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Reproductive parameters in some captive-bred cockatoo species (genus *Cacatua* and *Eolophus*)

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ABSTRACT

Background Cockatoo reproduction in captivity supplies a powerful tool to limit the economic motivation to capture endangered species from the wild; nevertheless, scientific data about reproductive parameters in cockatoos are very rare. The aim of the present work was to investigate the reproductive performance of different species of the *Cacatua* genus reared in the same facility to evaluate adaptability to captive breeding and to identify the main problems in ex situ conservation of some cockatoo species.

Methods Data of 28 eggs from 19 reproductive pairs from 9 cockatoo species were analysed. Statistical analysis was carried out by SAS NPAR1WAY procedure: species was considered source of variation.

Results Species effect does not significantly influence reproductive variables; differences were recorded in eggs fertility and embryo liveability. Bird adaptive ability to captive breeding has been described through reproductive parameters.

Conclusion Our results show the importance and the maintenance of natural species-specific behaviours and habits, and they underline the relevance of data collection about reproductive performance in endangered species kept in captivity to improve breeding management in conservation programmes.

INTRODUCTION

Cockatoos species are worldwide well known as pet birds[1]; their high economical value very often support the illegal trade of these endangered exotic species. Captive reproduction of cockatoos supplies a powerful tool for reducing the economic motivation to capture endangered species of birds from the wild.[2 3] Effective captive breeding programmes require high reproductive efficiency to be successful[4]; however, scientific data about reproductive parameters in cockatoos are very rare, considering the high number of species belonging to the genus *Cacatua*.

The term 'cockatoo' refers to 21 avian species belonging to the family Cacatuidae.[5] Cockatoos, together with the species belonging to the family Psittacidae (generically referred to as 'parrots'), form the order Psittaciformes. Some features differentiate cockatoos (Cacatuidae) from parrots (Psittacidae): most cockatoos show sexual dimorphism (even if it often is slightly visible), and they usually have monochromatic or dichromatic colourations. Cockatoos also have a typical geometrical feathering structure, without the shining and brilliant colours of the birds belonging to the family Psittacidae, because of the absence of the structure called 'dyck texture'. However, the most particular attribute is the typical and showy erectile crest on the cockatoos' head.[6] Other differences concern anatomical and physiological aspects, because Cacatuidae, differently from Psittacidae have a different disposition of the carotid arteries and have some differences in the cranial bones.[6] According to a recent work[7] revising nomenclature and classification for Psittaciformes family–group taxa mainly based on molecular investigation, cockatoos cluster in a separate group in parrot phylogeny. The genus studied in the present work includes *Eolophus* and *Cacatua*, part of the Tribe Cacatuini, subfamily Cacatuinae, family Cacatuidae, superfamily Cacatuoidea; the other superfamilies of order Psittaciformes are Strigopoidea and Psittacoidea.[7 8] The cockatoos present an area more confined than proper parrots' territory, because wild cockatoos live only in Australia and near islands. Eleven species live only on the Australian territory; 7 species live in Indonesia, New Guinea and other South Pacific islands; finally, 3 species live both in New Guinea and Australia.[9] Cockatoos mainly populate three different territory types: dense forests characterised by a high level of temperature and humidity, flat grassy countries and arid zones of savannah; in nature, cockatoos mainly eat nuts, fruits and seeds. Sometimes, the diet is integrated

Table 1 Morphological and biological characteristics (FS≥100=large, FS<100=small) (Juniper and Parr, 1998)

	Weight (g)	Length (cm)	Habitat	Breeding season	Diet	Flock size	Clutch size
Cacatua (*Cacatua*) *alba*	650	45	Forest	January–October	Omnivorous	Small	2
C (*Cacatua*) *moluccensis*	850	45	Forest	June–August	Omnivorous	Small	2
C (*Cacatua*) *galerita galerita*	600	45	Various	Various	Semivorous	Large	3
C (*Cacatua*) *galerita eleonora*	500	40	Various	Various	Semivorous	Large	3
C (*Lophochroa*) *leadbeateri*	400	40	Forest	August–December	Semivorous	Small	2–4
C (*Licmetis*) *sanguinea*	450	35	Various	Various	Omnivorous	Large	2–3
C (*Licmetis*) *tenuirostris*	650	40	Various	July–December	Omnivorous	Large	2–4
C (*Licmetis*) *ducorpsii*	350	35	Various	Unknown	Omnivorous	Small	Unknown
Eolophus roseicapillus	350	35	Various	August–October	Semivorous	Large	2–6

FS, flock size.

with little bugs.[10] Morphological, biological and ecological characteristics of the studied cockatoo species are summarised (table 1).

The aims of the present research were to investigate the reproductive performance of different cockatoo species reared in the same facility (standardised conditions: environment, diet and management), to evaluate the adaptability to captive breeding and to identify the main problems in breeding for conservation of these species.

MATERIALS AND METHODS

The birds included in this study (19 pairs, 9 species) were reared in a professional breeding facility, directly managed by the owner. The breeding facility is located in Northern Italy in Cremona province. The breeding pairs were housed as single pairs, in flying cages with a concrete floor (6.0 x 1.5 x 2.0 m, length x width x height). Only the frontal side of the aviary and one-third of the roof were made in wire mesh (20 x 20 mm; 3-mm thickness); the other sides and two-thirds of the roof were made in insulating boards. Every cage was equipped with two perches (8-cm diameter), secured on the lateral walls of the aviary (1.5 m high, 4.0-m distance to allow flying activity). Birds were fed ad libitum; drinking water was present 24 hours a day. A stainless-steel feeding bowl was positioned on a shelf, while the concrete drinking bowl was located on the floor of the cage, near the front side, made in wire mesh; water was constantly provided by a centralised filling system. No visual contact was possible between breeding pairs. Two different nests were supplied to each breeding pair: a vertical nest with two access holes (T shaped) and an upside-down L nest, so that birds could choose between the two. The nests were checked three times per day, all along the breeding season (March–June); after collection, the eggs were put in an incubator (Grumbach incubators, Asslar, Germany) and incubated for the species-specific incubation time. Incubation temperature was 37.2°C, and relative humidity (RH) was 50 per cent. Two days before hatching, the eggs were moved into a hatcher (Grumbach incubators, Asslar, Germany) set to T=37.0°C, RH=60 per cent–70 per cent. After hatching, brooding temperature was 35°C for the first 10 days; after that, it was gradually decreased until when the birds were feathered enough, depending on outdoor climate.

Breeders were fed a complete extruded diet for parrots, specifically formulated by an Italian food company (specific costumer formula; All Pet, Caronno Pertusella VA, Italy). The extruded diet analysis is crude protein: 17.1 per cent, crude fat: 10.8 per cent, crude fibre: 4.0 per cent and moisture: 6.1 per cent. The same diet was fed to all the birds and was daily integrated with seeds, fresh fruits and vegetables, depending on seasonal availability. During the reproductive season, the diet was integrated with sprouted or cooked legumes (mostly peas and beans) to stimulate courtship and breeding behaviour by increasing the protein content and fresh items within the diet.

The cockatoo chicks were fed an appropriate chicks' food specifically formulated for parrots (Zupreem Embrace hand-feeding formula for baby parrots; crude protein: 22.0 per cent, crude fat: 9.0 per cent, crude fibre: 4.0 per cent and moisture: 10.0 per cent).

Data on egg production and incubation performance were routinely collected according to an appropriate form filled daily by the breeder. Egg production was recorded daily per pairs; each egg was marked with the day of oviposition and weighed (g). The proportion of egg production was calculated in each pair according to the formula: eggs laid in a clutch within every pair/species reference number of eggs laid in a clutch (average, table 1). After setting, fertile eggs were recorded per species at candling (Grumbach candling lamp, Grumbach incubators, Asslar, Germany) performed on 7, 14 and 21 days of incubation. The number of live chicks per species was recorded at hatching. The percentage of fertile eggs was calculated at every candling; hatchability (per cent) was calculated per species on total egg set. The presence of deplumed areas and the presence of mutilations were assessed by direct visual evaluation of the birds not entering the

Table 2 List of species, N-P, N-EP and N-CP per species

Species	N-P	N-EP	N-CP
Cacatua (Cacatua) alba	1	6	3
C (Cacatua) galerita galerita	2	2, 2	1, 2
C (Cacatua) galerita eleonora	2	2, 6	1, 3
C (Cacatua) moluccensis	2	0, 2	0, 1
C (Lophochroa) leabeateri	5	0, 0, 3, 0, 2	0, 0, 2, 0, 1
C (Licmetis) sanguinea	1	2	1
C (Licmetis) ducorpsii	2	0, 0	0, 0
C (Licmetis) tenuirostris	1	1	1
Eolophus roseicapillus	3	0, 0, 0	0, 0, 0

N-CP, number of eggs (clutch/pair); N-EP, number of eggs (egg/pair); N-P, number of pairs.

aviaries before the start and at the end of the oviposition period; the assessment was always performed by the same researcher.

Statistical analysis was carried out by SAS system: mean and NPAR1WAY (Kruskal-Wallis) procedures were applied; cockatoo species was considered as a source of variation. A significance level of P≤0.05 was considered. Results for egg production, egg weight, fertility on different day of incubation and hatchability are reported as mean values with ±SD.

RESULTS

Cockatoo breeders (n=38) of different species have been considered and organised in pairs; all the birds were sexually mature and at the second reproductive season at least. The species considered, their distribution and the egg production features are reported in table 2.

In total, 28 eggs were collected during the reproductive season in Northern Italy (March–June) and included in this study. Results of egg characteristics and reproductive parameters included egg production, egg weight, fertility on different day of incubation and hatchability (table 3). Analysis of variance showed no significant differences between species for any of the reproductive parameters recorded (P≥0.16 for all variables); therefore, no clear associations of species and reproductive parameters were identified. However, the results provide relevant and unique comparative information on egg production and weight, fertility and hatchability in nine cockatoo species reared in similar captive conditions. The highest laying rate was recorded in *Cacatua alba* and corresponded to two eggs in each one of the three clutches (table 3). Also, *C moluccensis* recorded the same value. However, *C moluccensis* laid only one clutch and the eggs were infertile. *C leadbeateri* showed low fertility, corresponding to 34 per cent on day 7 of incubation, and no live chicks at hatching. The best results for fertility and hatchability were recorded in *C galerita*, including both subspecies *galerita* and *eleonora*. *C sanguinea* carried

Table 3 Results of egg production, egg weight, fertility on different day of incubation and hatchability (mean±SD) recorded in different *Cacatua* species during the reproductive season, of showing no significant differences between species

Species	Cacatua (Cacatua) alba	C (Cacatua) galerita eleonora	C (Cacatua) galerita galerita	C (Cacatua) moluccensis	C (Lophochroa) leabeateri	C (Licmetis) sanguinea	C (Licmetis) tenuirostris	C (Licmetis) ducorpsii	*Eolophus roseicapillus*
Eggs (N)	6±0	4.0±2.83	2±0	2±0	2.5±0.71	2±0	1±0	0±0	0±0
Clutch (N)	3±0	2.0±1.41	1.5±0.71	1±0	1.5±0.71	1±0	1±0	0±0	0±0
Egg production (%)	100±0	67±0	54±19	100±0	59±12	80±0	33±0	.	.
Laying range (days)	2±0	3.67±0.47	3.0±1.41	4±0	3±0	4±0	.	.	.
Egg weight (g)	24.30±0	22.44±0.83	28.01±3.29	29.98±0	13.29±0.69	14.13±0	21.2±0	.	.
Fertility day 7 (%)	83±0	100±0	100±0	0±0	34±47	100±0	100±0	.	.
Fertility day 14 (%)	83±0	100±0	100±0	0±0	0±0	100±0	100±0	.	.
Fertility day 21 (%)	83±0	100±0	75±35	0±0	0±0	50±0	100±0	.	.
Hatchability (%)	83±0	100±0	50±71	0±0	0±0	50±0	0±0	.	.

out a discrete reproductive performance, characterised by high laying rate, 100 per cent fertility and 50 per cent hatchability (table 3). According to the results, embryo mortality during artificial incubation was not recorded in *C alba* and *C eleonora*, whereas it occurred in other few species and in different days of incubation according to the species. Embryo mortality occurred within day 14 of incubation in *C leadbeateri*, after day 14 in *C galerita* and *C sanguinea*, and only during hatching time in *C tenuirostris*. These results suggest that the same incubation environmental conditions might not be suitable for all species, and further studies should investigate species-specific variations. *C ducorpsii* and *Eolophus roseicapillus* did not lay any egg. Liveability of newly hatched chicks was 100 per cent after 48 hours.

Plumage was intact in all the birds before the start and at the end of the reproductive period. No mutilation was observed in any bird during the two direct observation sessions.

DISCUSSION

A multifaceted analysis has been carried out on the breeding performance in different cockatoo species, providing new, objective and comparative results of scientific relevance to support the development of conservation programmes in cockatoo endangered species. Even though the results of the analysis of variance showed that the species effect was not significant for any of the reproductive variables, the present results do contribute to increasing the knowledge of species-specific features of cockatoo and the standardisation of husbandry and management procedures for birds reared in captivity.

When considering infertile eggs (*C moluccensis*), many different aspects related to males' reproductive physiology and behaviour should be taken into consideration.[11] The observations carried out on *C leadbeateri* pair with low breeding performance could be linked to the high territoriality, which characterises this species during the reproductive season: this characteristic drives these birds to defend a very large area around the nest according to Juniper and Parr.[9] *C galerita* subspecies show high reproductive performance with high adaptation to captive breeding and artificial incubation. These characteristics could facilitate adaptation to ex situ in vivo conservation. Many reproductive parameters are scarcely known in most cockatoo species, like *C. ducorpsii*.[5] The sampled pair did not lay any eggs. An accurate knowledge of natural reproductive habits could be very helpful in the improvement of housing and management procedure during the reproductive season in captivity. Scientific studies are needed for many cockatoo species to supply objective strategies for breeding programmes. *E roseicapillus* did not lay any eggs either. Considering their adaptability to different environments in nature,[5] an association between the reproductive performance in captivity and the high need for social interactions with other conspecifics during the reproductive period can be supposed; the characteristic of these birds in the wild is the high level of gregariousness, which can lead to different pairs nesting in a very small area in close vicinity.[9] In all breeding farms, in order to exclude the presence of pathologies which could negatively affect the reproductive performance, before the introduction of new birds, an accurate clinical examination is performed, including a celioscopy (laparoscopy) visualisation of the inner organs to assess reproductive apparatus condition, together with appropriate bacteriological and virological analyses.[12] Our results stress the importance of a stimulating environment able to lead the parrots to develop their specific ethogram.[13] Cockatoos living in the forests (table 1) have lower reproductive performance, corresponding to low fertility and embryo viability: we can suppose that these species are characterised by lower adaptive ability in captivity according to the results of Popp and colleagues.[14]

The importance of social attitude of birds should always be taken into consideration in breeding programmes, the socially poor environment can be considered really stressful in many species, reducing coping ability in captive life.[15] Cockatoos living in large flocks in nature should be considered to be physiologically and ethologically able to cope better with stressful situations like competition for food, nest and partner, as well as being naturally adapted to frequent social interactions and low territoriality.[9]

The diet fed to the birds fully meets their nutritional needs and therefore does not represent a source of variation in relation to cockatoos' reproductive activity. However, the use of feeding devices requiring birds to spend more time in foraging activity and allowing parrots to express feeding ethograms closer to natural ones could be suggested to improve housing conditions in captivity.[5 15–18]

The species that normally populate forest areas showed lower reproductive performances; it could be observed that greater attention should be given to the environmental enrichment in cages for these species.

The influence of social dynamics on reproductive success is not clear yet, but there are clear indications that flock size and population density may drive different behaviours in captivity.[19]

No behavioural problems such as feather damaging or self-mutilations were recorded in the present study, in contrast with data observed in other Psittaciformes.[19]

The results show how the studied cockatoos still perform their natural species-specific behaviours and habits, maintaining a status of tamed and not domesticated species. Although in captivity most of the important physiological needs are met, the need for an appropriate ethological and social environment is clearly underlined by the presented results. Although in this experimental trial environment, nutrition and management were excellent, only 10 pairs laid 19 eggs in total, showing how difficult is to breed cockatoos in captivity.

We had the rare opportunity to evaluate several species of cockatoos reared in standard conditions of environment, management and nutrition.

Through this study it was possible to analyse the reproductive performance of nine cockatoo species and to assess their adaptability to ex situ in vivo captive breeding. Data on reproductive parameters in nine cockatoo species have been reported. The natural ethogram of each species is still very influential because it could determine the success or failure of a breeding season. Our results define as critical points the lack of egg laying, suggesting a failure of the female reproductive function, and also embryo mortality recorded during artificial incubation. Accurate clinical examinations of birds before breeding season are needed in order to take under control anatomical and physiological variables influencing reproductive efficiency. Furthermore, selective breeding plans based on reproductive efficiency and on the adaptive ability of the birds to captive reproduction conditions could be programmed to improve breeding success of endangered species under conservation.

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