Determined survival and movement of an endangered species, based on previously-established VI and VS</td>
</tr>
<tr>
<td>Peake and McGregor 2001</td>
<td><em>Crex crex</em></td>
<td>estimated 24 males via mapping data and estimated 29 males via VI</td>
<td>no</td>
<td>80 nights</td>
<td>Pearson correlation coefficients</td>
<td>A successful attempt to better estimate census numbers of a cryptic endangered species that lives in dense vegetation</td>
</tr>
</tbody>
</table>

Abbreviations: VI: vocal individuality; VS: vocal stability; DFA: discriminant function analysis; SECR: spatially explicit capture-recapture
References


FORSHAW, J. M. 1964. Some field observations on the great palm cockatoo. Emu, 63, 327-331.


An adult green python *Morelia viridis* poses on a tree in the rainforest of Iron Range, after I spot it while spotlighting at night for fun.

Photo by: Martin Willis.
Chapter Two

The large and complex vocal repertoire of palm cockatoos (*Probosciger aterrimus*) on Cape York Peninsula

A male palm cockatoo calls loudly down a tree hollow, near the Claudie River. Photo by: Roland Seitre at CNZ’s study site.

This chapter will be submitted to the international journal, *Ethology*, and has been co-authored with N.E. Langmore and R. Heinsohn.
Abstract
Passerines often have song repertoires of long and varied songs, whereas parrots typically have call repertoires of short vocalisations. This difference may reflect the differing social structure between the two groups. Passerines typically use song repertoires to advertise territory ownership and/or attract a mate, whereas parrots typically remain paired year-round, have overlapping home ranges, and tend to use calls to mediate their fission-fusion societies. The palm cockatoo (*Probosciger aterrimus*) is unusual amongst parrots in its apparent defense of year-round territories and its non-flocking nature. I show that palm cockatoos combine multiple syllable types to form longer and more varied vocalisations, which appear to be analogous to simple songs. 19 out of 27 syllables (discrete vocal building blocks) in the vocal repertoire were used together in various combinations. These vocal techniques occurred almost exclusively in two behavioural contexts—display and call-exchange with intruders—and therefore may have both mate-attraction and territorial functions, respectively. A simultaneous vocal duet of the *Hello* call also occurred, which appears to function as coordinated territorial defence by mated pairs. These results suggest that territoriality and sexual selection may have played a role in the convergent evolution of complex vocal repertoires in palm cockatoos and passerines.
Introduction

Vocal communication differs between passerines and non-passerines at multiple levels, including the neural control of vocalisations (Streidter, 1994), the capacity for vocal learning (Farabaugh and Dooling, 1996), and the complexity of vocalisations. The songs of passerines ‘tend to be long, complex, vocalisations produced by males during the breeding season’ (Catchpole and Slater, 2008); whereas calls—which most parrot vocalisations are considered to be—‘tend to be shorter, simpler vocalisations and produced by both sexes throughout the year’ (Catchpole and Slater, 2008). One key difference between the vocal communication system of passerines and parrots is that passerines commonly combine multiple syllable types to create long, more complex vocalisations, whereas this is rarely seen in parrots.

Vocal learning has evolved in three (out of a total of 23) orders of birds: Passeriformes, Psittaciformes, and Apodiformes. Vocal learning occurs in multiple vocal nuclei in the forebrain (reviewed in Zeigler and Marler, 2008), the relative size of which has been positively correlated with song complexity and vocal repertoire size (Airey et al., 2000; Nottebohm et al., 1981). Like passerines (Passeriformes), parrots (Psittaciformes) have relatively large forebrains, and they are also famous for their cognitive abilities (e.g. Pepperberg, 1984). However, unlike passerines, parrots typically do not sing songs or combine multiple syllables. Instead, parrots typically have call repertoires that consist of 5-15 distinct call types (Cortopassi and Bradbury, 2006; Fernandez-Juricic and Martella, 2000; Martella and Bucher, 1990; Pidgeon, 1981; Rowley, 1990; Saunders, 1983; Taylor and Perrin, 2005; Toyne et al., 1995; Van Horik et al., 2007), which are not combined.

The differing social structure of passerines and parrots may in part explain their differing vocal communication systems. The larger repertoires in passerines have been associated with maintaining/acquiring territories (e.g. Krebs et al., 1978; Yasukawa, 1981; but see O’Loghlen...
and Rothstein) and/or for mate attraction (reviewed in Searcy and Andersson, 1986; and in Byers and Kroodsma, 2009), and these roles are likely to be more pronounced in passerines than parrots. Defence of a large exclusive territory (as distinct from a nest site) is common in passerines, but unusual in parrots, which instead typically display overlapping home ranges (Forshaw, 2002; Gilardi and Munn, 1998; Juniper and Parr, 1998). Further, formation of new pair bonds between breeding seasons is widespread in passerines, whereas parrots tend to remain paired year-round and possibly throughout their lives (Forshaw, 2002; Gilardi and Munn, 1998; Juniper and Parr, 1998). Parrots have been shown to use calls to mediate their flocking, fission-fusion societies (Balsby and Bradbury, 2009; Scarl and Bradbury, 2009), and parrot species that form large flocks generally display smaller repertoires than those that live in small, stable flocks (Brereton, 1971; Pidgeon, 1981). This has been attributed to a requirement for a greater amount of information transfer in stable social groups (Brereton, 1971) and greater efficacy of visual rather than vocal communication in flocking species (Pidgeon, 1981).

Here I describe the vocal repertoire of palm cockatoos, a species which is atypical among parrots in that they do not live in flocks and instead appear to defend year-round territories that include multiple nesting and display hollows (Murphy et al., 2003). In this aspect of social structure, the palm cockatoo more closely resembles typical passerines than other parrots. I examine whether this similarity has also led to a larger, more complex vocal repertoire in this species.

Methods

Study species and study site

For information about the study species, see Chapter 1 (General Introduction).

---

1 Male brown-headed cowbirds (Molothrus ater)—a passerine—are not territorial but still use complex song during display to attract a mate (O’Loghlen and Rothstein, 2010).
Call recordings and behavioural data were acquired in Iron Range National Park and surrounding aboriginal free-hold lands on Cape York Peninsula (far north QLD, 12° 47’S, 143° 18’E). This study took place from June-Dec. 2009, corresponding with the months of most vocal activity (Murphy et al., 2003). Ten study sites were used, which covered 71km² with a maximum of 31.5km between nest trees. Study sites were visited at least once a fortnight. Because the activity level of several study sites fluctuated throughout the field season, these sites were only visited once a month during times of low-activity. Each of the 10 study sites had 1-2 dirt roads with infrequent vehicle traffic. Study sites were chosen based on vegetation-type (Murphy et al., 2003) and apparent use by palm cockatoos.

**Recording individual bird calls**

I collected 210 hours of non-continuous recordings from wild, unmarked male and female palm cockatoos. Although the birds were unmarked, males and females could be differentiated by beak size (males have larger beaks), and several individuals (n = 6) could be identified for the duration of a breeding attempt due to their parental behaviour at a nest containing young. Other males were considered different individuals if they performed displays on hollows separated by at least 2km (mean = 14.4km, range 2.2-28.6km). Because males display on multiple hollows (Murphy et al., 2003), I cannot be certain that these displaying males were indeed different individuals. However, I believe that it is unlikely for a male to display on hollows more than 2km apart. Juveniles were distinguished from adults based on plumage differences; juveniles have yellow barring on underside, while adults have no barring (Forshaw, 2010).

All recordings were made using a Sennheiser ME K6 shotgun microphone (with a windscreen) and a solid-state Marantz PMD661 digital recorder set to a sampling rate of 44.1kHz. Automatic Level Control on the recorder was turned off; instead, manual level
control was adjusted frequently during focal watches of calling birds, according to the
distance to the birds. The recorder was set to mono-channel, with a recording format of PCM-
16. Neither mic attenuation (i.e. 0dB) nor high or low audio filters were used.

Fixed duration focal watches were not possible because focal birds could rarely be relocated
following a flight. Instead, I followed a focal individual for as long as possible and watches
lasted between 2 and 68 minutes (20 ± 1.66 s.e.). When birds were near a nest and appeared
disturbed by the observer’s presence, data collection ceased and the area was vacated so as to
minimise impact. Recordings and observations were only made on fine days (little wind and
no rain) and when the distance to the birds was within 100m. Spectrograms of the calls were
viewed and analysed using the sound analysis computer program, RavenPro v. 1.3 (Charif et
al. 2008).

Syllable Classification

In studies of bird vocalisations, an ‘element’ is generally defined as a continuous line on the
spectrogram (Catchpole and Slater, 2008). For this paper, I define a syllable as either a single
element, or a cluster of elements, that always occur together in a cohesive unit and in a
distinct order. Palm cockatoo vocalisations are harmonically rich, and the majority of energy
occurs in the fundamental frequency (i.e. the lowest-frequency harmonic in the vertical series
of harmonics, see Fig. 2.1 and 2.2). The fundamental frequency of each vocalisation was
measured in a standard, semi-automatic manner using RavenPro v. 1.3 (Charif et al. 2008)
(16-bit sample format; frame overlap = 50%; Hann Window, DFT = 512; frequency
resolution = 124 Hz).
Syllables were initially classified by ear and by visual inspection of spectrograms. I then used Discriminant Function Analysis (DFA) to test whether syllables were statistically distinct (JMP 6.0, SAS Institute Inc.). My aim was to identify syllables that were representative of the population, rather than possible idiosyncratic variation on calls produced by particular individuals. Therefore, I restricted this analysis to syllables that were recorded 4-7 times from a total of at least four different males from four different sites at least 2km apart. Because individuals were represented with more than one call per call-type in the data set, I performed DFA on the means of all call data (rather than on independent data from each call) to avoid non-independent data (Mundry and Sommer, 2007).

Thirteen syllables were sufficiently widespread and common enough to be included in the analysis. A further 14 syllables were recorded but had insufficient sample size to be included in the DFA analysis of syllable types. For the most part, syllables that were not significantly different from one another were lumped and re-classified as a single syllable type. However, some call measurements (e.g. precision of start and finish of the call, clarity of harmonics) cannot be quantified by sound analysis programs, so for those calls that overlapped in DFA canonical space but were visually different on a consistent and obvious basis (e.g. two elements versus one element), I still classified them as distinct syllable types.

Nine vocalisation parameters were incorporated into the DFA model using a stepwise procedure and only significant variables were included in the final model. The stepwise procedure eliminated two (centre frequency, high frequency) of the original nine measurements as redundant. In the end, seven syllable parameters were used in the DFA: centre time (the point in time at which the call is divided into two time intervals of equal energy), low frequency (the lower frequency bound of the call), inter-quartile
bandwidth (the frequency that divides the call into discrete sections based on the energy of the vocalisation), maximum frequency (the frequency at which maximum energy of the call occurs), length (the number of frames contained in a call), inter-quartile duration (the time that divides the call into discrete sections based on the energy of the call), and delta frequency (the difference between the upper and lower frequency limits of the vocalisation).

**Social Context of Syllables**

Using log-linear modelling in Genstat (version 12.2; VSN International Ltd), I tested whether there was an association between syllable types and behavioural contexts. After each focal watch, recorded calls were assigned to one of six behavioural categories: Flight, Display, Nesting, Call-exchange, Solo Call-bout, or Other (outlined in Table 2.1). A syllable was scored as being given in a certain behavioural context (e.g. in Flight) if it was given one or more times in that context during a focal watch. Vocalisations included in the analysis were from between one and seven males and one and five females.

**Results**

**Vocal Repertoire**

I found at least 27 syllables in the vocal repertoire of palm cockatoos (Fig. 2.1), plus three chick/juvenile vocalisations, in the Lockhart River region. To objectively determine if these syllables were statistically different in structure, I performed DFA on 13 syllables that were recorded with sufficient frequency for analysis. DFA eliminated three of these syllables (Croik, Wh. B Flat, Dbl C a) as redundant to three other syllables (Crack, Wh. B, x), so the former were not classified as syllables in the repertoire. DFA of syllables included in the repertoire is shown in Figure 2.2. There were an additional two sets of two calls that overlapped in canonical space (1) Dbl Wh. with Wh. B and 2) Crack with Chuh Intro). The latter were still considered to be distinct syllables because, although there is substantial overlap in
call structure (e.g. delta frequency, call duration, and max. frequency), the calls differed in some variables which are easy to hear but less easy to quantify, including precision of start and finish of the call and clarity of harmonics. Furthermore, Chuh Intro was almost always used as an introduction syllable to other syllables, whereas Crack was rarely used in conjunction with other syllables. Dbl Wh. and Wh. B were considered to be distinct call types (despite their overlap in DFA) because one is clearly always made up of two elements (Dbl Wh., see (aa) in Fig. 2.1), and one is clearly always made up of one element (Wh. B, see (d) in Fig. 2.1). The aforementioned explanations are supported by the fact that there was no misidentification of these calls by discriminant function analysis.

Most calls were given by both sexes, but Excited Whistle, Trisyllabic Whistle (see Appendix I), and Donkey Intro (see Fig. 2.1) were recorded from males only.

Vocal complexity

Bird song often comprises syllables or sequences of syllables that are ‘mixed and matched’ to form more complex vocalisations (Catchpole and Slater, 2008). Palm cockatoos appeared to use their call repertoire in an analogous manner. Syllables were considered to be components of more complex vocalisations if at least two syllable types were combined within 0.3 seconds, at least one of the combined syllables was also found to be combined with another syllable type (or given alone), and only if a syllable was used in this manner by at least two birds. Every syllable given was almost always preceded by Chuh Intro, so I did not classify this as a complex vocalisation but rather as an introduction syllable. Of the 27 syllable types, 19 were used in combination to create more complex vocalisations (for examples, see Fig. 2.3). Vocal complexity never exceeded seven syllables in succession and occurred almost exclusively during display and call-exchange (see ‘Behavioural Contexts’ below).
Table 2.1. Definitions of five behavioural contexts

<table>
<thead>
<tr>
<th>Context</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flight</td>
<td>When birds were in flight.</td>
</tr>
<tr>
<td>Display</td>
<td>Frequent calling by one focal bird, while performing at least two display activities* on or near a hollow. Male displays may also involve beating a fashioned stick on a hollow (&quot;drumming,&quot; Wood 1984). These displays may have a territorial and/or mate-attraction function.</td>
</tr>
<tr>
<td>Nesting</td>
<td>When birds were involved in relieving each other at the nest during incubation or brooding, or approaching to feed a chick.</td>
</tr>
<tr>
<td>Call-exchange</td>
<td>When four or more birds were involved in a rapid exchange of vocalisations, sometimes including foot-stomping, wing-spread and/or bowing when calling. These events always involved a degree of conflict, with one bird chasing another away (and calling consecutive Cracks) in apparent territorial dispute, often near a hollow. These call-exchanges may have resulted from non-resident pair intrusions.</td>
</tr>
<tr>
<td>Solo Call-bout</td>
<td>When one bird calls from a perch for an extended period of time, with no other birds present or responding. This context is not accompanied by display activities and may serve to contact call a mate.</td>
</tr>
<tr>
<td>Other</td>
<td>All other behaviour.</td>
</tr>
</tbody>
</table>

*Display activities: foot-stomping, wing-spread, wing-spread while grasping hollow edge with beak, bowing when calling, pirouetting, grinding edge of hollow loudly with beak.
Figure 2.1. Spectrograms of all discrete palm cockatoo syllables recorded from Iron Range and Lockhart regions in 2009. Out of the 27 adult vocalisations (rows 1-4), 19 were used for to make longer, more complex vocalisations (all except (y) and those in rows two and five). Row 4: Juvenile and chick vocalisations. (a) Er-Crack; (b) Crack; (d) Whistle A; (e) Whistle C; (f) Ascending Ear-clencher; (g) Magnificent Riflebird Whistle; (h) Descending Whistle; (i) Pop-toy; (j) Rare Call; (k) Flight Whistle; (l) x; (m) z; (n) Split Whistle a; (o) Split Whistle b; (p) z; (q) Trisyllabic Whistle a; (r) Hello a; (s) Hello b; (t) Excited Whistle Slide; (u) w; (v) Slide Middle; (w) Slide Intro; (x) Growl; (y) Chuh Intro; (z) Donkey Intro; (aa) Double Whistle; (bb) Juvenile Call; (cc) Feeding; (dd) Begging Grate. Of the 27 adult syllables, only six (Hello (Hello a + Hello b) and row 1: Crack, Er-Crack, Whistle A, and Whistle B) were previously illustrated (Higgins, 1999). Spectrograms were prepared using RavenPro v. 1.3 (Charif et al. 2008).
Figure 2.2. Discriminant Function Analysis of a sub-set (10/27) of palm cockatoo syllables recorded from males in 2009. Syllables included in this analysis were those with 5-10 replicates each from 4-7 males in the population. The size of the circle corresponds to a 95% confidence limit for the mean. Groups that are significantly different have nonintersecting circles. Abbreviations: Dbl = Double; Wh. = Whistle.
**Figure 2.3.** Examples of combining syllables (rows 1-3) and simultaneous duet (row 4) by palm cockatoos. Row 4: (left to right) Simultaneous *Hello* duet by two birds; *Hello* call by one bird; Simultaneous *Hello b* by two birds; *Hello b* by one bird. Arrows indicate the start time of two different birds. In both examples, both duetting birds complete the duet at the same time. Spectrograms were prepared using RavenPro v. 1.3 (Charif et al. 2008).
**Vocal Duet**

The term ‘avian duet’ describes the act of two birds coordinating joint acoustic displays with a degree of temporal precision (Farabaugh, 1982). One key feature of avian duets is a stereotyped call-structure that occurs repeatedly and predictably in time (Langmore, 2002). A simultaneous *Hello* duet (Fig. 2.3) was always given by a male and female (likely of a pair), was heard on four occasions by four different pairs, and occurred with such exact synchronisation of identical syllables that it gives the impression it is produced by only one individual. One or two syllables were used for duets: either *Hello b* (the second half of *Hello*) or *Hello a* and *Hello b* (the first and second half of *Hello*). Duets always occurred during call-exchange and were not accompanied by coordinated visual displays. It was unclear whether the male or female initiated the duets.

**Behavioural Contexts**

Vocalisations were used non-randomly in all five behavioural contexts; during Flight ($\chi^2_{14} = 157.6, P< 0.001$), the *Flight Whistle* was given almost exclusively; during Nesting ($\chi^2_{11} = 95.7, P< 0.001$), *Whistle A* and *Whistle B* were particularly common; whereas *Whistle A* and *Er-crack* mainly occurred during Solo Call-bout ($\chi^2_{14} = 34.6, P = 0.002$). By contrast, during display ($\chi^2_{14} = 163.5, P< 0.001$) and call-exchange ($\chi^2_{11} = 65.1, P< 0.001$), a large number of vocalisations were used. During display, *Whistles A, B* and *C* and *Hello* were particularly common; during call-exchange the entire repertoire was used, although the human-sounding *Hello* call was used most commonly. Spectrograms of the palm cockatoo vocal repertoire are presented in Figure 2.1. Spectrograms were cut into syllables for clarity of display and labelling (un-cut spectrograms can be viewed in Fig. 2.3). In all cases (total n=143) except four, combining syllables was restricted to either display or call-exchange.
Males were more vocally active than females in the field and were thus more represented in recordings (e.g. 46 male display focal watches; five for females). However, for solo call-bout, I recorded three times as many female focal watches than males. These discrepancies suggest that males give more displays than females, and females give more solo call-bouts than males. In contrast, both sexes were equally represented in the Flight context (males=18; females=17).
Discussion

This study is the first to describe the types and context of palm cockatoo vocalisations comprehensively. I found the vocal repertoire of palm cockatoos at Iron Range, Cape York Peninsula to be larger and more complex than most other parrots whose vocalisations have been studied in detail (Cortopassi and Bradbury, 2006; Fernandez-Juricic and Martella, 2000; Martella and Bucher, 1990; Pidgeon, 1981; Saunders, 1983; Van Horik et al., 2007; Wanker et al., 1998). I have shown that palm cockatoos combine multiple syllable types in a manner analogous to the more simple songs of some passerines. Furthermore, the social context in which they use different vocalisations is specific (see ‘Behavioural Contexts’ section), with use of the entire repertoire, as well as the combination of syllables, occurring primarily during displays and call-exchanges with intruders. Nineteen out of 27 syllables (discrete building blocks) were used in various combinations to make more complex vocalisations, and 21 of the 27 syllables had not previously been described (all syllables detailed in this paper except for Hello a and Hello b (combined is the Hello call) and row 1 in Figure 2.1: Crack, Er-Crack, Whistle A, and Whistle B (Forshaw, 2002; Higgins, 1999).

Palm cockatoo vocalisations are difficult to classify as either songs or calls. Songs ‘tend to be long, complex, vocalisations produced by males during the breeding season’; whereas calls ‘tend to be shorter, simpler and produced by both sexes throughout the year’ (Catchpole and Slater, 2008). Here, complexity refers to the combination of multiple syllables that make up songs. Thus palm cockatoo vocalisations have attributes of both songs and calls, being produced by both sexes throughout the year, but exhibiting a degree of complexity that is more typical of song. However, it is worth noting that this definition of song suffers from a severe northern hemisphere bias; both female birdsong and year-round song are in fact commonplace throughout the tropics and southern hemisphere (Langmore, 1998).
Passerines and parrots differ greatly in social structure and this may in part explain the differing communication systems between these two groups of birds. Passerines typically defend breeding or year-round territories and use their song to proclaim territory ownership (Krebs, 1977a; Nowicki et al., 1998b; Sprau et al., 2010; Yasukawa, 1981). By contrast, parrots more commonly live in complex fission-fusion societies with overlapping home ranges, and territorial behaviour is usually limited to defence of a nest site. Further, whereas parrots typically pair for life, passerines often form new pair-bonds in different breeding seasons (Black, 1996), perhaps leading to greater selection on passerines than on parrots for vocalisations that play a role in mate attraction. Instead, the long lifespan, long-term pair-bonds and intensely social nature of flock living in parrots may favour a role of vocalisations in individual recognition (Saunders, 1983; Wanker and Fischer, 2001), social mediation (Balsby and Bradbury, 2009; Scarl and Bradbury, 2009), and conveying information about social standing (Wanker and Fischer, 2001).

Unlike most parrots, palm cockatoos do not live in fission-fusion societies. They do not spend their days in flocks, nor roost in groups at night. Instead, they are usually seen in pairs and, less often, in family groups of three individuals (two parents and one juvenile; distinguished by plumage differences), and they appear to defend large territories comprising multiple nest hollows (Murphy et al., 2003). In this respect, palm cockatoo social structure is similar to that of passerines. Further, palm cockatoos appear to use their vocalisations in a similar manner and for similar functions to passerines. Vocalisations were used extensively during display and during call-exchange with intruders, where conflict between birds (e.g. loud consecutive Cracks, attack collisions in mid-air) was always evident. Based on context, these vocalisations appear to be analogous to solo song and counter-singing in passerines (Catchpole & Slater, 1995). Like passerines, palm cockatoos cycled through their repertoire in these contexts exclusively, and also combined syllables (Fig. 2.3) in a manner that
increased the complexity and diversity of their repertoire. Such repertoire elaboration in passerines has been shown to provide males with an advantage in territorial defence (Airey et al., 2000; Catchpole, 1980; but see Catchpole, 1983; Catchpole et al., 1984; Krebs et al., 1978; Yasukawa, 1981). Although the process of combining syllables to form more complex vocalisations resembles that of passerines, it is a relatively simple version of this process—a process that can in some passerines result in repertoires of hundreds or even thousands of different song types (Catchpole and Slater, 1995).

Two other parrot species also appear to use vocalisations for territorial defence. The African orange-bellied parrot, which is only seldom in large flocks (Juniper and Parr, 1998), also uses its longest and most complex vocalisation during aggressive display (also given during courtship display) (Venuto et al., 2000). Greater vasa parrots exhibit year-round territoriality, whereby females remain within 30m of the nesting site for the entire year (Ekstrom et al., 2007). They also combine syllables in territorial contexts, but this was only reported during the chick-rearing period (Ekstrom et al., 2007).

Four palm cockatoo pairs were also observed to produce vocal duets. Duetting in birds is particularly correlated with three major life history variables: monogamy, year-round territoriality and a tropical distribution (Hall 2004; Hall, 2009; Langmore, 1998; Farabaugh, 1982; Morton, 1966), all of which are characteristic of palm cockatoos. Like many duetting passerines, palm cockatoos produced duets during call-exchange, when conflict with other pairs was evident. Although I did not know the breeding stage of duetting pairs, the specific context in which duets occurred indicates that it may aid in cooperative territorial defence. Vocal duets occur in many parrots (Hall, 2009), the function of which vary across species. The red-fronted parrot (Poicephalus gulielmi) uses a simultaneous duet for pair-bond maintenance, with duet complexity increasing as the length of time a pair has spent together
increases (Venuto et al., 2001). Evidence from highly coordinated duets by new and old pairs of wild-caught canary-winged parakeets (*Brotogeris v. versicolor*) did not indicate a pair-bond maintenance function of duets, but rather a coordinated pair threat against conspecifics (Arrowood, 1988). Vocal duets of the yellow-naped amazon have features which suggest that males and females encode different, and possibly multiple, messages (Wright and Dahlin, 2007).

*Hello* calls were also occasionally given in immediate succession by two or three birds. (This was not considered a duet because it did not constitute a stereotyped structure that occurred repeatedly and predictably in time (Langmore, 2002) (e.g. sometimes the calls overlapped in time slightly; other times they were given immediately in succession). Successive *Hello* calls may serve as vocal matching, where individuals mimic other individuals to initiate contact with a specific individual (Adams et al., 2009; Janik, 2000). Bottlenose dolphins (*Tursiops truncates*) were found to have matching interactions where two whistles of the same type were produced by separate individuals within three seconds of one another (Janik, 2000). Although palm cockatoos were only heard to mimic *Hello* calls, not ‘signature’ calls specific to different individuals (Tyack, 2003), successional *Hello* calls by different individuals during group interactions may still serve to initiate communication between certain birds.

In conclusion, similarity in palm cockatoo vocalisations and that of several other parrot species to passerines suggests that year round territoriality, combined with complex interactions between the sexes, may have led to convergent evolution in the use of vocal repertoires by passerines and several psittacines. Similar social structure and breeding biology between passerines and palm cockatoos may explain their relatively similar vocal communication systems. Further research into both the social structure and breeding system
with regards to vocal communication in psittacines is needed to determine the generality of these results across psittacines.
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Photo by: Damon Brundage (at CNZ’s study)
Chapter Three

Vocal individuality of palm cockatoos
(*Probosciger aterrimus*)
on Cape York Peninsula

A male palm cockatoo (centre), about to feed its chick (right) sitting at the second hollow entrance. Photo by Peter Odekerken (at CNZ’s study site).

This chapter will be submitted to the national journal, *Emu*, and has been co-authored with N.E. Langmore and R. Heinsohn.
Abstract

Knowing the identity of individuals within populations is often a pre-requisite for a detailed understanding of the ecology and conservation requirements of species. However, some species, including large parrots, are notoriously difficult to catch and mark for individual identification. Palm cockatoos (*Probosciger aterrimus*) are a large, poorly understood species of parrot which may be in decline on Cape York Peninsula, Australia due to changed ecological conditions and poor nesting success. Palm cockatoos have a remarkably large repertoire of calls for a parrot, comprising at least 27 syllables, some of which are used in combination to make more elaborate and varied vocalisations. Here, I investigated whether three different palm cockatoo call types are individually distinct enough to be used as a non-invasive ‘marker’ to identify individuals over time. Using Discriminant Function Analysis, overall identification accuracy among all individuals for all call types was 85.6% (i.e. 137 out of 160 calls were assigned to the correct individual) on the basis of multiple temporal, energy (amplitude), and frequency measurements on the spectrogram. For three different call types, individual identification accuracy among males and females ranged from 81.3%-95%. However, limited sample sizes suggest that individual call structure, as quantified by call parameters, was not stable between years. I discuss the applicability of these results for future studies of palm cockatoos and other parrot species.
Introduction

Identification of individuals within a population is often essential for behavioural studies and monitoring of populations and over time can provide useful life-history data for population viability studies (Terry et al., 2005). Individual identification in birds is usually facilitated by leg-bands or wing-tags, but this process can be problematic for both the study species and researchers. Traditional capture techniques can be overly expensive and time-consuming, involve negative public perception (Mellor et al., 2004), and elicit multiple welfare issues for the study species. The latter can include injuries to the captured animals, avoidance of the capture area, suppressed immune responses, and loss of reproductive success (see Terry et al., 2005). Leg-bands and wing-tags can also cause physical damage over time (Meyers, 1994b), and marked individuals can experience increased predation (Saunders, 1988) and mortality rates (Saraux et al., 2011).

Besides welfare issues, there can also be substantial logistical issues in the capture process due to the habitat and/or behaviour of some species. For example, leg-bands are difficult to see on some cryptic bird species, like rails (Rallidae), which live amongst thick, tall reeds in wetlands, and also with nocturnal birds (e.g. Strigiformes). Some species are simply very difficult to capture (e.g. Black-throated Divers *Gavia arctica*, Gilbert et al., 1994). Large parrots in general are difficult to capture (pers. comm., R. Heinsohn; Meyers, 1994a; Gebhardt et al., 2009) and can also manipulate leg-bands with their strong beaks and mobile tongue (Meyers, 1994b), thereby hindering traditional techniques.

Vocal Individuality (VI) appears to be a common feature of vocal animals whereby an individual’s vocal features are individually distinct and remain constant enough to be associated with that individual over time. Individually distinctive vocalisations have been shown across multiple species and taxa, including birds, mammals (Terry et al., 2005),
dolphins (Tyack, 2003), and amphibians (Feng et al., 2009). Identification using VI may offer a useful non-invasive alternative to traditional capture-recapture techniques, but the extent and practicality of quantifying this trait will differ between species. For example, although vocal individuality has successfully been used for routine population censuses of the European bittern (Botaurus stellaris) in the UK for over ten years (Gilbert et al., 2002) and to increase the accuracy of population estimates for corncrakes (Crex crex) in Scotland (Peake and McGregor, 2001a), it may be unsuitable for species with low rates of vocalisation (e.g. Black-throated divers Gavia immer, Gilbert et al. 1994) or when species lack temporal stability of call structure (e.g. fallow deer Dama dama, Briefer et al., 2010; female white-throated magpie-jays Calocitta formosa, Ellis, 2008; ground squirrel Spermophilus fulvus, Matrosova et al., 2010; Loons Gavia immer, Walcott et al., 2006).

Vocal studies on parrots have mainly focused on vocal dialects (Baker, 2003; Baker, 2008; Bond and Diamond, 2005; Buhrman-Deever et al., 2007; Guerra et al., 2008; Kleeman and Gilardi, 2005; Ribot et al., 2009; Rowe and Bell, 2007), flock coordination (Balsby and Bradbury, 2009), vocal learning (Hile et al., 2005; Pepperberg, 1984; Pepperberg et al., 2000), and vocal behaviour (Balsby and Bradbury, 2009; Scarl and Bradbury, 2009; Van Horik et al., 2007; Venuto et al., 2000; Venuto et al., 2001), but relatively few have determined whether calls are individually distinctive (Saunders, 1983; WANKER and Fischer, 2001). Saunders (1983) used observer volunteers to match printed spectrograms of wild Carnaby’s cockatoo (Calyptorhynchus carnaby) calls into groups (each representing a different individual) and qualitatively found that an average of 87% of sonograms were correctly matched. WANKER & Fischer (2001) quantitatively found the calls of captive orange-fronted parakeets (Aratinga canicularis) to be individually distinctive based on six call parameters (peak frequency, maximum frequency, duration, energy, bandwidth, and
minimum frequency); most family groups could also be distinguished by similar call characteristics.

Palm cockatoos (*Probosciger aterrimus*) are a large, iconic species of parrot restricted to Cape York Peninsula (far north Queensland), as well as lowland New Guinea and some offshore islands (Higgins, 1999). At the state-level (Queensland), they are listed as ‘Near Threatened.’ Internationally, they are listed as ‘Least Concern’ ([http://www.iucnredlist.org](http://www.iucnredlist.org)). However, recent studies suggest that palm cockatoos in Australia may be in decline due to changed ecology (e.g. Russell-Smith et al., 2004) and low reproductive success (Heinsohn et al., 2009; Murphy et al., 2003). Heinsohn et al. (2009) stressed that further research on unknown demographic parameters, particularly nest site fidelity, age at first reproduction, and mortality rates of juveniles and adults, is urgently needed to understand the viability of the meta-population of palm cockatoos on Cape York Peninsula. These demographic parameters require identification of individuals, but previous attempts at capturing and marking individuals proved extremely difficult (unpublished data).

Palm cockatoos may be well suited for VI studies because both sexes vocalise and also because males are highly vocal at known display trees, meaning that a substantial sample size of calls can be obtained relatively easily. The current study aims to determine the extent and applicability of VI for use as a non-invasive identification technique to study this species. If successful, this technique would transform research on palm cockatoos and could also be applied to other parrot species worldwide, especially studies seeking individual-based demographic parameters necessary for population viability studies.

**Methods**

*Study Area and Species*
I collected palm cockatoo vocal recordings from wild, unmarked birds in Iron Range National Park and surrounding freehold aboriginal lands on Cape York Peninsula (far north QLD, 12° 47’S, 143° 18’E). This tropical region is characterised by two main seasons, with the majority of the annual rainfall of 2.1 m (Bureau of Meteorology) occurring during the wet (Jan.-April) and annual fires occurring in the dry season (May-Dec.). The study area contains a mosaic of multiple habitat-types, with often a distinct edge between the rainforest and savanna woodland.

Palm cockatoos are monogamous, obligate hollow-nesters that nest in savanna woodland adjacent to the rainforest (Murphy et al., 2003). They lay only one egg per nesting attempt, and the only study on their breeding biology suggests they only attempt reproduction every 2.2 years on average (Murphy et al., 2003). Limited data suggests that males defend and maintain an average of three to four potential nest sites (Murphy et al., 2003). Part of this maintenance involves males performing unique drumming displays on hollows, whereby they beat a fashioned stick (broken off a live tree branch) on the edge of a hollow (“drumming,” Wood, 1984) and also actively use body language (e.g. bowing and calling into the hollow, wing-spreading, foot-stomping, crest erection, and full exposure of their bare red cheek-patch) (Murphy et al., 2003). During these displays, males cycle through the majority of their vocal repertoire, which consists of at least 27 syllables, 20 of which are mixed and matched to make more varied vocalisations (see Chapter 2).

Locating and Recording Individual Palm Cockatoos

To find palm cockatoos, I first used broad vegetation maps to locate the rainforest/savanna edge and then slowly approached calling birds to minimise disturbance. Birds were usually found in pairs, alone, or (more rarely) in groups of three. Recording sites were located on the edge of the rainforest in open savanna woodland dominated by old growth Eucalyptus tetrodonta. I collected recordings on fine days (i.e. no rain and little wind), without the use of
playback, when birds were within 75m. Digital audio recordings were made using a Sennheiser ME K6 shotgun microphone (with a windscreen) connected to a solid-state Marantz PMD661 digital recorder, which was set to a sampling rate of 44.1kHz. Automatic Level Control on the recorder was turned off; instead, manual level control was adjusted for distance. The recorder was set to mono-channel, with a recording format of PCM-16. Neither mic attenuation (i.e. 0dB) nor high or low audio filters were used.

Focal watches of individual birds lasted between 2 and 68 minutes (mean = 20 +/- 1.66 s.e.) and provided around 2-15 useable calls (i.e. one of the three call types analysed in this study). When birds were near a nest and appeared disturbed by the observer’s presence, data collection ceased and the area was vacated so as to minimise impact. In total, 12 birds were identified. Although the birds were unmarked, males and females could be distinguished visually on the basis of bill length (Higgins, 1999) and several individuals (n = 6, four females and two males) could be identified for the duration of a breeding attempt due to their parental behaviour at a nest containing young. An additional six males were considered different individuals because they performed displays on hollows separated by at least 1.5km (mean= 6.1km, range = 1.5-16.5km). Because males display on multiple hollows (Murphy et al., 2003), I cannot be certain that these displaying males were indeed different individuals. However, I believe that it is unlikely for a male to display on hollows 1.5km apart. Juveniles were distinguished from adults based on plumage differences; juveniles have yellow barring on underside, while adults have no barring (Forshaw, 2010).

Although previous work by Murphy et al. (2003) showed that palm cockatoos do reuse the same nest between breeding attempts (even three years apart), changes in nest ownership between years were also documented. As such, for between-year analysis of call structure, I recorded birds at the same nest hollows in 2010 as in 2009, but there is a possibility that these birds may not have been the same individual.
Sound Analysis

Only calls with high signal-to-noise ratio and no interference from other calling birds were used for analysis. Three different call types (the Hello call, Whistle A, and Whistle B; see Fig. 2.1, Chapter 2) were recorded enough times from three to six birds of each sex to be included in each analysis. The Hello call appears to be a territorial defence call (also used for simultaneous duets), and Whistle A and Whistle B are contact calls (see Appendix I).

Recordings from adult females were less represented in the sample and analysis because males were more vocal than females. Using 12 individuals in total, I analysed 32 Hello calls from four males, 46 and 32 Whistle A calls from six males and four females, respectively, and 30 and 20 Whistle B calls from four males and three females. Spectrograms were viewed in RavenPro v. 1.3 (Charif et al. 2008), using the following: 16-bit sample format, frame overlap = 50%, Hann Window, DFT = 512, and frequency resolution = 124 Hz.

Figure 3.1. Spectrogram of three Palm Cockatoo calls. (a) Hello, (b) Whistle A, and (c) Whistle B. Spectrograms were prepared using RavenPro v. 1.3 (Charif et al. 2008).
Manual and semi-automatic call parameter measurements were made. All measurements were made on the fundamental frequency, except for Hello, where measurements were made on stacked harmonics.

Because of general differences in the structure of each call type, some but not all call parameters were applicable for each call type. To better account for individual differences in the spectrographic contour line of Whistle A (e.g. Fig. 3.1 vs. Fig. 3.2), I used the on-screen cursor in RavenPro to make two manual measurements: trough frequency (the frequency at the trough of the call) and ridge1 frequency (the frequency at the top of the first ridge of the call) (see Fig. 3.2).

For semi-automatic measurements, manual selection boxes on the whole call were made using the on-screen cursor, and summary information was then automatically calculated for a set of call parameters. One difficulty I found was that the start and end of each call was often difficult to identify exactly on the spectrogram. To reduce the subjectivity of these on-screen cursor measurements, I marked the start and end of each call according to the marked change in amplitude of the time-aligned waveforms (energy versus time). An additional four measurements (centre frequency, centre time, inter-quartile bandwidth, inter-quartile duration; see below) that were also used are robust signal measurements in that they vary little in relation to my placement of the on-screen cursor (Charif et al., 2008).

One temporal measurement was made for each call: length (the number of frames—comparable to milliseconds—contained in a call). Three measurements that account for the
relative spread of energy across the call were made for each call: centre time (the point in time where the call is divided into two time intervals of equal energy), inter-quartile bandwidth (the frequency that divides the call into discrete sections based on the energy of the vocalisation) and inter-quartile duration (the time that divides the call into discrete sections based on the energy).

To account for differing structure between each of the three call types, different frequency measurements were applicable for each call type. Due to unclear high and low frequency bounds of the Hello call, I did not measure these frequencies for this call and I instead defined the call using standardised high and low frequency bounds. All frequency measurements included: centre frequency (the frequency that divides the call into two equal frequency intervals), high frequency (the highest frequency bound of the call), low frequency (the lowest frequency bound of the call), maximum frequency (the frequency that has the highest power), trough frequency, and ridge1 frequency.

**Statistical Analysis**

*Vocal Individuality Test*

I used Discriminant Function Analysis (DFA) to determine whether a combination of call parameters could be used to discriminate between individuals (JMP 6.0, SAS Institute Inc.). Individuals used different call types at different rates, resulting in small sample sizes of comparable calls between individuals. As such, out of a total of 12 individuals recorded, only three to six could be included in each DFA analysis of each call type. Rather than using a stepwise selection of variables for the DFA model, I included all variables (length, centre time, inter-quartile bandwidth, inter-quartile duration, centre frequency, high frequency, low frequency, trough frequency, ridge1 frequency), in the model (regardless of their level of
significance) because that increased my power to discriminate between individuals, and I was less concerned with determining which call parameters contributed most to individuality. Males and females were analysed separately because they could be distinguished morphologically. Though male song complexity\(^2\) can correspond to periods of its mate’s fertility (Ballentine et al., 2003), this effect was not a problem in this study because we analysed individual syllables.

The probability that calls would be assigned to individuals by chance alone was calculated by taking the number of calls of each individual and dividing it by the number of total calls in the model. If this number was above the percent of calls correctly classified for that corresponding individual, then this is reported as greater than chance alone. For example, if the calls from Male A contributed to 10 out of 32 calls (31.25\%) in the Hello call model, and 9 out of 10 (90\%) of these calls were correctly classified, this was higher than chance alone for that individual.

**Vocal Stability Test**

For the purpose of this thesis, I use the term ‘vocal stability’ as the consistency in a bird’s call structure over time. To determine whether significant intra-individual variation in call structure occurred over time, I used multivariate (DFA, Fig. 3.4) and univariate techniques (Mann-Whitney U-tests). First, calls from the same individual in different recording sessions were entered in DFA as ‘different’ individuals. A significant difference between two call sessions (no overlap in the 95\% confidence circles) was interpreted as evidence that vocal stability was lacking for that individual.

\(^2\) As measured by (i) element repertoire size, (ii) proportion of distinct song variant, (iii) song versatility, and (iv) syntax consistency (Ballentine et al., 2003).
As an independent means of verifying the results of the DFA vocal stability analysis, I used Mann-Whitney U-tests to show which variables in particular were stable over time. Using only the most significant call parameters in DFA (as determined by the stepwise procedure of inclusion of variables), I independently compared each later call session with the first call session for each individual (Jones et al., 1993) (see Table 3.1a-c). Call sessions were separated by at least one month. Tests were performed on call parameter data from 6-10 calls of the same call type, recorded from the same individual in two or three different recording sessions. Using 129 calls from five birds in total, nine comparisons were made (five within-year comparisons; four between-year comparisons). To account for multiple pair-wise comparisons and increased probability of making a Type I error, I calculated critical p-values for each individual within each call-type by using the Dunn-Sidak method. If there was a significant difference between recording sessions for a call parameter, then that call parameter (for that call type) was not considered to be stable over time for that bird. I also report any significant differences at the standard level of P < 0.05.

The rate at which individuals used different call types differed across recording sessions and across individuals. As such, comparing the same call-type across different birds led to limited sample sizes. To address this difficulty, I had to analyse different call types for different individuals. To further increase the sample size, in one case, Whistle B calls from a nesting female (Female A) were pooled from four months to compare to calls from one recording session in the next breeding season. Due to these constraints, I consider this to be a preliminary analysis of vocal stability only.

Results

Vocal individuality
Overall, Discriminant Function Analysis classified 85.6% (137/160) of all calls to the correct individual. Among females 84.4%-95% of all calls were correctly classified; among males, 81.3%-87% of all calls were correctly classified. DFA could assign correct classifications in all cases to a percentage higher than would be expected by chance (Table 3.2).

*Hello call*

Among four males, DFA classified 81.3% (26/32) of *Hello* calls to the correct individual (Fig. 3.3). Successful classifications for each individual ranged from 66.7%-100%.

*Whistle A*

Among four females, DFA classified 84.4% (27/32) of *Whistle A* calls to the correct individual (Fig. 3.3). Successful classification ranged from 58.9%-100% among individuals. Among five males, DFA classified 87.0% (40/46) of *Whistle A* calls to the correct individual (Fig. 3.3). Successful classifications ranged from 66.7%-100% among individuals.

*Whistle B*

Among three females, DFA classified 95% (19/20) of *Whistle B* calls to the correct individual (Fig. 3.3). Successful classification ranged from 85.7% to 100% among individuals. Among four males, DFA classified 86.1% (31/36) of *Whistle B* calls to the correct individual (Fig. 3.3). Successful classification ranged from 70% to 100% among individuals.
Table 3.2. Percentage expected by chances, versus the percentage of correctly classified calls for each individual

<table>
<thead>
<tr>
<th>Bird ID</th>
<th>Expected by chance</th>
<th>% correctly classified</th>
<th>Expected by chance</th>
<th>% correctly classified</th>
<th>Expected by chance</th>
<th>% correctly classified</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male A</td>
<td>31.2%</td>
<td>80.0%</td>
<td>21.7%</td>
<td>100%</td>
<td>21.7%</td>
<td>80.0%</td>
</tr>
<tr>
<td>Male B</td>
<td>31.2%</td>
<td>80.0%</td>
<td>15.2%</td>
<td>71.4%</td>
<td>15.0%</td>
<td>70.0%</td>
</tr>
<tr>
<td>Male E</td>
<td>---</td>
<td>---</td>
<td>21.7%</td>
<td>90.0%</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Male F</td>
<td>---</td>
<td>---</td>
<td>21.7%</td>
<td>100.0%</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Male G</td>
<td>---</td>
<td>---</td>
<td>19.6%</td>
<td>66.67%</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Male H</td>
<td>18.8%</td>
<td>83.3%</td>
<td>---</td>
<td>---</td>
<td>21.7%</td>
<td>100%</td>
</tr>
<tr>
<td>Male I</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>13.0%</td>
<td>100%</td>
</tr>
<tr>
<td>Male J</td>
<td>18.8%</td>
<td>100%</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Female A</td>
<td>---</td>
<td>---</td>
<td>25.0%</td>
<td>75.0%</td>
<td>35.0%</td>
<td>85.7%</td>
</tr>
<tr>
<td>Female B</td>
<td>---</td>
<td>---</td>
<td>18.8%</td>
<td>83.3%</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Female C</td>
<td>---</td>
<td>---</td>
<td>28.1%</td>
<td>90.0%</td>
<td>30.0%</td>
<td>100%</td>
</tr>
<tr>
<td>Female D</td>
<td>---</td>
<td>---</td>
<td>28.1%</td>
<td>88.9%</td>
<td>35.0%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Vocal stability

For each call type, multiple call sessions from a given individual over time were included in the DFA model against other individuals (Fig. 3.4). Four out of eleven comparisons showed vocal stability: Female C, Whistle A, session 1 and 2; Female C, Whistle A, session 2 and 3; Male A, Whistle A, session 1 and 2; Male H, Hello, session 1 and 2.

Mann-Whitney U-tests indicated that most call parameters remained constant over time for all individuals but that different individuals were stable in different call parameters (Table 3.1a-c). For two females (Female C, Whistle A; Female A, Whistle B), no tested call parameters differed significantly different between any call session, suggesting that these females had particularly stable call structure over time. Only one individual (Male H, Hello call) had more than one call parameter that was significantly different between recording sessions.
Figure 3.3. Discriminant Function Analysis results for vocal individuality tests of palm cockatoo calls. *Whistle A* (top two plots); *Whistle B* (middle two plots); *Hello* (bottom right plot). Female calls in plots on the left; male calls in plots on right. The percent accuracy of identification of individuals is listed on the bottom right of each plot. The letters in the centre of each circle represents different individuals. The size of the circle corresponds to a 95% confidence limit around each multivariate mean of six to ten calls.
Figure 3.4. Discriminant Function Analysis results for vocal stability tests of palm cockatoo calls. Female calls in plots on the left; male calls in plots on right. *Wh.: Whistle*. The letters in the centre of each circle represents different individuals, and sequential call sessions from the same individual are denoted by a 1, 2, or 3, following the letter. The size of the circle corresponds to a 95% confidence limit around each multivariate mean. The two canonical axes combined represent all call measurements.
Comparisons using Mann-Whitney U-test were made between sessions 1 and 2 (significant differences marked in session 2) and sessions 2 and 3 (significant differences marked in session 3). * Indicates standard significance (p < 0.05). ** Indicates significance at corrected critical value. ‡ Indicates a recording session in 2010 (the second breeding season). All probabilities are for a two-tailed non-parametric test.

### Table 1a. Mean (± SE) for palm cockatoo *Hello* calls for each individual across recording sessions†.

<table>
<thead>
<tr>
<th>Individual</th>
<th>Session</th>
<th>n</th>
<th>Length</th>
<th>IQR BW</th>
<th>IQR Dur.</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Male A</td>
<td>1</td>
<td>10</td>
<td>219.9 ± 4.43</td>
<td>1050.83 ± 84.98</td>
<td>0.35 ± 0.02</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2‡</td>
<td>8</td>
<td>217.88 ± 6.95</td>
<td>807.5 ± 98.6</td>
<td>0.48 ± 0.04**</td>
<td></td>
</tr>
<tr>
<td>Male H</td>
<td>1</td>
<td>6</td>
<td>184 ± 3.49</td>
<td>1033.6 ± 20.29</td>
<td>0.47 ± 0.03</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>10</td>
<td>176.9 ± 1.68</td>
<td>757.98 ± 65.5**</td>
<td>0.33 ± 0.02*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>10</td>
<td>182.1 ± 4.16</td>
<td>1102.5 ± 69.49</td>
<td>0.22 ± 0.06</td>
<td></td>
</tr>
</tbody>
</table>

### Table 1b. Mean (± SE) for palm cockatoo *Whistle A* calls for each individual across recording sessions†.

<table>
<thead>
<tr>
<th>Individual</th>
<th>Session</th>
<th>n</th>
<th>Length</th>
<th>Centre Time</th>
<th>IQR BW</th>
<th>Peak1 F.</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Male A</td>
<td>1</td>
<td>10</td>
<td>79.6 ± 1.34</td>
<td>0.16 ± 0.01</td>
<td>473.72 ± 71.78</td>
<td>3927.4 ± 39.77</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>6</td>
<td>64.67 ± 3.85**</td>
<td>0.15 ± 0.02</td>
<td>488.08 ± 108.19</td>
<td>4010.83 ± 60.43</td>
<td></td>
</tr>
<tr>
<td>Female C</td>
<td>1</td>
<td>10</td>
<td>---</td>
<td>---</td>
<td>574.22 ± 45.39</td>
<td>3963.22 ± 63.85</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>10</td>
<td>---</td>
<td>---</td>
<td>602.94 ± 57.42</td>
<td>3993.6 ± 97.34</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>10</td>
<td>---</td>
<td>---</td>
<td>654.62 ± 44.85</td>
<td>3981.6 ± 40.69</td>
<td></td>
</tr>
<tr>
<td>Female D</td>
<td>1</td>
<td>8</td>
<td>---</td>
<td>---</td>
<td>398.36 ± 51.31</td>
<td>3832.75 ± 34.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2‡</td>
<td>6</td>
<td>---</td>
<td>---</td>
<td>459.38 ± 114.85</td>
<td>4163.67 ± 62.02**</td>
<td></td>
</tr>
</tbody>
</table>

### Table 1c. Mean (± SE) for palm cockatoo *Whistle B* calls for each individual across recording sessions†.

<table>
<thead>
<tr>
<th>Individual</th>
<th>Session</th>
<th>n</th>
<th>Centre Time</th>
<th>IQR Dur.</th>
<th>Low F.</th>
<th>High F.</th>
<th>Max. Freq.</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Male H</td>
<td>1</td>
<td>10</td>
<td>0.14 ± 0.01</td>
<td>---</td>
<td>---</td>
<td>4239.54 ± 47.41</td>
<td>3186.9 ± 100.28</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>9</td>
<td>0.14 ± 0.02</td>
<td>---</td>
<td>---</td>
<td>4117.13 ± 69.55</td>
<td>2879.3 ± 243.51</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3‡</td>
<td>10</td>
<td>0.22 ± 0.02**</td>
<td>---</td>
<td>---</td>
<td>4343.95 ± 42</td>
<td>3178.3 ± 154.83</td>
<td></td>
</tr>
<tr>
<td>Female A</td>
<td>1</td>
<td>7</td>
<td>---</td>
<td>0.16 ± 0.03</td>
<td>1918.19 ± 85.31</td>
<td>4378.56 ± 64.24</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2‡</td>
<td>7</td>
<td>---</td>
<td>0.16 ± 0.03</td>
<td>1868.97 ± 44.16</td>
<td>4578.8 ± 26.48</td>
<td>---</td>
<td></td>
</tr>
</tbody>
</table>

†Comparisons using Mann-Whitney U-test were made between sessions 1 and 2 (significant differences marked in session 2) and sessions 2 and 3 (significant differences marked in session 3). * Indicates standard significance (p < 0.05). ** Indicates significance at corrected critical value. ‡ Indicates a recording session in 2010 (the second breeding season). All probabilities are for a two-tailed non-parametric test.
**Discussion**

I set out to determine whether calls from individual palm cockatoos can be used as a non-invasive method for identifying individuals. My results based on a limited sample over time indicate that call structure is not sufficiently stable to allow re-identification of individuals over multiple years. Thus, the vocal individuality (VI) technique described here may not be reliable to use for this species, although further research is required to confirm this. Several aspects of their vocal behaviour and breeding system further preclude the usefulness the VI used here for identifying individuals of this species. An alternative VI option is discussed in Chapter 5 (Discussion).

Each of the three call types used in this study had a similar identification accuracy to those found in other VI bird studies that used similar techniques (Hill and Lill, 1998; Hoodless et al., 2008; Policht et al., 2009; Rognan et al., 2009). Among all call types, overall identification accuracy ranged from 81.3%-95%. Inclusion of more individuals in the model resulted in a greater likelihood of overlap between some individuals in call structure (as indicated by the 95% confidence limits in the DFA). As such, the number of individuals in each call-type model in this study has likely influenced the differing identification accuracies between the call types. For example, the highest level of accuracy occurred in the model with the fewest number of individuals (**Whistle B**, 3 females, 95%). Combined with the fact that identification accuracies for different call types did not differ drastically, this means that I cannot say which call-type is most individually distinctive; rather, all three call types showed similar, high levels of individuality.

**Whistle A** was the most effective call used in this study for several reasons. It was useful for DFA because it was the most widely used call by individuals (meaning ample sample sizes were obtained), and although its call structure varied across individuals, it was still relatively
easy to distinguish from other call types. *Whistle A* occurs during most behavioural contexts (see Chapter 1), and is heard across its range on Cape York (unpublished data). As with contact calls of most vocal animals, including other parrots (e.g. Berg et al., 2011), palm cockatoo pairs appear to use this call for individual recognition from a distance (e.g. when a male or female of a pair approaches the nest to relieve the other of incubating duties (see Appendix I)). It may be particularly important for palm cockatoos to recognise the call of an incoming conspecific to the nest, given that Murphy et al. (2003) found that 13.8% of unsuccessful breeding attempts failed because the chick or egg was crushed (but left uneaten), apparently by other palm cockatoos. *Whistle B* also appears to be used as a contact call, but to a lesser extent than *Whistle A*, and it is never used to initiate contact (see Appendix I).

The ability to recognise each other’s calls is also likely to be important during dangerous territorial clashes, when visual inter-individual recognition may not be possible through the foliage or across distances. In this social context (‘call-exchange’ with intruders), the *Hello* call occurs more than any other call in this context (see Chapter 1). As such, although I could not test this directly, the *Hello* call appears to be used as a means to identify one another during such disputes over hollows, where four or more birds frequently fly between trees up to 50m away (pers. obs.). These disputes can lead to forceful, mid-air clashes, where two birds grab each other by their feet and fight, sometimes until they fall to the ground. Although females did not use the *Hello* call as much as males (they are overall less vocal than males), they still participated in simultaneous *Hello*-duets with their mate (see Chapter 1). Although females may show a high level of distinctiveness in the *Hello* call, they did not use this call enough to be included in this study. Males, on the other hand, use the *Hello* call during displays, and long recording sessions are needed to obtain a sufficient number of calls for analysis.
Before VI is used to identify individuals in a population, the vocal stability of individuals must first be assessed. Without this knowledge, calls recorded at a later date could easily be misattributed to the wrong individual. For example, the individual assignment accuracy of female begging calls of white-throated magpie-jays decreased over time, rendering the VI technique unsuitable for monitoring that species over time (Ellis, 2008). Similarly, when male loons changed territories, they changed their vocalisations to maximise differences between their yodels and those of their new neighbors (Walcott et al., 2006). In contrast, in a study of five captive eagle owls (*Bubo bubo*), there were no significant differences in call parameters measured from calls recorded two years apart, indicating vocal stability for those individuals (Lengagne, 2001). DFA results from palm cockatoos in this study indicated that vocalisations of individuals are not stable enough for them to be re-identified either within a breeding season or between breeding seasons (Figure 3.4). Mann-Whitney U-tests further revealed that different individuals were stable in different call parameters (Table 3.1a-c), meaning that different individuals changed their calls in different ways over time. I stress however the small sample sizes used in these analyses and the potential for single aberrant data points (e.g., distorted or low amplitude recordings) to skew the results towards significant differences.

Palm cockatoos, and males in particular, are very vocally active, in part making them a good candidate for vocal studies. In particular, the greater the number of calls per individual included in the DFA, the greater the accuracy potential it has to discriminate between individuals. However, I unexpectedly discovered that palm cockatoos have an extraordinarily large and complex vocal repertoire for a parrot (see Chapter 2). Although this was an exciting discovery, it unfortunately made it difficult to record enough calls of the same call-type to compare across different birds. For example, males are highly vocal during displays and may
produce 35 or more calls in 15 minutes, but they tend to cycle through their repertoire in this context (see Chapter 1), with each male favouring different call types (unpublished data). This is in contrast to birds that give calls in a series (i.e. repetitive calls in succession within a short time period), such as ‘chattering’ raptors (Falconiformes) (e.g. Eakle et al., 1989), ‘hootsing’ owls (Strigiformes) (e.g. Lengagne, 2001; Rognan et al., 2009), or ‘booming’ bitterns (Ciconiiformes) (e.g. Gilbert et al., 2002). Furthermore, whereas Wanker and Fischer (2001) collected 50 comparable calls per individual in another parrot, the spectacled parrotlet (Forpus conspicillatus) I often could only collect six comparable calls per individual.

One aspect of palm cockatoo breeding biology that was problematic for this study is that birds nest every other year on average (Murphy et al., 2003). Birds recorded in 2009 were not seen nesting in 2010 (which was expected), and activity was either completely absent or very infrequent at the same nesting hollows in 2010. The birds that were found at the same hollows in 2010 as in 2009 were for the most part not vocal, probably because they were not leading up to breeding. This made it exceedingly difficult to acquire recordings of the same birds between seasons for the vocal stability part of this study. So although I recorded as many calls as possible from the same birds between breeding seasons, I only acquired enough calls from three birds for between-year vocal stability tests (Table 3.1a-c).

Overall, the present study shows that palm cockatoos are individually distinctive in their call structure but suggests that individuals are not stable enough in their call structure to be re-identified over periods of time greater than one year. Furthermore, aspects of their vocal behaviour and breeding preclude the practicality of this VI technique as a non-invasive method to identify individuals of this species. Future studies could trial the recently developed call-independent VI technique (comparing similarly structured call types between individuals, rather than the exact same call types) (Cheng et al., 2010; Fox et al., 2008) for
palm cockatoos, or test another non-invasive alternative to traditional marking techniques (see Chapter 4).
References


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A frill-necked monarch (*Arses lorealis*) sits in its carefully designed nest, constructed in between two hanging vines in the rainforest near my study site. Photo by: George Gornacz.
Chapter Four

Preliminary evaluation of photo-identification of individual palm cockatoos (*Probosciger aterrimus*)

A male palm cockatoo eats the fruit of a beach almond tree, near Lockhart River. Photo by Roland Seitre.
Abstract

Photo-identification (photo-ID) is used as a viable alternative to traditional invasive capture techniques for many species. Here, I provide preliminary evaluation of photo-ID as a non-invasive technique for use with palm cockatoos by comparing facial profiles within a catalogue of presumed individuals and by creating a matrix table of identifiable features. Preliminary evaluation of photographed birds yielded seven males and six females tentatively identified. A sub-set of photographs could not be separated into individuals, mainly due to a lack of distinctive beak features, unclear (low-resolution) photographs, and insufficient number of photos of the bird. Taking photos of four presumed individual birds over two or three days revealed that re-identification might be possible. Future directions for photo-ID of palm cockatoos are discussed.
Introduction

Identification of individuals can provide useful information to guide management strategies for the conservation of a species. Individual-based data is useful for behavioural studies and is essential in studies of life-history traits (e.g. home-range size, nest-site fidelity, mortality, nest turn-over rate), which can be used for population viability studies. Traditionally, researchers capture animals to apply individual markings, such as leg-bands on birds, toe-clippings of frogs, tattoos on mammal ears, or shell-shaving on turtle scutes for later identification. However, naturally distinctive features can also be used to identify individuals at a distance. These include voice (for review, see Terry et al., 2005), scent (e.g. Jordan et al., 2011), feathers (e.g. Heinsohn et al., 2007), hair (e.g. Gervasi et al., 2010), faeces (e.g. Muschett et al., 2009), and/or morphology (e.g. Wursig and Jefferson, 1990).

Photo-identification (photo-ID, hereafter), or using photographs to identify individuals based on distinctive physical features, is widely used to identify individual animals (e.g. Ardovini et al., 2007; Buray et al., 2009; Kelly, 2001; Petersen, 1972; Sherley et al., 2010), and it is becoming increasingly effective due to availability of affordable, high-quality equipment. Plumage is the individually distinctive natural feature that is usually used to identify individual birds (e.g. Yellow-headed amazon *Amazona oratrix*, Schindlinger, 2009; African penguins, *Spheniscus demersus*, Sherley et al., 2010). This is mostly only possible within moulting periods because the feathers are replaced with new ones but is nonetheless sometimes possible across moulting periods. Some species’ individuals, however, can be identified via unique scars and patterns on the beak (e.g. Hyacinth macaws *Anodorhynchus hyacinthinus*, Munn, 2006). For further introduction of the photo-ID technique, see Chapter 1 (General Introduction).
Palm cockatoos (*Probosciger aterrimus*) are well-suited for a photo-ID study because they have a large (~10cm long) beak (Forshaw, 2010) that is not only easier to photograph than small beaks but also has more space for unique natural features to occur. In addition, individually distinctive wear-and-tear may occur from cracking hard seeds (e.g. *Pandanus* sp.), and males’ beaks may be subject to additional wear (and therefore possibly more unique features) than females because males use their large beak to fashion large (1") sticks from live tree branches multiple times a day to use as drum-tools during display (Murphy et al., 2003). Furthermore, unique scars might occur on males’ beaks due to territorial clashes, whereby males collide and sometimes wrestle mid-air (while falling) and sometimes continue fighting on the ground (pers. obs.). This chapter provides preliminary evaluation of the photo-ID technique as a non-invasive method to identify individual palm cockatoos.

**Methods**

For an introduction of the study species, see Chapter 1 (General Introduction).

*Field Methods*

After noticing individual differences between palm cockatoos in close-range photos, I conducted this preliminary study simultaneously with a vocal individuality study (Chapters 2 and 3). I aimed to have photos of both the left and right facial sides, but this was not possible for all individuals. Birds were initially photographed at rest, but in this position the lower beak (and sometimes lower cheek-feathers) obstructed the view of the inner shape of the upper mandible. Thus, I later aimed to have photos taken of birds when they were calling because this yielded a clearer profile image. To avoid the problem of identifiable features being mistaken for differences caused by different beak positions with respect to the camera, only certain photos were used when extracting information about the outline of the beak. I used photos where the bird’s head was in perfect, or near perfect, profile with respect to the camera (i.e. the plane of the head was horizontally and vertically at a 90° angle to the
camera). When extracting information about the surface of the beak (e.g. a divot, streaking), photos were only compared if both photographs showed clear visibility (i.e. sufficient light, no obstructions) of the area of interest.

Some birds were known to be distinct from other individuals because they were seen at the same time together (meaning that they could not be the same bird). A sub-set of birds were photographed at two additional sites located 40km and 80km away from the Iron Range study site. The identity of these birds was assumed to be different than the birds at Iron Range, and both additional sites were assumed to contain different individuals from one another. I believe that these assumptions are correct because palm cockatoos in these areas appear to be sedentary, and geographical variation in their calls (with respect to the other sites) was apparent (unpublished data).

To take photos, one of two cameras was used: 1) a Canon EOS 50D camera with a 100-400mm f4.5-5.6 L IS USM lens, or 2) a Nikon D200 camera with a 200-400 zoom lens with an extender. Photos were taken in Iron Range National Park and surrounding aboriginal freehold lands on Cape York Peninsula (far north QLD, 12° 47’S, 143° 18’E). Photos were taken in September, October, and November 2009, corresponding with the end of the dry season (June-Dec.). When birds near a nest appeared disturbed by the observer’s presence, the area was vacated to minimise disturbance.

**Photo Analysis**

Using Microsoft Office Picture Manager (Microsoft 2003), I cropped and rotated all images for a standardised comparison (see Fig. 4.1). I then organised photos into a catalogue of apparent individuals, using PowerPoint (Microsoft 2004, v.11.5.7), and made a matrix table of identifiable features between individuals (Table 4.1). For features that could be unique to only one side of the beak (e.g. divot, Female B, Fig. 4.1), I only treated it as a unique feature
when comparing same face-side in other birds. A sub-set of presumed individual birds (three males and one female) was photographed across two or three days in an attempt to test this method (Figure 4.2).
Results

Two photos each were acquired for 15 out of 32 face-sides (from an estimated 16 wild individuals). Using the catalogue of photographed individuals, I made a matrix of identifiable features of individuals in Table 4.1 (Karczmarski and Cockcroft, 1998). With this, I was able to tentatively identify at least seven males and at most nine males (Male O and Male K may be the same individual) and 6 females. A sub-set of these individuals was photographed across two or three days and appeared to be successfully re-identified (Figure 4.2). An estimated 11 individuals could not be identified for reasons listed in Table 4.2.

Figure 4.2. Palm cockatoos can use their lower cheek feathers to partially cover the red cheek, which also partially covers their beak.
Table 4.1. Matrix of natural features of a probable 15-16 palm cockatoos (plus one captive bird).

<table>
<thead>
<tr>
<th>Location of bird</th>
<th>Sex</th>
<th>Lower knob on upper beak</th>
<th>Outer angle on upper beak</th>
<th>Inner angle on upper beak</th>
<th>Lower beak streaks</th>
<th>Other marks</th>
<th>Specific association with...</th>
<th>Remarks and idiosyncrasies</th>
<th>Probable ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conflict Hlw</td>
<td>M</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>---</td>
<td>---</td>
<td>Female A</td>
<td>one broad notch on lower beak</td>
<td>Male A</td>
</tr>
<tr>
<td>Conflict Hlw</td>
<td>F</td>
<td>yes</td>
<td>---</td>
<td>yes</td>
<td>no</td>
<td>yes</td>
<td>Male A</td>
<td>white spots on right red patch (may or may not be permanent)</td>
<td>Female A</td>
</tr>
<tr>
<td>Dunny Hlw</td>
<td>F</td>
<td>yes</td>
<td>no</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>Male C</td>
<td>lower beak streaks not prominent</td>
<td>Female C</td>
</tr>
<tr>
<td>Dunny Hlw</td>
<td>M</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>no</td>
<td>Female C</td>
<td>prominent streaks on lower beak (drums frequently; rarely seen with a female; frequently uses Double Whistle)</td>
<td>Male C</td>
</tr>
<tr>
<td>Hypodermic Hlw</td>
<td>M</td>
<td>yes</td>
<td>---</td>
<td>no</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>only small outer angle on upper beak</td>
<td>Male H</td>
</tr>
<tr>
<td>Lockhart feeding 1</td>
<td>F</td>
<td>no</td>
<td>yes</td>
<td>no</td>
<td>yes</td>
<td>no</td>
<td>Male A white spots on right red patch (may or not be permanent)</td>
<td>Female G</td>
<td></td>
</tr>
<tr>
<td>Lockhart feeding 2</td>
<td>F</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>Female F</td>
<td>cheek indented when beak open; prominent outer beak angle; streaks not prominent on lower beak</td>
<td>Female F</td>
</tr>
<tr>
<td>Moreton Telegr.</td>
<td>M</td>
<td>yes</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>---</td>
<td>---</td>
<td>shallow knob is pointed, not rounded</td>
<td>Male L</td>
</tr>
<tr>
<td>Moreton Telegr.</td>
<td>M</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>---</td>
<td>---</td>
<td>1/2 of beak unsmooth on left side; cataracts on eyes; upper knob rounded</td>
<td>Male K (?)</td>
</tr>
<tr>
<td>Moreton Telegr.</td>
<td>M</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>---</td>
<td>---</td>
<td>may be Male K (only have photo of right side)</td>
<td>Male O (?)</td>
</tr>
<tr>
<td>Moreton Telegr.</td>
<td>F</td>
<td>no</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>prominent upper knob</td>
<td>Female E</td>
</tr>
<tr>
<td>Moreton Telegr.</td>
<td>unk.</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>---</td>
<td>white patch on lower part of upper beak (juvenile morphology); one prominent streak</td>
<td>Juvenile A</td>
</tr>
<tr>
<td>Sewerage Pond Hlw</td>
<td>M</td>
<td>yes</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>---</td>
<td>Female B</td>
<td>white blotch on right lower beak- probably residual food</td>
<td>Male B</td>
</tr>
<tr>
<td>Sewerage Pond Hlw</td>
<td>F</td>
<td>no</td>
<td>yes</td>
<td>no</td>
<td>yes</td>
<td>---</td>
<td>Male B</td>
<td>divot on upper left side of top beak</td>
<td>Female B</td>
</tr>
<tr>
<td>Sewerage Pond Hlw</td>
<td>M</td>
<td>no</td>
<td>yes</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>Male B competing outer and inner angles are very slight</td>
<td>Male S</td>
<td></td>
</tr>
<tr>
<td>near Sewerage P.</td>
<td>M</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>Male B w/ B</td>
<td>straight section on inner upper beak, below upper knob</td>
<td>Male R</td>
</tr>
<tr>
<td>Zoo in Adelaide</td>
<td>M</td>
<td>no</td>
<td>yes</td>
<td>---</td>
<td>yes</td>
<td>---</td>
<td>---</td>
<td>prominent upper knob; angle on upper beak</td>
<td>Male P</td>
</tr>
</tbody>
</table>

--- Means unable to be assessed.
Figure 4.1. Terms used and natural features of likely one juvenile (j), 6-7 male (m), and four female (f) palm cockatoos. Male P is a captive bird.
Table 4.2. Reasons why some birds could not be identified by photo-ID

<table>
<thead>
<tr>
<th>Location of bird</th>
<th>Sex</th>
<th>No distinct beak features</th>
<th>Unclear photo</th>
<th>Wrong angle</th>
<th>Food obstruction</th>
<th>Feather covering*</th>
<th>Not enough photos</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moreton Telegr.</td>
<td>M</td>
<td>yes</td>
<td>---</td>
<td>yes</td>
<td>---</td>
<td>---</td>
<td>yes</td>
</tr>
<tr>
<td>Moreton Telegr.</td>
<td>M</td>
<td>yes</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>yes</td>
</tr>
<tr>
<td>Moreton Telegr.</td>
<td>F</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Moreton Telegr.</td>
<td>F</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>yes</td>
<td>---</td>
</tr>
<tr>
<td>Pascoe River Farm</td>
<td>F</td>
<td>yes</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Pascoe River Farm</td>
<td>F</td>
<td>---</td>
<td>yes</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>yes</td>
</tr>
<tr>
<td>Pascoe River Farm</td>
<td>unk.</td>
<td>---</td>
<td>yes</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Pascoe River Farm</td>
<td>M</td>
<td>yes</td>
<td>---</td>
<td>yes</td>
<td>yes</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Gadget Creek</td>
<td>M</td>
<td>---</td>
<td>yes</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>yes</td>
</tr>
<tr>
<td>Gadget Creek</td>
<td>M</td>
<td>---</td>
<td>yes</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>yes</td>
</tr>
<tr>
<td>Gadget Creek</td>
<td>F</td>
<td>yes</td>
<td>yes</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Relief Creek</td>
<td>F</td>
<td>yes</td>
<td>yes</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*birds move their lower cheek feathers upwards to cover their red cheek during times of uncertainty or fear (see Figure 4.2).
Figure 4.2. Four presumed individuals (three males and one female) appear to be re-identifiable using natural features (where arrows point). Identifiable features: Male R, straight portion; Male A: no large notches on lower beak edge; Male B, one broad notch on lower beak edge; Female A, divot.
**Discussion**

This study is a preliminary analysis of the photo-identification technique for palm cockatoos. I was able to tentatively identify seven males and six females out of 20-26 presumed individuals. For the sub-set of photographs that could not be separated into individuals, the main cause was a no distinct beak features, followed by unclear photographs, then not enough photographs (Table 4.2). Photographs of a presumed four birds (three males, one female) across two or three days indicated that this technique might allow for re-identification of individuals based on natural features (Figure 4.2).

Most other photo-ID studies used 3-4 photographs per individual (e.g. Van Tienhoven et al., 2007) and rarely is one photo used (Currey et al., 2008). I aimed to acquire two images per face-side per individual, but this was only achieved for 15 out of 32 face-sides (from 16 wild individuals, Table 4.1). Having both sides photographed is especially important when it is likely that an identifiable feature only occurs on one face-side (e.g. divot, Female A; single linear streaking, Male K), as opposed to when the identifiable feature is likely to be the same for both face-sides (e.g. straight portion on the upper beak, Male R; outer angle, Female F).

Some birds did not have distinct beak features, having the common shape of one steep inner knob mid-way up the beak (e.g. Male R, Fig. 4.1). Furthermore, although males had either one or two knobs on the inner upper beak, all females had only one knob. As such, without a matrix of identifiable features, many of these birds could not have been tentatively identified. For example, although Male A and Male B both have a steep upper knob as well as a shallow lower knob, Male B has a broad notch on at least the left side of his lower beak, which is lacking in Male A. Despite common beak shapes however, a more powerful lens and higher quality camera would likely accommodate an even larger library of individuals by capturing more of the subtle differences (e.g. thin, white marbled lines on the beak, lower beak
streaking pattern, relative depth and position of knobs) between individuals. However, these features are more likely to change than large, obvious ones, so caution should be taken as to the long-term stability of these features (See *Morphological stability* section).

Although this study focused on the upper beak, a higher quality camera/lens and more photos (to account for low-quality photos (e.g. wrong orientation of bird to camera, feathers covering lower beak, blurry photo)) may reveal further unique attributes of the lower beak. Also helpful would be a high-powered telephoto lens to acquire good-quality photographs from a distance. Palm cockatoos at Iron Range, Queensland are very alert and wary of people, sometimes being flushed from even 50m away, so a large lens is particularly important for this species. Lastly, the ideal opportunity to photograph palm cockatoos is when the birds feed on the ground on fallen fruits/nuts because this is when the photographer can be closest to them (e.g. Munn, 2006). I found the best chance at not flushing the birds was to be positioned at their nest or display hollow before they returned.

*Photo-ID used for other bird species*  
Opportunistic identification of individual birds is sometimes possible when feather patterns are individually distinctive during moult, but this usually only provides a short-term means of identification. Long-term identification has been possible with large, rainforest-dwelling red-and-green macaws (*Ara chloroptera*), in southeastern Peru. This was based on individually distinctive red feather-line patterns across their otherwise white featherless cheek, as well as marks and irregularities on the large upper beak (Munn, 1992). [Other macaws (*Ara spp.*) have also been identified in this way (pers. comm., J. Gilardi)]. In this study, 332 unique face sides were estimated to correspond to between 241 and 282 individuals. This technique was used to determine the rate at which individuals visit clay-licks, and population density estimates were generated via capture-recapture techniques (Munn, 1992).
One-hundred and twenty-one individuals were identified in a similar way using irregularities in the beaks of hyacinth macaws (*Anodorhynchus hyacinthinus*), which was apparently ‘always easy when the photos were of sufficient quality’ (Munn, 2006). Sherley et al. (2010) used motion-censored cameras to capture the individualistic, permanent spots on the breasts of African penguins *Spheniscus demersus*. In combination with a fully-automated computer system, this study was able to correctly identify 96.7% of over 73,000 individuals and to monitor the population with minimum disturbance and with minimum time and effort cost (Sherley et al., 2010).

*Morphological stability*

Behavioural studies often require proof of individual identity (e.g. numbered or coloured leg bands in birds). One challenge to identify individuals by using naturally occurring features as opposed to applying man-made features like leg-bands is that the individual features on animals may change over time. For example, because the trailing edge of dolphin fins is thin and does not regenerate, it can tatter and change its shape over time (e.g. Karczmarski and Cockcroft, 1998). As such, the long-term stability of individual morphological features must be addressed to determine the reliability of photo-ID for each species. (I term this ‘morphological stability’). With cetaceans, the issue of morphological stability has been addressed by regular sampling of individuals to track shape changes on the edge of the fin and update the library of identifiable features for individuals. During a study of free-ranging bottlenose and humpback dolphins, Karczmarski & Cockcroft (1998) used is a matrix of identifiable features to assist this process, whereby additional features were used to confirm identity, despite one feature being changed. In a photo-ID study of hyacinth macaws, E. Gonclaves took new photographs of an accessible sub-set of birds every 2-4 weeks to track the gradual changes in their beaks throughout the year (Munn, 2006).
Assessing the extent of morphological stability in palm cockatoo beaks was beyond the scope of this study. However, beaks do grow, albeit slowly, so any irregularities on the surface of the beak will move downward over time. Furthermore, their beak is used to crack open hard seeds such as *Pandanus* spp. and beach almond trees *Terminalia* sp., so the inner edge of the upper and lower beak may be subject to change from wear-and-tear, as well as from new injuries. I would expect more wear-and-tear to occur with male beaks than female beaks because males fashion drum-tools as wide as 1” from the branches of live trees for drumming displays as often as twice or more times per day. Captive birds can provide insight to assess this change by acquiring photographs of the same individuals over time. A photo comparison of a captive hyacinth macaw (photo not included due to copyright issues) revealed this bird’s upper beak grew ~5-7mm in 7 ½ months, but the lower beak did not change noticeably. In this bird, the surface features of the upper beak moved downward but remained largely intact.

The smaller the natural unique features being assessed to identify a bird, the more easy it is for the feature to go unnoticed if it changes over time.

**Computer-assisted photo-ID**

Early stages of photo-ID in cetaceans used observers to categorise photos into individuals (e.g. Bigg, 1982), but this manual method becomes more time consuming and error-prone as the number of individuals increase. Even identifying as few as 50 individual dolphins required taking and sorting through more than 15,000 photos (Wursig and Wursig, 1977). To help manage high quantities of photos, especially with large sample sizes of individuals (e.g. >400), computer-assisted photo-ID technology has been used as early as 13 years ago (Huele and De Haes, 1998). Over time, new computer programs have reduced the processing time of each photo (e.g. Kehtarnavaz et al., 2003) and probably increased the accuracy of identification as well. There are two main tasks accomplished by computer programs: 1) to digitally define individual differences (e.g. scars on a surface, notches on an edge, colour
patterns on a surface), and 2) matching query images to the best-matched image from a library of photographed individuals.

Multiple studies use computer programs to digitally define an edge (e.g. dorsal fin of a dolphin; flipper of a seal) for automatic comparison of individuals (Araabi et al., 2000; Huele and De Haes, 1998; Kehtarnavaz et al., 2003). Other programs detect colour patches (Cunningham, 2009; Gope and Kehtarnavaz, 2007; Kehtarnavaz et al., 2003; Rosso et al., 2008). Likewise, Van Tienhoven (2007) created a database of 221 spotted raggedtooth sharks (Carcharias taurus) by comparing the relative locations of unique colour patterns to three standard reference points on all sharks. In addition, individually distinctive locations and total area of colour patterns on New Zealand bottlenose dolphins (Tursiops truncates) have been quantified by manually and digitally tracing on top of black and white photos taken by laser photogrammetry (the use of two parallel lasers that project dots a known distance apart onto the object being photographed) (Currey et al., 2008).

While a computer program does not yet exist to assist with photo-ID of palm cockatoos, there is certainly potential for it. For example, from inspection of hundreds of up-close photos of palm cockatoos, I have noticed individual differences in the relative location of steep and shallow knobs on the inner upper beak. If this difference was quantified, it could add another column in the matrix of identifiable features of individuals. One possible way to quantify this feature is to calculate a ratio based on the relative positions of the two largest notches, which for dolphins is called ‘dorsal fin ratio’ (Defran et al., 1990). Because it is a ratio, rather than an actual measurement, the calculation is unaffected by the size of the subject in the image. A similar technique could work for the beak of palm cockatoos (Fig. 4.4).
Figure 4.4. Analogous comparison of the ‘Dorsal Fin Ratio’ to the potential ‘Beak Ratio’ in palm cockatoos. Left image from (Karczmarski and Cockcroft, 1998).

Of at least 14 different computer-assisted photo-ID programs in the literature, Fluke Matcher (Kniest et al., 2009) appears to have the best potential to enhance photo-ID of palm cockatoos (and probably other parrots too). This program (available at http://www.scu.edu.au/research/whales/fluke-matcher/index.php/3/) was originally designed for humpback whales (Megaptera novaeangliae) but cannot yet accommodate other taxa (pers. comm., E. Kniest). This program accounts for a wide range of features and unique properties in individuals (e.g. for palm cockatoos: inner beak edge, marbled line patterns, dots, divots, etc), which can be weighted based on how obvious the features are. This means that the program has a flexible searching procedure that will be more effective at searching for query images. In addition, this program can use photos of whale that are rotated (with respect to the camera) or partially underwater, so it may not be a problem to use photos of bird that are rotated or have their lower facial feathers covering part of their beak (Fig. 4.2).

Overall, the study presented here illustrates a promising potential for photo-ID to be used to identify individual palm cockatoos. Future photo-ID studies of palm cockatoos should use a better camera/lens and trial a computer program so as to quantify more individually distinctive features and to digitally compare images of individuals.
References


The most amazing shape I’ve seen in nature: presumably, the beginning stage of a small spider’s web (species unk.) in the Amazon rainforest of Peru. Photo by: Christina Zdenek.
Chapter Five

General Discussion

Christina Zdenek takes notes during fieldwork. Photo by: Roland Seitre.
In this thesis, I set out to determine if non-invasive techniques could reliably be used to identify individual wild palm cockatoos for the purpose of conservation and future studies of this iconic species. I primarily trialled vocal individuality (Chapter 3) and secondarily carried out a preliminary evaluation of photo-identification (Chapter 4). To carry out the VI study, the first step was to define the vocal repertoire of palm cockatoos, which I unexpectedly found to be more complex and extensive than most Psittacine species (Appendix I). The VI study showed that, although palm cockatoos are individually distinctive in vocal features of their calls, preliminary tests of vocal stability suggests that vocalisations are not stable over time. Although sample sizes for vocal stability were small, they nonetheless suggest that this technique is not reliable for this species. Furthermore, various aspects of their vocal and breeding behaviour precluded the practicality of using the VI technique for palm cockatoos (but see ‘VI alternative’ below). Photo-ID, however, showed promising prospects for identification of individuals and warrants further exploration.

**VI alternative**

Despite the impracticality of the VI technique for palm cockatoos, using recorded calls to identify individuals may still be a viable option by using a different, though similar, technique. The present study used a call-dependent VI technique (terminology used by Fox et al., 2008), meaning that determining the identity of individuals requires comparisons of the same call or song type across individuals. For species with large vocal repertoires, this aspect drastically limits the number of calls available for comparison across individuals and was, as such, one of the major limitations encountered in this study (see Chapter 3 ‘Discussion’). However, an alternative technique, called call-independent VI, can compare similar call or song types between individuals to determine individuality. This seemingly slight adjustment

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3 VI: using an individual’s vocal features for their identification.
4 Photo-ID: using photographs of an individual’s natural body features for their identification.
5 The consistency in a bird’s call structure over time.
to the technique makes a profound difference by greatly increasing the sample size of available calls to compare between individuals. Unfortunately, because this technique requires a completely different statistical analysis than was performed in this study, it was out of the scope of this study.

This new call-independent VI technique, first developed by Fox et al. (2008), utilises a human-speaker recognition technology (adjusted to account for field recordings of varying quality) to identify individuals based on the source-filter model. This model singles out individually distinctive mechanisms of vocal production (the ‘filter’ e.g. syrinx, tongue, bill), rather than measurements that account for the spectrographic contour of the signal (‘the source’ i.e. shape of the call). Using a MAT-lab based computer program developed by Fox et al. (2006), the identification accuracies in this study ranged from 69.3% to 97.1% for seven individuals from each of three passerine species: willie wagtails *Rhipidura leucophrys*, singing honeyeaters (*Lichenostomus virescens*), and common canaries (*Serinus canaria*). Another study, using similar techniques on Norwegian ortolan buntings (*Emberiza hortulana*), had identification accuracies ranging from 76.2% to 98.7% for 5-38 individuals (Trawicki et al., 2005). A recent study is also very promising for its application for other species: Cheng et al. (2010) used mel-frequency cepstral coefficients and Gaussian mixture models on four passerine species and found call-independent identification accuracies ranging from 89.1-92.5%.

Call-independent VI has three major benefits over call-dependent VI: 1) an individual’s identity can be known over time, regardless of whether the bird changes its repertoire, and 2) different individuals can be compared regardless of whether they share calls, making it much easier to acquire sufficient call sample sizes to compare between individuals (as mentioned above), and 3) time would be saved by not having to categorise calls into different call-types.
With regards to the first point, palm cockatoos appeared to be vocally unstable over time (Chapter 3). Call-independent VI could circumvent this limitation, if vocal instability reflects changes to call structure, but not if it reflects alterations to an individual’s voice, such as changes in pitch with age. With regards to the third point, categorising palm cockatoo calls into discrete syllables took a remarkably substantial amount of time, even requiring a systematic naming and organising system (see Chapter 1 and Appendix I). This process can be difficult for parrots in particular. For example, even after six years of studying the Galah, Rowley (1990) still found it difficult to determine the number of call-types in their repertoire because the calls ‘seemed to belong to a graded series.’ Venuto et al. (2001) also had difficulty in classifying calls of the African parrot (*Poicephalus ssp.*) because the calls appeared to have many structural variants, noting that classification would possibly be subjective.

In theory, the call-independent VI technique should be applicable to birds that have similarly structured calls (E. Fox, pers. comm.), but her technique has yet to be confirmed for any species beyond her study. The structural variation of palm cockatoo vocalizations may prove particularly challenging for the call-independent VI technique because the vocal mechanisms of production of the pure tone whistles are likely to be quite different from those that produce harsh, broad band notes. However, I believe that ample sample sizes, well beyond what was possible with the technique used in this study, can be achieved by using pure tone whistles only (e.g. l-q, Fig. 2.1, Chapter 2).

*Photo-ID*

A detailed comparison between the call-independent version of VI and photo-ID cannot be made because the former was beyond the scope of this Masters thesis. Broadly speaking, however, any version of the VI technique would have to be carried out mainly by researchers
due to the technical sound analysis aspect, which also requires a computer program not typically owned by lay-people. Photo-ID, on the other hand, requires a much more common skill (photography) and computer program (any basic photo-editing program) that lends itself for public involvement. For example, people could be encouraged to submit their high-quality, profile photos of palm cockatoos so as to acquire more data than would otherwise be possible. More than a larger sample-size, a backlog of years-past photos could even possibly be used to determine age and long-term dispersal/movements of some birds, if the same birds were photographed during the study and the identifiable features were distinctive enough. This would be of particular value because only an estimate exists for the life expectancy of wild palm cockatoos (40-60yrs), and this life-history trait is pivotal for population viability studies and determining the conservation status of this species. Also, age could be determined without having to wait that amount of time in years. Therefore, more public awareness and involvement could take place with the photo-ID technique, as opposed to VI, and therefore can be a more valuable research tool in the future.

The photo-ID technique is not without considerable challenges. With palm cockatoos, it is difficult to get close enough to the birds for up-close photographs that show the level of detail required for individual identification; their shy, alert, and elusive nature leads them to flush easily, even from a distance of 50m. Future photo-ID studies on palm cockatoos should therefore incorporate the use of a hide or multiple hides, which would likely result in more high-quality photographs of the birds because it would allow for closer photographs without flushing the birds. This would also probably lead to less feather-covering of the beak (see Fig. 4.2) and therefore greater sample sizes of usable photos.

Another challenge is sorting through and organising hundreds of photos, which can be a pain-staking and error-prone process. These difficulties can, in part, be ameliorated by the use of
computer-assisted photo-ID technology (for further discussion, see *Computer-assisted photo-ID*, Chapter 4).

Regarding a photo-ID study of hyacinth macaws, Munn suggests for an accessible subset of birds be photographed every 2-4 weeks to track the gradual morphological changes to the beak (Munn, 2006). Such a study for wild palm cockatoos should occur before the photo-ID technique is used for both long-term studies and studies involving a backlog of years-past photos. A similar pilot study can be performed on captive individuals, but the type, intensity, and frequency of physical changes to the beak likely varies from captivity to the wild due to differing diet and behaviour, thereby possibly limiting or undermining the benefit of a captive-bird study.

*Weather consideration for future vocal studies*

Regardless of which VI technique is used, recording vocalisations can only occur in fine weather, when there is no rain and little or no wind. Current recording equipment is not waterproof and wind adds white noise to recordings. More importantly, however, is that birds, including palm cockatoos (pers. obs.) are typically less vocal (or not vocal at all) during rainy and windy conditions. For example, I made more than four times more vocal recordings during the 2009 field season compared to the 2010 season, when there were unusually high levels of rainfall (Bureau of Meteorology, 2010). As such, the future weather prediction (due to climate change) of a region is a logistical factor that should be considered in the cost/benefit analysis of applying the VI technique for a species. Although there are no climate predictions made for the study area in particular, climate predictions for Darwin, Australia—an area with similar latitude and climate as the study area—indicate less rain during the dry season in the future (Guillaume et al., 2010). If this prediction holds true for the study area, the change in weather patterns for the study area will favour future VI studies on palm cockatoos on Cape York Peninsula.
Conservation implications

Vocalisations play a major role in animal behaviour, particularly for birds, having proved important in parent-offspring recognition (Jouventin et al., 1999; Lengagne et al., 2001; Taylor and Perrin, 2008), territorial defense (Catchpole, 1983; Hasselquist, 1998; Ward and Schlossberg, 2004), mate-attraction (Catchpole, 1983; Nowicki et al., 1998; Nowicki et al., 2002), female stimulation into reproductive condition (Kroodsma, 1976b), flock maintenance (Balsby and Bradbury, 2009; Scarl and Bradbury, 2009), alerting con-specifics of predators (Leavesley and Magrath, 2005), and neighbour and mate recognition (Bee and Gerhardt, 2001; Kroodsma, 1976a).

The current study has provided important insight into the previously unstudied vocal behaviour of palm cockatoos (Chapter 2 and Appendix 1). This has conservation implications because, for example, *Excited Whistle, Slide Whistle, Double Whistle*, and *Trisyllabic Whistle* were only recorded during display and call-exchange, when birds were almost always near a nesting or display hollow. As such, the presence of these calls in an area can be used as a quick proxy for identifying areas of special importance for palm cockatoos. In particular, this relatively quick method could prove helpful for biological consultant work during development applications. Understanding this vocal behaviour is especially relevant for conservation because 1) high-quality nesting hollows appear to be limiting (Murphy et al., 2003), 2) a changed fire ecology in the region (Russell-Smith et al., 2004) has led to a loss of woodland pockets (as ascertained from WWII aerial photos), as well as the nesting trees that used to occur there (pers. comm. Daryn Storch), and 3) nests are difficult to find (pers. obs.; pers. comm.: D. Storch, R. Heinsohn, and S. Murphy).

Understanding the function of their vocalisations is also important for conservation of this species. Along with anecdotal evidence, their vocal behaviour of vocal duets and combining
syllables during display suggests that these birds may exhibit year-round territoriality (see Chapter 2). Having this in mind should steer the direction future studies, such as the use of playbacks to test the extent of this behaviour and the size of their territories, the latter of which would be important for drawing land-protection boundaries and for any future relocation studies.

Conclusion

Compared to physically capturing individuals to mark them for subsequent re-identification, non-invasive techniques may provide a more feasible means of identification in many species (e.g. Cunningham, 2009; Gilkinson et al., 2006; Gope et al., 2005; Schofield et al., 2008; Sherley et al., 2010). A non-invasive method of identifying individual palm cockatoos would transform research on this species, allowing for long-term monitoring that has previously been impossible. Although this study has shown that the traditional vocal individuality technique is unlikely to be feasible for palm cockatoos (though a newer technique may be), photo-ID has potential and should be studied further to enhance future studies and conservation of palm cockatoos.
References


MUNN, C. A. 2006. Turn the other cheek: Hyacinth photo ID's are revealing. Psittacine. World Parrot Trust.


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A palm cockatoo pair inspect a hollow, in parallel. Photo by: Dean Portelli (at CNZ’s study site.)
Appendix One

Verbal description of all recorded palm cockatoo vocalisations

My means of transportation for the 2009 (top) and the 2010 field seasons (bottom).
<table>
<thead>
<tr>
<th>Call</th>
<th>Syllables</th>
<th>Behavioural Categories*</th>
<th># Sites</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whistle A</td>
<td>1</td>
<td>5/5; only females used it in flight</td>
<td>7/7</td>
<td>Given by both sexes. Most widespread and frequent call. Given either alone, with <em>Chuh Intro</em>, or as a syllable in other vocalisations. Sounds similar to Wh. B and Wh. C. Given alone or with <em>Chuh Intro</em>. Only other call besides <em>Flight Wh.</em> given in flight. Previously described as <em>whee-ooo</em> (Frith and Frith, 1993); also called <em>Disyllabic Whistle</em> (Forshaw, 1991), as in containing 2 syllables (the first syllable would have been the <em>Chuh Intro</em>). Appears to be the principle contact call.</td>
</tr>
<tr>
<td>Whistle B</td>
<td>1</td>
<td>4/5: not in flight.</td>
<td>6/7</td>
<td>Given by both sexes. Widespread and frequently given; particularly common during nesting. Typically the next call given after <em>Whistle A</em> during call sessions. Given alone or following <em>Chuh Intro, Donkey Intro,</em> or <em>Er-Crack.</em> Previously described as a ‘variant’ to Wh. A (Higgins, 1999). Males did not use it during solo call-bout. Sounds similar to Wh. A and Wh. C. Appears to be a contact call.</td>
</tr>
<tr>
<td>Whistle C</td>
<td>1</td>
<td>3/5: vocal-exchange, display, nesting</td>
<td>4/7</td>
<td>Given by both sexes. Usually given later on in a call session. Given infrequently. Sounds similar to Wh. A and Wh. C. The second loudest-sounding call. Given alone or with <em>Chuh Intro</em>. Appears to indicate elevated excitement.</td>
</tr>
<tr>
<td>Hello</td>
<td>2: Hello a + Hello b</td>
<td>3/5: vocal-exchange, display, solo call-bout</td>
<td>6/7</td>
<td>Given by both sexes, and particularly common during vocal-exchange and display. Sounds dissimilar to all other calls. Frequent given and widespread. <em>Hello b</em> occasionally stands alone, but <em>Hello a</em> never stands alone. Possibly a mimic call of the Spotted Catbird (also in study area) (Forshaw 1964). During vocal-exchange, occasionally given in immediate succession by 2-3 birds. Occasionally functions as a simultaneous duet between a male and female of a pair during vocal-exchange. On one occasion, recorded from a female when she re-joined her mate (who was in the hollow), just after she chased off an intruder from the hollow’s edge.</td>
</tr>
<tr>
<td>Flight Whistle</td>
<td>3–4: mult. <em>Chuh Intro + Flight syllable</em></td>
<td>1/5: flight</td>
<td>6/7</td>
<td>Given by both sexes, exclusively during flight, but not during every flight. Often given in the first few seconds of flight, and can be given up to four times during one flight, but not consecutively. Sounds dissimilar to all other calls. Given simultaneously with other birds when they all takeoff together.</td>
</tr>
<tr>
<td>Excited Whistle</td>
<td>3: Split a + Slide B + Wh. A</td>
<td>2/5: vocal-exchange, display</td>
<td>3/7</td>
<td>Recorded from males only, and only during vocal-exchange and display. Sounds most similar to <em>Double Wh. C</em> (with <em>Slide A</em>), but still easily discernable. Appears to indicate excited moods; hence its name.</td>
</tr>
<tr>
<td>Er-Crack</td>
<td>1</td>
<td>3/5: vocal-exchange, display, solo call-bout</td>
<td>6/7</td>
<td>Given by both sexes and mainly during vocal exchange. Frequently given and widespread. On two occasions was used as an intro syllable to Wh. B. Particularly common in solo call-bouts.</td>
</tr>
<tr>
<td>Donkey Intro</td>
<td>1</td>
<td>4/5: all except flight</td>
<td>5/7</td>
<td>Recorded from males only and mostly during display. Sounds dissimilar to all other calls. Infrequently given but widespread. Always occurs as an intro syllable to other calls, mainly Wh. B (but also Wh. A, <em>Descending Wh.</em>, or <em>w</em>). Sounds very similar to the first syllable of a typical donkey vocalisation, hence the name.</td>
</tr>
<tr>
<td>Magnificent Riflebird Whistle</td>
<td>1</td>
<td>3/5: vocal-exchange, display, solo call-bout</td>
<td>3/7</td>
<td>Given by both sexes, but mainly by females in solo call-bout. Sounds dissimilar to all other calls and remarkably similar to the Magnificent Riflebird (commonly heard in the study area). Not frequently given and not very widespread. Never used in combination with other syllables.</td>
</tr>
<tr>
<td>Slide Whistle</td>
<td>4: Slide Intro + Split a + Slide A + Wh. A</td>
<td>3/5: vocal-exchange, display</td>
<td>3/7</td>
<td>Given by both sexes, but mainly by males. Only occurs during vocal-exchange and display. The longest continuous call given. <em>Slide Intro</em> never occurs elsewhere and always serves as the beginning syllable for this call. The final three syllables are sometimes given independently of <em>Slide Intro as Double Wh. B.</em> (with <em>Slide A</em>).</td>
</tr>
<tr>
<td>Trisyllabic Whistle</td>
<td>3: Trisyll. a + Slide A + Wh. A</td>
<td>2/5: vocal-exchange, display</td>
<td>2/7</td>
<td>Recorded from males only and only in display and vocal-exchange. The first two elements make up <em>Trisyll. a.</em></td>
</tr>
<tr>
<td>Call Type</td>
<td>Context</td>
<td>Duration</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>----------------</td>
<td>---------</td>
<td>----------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Double Whistle</td>
<td>1 (two elements)</td>
<td>2/5: vocal-exchange, display</td>
<td>Recorded from males only. Contains two elements that are nearly identical; hence its name. Frequency use appears to vary greatly among individuals. Appears to be indicative of display-type activities.</td>
<td></td>
</tr>
<tr>
<td>Chuh Intro</td>
<td>1</td>
<td>5/5</td>
<td>7/7 Given by both sexes. Used as a quick introductory syllable to the majority of calls the majority of time. Can be given alone, where it has previously been described a 'soft clicks' (see Higgins 1999). On rare occasions, given after Donkey Intro, as a second introductory syllable.</td>
<td></td>
</tr>
<tr>
<td>Crack</td>
<td>1</td>
<td>5/5</td>
<td>7/7 Given frequently by both sexes. Often used in succession (consecutive Crack) during conflict or as an alarm call.</td>
<td></td>
</tr>
<tr>
<td>Double Whistle B</td>
<td>2-3: Split a + (Slide A) + w or Wh. A</td>
<td>---</td>
<td>2/7 Given by both sexes. Sounds similar to Double Whistle, but structurally very different; also contains syllables, unlike Double Whistle. Sometimes contains Slide A between the two syllables.</td>
<td></td>
</tr>
<tr>
<td>Double Whistle C</td>
<td>2-3: x + (Slide A) + w or z</td>
<td>---</td>
<td>5/7 Given by both sexes. Sounds similar to Double Whistle, but structurally very different; also contains discretely different syllables than Double Whistle. Sometimes contains Slide A.</td>
<td></td>
</tr>
<tr>
<td>Split Whistle</td>
<td>2: Split a + Split b or z or y</td>
<td>---</td>
<td>5/7 Given by both sexes. Always contains two syllables, with the second syllable being variable.</td>
<td></td>
</tr>
<tr>
<td>Ascending Ear-clencher</td>
<td>1 (two elements)</td>
<td>---</td>
<td>2/7 Given by both sexes. Second element is a pure-tone whistle. Call sounds dissimilar to all other calls; the loudest-sounding (i.e. highest amplitude) call. Besides Donkey Intro and both chick vocalisations, only call with a pure-tone (mono-tone) syllable. The first element ascends in frequency with time, hence the name.</td>
<td></td>
</tr>
<tr>
<td>Descending Whistle</td>
<td>1</td>
<td>---</td>
<td>5/7 Given by both sexes. Sounds most similar to Whistle A, but still discernable in the field. Has a descending frequency, hence the name.</td>
<td></td>
</tr>
<tr>
<td>Wicky-ou</td>
<td>3-5: multiple Chuh Intro + Growl</td>
<td>---</td>
<td>3/7 Given by both sexes. Almost always accompanied by a prolonged wing-spread, as part of a display or during vocal-exchange. Invariably given in the presence of birds of the opposite sex. Appears to be several variations of this call, but each given in the same behavioural manner.</td>
<td></td>
</tr>
<tr>
<td>Pop-Toy</td>
<td>1</td>
<td>---</td>
<td>4/7 Recorded from both sexes. Typically immediately follows consecutive Cracks. Sounds dissimilar to any other call. Sounds like the kid’s pop-toy toy, hence the name. Infrequently given, but fairly widespread. Mainly given upon landing.</td>
<td></td>
</tr>
<tr>
<td>Rare Call</td>
<td>1 (two elements)</td>
<td>---</td>
<td>3/7 Unknown which sex gives call. Sounds dissimilar to any other call. The most infrequently given call; hence its name. Contains two elements—both unique to this call. Recorded only when other birds were present and only during vocal-exchange.</td>
<td></td>
</tr>
<tr>
<td>Food Begging Call</td>
<td>1</td>
<td>---</td>
<td>2/2** Only given by nestlings during parental feeding. A drawn out vocal train in series (i.e. repeated over and over again). Can be heard up to 80m away in the woodland. Call looks (spectrographically) similar to that of another cockatoo, the Carnaby Cockatoo (Calyptrorhynchus funereus latirostris) (Saunders, 1983).</td>
<td></td>
</tr>
<tr>
<td>Feeding</td>
<td>1</td>
<td>---</td>
<td>2/2** Only given by nestlings and only when it is being fed. A rapid vocal train in series (i.e. repeated over and over again). The frequency range, call duration, and inter-call duration of this call looks similar to that of another cockatoo, the Carnaby Cockatoo (Calyptrorhynchus funereus latirostris) (Saunders, 1983).</td>
<td></td>
</tr>
<tr>
<td>Juvenile Call</td>
<td>1</td>
<td>---</td>
<td>2/2** Recorded from one 9-month old juvenile fledgling, 50m from its nest hollow; also heard at least one site by S. Murphy (S. Murphy, pers. comm.). Following this call from the juvenile, its presumable parent came to feed it, so may serve as a food-begging call outside the nest. Sounds dissimilar to any other vocalisation, although reminiscent of the Feeding vocalisation. Involves repeated, rapid staccato that lasts about two seconds.</td>
<td></td>
</tr>
</tbody>
</table>

*Behavioural Categories indicates which context the calls were given: Display, Nesting, Call-exchange, Solo Call-bout, or Other (defined in Table 2.1, Chapter 2). **Out of the two sites that chicks/juveniles were observed, this call occurred at both. Abbreviations: Dbl = Double Whistle; Wh. = Whistle; Trisyll. = Trisyllabic. Sites=areas separated by 2km or more. All syllables are shown in Figure 2.1. The final three rows are non-adult vocalisations (ie. from chick and juvenile).
A male palm cockatoo slowly proceeds down a nesting hollow to perform incubating duties. Photo by: Martin Willis (at CNZ’s study site).
This is the end of my thesis but the beginning of my career. To follow my next adventures, join my e-newsletter by emailing ChristinaZdenek@gmail.com.