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New records and a review of animal foods in the diets of the Brolga *Antigone rubicunda* and Australian Sarus Crane *A. antigone gillae*

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Abstract. Cranes are opportunistic omnivores, sometimes considered to be primarily vegetarian. However, there is limited knowledge in Australia of their animal prey and its importance in their diets. From field records in 2006–2021, we report novel foods including fish and crabs taken by adult Australian Sarus Cranes *Antigone antigone gillae* and the first records of the foods of their dependent young (crabs and grasshoppers). For Brolgas *A. rubicunda*, we report the first records of ducklings as prey, and of crabs, beetles and grasshoppers fed to dependent young. Both species have learnt to prey on rodents displaced or killed by sugar cane harvesting machinery in northern Queensland. A review of diet records since 1810 also reveals some overlooked foods and food-handling methods but, despite a sighting of a Brolga ingesting a whole Cane Toad *Rhinella marina*, there is no evidence of immunity to the toad's toxin in either species of crane. The plant and animal components of the diet of the dependent young of both species remain almost unknown and there are also significant knowledge gaps for the animal prey of adult Australian Sarus Cranes; the vertebrate prey of adult Brolgas; and the balance of prey types for both species in the breeding and non-breeding seasons. To advance knowledge of crane diets and nutritional ecology in Australia and New Guinea, direct field techniques including faecal sampling, collection of shed feathers and camera trapping could be undertaken, supported by remote electronic technologies in relatively inaccessible breeding wetlands. Meanwhile – in anticipation of the forthcoming revision of the *Handbook of Australian, New Zealand & Antarctic Birds* – we urge fieldworkers, birdwatchers and others to examine their field notes for unpublished information on crane foraging and food items, especially for the dependent young of Brolgas and Australian Sarus Cranes.

Introduction

The Brolga *Antigone rubicunda* and Australian Sarus Crane *A. a. gillae* are opportunistic omnivores (Marchant & Higgins 1993; Mirande & Harris 2019): like most crane species, they are considered to be primarily vegetarian, sometimes taking a range of animal prey, and adapting readily to new circumstances and foraging methods (Marchant & Higgins 1993; Allan 1996; Nevard *et al*. 2019). There are both costs and benefits for cranes in securing, handling and digesting plants, invertebrates and vertebrates. For example, populations of Sandhill Crane *A. canadensis* that rely on seeds like Maize *Zea mays* for energy also prey on animals, which take more time to collect and process but give additional protein and elements such as calcium and phosphorus to support them during daily movements, migration and breeding (Reinecke & Krapu 1986; Roessingh 2012). Invertebrates and vertebrates are both high in protein and birds metabolise a similar proportion of the energy that these provide (Karasov 1990), but vertebrates may offer more micronutrients including calcium (e.g. Phalen *et al*. 2005). Although Brolgas and Australian Sarus Cranes are believed to be relatively sedentary or to undertake only intra-regional migration (Veltheim 2018; Nevard *et al*. 2020; Veltheim *et al*. 2022), nutritional demands increase during breeding (e.g. for egg formation by females, and the survival and growth of young), and in response to marked variations in wetland and other habitats. Diet has implications for other aspects of crane ecology, for example as noted by Veltheim (2018), digestion times determined by different food types may influence daily movements between foraging and wetland refuge sites. However, there have been only limited studies of crane diets and nutritional needs in breeding or non-breeding (flocking) habitats in Australia.

In the Ord River Irrigation Area in the Kimberley region of Western Australia, Gowland (1989) investigated loss of grain crops to birds, including large numbers (1000+) of Brolgas in the flocking seasons of 1978–1981. He collected 54 Brolga specimens and, from the stomach contents, found that 93.4% of diet by volume was from plants and 6.6% from invertebrates such as grasshoppers and larvae of a crop pest, the Northern Armyworm *Mythimna separata*. He estimated that an adult Brolga needed ~150 g of food per day if most of the diet was grain, but found no evidence of vertebrate prey from stomachs or from 10,596 field observations over 3 years. Extensive field surveys were conducted on coastal wetlands in North Queensland from 1959 to the 1970s (e.g. Lavery 1964) and hundreds of Brolga specimens were collected (Blackman 1971). However, only general statements were published on foods, foraging methods and the seasonal importance of Bulkuru Sedge *Eleocharis dulcis* tubers in the Brolga's diet (e.g. Lavery & Blackman 1969; Blackman 1983a).

Brolgas and Sarus Cranes are sympatric in northern Queensland. In the Gulf Plains, North West Queensland. Sundar *et al*. (2019) collected feathers shed by preening Sarus Cranes and Brolgas in the breeding season: analysis of stable isotopes showed that Sarus Cranes had a more herbivorous diet and Brolgas fed on a wider trophic range of foods. In the flocking season on the Atherton

Tablelands, Far North Queensland, Nevard *et al*. (2019) found that both species were seen to ingest small non-seed items while foraging on post-harvest crop residues. Most of these had the appearance of unidentified beetle larvae ('grubs'), although some might have been other unidentified invertebrates or, much more rarely, small vertebrates.

There are many anecdotal reports of adult Brolgas preying on a wide range of invertebrates, but much is still unknown about their vertebrate prey. For wild adult Sarus Cranes, Marchant & Higgins (1993) cited two records of animal prey (grasshoppers in the Gulf Plains and rodents on the Atherton Tablelands: Walkinshaw 1973; Archibald & Swengel 1987), but no data on any foods of their dependent young. Arnol *et al*. (1984) noted the paucity of data on the foods of Brolga chicks. Marchant & Higgins (1993) cited only 'indirect' evidence of insects in the chicks' diet, later enhanced by records of seeds of rushes *Juncus* sp. (Herring 2001) and insects and spiders (Reardon 2007). In this paper we present new records of animal prey of Sarus Cranes and Brolgas and their dependent young in Australia, and review evidence of their animal prey from 1810 to the present. We also consider possible avenues for further work to investigate crane diets in Australia, including the almost unknown diets of their dependent young.

Methods

We searched for reports of stomach contents or faecal analyses for the Brolga and Australian Sarus Crane. TDN and JDAG extracted records from field surveys in northern Queensland in 1995–2020 and 1996–2021, respectively. We focused our search for other records on the knowledge gaps noted above, namely: animal foods of adult Australian Sarus Cranes; vertebrate foods of adult Brolgas; and all foods of dependent young of both species. We searched literature, archives including newspapers (Trove, National Library of Australia), volunteer bird records (eBird) and the image database Flickr. Searches included records from other populations of Sarus Cranes and aviculture. To avoid duplication, we excluded general texts such as field guides, and in sources on natural history we selected only the first available report of each food type or foraging method. In texts from the 19th and early 20th centuries, and still today among rural and indigenous people, herons and egrets (*Ardea* or *Egretta* species) in Australia and New Guinea are often mistermed 'crane': we ensured that all selected reports referred only to Brolgas ('Native Companions'). We appealed on social media for records and images of vertebrate prey taken by Brolgas and any animal prey taken by Sarus Cranes in Australia. We noted whether observations were made in the breeding or flocking season and whether sources were direct observations, or part of an account compiled from multiple records.

We refer to young cranes as 'chicks' when they are still downy, up to *c*. 14 days old. 'Unfledged young' refers to all young from hatching until they can fly, at *c*. 3 months of age (thus 'fledged young' can fly, from *c*. 3 months). 'Dependent young' still rely on receiving food from the adults, even if partly foraging for themselves, that is from hatching up to *c*. 5–6 months of age. Quotations are verbatim except where ellipses indicate omitted text and square brackets indicate our additions. Queensland regions (e.g. North Queensland, North West Queensland and Far North Queensland) are as defined by the Queensland Government (2022) and 'northern Queensland' refers to Queensland north of the Tropic of Capricorn generally.

Results

Field observations and specimens

New field observations of animal prey taken by Australian Sarus Cranes and Brolgas are presented in Table 1. These include the first reports of food items for dependent young of Australian Sarus Cranes [crabs (Decapoda) and grasshoppers (Orthoptera)] and the first records of fish and crabs in their adult diet (Figure 1). Dependent Brolga young were observed being fed crabs (Crustaceae), beetles (Coleoptera) and grasshoppers (Orthoptera) (Figures 2–3). Field records also included novel foraging methods: adult Sarus Cranes were photographed probing deeply into cracks in dry ground to extract crabs in North West Queensland (Figure 1) and both species have learnt to prey on rodents displaced (this study) or killed (Figure 4) by sugar-cane-harvesting machinery in northern Queensland. Although there are several records of Brolgas taking fish (Marchant & Higgins 1993; this study), there is only one known image of this behaviour, on video (Taylor & Horne 1972; H.J. Lavery pers. comm.). The sighting of an adult Brolga swallowing a Cane Toad *Rhinella marina* (Roberts 2011) is the first record of this toxic amphibian as prey of a crane in Australia (see Discussion). For Brolgas in Victoria, D.M. White and P. Du Guesclin contributed reports of adults taking ducklings and a small rodent. Records from crane stomachs in Australia from 1844 to 1979 are shown in Table 2. These include a probable reference to frogs for Brolga, but no trace of animal foods for Sarus Crane. Samples of stomach contents from 579 Brolga specimens

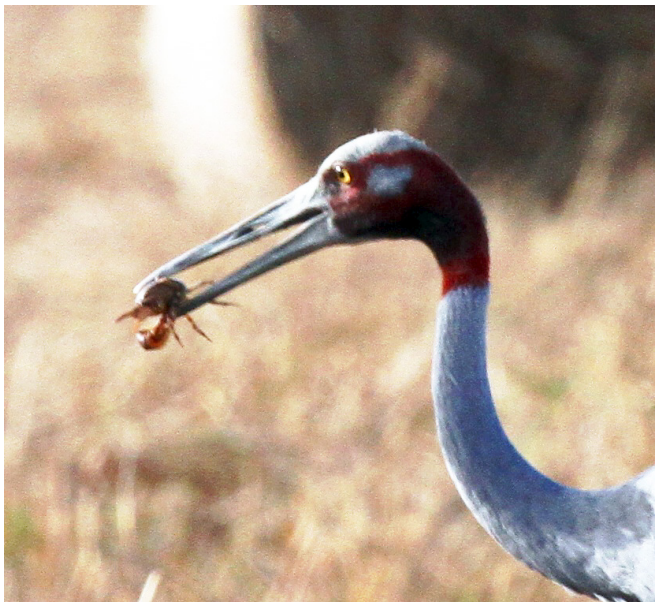

Figure 1. Adult Sarus Crane eating crab, Miranda Downs, North West Queensland, June 2014. The crane probed into deeply cracked clay in a harvested hay paddock to extract the crabs. Photo: Timothy D. Nevard

Table 1. New field observations of animal prey of Australian Sarus Cranes and Brolgas recorded in this study. Species: B = Brolga, SC = Sarus Crane. Location: FNQ = Far North Queensland, NQ = North Queensland, NWQ = North West Queensland, SEQ = South East Queensland, SWV = south-western Victoria. Source/observer: DMW = D.M. White, IV = Inka Veltheim, JDAG = John D.A. Grant, PDG = Philip Du Guesclin, TDN = Timothy D. Nevard. Season: Br = breeding, Fl = flocking, ns = not stated. Dates are given as day/month/year

Crane	*Prey*	*Season: date*	*Location*	*Details*
SC	Crabs	Br: May 2006 and 2012	Gulf Plains, NWQ	Adult Sarus Cranes on breeding territories (e.g. borrow pits) eating crabs & feeding them to young (JDAG)
B	Small frogs	Fl: 1745 h–dusk, 12/8/2006	Mareeba Wetlands, Biboohra, FNQ	5 adults, 2 young of the year catching and eating small frogs and aquatic invertebrates in heavily vegetated shallow water (TDN)
B	Cane Toad *Rhinella marina*	Fl: 18/10/2011	Toorbul, SEQ	Adult-size toad swallowed whole. Foraging in tall flooded grass (Roberts 2011)
B	Rat (Canefield?)	Fl: 24/6/2012	Ingham, NQ	Rat killed by cane harvester, scavenged by B, removed to cover to eat (Figure 4, Ashton 2012)
B	Crabs and grasshoppers	Br: April 2014	Normanton, Gulf Plains, NWQ	Pair feeding chick (Figure 1, TDN)
B	Crabs and beetles	Br: May 2014	Miranda Downs, Gulf Plains, NWQ	Feeding unfledged young (Figure 2, TDN)
SC	Crab	Fl: 3/6/2014	Miranda Downs, Gulf Plains, NWQ	Probing bill into deep cracks in clay to extract crabs (Figure 3, TDN)
SC	Mice (sp. ?)	Fl:1700 h–dusk, 4–5/6/2014	Miranda Downs, Gulf Plains, NWQ	5 adults catching and eating mice in harvested hay paddock (TDN)
SC	Mouse (sp. ?)	Fl: 0715 h, 11/7/2015	Innot Hot Springs, FNQ	1 adult catching and tossing mouse before eating
B	Small rodents (sp. ?)	Fl: 2015	Bromfield Swamp, Tablelands, FNQ	Hunting like herons in grass adjoining swamp (TDN)
B & SC	Rats (Canefield?)	Fl: 1215–1300 h, 19/10/2016	Arriga, Mareeba Shire, FNQ	Flock (Bs + a few SCs) catching and eating rats on edge of sugar cane crop being harvested (TDN)
SC	Small fish	Fl: 1453 h, 20/7/2020	Normanton, Gulf Plains, NWQ	In a freshwater pool, depth to full length of leg (images: Dunne 2020)
SC	Grasshoppers	Br/Fl: May 2021	Normanton, Gulf Plains, NWQ	Adults and fledged young feeding on grasshopper swarms (JDAG & IV)
B	Ducklings	ns: pre 1983	SWV	Pummelled until they break up or swallowed whole (DMW)
B	Small rodent	Fl: *c*. 2000	Stavely, SWV	Captured prey on cereal stubble, mobbed by other Bs (PDG)

collected in North Queensland from 1959 to the 1970s (Blackman 1971) were disposed of in *c*. 2010 (C. Smith pers. comm.), without publication and apparently without analysis (see Discussion). To our knowledge there have been no studies of faecal samples from cranes in Australia.

Literature review

Results of a literature review of vertebrate prey of the Brolga and Sarus Crane are shown in Appendix 1. Detailed records of vertebrate prey of wild Sarus Cranes were available only for the well-studied Indian population *A. a. antigone*, including multiple species of amphibians and reptiles and a recent, novel report of an adult pair feeding their chick with dismembered Grey-headed Swamphen *Porphyrio poliocephalus* nestlings (Wahraich & Sundar 2022). Archibald *et al*. (2003) listed snakes as a food of Australian Sarus Cranes (apparently on the Atherton Tablelands) but the details and source are unknown, and we found no records of Australian Sarus Cranes preying on amphibians. Records of captive cranes included novel observations of Brolgas preying on live Guinea Pigs *Cavia porcellus* (Anon. 1902) and methods used by (Indian) Sarus Cranes to process (probably previously killed) mammals and birds (Hartert & Young 1928). We found no records of animal prey taken by captive Australian Sarus Cranes; the International Crane Foundation (C. Gitter & G.W. Archibald pers. comm.) advised that captive Sarus Cranes seen preying on live House Mice *Mus musculus* in the United States of America (Brown & Archibald 1977; Marchant & Higgins 1993) were not the Australian subspecies. We found no records of animal prey of Brolgas in New Guinea. Marchant & Higgins (1993) cited Rand & Gilliard (1967, p. 106) for Brolgas in New Guinea using the bill as a “hammer or spear” to kill prey such as snakes, but Rand & Gilliard made no direct statement about Brolga diet or foraging in New Guinea; the quoted text is in their introduction to the family Gruidae in general. Very few anecdotal diet records could be attributed to season (breeding/flocking). Although some eBird (2020) observers reported foraging by either or both species, they did not

Figure 2. Brolga feeding an unfledged chick on crabs and grasshoppers in open wet sedge/grass pasture, Normanton, North West Queensland, April 2014. Photo: Timothy D. Nevard

Figure 4. Brolga taking a rat (probably Canefield Rat), killed by a sugar-cane harvester near Ingham, North Queensland, June 2012. Photo: Tony Ashton

note the foods taken; similarly, the Flickr database (2022) yielded several images of Brolgas feeding young in the wild but provided no information on food items. To date, we have received no response to our appeal for images or records from social media. The accuracy of some natural history accounts of Brolgas taking vertebrate prey, and the implications for understanding the Brolga's foraging ecology, are considered in the Discussion.

Discussion

More than 200 years after the Brolga was first described as a species (Perry 1810) and nearly 60 years after the

Figure 3. Brolga feeding crab to fledged young in mown grass close to homestead, Miranda Downs, North West Queensland, May 2014. Young were also fed beetles. Photo: Timothy D. Nevard

Sarus Crane was first recorded in Australia in 1966 (Gill 1969), there are still major gaps in our knowledge and understanding of the foraging ecology of these species. For flocking Brolgas, time spent variously on foraging, loafing or interacting during the day depends on habitat quality (King 2008), but for both species only fragments of information are known on food items, prey capture and handling techniques, needs at different ages, intake, adjustments of diet by season (breeding/flocking), or in different habitats or environmental conditions.

The importance of animal foods in diets

Allan (1996) cautioned against assuming significant carnivory in crane species without year-round dietary analyses, which are not available for Australian cranes. As well as crop damage that affected them economically (e.g. Bransbury 1991), early European settlers in Australia tended to report Brolgas capturing noticeable vertebrates and the number of these reports could overemphasise the importance of animal foods in the Brolga's diet. Even so, studies of foraging by Brolgas and Sarus Cranes in northern Queensland in both the flocking and breeding seasons (Nevard *et al*. 2019; JDAG unpubl. data) have resulted in additional observations of animal prey, notably rodents (this study), and the extent of carnivory in adults is probably under-represented by anecdotal accounts.

For dependent young of both species – except for one record of seeds fed to Brolga chicks (Herring 2001) – known diet items in Australia are all animals (Reardon 2007; this study), which may overemphasise the importance of animal foods in the diets of young. Moreover, although growing young need protein, the appropriate proportions and types of animal foods suitable for them are likely to be limited. Serafin (1982) found that leg and wing abnormalities in captive crane chicks were caused by diets too high in protein, especially sulphur amino acids (SAAs): he recommended no more than 24% protein and

Table 2. Diet items from stomachs of Brolgas and Australian Sarus Cranes, 1844–1979, reported in the literature. Species: B = Brolga, SC = Sarus Crane; sex where specified: F = female, M = male. Season: All = all seasons, Br = breeding, Fl = flocking, ns = not stated. Locations: FNQ = Far North Queensland, KIM = Kimberley region, Western Australia, NQ = North Queensland, SEQ = south-eastern Queensland. *Specimen from the Atherton Tablelands, FNQ (Queensland Museum O11076; H.J. Lavery pers. comm.).

Date	*Species (& no. & sex)*	*Season*	*Location*	*Details*	*Source*
Oct. 1844	B (1 F)	Fl	SEQ	Many large pebbles, seeds of swamp grass, beetles, vegetable matter	Chisholm (1944)
All months, 1959–1971	B (321 M) B (217 F) B (16 subadult) B (18 yearling) B (7 young of year)	All	NQ	Teeth, bones and barbed wire explicitly stated (other items probably identical to field observations from sources cited: tubers, invertebrates, frogs, crops)	Lavery & Blackman (1969); Blackman (1971)
1965–1968	B (1)	ns	NQ	Bulkuru Sedge tubers, grasshoppers, other unidentified insects	Lavery (1969)
Oct. 1967	SC (1)*	Fl	FNQ	Presumed, from source: maize seeds, native grasses	Lavery & Blackman (1969)
May 1968	B (1 M)	Fl	KIM	Tubers, pebbles	Hall (1974)
1963–1978	B (2)	ns	ns	Plant remains; seeds	Barker & Vestjens (1979)
1978–1979	B (54)	All	KIM	Full details in source. By volume: plants 93.4%, invertebrates 6.6%	Gowland (1989)

0.73% SAAs in diets of captive cranes. These thresholds may not be as critical in populations (e.g. in Australia) which are sedentary or migrate only intra-regionally, and have a slower rate of growth and a more consistent food supply (Serafin 1982), but freshwater crabs (as reported for young of both species: this study) contain a high proportion of SAAs, ~6% (Mukandan *et al*. 1981). Some invertebrates have a lower but still significant proportion, for example Wiesenborn (2012) tested arthropods in restored riparian habitat in Arizona, USA, and found that sulphur content varied by order and trophic level: spiders contained 1.4%, insect predators such as assassin bugs 0.73%, and herbivores such as grasshoppers 0.64%. In the Gulf Plains, North West Queensland, large swarms of grasshoppers can appear in the cranes' breeding season (e.g. Anon. 1912) and continue for several months (Walton *et al*. 2003), and may be an important food source for young, growing cranes. Protein low in SAAs may also be gained from plant foods including seeds, but this needs further investigation.

The effect of soil fertility on the plant and animal foods of Australian cranes is unknown. Most Australian soils are low in plant macronutrients, resulting in low-nutrient vegetation, which has affected in many and varied ways the diets of Australian fauna (Orians & Milewski 2007). However, the tubers of Bulkuru Sedge have high nutritional value (Blackman 1983a) and, following extensive use of fertilisers and soil-conditioners, large areas of cropped land and improved pasture now have enhanced fertility (Price 2006). Moreover, some smaller cropped areas, such as the Atherton Tablelands, are naturally fertile (Malcolm *et al*. 1999) and are used annually by large numbers of cranes (Nevard *et al*. 2020; Scambler *et al*. 2020). In this context, the primarily vegetarian diet of breeding adult Sarus Cranes in the Gulf Plains (Sundar *et al*. 2019) – based on C3 plants apparently unaccompanied by an increase in animal foods – is notable. Plants with the C3 photosynthetic pathway are generally considered to have higher nutritional value and protein levels than plants with the C4 pathway (Barbehenn *et al*. 2004). In the non-breeding season, Sandhill Cranes, like Sarus Cranes on the Atherton Tablelands, forage more on C4 plants, particularly maize, and switch to more C3 plants during breeding (Heckathorn *et al*. 1999; Boggie 2018). However, Sandhill Cranes increase consumption of animal foods at this time (Mullins & Bizeau 1978; Roessingh 2012), as do Sarus Cranes in India while breeding (Mukherjee 1999). Even so, and notwithstanding generally low regional soil fertility, Sarus Cranes in the Gulf Plains have one of the highest rates of breeding success of all world cranes (Sundar *et al*. 2019; JDAG unpubl. data). A detailed investigation of diet in the flocking season on the Atherton Tablelands and sources of protein in the Gulf Plains breeding grounds could help explain this apparent anomaly.

Animal foods, food handling and learning by the young

Anecdotal natural history records from 1810 provide valuable information on animal prey of adult Brolgas. Although Fountain and Ward's (1907) book was (rightly) subject to considerable criticism for inaccuracies (e.g. Anon. 1907; Whittell & Serventy 1947), the items of animal prey that they listed for the Brolga were all either previously or subsequently confirmed by other, reliable observers, including "the young of marsh-breeding birds" (Fountain & Ward 1907, p. 34; D.M. White pers. comm.). Sandhill Cranes in Idaho, USA, prey opportunistically on the nestlings (and eggs) of several bird species in breeding wetlands (Harvey *et al*. 1968; Mullins & Bizeau 1978) and recently, for the first time, Brolgas have been recorded preying on eggs (of Australasian Grebe *Tachybaptus*

novaehollandiae: Dunne & Scambler 2020). The taking of rodents disturbed by cane harvesters and records of Brolgas pecking the eyes of fallen stock in droughts (this study) underline the adaptability of cranes to diet opportunities, arising from agriculture, for animal foods in addition to their better-studied exploitation of grain crops. The array of amphibians and reptiles taken by Brolgas and by Indian Sarus Cranes suggests that, where available, these are also potential prey items for Australian Sarus Cranes. However, we consider that it is still unknown whether cranes can safely consume Cane Toads. Roberts (2011) recorded a Brolga swallowing a Cane Toad whole with no immediate effect, but was able to monitor the bird for only a short time (G. Roberts pers. comm.). Beckmann & Shine (2009, Appendix S3) assumed that "cranes, *Grus* sp." could safely consume the toad. Their view was based on a report by Covacevich & Archer (1975, p. 309), who relied upon a *pro forma* response to a community survey, stating "Crane; ingesting; no effects reported". As noted above, the term 'crane' has long been in popular use in Australia for other waterbirds and, moreover, was very rarely applied to Brolgas. We argue that this survey response cannot be interpreted to assume safe ingestion of Cane Toads by cranes and that it should be discounted. Nevertheless, in Florida, USA, where the range of the closely related Giant Toad *R. horribilis* is expanding, there are no reports of apparent injury to Sandhill Cranes or of that species feeding on the toads (T. Dellinger pers. comm.). Captive Whooping Cranes *Grus americana* have been seen capturing, but then spitting out, toxic American Toads *Anaxyrus americanus* (C. Mirande pers. comm.).

The estimated weights of mammalian prey (Wilson & Reeder 2005) reported for Brolgas and Sarus Cranes ranged from ~40 g (House Mouse), through 160 g (Canefield Rat *Rattus sordidus*) to ~400 g (small Guinea Pig). The food items and foraging and handling methods described in the results of our review (Appendix 1) are consistent with observations of food and behaviour of Brolgas, Sarus Cranes and other crane species in the wild (Walkinshaw 1973; Marchant & Higgins 1993; Mukherjee 1999; this study) and in captivity (e.g. Brown & Archibald 1977). Smaller prey is speared or grasped and crushed with the bill and swallowed whole, sometimes first being tossed into the air; larger prey is dismembered. Observations of captive Brolgas and Sarus Cranes dipping and shaking mammalian prey in water have been interpreted as drowning prey (Anon. 1902), 'washing' (in the sense of cleansing), or making it easier to swallow (Hartert & Young 1928). Young cranes learn new food types and feeding behaviours from the adults while still dependent (Horwich 1996), including for vertebrate prey, for example Whooping Cranes teach young to forage on vertebrates by half-killing them and laying them beside the young to process and eat (Caven *et al*. 2021). Cranes also learn from watching others forage in the social (flocking) season or by individual learning through trial and error. Over time, these individual learnings are acquired by others and become traditional across populations (Geluso *et al*. 2013; Barzen *et al*. 2018; Teitelbaum *et al*. 2019). For example, Blackman (1983b) considered that foraging by Brolgas on Bulkuru Sedge was traditionally learnt, implying that this learning occurred socially in the flocking season. It is therefore possible that Brolgas recorded taking vertebrate prey in captivity are exhibiting skills and diet preferences learnt in the wild, or learnt from originally wild parents.

Future diet studies

Methods of studying diet have differing advantages and disadvantages. Stomach contents depend on the stage of feeding and digestion of the animal when killed: soft foods, or parts of foods, are digested quickly, and cranes ingest large amounts of grit and pebbles which may grind food into unidentifiable fragments. Faecal sampling is non-invasive but may not be fully informative in isolation. For example, Luo *et al.* (2015) found that maize, other seeds and fish were the most common residues in stomachs of Red-crowned Cranes *Grus japonensis*, but faeces contained remnants of reeds and tiny animals from lake sediments; they recommended combining both methods. Comparison of results from faecal sampling of four crane species at Poyang Lake, China, with observational records found that such sampling under-reported soft foods such as insect larvae, which are digested before defaecation, and over-represented foods with hard remains such as molluscs (Hou *et al*. 2021).

The destruction of samples from 579 Brolga stomachs reportedly taken in North Queensland between 1959 and the 1970s (Blackman 1971) – without analysis or publication of results – remains both a mystery and a tragedy of Australian ornithology. The birds were collected for a major study on diet (including crop damage) and population size and fluctuations, initially by the Fauna Conservation Branch of the Queensland Department of Primary Industries (Blackman 1971). Its successor organisation, the Queensland (National) Parks and Wildlife Service, concentrated on other priorities such as landscape-scale mapping and studies of important wetlands in Queensland (e.g. Blackman *et al*. 1999). Only biometric data and general comments on Brolga diet were published in several articles up to 1971 (e.g. Lavery & Blackman 1969; Blackman 1971). Stomachs are now unlikely to be available for study in Australia except from deaths of cranes by accident, yet recommendations (e.g. for cranes killed on powerlines on the Atherton Tablelands) to be secured for research (Ozcranes 2016), have yet to be taken up.

Faecal sampling, observational studies, including by fixed cameras and stable-isotope analyses of shed feathers, are the most likely sources of future data on crane diets in Australia. These direct field methods are feasible in more accessible regions, but some breeding wetlands such as the Gulf Plains nesting habitat of Sarus Cranes (and sympatric Brolgas) are almost inaccessible in the wet season and traditional observational fieldwork is extremely difficult. The use of drones, data loggers and other electronic technologies could facilitate the gathering of data in the wet season and new studies should attempt to incorporate these methods. In the meantime, we urge fieldworkers, birdwatchers and wetland managers in Australia to examine their field notes for unpublished information on crane foraging and food items, especially for the dependent young of Brolgas and Sarus Cranes.

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Appendix 1. Published records of vertebrate prey of Brolga and Sarus Crane in 1810–1999, in taxonomic order (ICZN 2022), excluding eggs (for eggs, see Dunne & Scambler 2020). Record type: C = compilation, O = direct observation. Season: Br = breeding, Fl = flocking, ns = not stated. Location abbreviations: AU = Australia, FNQ = Far North Queensland, NQ = North Queensland, NSW = New South Wales, NT = Northern Territory, Pt = Point, UK = United Kingdom, USA = United States of America, Vic. = Victoria, WA = Western Australia; ns = not stated. *Most were dead before being fed to captive birds. We exclude Marchant & Higgins' (1993) citation of Gowland (1989) for 'frogs' in the Brolga diet; Gowland (1989) cited Lavery & Blackman (1969) for frogs and reported no vertebrates from his study.

(a) Vertebrate prey and food-handling behaviour of Brolga

Prey	*Record type*	*Season*	*Location*	*Details*	*Source*
Fish					
Barred Mudskipper *Periophthalmus argentilineatus*	O	Fl	Townsville, NQ		Walkinshaw (1973)
Sea Mullet *Mugil cephalus*	O	ns	Congewoi Pt, Lower Hawkesbury, NSW	Brolga watched pool intently; head and neck dipped rapidly into water, up with fish held in bill; took flight holding fish; swooped by Eastern Osprey *Pandion cristatus*, dropped fish	Smith (1862)
Eels	C	ns	AU		Fountain & Ward (1907); Roberts (1943)
Fish	C	ns	AU		Perry (1810); North (1913–1914)
Small fish	O	ns	NT	Stabbed in pool, lifted head, fish in mandibles, head back and swallowed	S. Clegg in Marchant & Higgins (1993)
Small fish	O	ns	AU	Occasionally	Blackman (1983b)
Fish	O	ns	Townsville, NQ	(Image) ~17 cm, held in bill	Taylor & Horne (1972)
Amphibians					
Frogs	O	ns	Orange, NSW		W.M. Thomas in North (1913–1914)
Frogs	O	ns	Northern Vic.	Stand in a reedy swamp on one leg for hours at a time catching frogs and other prey	E.J. Christian in Mathews (1913–1914)
Frogs	C	ns	AU	Standing on one leg in swamp for hours	Perry (1810)?; Anon. (1860); Fountain & Ward (1907); North (1913–1914)
Frogs	O	ns	NT; FNQ		Lavery & Blackman (1969); S. Clegg in Marchant & Higgins (1993)
Reptiles					
'Aquatic reptiles'	O	ns	AU	"It searches, with much patient care and attention, on the banks of stagnant pools and rivers in the manner of our own English Heron"	Perry (1810)
Small reptiles	C	ns	AU		North (1913–1914)
Lizards	O (& C?)	ns	Hunter River, northern NSW		Gould (1848)
Lizards	C	ns	Darling River central NSW		Fountain & Ward (1907)
Snakes	C	ns	AU		Campbell (1901); Fountain & Ward (1907)
Snake	O	Fl	Fitzroy River, north-western WA	"Two feet" long: beaten on ground a few times before swallowing	G.A. Keartland in North (1913–1914)
Small carpet snake	O	ns	Captivity, NQ		Anon. (1906)

Appendix 1a continued

Prey	*Record type*	*Season*	*Location*	*Details*	*Source*
Birds					
Young of marsh-breeding birds	C	ns	Darling River, central NSW	Often	Fountain & Ward (1907)
Eyes and brain of pet Black Swan	O	ns	Captivity, Geelong Vic.	Pet Brolga pecked out eyes and brain of pet swan	Anon. (1851)
Domestic fowls	O	ns	Northern Vic.	"Wringing their necks"	E.J. Christian in Mathews (1913–1914)
Birds	C	ns	Vic.	See Table 1	White (1987)
Mammals					
House Mouse *Mus musculus*	O	Br	Captivity, USA	Live mice: jabbed with bill, threw in air, swallowed	Brown & Archibald (1977)
House Mouse	O	ns	Captivity, NQ & NSW	Pet Brolgas took mice (caught in house traps), swallowed whole	Macdonald (1913); Devaney (1939)
Guinea pig *Cavia porcellus*	O	ns	Captivity, NQ	Strode after prey, seized in bill, held underwater to drown, swallowed	Anon. (1902)
*Mice	O	ns	Captivity, NT	1–2 mice daily in Brolga diet	Veyret (2006)
Rodents	O	Fl	Atherton Tablelands, FNQ	In maize stubble; walk slowly, search with heads down, grasp food items	Archibald (1981); Archibald & Swengel (1987)
Rats	O	ns	Darling River, central NSW		Fountain & Ward (1907)
Calves *Bos taurus*, Sheep *Ovis aries*	C	ns	AU	Pecked out eyes of fallen calves and sheep	Anon. (1881); North (1913–1914)

Appendix 1 continued

(b) Vertebrate prey and food-handling behaviour of Sarus Crane

Sarus Cranes in captivity were Indian or Eastern Sarus Cranes *A. a. antigone* or *A. a. sharpii*. As well as the vertebrates listed below, breeding Sarus Cranes in India also consumed large numbers of invertebrates.

Prey	*Record type*	*Season*	*Location*	*Details*	*Source*
Fish					
Catfish *Clarias magur*	O	ns	Captivity, India	Recently wild, took live fish from domestic vessels	Law (1930)
Fish in paddy fields, marshes & canals	O	Br	Gujarat, India	Manipulate in bill, swallow with jerk (head up); size to length of bill: 17–18 cm	Mukherjee (1999)
Fish	O	Br	Captivity, USA	Picked up dead fish, thrashed it back and forth in water, then swallowed whole	Walkinshaw (1947)
Amphibians					
Six identified species	O	Br	Gujarat, India	Chased, pecked with open bill, held tightly, hammered on ground and swallowed	Mukherjee (1999)
Large frog	O	Fl	Bharatpur, India		Spitzer (1979)
Frogs	O	ns	India		Hume & Marshall (1879); Baker (1929)
Reptiles					
Three identified species of skink	O	Br	Gujarat, India		Mukherjee (1999)
Fan-throated Lizard *Sitana ponticeriana*	O	Br	Gujarat, India		Mukherjee (1999)
Checkered Keelback *Fowlea piscator*	O	Br	Gujarat, India	Snakes 15–50 cm length; Shaken side to side, hammered; sometimes foot also used to hold prey; consumed in 1–2 jerks	Mukherjee (1999)
Checkered Keelback	O	Fl	Bharatpur, India	Pushed snake underwater multiple times, then thrashed on ground, swallowed whole	Walkinshaw (1973)
All small reptiles	O?	ns	India		Hume & Marshall (1879)
Lizards	C	ns	India		Baker (1929)
Water snakes	O	Fl	Bharatpur, India	Seized by head, shaken until limp	Spitzer (1979)
'Snakes'	O	ns	Tablelands, FNQ?		Archibald *et al*. (2003)
Birds					
*House Sparrows *Passer domesticus*	O	ns	Captivity, UK	'Wash' in water; tear and shake off tails and wings before eating, rest swallowed whole	Hartert & Young (1928)
Nestlings of Grey-headed Swamphen, *Porphyrio poliocephalus*	O	Br	India	Dismembered and fed to chick	Wahraich & Sundar (2022)
Mammals					
House Mouse *Mus musculus*	O	Br	Captivity, USA	Threw live mouse in air 3 times before eating	Brown & Archibald (1977)
*House Mouse	O	ns	Captivity, UK	'Wash' in water, swallow whole	Hartert & Young (1928)
Rodents	O	Fl	Atherton Tablelands, FNQ	In maize stubble; walk slowly, search with heads down, grasp food items	Archibald (1981); Archibald & Swengel (1987)
*Rats, *European Mole *Talpa europaea*	O	ns	Captivity, UK	'Wash' in water, crush and shake until most skin comes off	Hartert & Young (1928)