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Diet of Nankeen Kestrels *Falco cenchroides* at Brisbane Airport

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Summary. The diet of the Nankeen Kestrel *Falco cenchroides* in Australia is fairly well known, but has rarely been quantified. We analysed stomach contents of dead Kestrels collected in the grounds of Brisbane Airport in 2011–2013 to determine the preferred prey of the Airport's Kestrel population. Diversity of the prey items was quantified using Simpson's and Shannon's Indices, as well as a relatively new index, the Index of Relative Importance. The stomach contents of 17 Kestrels were examined, and 183 individual prey items identified. The majority of the prey items were orthopteran insects, which occurred in 94% of the sampled stomachs, and in greater numbers than any other prey taxon. The dominance of the diet by orthopterans indicates that this taxon is of high value to the resident Kestrels. We speculate that this importance may be related to the high numbers of orthopterans present on the Airport grounds, and their relative ease of capture in comparison with vertebrate prey. The diet of the Kestrels at Brisbane Airport is similar to that reported previously for this species. The data from this study may facilitate better management of the bird-strike threat from this species at the Airport in the future.

Introduction

The feeding habits of raptors have been of interest to researchers for nearly a century (Johnson 1981). In Australia, much of the research on raptor diets has been qualitative, rather than quantitative, and comes mainly from opportunistic observations. As a result, the general diet of common species such as the Nankeen Kestrel *Falco cenchroides* is relatively well known compared with some of Australia's rarer raptors (Marchant & Higgins 1993; Aumann 2001). Nankeen Kestrels typically feed upon small vertebrates such as rodents (Hayward & MacFarlane 1971; Starr *et al.* 2004), lizards (Bollen 1991; Aumann 2001), frogs (Wheeler 1973; Barker & Vestjens 1989) and bats (Lewis 1987), as well as small birds, such as pipits, sparrows and finches (Sharland 1931; Czechura 1971; Bollen 1991). Sometimes, birds of similar size and weight to Kestrels, such as the Spotted Dove *Streptopelia chinensis* (Pacher 2010) and Crested Pigeon *Ocyphaps lophotes* (Oliver 2004), are taken as prey. Invertebrates make up a large part of the Kestrel's diet, with orthopterans (e.g. grasshoppers and crickets) being the most commonly taken arthropods (Bedggood 1972; Genelley 1978; Olsen *et al.* 1979; Cupper & Cupper 1981; Paull 1991; Debus *et al.* 2007; Schulz & Lumsden 2009).

Most data on the diet of Nankeen Kestrels come from direct behavioural observations of breeding pairs or foraging birds, with notable exceptions being the studies conducted by van Tets *et al.* (1977), Olsen *et al.* (1979), Baker-Gabb

(1984) and Aumann (2001). Van Tets *et al.* (1977) described the stomach contents of 19 Kestrels obtained from airfields in New South Wales, the Northern Territory, Victoria and Queensland. Olsen *et al.* (1979) re-examined the contents of the digestive tracts of the Kestrels analysed by van Tets *et al.* (1977), as well as those of an additional 16 Kestrels (mainly road-kills), in addition to conducting pellet analysis and searching for prey remains at nests. Baker-Gabb (1984) conducted pellet analysis and searched for prey remains at nests in north-western Victoria. Aumann (2001) reported observational data on Kestrel diets from 28 territories in the south-west of the Northern Territory. These studies were the first to accurately quantify the diet of the Kestrel. More recently, Schulz & Lumsden (2009) used prey remains at perches to investigate the diet of Kestrels on Christmas Island.

Many researchers have stated that birds are attracted to airport environments by the quality of the habitat, which often provides food and water as well as shelter and perches (Sodhi 2002; Cleary & Dolbeer 2005; Dolbeer 2011). Consequently, management programs often aim to manipulate the habitat at an airport so that it becomes unattractive to or unsuitable for birds (Allan & Orosz 2001; Barras & Seamans 2002). One common method is the removal or reduction of food sources at the airport (van Tets 1969; Blackwell & Wright 2006; Thomson 2007).

Here we present the results of a quantitative analysis of the stomach contents of 17 Nankeen Kestrels obtained from Brisbane Airport. In addition, the relationship between body size of the Kestrels and their prey preference is investigated. The aims of this study were to determine the diet of the Airport's resident Kestrels and to assess whether certain taxa were preferentially targeted as prey, in order to facilitate better management of the bird-strike risk from this species.

Methods

The Nankeen Kestrels examined in this study were birds that were either struck and killed by aircraft or euthanised by wildlife management staff at Brisbane Airport, operating under a Damage Mitigation Permit (issued by the Queensland Department of Environment and Heritage Protection). All birds were collected on the Airport grounds by staff from the Airside Operations Centre (hereafter AOC) at Brisbane Airport in 2011–2013 (D. Selby pers. comm.). Birds were stored in a freezer at the AOC but were thawed before being measured and dissected.

Study site

Brisbane Airport is situated on a reclaimed portion of the Brisbane River delta (27°23'S, 153°07'E) and occupies 2700 ha of land. It is the second-busiest international terminal in Australia, with 21.2 million passengers using the airport in 2011–2012 (BAC 2013). Thomson (2007) identified five major habitat types surrounding the Airport, including *Casuarina* plantations, wetlands, mangrove forests, and the tidal mudflats of Moreton Bay, all of which are suitable habitat for a diverse assemblage of Australian raptors (Thomson 2007; Debus 2012). Much of the habitat in the Airport grounds (especially the grassy areas around the runways and taxiways) is grassland that is regularly mown and maintained by airport staff; elsewhere, there are some areas of grasses that are either unmanaged or swampy, and small areas of *Casuarina* or mangrove forest.

Measurements

Dead birds provided valuable descriptive statistics about the Nankeen Kestrel population living at Brisbane Airport. Standard measurements taken for each bird included total length, and lengths of tail, wing, head–bill, bill, culmen (without cere), cere and tarsus (with foot) (Lowe 1989). Weight in grams was recorded, using a spring balance or digital scales. Tarsus length and weight were used as proxies for overall size in the data analysis. The presence or absence of juvenile plumage characteristics (see Marchant & Higgins 1993; Debus 2012) was also recorded.

Analysis of stomach contents

The contents of the stomach of each bird were removed, weighed on digital scales, stored in 70% alcohol and then examined with a microscope. Vertebrate and invertebrate prey items in each stomach were identified, counted and sorted into categories, vertebrates to the lowest possible taxon and invertebrates to order. Unrecognisable stomach contents were also retained. Presence/absence of each prey category across all stomachs was calculated to give frequency of occurrence.

Individual prey items can be quantified by counts of individuals or by calculating biomass (percentage of the total weight of the stomach contents) (McAtee 1912; Johnson 1981). Biomass gives the best representation of the importance of an individual prey item or taxon in the diet, but tends to overestimate the importance of larger prey items (Hart *et al.* 2002). Similarly, individual counts favour smaller prey items such as insects, which may be well represented numerically but make up only a fraction of the total biomass (Hart *et al.* 2002). Therefore, both methods of quantification were used in this study to avoid possible sources of bias: counts of individuals in each prey category were expressed as a percentage of the total number of individuals, and the biomass of prey categories was expressed as a percentage of the total identifiable biomass.

Mammals were identified by consulting Menkhorst & Knight (2010) or by comparing skulls or jawbones with a reference collection held at the Queensland Museum (following the recommendations of Marti *et al.* 2007). Birds were identified by comparing recognisable bones or feathers with the Queensland Museum reference collection. Reptiles were identified using the key and pictures provided by Wilson (2005). Amphibians were identified by comparing skin patterns with illustrations in Tyler & Knight (2011) and by comparison with the Queensland Museum's reference collection. Invertebrates were sorted to ordinal level using a microscope, with Zborowski & Storey (2010) and the key in *The Insects of Australia* (CSIRO 1991) as references.

Vertebrates were counted by recognisable parts such as skulls or tarsi. The numbers of arthropod prey items present in each stomach were quantified by counts of mandibles or other recognisable appendages. After sorting, each sample was placed in an oven at 40°C until dry, to allow for the possibility that different prey types had dissimilar water retention (Anderson *et al.* 1999). When dry, each sample was weighed using digital scales. On average, each of the 17 stomachs lost 74% of its wet weight when dried.

Data analysis

The diversity of the Nankeen Kestrel's diet was quantified by two indices commonly used in ecological studies: Simpson's Index and Shannon's Index, both of which incorporate measures of richness and evenness (Shannon & Weaver 1949; Simpson 1949; Pielou 1966; Peet 1975; Ghent 1991; Marti *et al.* 2007). Simpson's Index (D) is derived from the following formula:

$$D = \sum p_i^2$$

where p_i is the relative proportion of each species in the sample (Simpson 1949). This formula results in values between 0 and 1. Simpson's Index is affected strongly by those species which are most plentiful in a sample, and thus can be seen as a measure of 'dominance' (Whittaker 1965; Hill 1973; DeJong 1975). Consequently, larger values of D correspond with lower diversity in the sample population. For this reason, it is common to calculate Simpson's Index of Diversity (D'), or the complement of D , given by:

$$D' = 1 - D$$

where D is Simpson's Index as shown above (Pielou 1969; DeJong 1975; Smith & Wilson 1996). This transformation ensures that larger values of D' correspond with greater diversity in the sample.

Shannon's Index is calculated using the following formula:

$$H' = -\sum p_i \log p_i$$

where p_i represents the relative proportion of each species in the sample (Shannon & Weaver 1949). Any logarithmic base can be used in the formula, as long as consistency is maintained. The natural logarithm (\ln) was used in this study. To enable direct comparison with the results of Aumann (2001), a measure of evenness (that is derived from Shannon's Index) known as Pielou's Index (J') (Pielou 1969) was also calculated:

$$J' = H' / \ln(\text{number of prey categories}).$$

Following the recommendations of Hart *et al.* (2002) and Marti *et al.* (2007), the Index of Relative Importance (IRI) was also calculated. This index uses a combination of the numerical percentage, volumetric (or mass-based) percentage, and frequency percentage of each food type in an animal's diet to estimate the relative importance of each food to that animal (for further explanation, see Pinkas *et al.* 1971; Hart *et al.* 2002; Paltridge 2002). The IRI of each prey item is calculated using the formula:

$$IRI = (N + M)F$$

where N is the numerical percentage of a certain prey item, M is the mass percentage of the prey item (or biomass percentage), and F is the frequency of occurrence of that prey item across all samples (*sensu* Pinkas *et al.* 1971). The stomach contents data from all 17 Nankeen Kestrels were pooled before the calculation of each index.

A multiple linear regression model was used to determine if the number of prey individuals taken by Nankeen Kestrels varied between prey categories. In this analysis, prey was placed into three categories—orthopterans, other invertebrates, and vertebrates—as orthopterans had previously been reported to be the most common invertebrate prey of the Kestrel (Paull 1991; Schulz & Lumsden 2009). Linear regression models were then used to investigate the relationships between body size (for which the proxies of tarsus length and bird weight were used as predictor variables) and the number of individual prey items taken. As all data analysed were count data, diagnostic plots were used to check whether the data satisfied the assumptions of these models (i.e. if data were approximately normal) (Fowler & Cohen 1995); as assumptions of each model were met, no transformations to the data were necessary. The significance level (α) used in all regression models was 0.05.

Results

Measurements

Table 1 presents the mean measurements of Nankeen Kestrels collected at Brisbane Airport. Some birds were not suitable for all measurements (because of damage

Table 1. Mean measurements of Nankeen Kestrels sampled at Brisbane Airport.

<i>Measurement</i>	<i>Total length</i> (mm)	<i>Wing length</i> (mm)	<i>Tarsus length</i> (mm)	<i>Weight</i> (g)	<i>Stomach weight</i> (g)
Mean	297.3	251.9	45.5	138.7	6.05
Standard error	12.1	2.1	0.4	6.1	0.87
Sample size	16	16	17	15	17

sustained from bird-strike incidents) and were not used for those measurements, so sample size is given with each measurement. Tarsus length given is tarsus (with foot) length (see Lowe 1989); stomach weight given is that before processing (i.e. before extracting and drying the stomach contents). The majority (13 of 17) of the Kestrels appeared to be juveniles, based on plumage characteristics given by Marchant & Higgins (1993) and Debus (2012).

Analysis of stomach contents

The stomach contents of 17 Nankeen Kestrels contained a total of 182 individual prey items, representing 10 taxa. The diet of the Kestrels at Brisbane Airport by taxon, and the *IRI* values for each taxon, are presented in Table 2.

On average, each stomach contained parts of 10.7 prey items (range 1–49), although the number and taxa of prey items present in each stomach were variable. Simpson's Index of Diversity (D') for the identifiable prey assemblage of the Nankeen Kestrels was 0.217, Shannon's Index (H') was 0.59, and Pielou's Index (J') was 0.25. Only one bird had a single prey item in its stomach: a skink. Some birds had fed on several prey taxa in close succession, including vertebrates and invertebrates.

Invertebrates were present in the majority (16 of 17) of the stomachs, and about two-thirds of the stomachs (11 of 17) contained only invertebrates. Orthopterans, including short- and long-horned grasshoppers (Acrididae and Tettigoniidae), field crickets (Gryllidae) and mole crickets (Gryllotalpidae), were the most commonly encountered arthropod order, occurring in 94% of the sampled stomachs. Dominance of the Nankeen Kestrels' diet by this taxon is reflected by the *IRI* value: orthopterans made up 96.3% of the total *IRI*. Quantification of orthopteran numbers in the stomach contents was based on counts of recognisable parts, most often the mandibles, which appeared to persist in the stomachs for longer than other parts of the exoskeleton. The discovery of intact orthopteran heads allowed for identification of different mandible shapes and sizes between species, although only the mandibles of Gryllotalpidae and Acrididae could be reliably separated using this method. For this reason, counts of orthopterans are reported, as opposed to family-level counts. When possible, counts of other recognisable parts (e.g. cerci in Gryllotalpidae) were compared with the mandible counts, often with very similar results. An exception to this pattern was a single stomach, in which 90 mandibles were found without any other recognisable body parts being

Table 2. Prey items identified in the stomach contents of Nankeen Kestrels at Brisbane Airport, listed by frequency of occurrence (number and percentage of stomachs containing that prey), total number of prey items, biomass, and Index of Relative Importance (IRI; see text) (total number of stomachs = 17). Unidentified stomach contents were excluded from these analyses.

Taxon	Stomachs with prey		No. of prey items		Prey biomass		IRI	
	No.	%	No.	%	g	%	Total	%
Arthropods								
Spiders (Araneae)	3	17.7	3	1.7	0.1	0.7	40.47	0.3
Insects (Insecta)								
Dragonflies (Odonata)	3	17.7	3	1.7	<0.1	<0.1	29.09	0.2
Cockroaches (Blattodea)	2	11.8	5	2.8	0.2	1.3	47.50	0.3
Grasshoppers, crickets (Orthoptera)	16	94.1	161	88.5	10.5	67.7	14 701.5	96.3
Cicadas (Hemiptera)	1	5.9	1	0.6	<0.1	<0.1	3.23	0.02
Caterpillars (Lepidoptera)	1	5.9	1	0.6	<0.1	<0.1	3.23	0.02
Amphibians								
Striped Marsh frog <i>Limnodynastes peronii</i>	3	17.7	3	1.7	1.5	9.7	199.87	1.3
Reptiles								
Garden Skink <i>Lampropholis delicata</i>	3	17.7	3	1.7	1.2	7.7	165.71	1.1
Birds								
Passerine (unidentified)	1	5.9	1	0.6	0.8	5.2	33.59	0.2
Mammals								
House Mouse <i>Mus musculus</i>	1	5.9	1	0.6	1.2	7.7	48.77	0.3
Total			182		15.5		15 273	

present. Orthopteran individuals occurred in greater numbers than those of any other taxon ($P < 0.001$, $R^2 = 0.614$).

As Table 2 illustrates, other arthropods taken by Nankeen Kestrels at the Airport were cockroaches (Blattodea), dragonflies (Odonata), spiders (Araneae), cicadas (Hemiptera), and butterfly larvae (Lepidoptera). Frogs (tentatively identified as Striped Marsh Frogs *Limnodynastes peronii*) and Garden Skinks *Lampropholis delicata* were the most common vertebrate prey items taken by the Kestrels, and had the second (1.3%) and third (1.1%) highest *IRI* values, respectively. Other vertebrate prey items included a House Mouse *Mus musculus* and an unidentifiable passerine bird. Unidentifiable feathers were found in four stomachs but, given the absence of other remains, probably came from self-preening by the Kestrels. Grass was found in three stomachs, and a leaf was found in one. Sand and grit were found in one stomach, although these items were presumably too small to be 'rangle', i.e. stones used as purgatives in some raptor species, including kestrels (Michell 1970; Olsen *et al.* 1979). The unidentifiable stomach contents were generally chitinous or soft parts of insect bodies that had been partially digested.

The unidentified stomach contents made up the majority of the stomach weights overall, accounting for 46% of the total weight of all stomachs. When the unidentified contents were removed from the analysis, however, orthopterans (65.5%) made up the majority of biomass in the Kestrels' stomachs, followed by frogs (10.3%), skinks (8.3%), the mouse (8.3%) and the bird (5.5%). Blattodea represented 1.4% of the biomass, and spiders just 0.6%; all other arthropod orders represented <0.1% of the total biomass. There was no relationship between bird size and total number of prey items, using tarsus length ($P = 0.45$, $R^2 = 0.027$) or bird weight ($P = 0.0503$, $R^2 = 0.232$) as the indicator of size.

Discussion

The diet of Nankeen Kestrels at Brisbane Airport is generally similar to that reported previously for this species in Australia (Marchant & Higgins 1993). In particular, the dominance of diet by orthopterans found in the present study, evident in the extremely high *IRI* value for this prey category (Table 2), is similar to the results of van Tets *et al.* (1977), Olsen *et al.* (1979), Paull (1991) and Schulz & Lumsden (2009). The Kestrels also preyed upon other invertebrates, skinks, frogs, mice and birds in this study, albeit seemingly far less often than on orthopterans.

Other researchers have found that the diet of Nankeen Kestrels can be dominated by lizards (Aumann 2001) or mice (Hayward & MacFarlane 1971; Hobbs 1971), which had comparatively low *IRI* values in this study. In these published studies, however, lizards and mice were the most common prey items available at the time in those study areas. As only a 'snapshot' of an animal's diet is provided by analysis of stomach contents (Stevenson 1933), other prey categories may be more commonly exploited at the Airport than suggested by the data in this study. Because of the nature of working at the Airport, however, other methods of dietary analysis that may have increased the sample size (e.g. pellet analysis) were impractical. Regardless, the presence of a wide range of taxa in the Kestrels' diet indicates that Kestrels are observant when foraging, respond to changes in their

immediate environment, and exploit opportunities as they arise. They may also learn to exploit somewhat unusual prey, such as frogs.

Karasov (1990) demonstrated that there is apparently no significant difference in the energy content of vertebrate and invertebrate prey. Therefore, the prey that is most readily available to Nankeen Kestrels at the Airport should be the most preferred (Schoener 1971). The Kestrels are likely to target orthopterans because of high abundance, ease of detection and capture, and low handling time (i.e. requiring little preparation for ingestion)—the combination of these factors gives orthopterans their high prey value relative to vertebrate prey (Schoener 1971).

The average total length of the Nankeen Kestrels sampled in this study was slightly less than that given by both Slater & Slater (2010) and Pizzey *et al.* (2012), and average weight was less than that stated for both adult and juvenile birds by Marchant & Higgins (1993) (see Table 1). These results indicate that the majority of the birds obtained from the Airport were juveniles, as also did the plumage characteristics recorded. Juvenile Kestrels may need to learn how to capture and handle larger prey. The results of this study support the suggestion that smaller birds may prefer invertebrate prey, which is easier to capture and handle (Bond 1936; Tarr 1952). However, in times of increased prey abundance, such as during a mouse plague, Kestrels may switch from targeting invertebrate prey to mice, as demonstrated by Hayward & MacFarlane (1971) and (Hobbs 1971). Additionally, the diet of Kestrels at Brisbane Airport is likely to change slightly with the seasons, and could also be affected by the breeding status of individual birds.

The Simpson's Index of Diversity for the prey assemblage was fairly low, but was affected by the coarse level of taxonomic resolution in the invertebrate prey categories. The values calculated for Shannon's Index ($H' = 0.59$) and Pielou's Index ($J' = 0.25$) in this study are smaller than those of Aumann (2001) for the same species (0.75 and 0.54, respectively). Aumann's (2001) study, however, was located in the arid south-west of the Northern Territory, where prey availability for any particular prey item is presumably lower than at Brisbane Airport. The Nankeen Kestrels in Aumann's (2001) study probably took food items of lower value out of necessity, thus leading to a higher diversity in their diet. In contrast, Kestrels at Brisbane Airport can select high-value prey items, because of the relative abundance of prey. These conclusions are supported by the values of H' and J' in this study in comparison with Aumann (2001), and support the foraging theory that a decrease in the availability of prey should lead to an increase in diet breadth (Emlen 1966; Atkinson & Cade 1993). It follows that, if food is readily available, predators are more likely to specialise on certain types of prey, such as orthopterans, as in the current study.

Management strategies to reduce the abundance of orthopterans in the grassy areas of Brisbane Airport, such as the planting of unpalatable vegetation (Linnell *et al.* 2009), should be explored. If prey abundance were reduced, the Nankeen Kestrel population may decline rapidly, as birds emigrate to areas of higher prey availability (Jaksić *et al.* 1992; Salamolard *et al.* 2000). For further information on management strategies to reduce the bird-strike risk of Kestrels at Brisbane Airport, see Leach (2013).

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