



## Research

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# Individual preferences for sound tool design in a parrot

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The rarity of tool manufacture in wild parrots is surprising because they share key life-history traits with advanced tool-using species, including large brains, complex sociality and prolonged parental care. When it does occur, tool manufacture in parrots tends to be innovative, spontaneous and individually variable, but most cases have been in captivity. In the wild, only palm cockatoos (*Probosciger aterrimus*) have been observed using tools regularly. However, they are unusual because they use tools to enhance their displays rather than for foraging or self-maintenance. Males in northern Australia make two types of tool from sticks and seed pods, which they tap rhythmically against a tree during display. We analysed 256 sound tools retrieved from 70 display trees. Drumsticks (89% of tools) were used more often than seed pod tools; most males manufactured only drumsticks, but some made both types. Individual males differed significantly in the design of their drumsticks including the length, width and mass but we found no evidence that neighbours copied each other. We discuss the highly individualized preferences for sound tool design in context of the behavioural predispositions behind the rarity of tool manufacture in wild parrots.

## 1. Introduction

Tool use is widespread among animals, but habitual tool use and tool manufacture are restricted to a small number of bird and mammal species [1]. Among non-human primates, most tools are used for foraging, but some are used for other purposes [2]. For example, wild chimpanzees (*Pan troglodytes*) and orangutans (*Pongo* sp.) use a variety of tools for foraging, self-maintenance and social functions [3–6]. By comparison, tool use among wild birds seems to be more confined to the context of procuring food. This raises the possibility that the ability to manufacture tools in birds has evolved to solve specific problems concerning food retrieval, and may not reflect broader cognitive abilities [7]. The advanced cognition shown by tool manufacturing bird species within this setting is nonetheless remarkable, with some on par with chimpanzees and orangutans [8,9].

Tool use has only rarely been observed in wild parrots even though they share key life-history traits with primates, including large brains and advanced cognitive abilities, complex sociality, and prolonged parental care [10,11]. Parrots probably rarely have the need to make tools in the wild given that their powerful feet and beaks have evolved to allow them to reach the most difficult places and to manipulate and break open the hardest fruits and seeds [12,13]. Yet one of the earliest reports of non-human tool use was from a wild parrot. During his mid-nineteenth century travels to the Aru islands Alfred Russel Wallace observed a palm cockatoo (*Probosciger aterrimus*) manipulating a canary nut (*Canarium* sp.) by using a leaf to aid its grip [14]. More than 100 years later, palm cockatoos were observed to manufacture tools in a non-foraging context. Males in northern Australia manufacture two types of sound tool for use during complex displays [15]. They make drumsticks by cutting a tree branch and trimming

it to a roughly constant length, and a second type of tool by modifying the shape of the large hard seed pod of *Grevillea glauca* (bushman's clothes peg). Males grasp the drumstick or seed pod tool, usually in the left foot, and beat it against a tree limb or hollow trunk in a rhythmic performance [16]. Parrots have only occasionally been observed using tools in the wild [17,18], with most sophisticated tool use being observed in captive settings [19,20]. Manufacture of complex foraging tools by wild parrots was confirmed recently in Goffin's cockatoos (*Cacatua goffiniana*), with the sophistication of the tool set converging on that observed in primates [21].

Tool manufacture and use in palm cockatoos is unusual among advanced tool-making vertebrates for several reasons. First, it is an example of a tool used to produce or amplify sounds to aid communication. Examples of sound tools are rare in non-human species, and include orangutan 'kiss squeaking' with leaves [22] and wild chimpanzees selectively throwing stones against trees to produce resonant sounds [3]. Second, palm cockatoos produce tools for sexual display rather than for foraging and other survival-related purposes. Rare examples of such behaviour include stone throwing by female capuchin monkeys to get male attention [23] and leaf clipping as part of chimpanzee courtship displays [24]. Third, palm cockatoos make two entirely different types of tool from different raw materials. Multiple tool types are not uncommon among habitual tool using species but are often made to achieve different goals such as when foraging in different substrates or for different prey [9]. Such behaviour in palm cockatoos is puzzling because the two types of tool appear to be used for the same broad purpose and require different skill sets to produce.

Previously, we have shown that drumming by palm cockatoos shares the key rudiments of human instrumental music, including manufacture of a sound tool, performance in a consistent context, regular beat production, repeated components and individual styles [16]. Here, we show that tool design itself is a further highly individualized component of the birds' display. Individual palm cockatoos often preferred only one tool type, but some mastered the two different skill sets and made both types of tool. Individual expression was then further manifested by consistent, individually different drumstick designs. Taken together our results reveal that, alongside the rhythms they produce, sound tool design in these birds is a further component of their intraspecific displays with a high degree of individual choice and expression. Our results expand our perspective on tool manufacture in non-human species including the role of individual expression in tool design when the tools are used for display rather than foraging and self-maintenance.

## 2. Material and methods

### (a) Study site and species

This study was conducted in and around Kutini-Payamu (previously Iron Range) National Park including Aboriginal freehold lands near Lockhart River on the eastern coast of Cape York Peninsula, Australia (figure 1). Methods for locating palm cockatoos in the landscape and documenting their displays including drumming behaviour are described elsewhere [16,25,26].

Palm cockatoos are large birds (650–1040 g) restricted to Cape York Peninsula in northern Australia, lowland New

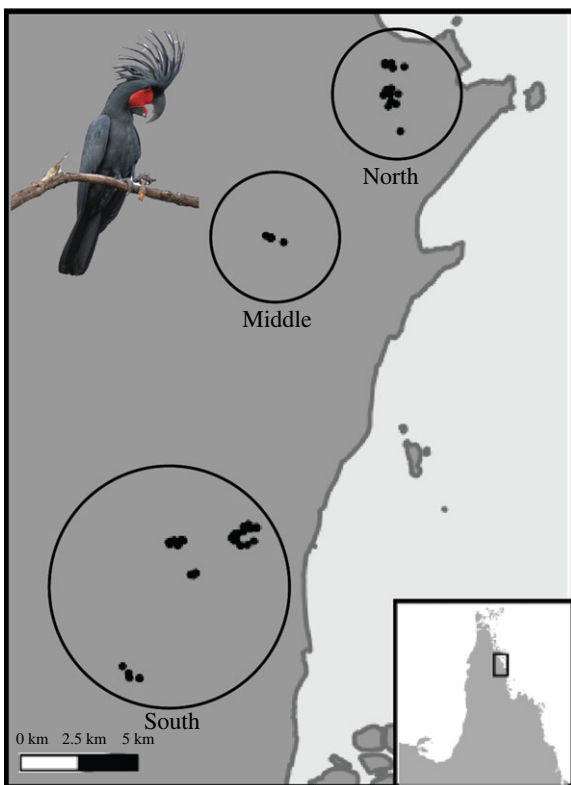
Guinea and some offshore islands [27]. On Cape York Peninsula, palm cockatoos are a monogamous, slowly reproducing, non-flocking species that defends breeding territories incorporating multiple tree hollows. These hollows are used for nests and displays although females only lay a single-egg clutch every 2.2 years on average [28]. Molecular analysis has shown that pairs show nest-site fidelity between years, and long-term observations have shown that males aggressively exclude other males from the immediate vicinity of their hollows [28]. Males perform complex displays to females and for territorial defense, whereby they vocalize loudly, including calling into the hollow, and bow, spread their wings, stomp their feet, erect their crests, flush their bare crimson cheeks, and drum using a foot only or a manufactured sound tool held in the foot (see below). They do not use their beaks percussively. During their displays, males cycle through their large vocal repertoire consisting of at least 27 syllables, 19 of which are mixed and matched to make longer, more varied vocalizations [29].

### (b) Sound tool construction

To our knowledge, sound tool use by palm cockatoos has only been recorded from Australia, with most observations recorded at the Iron/McIllwraith Ranges on the east coast of Cape York Peninsula, Queensland Australia [15,16]. In New Guinea, there are anecdotes of drumming by male palm cockatoos using only their foot, which is also common on Cape York Peninsula, and not with a tool (R.H. 2023, unpublished data).

On Cape York Peninsula Palm cockatoos manufacture two types of sound tool [30]. They make drumsticks by breaking off branches, snipping off the foliage, and trimming them to approximately 20 cm (see results). Drumstick making and use occurs alongside their construction of nesting platforms inside tree hollows. They collect sticks from neighbouring trees and break and splitter them into smaller pieces before being adding them to nesting platform. Only some sticks are used for drumming. Making of the drumsticks typically proceeds as follows: (i) the male displays, which involves calling frequently using specific vocalizations [29], wing-spreading, foot-stomping and wingspread pivoting where he holds onto a branch with his beak, wings outspread, and slowly twists left and right for 2–5 s to showcase the wingspan in different directions, (ii) the female usually arrives and watches the male either quietly or calling occasionally, (iii) the male walks, hops or makes a short flight within the same tree or to a nearby tree within approximately 50 m of the hollow, to find a live or dead branch from which to make his drumstick, (iv) he tilts his head to position his beak on the distal end of the branch and breaks the leafy end off, (5) he snips off any side-branches as he moves proximally down the branch, and finally (v) at a distance from the first snip of his choosing, he snips the second end off, freeing the stick from tree, and holding it in his bill until he goes to where he wants to drum. Both the habitat type (dry sclerophyll woodland dominated by *Eucalyptus tetrodonta*) and the large number of sticks used to build nesting platforms suggests that sticks are not in short supply. Males use several trees in the vicinity of their display tree to select branches for drumstick making and will carry their tools with them as they move between display trees ( $n = 2$  observations, one with a drumstick carried approximately 50 m, the other with a seed pod tool carried over 100 m; C.N.Z. 2023, unpublished data). The sounds from foot-stomping without a tool appear to differ markedly from those using a tool and are the subject of further analysis not presented here (R.H. 2023, unpublished data).

Drumsticks are easily recognized after they are discarded by the birds. The cut marks on the sticks are a consequence of the shape and physical properties of their bills. The sticks are cut at a 45° angle, sometimes from only one side but often from



**Figure 1.** Map of the study area at Kutini-Payamu National Park on Cape York Peninsula, Queensland, Australia. Dots denote display trees. Three clusters of display trees used for analysis are circled: North, Middle and South. Palm Cockatoo drumming image by C.N.Z.

both sides of the stick when the bird was unable to cut it from only one side (figure 2). Breakage of sticks does not usually occur during drumming ( $n=74$ ; C.N.Z. 2023, unpublished data), but males may splinter drumsticks after drumming and throw them into the hollow to add to the nesting platforms.

The second type of tool used is a hard seed pod from *Grevillea glauca* (bushman's clothes peg), a common shrub or small tree in the study area. The seed pods used are usually the outer shell of the pod which has opened after release of the seed. The birds may adjust the shape of these using their beak to gauge pieces out of them. Large pieces are removed in a characteristic way that differs from the marks a rodent might make with its incisors (figure 2). Minor marks on the pod can occur during drumming, but chunks are only removed when males chew them off. We did not record the availability of seed pods near each display site but note that (a) the shrub was common in the study area, (b) males that used seed pods had display sites very close to males that did not (see results), and (c) males have been observed travelling over 100 m with a seed pod tool (C.N.Z. 2023, unpublished data) suggesting they can search a large area to locate them.

### (c) Acquisition and measurement of sound tools

In total, 256 tools (29 seed pod tools and 227 drumsticks) were collected from 70 display trees at Kutini-Payamu National Park and surrounding areas from 2013 to 2015. Sixty-four drumsticks and seven seed pods were seen to be used by the birds for drumming and collected immediately when dropped after use. The remainder of the drumming tools analysed were found at the base of the trees during periods when males were known to be actively drumming. Drumsticks were easily identified by the actions of the birds' sharp beaks (see above). Modified sticks are also used for building a nesting platform inside the hollow. However, these are typically split longitudinally in half. All unsplit sticks observed dropped by the birds to the ground

were used for drumming first (C.N.Z. 2023, unpublished data;  $n=74$  drumming observations). All collected drumsticks were assigned to two categories, 'fresh' (from the current season) or 'old' where we could not rule out it was from previous years. Fresh sticks included those seen to be used by the birds or with evidence they were recently made including being made from live wood or having fresh cuts on dead wood, and being found unsoiled on top of the leaf litter. Seed pod tools were also readily identified as they are often modified by the birds who whittle them to a smaller size using their beaks and because they are only brought to the display trees for drumming displays (figure 2).

All sound tools were preserved in a dry environment and were fully desiccated by the time they were measured. The following measurements of drumsticks were taken by one of us (D.A.) using a flexible measuring tape and digital callipers and scales: (i) length (mm), measured end to end following the natural contours of the drumming tool; (ii) mean width (mm), the mean of three measurements including within 1 cm of each end and in the middle of the stick; (iii) chord (mm), the shortest distance between the endpoints of the stick providing an adjusted measure of length accounting for curvature of the stick; (iv) dry mass (g), the mass of the stick when fully desiccated; and (v) the number of protruding stubs where smaller branches had been removed by the birds. In addition, (vi) drumstick curvature was estimated by dividing the stick length by its chord.

### (d) Statistical analysis

Statistical analyses were performed in R [31] and MATLAB [32]. For analysis of individual preferences for drumsticks versus seed pod tools, we first tested whether the use of seed pods was affected by the sample size of tools collected at a display tree using a GLM with a binomial response variable where 1 (yes) was set as use of both tool types and 0 (no) was set as only use of drumsticks. We then examined 13 individual male palm cockatoos each with a minimum sample size of six tools ( $n=6-18$ ) found beneath their display sites. We used a multiple category ( $13 \times 2$ ) Freeman-Halton exact test to examine whether the numbers of each tool type used by individuals were randomly distributed. We further tested our results by excluding any tools from the first year (2013) that we were not confident were made in that year. This led to a multiple category test with reduced dimensions ( $11 \times 2$ ).

Twelve individual males with a sample of at least six drumsticks each ( $n=6-22$ ) (one male from above used mostly seed pod tools and did not use enough drumsticks to be included) were analysed for individual preferences in length, width, chord, mass, stub number and curvature using generalized linear models. We also ran a principal component analysis using all continuous measurement variables and compared the first two principal components between individual males using generalized linear models. We further tested our results by running the same analyses on a reduced sample of nests with sufficient drumsticks ( $n=6-13$ ) collected in only one year (2014). We could not examine the consistency of males in their tool design between years because their sample sizes between years were usually uneven (electronic supplementary material, table S1). This is because females do not lay every year and males are less active in their displays in those years. Seed pod size and shape were not analysed for individual differences between males due to small sample sizes.

We examined possible spatial influences on the total number and shape of manufactured tools over the landscape. We performed spatial autocorrelation analyses to test whether nearby hollows had more similar tools than those further apart. To do this, we divided up all distances between all hollows into



**Figure 2.** Examples of palm cockatoo drumming tools. (a) Three drumsticks of varying length. (b) (i) Unaltered seed pod (*Grevillea glauca*), and (ii–iv) altered seed pod drumming tools.

groups within 50 m and 100 m intervals (bins). We correlated measurements of drumsticks (length, width, mass and curvature) between all pairs within each distance interval and asked if the autocorrelation coefficients showed any pattern with distance unit.

We then used GLMs to relate number of tools found at display trees (drumsticks, seed pods, total tools) to the distance to the nearest neighbour (m) to examine the effect of display tree density.

### 3. Results

Mean dimensions for 227 drumsticks were width (mm),  $12.8 \pm 3.9$  s.d., length (mm),  $208.6 \text{ mm} \pm 62.4$  s.d., chord (mm),  $209.6 \pm 85.8$  s.d., mass (g),  $15.8 \pm 10.5$  s.d., number of stubs,  $2.2 \pm 2.1$  s.d. and curvature,  $1.020 \pm 0.019$  s.d. Seed pod tools ( $n=29$ ) had the following mean dimensions, length (mm),  $39.1 \pm 7.6$  s.d., width (mm),  $41 \pm 4.8$  s.d., breadth (mm),  $33.9 \pm 4.2$  s.d.

Samples of video material showing palm cockatoos (two examples each): (a) drumstick fashioning, (b) drumming with drumstick and (c) drumming with a seed pod tool and altering its shape can be viewed at <https://www.youtube.com/watch?v=vaauMYHluc4>.

#### (a) Individual use of drumsticks and seed pod tools

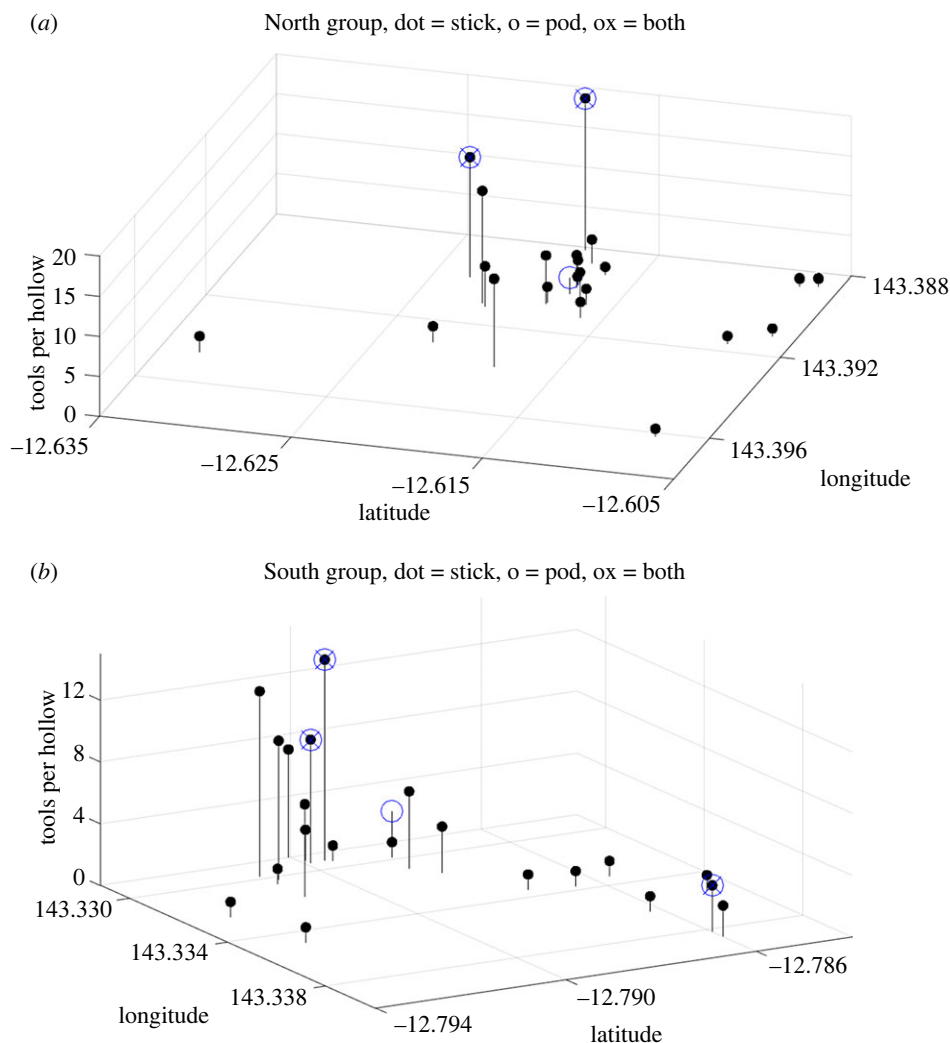
The likelihood of a male using seed pod tools as well as drumsticks increased significantly as the number of tools collected from his nest tree increased ( $p < 0.001$ ; electronic supplementary material, figure S1). Figure 3 maps the distributions of hollows with drumsticks and seed pod tools for the North and South groups of nest trees, and shows that males using both types of tool occurred in close proximity to males that only used drumsticks. We confirmed that male palm cockatoos actively shape and reduce the size of seed pod tools by using their beaks ( $n=9$  out of 11 observations of drumming with a seed pod, three of which were videoed). See sample video above, including a male manipulating a seed pod tool during his display suggesting the

possibility that they do this according to the feedback they get from tapping them.

Seven out of 13 males with a sample of six or more tools (sticks plus seed pods) only used drumsticks, but none of the males exclusively used seed pod tools. Use of drumsticks and seed pod tools was not distributed randomly across these nest sites (Freeman–Halton exact test,  $p < 0.0001$ ). One male used seed pod tools almost exclusively (13/14 tools), five other males used seed pod tools some of the time (figure 4a). We examined the influence of the male with most seed pod use by excluding him from the analysis and confirmed that use of drumsticks and seed pod tools was not distributed randomly across this smaller sample of display trees (Freeman–Halton exact test,  $p = 0.0005$ ). As a further test, we eliminated all tools from 2013 where we could not be certain they were manufactured that year. This further confirmed that use of tool types was not distributed randomly across display trees (Freeman–Halton exact test,  $p = 0.03517$ ).

#### (b) Individual preferences for drumstick size

Individual males ( $n=12$ ) with samples of six or more tools (range = 6–14 tools) varied significantly in the length ( $F_{11,112} = 2.68$ ,  $p = 0.004$ ; figure 4b) and chord ( $F_{11,112} = 2.73$ ,  $p = 0.004$ ) of their drumsticks but not width ( $F_{11,112} = 1.72$ ,  $p = 0.077$ ), mass ( $F_{11,112} = 1.79$ ,  $p = 0.0863$ ), number of stubs ( $F_{11,112} = 1.66$ ,  $p = 0.093$ ) or curvature ( $F_{11,117} = 0.80$ ,  $p = 0.638$ ). Analysis using the first principal component of stick measurements also showed significant differences between individuals (electronic supplementary material, table S2). There were five males with sufficient sample size ( $n=6$ –13 drumsticks) to test for differences within a single season (2014). These confirmed a significant difference between the length of individual males' drumsticks ( $F_{4,39} = 2.07$ ,  $p = 0.031$ ; figure 5a), and also showed significant differences in chord ( $F_{4,39} = 2.99$ ,  $p = 0.030$ ), width ( $F_{4,39} = 4.18$ ,  $p = 0.006$ ; figure 5b) and mass ( $F_{4,39} = 4.04$ ,  $p = 0.008$ ; figure 5c), but not number of stubs ( $F_{4,39} = 1.74$ ,  $p = 0.162$ ) or curvature ( $F_{4,39} = 1.91$ ,  $p = 0.128$ ). We did not find any interaction with year ( $0.10 > p > 0.76$ ) for



**Figure 3.** Distribution of display trees in (a) North group and (b) South group where drumsticks (filled circles), seed pod tools (open circles) or both types of tool (open circle with cross) were used.

the above variables suggesting that males were consistent in their preferences. However, samples sizes were biased between years so this result should be treated with caution (electronic supplementary material, table S1).

As outlined above, males do not appear to be limited in their availability of sticks to make into tools. Live and dead branches appear plentiful in their dry sclerophyll woodland habitat, they collect large numbers of sticks to build nesting platforms, and males are not restricted to just the display tree and instead use several trees in the vicinity. They are also known to carry the tools large distances. We used video footage of 18 males making drumsticks to confirm that they rarely need to cut a branch at its base and instead can actively choose where they cut it and therefore how long to make their drumsticks. Only one male out of 18 cut a branch close to its base. Electronic supplementary material, figure S2 shows example images from these videos of eight males cutting their tools, including the one male that cut the branch close to its base. The lack of difference in the number of protruding stubs on each drumstick also suggests that males were working from similar materials (branches).

### (c) Spatial influences on tool type and size

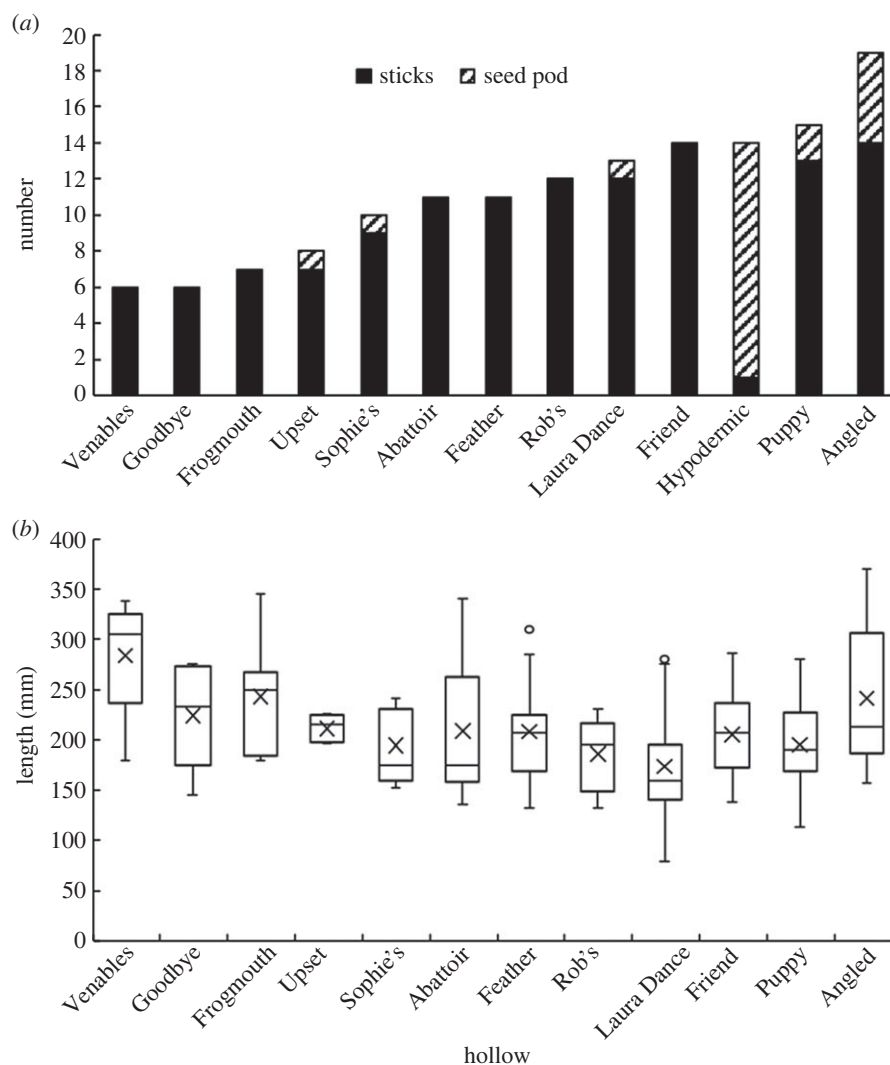
We found no evidence of spatial autocorrelation in the mass, chord, length, width or curvature of drumsticks.  $r$ -values (beyond zero metres) were not significant using either 50 m

or 100 m bins after Benjamini-Hochberg corrections for multiple tests were applied.

Both the total number of tools (Poisson GLM,  $p = 0.0241$ ) and the number of seed pod tools (Poisson GLM,  $p = 0.0439$ ) found at nest trees decreased significantly with the distance to the nearest neighbour. The number of drumsticks was not significantly related to nearest neighbour distance (Poisson GLM,  $p = 0.0808$ ). Four outliers were detected (electronic supplementary material, figure S3), and when these were removed, the above statistical relationships became stronger. However, when we excluded old tools found at nest trees in 2013 these relationships were no longer significant (total number of tools,  $p = 0.1248$ ; drumsticks,  $p = 0.2155$ ; seed pod tools,  $p = 0.3098$ ). When two outliers were removed, only the relationship between number of drumsticks and nearest neighbour distance was found to be significant (total number of tools,  $p = 0.0534$ ; drumsticks,  $p = 0.0036$ ; seed pod tools,  $p = 0.3447$ ).

## 4. Discussion

Our results provide a rare perspective on tool manufacture in non-human species including the role of individual expression in tool design. Tool manufacture is uncommon among wild parrots, and in palm cockatoos is especially unusual because the tools are not used for foraging or



**Figure 4.** (a) Distribution over 13 display trees of seed pod tools and drumsticks. (b) Box plot for drumstick length over 12 display trees.

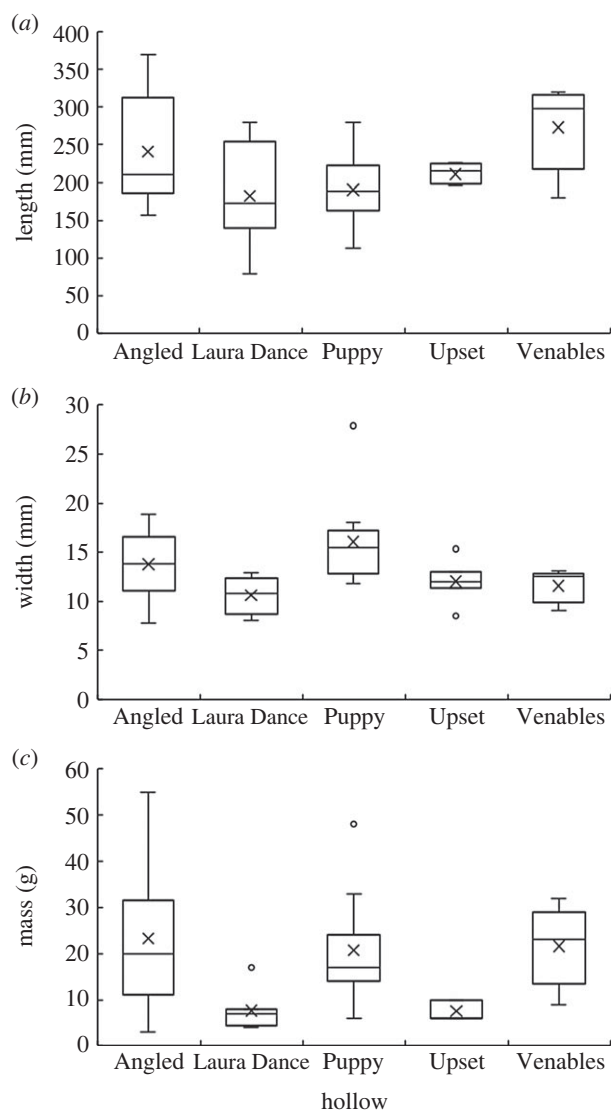
self-maintenance, and instead are used in display by males to females and for territorial defence [16,29]. Interestingly, two types of sound tool, drumsticks and seed pod tools, are constructed from different materials although both are used for the same general purpose [15]. Our results revealed that all individuals had preferences for a tool type though some manufactured both types, and we also detected differences between individuals in the design of their drumsticks.

Individual specialization in tool type is usually described in the context of foraging, whereby different tools are used for different purposes. Such 'parallel tool industries' were important in the pre-evolutionary history of humans and involved the sexual division of labour whereby males and females used different tools for different tasks [33]. Individual specialization to different foraging tools without sex differences has been described for New Caledonian crows (*Corvus moneduloides*) [34]. The two types of tool described for palm cockatoos, and individual preferences for them, show some of the hallmarks of parallel tool industries. Although the two tool types appear to be functionally similar, they require different raw materials, and the final shape of the tools differ, along with the skills required to shape them. This may imply that individuals that make both types have broader skill sets. Although tree-branches suitable for drumstick tool making are widely available throughout the study area, we could not control for the availability of *Grevillea* seed pods, and therefore it is possible that these were not equally available to all birds.

However, this seems unlikely because *Grevillea glauca* is common throughout the study area, males that did not use seed pods were close to others that did (figure 3), and males make daily long-distance movements (greater than 1 km) and have been observed carrying seed pod tools at least 100 m (C.N.Z. 2023, unpublished data).

Our previous analysis showed that male palm cockatoos drum rhythmically with their drumsticks or seed pod tools, and have a high degree of individuality in their drumming sequences such that each has its own distinct drumming signature [16]. The results presented here demonstrate further individuality in the drumming display. Alongside some individuals favouring one type of tool, our analysis showed individual consistency (high fidelity) in drumstick design. The individual preferences in length, chord, width and mass of drumsticks (figures 4 and 5) suggests that individuals develop their own template for the design of their tools. There was no indication that the availability of stick sizes differed between males and video evidence showed they almost always had the option of making their sticks larger.

A diversity of tool type and shape may result from the cultural accumulation of innovations [9,35,36]. Such cultural processes depend on individuals learning from others, [5,37], which may happen through copying either their actions (imitation) [38] or the results of their actions (emulation) [39]. However, our spatial analyses did not provide evidence that preference for tool types or styles were copied



**Figure 5.** Box plots of tool dimensions over five palm cockatoo display trees in 2014 for (a) drumstick length, (b) drumstick width and (c) drumstick mass.

or shared by neighbours. Male palm cockatoos are very defensive of their nest and display trees and quickly expel intruders, possibly limiting the opportunity to observe each other making tools. However, on one occasion a male was observed drumming approximately 2 m from another male before attacking and chasing him (R.H. & C.N.Z. 2023, unpublished data), so some learning opportunities could arise in the brief periods before intruders are expelled. Learning by emulation of finished discarded tools, as suggested for New Caledonian crows [39], is unlikely in palm cockatoos as intruders would need access to the base of the display tree, which has never been observed in over 20 years of the field study (R.H. & C.N.Z. 2023, unpublished data).

The lack of evidence of the spatial dependence in drumstick dimensions suggests that social transmission (if any) in tool dimensions may be vertical rather than horizontal. In parrots, including palm cockatoos, the model for a young male is likely to be his father because juveniles stay with their parents for extended periods, sometimes several years, and have ample opportunity to imitate their behaviour [13]. Male palm cockatoos have been observed drumming while a juvenile was present in the same tree ( $n=3$ ; R.H. & C.N.Z. 2023, unpublished data). Individual preferences for tool types were also suggested to be vertically inherited (parent to offspring) in New Caledonian crows

[34]. We have not observed any cases of unrelated palm cockatoos, for example immature birds, displaying near older birds as has been recorded for some bowerbirds (Ptilonorhynchidae) where younger males may build smaller bowers near those of mature males [40].

The patchy distribution of flexible tool use across taxa indicates that it varies dramatically between even closely related species and that only a select few have the psychological predisposition, need, or environmental circumstances to develop the trait naturally in the wild [41]. Parrots are an excellent taxon for attempting to isolate why a cognitively capable species has rarely evolved tool use, particularly given their life-history traits and sociality are similar to other sophisticated tool makers [10,11]. For most parrots, it would appear that tools are simply not needed for foraging or other practical purposes, as the birds' powerful bills, dextrous tongues and zygodactyl (2 toes forward and 2 backward) foot-gripping agility allow them to reach and extract even the most challenging of their food sources. The most likely explanation for the manufacture of sound tools in palm cockatoos lies in key modifications of pre-existing behaviour so that the making of tools requires only minor innovations. Males prepare the nest by building stick platforms inside the large hollow [28]. Because the hollows are large and skyward facing, they are prone to filling with water in heavy rain, and the stick platforms raise the nest above where water may accumulate inside the nest. The males collect sticks and ostentatiously split and toss them into the nest hollows in front of the attentive females who inspect the platforms and only lay their single egg if the platform construction is large and solid [28]. In this scenario, the males are already handling sticks with their feet, and it is a small step to then tap one against the tree, and a further small step for the female to show her approval. This route to drumming with a sound tool seems especially likely given that the males already stomp their feet on the tree branch with an open or clenched foot as part of their display. Use of a hard stick (or seed pod) to tap the tree produces louder sounds with different properties from those using the foot only although the nature and function of these different sounds have not yet been analysed (R.H. 2023, unpublished data). Such a scenario explains the psychological predisposition behind drumstick manufacture, however it is noteworthy that seed pods are also fashioned into sound tools even though they are not used in nest construction. This suggests that seed pod tools were a further innovation once drumming behaviour from sticks had arisen.

**Ethics.** This research was carried out under ANU Ethics protocol C.RE.62.09. Research permits were given by the Queensland Department of Environment and Resource Management (permit no. WITK06171009).

**Data accessibility.** The datasets supporting this article are available from the Dryad Digital Repository [42].

Supplementary material is available online [43].

**Declaration of use.** We have not used AI-assisted technologies in creating this article.

**Authors' contributions.** R.H.: conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology, project administration, resources, writing—original draft; C.N.Z.: conceptualization, data curation, methodology, project administration; D.A.: data curation, formal analysis, methodology; J.A.E.: conceptualization, formal analysis, investigation, methodology.

All authors gave final approval for publication and agreed to be held accountable for the work performed therein.

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