BRILL

Behaviour 160 (2023) 837–856

Behaviour
brill.com/beh

Comments/Reflections

Dynamic object–fruit combinations by introduced Tanimbar corellas (*Cacatua goffiniana*) in Singapore

Berenika Mioduszewska [a,*], **Mark O'Hara** [a], **Frank E. Rheindt** [b] **and Alice M.I. Auersperg** [a]

[a] Messerli Research Institute, University of Veterinary Medicine Vienna, Medical University Vienna, University of Vienna, Veterinaerplatz 1, 1210 Vienna, Austria
[b] Department of Biological Sciences, National University of Singapore, 14 Science Drive 4, Singapore 117558, Singapore
[*]Corresponding author's e-mail address: berenika.mioduszewska@vetmeduni.ac.at
ORCID iDs: Mioduszewska: 0000-0002-2068-1830; O'Hara: 0000-0001-9571-9015; Rheindt: 0000-0001-8946-7085; Auersperg: 0000-0001-7405-9791

Received 18 November 2022; initial decision 24 January 2023; revised 14 June 2023; accepted 20 June 2023; published online 4 August 2023

Abstract

Tanimbar corellas, an important model in comparative cognition research, are endemic to the Tanimbar Islands, Indonesia, but were also introduced to several other locations with a tropical climate. Introduced psittacines offer valuable opportunities to test hypotheses at large temporal and spatial scales, such as geographic distribution of behaviours. Here, we report two opportunistic observations of Tanimbar corellas combining small wooden fragments with two types of tropical fruit (Ketapang and Pong-pong) in Singapore. The observations were recorded and uploaded to YouTube by a local bird-watcher. We analyse the behavioural similarities and differences between object combinations with the Pong-pong fruit in Singapore and extractive tool use on the Wawai fruit in Indonesia. Repeated insertions of the wooden fragment into the fruit and visible ingestion suggest that the combinatory behaviours were most likely related to foraging. This report provides first insights into the presence of advanced technical abilities in geographically separated Tanimbar corellas.

Keywords

citizen science, foraging, object combination, Tanimbar corella.

Published with license by Koninklijke Brill NV | DOI: 10.1163/1568539X-bja10231
 | ISSN: 0005-7959 (print) 1568-539X (online)

1. Introduction

The observation of psittacines (parrots and cockatoos; order Psittaciformes), while undoubtedly captivating, can often present challenges when attempting to detect individuals visually. Psittacines are distinct among birds due to their extensive exploratory behaviours and manipulatory abilities that stem from unique morphological adaptations to foraging on seeds and nuts, a high level of coordination between different body parts (including the powerful yet sensitive beak, dexterous tongue, and grasping zygodactyl feet; Homberger & Brush, 1986; Demery et al., 2011; Homberger, 2017), as well as from relatively large brains and advanced cognitive abilities (for a review, see Auersperg & von Bayern, 2019).

Behavioural observations of forest-dwelling species are challenging to obtain as most activity typically occurs high in the tree canopy (Collar, 1997; Morand-Ferron et al., 2016). Therefore, most reports of complex behaviours in wild psittacines refer to species that are easy to observe owing to their conspicuously large size (Hyacinth macaws, *Anodorhynchus hyacinthinus*; e.g., Schneider et al., 2006; Palm cockatoos, *Probosciger aterrimus*; e.g., Wood, 1984; Heinsohn et al., 2017), boldness towards humans (Kea, *Nestor notabilis*; e.g., Diamond & Bond, 1999; Gajdon et al., 2004), temporary placement in capture-release aviaries (Tanimbar corellas, *Cacatua goffiniana*; Rössler & Mioduszewska et al., 2020; O'Hara et al., 2021), or their occupancy of easily accessible environments (e.g., urban areas; Yellow-headed parrots, *Amazona oratrix*; Martens & Woog, 2017; Sulphur-crested cockatoos, *Cacatua galerita*; Aplin et al., 2021; Klump et al., 2021).

The Tanimbar corella (*Cacatua goffiniana*; alternative common name: Goffin's cockatoo; indigenous Tanimbarese name: Manik tilgnoi; hereafter: Goffin) is a medium-sized (30–32 cm) white corella species from the cockatoo family (Eaton et al., 2016). It is endemic to the remote Tanimbar Islands in southeast Indonesia and is encountered primarily in dense, seasonal tropical forests and agricultural fields (Jepson et al., 2001; O'Hara et al., 2019; Mioduszewska et al., 2022). The Goffin is an important model in comparative research due to its advanced cognitive skills in the technical and social domains (Auersperg & von Bayern, 2019). Captive hand-raised Goffins exhibit a strong intrinsic motivation for varied combinatory object play (including insertions of objects into the substrate) and exploratory behaviours, which reportedly support flexibility and innovation in problem-solving through technical information gathering (Gardiner, 2010; Auersperg et al., 2015; Bjorklund & O'Hara & Auersperg, 2017). Goffins are also known for advanced problem-solving skills as well as innovative, flexible use and manufacture of several types of tools for multiple functions (for a review, see Auersperg, 2015).

In their natural habitat, Goffins are opportunistic feeding generalists consuming a variety of partially seasonal food sources, including some that require extraction (e.g., young coconuts or papayas; Mioduszewska et al., 2018, 2022; O'Hara et al., 2018). Notably, the presence of extractive foraging has been associated with the capacity to innovate tools (for a review, see Parker, 2015; Huber & O'Hara, 2016). In line with the extractive foraging hypothesis (Parker & Gibson, 1977), Goffins on the Tanimbar Islands were recently observed to manufacture and use complex tools (a tool set) to access the embedded seed matter of a tropical fruit (Wawai, *Cerbera manghas*; O'Hara et al., 2021). In addition to the native population, introduced Goffins can be found in several locations with a tropical climate (Calzada Preston & Pruett-Jones, 2021). Groups can be observed in urban parks and gardens in Singapore (Neo, 2012) and Taiwan (Lin & Lee, 2006), whereas sightings of a few individuals were also reported in Puerto Rico (Falcón & Tremblay, 2018) and Hawaii, among other locations (for a review, see Calzada Preston & Pruett-Jones, 2021). Introduced psittacine populations provide valuable opportunities to study adaptation to urban habitats and to test hypotheses at large temporal and spatial scales, such as life history traits (for a review, see Kiacz & Brightsmith, 2021) or geographic distribution of behaviours.

Object combinations represent one category of behaviours of significant scientific value, as they provide an externally observable measure of technical intelligence skills (Seed & Byrne, 2010; Sugasawa et al., 2021). Object combinations are a type of complex object manipulations that involve placing an object in relation to another object (Westergaard & Suomi, 1994) or substrate (Fragaszy & Adams-Curtis, 1991). Furthermore, such combinations can either establish a static spatial relationship (e.g., placement of a wooden fragment on top of a fruit) or produce dynamic mechanical interactions (e.g., repeated insertions of a wooden fragment into a fruit; St Amant & Horton, 2008; Fragaszy & Mangalam, 2018). Observations of object combinations in free-ranging individuals are not always anticipated, especially during opportunistic encounters.

Anecdotes (here referred to as 'opportunistic observations' to avoid anthropomorphic associations) are somewhat diversely defined as either rare (or even single) records of behavioural events (McGrew, 2004), narrative descriptions of unique or frequent behaviours (Mitchell et al., 1997), or reports of behaviours that occur regularly but are challenging to observe (Sarringhaus et al., 2005), such as birth or predation attempts. Opportunistic reports have been proposed as the most feasible method (other than ad libitum sampling) for revealing unanticipated events (for a review, see Ramsay & Teichroeb, 2019). Therefore, they are considered a valuable source of information on animal behaviour and cognition that helps identify behavioural variants across geographical locations and facilitate comparative analysis (Rollin, 2000; Sarringhaus et al., 2005; Bates & Byrne, 2007; Nelson & Fijn, 2013; Ramsay & Teichroeb, 2019). However, opportunistic observations need to be discussed with care to avoid overinterpretation of limited data or misleading overgeneralisations (Sarringhaus et al., 2005; for a recent example on 'tool use in seabirds' and the associated debate, see Auersperg et al., 2020; Farrar, 2020; Sándor & Miklósi, 2020). To avoid these risks, opportunistic reports should be carefully evaluated, highlight alternative explanations for the observed events, and be ideally supported by confirmatory data (photographs or videos, which do not necessarily have to be collected by scientists; Krueger et al., 2019; Sándor & Miklósi, 2020).

Citizen science, the collection and sharing/uploading of data by the general public (for a review, see Dickinson et al., 2010), has become an important tool in scientific research. One section of citizen science projects is based on data from public footage repositories (Jagiello et al., 2019). Specifically, YouTube, a popular video-sharing platform, has proven to be a valuable initial source of behavioural footage to further investigate known ethograms (e.g., Burn, 2011; Nelson & Fijn, 2013; Dylewski et al., 2017; Jagiello et al., 2019; Tryjanowski et al., 2020), explore rare behaviours (otherwise not suited for standardised observation methods due to their low frequencies, short durations, or animal elusiveness; e.g., Krueger et al., 2019, 2021; Pokharel et al., 2022), or provide evidence for the occurrence of previously unobserved behaviours (e.g., Osuna-Mascaró & Auersperg, 2018).

Here we report two opportunistic observations of introduced Goffins in Singapore manipulating small wooden fragments and combining them with a Ketapang (Sea almond; *Terminalia catappa*) and a Pong-pong (*Cerbera odollam*) fruit, originally uploaded to YouTube by a local bird-watcher. Some of the recorded behaviours resemble the wooden fragment interactions observed during tool use by wild Goffins on the Tanimbar Islands. We conducted a descriptive comparative analysis of the recorded behaviours and provide the most likely interpretation as well as potential alternative explanations.

2. Methods

2.1. Study species

Singapore is one of few locations worldwide hosting naturalised Goffins (Calzada Preston & Pruett-Jones, 2021). They were introduced after 1980 (exact date unknown; Neo, 2012) and established a small but stable breeding population (Yeo & Chia, 2010; Jeyarajasingam, 2012; Neo, 2012; Nature Society Singapore Bird Group Records Committee, 2021), which is considered to possibly comprise several hundred individuals (F.E.R., personal observation). Goffins in Singapore likely stemmed from individuals wild-caught on the Tanimbar Islands that were either released by their owners, accidentally escaped from the pet trade (psittacines are one of the most heavily traded bird groups worldwide; Scheffers et al., 2019), or were released at Buddhist religious ceremonies during the Vesak Day holiday (Agoramoorthy & Hsu, 2007; Neo, 2012). Pet cockatoo keeping has been a popular hobby in Singapore in recent years (Chiok & Chng, 2021) and Goffins are actively traded (although they are seemingly not a common choice; J. Lee, personal communication, 23 May 2022). Therefore, it cannot be entirely excluded that home-bred or wild-caught individuals might occasionally join the introduced population (W.X. Chiok, personal communication, 26 April 2022).

2.2. Data collection

After the first observation of tool use in wild Goffins, we sought to collect more data on the potential presence and frequency of this behaviour in other populations of Goffins. Singapore has an active bird-watching community which posts videos and photographs online. We checked footage available via the Bird Ecology Study Group (BESGroup; a bird-watching group of the Nature Society — Singapore) blog, YouTube and eBird (a popular online database of bird sightings), as well as conducted a photographic search via the Google search engine. Our primary focus was obtaining original unedited video material (‘raw footage’) through YouTube™ as the majority of public content uploaded to this platform consists of either few or single shots of raw footage that has been minimally or not edited (Nelson & Fijn, 2013).

We searched for keywords related to object manipulation, foraging, fruit and Goffins.

2.3. Footage

Through the online search, we encountered video footage of an introduced Goffin combining a small wooden fragment with an immature Pong-pong fruit in Singapore, recorded and uploaded to YouTube by Joyce Chia, a local bird-watcher. After contacting the bird-watcher via the BESGroup, she kindly provided us with the original footage, additional information about the recordings, and permission to analyse the videos. Furthermore, two more videos from the same Pong-pong fruit interaction event (19 February 2018, 10:24–10:32 am) were supplied, totalling four short videos (38 s, 77 s, 17 s and 39 s; total duration: 171 s) with small recording gaps (recording started at 10:24, 10:26, 10:29, 10:32 am). The bird-watcher also provided a single video (27 s) from another opportunistic observation of a Goffin handling a mature Ketapang fruit (6 November 2017, 9:52 am), modifying a small wooden fragment, and combining it with the fruit. Both observations were recorded in Labrador Park at the Berlayer Creek Boardwalk, Singapore, a popular medium-sized (16.8 ha) park. Due to the opportunistic nature of the collected data, the identity and attribute information (e.g., origin, sex, age, personality type; Rutz & Webster, 2021) about the recorded Goffins is unknown. It is possible that the same individual was recorded in both instances, as both recordings were obtained in the same medium-sized park. No further members of the BESGroup reported observing object-fruit combinations in Goffins.

2.4. Video analysis

The footage quality was high (Ketapang fruit: 1920 × 1080, 1080p, Full High Definition; Pong-pong fruit: 1280 × 720, 720p, High Definition), recorded with a Canon EOS 70D Digital Single-Lens Reflex (DSLR) camera. In most Pong-pong footage, the focal individual and its behaviours were fully visible (for an example, see Figures 1 and 2). However, on two occasions, the subject repositioned itself with the back facing the camera, which limited the visibility of object and fruit manipulations (for an example, see Video 2 at 10.6084/m9.figshare.23668938). On three occasions, the recording moved away from the subject to briefly record a juvenile individual nearby. Once the wooden fragment was inserted into a fruit, it was no longer visible.

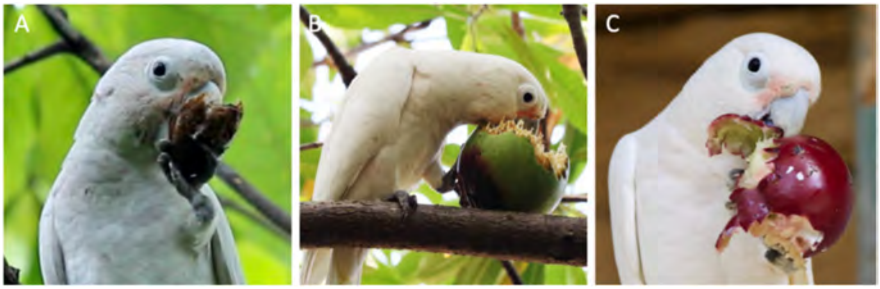

Figure 1. Comparison of shapes, sizes, and maturation states of (A) Ketapang, (B) Pong-pong and (C) Wawai fruit manipulated by Goffins in Singapore (A–B) and on the Tanimbar Islands (C). Panel B presents the opportunistically recorded event in Singapore where only the upper part of the fruit was removed by the individual. In contrast, Panel C presents the typical fruit handling recorded on the Tanimbar Islands, where all flesh was always removed before engaging in tool use (the photograph depicts an individual removing fruit flesh until the inner endocarp is exposed). Photo credits: A–B, Joyce Chia; C, Mark O'Hara.

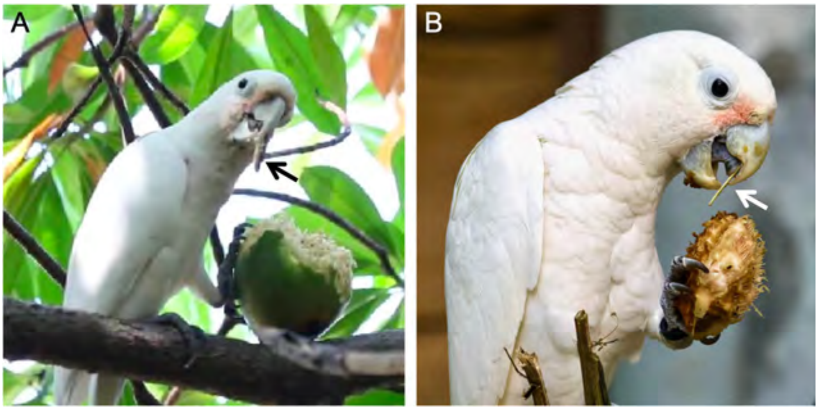

Figure 2. Similarities and differences between wooden fragment manipulations observed (A) in Singapore and (B) on the Tanimbar Islands (O'Hara et al., 2021). Both individuals hold a wooden fragment by pushing it against the upper mandible with the tongue. During the opportunistically observed event in Singapore (A), the fragment was inserted into the midsection of a partially-exposed Pong-pong fruit and stabilised by a foot against a branch (clamping). On the Tanimbar Islands (B), the fragment (used as a tool) was inserted into the dorsal fissure of a fully exposed Wawai endocarp, which was held and lifted in the foot (grasping). Arrows indicate the wooden fragments held inside the beak. Photo credits: A, Joyce Chia; B, Mark O'Hara.

In the Ketapang footage, the focal individual was fully visible during the whole duration of the recording. Hugh Tan, a botanical specialist from the National University of Singapore, was consulted to identify the fruits visible in the footage. Behavioural analysis of the video recordings was conducted by implementing an adjusted ethogram developed to code the tool use and manufacture in wild Goffins on the Tanimbar Islands (O'Hara et al., 2021). Behaviours related to fruit and wooden fragment manipulations (Table A1 in the Appendix at 10.6084/m9.figshare.23668938) were coded frame-by-frame in BORIS software (v.7.9.8; Friard & Gamba, 2016).

3. Results

The (chronologically first) Ketapang fruit interaction lasted the whole duration of the recording (27 s). The individual manipulated a Ketapang fruit partially opened prior to the recording (Figure 1A; Video 1 at 10.6084/m9.figshare.23668938), removed bark from a small wooden fragment held in the beak, shortened the length of the fragment, and briefly inserted it into the fruit before discarding both the fruit and the wooden fragment.

During the (chronologically second) Pong-pong fruit interaction, the focal individual was visible in 67% of the recording (115.08 out of 171 s). The individual manipulated a Pong-pong fruit with a partially removed pericarp (it was unclear whether the endocarp was exposed as the inside of the fruit was not visible due to the angle of the recording; Figure 1B; Video 2 at 10.6084/m9.figshare.23668938). The individual visibly combined wooden fragments with the middle section of the exposed part of the fruit (Table 1) and the wooden fragment seemed to be inserted into the fruit (although the effect the object had on the fruit was not evident in the footage). Ingestion occurred once (a small piece was attached to the wooden fragment after it was inserted; it was unclear whether residual fruit flesh or seed matter was ingested), and licking of the wooden fragment occurred twice. Additionally, a potential levering of a wooden fragment inserted into the Pong-pong fruit was observed once shortly before the ingestion (Video 2 at 10.6084/m9.figshare.23668938) but not included in the analysis as the action was brief, not repeated, and not clearly visible.

The complete action sequences were not recorded during these opportunistic observations. Despite this limitation, most behaviours related to the

Table 1.
Observed behaviours related to fruit and wooden fragment manipulations.

Fruit	Category	Behaviour	Duration			
			Freq.	s	Mean (s)	SD
Pong-pong	Fruit	Holding	4	115.505	28.876	20.167
		Inspection	1	NA	NA	NA
		Biting	6	28.88	4.813	2.66
		Locomotion	2	6.68	3.34	2.97
		Ingestion	1	NA	NA	NA
	Wooden fragment	Probing	1	2.16	2.16	NA
		Interaction	5	48.825	9.765	7.638
		Modification	1	3.88	3.88	NA
		Combination	3	13.2	4.4	3.229
		Insertion	3	NA	NA	NA
		Subsequent	1	NA	NA	NA
		Flipping	1	NA	NA	NA
		Licking	2	NA	NA	NA
		Dropping	1	NA	NA	NA
	Focal	Proximity	2	131.16	65.58	6.93
Ketapang	Fruit	Holding	1	10.240	10.240	NA
	Wooden fragment	Interaction	1	8.520	8.520	NA
		Modification	1	2.760	2.760	NA
		Combination	1	5.240	5.240	NA
		Insertion	1	NA	NA	NA

fruit (5/6 coding categories) and the wooden fragment (9/14 coding categories) were observed during the Pong-pong fruit interaction. The unobserved behaviours included: beak insertions into the endocarp, manufacture (the detachment of the wooden fragment from the branch), vertical motions of the wooden fragment (employed likely for piercing through the inner seed coating during Wawai foraging), horizontal head and wooden fragment motions (employed for removing large pieces of seed matter during Wawai foraging), extraction of seed matter, and saving (the whole action sequence is needed to properly evaluate the presence of this category).

4. Discussion

Introduced Goffins in Singapore were opportunistically observed to modify and combine wooden fragments with two types of tropical fruit, a mature

Ketapang and an immature Pong-pong. The online data collection revealed only two, relatively short, opportunistic observations of object–fruit combinations. This small number might stem from the fact that combinatory activities are rare or location-specific (Ramsay & Teichroeb, 2019), the behaviour is challenging to record in free-ranging Goffins due to its inconspicuous nature (such as intraoral handling of the wooden fragments (Mioduszewska et al., 2022); the bird-watcher who provided the recordings only noticed the wooden fragment combinations after the authors indicated and described them), or other behaviours attract more attention (such as foraging on large food sources; Osuna-Mascaró & Auersperg, 2018). Goffins in Singapore are comparatively more visible (due to less dense habitat and habituation to humans) and thus easier to observe than their wild counterparts on the Tanimbar Islands (B.M., personal observation). However, they do not closely approach humans as some large cockatoo species living in urban parks do (Sulphur-crested cockatoos; e.g., Kirksey et al., 2018; Klump et al., 2021). Therefore, the arboreal lifestyle and relatively small body size of Goffins might limit the possibility of opportunistic observations (Bates & Byrne, 2007).

The comparative evaluation focused on the recorded Pong-pong fruit interactions because no ingestion or licking was observed during the Ketapang fruit interaction. The fruit was also already open during the recording, which might have influenced the short duration of this object-fruit combination. Additionally, Goffins might be able to crack open the endocarp of the Ketapang fruit because of its relatively small size, a corky rind, and numerous tiny air cavities in the outer part of the endocarp (van Valkenburg & Waluyo, 1991).

4.1. Comparative evaluation

The behaviours involved in the manipulation of wooden fragments observed in Singapore are not entirely novel as they resemble actions performed during tool use on the Tanimbar Islands (O'Hara et al., 2021). The replicability of behaviours first reported as novel is crucial for understanding animal behaviour and cognition (Sarringhaus et al., 2005). Therefore, this report adds information on the presence of advanced technical abilities in free-ranging Goffins from geographically separated locations, supporting the potential for independent tool use development. Similarities in the fruit morphology of the taxonomically related Pong-pong and Wawai plants might result in similar affordances (what an environment offers an animal; Gibson, 2015). Specifically, they might allow playful manipulation and combination of objects with the textured surface of the endocarps. Such affordance overlaps limit action possibilities available to the individuals and could shape spontaneous object-assisted foraging innovations (tool use) in a similar direction. Pong-pong and Wawai trees are typically planted for ornamental reasons only, as the fruits are highly toxic to humans (Khanh, 2001; for more details, see the Appendix at 10.6084/m9.figshare.23668938). However, psittacines are known to consume food sources with measurable toxicity levels without harmful effects, and tropical fruit seeds are generally highly nutritious, thus potentially providing survival benefits (Gilardi & Toft, 2012).

Conversely, marked differences were also observed between the recorded object-fruit combinations in Singapore and the tool use behaviours observed on the Tanimbar Islands, as well as between the handling of Pong-pong and Wawai fruits (Figure 2). The focal individual feeding on the Pong-pong fruit held it against the branch, whereas the Wawai fruit was freely held in one foot. Additionally, in contrast to the Wawai foraging, where all fruit flesh was removed to expose the embedded endocarp, only half of the Pong-pong fruit flesh was removed, which is also atypical because psittacines usually remove seed coating before feeding. Differences in the fruit anatomy and maturity stages (for more details, see the Appendix at 10.6084/m9.figshare.23668938) likely contributed to the observed differences in fruit handling and the extent of the removed pericarp. Firstly, Pong-pong fruit are generally larger and rounder than Wawai fruit (Figure 1B–C), likely making them more challenging to handle for pericarp removal. Secondly, Wawai fruit contain endocarps that are transitional to the fibres of the inner mesocarp (fruit flesh). In contrast, Pong-pong fruit lack a clear distinction between mesocarp and endocarp (Tomlinson, 2016), which might make their flesh harder to remove.

4.2. Behavioural interpretation

Opportunistic observations present limited data and should not be used to argue about mental processes (Sándor et al., 2021). Therefore, we focus on the directly observable aspects of the recorded behaviours (St Amant & Horton, 2008) and refrain from making inferences about potential underlying mechanisms involved in the emergence of the observed behavioural forms. We also avoid describing the recorded behaviours as tool use (or ‘tooling’, where a body-plus-object system creates a biomechanical interface between a held object and the target; Fragaszy & Mangalam, 2018), because the whole action sequence was not recorded and the exact target (fruit flesh or seed matter) could not be identified. Instead, we focus on the potential onset, which may include accidental occurrence, play, or foraging activity. We also discuss possible causes for the absence of visible seed material extraction.

Unanticipated behaviours might stem from a singular coincidence that does not provide reliable information on animals' behavioural repertoire (McGrew, 2004; Bates & Byrne, 2007). However, the probability that an observed behaviour was accidental decreases with the number of times it was observed (Bates & Byrne, 2007). The level of repetition can vary and be either within one recorded event (repetitions of actions observed within one encounter) or between recorded events (how many independent events were recorded). Although only two object-fruit combination events were recorded, the Pong-pong fruit interaction involved multiple (three) insertions of a wooden fragment into the fruit. Therefore, it is unlikely that the observed object-fruit combinations were accidental (or a "lucky coincidence of events"; Sándor et al., 2021).

Alternatively, some object combinations might resemble a deliberate use of objects but also seem playful (Shumaker et al., 2011). Play behaviour is challenging to define due to its nontypical nature, although various criteria were proposed to differentiate play from other behaviours. These criteria include: (1) intrinsic motivation; (2) serving no purpose (incomplete functionality); (3) repeated performance; (4) voluntary initiation under (5) relaxed conditions (when all needs are fulfilled); and (6) positive mood during the behaviour (for a review, see O'Hara & Auersperg, 2017). In non-human animals, play is commonly categorised into social, solitary/locomotor, and object play. Object play describes events where objects are held or manipulated without any clear purpose (Shumaker et al., 2011), hence in a non-foraging context as play is thought to discontinue when an individual is hungry (Bateson & Martin, 2013).

The persistent and repeated insertions of the wooden fragment into the Pong-pong fruit, combined with the presence of ingestion and licking of the wooden fragment, suggest that the observed behaviours were most likely related to foraging. The absence of visible inner seed material extraction might have resulted from several potential circumstances: (a) the recording depicted the final foraging stages where the inner seed material was already depleted, (b) the behaviour was not fully formed and therefore was not successful/efficient in extraction, or (c) the recorded behaviour was a "malfunction" (Sándor & Miklósi, 2020) where the individual performed the correct behavioural sequence but on an incorrect substrate (wrong type of fruit).

Another indicator that the observed foraging might not have been entirely optimal was the employed 'clamping' fruit handling technique. During clamping (or tether-footing), the food item is clasped between the holding foot and the substrate (perch or the ground; for a review, see Harris, 1989). However, clamping can decrease vigilance as the head is often lowered and must be repeatedly raised to scan the area for danger. In contrast, during 'grasping' (or prehensile-footing), the food item is held in the foot and lifted towards the beak, which is lowered to meet the foot halfway (Collar, 1997). This technique is used during most feeding events in psittacines, making the endocarp easier to carry and manoeuvre during seed matter extraction.

4.3. Future directions

Complex object manipulations were suggested to be potential precursors for tool use in human infants and non-human primates (for a review, see O'Hara & Auersperg, 2017). Goffins have the potential to develop complex behaviours individually, and innovative spontaneous tool-mediated problem-solving has also been reported to be within this species' cognitive capacity (Auersperg et al., 2012). The emergence of advanced technical skills has been suggested to result from a complex interplay between several factors (for a review, see Kenward et al., 2006; Bandini & Tennie, 2020; Tennie et al., 2020; Mioduszewska et al., 2022): (1) the genetic setup of an individual (inherited traits, morphology, species-specific motor repertoire, general behavioural tendencies, such as persistent object manipulations and combinations), (2) cognitive mechanisms (individual and social learning, memory, motivation, attention, physical cognition, causal reasoning, information processing), (3) pre-experience (encounters with objects in different contexts), and (4) environmental conditions (ecological opportunities).

Opportunistic observations can be highly valuable for revealing interesting behavioural forms before larger projects can be conducted (Sarringhaus et al., 2005) and directing studies into potentially fruitful areas of research by generating new research questions and hypotheses (Bates & Byrne, 2007; Nelson & Fijn, 2013; Dechaume-Moncharmont, 2020). However, to avoid misleading overgeneralisations to a population level (Sándor & Miklósi, 2020), more behavioural data is needed to explore the complexity and prevalence of object-fruit combinations within and between various populations of Goffins. Additionally, further research is needed to compare the anatomical features of Pong-pong and Wawai fruits (crucial for understanding their affordances), their nutritional and toxic contents, and whether insects are commonly encountered inside the fruit (and could thus be a potential target of object-fruit combinations). Controlled experiments are needed to investigate the mechanisms and relative contributions of various factors underlying the emergence of such complex behaviours, for example, by providing naïve individuals with ecologically-relevant materials (Bandini & Tennie, 2017) or by exploring the ontogeny of object manipulations in Goffins (for a review, see Kenward et al., 2011; Rutz & St Clair, 2012).

4.4. Conclusions

Rapid publishing of opportunistic observations is valuable for immediate knowledge transfer, which contributes to deciphering the overall behavioural variability of a species (McGrew, 2004; Pokharel et al., 2022). Footage posted on YouTube was considered to be “scraps, detritus”, but “some of it also treasure” (White, 2006: p. 3), as is the case with recorded unanticipated behavioural events (Nelson & Fijn, 2013). This report also emphasises the value of citizen science in collecting opportunistically recorded unanticipated events, which help chart the geographical distribution of complex behaviours and thus contribute to our understanding of the evolution of advanced animal technology.

Acknowledgements

These observations would not have been possible without the keen nature interest of the bird-watching community in Singapore. We thank Joyce Chia for providing permission to analyse the footage, further information about the opportunistic encounters, and photographs of the object-fruit combinations, Yeow-Chin Wee for his kind support in providing contact within the Singapore wildlife community, and Jeremiah Loei (BESGroup) for providing contact with bird-watchers. We thank Hugh Tan (National University of Singapore) for helping with plant identification as well as Kee Jing Ying and Sivasothi N. (National University of Singapore) for sharing their report on the presence and behaviour of Goffins in Changi Point. We thank Jessica

Lee (Mandai Nature), Anuj Jain (BirdLife International — Asia), Ding Li Yong (Nature Society — Singapore), Tan Gim Cheong (Nature Society — Singapore) and Wen Xuan Chiok for providing information about psittacine pet trade and introduced Goffins in Singapore. We thank Theresa Rössler for helpful comments on an earlier version of the manuscript. This research was funded by the Messerli Foundation. B.M. and A.M.I.A. were funded by the Austrian Science Fund (FWF), and the Vienna Science and Technology Fund (WWTF) grants awarded to A.M.I.A. (FWF START project: Y01309; WWTF project: CS18–023). M.O. was funded by the Austrian Science Fund (FWF project: J4169–B29).

References

Agoramoorthy, G. & Hsu, M.J. (2007). Ritual releasing of wild animals threatens island ecology. — Hum. Ecol. 35: 251-254.

Aplin, L.M., Major, R.E., Davis, A. & Martin, J.M. (2021). A citizen science approach reveals long-term social network structure in an urban parrot, *Cacatua galerita*. — J. Anim. Ecol. 90: 222-232.

Auersperg, A.M.I. (2015). Exploration technique and technical innovations in corvids and parrots. — In: Animal creativity and innovation (Kaufman, A.B. & Kaufman, J.C., eds). Elsevier, Amsterdam, p. 45-72.

Auersperg, A.M.I. & von Bayern, A.M.P. (2019). Who's a clever bird — now? A brief history of parrot cognition. — Behaviour 156: 391-407.

Auersperg, A.M.I., Szabo, B., von Bayern, A.M.P. & Kacelnik, A. (2012). Spontaneous innovation in tool manufacture and use in a Goffin's cockatoo. — Curr. Biol. 22: R903-R904.

Auersperg, A.M.I., van Horik, J.O., Bugnyar, T., Kacelnik, A., Emery, N.J. & von Bayern, A.M.P. (2015). Combinatory actions during object play in Psittaciformes (*Diopsittaca nobilis*, *Pionites melanocephala*, *Cacatua goffini*) and corvids (*Corvus corax*, *C. monedula*, *C. moneduloides*). — J. Comp. Psychol. 129: 62-71.

Auersperg, A.M.I., Schwing, R., Mioduszewska, B., O'Hara, M. & Huber, L. (2020). Do puffins use tools? — Proc. Natl. Acad. Sci. USA 117: 11859.

Bandini, E. & Tennie, C. (2017). Spontaneous reoccurrence of "scooping", a wild tool-use behaviour, in naïve chimpanzees. — PeerJ 5: e3814.

Bandini, E. & Tennie, C. (2020). Exploring the role of individual learning in animal tool-use. — PeerJ 8: e9877.

Bates, L. & Byrne, R. (2007). Creative or created: using anecdotes to investigate animal cognition. — Methods 42: 12-21.

Bateson, P.P.G. & Martin, P. (2013). Play, playfulness, creativity and innovation. — Cambridge University Press, Cambridge.

Bjorklund, D.F. & Gardiner, A.K. (2010). Object play and tool use: developmental and evolutionary perspectives. — In: The Oxford handbook of the development of play (Nathan, P. & Pellegrini, A.D., eds). Oxford University Press, p. 1-36.
Burn, C.C. (2011). A vicious cycle: a cross-sectional study of canine tail-chasing and human responses to it, using a free video-sharing website. — PLoS ONE 6: e26553.
Calzada Preston, C.E. & Pruett-Jones, S. (2021). The number and distribution of introduced and naturalized parrots. — Diversity 13: 412.
Chiok, W.X. & Chng, S.C.L. (2021). Trading faces: live bird trade on Facebook in Singapore. — TRAFFIC, Southeast Asia Regional Office, Petaling Jaya.
Collar, N.J. (1997). Family Psittacidae (parrots). — In: Handbook of the birds of the world. Vol. 4: Sandgrouse to cuckoos (del Hoyo, J., Elliott, A. & Sargatal, J., eds). Lynx Editions, Barcelona, p. 286-324.
Dechaume-Moncharmont, F.-X. (2020). Touchy matter: the delicate balance between Morgan's canon and open-minded description of advanced cognitive skills in the animal. — PCI Ecol. 1: 100042.
Demery, Z.P., Chappell, J. & Martin, G.R. (2011). Vision, touch and object manipulation in Senegal parrots *Poicephalus senegalus*. — Proc. Roy. Soc. Lond. B: Biol. Sci. 278: 3687-3693.
Diamond, J. & Bond, A.B. (1999). Kea, bird of paradox: the evolution and behavior of a New Zealand parrot. — University of California Press, Berkeley, CA.
Dickinson, J.L., Zuckerberg, B. & Bonter, D.N. (2010). Citizen science as an ecological research tool: challenges and benefits. — Annu. Rev. Ecol. Evol. Syst. 41: 149-172.
Dylewski, Ł., Mikula, P., Tryjanowski, P., Morelli, F. & Yosef, R. (2017). Social media and scientific research are complementary — YouTube and shrikes as a case study. — Sci. Nat. 104: 48.
Eaton, J.A., van Balen, B., Brickle, N. & Rheindt, F.E. (2016). Birds of the Indonesian archipelago. Greater Sundas and Wallacea. — Lynx Edicions, Barcelona.
Falcón, W. & Tremblay, R.L. (2018). From the cage to the wild: introductions of Psittaciformes to Puerto Rico. — PeerJ 6: e5669.
Farrar, B.G. (2020). Evidence of tool use in a seabird? — PsyArXiv: 463hk.
Fragaszy, D.M. & Adams-Curtis, L.E. (1991). Generative aspects of manipulation in tufted capuchin monkeys. — J. Comp. Psychol. 105: 387-397.
Fragaszy, D.M. & Mangalam, M. (2018). Tooling. — Adv. Stud. Behav. 50: 177-241.
Friard, O. & Gamba, M. (2016). BORIS: a free, versatile open-source event-logging software for video/audio coding and live observations. — Methods Ecol. Evol. 7: 1325-1330.
Gajdon, G.K., Fijn, N. & Huber, L. (2004). Testing social learning in a wild mountain parrot, the kea (*Nestor notabilis*). — Anim. Learn. Behav. 32: 62-71.
Gibson, J.J. (2015). The theory of affordances. — In: The ecological approach to visual perception (original work published 1979). Psychology Press, London, p. 119-135.
Gilardi, J.D. & Toft, C.A. (2012). Parrots eat nutritious foods despite toxins. — PLoS ONE 7: e38293.
Harris, L.J. (1989). Footedness in parrots: three centuries of research, theory, and mere surmise. — Can. J. Psychol. 43: 369-396.

Heinsohn, R., Zdenek, C.N., Cunningham, R.B., Endler, J.A. & Langmore, N.E. (2017). Tool-assisted rhythmic drumming in palm cockatoos shares key elements of human instrumental music. — Sci. Adv. 3: e1602399.

Homberger, D.G. (2017). The avian lingual and laryngeal apparatus within the context of the head and jaw apparatus, with comparisons to the mammalian condition: functional morphology and biomechanics of evaporative cooling, feeding, drinking, and vocalization. — In: The biology of the avian respiratory system (Maina, J.N., ed.). Springer, Berlin, p. 27-97.

Homberger, D.G. & Brush, A.H. (1986). Functional-morphological and biochemical correlations of the keratinized structures in the African Grey Parrot, *Psittacus erithacus* (Aves). — Zoomorphology 106: 103-114.

Huber, L. & O'Hara, M. (2016). Extractive foraging hypothesis, the (Parker and Gibson 1997, 2015). — In: Encyclopedia of evolutionary psychological science (Weekes-Shackelford, V., Shackelford, T.K. & Weekes-Shackelford, V.A., eds). Springer International, Cham, p. 2858-2861.

Jagiello, Z.A., Dyderski, M.K. & Dylewski, Ł. (2019). What can we learn about the behaviour of red and grey squirrels from YouTube? — Ecol. Inform. 51: 52-60.

Jepson, P., Brickle, N. & Chayadin, Y. (2001). The conservation status of Tanimbar corella and blue-streaked lory on the Tanimbar Islands, Indonesia: results of a rapid contextual survey. — Oryx 35: 224-233.

Jeyarajasingam, A. (2012). A field guide to the birds of Peninsular Malaysia and Singapore. — Oxford University Press, Oxford.

Kenward, B., Rutz, C., Weir, A.A.S. & Kacelnik, A. (2006). Development of tool use in New Caledonian crows: inherited action patterns and social influences. — Anim. Behav. 72: 1329-1343.

Kenward, B., Schloegl, C., Rutz, C., Weir, A.A.S., Bugnyar, T. & Kacelnik, A. (2011). On the evolutionary and ontogenetic origins of tool-oriented behaviour in New Caledonian crows (*Corvus moneduloides*). — Biol. J. Linn. Soc. 102: 870-877.

Khanh, T.C. (2001). *Cerbera* L. — In: Plant resources of south-east Asia no 12(2): medicinal and poisonous plants (van Valkenburg, J.L.C.H. & Bunyapraphatsara, N., eds). Backhuys, Leiden, p. 151-155.

Kiacz, S. & Brightsmith, D.J. (2021). Naturalized parrots: conservation and research opportunities. — In: Naturalized parrots of the world: distribution, ecology, and impacts of the world's most colorful colonizers (Pruett-Jones, S., ed.). Princeton University Press, Princeton, NJ, p. 71-86.

Kirksey, E., Munro, P., van Dooren, T., Emery, D., Maree Kreller, A., Kwok, J., Lau, K., Miller, M., Morris, K., Newson, S., Olejniczak, E., Ow, A., Tuckson, K., Sannen, S. & Martin, J. (2018). Feeding the flock: wild cockatoos and their Facebook friends. — Environ. Plan. E: Nat. Space. 1: 602-620.

Klump, B.C., Martin, J.M., Wild, S., Hörsch, J.K., Major, R.E. & Aplin, L.M. (2021). Innovation and geographic spread of a complex foraging culture in an urban parrot. — Science 373: 456-460.

Krueger, K., Esch, L. & Byrne, R. (2019). Animal behaviour in a human world: a crowdsourcing study on horses that open door and gate mechanisms. — PLoS ONE 14: e0218954.

Krueger, K., Esch, L. & Byrne, R. (2021). Need or opportunity? A study of innovations in equids. — PLoS ONE 16: e0257730.

Lin, R.-S. & Lee, P.-F. (2006). Status of feral populations of exotic cockatoos (genus *Cacatua*) in Taiwan. — Taiwania 51: 188-194.

Martens, J.M. & Woog, F. (2017). Nest cavity characteristics, reproductive output and population trend of naturalised Amazon parrots in Germany. — J. Ornithol. 158: 823-832.

McGrew, W.C. (2004). The cultured chimpanzee: reflections on cultural primatology. — Cambridge University Press, Cambridge.

Mioduszewska, B., O'Hara, M., Haryoko, T., Auersperg, A.M.I., Huber, L. & Prawiradilaga, D.M. (2018). Notes on ecology of wild Goffin's cockatoo in the late dry season with emphasis on feeding ecology. — Treubia 45: 85-102.

Mioduszewska, B., Auersperg, A.M.I. & O'Hara, M. (2022). Treasure islands: foraging ecology and the emergence of tool use in wild Goffin's cockatoos. — Curr. Opin. Behav. Sci. 45: 101118.

Mitchell, R.W., Thompson, N.S. & Miles, H.L. (1997). Anthropomorphism, anecdotes, and animals. — State University of New York Press, Stony Brook, NY.

Morand-Ferron, J., Cole, E.F. & Quinn, J.L. (2016). Studying the evolutionary ecology of cognition in the wild: a review of practical and conceptual challenges. — Biol. Rev. 91: 367-389.

Nature Society Singapore Bird Group Records Committee (2021). Birds of Singapore Checklist 2021 Edition. Nature Society, Singapore.

Nelson, X.J. & Fijn, N. (2013). The use of visual media as a tool for investigating animal behaviour. — Anim. Behav. 85: 525-536.

Neo, M.L. (2012). A review of three alien parrots in Singapore. — Nat. Singap. 5: 241-248.

O'Hara, M. & Auersperg, A.M.I. (2017). Object play in parrots and corvids. — Curr. Opin. Behav. Sci. 16: 119-125.

O'Hara, M., Mioduszewska, B., Haryoko, T., Prawiradilaga, D.M., Huber, L. & Auersperg, A.M.I. (2018). Extraction without tooling around — the first comprehensive description of the foraging- and socio-ecology of wild Goffin's cockatoos (*Cacatua goffiniana*). — Behaviour 156: 661-690.

O'Hara, M., Mioduszewska, B., Mundry, R., Yohanna, A., Haryoko, T., Rachmatika, R., Prawiradilaga, D.M., Huber, L. & Auersperg, A.M.I. (2021). Wild Goffin's cockatoos flexibly manufacture and use tool sets. — Curr. Biol. 31: 4512-4520.

Osuna-Mascaró, A.J. & Auersperg, A.M.I. (2018). On the brink of tool use? Could object combinations during foraging in a feral Goffin's cockatoo (*Cacatua goffiniana*) result in tool innovations? — Anim. Behav. Cogn. 5: 229-234.

Parker, S.T. (2015). Re-evaluating the extractive foraging hypothesis. — New Ideas Psychol. 37: 1-12.

Parker, S.T. & Gibson, K.R. (1977). Object manipulation, tool use and sensorimotor intelligence as feeding adaptations in cebus monkeys and great apes. — J. Hum. Evol. 6: 623-641.

Pokharel, S.S., Sharma, N. & Sukumar, R. (2022). Viewing the rare through public lenses: insights into dead calf carrying and other thanatological responses in Asian elephants using YouTube videos. — Roy. Soc. Open Sci. 9: 211740.

Ramsay, M.S. & Teichroeb, J.A. (2019). Anecdotes in primatology: temporal trends, anthropocentrism, and hierarchies of knowledge. — Am. Anthropol. 121: 680-693.

Rollin, B.E. (2000). Scientific ideology, anthropomorphism, anecdote, and ethics. — New Ideas Psychol. 18: 109-118.

Rössler, T., Mioduszewska, B., O'Hara, M., Huber, L., Prawiradilaga, D.M. & Auersperg, A.M.I. (2020). Using an innovation arena to compare wild-caught and laboratory Goffin's cockatoos. — Sci. Rep. 10: 8681.

Rutz, C. & St Clair, J.J.H. (2012). The evolutionary origins and ecological context of tool use in New Caledonian crows. — Behav. Process. 89: 153-165.

Sándor, K. & Miklósi, Á. (2020). How to report anecdotal observations? A new approach based on a lesson from "puffin tool use". — Front. Psychol. 11: 555487.

Sándor, K., Könnyű, B. & Miklósi, Á. (2021). Uncertainty in experts' judgments exposes the vulnerability of research reporting anecdotes on animals' cognitive abilities. — Sci. Rep. 11: 16255.

Sarringhaus, L.A., McGrew, W.C. & Marchant, L.F. (2005). Misuse of anecdotes in primatology: lessons from citation analysis. — Am. J. Primatol. 65: 283-288.

Scheffers, B.R., Oliveira, B.F., Lamb, I. & Edwards, D.P. (2019). Global wildlife trade across the tree of life. — Science 366: 71-76.

Schneider, L., Serbena, A.L. & Guedes, N.M.R. (2006). Behavioral categories of hyacinth macaws (*Anodorhynchus hyacinthinus*) during the reproductive period, at south Pantanal, Brazil. — Rev. Ethol. 8: 71-80.

Seed, A. & Byrne, R. (2010). Animal tool-use. — Curr. Biol. 20: R1032-R1039.

Shumaker, R.W., Walkup, K.R. & Beck, B.B. (2011). Animal tool behavior: the use and manufacture of tools by animals. — The Johns Hopkins University Press, Baltimore, MD.

St Amant, R. & Horton, T.E. (2008). Revisiting the definition of animal tool use. — Anim. Behav. 75: 1199-1208.

Sugasawa, S., Webb, B. & Healy, S.D. (2021). Object manipulation without hands. — Proc. Roy. Soc. Lond. B: Biol. Sci. 288: 20203184.

Tennie, C., Bandini, E., van Schaik, C.P. & Hopper, L.M. (2020). The zone of latent solutions and its relevance to understanding ape cultures. — Biol. Philos. 35: 55.

Tomlinson, P.B. (2016). Family: Apocynaceae. — In: The botany of mangroves. Cambridge University Press, Cambridge, p. 174-179.

Tryjanowski, P., Hetman, M., Czechowski, P., Grzywaczewski, G., Sklenicka, P., Ziemblińska, K. & Sparks, T.H. (2020). Birds drinking alcohol: Species and relationship with people. A review of information from scientific literature and social media. — Animals 10: 270.

van Valkenburg, J.L.C.H. & Waluyo, E.B. (1991). *Terminalia catappa* L. — In: Plant resources of south-east Asia no 3: dye and tannin-producing plants (Lemmens, R.H.M.J. & Wulijarni-Soetjipto, N., eds). Pudoc, Wageningen.

Westergaard, G.C. & Suomi, S.J. (1994). Hierarchical complexity of combinatorial manipulation in capuchin monkeys (*Cebus apella*). — Am. J. Primatol. 32: 171-176.
White, R. (2006). Treasure tube. — Film Q. 60: 3.
Wood, G. (1984). Tool use by the Palm Cockatoo *Probosciger aterrimus* during display. — Corella 8: 94-95.
Yeo, D.C.J. & Chia, C.S.W. (2010). Introduced species in Singapore: an overview. — Cosmos 6: 23-37.