Deaths and injuries to Grey-headed Flying-foxes, *Pteropus poliocephalus* shot at an orchard near Sydney, New South Wales

Anja Divljan[1, 3], Kerryn Parry-Jones[1], Peggy Eby[2]

[1] Institute of Wildlife Research, School of Biological Sciences, Heydon-Laurence Building (A08), The University of Sydney, Sydney, NSW 2006

[2] 9 Albert Lane, Bronte, NSW 2024

[3] Corresponding author. Email: anja.divljan@sydney.edu.au

ABSTRACT

For several years, animal welfare concerns have been raised over the practice of shooting Grey-headed Flying-foxes (GHFF) in commercial fruit orchards in Australia, and the role of government agencies in licensing the kill. In NSW the practice is poorly monitored and insufficient evidence has been available to assess welfare concerns. This study reports the first systematically acquired data on flying-foxes shot under licence in NSW. In the 2006/07 season the average number of GHFFs licensed to be harmed was <40 individuals per licence. Despite this, a total of 164 dead or injured flying-foxes were collected (n = 146) or observed (n = 18) from an orchard in western Sydney over two weeks in spring 2007, after shooting had occurred at the orchard to protect fruit crops. Detailed information, including sex, reproductive state, age and description of injuries, was compiled on 136 collected bats. The sex ratio was strongly skewed towards females (1:1·73), of which 54 (65%) were lactating at the time. Thirteen of these were shot while carrying their dependent young, while 41 neonates would have been left behind in the camp to die. Hence, the total estimate of flying-foxes that died due to shooting in the orchard over the two-week period was 205. Collected bats suffered from various injuries, and at least 30% (44% including the neonates left in the camp) were alive and unattended more than 8.5 hours after shooting. This is in contravention of the definition of 'humane killing' and the *Prevention of Cruelty to Animals Act 1979*. Importantly, the GHFF is vulnerable under NSW and Federal legislations and the killing of reproducing females in crops contributes to its declining numbers, making Sydney Basin an ecological trap for this species.

Key words: Flying-fox, *Pteropus poliocephalus,* shooting, orchard, humane killing, animal welfare

Introduction

The Grey-headed Flying-fox, GHFF, *Pteropus poliocephalus* is a large bat endemic to Australia. Its distribution extends along the eastern coast, from mid Queensland to southern coastal Victoria (Hall and Richards 2000). It is listed as vulnerable in NSW (*Threatened Species Conservation Act 1995*), Victoria (*Flora and Fauna Guarantee Act 1988*) and under Federal legislation (*Environment Protection and Biodiversity Act 1999*). This listing is a direct result of a reported population decline of 30% over ten years (Parry-Jones 2000), attributed mainly to the loss and degradation of foraging and roosting habitat (Tidemann *et al.* 1999; Dickman and Fleming 2002; Eby and Lunney 2002; Department of Environment and Climate Change (NSW) 2008). The vulnerability of the species is linked to its life history, which is at the slow end of the slow-fast continuum (Read and Harvey 1989).

A 'slow' characteristic of the life history of *P. poliocephalus* is the relative high investment that is put into individual young. The species has a low reproductive rate (Jones *et al.* 2003): the majority of females do not reproduce until they are three years old (Divljan 2008) and there is a relatively high level of post-natal care. Females are pregnant for six months (Nelson 1965; Martin *et al.* 1987; O'Brien 1993) and have only one young a year (Ratcliffe 1931; Nelson 1965; Martin and McIlwee 2002). The mothers carry neonates continuously for the first three weeks of their life and then leave them with other flightless young at a camp site at night while they feed (Nelson 1965). As the young do not fly under three months and they are weaned between the age of four to six months old (Nelson 1965; Hall and Richards 2000) a juvenile flying-fox left in the camp at night is dependent on its mother for at least three months and if she fails to return from her foraging trips the young flying-fox will die (Parry-Jones 2000).

P. poliocephalus preferentially feeds on nectar and pollen from native myrtaceous species (e.g. species of *Eucalyptus*, *Corymbia* and *Melaleuca*) but also eats various native and introduced fruits (Parry-Jones and Augee 2001). At times flying-foxes feed on orchard fruit and historically this behaviour resulted in them being considered a pest species and the subject of various attempts at eradication (Ratcliffe 1931; Ullio 2002). Crops grown in coastal areas in NSW and southern Queensland are most commonly affected, and the perception is that the incidence of fruit damage by bats has been increasing in the recent years (Biel 2002). However, in a study of flying-fox droppings in the Sydney area, Parry-Jones and Augee (2001) showed that the stone fruit (plums, nectarines and peaches) is only a part of the flying-fox diet over a couple of days in November and December in some years, and a couple of weeks in other years. The pattern is highly variable in both the time the fruit is found and the percentage of droppings that contain stone fruit. This agrees with recent observations that the incidence of flying-foxes in orchards in the Sydney Basin is highly variable between nights, between years, between orchards and between fruit varieties (Dang *et al.* 2009, in preparation).

One of the most common ways of controlling flying-foxes in orchards has been to shoot them (Ratcliffe 1931; Tidemann *et al.* 1997). Commercial fruit growers in NSW can apply to the Department of Environment and Climate Change and Water NSW (DECCW) for a licence to harm or kill a limited number of flying-foxes under Section 120 of the NSW *National Parks and Wildlife Act 1974* (Department of Environment and Conservation (NSW) 2005). Licences to shoot flying-foxes in crops are issued with the expectation that fruit growers will shoot to scare the animals, but that some incidental harm is likely to result (Waples 2002). The maximum number and species of flying-foxes that may be harmed are specified in the licences and there are specific restrictions in the shooting method. For example, a 12 gauge shotgun and No. 4 lead shot must be used and shooting must be confined to the type of crop specified in the licence and the area of that crop. Only persons authorised under the licence are permitted to shoot, and they "… must locate each animal shot and promptly alleviate the suffering of any injured flying-fox by gunshot to either the head or thorax of the animal" (Department of Environment and Climate Change (NSW) 2007). This provision, to prevent any unnecessary pain or suffering to the animals, is mandated directly by the *Prevention of Cruelty to Animals Act 1979* (*POCTA 1979*), and failure to comply with this *Act* is an offence that can result in prosecution and heavy penalties.

Most licences to harm or kill flying-foxes in NSW are issued to orchardists on the outskirts of Sydney (Department of Environment and Climate Change (NSW) 2007). Shooting is practised by 75% of growers in Sydney Basin (Dang *et al.* 2009, in preparation) in comparison with a greater reliance on netting to protect crops in other parts of the State. The number of permits issued to shoot flying-foxes has decreased over the years; however there is an issue with non-compliance: in the past, 69% of orchardists have been reported as shooting without a licence or outside licence provisions (Wahl 1994) and DECCW acknowledges that insufficient resources are available to its field staff to adequately monitor compliance with licence conditions (McLachlan 2002; Waples 2002). Although licensees are required to provide reasonable access to their land for inspection by DECCW officers, neither the number of animals killed nor the prompt, humane killing of injured animals is monitored.

In past years there has been further evidence of many injured flying-foxes not being subsequently killed by orchardists and of the ethical guidelines for humane killing not being routinely followed. This evidence consists of reports of: a) flying-foxes being found injured or dead from shotgun pellets outside orchards, in areas adjacent to orchards (WIRES records), and b) large numbers of dead and dying young being found without their mothers in camp sites within foraging range of orchards (Parry-Jones 2000). Consequently, animal welfare concerns have been raised in various jurisdictions over the practice of shooting flying-foxes in commercial fruit orchards in Australia, and the role of government agencies in licensing this activity (AWAC 2008; Department of Environment and Climate Change (NSW) 2008; I. Temby, Department of Sustainability and Environment (Victoria), 2009 pers. comm.; Woodhead *et al.* 2009). In 2008, the Animal Welfare Advisory Committee of Queensland advised the Minister for Primary Industries that shooting flying-foxes for crop protection is inhumane and as a result the practice has been discontinued in that state (AWAC 2008). Matters pertinent to these discussions include: i) the unknown accuracy of shots fired at flying animals at night; ii) the capacity of shooters using shotguns to achieve instant death via a shot to vital organs (brain or heart/lungs); iii) the extent of injuries sustained by animals that are not killed immediately, the fate of those animals and the pain experienced; iv) the capacity of shooters to locate injured animals quickly and kill them humanely; and v) the fate and pain experienced by non-volant, dependent young whose mothers are killed in crops while they remain in camps.

The shooting of flying-foxes, under licence in NSW, and the animal welfare considerations pertinent to this procedure have not been assessed previously. Hence, this study reports the results of shooting by a licensed orchardist in western Sydney during a fruit season in which, overall orchard damage by flying-foxes in the Sydney Basin was considered low (Dang *et al.* 2009, in preparation). The licensees, who believed themselves to be acting within the bounds of normal, acceptable industry practice, granted permission for flying-foxes to be collected from their orchard during a short period of shooting for crop protection. The aims of the study are to describe, both qualitatively and quantitatively, the animals that were shot in the orchard and to determine whether the legal requirements of shooting in crops were followed or are adequate to the situation. In particular, it documents the number of animals that were shot, their reproductive status, and age structure, the types of injuries they received, and the degree to which the relevant animal welfare and animal ethics guidelines were followed with respect to the humane killing of injured animals.

Methods

Study area

The study took place in a stone fruit orchard in the Lower Hawkesbury district west of Sydney, NSW. The orchard is located on undulating land in a mixed landscape of agricultural holdings, rural residential developments, small townships, small remnants of native vegetation and expansive areas of native forest. It is within three kilometres of the boundary of the Greater Blue Mountains World Heritage Area. Native food sources for flying-foxes within 10 km of the orchard include 15 species of flowering trees and at least nine species of rainforest fruit. The nearest flying-fox camp is six kilometres from the orchard. Two additional camps are located within nightly foraging distance of the orchard (20 km). Each of these camps was occupied at the time of the study.

The orchard is classified as 'small' according to Fleming and Dang (2009). It consists of approximately four hectares of mature nectarine trees set out in two large blocks with an intervening smaller block of immature trees and some cleared land (Figure 1). The trees in each block are planted in parallel rows approximately 4.5m apart which leaves a 1.5-2.0m open space between rows for vehicle access. The orchard is surrounded by cleared land containing farm structures and scattered trees and a 50-60m strip of remnant native vegetation consisting of tall trees (the 'windrow') located along the north-west boundary of the orchard. The two week study occurred within the time when the nectarine crop was ripening and being harvested.

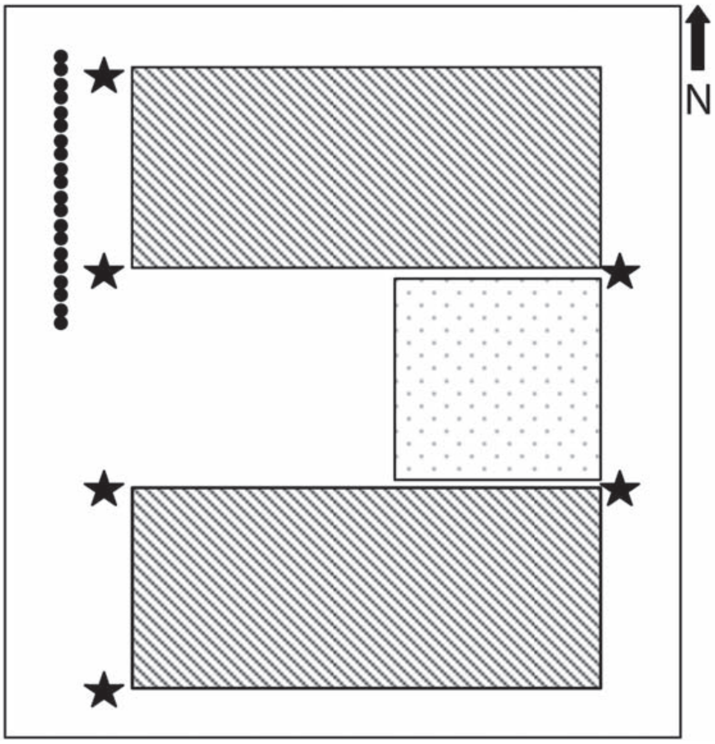

Figure 1. A schematic representation of the study area showing the relative positions of blocks of mature plantings , immature plantings , and cleared land . The two blocks (4ha) of mature nectarines (3m tall) were separated by 1.6ha of combined clear land and immature fruit trees (<1m tall). A tall windrow (••••) of native trees was located along the north west boundary of the orchard, and a 50-60m strip of remnant native vegetation ran along the northern boundary (not shown). The orchard was surrounded by cleared land containing farm structures and scattered trees. The positions taken by shooters when stationary are indicated by stars (★). Mobile shooters moved along open spaces that separated lines of fruiting trees. Diagram is not to scale.

Animal collection

Dead and injured flying-foxes were collected in the study area from 9 November to 22 November, 2007. The nightly shooting was finished by 10.30 PM and the flying-foxes were collected from 7 AM the next morning. Two or three people were involved in the daily search of the study area which included the orchard, the windrow and immature plantings. Each row of trees was traversed and the ground cover and canopy vegetation were searched thoroughly. A band around the orchard approximately 15 m wide was also searched although not as thoroughly as other areas.

Dead flying-foxes were collected, placed in individual bags and transferred to a freezer for storage. Dead females were checked for the presence of live young. Live, injured animals were captured and placed in small cages or cloth bags depending on the level of injury and taken to a veterinarian. There they were sedated with Zolatil prior to their injuries being assessed. Where their injuries were deemed too severe to allow recovery to a standard suitable for release into the wild, the animals were euthanased using Lethabarb. Where rehabilitation was considered possible, animals were transferred to members of a licensed wildlife rehabilitation organisation. Dependent young were left with injured mothers until a veterinary assessment was made. In cases where a female carrying young was euthanased, the young was removed and transferred to a wildlife rehabilitation group.

Data recording and the assessment of dead individuals

The bodies of dead flying-foxes were banded with numbered metal bands for future identification. The sex, body mass (g) and forearm length (mm) of each individual were recorded, and the left mandibular 1st premolar was extracted from sub-adults and adults for ageing purposes (Divljan *et al.* 2006).

Female reproductive status was assessed using five categories (Divljan 2008), animal: i) had never lactated, ii) showed signs of 'pseudo-lactating' (producing discharge, but nipples not enlarged), iii) was pregnant, iv) was lactating (nipples enlarged and producing milk with no fur around the nipple; the loss of fur around the nipple is the direct consequence of the offspring suckling consistently for several weeks) v) had lactated before but was not lactating at the time (nipples had somewhat regressed and fur around them had grown back). Males $\geq$ 3 years old were classed as reproductive.

All bodies were examined for external signs of injuries. Wing damage (bone fractures and membrane damage), body, leg and head injuries (fractures, pellet marks and external haemorrhaging) were noted. The injuries of the euthanased flying-foxes that were alive at least 8.5 hours after shooting and those that were dead when collected were compared statistically using a Chi-square (χ^2) analysis and Fisher's Exact test if the expected frequencies were lower than five (Quinn and Keough 2002).

All the euthanased flying-foxes and a random collection of the animals that were dead when collected were autopsied by a veterinarian (Dr T. Bellamy, Austral Vet Clinic). A detailed external examination was conducted and the animals were X-rayed to document the extent of bone damage and locate shotgun pellets. The autopsy commenced with an incision in the anterior chest and abdominal wall. Then the ribs and sternum were excised to expose the internal organs and the extent of internal body trauma was assessed. Contusions of the body wall and muscle were documented, as were damage to organs, haemorrhages and fractures. Direct signs of pellets: round holes in wing membranes, points of entry into the body cavity, and remnants of the embedded pellets, were also recorded. The head and neck area were assessed for signs of cranial fractures, haemorrhaging and/or contusion. Photographs were taken to document the extent of injuries. The injuries of the two groups of flying-foxes were subdivided into more detailed categories and compared statistically using Chi-square (χ^2) analysis and Fisher's Exact test (Quinn and Keough 2002).

Results

Animal collection

A total of 164 dead or injured flying-foxes were collected or directly observed over the 14 day study period (Table 1). Of the 164 flying-foxes, 102 animals were dead when collected (this included five neonates that were found on dead mothers) and 12 animals were dead but not able to be collected because their bodies were located out of reach in the windrow trees (Table 1). The remaining 50 flying-foxes were alive at the time of collection. Six of these injured live animals were unable to be caught as they were located high in the windrow (one was a neonate that was heard calling from the top of one of the casuarinas near a dead female for four consecutive days). The accessible 44 injured animals were collected. Hence 30% of the total number of flying-foxes observed or collected from the orchard, were alive at least 8.5 hours after being shot.

All the dead flying-foxes were found inside the orchard and the windrow and all but one was found on the ground (the other being found in a fruit tree). In contrast, injured animals were typically found roosting in the canopy of orchard trees. A small number were located hanging low to the ground and five were collected from the ground. Some injured flying-foxes were found outside the orchard, roosting in unexpected locations such as on fence posts or on plastic guards used to protect new plantings. Animals in trees were difficult to locate as they often roosted in dense foliage and did not move when approached. While care was taken throughout the study to carefully search all of the fruit trees, it should be noted that some injured animals may not have been located.

The number of flying-foxes collected from the orchard varied substantially between days. The maximum number of dead and injured flying-foxes collected on a single day was 43 while on three of the 14 days no flying-foxes were collected. At least one injured live flying-fox was collected each day that injured or dead animals were collected from the orchard (n = 11 days).

Of the 44 collected injured flying-foxes, 34 were euthanased after veterinary assessment. All live injured adults were euthanased. Among these were eight females with live neonates attached. (None of the dead females when collected in the orchard had live neonates on them). The neonates were removed from their mothers and with two sub-adult animals that were considered to be curable, were passed to a licensed wildlife care organisation for care and rehabilitation. No further data were able to be obtained from these 10 injured but potentially releasable animals, and so the detailed investigation of the bodies of the collected animals was restricted to the 136 animals that were actually removed from the orchard and were dead when collected (n = 102) or were subsequently euthanased (n = 34).

Sex ratios, reproductive condition and age structure

Of the 136 animals collected, 131 were either adults or sub-adults that visited the orchard. A significantly higher number of females than males were shot in the orchard (female n = 83, male n = 48; χ^2 = 9.351, $d.f.$ = 1, P =

Table 1. The number of *P. poliocephalus* collected or directly observed during the two-week study period in November 2007 in a stone fruit orchard (Lower Hawkesbury district west of Sydney, NSW), and the minimum number of the neonates left behind in the camp. a – One neonate was heard calling for four days next to dead mother high in casuarinas. b – Seven neonates were successfully raised by a wildlife rehabilitation organisation (one young died one day after being rescued from an euthanased mother). c – The minimum number of dependent neonates left in the camp based on the number of collected dead lactating females (and excluding the collected and/or observed neonates). It is possible that more lactating females were present in the samples of adults that were not collected (12 and 5), which would increase the total number of neonates left to die in the camp.

	Neonates	Sub-adults and adults	
Dead collected	5	97	
Dead not collected		12	
Injured euthanased		34	
Injured (or neonate) not collected	1a	5	
Injured (or neonate) and taken into care	8b	2	
Minimum no. left in the camp	41c		
Total	55	150	205

0.0022). Of the females, 61 (73%) were reproductive: 54 of these were lactating, four were pregnant and three had lactated previously but were not currently lactating. Of the lactating females 13 were shot while carrying a neonate. Forty one females had therefore left dependent young at a camp site. Eight of the non-reproductive females were showing signs of 'pseudo-lactation', a state which was frequently observed in sub-adult females. Of the 48 males, 29 (60%) were reproductive (≥3 years old). If the 41 neonates left to die at the camp are included in the overall mortality from the orchard, the percentage of animals that survived ≥8.5 hours from when shooting ceased increased from 30% to 44%.

The age structure of the animals killed by shooting in the orchard was assessed using all the animals that were collected from the orchard (n = 136) and the neonates that would have been left back in the flying-fox camp (n = 41). The age structure of this group of 177 animals is summarised in Figure 2. The age of animals of both sexes ranged from neonates to adults at least 12 years old, and 87% of the sample were aged ≤6 years old. Males predominated in the younger, non-breeding age groups but from the age of three, when most females breed, females were more numerous (Figure 2). Overall, 59 (88%) of the females ≥3 years old (n = 67) were reproductive at the time of the study. The shape of the age distribution of shot flying-foxes was consistent with the general pattern observed for *P. poliocephalus* sampled in Sydney Basin (Kolmogorov-Smirnov test: D = 0.2941, P = 0.387; data from Divljan 2008).

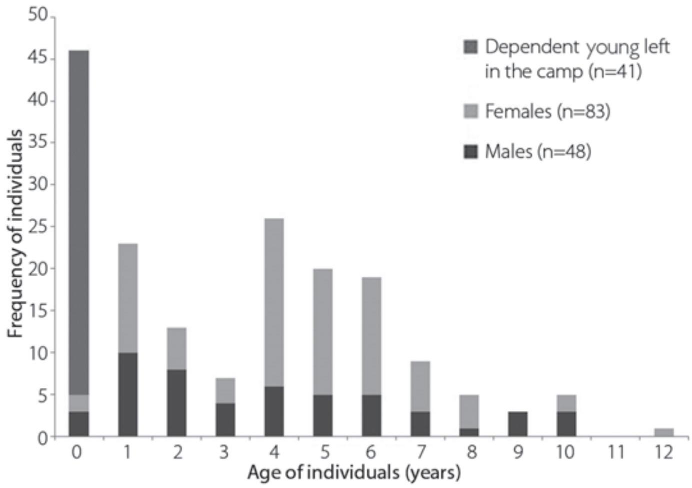

Figure 2. Age distribution of the shot flying-foxes collected in November 2007, and dependent young that would have been left in the camp. The age distribution is driven primarily by the larger sample of female bats, particularly between the ages 4-6.

Assessment of injuries

Incidence and description of external injuries

All 136 collected bats were externally assessed for injuries resulting from shooting. Of the 131 sub-adult and adult bats, 34 had been alive at collection but subsequently euthanased. The injuries sustained by all 136 animals are presented in Table 2.

On external examination, fractures of the long bones in wings (humerus, radius and ulna) were most common and documented in 108 (82%) cases (Figure 3). Wing membrane was damaged in at least 85 animals (65%), and 61 flying-foxes (47%) had body-related injuries. The incidence of external haemorrhaging was low and depended on the size and nature of the open wound. Bleeding from the mouth and nose was noted in a small number of bats who generally had a fractured mandible and/or maxilla. Overall 19 animals (15%) showed external signs of head trauma, characterised by fractures of the cranium, mandible and/or maxilla and haemorrhaging in the head region, but of these only three had cranial injuries indicating brain damage. An additional three bats had injuries consistent with being shot at close range from above and it is likely that they were dispatched by a shotgun burst to the top of the head while on the ground (Figure 4). Provided that these three were shot shortly after falling to the ground, there is evidence that six bats died rapidly from a direct brain damage.

Table 2. An overview of the documented injuries in euthanased animals. All animals had multiple types of trauma, however their severity varied considerably. Similar injuries were recorded in the random sample of autopsied bats that died, with a small number of bats suffering a direct brain trauma as well.

Type of trauma observed	Body part/area affected	**Description** (damage is primarily associated with the high force impact of the penetrating pellets, and at times the impact upon fall/crash landing)
Haemorrhaging	Free blood observed in the head (but cranium intact), neck, chest and/or abdomen	Bleeding externally (from mouth, nose, or open wound), internally from tissue/organ damage
Bone fracture (often multiple)	Axial skeleton: mandible, ribs, sternum, vertebrae Appendicular skeleton: limb bones, girdles	A broken bone - several ways observed, e.g. closed (complete, incomplete and multi-fragmentary) and compound
Superficial tissue penetration	Muscle and body wall, wing membrane	A hole left in the tissue as the high force pellet passes through
Contusion	Organs (e.g. eye, lungs), muscle and body wall particularly in the neck and chest area	Damage to the capillaries in the tissue often associated with more serious trauma (fracture, haemorrhaging)

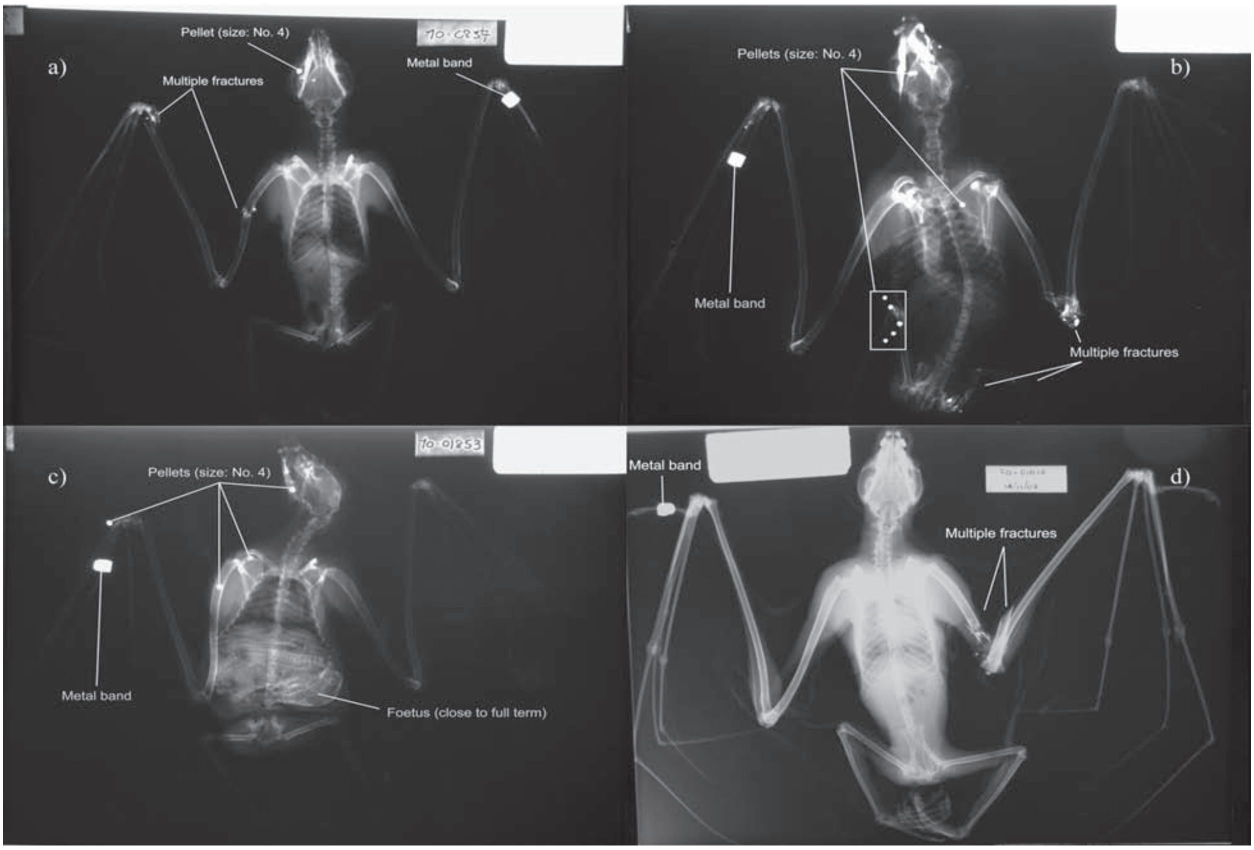

Figure 3. Examples of injuries in shot flying-foxes. a) A bat that has been shot in the head. The autopsy revealed haemorrhaging around the right eye socket (the pellet is still embedded in the region), fractures of the right humerus and distal radius and ulna, several holes in the wing membranes and contusion of the right lung. b) X-ray of a shot flying-fox with extensive body trauma: internal haemorrhaging, rib and sternum fractures, and limb bone fractures. Note, however, the pellet imbedded in the head, which fractured the left dentary on impact, but caused no direct brain damage (cranium was intact). c) X-ray of a pregnant female. The autopsy revealed anterior skull fractures and damage to the right wing (three pellets can still be seen on the X-ray). d) A bat with a compound fracture of the left humerus and minor wing membrane damage. The autopsy revealed no other signs of injury. In all cases the fractures of long bones of the arm were deemed severe and animals would not have been able to fly again.

Figure 4. External assessment of a head injury showing a compound fracture of a large portion of the cranium exposing the brain. The nature and position of the injury indicates a close-range shot of the bat on the ground (it was probably brought to the ground, but not immediately killed, by another shot that shattered one wing).

The χ^2 analyses and/or Fisher's Exact tests of the 2x2 contingency tables compared the types of external injuries observed in the animals that died within the 8.5 hour period (those that were collected dead) and the animals that survived this period (those that were euthanased). The observed numbers of bats with external injuries of the neck and legs were not significantly different between the two groups (Table 3). The odds of observing an external wing bone or membrane injury were 9.68 and 3.27 times greater respectively in bats that were collected alive compared to collected dead. Conversely, the bats that were collected dead had higher odds of having external head and body injuries compared to those that were collected alive (Table 3).

Of the dead collected neonates, four had been shot in the body (signs of external haemorrhaging were apparent at the site of impact). One had a fractured skull, a probable result of the direct impact from a shot aimed at the mother.

Autopsied animals: internal injuries and euthanasia

Autopsies were carried out on 58 flying-foxes: 34 euthanased animals and 24 randomly selected from the animals that were collected dead. All 34 euthanased bats had signs of wing trauma including fractures of arm or shoulder bones, hand bones and/or membrane damage (Figure 3), and 31 (91%) cases had fractures of a long bone (Table 4).

Table 3. Observed values and statistical results comparing external injuries documented in the bats collected dead (n = 97) and alive (and had to be euthanased, n = 34). Fisher's Exact tests were used in cases when the expected values were <5. The asterisk (*) denotes significant results.

External injury (type and location)	Euthanased (injury observed)	Euthanased (injury not observed)	Dead collected (injury observed)	Dead collected (injury not observed)	Chi-value (without Yates correction)	P or Fisher's exact P	d.f.	Odds ratio	Confidence interval (for odds ratio)	
Head	1	33	18	79		0.0249*	1	0.1330	0.022	0.822
Neck	1	33	3	94		1.0000	1	0.9495	0.132	6.949
Body	6	28	55	42	15.432	0.0001*	1	0.1636	0.059	0.388
Wing bone	33	1	75	22	6.777	0.0092*	1	9.6800	1.579	58.316
Wing membrane	28	6	57	40	6.149	0.0131*	1	3.2749	1.269	8.399
Leg	5	29	10	87		0.5350	1	1.5000	0.496	4.578

Table 4. Observed values and statistical results comparing internal injuries documented in the random sample of bats collected dead (n = 24) and alive (and euthanased, n = 34). Fisher's Exact tests were used in cases when the expected values were <5. The asterisk (*) denotes significant results.

Internal injury (type and location)		Euthanased (injury observed)	Euthanased (injury not observed)	Dead collected (injury observed)	Dead collected (injury not observed)	Chi-value (without Yates correction)	P or Fisher's exact P	d.f.	Odds ratio	Confidence interval (for odds ratio)	
	Brain	0	34	2	22		0.1670	1	0.0000	0.011	1.563
Haemorrhaging	Chest	6	28	15	9	12.254	0.0001*	1	0.1286	0.039	0.422
	Abdomen	5	29	2	22		0.6880	1	1.8966	0.380	9.226
	Neck	1	33	1	23		1.0000	1	0.6970	0.069	7.013
Bone fracture (with some bleeding and/or contusion)	Head (mandible and maxilla)	4	30	4	20		0.7062	1	0.6667	0.162	2.742
	Chest (ribs and sternum)	18	16	17	7	1.882	0.1700	1	0.4632	0.156	1.379
Bone fracture (with contusion and/or membrane damage)	Wing (arm/shoulder)	31	3	19	5		0.2554	1	2.7193	0.634	11.528
	Wing (hand bones)	14	20	10	14	0.001	0.9700	1	0.9800	0.344	2.787
	Wing (membrane)	25	9	20	4	0.778	0.3779	1	0.5556	0.158	1.985
	Legs	5	29	5	19		0.7261	1	0.6552	0.176	2.427

Wing damage was the only injury detected in 15 euthanased flying-foxes. Fractures of the axial skeleton were also documented, with six bats suffering from broken ribs and/or sternum, while four individuals had damage to their mandible and/or maxilla. A further six individuals suffered from internal bleeding from chest injuries (Figure 5).

Of the 24 flying-foxes that were collected dead, all had some form of wing damage. Chest haemorrhaging was identified in 15 (63%) of the animals that died during the night, and seven bats suffered from fractured ribs and/or sternum. In comparison with the euthanased animals, two dead bats had direct brain damage, but none of the autopsied bats had any direct damage to either heart and/or both lungs. Common to both groups was bruising of the muscle and body wall most likely caused by the fall to the ground after being shot (Table 4).

The incidence of internal chest haemorrhaging was significantly higher in the animals that were collected dead compared with the animals that were collected alive ($\chi^2 = 12.254$, *d.f.* = 1, $P = 0.0001$, Table 4), and the odds of observing internal bleeding in the chest area were 7.78 times greater in the dead bats. All other types of injuries were similarly distributed between the two groups.

Discussion

This study is unique. It is the first time a commercial fruit grower in Australia has allowed free access to their property, enabling a systematic assessment to be made of flying-foxes shot for crop protection. This level of co-operation could not be duplicated elsewhere at the time and is unlikely to be repeated in the near future. Interpretations of these results are therefore limited by a lack of replication. Nevertheless, the results of the study support long-held, but poorly substantiated views about biases in the sex and reproductive status of flying-foxes killed in orchards and poor compliance by orchardists with license conditions that specify the maximum numbers of animals to be killed and the killing methods to be used (Wahl 1994; Tidemann *et al.* 1997; Parry-Jones 2000; McLachlan 2002). The results are consistent with propositions that shooting in orchards impacts the reproductive potential of this vulnerable species, contributes to the overall decline of the species and does not comply with legal and ethical standards for humane killing of animals (Dickman and Fleming 2002; Martin and McIlwee 2002; McIlwee and Martin 2002; Booth 2007; Department of Environment and Climate Change (NSW) 2008; Divljan 2008).

Description of the animals involved

The flying-foxes that suffered mortality as a result of shooting during the course of this study had an age structure that indicated a relatively young population, considering the reported longevity of the species (Divljan *et al.* 2006). However the same pattern was observed in age distributions of both dead individuals collected between 1999-2007 in Sydney and a live camp study in the Sydney Basin (Divljan 2008), indicating that this age structure is the typical one found in Sydney's *P. poliocephalus*. Hence the shooting in the orchard did not favour any particular age class but rather appeared to be random.

As there is evidence of high fecundity rates in female flying-foxes (Eby 1999), the young population is not likely an effect of variable recruitment into the population, but the result of overall high adult mortality (Divljan 2008). A linear time-invariant population model, based on such an age distribution showed a negative population growth rate ($\lambda = 0.898$) (Divljan 2008). The model further demonstrated a population halving time to be 6.47 years, which would lead to the extinction of this species within the next 84 years. The high mobility of flying-foxes (Eby 1991a) and lack of genetic differentiation within the species (Webb and Tidemann 1996; S. Fox, James Cook University, 2009 pers. comm.) suggest that this model is applicable throughout the range of *P. poliocephalus*. However further research is needed to support this hypothesis, or its alternative, that the Sydney region is acting as an ecological trap (Delibes *et al.* 2001; Battin 2004) where the flying-foxes that regularly visit the Sydney Basin are particularly at risk, and have a particularly high adult mortality rate. In either case, as over 20% of the entire population of *P. poliocephalus* can be resident at Sydney's camp sites (Smith 2007), high adult mortality within the Sydney Basin must impact negatively on the entire species.

Figure 5. An example of a body shot showing internal haemorrhaging in the chest. A pellet penetrated the anterior chest body wall and muscle causing damage to the left lung and extensive internal haemorrhaging. The heart was not damaged.

While there was no evidence of the animals foraging in orchards having an age bias compared with the rest of the Sydney population, there was considerable evidence for breeding females to be over-represented among the orchard bats. It is generally accepted that flying-foxes have a 1:1 male to female sex ratio (Martin and McIlwee 2002; Welbergen 2005), but in the orchard bats the male to female ratio of 1:1·73 was significantly different from this and a large proportion of the females were either pregnant or lactating. That breeding females made up the largest demographic group was not an unexpected result (Tidemann *et al.* 1997; Duverge *et al.* 2000). The energy requirements of pregnant and lactating females are high due to the elevation in basal metabolic rate and increase in thermoregulatory needs induced by their reproductive status (Welbergen 2005).

Wild GHFF are sequential specialists (Parry-Jones and Augee 1991) foraging on a wide range of foods, in a hierarchy of preference (Parry-Jones and Augee 2001): blossom from myrtaceous and proteaceous species form the top layer of this hierarchy, while cultivated fruit is found towards its bottom (Gopalan 2004). The pollen of the preferred blossom is high in protein (Parry-Jones 1993; Stace 1996) and highly attractive to flying-foxes (Gopalan 2004), however fruit while low in protein is high in carbohydrate (Steller 1986). Hence it is likely that flying-foxes utilise an optimal foraging strategy in order to maximise their chances for survival. In the absence of abundant blossom, a proportion of animals (particularly those with high energetic needs, such as pregnant or lactating females) may utilise orchards in combination with available native food resources. For example commercial fruit could be used as an energy source to power flight to more distant native food supplies or to other camps. This scenario is supported by an observation that a few shot bats from this study had considerable amounts of pollen on their fur: they had been feeding on native blossom elsewhere, before coming into the orchard.

If the results of this study are extrapolated for the entire period of the spring and early summer harvest and include all the orchards in which shooting occurs, the high percentage of reproductive females (73%) among the shot females, and the high percentage of shot animals whose death would also result in the death of their young (42%) indicate a considerable loss in reproductive potential for this vulnerable species as a result of shooting in orchards. This loss extrapolated over many years could be a significant factor in the observed high mortality of Sydney's flying-foxes and the overall decline of the species (Department of Environment and Climate Change (NSW) 2008).

Legal and ethical compliance

The 164 flying-foxes recorded as killed or injured during this study should be considered the minimum number of animals shot in the orchard over the fortnight. This number does not include animals that were missed in the orchard search or that flew beyond the search area despite having sustained injuries that sooner or later would result in their death. While the actual number of animals specified under the licence conditions are not known for this particular orchardist, the average number of *P. poliocephalus* licensed to be harmed in the 2006/2007 season was less than 40 flying-foxes per licence (Department of Environment and Climate Change (NSW) 2007). Hence, it is likely that this orchardist shot outside the licence provisions, and has alone contributed to ~20% of the reported shot flying-foxes for the season (Table 5). The orchardist indicated that usual standards of practice were being applied during the study period, suggesting low compliance with licence provisions throughout the fruit growing community. As a result, we suggest there are reasons to question the veracity of the data collected from orchardists and used by DECCW to document the numbers of flying-foxes shot in orchards (Table 5).

Table 5. Summary of licensed shooting practices for the past nine seasons. The numbers of harmed GHFFs are reported from the flying-fox return sheets (FFRS) received by the NSW National Parks and Wildlife Service (NPWS) from the licensed orchards, and do not include animals that have been shot, but not reported, or ones shot illegally (Department of Environment Climate Change and Water (NSW) 2010).

Season	Number of licences issued (including variations)	Allowed GHFF	Shot GHFF	Percentage of returned reports (%)
1998/1999	92	1959	516	48
1999/2000	44	895	208	44
2000–2001	67	1793	864	61
2001–2002	70	1650	1058	76
2002–2003	62	2358		
2003–2004	71	2316	1391	60
2004–2005	27	852	241	56
2005–2006	41	1320	954	88
2006-2007	34	1155	801	84
Mean (μ)		1589	753	
Total		14298	6027	
Range		852–2358	202–1391	

'Humane killing'

Vertebrate pest species cause large damage and risk to the environment and primary production industries, justifying the need for their effective control and management. Still, there is a public expectation that this control is conducted so that the target species are managed in a manner that causes them no unnecessary pain. This expectation is mandated in the *POCTA 1979*. The legislation recognises that while certain activities such as hunting, shooting and destroying animals may be necessary, they must be conducted "... in a manner that causes the animal to die quickly and without unnecessary pain" (where pain is defined as distress or suffering). Failure to comply with the *Act* may render an individual or corporation liable to prosecution.

If animals are injured (and in pain) rather than killed immediately there are legal requirements for 'humane killing' that enshrine various ethical values. For example the guidelines defined by the Australian National Health and Medical Research Council (NHMRC 2004) state that if "... pain, distress or suffering (of the animal) ... cannot be alleviated promptly", it is necessary to humanely kill the animal in a way that "... must avoid pain or distress, be reliable and produce rapid loss of consciousness until death occurs". This is recognised in the DECCW Section 120 licence provisions that state that all authorised persons "… must locate each animal shot and promptly alleviate the suffering of any injured flying-fox". This study found no evidence of any serious attempt to follow these licence provisions. Almost a third of flying-foxes that were shot were alive at least 8.5 hours after the cessation of shooting and if the total number of animals impacted by the shooting in the orchard is considered (that is if the number of orphan flying-foxes left to die in the camp sites is included in the calculations) then 44% of these animals stayed alive for ≥8.5 hours, and it is known that one young left at a camp took at least four days to die. Hence the treatment of flying-foxes as documented in this study is in contravention of the definition of 'humane killing' as defined by the NHMRC (2004) and contravenes the DECCW licence provisions.

The degree of non compliance with the ethical requirement of the licence provisions is likely to be even higher than stated above as the animals that were collected dead could have died at any time up to 8.5 hours after being shot. External comparisons of the injuries in bats that were collected dead and alive (and had to be euthanased) showed that although the animals experienced similar overall type of injuries (Table 2), head and body injuries were more common in animals that were collected dead. Detailed autopsies confirmed that this was particularly associated with the internal bleeding in the chest area, which affected 62% of the random autopsied dead animals compared to the 25% of euthanased bats. Additionally, while there was no significant difference in brain damage between the groups, this type of injury occurred only in the bats that were collected dead. This might suggest that the brain damage and chest haemorrhaging are more likely to lead to death within the given 8.5 hour time frame, which is expected given that these are the target areas identified in the licensing regulations. However, even such injuries may not have resulted in a quick death as six of the bats that were alive at the time of collection had chest haemorrhage. Furthermore the remaining seven autopsied dead bats had injuries that were not statistically different from those found in majority (82%) of the euthanased bats, suggesting that time to death for these bats was not necessarily rapid as required under the terms of the license.

Under the NSW Department of Industry and Investment (formerly the Department of Primary Industries) humane pest control Code of Practice (COP) and Standard Operating Procedures (SOPs) for listed pest species (Department of Primary Industries (NSW) 2005), it is mandatory that problem animals are shot in the head (brain) or chest (heart/lungs) to ensure rapid humane death. However, these areas are particularly difficult to hit as flying-foxes are small, moving, dark targets against the night sky (Figure 6). Furthermore, GHFF are denser with heavier bones than birds of equivalent size (J. G. Parsons, James Cook University, 2007 pers. comm. in Booth 2007), which makes pellet penetration through the body wall, muscles and bones to the vital organs more difficult. Given that no autopsied animals showed signs of the direct damage to the heart and/or both lungs (despite many bats suffering some form of chest injury), shooting an animal in the chest, while in flight, is unlikely to result in humane instantaneous death. Consequently, if it is assumed that only shots that pierced the cranium or hit the heart/lungs caused rapid death, then only two of the bats that were collected dead and were subsequently autopsied fall into this category. In both animals the bullet penetrated the brain. These bats represent just over 8% of the 24 dead animals autopsied. If this percentage is applied to the adult and sub-adult animals that were collected dead ($n = 97$) then possibly eight animals in total, died instantaneously.

Figure 6. *P. poliocephalus* flying at dusk. Individuals are small, dark and difficult to see, and most of the exposed surface area of flying-foxes is the large wing span. Hence, to ensure that the problem flying-foxes are killed in a humane way (targeting the head or the chest), expert skill and good judgement of the shooter are required. Photograph: Vivien Jones.

Humane killing must produce rapid death that alleviates pain and suffering of an injured animal (NHMRC 2004) and in the DECCW Section 120 licence provisions injured animals are required to be killed "... by gunshot to either the head or thorax of the animal". The injuries caused by a close range shot are unmistakable (Figure 4) and in the total sample of animals that were collected dead, only three animals had been shot on the ground after an initial injury in an apparent attempt at euthanasia. If eight animals died immediately from the initial shot, then of the 164 flying-foxes observed or collected in the orchard, the percentage of the 156 injured flying-foxes 'mercy killed' was just 1.9%. If the orphaned juveniles left in the camp site are considered the percentage falls to 1.5%.

Injured animals

Flying-foxes forage in orchards at night and most of the dark shape of a flying-fox flying against the dark sky is made up of wing. Of the 34 collected animals that were assessed by autopsy, the animals that were collected alive and subsequently euthanased had fewer head and body injuries (56%) than did the animals that were collected dead (92%). The remaining fifteen animals had no obvious life-threatening injury, but critical wing damage, and/or leg fractures, that in itself would not have killed the animal (Bellamy 2008). In the absence of the current study, these animals would have taken days to die from starvation, dehydration, secondary infection or predation (Bellamy 2008). For example one female was observed with a live young attached, climbing out of a fruit tree, crawling across the ground to the casuarinas in the windrow and climbing them despite compound fractures of her main wing bones. If the animal was able to repeat this behaviour at night and forage in the orchard, its life would have been prolonged for several days had she not been caught and euthanased as part of this study.

Conclusions

There is considerable evidence that a high percentage of flying-foxes shot in orchards do not die from the initial shotgun blasts. If POCTA provisions are adhered to, then it is the responsibility of the orchardists to take the time and effort to locate injured animals and kill them humanely. Very few injured flying-foxes were 'mercy killed' by the orchardist in this study and a relatively large percentage of injured animals (44%) could potentially have lived for many days before dying. Hence neither the legal requirements of the DECCW licence nor the ethical guidelines suggested by NHMRC (2004) were followed. However, even if the provisions of the licence and the welfare issues regarding the problem flying-foxes in the orchards had been fulfilled, it is unlikely that the shooting of flying-foxes could ever be seen as humane under the *POCTA 1979*. The fruit ripening season in most of the Sydney Basin coincides with the breeding season of the flying-foxes and this study has shown that a large proportion (20%) of the affected animals were young left behind in the camp. Thus, given that the ethical guidelines state that "... dependent offspring of animals being killed must also be killed or appropriate provision made for their care" (NHMRC 2004), any young left behind at the camp sites would have to be located and managed. Flying-foxes are highly mobile and the young of females injured or killed in orchards could be located at any camp site that is within a night's foraging flight. This distance is likely to be 20 km and could be in excess of 50 km (Eby 1991b) in any direction. Even if the sites are located, it is highly unlikely that abandoned young could be identified or accessed for humane handling. The young are most likely to be in inaccessible canopy trees. Therefore, despite any efforts, a proportion of young flying-foxes will inevitably be orphaned at the camp and die of starvation as a consequence of shooting (Parry-Jones 2000).

There is evidence that flying-foxes that were shot to protect fruit crops were subjected to cruelty in that a high percentage survived with injuries for considerable lengths of time. This is an offense under the *POCTA 1979* and this cruelty would be unacceptable even if the animal was a feral pest. However *P. poliocephalus* is a native animal that is listed as vulnerable under State and Commonwealth legislation and there are legal requirements (such as the production of a Recovery Plan (Department of the Environment Water Heritage and the Arts 2009) that should give this vulnerable species additional protection. Still, while the licences to shoot in orchards are issued, large numbers of the breeding and young animals will die each year and as the population decline of *P. poliocephalus* is linked to high adult mortality, shooting in orchards, timed as it is during the breeding season of the animals, is likely to be a major factor in its decline.

Acknowledgements

We appreciate the assistance of the orchardist who provided access to their property. Also, many thanks to the volunteers who have searched the orchard, and collected the dead and injured flying-foxes. Special thanks to Dr T. Bellamy for performing the autopsies and X-rays on the 58 flying-foxes, and the Ku-ring-gai Bat Conservation Society Inc. for providing the funding for this work.

References

AWAC. 2008. Animal Welfare Advisory Committee's Recommendations. Advice to the Minister for Primary Industries and Fisheries, The Honourable Tim Mulherin Animal Welfare Advisory Committee (Qld) Queensland.

Battin, J. 2004. When good animals love bad habitats: Ecological traps and the conservation of animal populations. *Conservation Biology* **18**:1482-1491.

Bellamy, T., BVSc (Hons), DipWMEH, MENVSc, CAM. 2008. Interim Report on Non-fatal Shooting Injuries Affecting Grey-headed Flying-foxes.

Biel, E. 2002. The cost to orchardists in the management of the Grey-headed Flying-fox. Who pays? A community benefit approach. Pages 47-52 *in Managing the Grey-headed Flying-fox as a Threatened Species in New South Wales*, edited by P. Eby and D. Lunney.. Royal Zoological Society of New South Wales, Mosman, NSW.

Booth, C. 2007. Animal Welfare Implications of Flying-fox Control in Orchards by Shooting: A Response to Questions by the Animal Welfare Advisory Committee. Queensland Conservation Council, Queensland.

Delibes, M., Gaona, P., and Ferreras, P. 2001. Effects of an attractive sink leading into maladaptive habitat selection. *The American Naturalist* **158**:277-285.

Department of Environment and Climate Change (NSW). 2007. Annual Report on Licences issued under the DECC Policy and Procedural Guidelines for the Mitigation of Commercial Crop Damage by Flying-foxes for the 2006-07 Fruit Growing Season Department of Environment and Climate Change (NSW), Hurstville, NSW.

Department of Environment and Climate Change (NSW). 2008. Draft National Recovery Plan for the Grey-headed Flying-fox *Pteropus poliocephalus*. Prepared by Dr Peggy Eby. Department of Environment and Climate Change, NSW, Sydney.

Department of Environment and Conservation (NSW). 2005. DEC Policy for the Mitigation of Damage to Commercial Fruit Crops by Flying-foxes, Updated June 2005. Department of Environment and Conservation (NSW), Hurstville, NSW.

Department of Environment Climate Change and Water (NSW). 2010. The NPWS commercial crop damage mitigation policy. *Available from*: <http://www.environment.nsw.gov.au/threatenedspecies/TheNPWSCommercialCropDamageMitigationPolicy.htm>. *Accessed*: 25 February, 2009.

Department of Primary Industries (NSW). 2005. Humane pest animal control: Code of Practice and Standard Operating Procedures. *Available from*: <http://www.dpi.nsw.gov.au/agriculture/pests-weeds/vertebrate-pests/codes/humane-pest-animal-control>. *Accessed*: 04 November, 2009.

Department of the Environment Water Heritage and the Arts. 2009. Biodiversity -Threatened species: Recovery plans. *Available from*: <http://www.environment.gov.au/biodiversity/threatened/recovery.html>. *Accessed*: 25 November, 2009.

Dickman, C. R. and Fleming, M. 2002. Pest, or passenger pigeon? The New South Wales Scientific Committee's assessment of the status of the Grey-headed Flying-fox. Pages 20-28 *in Managing the Grey-headed Flying-fox as a Threatened Species in New South Wales*, edited by P. Eby and D. Lunney.. Royal Zoological Society of New South Wales, Mosman, NSW.

Divljan, A. 2008. Population ecology of the Grey-headed Flying-fox, *Pteropus poliocephalus*: A study on the age-structure and the effects of mortality on a vulnerable species. PhD thesis. University of Sydney, Sydney, NSW.

Divljan, A., Parry-Jones, K., and Wardle, G. M. 2006. Age determination in the Grey-headed flying fox. *Journal of Wildlife Management* **70**:607-611.

Duverge, P. L., Jones, G., Rydell, J., and Ransome, R. D. 2000. Functional significance of emergence timing in bats. *Ecography* **23**:32-40.

Eby, P. 1991a. "Finger-winged night workers"; managing forests to conserve the role of Grey-headed Flying-foxes as pollinators and seed dispersers. Pages 91-100 *in* D. Lunney, editor. Conservation of Australia's Forest Fauna. Royal Zoological Society of New South Wales, Mosman, NSW.

Eby, P. 1991b. Seasonal movements of Gray-headed Flying-foxes, *Pteropus poliocephalus* (Chiroptera, Pteropodidae), from two maternity camps in northern New-South-Wales. *Wildlife Research* **18**:547-559.

Eby, P. 1999. Low reproductive output in Grey-headed Flying-foxes associated with a short period of food scarcity. *Australasian Bat Society Newsletter* **14**:17-20.

Eby, P. and Lunney, D. 2002. Managing the Grey-headed Flying-fox *Pteropus poliocephalus* as a threatened species: A context for the debate. Pages 1-15 *in Managing the Grey-headed Flying-fox as a Threatened Species in NSW*, edited by P. Eby and D. Lunney,. Royal Zoological Society of New South Wales, Mosman, NSW.

Fleming, M. and Dang, H. 2009. A presentation to the DECC Review Panel on: the issues for the horticultural industry with respect to flying-fox damage, including Grey-headed Flying-foxes in orchards project.

Gopalan, P. 2004. Food preference of the grey-headed flying-fox *Pteropus poliocephalus*. Honours thesis. University of Sydney, Sydney, NSW.

Hall, L. S. and Richards, G. 2000. *Flying Foxes: Fruit and Blossom Bats of Australia.* University of New South Wales, Sydney, NSW.

Jones, K. E., Purvis, A., and Gittleman, J. L. 2003. Biological correlates of extinction risk in bats. *The American Naturalist* **161**:601-614.

Martin, L. and McIlwee, A. P. 2002. The reproductive biology and intrinsic capacity for increase of the Grey-headed Flying-fox *Pteropus poliocephalus* (megachiroptera), and the implications of culling. Pages 91-108 *in Managing the Grey-headed Flying-fox as a Threatened Species in New South Wales*, edited by P. Eby and D. Lunney. Royal Zoological Society of New South Wales, Mosman, NSW.

Martin, L., Towers, P. A., McGuckin, M. A., Little, L., Luckhoff, H., and Blackshaw, A. W. 1987. Reproductive biology of flying foxes (Chiroptera: Pteropodidae). *Australian Mammalogy* **10**:115-118.

McIlwee, A. P. and Martin, L. 2002. On the intrinsic capacity for increase of Australian flying-foxes (*Pteropus* spp. Megachiroptera). *Australian Zoologist* **32**:76-100.

McLachlan, B. 2002. NPWS Operational management of commercial crop damage by flying-foxes – licensing in practice a far north coast perspective. Pages 80-83 *in Managing the Grey-headed Flying-fox as a Threatened Species in New South Wales*, edited by P. Eby and D. Lunney.. Royal Zoological Society of New South Wales, Mosman, NSW.

Nelson, J. E. 1965. Behaviour of Australian Pteropodidae (Megachiroptera). *Animal Behaviour* **13**:544-557.

NHMRC. 2004. Australian Code of Practice for the Care and Use of Animals for Scientific Purposes, 7th edition. NHMRC - National Health and Medical Research Council, Canberra, ACT.

O'Brien, G. M. 1993. Seasonal reproduction in flying foxes, reviewed in the context of other tropical mammals. *Reproduction, Fertility and Development* **5**:499-521.

Parry-Jones, K. 1993. The movements of *Pteropus poliocephalus* in New South Wales. PhD thesis. University of New South Wales, Kensington, New South Wales.

Parry-Jones, K. 2000. Historical declines since the early 1900s, and current mortality factors and abundance of the Grey-headed Flying-foxes in NSW. Pages 56-65 *in* Proceedings of a Workshop to Assess the Status of the Grey-headed Flying-fox in New South Wales.

Parry-Jones, K. and Augee, M. L. 1991. Food selection by Grey-headed Flying foxes (*Pteropus poliocephalus*) occupying a summer colony site near Gosford, New-South-Wales. *Wildlife Research* **18**:111-124.

Parry-Jones, K. and Augee, M. L. 2001. Factors affecting the occupation of a colony site in Sydney, New South Wales by the Grey-headed Flying-fox *Pteropus poliocephalus* (Pteropodidae). *Austral Ecology* **26**:47-55.

Quinn, G. P. and Keough, M. J. 2002. Experimental Design and Data Analysis for Biologists. Cambridge University Press, Cambridge, UK.

Ratcliffe, F. N. 1931. The flying fox (*Pteropus*) in Australia. *Bulletin of CSIRO* **53**:1-80.

Read, A. F. and Harvey, P. H. 1989. Life history differences among the eutherian radiations *Journal of Zoology (London)* **219**:329-353.

Smith, A. 2007. Population composition and feeding ecology of the grey-headed flying fox, *Pteropus poliocephalus* (Megachiroptera) in the Sydney region. Honours thesis. University of Technology, Sydney, Sydney, NSW.

Stace, P. 1996. Protein content and amino acid profiles of honeybee-collected pollens. *Available from*: <http://www.honeybee.com.au/Library/Pollenindex.html>. *Accessed*: 03 March, 2009.

Steller, D. C. 1986. The dietary energy and nitrogen requirements of the Grey-headed Flying-fox *Pteropus poliocephalus* (Temminck) (Megachiroptera). *Australian Journal of Zoology* **34**:339-350.

Tidemann, C., Eby, P., Parry-Jones, K., and Vardon, M. 1999. Grey-headed Flying Fox *in* A. Duncan, B. Baker, and N. Montgomery, editors. The Action Plan for Australian Bats. Natural Heritage Trust, Canberra, ACT.

Tidemann, C. R., Kelson, S. L., and Jamieson, G. 1997. Flying-fox damage to orchard fruit in Australia - incidence, extent and economic impact. *Australian Biologist* **10**:179-186.

Ullio, L. 2002. To net or not to net that is the question! But is it the answer? Pages 70-76 *in Managing the Grey-headed Flying-fox as a Threatened Species in New South Wales*, edited by P. Eby and D. Lunney.. Royal Zoological Society of New South Wales, Mosman, NSW.

Wahl, D. E. 1994. The management of flying foxes (*Pteropus* spp.) in New South Wales. Degree of Master of Applied Science. University of Canberra, Canberra, ACT.

Waples, K. 2002. Review of the NPWS policy on the mitigation of commercial crop damage by flying-foxes. Pages 39-46 *in Managing the Grey-headed Flying-fox as a Threatened Species in New South Wales*, edited by P. Eby and D. Lunney.. Royal Zoological Society of New South Wales, Mosman, NSW.

Webb, N. J. and Tidemann, C. R. 1996. Mobility of Australian flying-foxes, *Pteropus* spp (Megachiroptera): Evidence from genetic variation. *Proceedings of the Royal Society of London - Series B: Biological Sciences* **263**:497-502.

Welbergen, J. A. 2005. The social organisation of the grey-headed flying-fox, *P. poliocephalus*. PhD thesis. University of Cambridge, Cambridge, UK.

Woodhead, A., Biel, E., O'Shannessy, D. S., and Martin, L. 2009. NSW Flying-fox Licensing Review Panel Report to Landscapes and Ecosystems Conservation Branch, NSW Department of Environment and Climate Change. *Available from*: http://www.environment.nsw.gov.au/resources/threatenedspecies/NSWflyingfoxreview.pdf *Accessed*: 16 November, 2009.