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Contribution to the knowledge of the New Caledonian imperial pigeon *Ducula goliath* (Gray 1859) with emphasis on sexual dimorphism

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Abstract Hunters of the endemic imperial pigeon (*Ducula goliath*) or notou in the Forêt Plate site, New Caledonia, in Apr 2001 and Mar 2002, allowed us to collect some biological material, measurements and descriptions from 63 pigeons. The sample included 5 immature imperial pigeons, and 58 adults. Several measurements of adult birds differed significantly between the sexes: weight, body length, wing length, tail length, tarsus length, and head length and width being greater in males (n = 28) than females (n = 30). A cross-validated classification using a discriminant function analysis on these variables allowed 74 % of the birds to be correctly classified as male or female. None of the qualitative characters (colour of skin, bill, iris, feet, feathers) was different between the sexes. Sexing birds using a bio-molecular analysis proved to be 100% reliable. The small gonads and the thin wall of the midgut indicated that the notou were not breeding at the time of collection. They had completed, or almost so, their wing moult. Fruits of 22 tree species and the leaves of trees and ferns were identified in material taken from digestive tracts. No internal parasites and few external parasites — of a low pathogenicity — were recorded. These results improve knowledge of this endemic species and should be useful in this popular game bird's conservation and management.

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Keywords New Caledonia; imperial pigeon; notou; *Ducula goliath*, sex; biometry; foods

INTRODUCTION

The genus *Ducula* includes 36 species distributed from the Himalayas to Polynesia, but the greatest diversity occurs in New Guinea, with only 2 and 1 species in Asia and Australia, respectively (Gibbs *et al.* 2001). These large to very large pigeons (300-1000 g) are arboreal and frugivorous, and their dominant plumage colours are grey, pink, and maroon. Whereas true pigeons (*Columba* spp.) and the New Zealand *Hemiphaga* have 12 tail feathers, *Ducula* spp. have 14 (Goodwin 1967). Four *Ducula* allospecies of Melanesia, called the *brenchleyi* species group by Goodwin (1960), exhibit strong affinities (Salvadori 1893; Gibbs *et al.* 2001): *D. latrans*, Fiji; *D. brenchleyi*, Solomons; *D. bakeri*, Vanuatu; and *D. goliath*, known locally as notou, New Caledonia. According to Salvadori (1893), the *D. goliath* type is an adult — preserved in the The Natural History Museum (formerly British Museum (Natural History) — which was collected at the Isle of Pines (to the south of Grande Terre, New Caledonia). It was described under the name *Carpophaga (Phaenorhina) goliath*, the subgeneric division being determined by the entirely exposed openings of the nostrils (Gray 1859). The notou is currently categorised as "near threatened" by the IUCN (BirdLife International 2000), but it was found to be "common" or "fairly common" in the humid forests of Grande Terre, New Caledonia by Ekstrom *et al.* (2002).

The descriptions of *D. goliath* given by Goodwin (1967) and Gibbs *et al.* (2001) stated that, as for all

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Table 1 Measurements (weight, g; dimensions, mm) for 28 male and 30 female New Caledonian imperial pigeons *Ducula goliath* from Forêt Plate, New Caledonia. Bill (n-t) or nalospi: from bill tip to nostril; bill width and depth at the nostril; inner-outer toe : size difference between toes; testes (n = 28); ovocyte, dia. of largest; NS, not significant at P = 0.05.

	Males				Females				Significance
	Mean	SD	Min	Max	Mean	SD	Min	Max	P; t-test
Weight	846.7	70.7	712	995	785.7	75.7	630	890	< 0.003
Body length	517.3	14.6	495	550	499.8	13.9	465	520	< 0.000
Wing length	301.4	7.0	286	316	293.0	7.4	280	310	< 0.000
Tail length	231.8	8.3	214	246	225.2	9.0	210	247	< 0.004
Wing span	899.8	35.0	830	970	896.8	27.0	840	960	NS
Head length	77.3	1.44	73.4	79.5	75.2	1.64	71.6	78	< 0.000
Head width	28.07	1.06	26.3	29.6	26.8	1.69	22.4	28.4	< 0.003
Bill length	30.93	1.60	28.4	34.2	30.59	1.6	27.4	33	NS
Bill (n-t)	23.09	0.91	20.3	25.3	22.83	1.05	20.6	24.6	NS
Bill width	10.93	0.61	10.0	12.3	10.64	0.73	9.5	12.3	NS
Bill depth	8.89	0.56	7.90	9.90	8.65	0.71	7.3	10.4	NS
Tarsus length	41.04	1.40	37.80	44.0	39.73	1.73	37	44	< 0.003
Middle claw	15.46	0.8	13.8	17.8	15.05	0.77	13	16.7	NS
Inner-outer toe	3.61	1.36	0.00	6.60	3.81	1.49	0.9	6.5	NS
Testes (L)	8.02	1.94	5.15	13.25					
Ovocyte					2.27	0.87	1.0	4.2	

Ducula spp. except *D. carola*, the sexes are alike. Taking the opportunity to make observations and measurements of imperial pigeons shot by hunters, we tried to discriminate the sexes using phenotypic characters and measurements. Foods in their digestive tracts were identified and the parasites of these pigeons were collected and analysed. Considering the scarcity of data on notou in the literature, the information we present may contribute to the conservation of this endemic but popular game bird.

MATERIAL AND METHODS

Hunting

The official hunting season of notou is during the weekends in Apr, with a quota of 5 birds hunter^{-1} day^{-1} (Délibération Territoriale, Feb, 25, 1982 ; Boulet, 1995). Forêt Plate is in the central mountains of the main island (Grande Terre) of New Caledonia, in the municipality of Pouembout. Hunting of notou was not permitted in Forêt Plate from 1998 to 2000, but 9 hunters were allowed to hunt it for a single day (22 Apr 2001), with a limit of 3 or 4 birds hunter^{-1}. Hunting started at 0700 h (local time) and ended when the quota of birds had been collected. To check whether an earlier hunting period, fitting more precisely with that of the Melanesian "yam feast" during which notou are killed traditionally, would coincide with the notou breeding season, hunting was again permitted the next year, 1 month earlier (16 Mar 2002).

Measurements

Immediately after being shot, pigeons were weighed and the following dimensions measured: body length; wing length; wingspan; tail length; tarsus length; inner/outer toe size difference (Frémaux 1998); median toe and claw length; head length; head width; bill length; nallopsis (from nostril to tip) length; bill width; and bill thickness at the nostrils. The colours of the feet, the base and tip of bill, and the eye rings and iris were recorded. The intensity and extent of the brownish-red colour on the abdomen, on the inner webs of tail feathers, and on the undertail coverts were recorded, as was the abundance of bifurcated dark-grey feathers on the breast and neck. The state of moulting of the remiges was noted. Feathers were examined in the field and laboratory for ectoparasites.

Autopsy

Fruits were removed from the mouth, crop, and intestine and placed separately in 3 jars. The crop was carefully examined for wall thickness and secretions that could indicate that the bird was feeding a chick (Gibbs *et al.* 2001). The digestive tract was retained for parasitological investigation in the laboratory. The state of fatness was recorded, ranking from 1 (not/not very fat) to 3 (very fat) based on the amount of fat deposited in the abdomen. A small piece of flesh and skin was removed and preserved in 70 % ethanol for bio-molecular investigations. We collected both testes or the ovary; the testes and the largest ovum were measured.

In the laboratory, material in the cloaca was examined under a microscope (250 ×) for helminth eggs and protozoa. The digestive tract was opened, the contents flushed with water through a 125 μ - mesh filter, and the remains examined under a stereomicroscope for parasitic worms.

Foods
Fruits and leaves were identified to the species level whenever possible. Fruits were also measured, and their contribution to the diet calculated by volume.

Bio-molecular sexing
The accuracy of a bio-molecular method for sexing this pigeon was tested. Based on the recognition of the genes coding for the chromo-helicase DNA binding protein (CHD) (Ellegren 1996), which have different size on the sexual chromosomes (CHD1W, 470 bases; CHD1Z, 680 bases), the procedure described by Fridolfson & Ellegren (1999) was followed to determine the sex of the 31 pigeons collected in Apr 2001. DNA was extracted in the laboratory from 25 mg of flesh and skin, using a Qiagen R extraction kit (Dneasy ™ Tissue Kit 50). Using the primers 2550 F and 2718 R, PCR amplification was performed using a thermal cycler (Perkin-Elmer 9700 ®) and Taq polymerase (Qiagen ®). PCR products were migrated on 2% agarose gel (NuSieve GTG ®) for 2 h (100 V). The presence of 2 bands on the agarose gel indicates a female, and 1 band a male.

Statistical analysis
We followed Sokal & Rohlf (1998), and performed analyses using SPSS 9.0 software (SPSS 1999). After checking the normality and the homoscedasticity of data (Kolmogorov-Smirnoff and Levene test), differences between sexes for quantitative data were tested using a *t*-test where appropriate, or using the equivalent non-parametric Mann-Whitney *U*-test when assumptions of parametric tests were not met. Discrimant function analysis has been used to separate males and females using a combination of quantitative parameters. All variables were transformed in Log_{10} (X+1) to normalise the data and stabilise variances. We first entered in the model all the variables that differed significantly between sexes, and then selected the best model based on Wilks' Λ and percentage of cases correctly classified using a cross-validation (each case is classified by the functions derived from all cases other than that case) (SPSS 1999). We investigated a possible effect of the hunting month on the weight of birds shot (Apr 2001, Mar 2002) using a 2-way ANOVA (sex and month as fixed factors), and on the size of testes (mean length of the 2 testes), and the largest ovum diameter using 1-way ANOVA (month as fixed factor).

RESULTS

Hunting efficiency
Each of the 9 hunters involved in the 2 hunting sessions considered that the notou was abundant in Forêt Plate. Most of the 63 birds examined were collected during 0700 - 1100 h; 31 in Apr 2000, 32 in Mar 2002, with a mean of 2 h to collect a bird.

Age ratio
In total, 58 of the pigeons had the adult colouration of plumage, bill, eyes and feet (Gray 1859; Gibbs *et al.* 2001). The other 5 pigeons (1♂, 4♀♀♀♀) were much lighter (500 - 570 g, as against 630 g for the next lightest bird), and had a duller plumage than the other birds. Their mean rank of fat deposit (1.4) was also significantly lower than for adults (2.3). These 5 birds were considered to be immature.

Sex ratio, sexually distinguishing criteria
None of the hunters was able to discriminate males from females by behavioural or morphological traits. Based on autopsy results, 29 males and 34 females (1.17 female/male) were shot. Bio-molecular analyses confirmed the sexual classification of all individuals. Table 1 shows the mean measurements on the 58 birds in adult plumage (28 ♂♂, 30 ♀♀). Half of the traits differed significantly between the sexes. Males were heavier and larger (body length, wing length, tail length, tarsus length, head length and width) than females (Student *t*-test, 48 - 56 *df* according to missing values, $P<0.05$). Other quantitative parameters did not differ significantly between the sexes (Student *t* test or Mann-Whitney *U* test; 50 - 56 *df* according to missing values, $P>0.05$). The colours of the eyes, bill, and legs were similar in the sexes, as was the extent of the brownish-red plumage over the abdomen and undertail coverts, the brown on both webs of the tail feathers, and the abundance and brilliance of bifurcated grey neck feathers (Pearson χ^2, 1 *df*, $P > 0.05$). Adiposity was usually important and similar in males and females (score: ♂♂ 2.3; ♀♀ 2.2).

Discriminant function analysis was used to separate males and females according to a combination of the quantitative variables measured. The selected model, combining 6 variables (weight, body length, wing length, tarsus length, head length, head width), indicated a significant difference in the 2 group centroids (χ^2 Wilks' Λ, 5 *df*, $P = 0.001$). Over all, the cross-validated classification allowed 74.1% of the 58 birds to be correctly classified, females being more efficiently classified than males (76.7% and 71.4%, respectively). There was no significant effect in the mean weight of males (858 ± 79.8 g v 845 ± 54.4 g) or females (810 ± 70.8 g v 765.3 ± 83 g) for the Apr 2001 and Mar 2002 hunting sessions.

Reproductive activity and moulting pattern
The midgut wall was thin in all adults in both hunting months. The testes were short: 8.23 ± 2.37 mm, Mar 2002; 7.99 ± 1.39 mm, Apr 2001 ($P > 0.05$).

Table 2 Fruits eaten by New Caledonia imperial pigeons *Ducula goliath* in Forêt Plate, New Caledonia in Apr 2001 and Mar 2002 and an evaluation of their relative importance in the diet (volume, ml).

		Percentage occurrence								
		In birds			Of total fruits			By volume		
Family	Hunting session/(*n*) Tree species	2001 (31)	2002 (32)	Total (63)	2001 (379)	2002 (1145)	Total (1524)	2001 (758)	2002 (448)	Total (1206)
Burseraceae	*Canarium oleiferum*	29.0	25.0	27	9.5	2.2	4	47.5	39.7	44.6
Ebenaceae	*Diospyros macrocarpa*	22.6	3.1	12.7	2.6	0.1	0.7	15.2	2.6	10.5
Lauganiaceae	*Neuburgia neocaledonica*	16.1	6.3	11.1	9.5	0.2	2.5	16.6	1.6	11
Moraceae	*Ficus* sp.	16.1		7.9	26.4		6.6	2.6		1.7
Unident. 1	"small green with 4 seeds"	9.7		4.8	39.8		9.9	4		2.5
Unident. 2	"small, blue pulp"									
Araliaceae	*Schefflera gabrielae*	6.5	3.1	4.8	3.4	0.2	1	7.7	2	5.6
Arecaceae	*Burettokentia vieillardii*	3.2		1.6	5.5		1.4	0.6		.3
	Basselinia gracilis	3.2		1.6	0.8		0.2			0
	Palm tree sp.		3.1	1.6		0.1	0.1		0.9	0.3
Flagellariaceae	*Flagellaria* sp.		9.4	4.8		58.4	43.9		14.3	5.3
Elaeocarpaceae	*Elaeocarpus gummatus*	3.2		1.6	0.8		0.2	1		0.6
	Elaeocarpus sp.									
Proteaceae	*Kermadecia rotundifolia*		6.3	3.2		0.2	0.1		8	3
Unident. 3	"fruit axis"		6.3	3.2		0.2	0.1		2.2	0.8
Rubiaceae	*Gardenia oudiepe*		3.1	1.6		0.4	0.3		2.9	1.1
	Guettarda wagapensis		3.1	1.6		0.1	0.1		0.7	0.2
Anacardiaceae	*Semecarpus neocaledonica*	3.2		1.6	1.3		0.3	4.6		2.9
Monimyaceae	sp.		3.1	1.6		4.5	3.3		2.2	0.8
Unident 4	"oyster seed"		3.1	1.6		0.3	0.3		2.2	0.8
Unident 5	"squale tooth seed"	3.2		1.6	0.3		0.1	0.1		0.1
Unident 6	"melon rib"		3.1	1.6		0.1	0.1		0.4	0.2

Also, the largest ovules were small: 2.48 ± 0.82 mm, Mar 2002; 1.87 ± 0.85 mm, Apr 2001 ($P > 0.05$). Moulting of wing primaries was either complete (birds with a fresh plumage) or nearly so (1 or 2 worn external primaries remaining) in 52% of the adults shot in Mar 2002 and in 55% of those in Apr 2001. Other birds were in partial moult, with 3-10 worn wing primaries remaining.

Foods

The muscular wall of the gizzard is thin, but the internal layer is lined by 24 horned knobs in rows of 2 or 3, following a 3-3-3-3-2-3-2-3-2 sequence along the proventricular axis. The knobs act like the teeth of a rasp. Fruits from at least 22 tree species had been eaten by the pigeons (Table 2), *Canarium oleiferum* fruits were found in 27 % of the birds, but because of its large size (42 × 30 × 15 mm, *c.* 10 ml each), represented 44.6 % by volume of the diet. About 80 % of all the items consumed were small black fruits of an unidentified species of the family Flagellariacae and 2 unidentified small fruits (1 green, 1 blue: unidentified 1 and 2 in Table 2). A species of *Diospyros*, a *Ficus* sp., and a Lauganiacae (*Neuburgia neocaledonica*) were also well represented in the sample. It was evident that all seeds, even the large (35-40 mm × 25-28 mm) *Canarium* nuts, were voided intact through the cloaca. In addition to fruits, 9 notous (14.3%), 5 in Apr 2001, 4 in Mar 2002, had ingested mature (bearing sori on their undersides) fronds of 2 ferns, including *Dictymia mackeei* (2 pigeons each year, total 25 ml), and the mature leaves of 3 unidentified trees (3 birds in 2001, 2 in 2002, total 62 ml of leaves). Leaves represented 7% by volume of the material in the digestive tracts.

Parasites

Most pigeons had a few feather mites, apparently *Cheiloceras serrulatum* (Atyeo & Gaud, 1978). An hippoboscid, morphologically different from *Ornithoctona plicata* described by Sinclair from a notou (1997) was collected from 1 pigeon. No feather lice were found, and no helminths or protozoa were found in the digestive tracts.

DISCUSSION

A 1999-2000 survey in Forêt Plate yielded an estimate of 500-900 notous in the 2300 ha of humid forests on the mountain slopes (Barré & Manceau 2001), approaching the density encountered in the protected forests of the Parc Provincial de la Rivière Bleue in the south of the island (Létocart 1998). Notous were common in Forêt Plate during the 2 hunting days in 2001 and 2002. Consequently, most hunters shot their quota within a few hours at each session. Hunting efficiency was equivalent in 2001 and 2002 suggesting that this level of

hunting is probably not having a major impact on the notou population at Forêt Plate. None of the 58 adult pigeons examined in mid Mar 2002 and late Apr 2001 showed evidence of reproductive activity (small gonads, thin walled mid-gut). This is in agreement with observations of Létocart (1998) that notous lay from Jun to Dec. Five of the 63 pigeons were presumed to be juveniles, and if so would have hatched late in the 2000 and 2001 breeding seasons.

None of the features examined (including the extent and intensity of maroon, and the colour of bare parts) allowed males to be distinguished from females. However, some measurements differed significantly between the sexes (body length, wing length, tail length, head length and width, weight). Létocart (1998), based on a smaller sample of birds (4 ♂♂, 4 ♀♀), came to the same conclusion. In a discriminant function analysis combining these variables, the sex was predicted correctly for 77 % of females, and 71 % of males. The bio-molecular approach for sexing birds, following the procedure of Fridolfson & Ellegren (1999), was 100% reliable, and living birds can be sexed, the DNA being extracted from the base of contour feathers. Using DNA to sex birds for conservation management measures when known-sex birds are required is recommended.

Birds were in the last phase of moulting in Apr 2001. In comparison, Létocart (1998) did not observe any wing moult among 30 notous examined in the Parc Provincial de la Rivière Bleue from Jun to Oct. These observations indicate a specific seasonal moult for this pigeon that may occur during Jan-May following breeding.

At Forêt Plate, 22 fruit species were consumed by the 63 birds examined, including large fruits, such as *Canarium oleiferum* (42 × 30 mm) or *Diospyros macrocarpa* (52 × 30 mm), and small fruits such as *Ficus* sp. (10 × 8 mm). Our list is obviously incomplete because it reflects only preferences of notous in the late summer of these particular years and for this particular site. Based on a long-term study, Létocart (1998) reported fruits of 40 tree species being eaten by notous in the Parc Provincial de la Rivière Bleue, about 200 km south of Forêt Plate. Some fruits were eaten at both sites, but notou in Forêt Plate ate fruits of tree species also present in Rivière Bleue, but not apparently consumed there (*Schefflera* sp., *Basselinia* sp.). Consumption of young leaves of 3 tree species and flowers of *Gardenia* sp. was also recorded by Létocart (1998). Ferns appear to be occasionally consumed by notous (2 birds from each hunting session).

No internal parasites were observed in the digestive tracts of the 63 notous examined, which agrees with the findings of Beugnet *et al.* (1996) for 20 notous. The lack of parasites may be related to the bird's ecology: notous do not come to the ground and therefore are unlikely to ingest infective larvae developing from parasite eggs in the faeces dropped from trees. Moreover, few external parasites were recorded; the *Cheiloceras serrulatum* mite being the most frequently observed, but like other feather mites, it has no known pathological effect. In addition to the large fat deposits found, these results indicate the excellent health of the notou at Forêt Plate, which was even better than that observed for birds in the Parc Provincial de la Rivière Bleue (Beugnet & Chardonnet 1996; Beugnet *et al.*, 1996).

Our study was part of a wider programme of research on the ecology, biology, and status of this poorly known bird in New Caledonia. It was implemented by the French Ministry of the Environment, provincial authorities and research organisations and the information obtained is expected to contribute to the conservation and management of this endemic game bird. Our data suggest that the legal hunting period of notou during Apr occurs at a suitable period, after the breeding season. However, notous are traditionally hunted for the yam feasts which occur from late Feb to early May (usually earlier in the southern tribes, later in the northern ones), irrespective of the dates of the legal hunting. Hunting could be advanced to Mar so that it coincides more precisely with some of the traditional yam feasts. The worst case would be legal hunting in 2 different months, in the south during Mar and in the north during Apr, as this would allow hunters to move between regions, and so generate increased pressure on the notou. We recommend that legal hunting be maintained in Apr and that information on provincial legislation be strengthened.

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