A review of our current knowledge of clouded leopards (Neofelis nebulosa)

Abstract

Little is known about clouded leopards (Neofelis nebulosa), who have a vulnerable population that extends across southern Asia. We reviewed the literature and synthesized what is known about their ecology and behavior. Much of the published literature either note detections within and on the edges of their range, or are anecdotal observations, many of which are decades if not over a century old. Clouded leopards are a medium-sized felid, with distinctive cloud-shape markings, and notably long canines relative to skull size. Estimates for population densities range from 0.58 to 6.53 individuals per 100km². Only 7 clouded leopards have been tracked via radio-collars, and home range estimates range from 33.6-39.7km² for females and 35.5-43.5km² for males. Most accounts describe clouded leopards as nocturnal, but radio telemetry studies showed that clouded leopards have arrhythmic activity patterns, with highest activity in the morning followed by evening crepuscular hours. There has never been a targeted study of clouded leopard diet, but observations show that they consume a variety of animals, including ungulates, primates, and rodents. We encourage future study of their population density and range to inform conservation efforts, and ecological studies in order to understand the species and its ecological niche.

Keywords: activity patterns, clouded leopard, distribution, neofelis nebulosa, prey, population status

Abbreviations: SECR, spatially explicit capture recapture

Population status and distribution

The global population of clouded leopards (Neofelis nebulosa) is considered vulnerable worldwide,¹ and were considered to be less abundant globally the 2016 assessment by the IUCN than the previous assessment in 2007.² Clouded leopards currently range from the southeastern Himalayas across southeastern Asia, extending through southern China and into peninsular Malaysia³–⁶ (Figure 1). They have been extirpated from Taiwan,¹ and possibly from Bangladesh.¹ Clouded leopards are protected in most countries across their range,² but a large reason for population declines is unregulated hunting for pelts,⁴,⁵ as well as habitat fragmentation and regional declines in habitat quality.⁴ Clouded leopards may be expanding their range recently in the southeastern Himalayas. Clouded leopards were historically found in Nepal,⁹ but were thought to have become extinct in the last century. They were rediscovered in the 1980’s,¹⁰ and have now been documented as far west as Annapurna in central Nepal.¹⁰ Similarly, clouded leopards were historically found in India and may have been common.¹¹ They are now much less common, and were documented for the first time in decades in the northeastern state of Mizoram,¹² and were also detected during multiple surveys during recent decades in the northeastern state of Arunachal Pradesh,¹³,¹⁴ and Assam.¹⁵ Future studies to document and confirm the global and local ranges of clouded leopards are important in order to set realistic and appropriate conservation goals. It is possible that the range is both expanding and contracting in different areas, making local conservation needs potentially different than those for the species as a whole. The expansions of the ranges of clouded leopards in the past few decades in Nepal and India,¹²,¹³,¹⁴,¹⁵ are encouraging. Although reintroductions are often difficult, because clouded leopards are naturally recolonizing areas it is possible that reintroduction efforts could also be successful. The causes of the original extirpation in the area need to be addressed and the long-term viability of the population considered before any reintroductions efforts begin.

Population densities and abundance

The population density estimates of clouded leopards range from 0.58 to 6.53 individuals per 100km² (Table 1). Advances in technology (i.e., motion-triggered cameras)¹⁶ and statistical methods (i.e. n-mixture models,¹⁷ and spatially-explicit capture recapture [SECR] models,¹⁸) make population densities easier to obtain in the past. As a result there has been a notable increase in the studies estimating clouded leopard population densities in the last decade. We strongly encourage this increase, with the goal of obtaining estimates of population densities across their entire range. This would allow...
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Due to their cryptic nature of clouded leopards have been notoriously difficult to document in the past, but the development of commercial camera traps has increased the ability for researchers to document clouded leopards (Table 2). Many of the past population estimates from camera data have large error values, however, and an area of research need is to determine methods of increasing accuracy. Methods of increasing detection rates, including the possible use of lures (e.g.,)\(^6\) and increasing the accuracy of the target locations should be considered. Another solution is to increase the density of cameras, along with possibly reducing the overall grid size, in order to increase the capture effectiveness. This may allow for greater capture and recapture of individuals, which would decrease the error values in population estimates. In SECR models, however, the maximum number of days for a capture from published literature with >3 photos, with effort estimates are in mean 3.46 density.

Table 1 The population density estimates available for clouded leopards from location and statistical method of estimation

| Study               | Density | SE  | Country         | Statistical method           |
|---------------------|---------|-----|-----------------|------------------------------|
| Goswami & Ganesh    | 0.58    | -   | Assam, India    | Relative Abundance Index     |
| Borah et al.\(^6\)  | 5.5     | 1.8 | Assam, India    | Jackknife Estimation in Capture |
| Borah et al.\(^6\)  | 6.53    | 1.88| Assam, India    | Pledger Models in Mark       |
| Borah et al.\(^6\)  | 4.73    | 1.43| Assam, India    | Spatially-Explicit Capture Recapture |
| Mohamad et al.\(^8\) | 3.46    | 1   | Peninsular Malaysia\(^1\) | Spatially-Explicit Capture Recapture |
| Mohamad et al.\(^8\) | 1.83    | 0.61| Peninsular Malaysia\(^2\) | Spatially-Explicit Capture Recapture |

Table 2 The camera trapping effort estimates available for clouded leopards from published literature with >3 photos, with effort estimates are in mean number of days for a capture

| Study               | Effort days | Country         |
|---------------------|-------------|-----------------|
| Datta et al.\(^23\) | 768         | Arunachal Pradesh, India |
| Goswami & Ganesh    | 272.3       | Assam, India    |
| Mohamad et al.\(^8\) | 128.8       | Peninsular Malaysia\(^1\) |
| Mohamad et al.\(^8\) | 149.2       | Peninsular Malaysia\(^2\) |
| Moo et al.\(^7\)    | 528.4       | Myanmar         |
| Ngoprasert et al.\(^7\) | 567.7     | Thailand        |
| Tan et al.\(^7\)    | 173.2       | Peninsular Malaysia |
| Tempo et al.\(^9\)  | 113.1       | Bhutan          |

Physical and genetic characteristics

Although belonging to Pantherinae, clouded leopards are a medium-sized felid, weighing between 11-23kg.\(^3\)\(^-\)\(^22\) They have distinctive large dark, cloud-shape markings, a tail typically as long as its head-body length (up to 80-90cm).\(^1\)\(^-\)\(^2\) Clouded leopards are notable for their relatively the long canine relative to skull size (3.8-4.5cm),\(^1\) the longest of living felids and reminiscent of saber-toothed tigers.\(^23\)\(^-\)\(^24\)

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Home range and movement patterns

Over the last two decades researchers placed the first radio tracking collars on free-ranging clouded leopards.\(^36\)\(^-\)\(^39\) Tracked 2 adult clouded leopards in Thailand and reported that they occupied similarly sized home ranges (39.5km\(^2\) for 1 female and 42.2km\(^2\) for 1 male, 95% fixed kernel).\(^36\) Results in Thailand also showed no obvious differences of

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home range size (95% fixed kernel) between 2 adult males (35.5 and 43.5 km²) and 2 adult females (33.6 and 39.7 km²) in another area in Thailand. In addition, during camera trapping estimates from India individual clouded leopards were detected at cameras placed 2.0 to 13.6 km apart. It is difficult to draw conclusions from such small sample sizes, but we note 2 observations of interest. First, the home range size of male and female clouded leopards appear to be similar in size, although male solitary felids tend to have notably larger home range sizes than females.40–44 Second, although there is a positive correlation between home range size and body size,41–43 the home range size reported for clouded leopards in Thailand18,38,40 are twice as large as male leopard (Panthera pardus) home ranges (18 km²) reported elsewhere in Thailand.46 We are not sure if the reported home ranges are accurate for clouded leopards across their range, or if they are affected by local factors. A large variation in home range size has been observed in many solitary felid species, with a 10-fold variation in HRS common for species including bobcats (Lynx rufus),40 jaguars (Panthera onca),14,40,50 leopards,41,42,44 and pumas (Puma concolor).15,52 Based on this potential variation, we do not know where the current estimates of clouded leopard home range size fall on the spectrum. Many of these studies have concluded that prey distribution and abundance, at least in part, is associated with home range size and population dynamics.40,44,50,53,54

Austin in 2002 tracked 2 radio-collared clouded leopards and reported that the female had a mean daily movement distance of 977 m; the male had a mean daily movement distance of 1,168 m, while Grassman90 reported an average 1,932 m for 4 radio-tracked clouded leopards (range 122-7,724 m). These are based on straight-line measurements and the distance moved could be higher when animals meandered between sampling locations. No dispersal data about clouded leopards are available. One subadult male clouded leopard was caught by local villagers in Nepal, and was then radio-collared and translocated 100 km east of the original capture site. During the first 8 days of tracking it occupied an area less than 1 km², and then moved west toward where it was originally captured before the collar fell off after 10 days.91 Considering the large range of clouded leopards there are likely many factors that affect home range size, movement patterns, and dispersal. We are a proponent of non-invasive studies whenever possible, however, placing more radio-collars on clouded leopards as mainly arboreal based on local surveys and captive observations,20,21,45,71 Findings from studies using radio telemetry, however, suggested that clouded leopards may travel on the ground more often than in the trees.5,10,72 Contended that it could be difficult for clouded leopards to travel long distances through the trees. However, comparing the ratio of the sighting records in trees, clouded leopards are likely not primarily arboreal and instead uses trees as resting and hunting sites.56,73 But variations may occur in different habitats or regions.

Habitat use

Early literature indicated that clouded leopards occurred in dense primary forests,75,20,74 Recent information, however, shows that clouded leopards are versatile and could occur in many different habitats. These habitats include: grassland,3 secondary or selectively logged forests,71 mature evergreen rain forests.74 These accounts however are opportunistic, and based on local interviews and records from hunting, tracks, and direct observations. Radio telemetry studies in Thailand showed variations in forest use comparing closed primary forest and more open secondary forest-grassland habitat.38,59 Three of the six clouded leopards tracked used vegetation types proportionally and two preferred closed primary forest. One occurred more in the open forest-grassland, which led90 to suggest that this particular clouded leopard used edges as hunting sites. Their results provided support for the generally held belief that clouded leopards occur in primary evergreen forest.7 Camera trapping in peninsular Malaysia has shown a preference in clouded leopards for forested habitats, and detections were more frequent with increasing distance from water bodies.25

Much of the literatures suggests that clouded leopards occur most often in lowlands.17,19,66,68,70 Other studies show that clouded leopards could occur as high as 2,585 m in northeastern India,71 and clouded leopard detection at cameras was associated with higher elevations than lower elevation in Thailand.74 In peninsular Malaysia clouded
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leopard detections at cameras increased at higher elevations.75 However, occurrences of clouded leopards at these higher altitudes were extremely rare in the literature and were mostly indirect records based on interviews except a sighting by biologists at altitude 2,157m in northeastern India,12 and being found at nearly 3,000m in Nepal.13 Future studies of habitat based on explicit data are needed to understand the habitat clouded leopards are selecting for, and what drives this selection.14 Found that clouded leopard occurrence was linked to habitat used by red muntjac (Muntiacus muntjak) and Eurasian wild pigs (Sus scrofa), but further studies are needed to understand if habitat use is linked to habitat preferred by prey, or other factors such competition refuges from larger carnivores (e.g.,),16,17 and avoidance of people. Habitat use and elevation preferences are needed for setting realistic and effective conservation goals.

Activity patterns

Most accounts describe clouded leopards as nocturnal due to rare observation.2,19,21,68–70,77 Since clouded leopards have sometimes been seen traveling or hunting during daytime,49 they may not be as strictly nocturnal as previously assumed. Radio telemetry studies in Thailand showed that clouded leopards have arrhythmic activity patterns,18,39 with highest activity in the morning (801-1200) followed by evening crepuscular hours (1801-2000).39 Camera trapping in Thailand showed that 73% of observations were nocturnal.39 A future area of research is to determine the activity patterns of clouded leopards, if they vary in different areas, and if so, what causes the variation.

Two variables that may affect the activity patterns of clouded leopards are the activity patterns of prey and dominant carnivores.79 Proposed that predators track the activity periods of their prey, the activity patterns of felids, including ocelots (Leopardus pardalis), jaguars, and pumas, are related to those of their prey.60 Felids are also known to shift their temporal activity to avoid times when dominant carnivores are active, and in Thailand times of activity for clouded leopards most overlapped leopard cats (Prionailurus bengalensis) and tigers (Panthera tigris), with least overlap of leopards and marbled cats (Pardofelis marmorata).39 The use of radio tracking collars will be able to document activity patterns of clouded leopards, while the use of motion-triggered cameras could be used to determine activity patterns of clouded leopards as well as their prey and any dominant carnivores in the area.

Food habits

Like many other felids, clouded leopards consume a variety of animals, including ungulates, primates, rodents, domestic animals, and sometimes fish and snakes (Table 3). Our current understanding of clouded leopard diet is primarily from isolated observations, and is sure to be incomplete and not entirely accurate. For example, domestic animals are frequently reported, but this is likely because people are most likely to observe clouded leopards feeding on domestic animals. In contrast to Sunda clouded leopards, no birds have yet been noted in the diet of clouded leopards, but this is likely due to the very small sample of observations of clouded leopard prey to date. Also, although39 reported small mammals such as the Indochinese ground squirrel (Menetes berdmorei) and Muridae species in the diet, the stocky build, large canines and the large post canine space make clouded leopards capable of killing relatively large prey.57,19,21,81 It has historically been reported that clouded leopards will return to unfinished kills21,82,83 recently confirmed this by discovering a dead domestic goat cached on a tree branch 4m above the ground and saw a clouded leopard return to the kill the next day. Returning to feed on prey for multiple days until it is consumed is common in solitary felids (e.g.,42,55 especially when killing large prey that take multiple days to consume. Considering how important feeding ecology is to carnivores, remarkably little is known about the diet and feeding patterns of clouded leopards. We encourage future studies on the feeding ecology of clouded leopards, including diet composition, duration of feeding bouts, and how diet affects the energetic of clouded leopards. These studies could easily tie in with studies of activity patterns and how they are affected by prey species, how prey availability affects home range size, and how prey density affects the population densities of clouded leopards.

Table 3 The known prey items of clouded leopards. Studies are listed in chronological order, with their location, type of study, and whether the known frequent prey types were observed during the study. In the footnotes we list the known food items in as much detail as possible from the given study. Prey items. 1. Goats and Pigs, 2. Deer, 3. Cattle, 4. Porcupine, 5. Pig-Tailed Macaque (Macaca nemestrina), 6. Goats, 7. Hog Deer (Axis porcinus), 8. Malayan Pangolin (Manis javanica), 9. Slow Loris (Nycticebus coucang), 10. Bush tailed porcupine (Atherurus macrourus), 11. Indochinese ground squirrel (Menetes berdmorei)

| Source            | Location | Type        | Ungulates | Primates | Birds | Domestic | Rodent |
|-------------------|----------|-------------|-----------|----------|-------|----------|--------|
| Tickell87         | India    | Observation | No        | No       | No    | Yes      | No     |
| Swinhoe2          | Formosa  | Observation | Yes       | No       | No    | No       | No     |
| Brownlow          | Tavoy    | Observation | No        | No       | Yes   | No       | No     |
| Editors           | India    | Observation | No        | No       | No    | Yes      | No     |
| Davies66          | Thailand | Observation | Yes       | No       | No    | Yes      | No     |
| Hazarika83        | Assam    | Observation | No        | No       | No    | Yes      | No     |
| Grassman et al.38 | Thailand | Observation | Yes       | No       | No    | No       | No     |
| Grassman et al.38 | Thailand | Scat/Trap   | No        | Yes      | No    | No       | Yes    |

Recommendations for future studies

The ecology and behavior of clouded leopards is relatively unknown when compared to other Panthera species. However, their populations are vulnerable world-wide,1 and are split into distinct sub-populations, many of which are declining.1 Considering their vulnerable status and their standing as a Panthera species, which are often flagship species for conservation,84 they are a species that needs more study. Many of the published studies about clouded leopards either a) note detections within and on the edges of their range, or b) are anecdotal studies recording observations, many of which are decades if not over a century old. Only 7 clouded leopards have ever had radio-collars placed on them, and these individuals are restricted to a small portion of the distribution of clouded leopards.85–86

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Conclusion

Our areas of emphasis for future work include: 1) Population density and range. We consider an increased number of studies on clouded leopard population densities to be essential in future conservation of the species. The use of camera traps and new statistical methods appear to be good methods for estimating densities, and can be applied across their range. 2) Home range and movement. In order to understand clouded leopards we need to understand basic ecology, such as how much space they use, and understanding movement patterns will also be important for creation of corridors for conservation. 3) Ecological studies. There is much room for ecological studies, with recent studies have allowed us to remove folklore such as clouded leopards being primarily arboreal. However, little is still known about prey and hunting tactics, energetic, scent marking and communication, or interactions with other carnivores. Understanding these areas of clouded leopard natural history and ecology will help in creating effective conservation goals, and understanding the species and its ecological niche.

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Conflict of interest

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

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