Kittle, A. M., Watson, A. C., Chanaka Kumara, P. H., and Nimalka Sanjeewani, H. K. (2014). Status and distribution of the leopard in the central hills of Sri Lanka. Cat News 56: 28-31.

Keywords: 4LK/abundance/camera trap/camera trapping/distribution/fishing cat/leopard/Panthera pardus/Panthera pardus kotiya/Prionailurus viverrinus/Sri Lankan leopard/status

Abstract: The Sri Lankan leopard *Panthera pardus kotiya* is an endangered sub-species and data on its status, distribution and abundance in the island's central hills is lacking. A main objective of this long term study (2003-2011) is to determine these fundamental aspects of leopard ecology in this highly fragmented wet zone region. Here we report results from presence/absence surveys, camera trap surveys initiated to estimate leopard abundance, and trail index surveys comparing relative abundance between two contrasting highland sites, the first a mid-elevation secondary wet zone forest adjacent to a large town (pop. 100 000) and the other a mix of regenerating secondary and primary montane forest adjacent to a large (98 km^2) protected area. Results indicate that leopards inhabit a wide variety of landscapes in the region ranging from large intact forest swaths to small (<5 km^2), isolated patches of heavily impacted secondary forest. Long term (minimum 6 years) use of small patches by individually identified leopards and repeated cub-rearing confirms residency, highlighting the importance of these seemingly marginal lands. Leopard abundance differs markedly between hill country sites with a higher relative abundance in areas adjacent to large, intact forests than more isolated forest patches. Leopards are using a range of landscapes within the region including established and regenerating forests, plantation lands (e.g. pinus, eucalyptus, tea), and areas in close proximity to human settlement.

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Status and distribution of the leopard in the central hills of Sri Lanka

The Sri Lankan leopard *Panthera pardus kotiya* is an endangered sub-species and data on its status, distribution and abundance in the island's central hills is lacking. A main objective of this long term study (2003-2011) is to determine these fundamental aspects of leopard ecology in this highly fragmented wet zone region. Here we report results from presence/absence surveys, camera trap surveys initiated to estimate leopard abundance, and trail index surveys comparing relative abundance between two contrasting highland sites, the first a mid-elevation secondary wet zone forest adjacent to a large town (pop. 100 000) and the other a mix of regenerating secondary and primary montane forest adjacent to a large (98 km²) protected area. Results indicate that leopards inhabit a wide variety of landscapes in the region ranging from large intact forest swaths to small (<5 km²), isolated patches of heavily impacted secondary forest. Long term (minimum 6 years) use of small patches by individually identified leopards and repeated cub-rearing confirms residency, highlighting the importance of these seemingly marginal lands. Leopard abundance differs markedly between hill country sites with a higher relative abundance in areas adjacent to large, intact forests than more isolated forest patches. Leopards are using a range of landscapes within the region including established and regenerating forests, plantation lands (e.g. pinus, eucalyptus, tea), and areas in close proximity to human settlement.

The Sri Lankan leopard is an endangered endemic sub-species (Miththapala et al. 1996, Uphyrkina et al. 2001). It is the top predator on the island, the only leopard population known to have evolved as the apex carnivore in its ecosystem (Guggisberg 1975, Turner 1997), isolated from intra-guild competition at least since Sri Lanka split from the Indian sub-continent ~5,000-10,000 ybp (Deraniyagala 1992, Yokoyama et al. 2000). This unique scenario may make the species of keystone importance (Paine 1966). Despite this status and the potential to broadly impact other trophic levels, there is a paucity of information about the leopard here. In the low country dry zone, which comprises the majority of Sri Lanka's land area, leopards are widely distributed, especially in the north-western and eastern regions where most of the country's large protected areas are located (Watson & Kittle 2004). In Yala National Park (YNP) on the arid south-east coast a high prey base supports a high leopard density (Santiapillai et al. 1982, De Silva & Jayaratne 1994, Kittle & Watson 2004) consistent with observed worldwide patterns (Marker & Dickman 2005). Outside the dry zone information is almost entirely absent (but see Ranawana et al. 1998). This absence of data is recognized as a barrier to designing conservation and management action plans aimed at ensuring the leopard's continued survival in the wild (Samarakoon 1999).

Fig. 1. Map of Sri Lanka with forest cover by class. Approximate extent of central highlands is outlined in red with hill country study sites indicated by arrows.

Since 2003 The Leopard Project (TLP) has been investigating leopard distribution and ecology in the data deficient central hills. TLP has conducted presence/absence surveys throughout the region and more detailed investigations in two main study sites: Dunumadallawa and Agrapatana (Fig. 1). The research objective is to determine fundamental aspects of leopard ecology in the hills, with an initial focus on status, distribution and abundance. The central hills have a high human population density (320-427/km²) and highly heterogeneous land cover with intact forest areas small and widely spaced. Therefore humans and leopards frequently utilize the same habitat, increasing the potential for human-leopard conflict. To ensure the leopard's future survival in this region it is important to first document their distribution and abundance.

Regionally specific information is important in Sri Lanka, a small nation (65,610 km²) with a variety of habitats including arid coastal lowlands, rainforest-clad hills and wind-swept mountains (>2,500m). Furthermore a relatively large (>21 million) mostly rural (74-78%, 2001 Dept of Census & Statistics) human population ensures human/wildlife interaction is inevitable. Leopards get poached directly as well as caught in illegal snares set for other animals (e.g. wild boar *Sus scrofa*) (Kittle & Watson 2002). Of the 13 leopards known to have been killed in the central hills since 2007, nine were inadvertently snared.

Study Areas

The central hills occupy a section of about 2,400 km² of Sri Lanka's south-central interior (Fig. 1), encompassing a vast expanse of often-rugged terrain varying greatly in elevation, topography and climate.

The Dunumadallawa forest reserve is at the northernmost terminus of the Central massif (Fig. 1). It consists of 480 hectares of secondary growth mid-country wet zone forest 550-980 meters above sea level (Fig. 2a). Temperatures range from 20-25° C with moderate seasonal rainfall (1,500-3,000 mm/year). Originally a working estate, the area was released from plantation use (tea, coffee and cocoa) in the early 1900s and now protects the watersheds of 2 reservoirs which provide for the town of Kandy (pop ~100,000). The reserve is within official town limits. Post-release natural regeneration has occurred with some active reforestation of native plant species in the past 10 years. Dunumadallawa is characterized by high canopy mixed forest dominated by several species including *Albizia sp.* and jak *Artocarpus hete-*

rophyllus remaining from active estate days. Large-leaf mahogany *Sweitinia macrophylla*, Ceylon almond *Canarium zeylanicum* and various *Ficus* species are also conspicuous. Tea, coffee and cocoa plants, now growing wild, dominate the understory in some areas whereas ironwood *Mesua ferrea* is dominant in others. Grassland patches are scattered throughout the reserve. The abundant jak provides an important continuous food source for toque macaques *Macaca sinica aurifrons*, barking deer *Muntiakus muntjak* and wild boar. Porcupine *Hystrix indica* are also extant. The forest reserve includes a small (44 ha) *Pinus* plantation at its highest point (980 m) (Fig. 2a). The surrounding region is highly disturbed, characterized by a dense conglomeration of land-use types including moist mid-elevation or sub-montane forest, tea estates, pinus and eucalyptus plantations, open scrub, home gardens and villages. Surrounding villages (Fig. 2a) utilize the forest for firewood and fruit collection.

The second study area, Agrapatana, is near the southern extent of the central massif in the heart of the tea industry's vast plantation lands (Fig. 1). At the centre of the study area is a 50 hectare regenerating forest that was part of a neighbouring tea estate until the 1990s. This land adjoins the Agra-Bopats forest reserve, a 98 km² sub-montane and montane forest bordered on three sides by tea estates but connected in the southeast to Horton Plains National Park (31,6 km²) (Fig 2b). Characterized by thickly vegetated, montane cloud forest this area ranges in elevation from 1,500-2,500 m and at < 20° C is cooler than the northern site. Average rainfall is 1,500-3,000 mm/year. Sambur deer *Cervus unicolor*, wild boar, toque macaque, purple-faced langur *Trachypithecus vetulus* and porcupine all reside within the forest reserve.

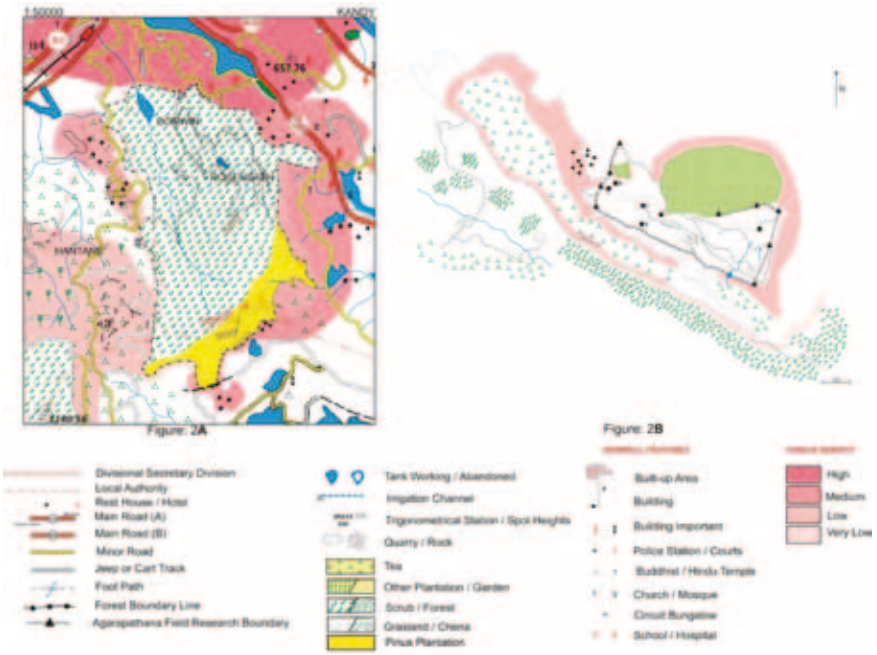

Fig. 2. Map of (a) Dunumadallawa forest reserve and (b) Agrapatana study area with index trails indicated. Areas of high, medium and low human population pressure are shown.

Materials and Methods

Presence/absence surveys have been conducted throughout the central hills since 2004. Signs (scrapes, scat, pugmarks, kills) along forest trails, tea estate roads and village boundaries are the primary indicators of presence with interviews with local residents providing supplementary information. These interviews employ photographs to verify observations due to the high incidence of confusion between the leopard and fishing cat *Prionailurus viverrinus*.

In January 2009 a camera trap survey was initiated at Agrapatana and followed with a similar grid-based design in Dunumadallawa in August (Karanth & Nichols 1998). We used 5 camera traps (Trailmaster TM1550, active infra-red, Lenexa, Kansas) with dual cameras to record both flanks of photographed leopards. One trap was stolen during the first trapping period reducing the effective number of traps to 4. Traps were set ~ 40 cm above ground on wooden stakes or existing trees. Traps were active from 18:30-7:00 on sections of trail where spoor had previously been detected or previous experience indicated a high likelihood of leopard activity. Traps were removed during the day to reduce the possibility of theft. The smallest recorded home range size for an adult female leopard in Asia was 8 km² (Grassman 1999), so traps were spaced ≤ 2km apart to ensure no gaps in the grid (Karanth & Nichols 1998). At Agrapatana there were two trapping sessions at 8 different sites, the first four for 10 nights and the second for 16 nights. Total trapping effort was 104 nights over a 35 day period. At Dunumadallawa total trapping effort was 132 nights over 68 days at 9 sites. Here traps were relocated 4 times with the initial session 8 nights and each subsequent session 10 nights. The sampled area was determined by the area enclosed by the outermost trap locations plus a buffer half the maximum distance moved between re-captures (Karanth & Nichols 1998). No leopards were captured more than once at Dunumadallawa so a buffer was not added. The total area covered by the grid was 20.8 km² + 500m buffer at Agrapatana and 5.9 km² at Dunumadallawa. The coverage at Dunumadallawa was restricted due to the small size of the reserve and the impracticality of expanding beyond the reserve boundaries.

Relative leopard abundance was determined using sign indexes on selected trails in each site (Henschel & Ray 2003). Trails were traversed between 6:00-9:00 h and scat, scrapes and pugmarks counted, recorded and collected or removed to avoid re-counting on subsequent indexes. Three trails within the Dunumadallawa forest reserve (Hantane 1,900m,

Fig. 3. Young adult female leopard camera trapped at the Agra Arboretum, near Agrapatana, Nuwara Eliya District, 21 January 2009.

Fig. 4. Adult female leopard and cub (partially hidden on left) photographed at the Dunumadallawa forest reserve near Kandy on August 14, 2009. This female was previously photographed in the same reserve in November 2003 at which time she also had a cub.

Gal Machine 2,000 m, Kosgolla 1,600 m) were traversed three times each; two trails, one within the regenerating forest region (Arboretum 2,900m) and one along the Agra-Bopats forest reserve boundary (Upper tea 3,500 m), were traversed twice each at Agrapatana (Fig. 2ab). A two week gap was maintained between successive trail indexes at both sites.

Results

Leopards are distributed throughout the central hills from the Mahaweli Ganga at Kandy in the north to the Peak Wilderness Sanctuary in the south and extant in most forest patches, including small (<5 km²) ones surrounded by non-forest areas. Leopards utilized non-forest habitat (tea estates, grasslands, home gardens) and treed plantations (Pinus, *Eucalyptus*) to move between forest patches. Leopards are not only utilizing small, terminal forest patches (e.g. Dunumadallawa reserve) but are residing and reproducing there.

Due to an inadequate number of re-sightings in both study areas we were unable to determine leopard abundances. Three photo captures were made at Agrapatana of the same young adult female leopard (Fig. 3) who was documented using multiple habitat types including dense montane zone forest, a mature Eucalyptus plantation and a small patch of regenerating secondary forest. Spoor evidence indicated she also used the working tea estate that the forest borders. In Dunumadallawa we captured two individuals in a single photograph. We were thus able to confirm that the reserve is utilized by leopards. Furthermore one of the individuals captured was the same adult female photographed 6 years previously (Fig. 4) when work by TLP found a resident female and cubs within the reserve and the occasional presence of an adult male (Watson & Kittle 2004). Other recent results include the camera capture of a previously undetected young male in the study site (Fig. 5), photographed during an ad hoc survey. This young male is the third individual leopard directly observed in this small forest reserve although signs (pugmarks and other spoor) indicate that other individuals have also used the area.

Fig. 5. Camera trap photo of young adult male leopard at Dunumadallawa forest reserve near Kandy in December 2008.

A secondary objective for the camera trapping surveys is to increase our knowledge of the biodiversity within the hill country forest patches as the traps are effective at capturing secretive, nocturnal species otherwise difficult to detect. We have captured photographs of a number of these species including fishing cat, golden palm civet *Paradoxurus zeylonesis*, common ring-tailed civets *Viverricula indica* and mouse deer *Moschiola meminna* (Fig. 6).

Leopard relative abundance differed substantially between the two sites but not within each site with leopards occurring at a higher relative abundance in Agrapatana (0.93 signs/km) than Hantane (0.42 signs/km; Fig. 7).

Discussion

Many areas inhabited by leopards in the central hills are also heavily impacted by people, as both Agrapatana and Dunumadallawa exhibit. Despite this overlap in habitat use, incidents of direct human-leopard conflict are relatively rare possibly due to temporal niche partitioning characterized by landscape utilization by people during daytime and leopards at night.

The leopard's adaptability and elusive nature allows it to inhabit forest patches such as Dunumadallawa which falls within the city limits of a town of about 100,000 people. At least three leopards have been poached from the vicinity of this forest reserve in the past 6 years and signs show that new individuals have quickly replaced them, indicating that the forest reserve is not isolated. This high turnover is of concern and begs the question whether this forest reserve is acting as a population sink. However, that the same female has been residing, and reproducing, here for over 6 years seems to counter this argument and may be testament to the reserve's value as part of a potentially stable system.

The higher relative abundance of leopards observed at the Agrapatana site is expected given that this area, although disturbed, is in close proximity to one of the larger patches of intact montane forest in the region whereas Dunumadallawa has an extremely high human disturbance factor. Furthermore sambhar are not uncommon at Agrapatana and

Fig. 6. A fishing cat (left), a common ring-tailed civet (centre) and a golden palm civet (right) photographed in the Dunumadallawa forest reserve near Kandy.

it is expected to have a substantially higher available prey biomass than Dunumadallawa. This highlights the importance of site-specific research as even within the relatively small confines of the central hills several very different habitat types are found, each with its own faunal composition and correspondingly different leopard abundances.

Acknowlegements

Thanks to the Department of Wildlife Conservation (DWC), Forest Department (FD) and Kandy Municipal Council for permissions. Funding was provided by a PTES (People's Trust for Endangered Species) UK grant and contributions from CERZA Conservation, France.

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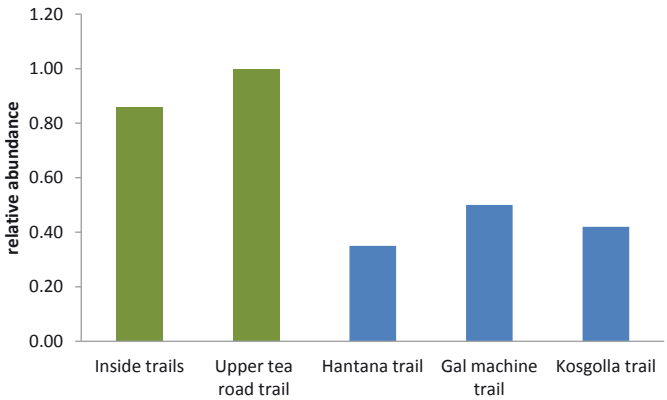

Fig. 7. Relative abundance (signs/km) of leopards in Dunumadallawa forest reserve and the Agrapatana study site. Agrapatana trails are in green and Dunumadallawa trails in blue.