

Nesting behaviour of a pair of Bat Hawks *Macheiramphus alcinus* in South Africa, recorded by time-lapse video images

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ABSTRACT

We studied activities at a Bat Hawk nest over almost the entire 126-day nesting cycle (52 day incubation, 74 day nestling periods), during September 1991 to February 1992. We recorded parental and chick behaviour using time-lapse video images, taken each second over 24 hours and under infra-red at night. The sexes shared incubation almost evenly (male 48%, female 52%), but the female brooded more (81%), almost all in the first 40 days of the nestling period. Most prey (89%) was delivered around dusk and dawn, but with some deliveries throughout the night. Nocturnal deliveries were more frequent and inter-prey delivery times longer on moonlit nights, although the mean prey delivery rate was the same as on moonless nights. Bats comprised the main prey, together with a few small birds.

The male brought twice as many prey items to the nest during incubation, but did not provision the female. During the nestling period, both sexes delivered equal numbers of prey, but the female fed the chick more often (58%). Nightly prey deliveries averaged 1.2 (range 0-5) during the incubation and 4.7 (range 0-9) during the nestling period. The long breeding cycle is equivalent to that of a petrel rather than a raptor of the same body mass.

INTRODUCTION

The Bat Hawk *Macheiramphus alcinus* is the size and shape of a large falcon (body mass about 600g), but with no obvious sexual dimorphism in size or colour. The sooty-brown plumage is relieved only by white eyelids, nuchal patches, concealable belly feathers and thin bars across the tail, by pale grey feet and cere, and by large yellow eyes. The nest of sticks is usually built on an uncluttered horizontal branch, high up in an emergent pale-barked tree (Harris *et al.* 1990). The Bat Hawk is remarkable among diurnal birds of prey, order Falconiformes, for being primarily crepuscular and nocturnal, for feeding mainly on bats that are caught and swallowed in flight (Eccles *et al.* 1969; Fenton *et al.* 1977; Black *et al.* 1979), and for its single chick reared over a prolonged nesting cycle (Steyn 1982; Harris *et al.* 1990; Hartley & Hustler 1993; Hartley 1995).

We report here on the breeding biology of a pair of Bat Hawks at the southern tip of their African and Asian range, assisted by time-lapse video images. This was part of a broader study of two neighbouring pairs, which included analysis of pellets and prey, use of telemetry to determine their large 200-250 km² home and hunting range, and taped recordings of their vocalisations and behaviour (Harris *et al.* 1990).

METHODS

Study sites and pairs

Two neighbouring nest sites of Bat Hawks were observed in the Tzaneen area (23°56'S, 30°07'E), Northern Province, South Africa, from 1986-1992. Both nests were built on 50 x 50 cm metal mesh platforms that we attached 25-30m above the ground on a lateral branch of a large *Eucalyptus* tree. The nest tree and surrounding trees were larger than others in the area and were situated within mixed exotic plantations of smaller *Eucalyptus* and *Pinus* trees. Both nests were in hilly country and on the crest of a ridge. The adults hunted in valleys around the nest area and over flat lowlands about 5km to the east. At least one member of each pair was marked with a coloured or metal leg band to facilitate separation of the sexes during observations.

Nest observation techniques

We monitored one nest with a video camera and time-lapse recorder during September 1991 to February 1992. We then analyzed the recordings for 24 hours of each day and covering almost the full nesting cycle. Additional observations at both nests, during the same and previous seasons back to 1988, were made from about 40-50m away on the ground. We used night-vision binocular equipment mounted on a tripod, plus a mirror angled above each nest surface.

At the study nest, a video camera was mounted on a bracket approximately 3m above the level of the nest and 5m from it. A recorder and monitor were housed 80 m away on the ground, in a small lockable trailer that was parked inside a tent and protected externally with a security fence. A 220V AC power supply for the system was drawn from a powerline about 100m away. To reduce time lost due to power failures, usually caused by the earth-leakage relay tripping because of lightning strikes, a radio transmitter was fitted to the system to alert an assistant who lived nearby and changed the tapes at 4-day intervals.

The nest was monitored continuously by a Panasonic CCD video camera (model WV-CD22) with a 50mm f/1.8 auto-iris lens (model WV-LA50). The camera was linked with 80m of co-axial cable to a Panasonic time-lapse video recorder (model AG-6010) and monitor (WV 5340). To record at night, an external light source was used that was switched on and off automatically by a light-sensitive switch. The lighting came from one of two 6V 15W halogen lights and the second acted as a standby that could be switched on by remote control. The lights were fitted with a RG830 Schott longpass filter and so provided light in the near-infrared range (wavelength >700 nm) that was invisible to humans.

The camera's internal IR filter was removed to obtain maximum sensitivity. The camera was modified to focus automatically from daytime (normal) to nighttime (near-infrared) recording by means of a small geared DC motor coupled to a ring-gear mounted on the lens and controlled by limit switches. The light-sensitive switch simultaneously activated the external light and the focus motor.

Sound recordings could be made when the recorder was switched manually from time-lapse to continuous-record mode. An AKG D900 microphone, its signal boosted with a pre-amplifier, was mounted on rubber above the nest.

Equipment protection

The camera was mounted in a sealed weather-proof housing, extended in front to reduce glare from direct sunlight. The recorder was mounted in a dust-proof, fan-ventilated (negative pressure) container with dust-filtered vents. All cables were enclosed in a PVC tube which, on the tree, was supported by saddles nailed to the trunk and, at the base of the tree, was buried underground in a

pipe. Experience showed that all cables, secured to the tree on sturdy galvanised brackets, had to be attached to threaded stainless steel pegs that projected at least 30mm away from the trunk. This gap provided sufficient tolerance for growth to take place without forcing the brackets off the tree. A number of protruding flat metal bars (50cm x 30mm x 6mm) were mounted about 50cm above the camera and lights, and the microphone was housed in a 75mm PVC tube. This provided protection from the wind, weather, falling strips of bark and loose branches, which proved to be a major problem with alignment of equipment.

Initially, lightning proved a major problem that resulted in loss of equipment, particularly when cables were slung above ground. This necessitated a rigorous protection system which consisted of an earth-leakage unit on the main supply cable and an 8mm bare copper cable, connected to the camera and its housing and earthed with 3 x 1m copper-coated spikes over a length of 5m at the base of the tree. At both ends of the system, the 220V power cables were linked together and down to earth with voltage dependent resistors (varistors), rated at 275V applied voltage and capable of clamping currents up to 4000 amps. The 12V DC supply on the camera was similarly protected with 12V varistors and the video cables were also protected at both ends by in-line coaxial earthing connectors. The audio circuit was protected using commercial in-line protection connectors at the microphone output and recorder input (Strike-Tek 250mA, Vmax 17.5). Finally, the main supply cable was earthed with an 8mm copper cable via earthing spikes, and the security fence, trailer and recording equipment were also earthed to this. The whole system later sustained a direct strike with no damage to equipment.

Recording and analysis of data

Data were collected, from egg-laying to fledging, as a series of video frames, recorded each second and annotated with date and time. Frames were collected in 96-hr bouts of continuous recording, achieved using a 4-hour video tape with the recorder-selector set on 72-hour mode. This necessitated a tape change only every four days.

The monochrome video recordings were then played back in sequence. The onset and cessation of each category of Bat Hawk behaviour was noted to the nearest second, using the date and time data which formed part of the original recordings. The sex of each adult at the study nest was noted whenever possible, based on the presence of a leg band on the male and the absence of bands on the female. Dates and times for phases of the moon, moonrise and moonset were supplied by the South African Weather Bureau.

RESULTS

Data were collected on 30 4-hour video tapes, representing about 2880 hrs of recording. Time lost due to power failures, tape changes and other technical problems were logged as 'no-data'. Over the 126-day nesting cycle, a total of 7.4 (5.9%) days were lost, in 47 no-data periods ranging from 24-86400 secs (86400 secs = 1 day, Table 1). Behaviours prior to brief time losses of <383 secs were scored as continuing across that interval (25 of these were tape changes of <164 secs (2.7 mins) made during the day when the Bat Hawks were inactive). However, complete days were excluded from the analysis when time loss $\geq$ 383 secs (6.4 mins). Most of these longer periods occurred during the periods of crepuscular or nocturnal activity and only a few were for long periods during the day. Their omission from various data sets resulted in a maximum exclusion of 4/52 days from the incubation period and 17/74 days from the nestling period.

Table 1. Duration and timing of data losses due to various technical problems with time-lapse video recording at a Bat Hawk nest.

<i>No-data periods due to technical problems</i>	<i>secs</i>	<i>days</i>
Continuous time loss <383 secs	1416	0.02
Continuous time loss $\geq$ 383 secs	640567	7.4
Time lost during incubation period	57681	0.7
Time lost during nestling period	583553	6.7

Identification of sex

Individuals were identified to sex as either ‘definite’, when a good view was available of the legs to record the presence or lack of a leg band, or ‘probable’ if there was any doubt (Table 2). The level of certainty increased for activities during the nestling period, probably because the birds tended to stand for longer periods and offer a better chance of seeing both legs.

Table 2. Accuracy of definite sex determination for members of a pair of Bat Hawks during different behaviours at their nest, as recorded from video images.

Nesting behaviour	% definite sex determination (n)	
	Male	Female
Incubation	74 (226)	74 (284)
Brooding	82 (68)	90 (197)
Prey delivery	77 (187)	86 (169)
Feeding	100 (56)	83 (78)

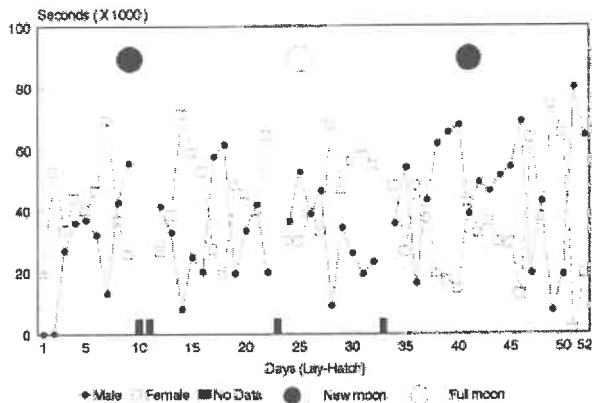
Incubation period

The incubation period (egg-laying-hatching) was recorded at just over 52 days (1250.4 hrs, Table 3). At the second nest, a period of 53+0.5 days was recorded in the same season, based on morning and evening observations via the nest mirror. Egg-laying and hatching at the study nest took place in the early evening (Table 3). At the second nest, these activities took place between dusk and dawn, after the last evening check. At the study nest, egg-laying occurred six days after, and at the second nest 14 days after, the full moon. Hatching then occurred two days before and 7 days after full moon respectively.

Table 3. Exact laying, hatching and fledging details at the Bat Hawk study nest, recorded from time-lapse video.

Activity	Date	Time	Duration to next activity			
			days	hrs	mins	secs
Egg-laying	30.Sep.91	18:28:37	52	02	26	18
Hatching	20.Nov.91	21:54:55	74	07	20	38
Fledging	02.Feb.92	05:15:33				
TOTAL:			126	09	46	56

Figure 1. Incubation role for each sex of a pair of Bat Hawks, in relation to moon phase (full moon = open circle; no moon = solid circle; excluding four “no data” days from the 52-day incubation period).



Both sexes at the study nest shared incubation almost evenly overall (male 48%, female 52%, Table 4, Fig. 1), but with considerable individual variation between days. Female effort appeared to show a slight decrease over time, which was countered by a slight increase in male effort.

Table 4. Sex roles of members of a pair of Bat Hawks during the 52-day incubation period.

<i>Activity</i>	<i>Comparison of sex roles</i>	
	<i>Male</i>	<i>Female</i>
Days recorded incubating	51	52
Days analyzed (less 4 no-data days)	47	48
Total incubation effort (hrs)	491.9	537.8
Percent of incubation effort	48	52
Mean daily incubation (hrs)	10.5	11.2
Minimum daily incubation (mins)	3.5	22.6
Maximum daily incubation (hrs)	22.2	20.6
S.E. daily incubation bouts	5.3	4.8
Mean daily dark phase incubation (hrs)	8.0	5.0 ^a
Mean daily light phase incubation (hrs)	5.3	5.6 ^b
Mean daily daytime incubation (hrs)	5.1	5.6 ^c
Mean daily nighttime incubation (hrs)	5.6	5.4 ^d

^a Dark phase of the moon. In general this spanned 7 days before to 7 days after New Moon, with a variation of +- 2 days (1800-0500 hrs).

^b Light phase of the moon. In general this spanned 7 days before to 7 days after Full Moon, with a variation of +- 2 days (1800-0500 hrs).

^c daytime = 0600-1700 hrs.

^d nighttime = 1800-0500 hrs.

Nestling period

The nestling period (hatching to first flight from the nest) was recorded at just over 74 days (1735.3 hrs) and the chick fledged in the early morning (Table 3), two days before no moon. There was a noticeable change in parental behaviour at about 41 days after hatching, four days before no moon (Table 5, Figs. 2 & 3). Up to this time, the chick was regularly brooded and fed by the parents and after this, for the remaining 33 days of the nestling period, it fed and maintained itself. During the first 41 days, the chick was brooded for 81% of the time by the female and 19% by the male (Table 5, Fig. 2).

Figure 2. Brooding role for each sex of a pair of Bat Hawks, in relation to moon phase (full moon = open circle; no moon = solid circle; excluding 17 “no data” days from the 74-day nestling period).

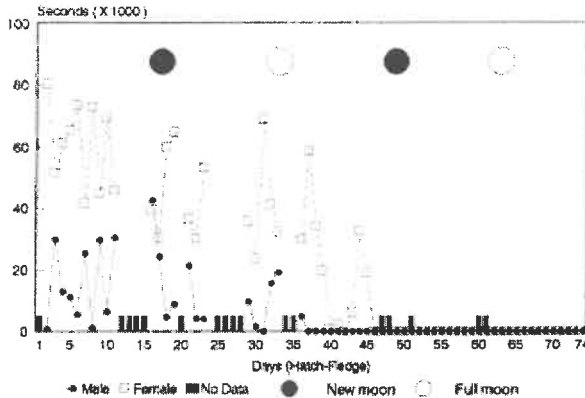


Table 5. Sex roles of members of a pair of Bat Hawks during the 74-day nestling period, divided into the periods before and after the chick requires no further brooding and feeding.

Activity	Comparison of sex roles Before/after 41 days	
	Male	Female
Number of days of brooding behaviour	36/0	41/4
Days analyzed (less 12/5 no-data days)	24/0	29/4
Total brooding effort (hrs)	87.1/0	365.2/16.2
Percent of total nestling period	4.9/0	20.5/0.9
Percent of brooding effort	19/0	81/100
Mean daily brooding (hrs)	2.7/0	12.6/0.6
Minimum daily brooding (mins)	0/0	13.4/0
Maximum daily brooding (hrs)	8.4/0	22.3/0
S.E. daily incubation bouts	2.9/0	5.7/2.0
Mean daily dark phase brooding (hrs/day)	3.8/0	12.3/1.2 ^a
Mean daily light phase brooding (hrs/day)	2.3/0	13.7/0 ^b
Mean daily daytime brooding (hrs/day)	2.2/0	4.6/0 ^c
Mean daily nighttime brooding (hrs/day)	1.4/0	8.0/4.0 ^c

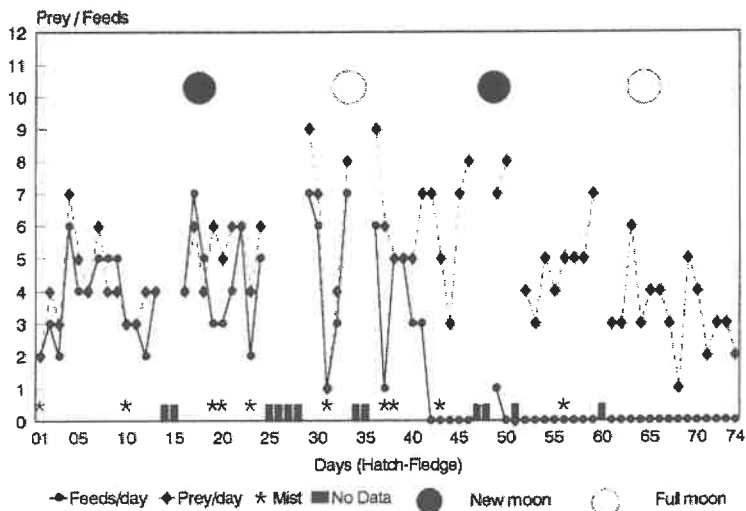
^a Dark phase of the moon. In general this spanned 7 days before to 7 days after New Moon, with a variation of $\pm$ 2 days (1800-0500 hrs).

^b Light phase of the moon. In general this spanned 7 days before to 7 days after Full Moon, with a variation of $\pm$ 2 days (1800-0500 hrs).

^c daytime = 0600-1700 hrs.

^d nighttime = 1800-0500 hrs.

Figure 3. Total daily prey deliveries and feeds given to the chick by a pair of Bat Hawks, in relation to moon phase and nights with dense mist (full moon = open circle; no moon = solid circle; excluding 12 “no data” days from the 74-day nestling period).



Diet and prey delivery

Identification of prey species was usually not possible in this study. The majority of identifiable prey appeared to be bats, with only two suspected birds delivered based on the plucking behaviour of the Bat Hawks. However, a previous analysis of prey at this nest site, based on pellets collected

over a two year period, showed that prey during the breeding season consisted mainly of *Pipistrellus*, *Tadarida* and *Scotophilus* bats, together with some small birds (swifts, swallows, small diurnal passerines, nocturnally-migrating button-quail).

Usually, the adult that arrived with prey fed the chick. The male only passed nine prey items to the female, who then fed the chick, while the female only passed a single item to the male, which he then passed to the chick.

During the 52-day incubation period, the male delivered almost twice as many prey items as the female (Table 6, Fig. 4). The first recorded delivery of prey, by the male, only took place on day-10 of the incubation period (not shown on Fig. 4 because it was one of the excluded 'no-data' days). A maximum of five prey items/day were delivered to the nest during this period.

Table 6. Sex roles in prey delivery to the nest by members of a pair of Bat Hawks.

<i>Nesting stage and activity</i>	<i>Comparison of sex roles</i>		
	<i>Male</i>	<i>Female</i>	<i>Combined</i>
Incubation period:			
Days with prey deliveries	26	18	26
Days analyzed (less 3 no-data)	49	49	49
No. prey items delivered	39	21	60
Percentage contribution	65	34	100
Prey items/day (n = 49 days)	0.8	0.4	1.2
Range per day	0-3	0-3	0-5 ^a
S.E. of daily deliveries	0.8	0.6	1.0
Nestling period:			
No. prey items delivered	148	148	296
Percentage contribution	50	50	100
Prey items/day (n = 63 days)	2.35	2.35	4.70
Range per day	0-5	0-6	0-9
S.E. of daily deliveries	1.3	1.4	1.9
Nestling period, before/after 41 days			
Days with prey deliveries	-	-	42/33
Days analyzed (less 8/3 no-data)	-	-	33/30
Prey items delivered	88/61	78/69	166/130
Mean prey items/day	2.7/2.0	2.4/2.3	5.1/4.3
Percentage contribution	53/46	47/54	100/100
Prey range/day	0-5/0-5	0-6/1-6	1-9/1-8 ^{b,c}
Mean prey/day, dark phase ^d	2.8/2.3	3.0/2.2	5.8/4.5
Mean prey/day, light phase ^e	3.3/1.9	2.4/2.8	5.7/4.7
Prey deliveries before midnight	45/33	39/35	84/68
Prey deliveries after midnight	43/27	39/35	82/62
Timing over total nesting cycle:			
No. prey items delivered	187	169	356
During dark phase (n = 48 days) ^d	89	90	179
During light phase (n = 50 days) ^e	98	79	177
Prey items/day, dark phase ^d	1.85	1.87	3.72
Prey items/day, light phase ^e	1.96	1.58	3.54
Prey deliveries before midnight	90	79	169
Prey deliveries after midnight	97	90	187

^a Although individual maxima was 3, the combined total on a given day was never more than 5.

^b A least one sex delivered a minimum of 1 prey item when the other sex delivered nothing.

^c Although individual maxima were 5 and 6, the combined total on a given day was never more than 9.

^d Dark phase of the moon. In general this spanned 7 days before to 7 days after New Moon, with a variation of +- 2 days (1800-0500 hrs).

^e Light phase of the moon. In general this spanned 7 days before to 7 days after Full Moon, with a variation of +- 2 days (1800-0500 hrs).

Figure 4. Total daily prey deliveries by each sex of a pair of Bat Hawks during the incubation period, in relation to moon phase (full moon = open circle; no moon = solid circle; male n=39, female n = 21; excluding three “no data” days from the 52-day incubation period).

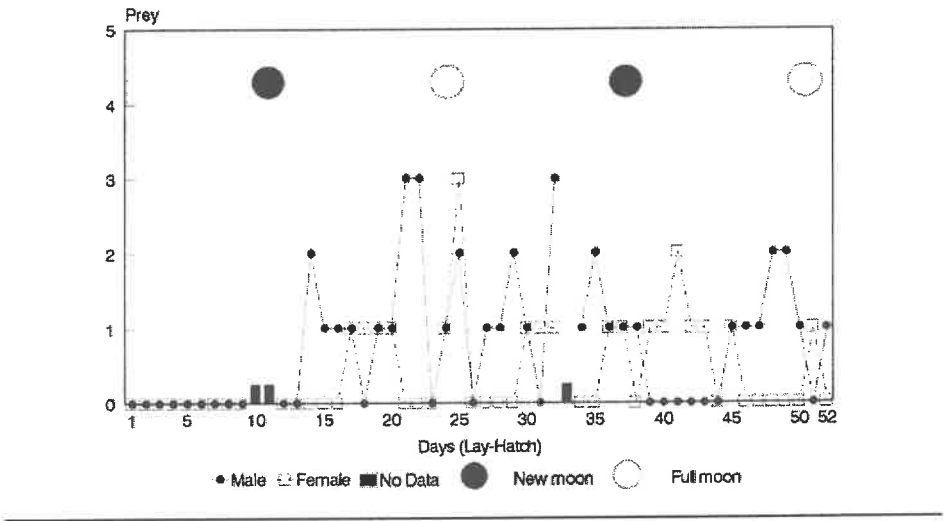
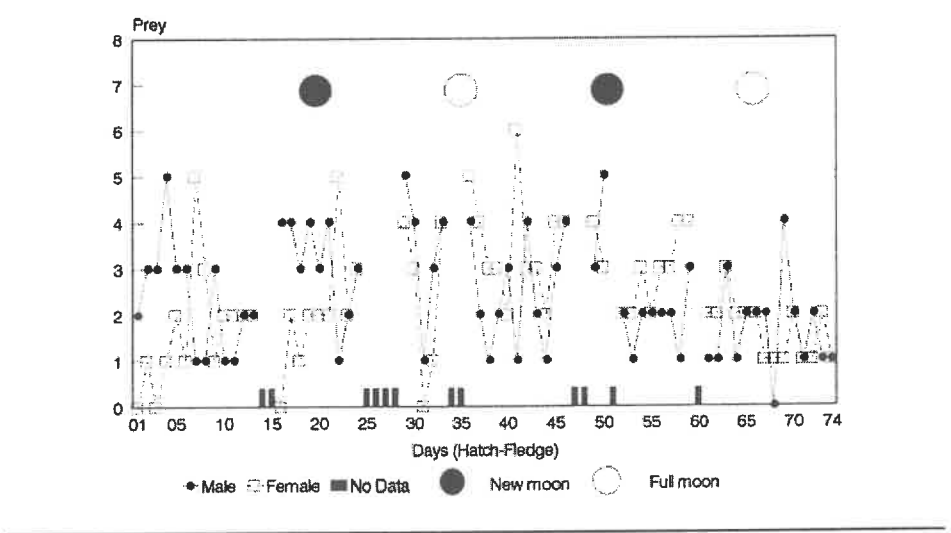


Figure 5. Total daily prey deliveries by each sex of a pair of Bat Hawks during the nestling period, in relation to moon phase (full moon = open circle; no moon = solid circle; male n=148, female n = 148; excluding 12 “no data” days from the 74-day nestling period).



During the 74-day nestling period, deliveries continued throughout, from hatching to fledging, with a maximum of nine prey items delivered in one night (Table 6, Figs. 3 & 5). The chick swallowed prey items whole at the age of 15 days and was feeding itself at 41 days old. During the period up to 41 days of age, the male delivered more items than the female (53:47%), but this was reversed during the period from 42 days of age to fledging (46:54%). Overall, the male and female shared

deliveries almost equally, but the female fed the chick on the nest slightly more often than the male (58:42%, Table 7).

Table 7. Sex roles on the nest in feeding of the chick up to 41 days old by members of a pair of Bat Hawks.

Activity	Comparison of sex roles		
	Male	Female	Combined
No. of feeding bouts	56	78	134 ^a
Percentage contribution	42	58	100
Mean no. of bouts/day	1.7	2.4	4.1
Mean duration of bouts (mins)	3.7	9.8	1.2
Minimum bout duration (secs)	7	11	54
Maximum bout duration (mins)	46	35	1.5
S.E. of bout duration	-	-	12 secs
Mean no. of bouts/day, dark phase	1.7	2.1	-
Mean no. of bouts/day, light phase	2.9	2.4	-
No. bouts before midnight	27	32	59
No. bouts after midnight	30	46	76

^a Male delivered 9 prey items which were handed to the female, who then fed the chick. The female only handed the male a single prey item which he then handed to the chick. Only a single bout of feeding was recorded when the chick was older than 42 days, when an item was delivered by the male and fed to the chick by the female.

Prey deliveries took place at dusk, dawn and in the night, between about 17:30-06:00 hrs. Prey delivery was strongly bimodal, with 89% of deliveries taking place between 17:00-20:00 hrs and 04:00-06:00 hrs (Table 8, Fig. 6). Overall, more deliveries occurred at dawn (after midnight, 53%) than at dusk (before midnight, 47%). This result is also reflected in data on feeding of the chick (Table 7, Fig. 7), with 44% of feeds before midnight and 56% after. More prey was also brought during these peaks in the dark phase of the moon than in the light phase (Fig. 8). Although the total number of prey items delivered during these two peaks was similar, during the light phase of the moon more prey (4%) was brought between these peaks, in the middle of the night, than during the dark phase (1%).

Table 8. Number of prey deliveries and chick feeding bouts recorded per hour during the dark and light phases of the moon by a pair of Bat Hawks during their total nesting cycle.

<i>Activity and moon phase</i>	<i>Hour initiated recording</i>																								%	(n)
	0	1	2	3	4	5	6	7	8	9	/	16	17	18	19	20	21	22	23							
Prey delivery:																										
Dark phase	0	1	0	3	70	18	1	0	0	0	/	0	0	10	75	0	0	1	0	50.3						(179)
Light phase	3	4	3	4	53	26	1	0	0	0	/	0	1	7	55	2	3	11	4	49.7						(177)
Total	3	5	3	7	123	44	2	0	0	0	/	0	1	17	130	2	3	12	4	100.0						(356)
Feeding bouts:																										
Total	3	1	1	8	58	3	1	0	1	0	/	0	1	8	42	0	0	6	2	100.0						(135)

DISCUSSION

The main limitation with video recording is that the effective field of vision is restricted by the camera lens and, in this study, includes only a single nest and its immediate surroundings. However, this is balanced against the feasibility of monitoring the entire nesting cycle of the inaccessible, little-known and nocturnal Bat Hawk.

Figure 6. Prey deliveries per hour by a pair of Bat Hawks during the entire nesting cycle (n = 356; within one hour of starting time indicated; excluding 15 “no data” days from the 126-day nesting period).

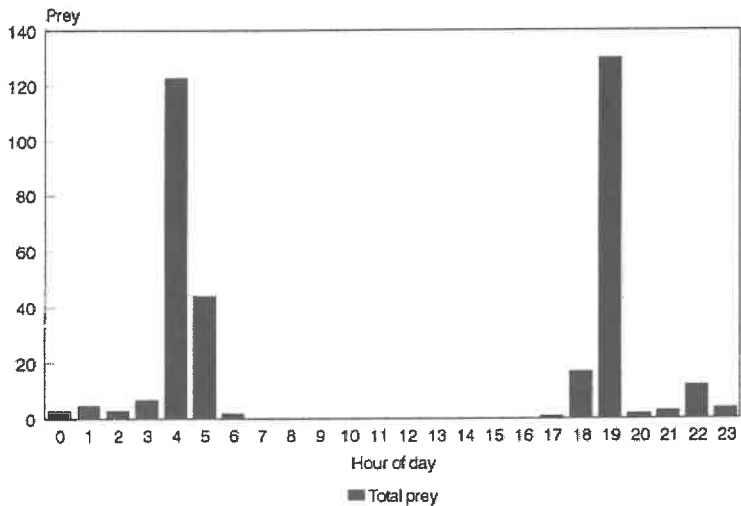
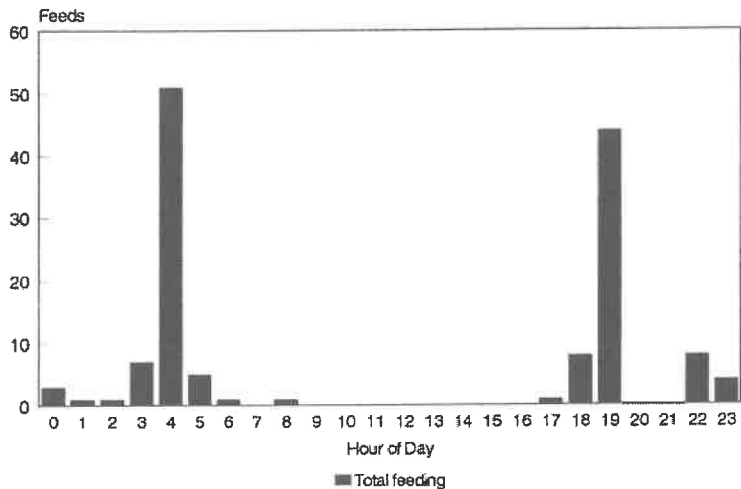
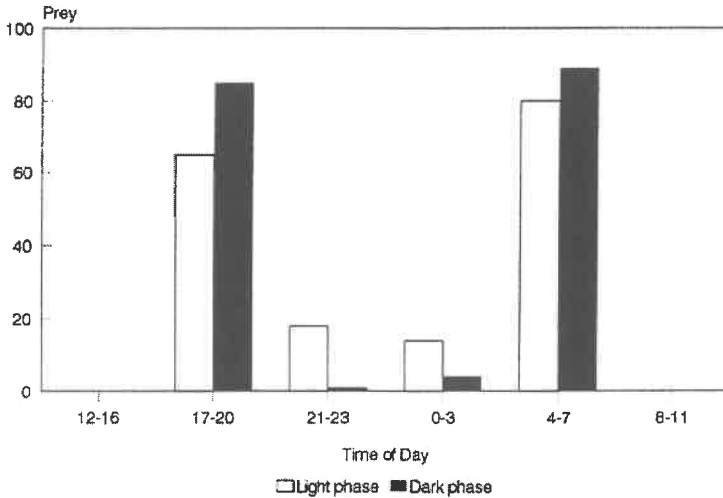


Figure 7. Feeding bouts per hour of the chick by a pair of Bat Hawks during the 74-day nestling period (n = 135; within one hour of starting time indicated; excluding 12 “no data” days from the 74-day nestling period).



Both sexes shared incubation and brooding, even though definite identification of the male, based on the presence of a leg band, was only 74% and 82% respectively (Table 2). The sexes shared incubation about equally, but the female brooded the chick more than the male (Tables 4 & 5). Previous briefer studies suggested that only the female incubated (Hartley 1988, 1995), or that the male incubated much less than the female (Hustler 1983), and there might be some individual variation between pairs. Brooding was intense up to about 20-30 days (cf. to 22 days, Hartley 1995) but then declined to almost nothing by 40 days and for the rest of the nestling period (Fig. 2).

Figure 8. Total prey deliveries to the nest by a pair of Bat Hawks during the entire nesting cycle, for different hourly periods of the day, and for the weeks preceding and following full and no moon respectively (n=356; excluding 15 “no data” days from the 126-day nesting period).



Our two accurate records of a 52-53 day incubation period agree with one of 53 days reported by Hartley (1995), but our record of a 74-day nestling period is slightly more than the 67 days that he reported. While little variation is expected in the incubation period, more variation might be expected in such a prolonged nestling period, due to the effects of weather (e.g. mist, Fig. 4), food availability and hunting success on chick development.

The total nesting cycle of 126 days greatly exceeds that of about 70 days for a 600g falconiform, as predicted by an allometric regression against female body weight (Newton 1979). One of the principal factors to influence the fledging period in birds is growth of their relatively long wing bones (Carrier & Auriemma 1992). African Bat Hawks, with a mean ulna length of 124mm (SD 7.1, n = 35, our measurements of museum specimens), do have markedly longer bones than equivalent-sized falcons, such as Lanner *Falco biarmicus* (99mm, SD 4.8, n = 27) or African Peregrine *F. peregrinus minor* (86-98mm, n = 2, Mendelsohn *et al.* 1989).

Such long wing bones, a clutch size of one, slow development, a prolonged nesting cycle and nocturnal habits are, however, typical for petrels of similar size to Bat Hawks (Anonymous 1992; Carrier & Auriemma 1992; Hartley & Hustler 1993; Hartley 1995; Warham 1996). The long nestling development of the single petrel chick has been related to low provisioning rates by the parents, where they alternate incubation and brooding and where food delivery to the chick is at long and erratic intervals. In the Bat Hawk, the sexes shared incubation, brooding and hunting for the chick, but still achieved only a low and erratic food supply (mean 4.7 prey items/day, range 0-9, Table 6, Fig. 3).

As expected, bats comprised the main prey, with only a few items of small birds (Harris *et al.* 1990; Hartley 1995). The bimodal dusk and dawn delivery of prey conforms to the mainly crepuscular foraging reported for the Bat Hawk (Eccles *et al.* 1969; Black *et al.* 1979; Brosset & Erard 1986; Hartley 1995). It also conforms with dusk and dawn peaks of insect and bat activity (Fenton *et al.* 1977; Erkert 1982; Rautenbach *et al.* 1988). However, other studies have mainly recorded Bat Hawk activity at dusk, while we found that even more prey was delivered after (53%) than before (47%) midnight. Although many factors will influence provisioning rates, it does suggest that the dawn peak in aerial arthropod and bat activity may not be smaller than the dusk peak in all seasons or for

all species. Different species of bats are also active at different times of the night and at different altitudes above ground (Fenton *et al.* 1977), and bat activity is further influenced by the weather, especially by rain and cold (Fenton *et al.* 1977), all of which could affect Bat Hawk hunting behaviour (Fig. 3).

The nesting cycle of the Bat Hawk covers 4.5 lunar cycles. Although the nightly number of prey deliveries to the nest was similar during dark and light phases of the moon, the time at which prey was delivered differed. During the light phase, and particularly around full moon, some prey was brought in throughout the night. Similar observations were made at both nests, using night-vision and telemetry studies of hunting adults (Harris *et al.* 1990). Despite improved visibility on moonlit nights, and prey delivery at similar overall rates to moonless nights, the crepuscular delivery of prey on moonlit nights was lower and the mean interval between deliveries longer. This suggests that prey was less available than on dark nights and that the Bat Hawks had to hunt for longer periods throughout the night. A similar increase in foraging behaviour has been observed in the insectivorous Common Poorwill *Phalaenoptilus nuttallii* (Brigham & Barclay 1992).

During moonlight, bats are known to alter their roost departure time, to decrease their activity and to resort to the shadows of more densely foliated areas (Fenton *et al.* 1977; Beith 1982; Law 1997). These changes in bat activity have been interpreted as predator-avoidance behaviour, but the situation may not be that simple since many insects are also known to be lunaphobic, especially moths (Mills 1986).

However, Bat Hawks are also capable of catching prey when there is no moon- or starlight (Harris *et al.* 1990, Fig. 8). We even have an observation at the second nest, where an adult left the nest and caught a bat within 50m on a pitch black night. The emergent pale-barked trees favoured as nest sites (Harris *et al.* 1990; Hartley 1995) may also be important 'beacons' when Bat Hawks return to their nest after dark.

Bat Hawks at perch and on the nest at night often twitched their heads from side to side, as if listening for something. Tests with natural bat sounds elicited no obvious response, nor were any obvious specialisations to the external ear found on museum anatomical specimens, so the exact technique by which Bat Hawks locate some of their prey in the dark remains unresolved. Hunting Bat Hawks are attracted to towns and artificial lights (Hartley & Hustler 1993; Hartley 1995; pers. obs.), but this might be due to the lights attracting insects that attract bats, rather than improved visibility for the Bat Hawks.

Since Bat Hawks lack marked sexual size dimorphism, despite hunting agile prey, the sexes are expected to share hunting and provisioning to the nest (Mendelsohn 1986, 1987; Auburn 1987). In this study, both sexes brought prey to the nest during the incubation period, with the male bringing almost twice as much as the female. However, no provisioning of the female by the male was recorded during incubation, although during the nestling period the chick was fed mainly by the female on the nest, as in previous studies (Hustler 1983; Hartley 1995). During the nestling period, the female delivered more prey to the nest than the male (58%:42%), and Hartley (1995) also reported deliveries by both sexes to the chick (12 prey deliveries, male 7, female 4, unknown 1).

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