

**Habitat Ecology of Royle's Pika (*Ochotona roylei* Ogilby) along
Altitudinal Gradient with Special Reference to Foraging Behavior in
Western Himalaya, Uttarakhand**

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By

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CERTIFICATE

This is to certify that the thesis of Mr. Sabuj Bhattacharyya entitled “Habitat Ecology of Royle’s Pika (*Ochotona roylei* Ogilby) along Altitudinal Gradient with Special Reference to Foraging Behavior in Western Himalaya, Uttarakhand” is an original piece of work submitted to the Saurashtra University, Rajkot (Gujarat) for the award of Doctor of Philosophy in Wildlife Science.

Mr. Bhattacharyya has put in more than six terms of the research work embodied in this thesis under our guidance and supervision. The work presented here has not been submitted to any other University or Institution.

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Summary

The relationship of a species with its environment has always been of primary interest among ecologists. The species living in highly seasonal environment and special habitats at high altitudes reflect peculiar evolutionary and adaptive behavior. The small mammals living at high altitudes such as pikas (*Ochotona* spp.) are of particular ecological interest as they exhibit high energy demands, limited dispersal capability and sensitivity towards climatic variation. Though seven species of pika are reported from the Himalayan region, none of the species have been studied in terms of their ecology and response to environmental variation. Keeping this in view, Royle's pika (*Ochotona roylei*), a small lagomorph and widely distributed in western Himalaya was selected to understand its habitat use pattern and behavioural ecology. The objective of the study were: (i) To characterize micro-habitat features associated with Royle's pika along a subalpine alpine ecotone and identify the factors which governs its occurrence, (ii) To study the topographical and bioclimatic factors affecting its land scape level distribution, (iii) To understand factor governs abundance of Royle's pika along altitudinal gradient, (iv) To document behavioural repertoire of Royle's pika in various season, (v) To study the influence of habitat microclimatic condition on activity of Royle's pika, (vi) To identify the factors which governs the food selection decision of Royle's pika.

The study was conducted in Chopta Tungnath area of Kedarnath Wildlife Sanctuary, Uttarakhand, India. This area was selected due to availability of pika habitat along altitude gradient, gentle slope and year round accessibility.

Influence of habitat characteristics on Royle's pika occurrence

Habitat characteristics of pika were studied during 2008- 2012 within forty randomly selected plots along an altitudinal gradient from 2650 to 3680m. Each study plot was divided into one hundred, 5m×5m squares to record data on different habitat related variables (such as crevices size and rock dispersion). Various ecological hypotheses on the influence of habitat characteristics on pika occupancy were formulated and tested through discrete choice analysis. The lowest distribution limit of Royle's pika in the study area was rocky talus habitat in an oak-rhododendron mixed forest opening at 2650m, whereas highest was talus habitat in alpine zone at 3680m. Uniformly distributed rock cover with small crevices was most peculiar habitat for pikas as such features allow pikas to access and feed on a larger area and also provide an escape cover from predators. As Royle's pikas are not physically efficient to make burrows, they use small crevices as their nests. Hence, apart from high variation in climatic condition, changes in physical

features of the habitat may reduce fitness of the pika population due to habitat loss as well as increase the predation risk.

Factors influence Royle's pika distribution

To understand how various bioclimatic and topographic factors affect pika distribution, occupancy data were collected from four high altitude protected areas in Uttarakhand. Various climatic (Bioclim) as well as topographic variables were selected based on a priori ecological knowledge. Pika distribution map was generated using maximum entropy algorithms (Maxent) in a geographical information system (GIS) and remote sensing domain. Majority of high probability pika occurrence locations were found to be in Kedarnath WS, Valley of Flowers NP, and Nanda Devi BR in Chamoli district whereas Gangotri NP in Uttarkashi came under medium to low presence probability category. Mean Temperature of warmest quarter, elevation and precipitation of warmest quarter were found to be the important factors governing Royle's pika distribution in Western Himalaya. As Royle's pika is talus dwelling species and prefer open area, thus high canopy cover in a habitat (NDVI) decrease the probability of pika occupancy. Snow acts as thermal insulation for pikas which thus high precipitation during coldest quarter protects them from high diurnal temperature and severe cold. High precipitation during warmest quarter (Summer-monsoon) also positively influence the growth of pika food plants, thus have a positive influence on Royle's pika occupancy.

Influence of snow and habitat characteristics on the abundance of Royle's pika

Regression models were used to identify factors that influence the abundance of adult and juvenile pika, and the timing of juvenile emergence. Best fit models indicated that adult pika abundance was significantly governed by the interactive effects of snow-cover period and altitude, whereas juvenile pika abundance was governed by food availability, amount of rock cover and spring snow depth. Juvenile pika emergence time was influenced by the interactive effects of snow cover period and altitude. The findings suggest that short snow cover period and thin snow layer during spring lead to high adult and juvenile pika mortality, probably due to cold stress. Rock cover reduces predation risk, and high food availability provides optimum nutrition to the juvenile pikas. This study showed that variation in different snow attributes or habitat structure significantly influences the abundance of Royle's pika in Western Himalaya.

Seasonal variation in time activity budget of Royle's pika

Seven behavioural states were observed in adult and juvenile pikas through focal sampling methods from 0600hrs to 1900hrs. Royle's pika shows bimodal activity pattern. High activity was observed during morning and evening hours whereas low activity was observed during midday hours. Behavioural sequences were estimated by Z-scores. Adult

pikas spent highest amount of their activity budget in foraging and least amount in vocalization. Pikas spent more time in locomotion and musing during autumn. Vigilance was high during summer as well as in habitat with low escape cover possibly due to high predation risk. Locomotion and foraging were predominant behaviour among juveniles in summer; monsoon and they did not show any long musing behaviour. Behavioural sequence analysis showed majority of summer behaviour was followed by locomotion whereas during monsoon it was grooming or vocalization and autumn either foraging or locomotion. This study reveals how pikas allocate time during different seasons, thus it can serve as baseline information for future pika research which aimed on ecology and bioenergetics.

Influence of microclimate on Royle's pika activity

The influence of microclimatic conditions (ambient temperature and relative humidity, burrow temperature and relative humidity) on activity pattern of Royle's pika was studied during May to August in permanently marked plots for four years (2008-2011). The activity pattern of pikas was recorded through direct observation from 0600hrs to 1900hrs and indexed as a percentage of individuals observed in an interval relative to the maximum number of individuals sighted on that particular day in that plot. Microclimatic data of pika habitat were recorded through altitudinal zone by automatic data loggers, a soil thermometer and a hygrometer placed about 20cm within the burrow and at a random location within the site during each observation interval. Pika activity was (binary response) modeled as the number of individual active versus inactive with logical alternate combinations of habitat microclimatic parameters as well as altitude zone and time group using linear mixed effect models. Royle's pika exhibited a bimodal activity pattern with high activity in the morning and evening hours and low activity during midday. The best fit candidate model showed pika activity increased with ambient humidity and decreased with temperature. It also shows pika activity is significantly low during midday hours than morning or evening hours. Inactive period for pikas in sub-alpine zone was much longer than that of alpine zone. The reduction of activity due to increase in temperature was significantly high in subalpine zone (2900 -3150m) a.s.l than alpine zone (3400-3520 m a.s.l). The study indicates that Royle's pika avoid heat stress by reducing activity during warm midday hours and taking shelter in micro climatically favorable cooler burrows. This study shows change in habitat microclimatic conditions, specifically increase in temperature might significantly restrict Royle's pikas day time activity.

Factors influence food selection in Royle's pika

To enhance the knowledge of plant-herbivore interaction and its influence on herbivores forage selection decision, Royle's pika was used as study species. The bite count related

to pika food plants was recorded through focal sampling in three permanently marked plots along an altitudinal gradient. Food plant abundance was recorded through quadrat method whereas food selection was estimated through Jacob's selection index. Cafeteria experiments were conducted to check whether food selection criteria change with alteration in food plant composition. Leaf morphology and nutritional analysis of major food plants and high available non-food plants were also performed. Linear regression models were used to test various competitive hypotheses to identify factors which govern food selection. The best model was selected through an information theoretic approach. Royle's pika was found to feed on 17 plant species and their food selection decision was positively governed by leaf area index and negatively by amount of avoided substance (NDF, ADF, ADL and tannin) in food plants. Furthermore, the interaction of leaf size and avoided substance indicates that a plant with larger leaves will be selected only if it contains low avoided substance. The food selection criteria did not change between field and cafeteria observation. The parameter estimates of best fit models indicate that the influence of leaf size or amount of avoided substance on pika food selection decision depends on the magnitude of predation risk

1.1 Introduction

One central theme of animal ecology study is to understand mechanism through which an animal select various resources, like food and habitats (Johnson 1980). Based on the physiological, morphological and behavioral characteristics, some species select resources proportionally to its abundance where as some select resources preferentially over others (Levins 1968). Thus, resource selection allows a mobile organism to adapt to changing conditions and influence nearly its every subsequent choice (Cody 1985). It also influences resource acquisition and reproductive success and finally fitness of an individual animal (Cody 1985). Therefore, studies focused on habitat and behavioural ecology has a great importance in both ecological theory and individual based modeling. Furthermore, habitat ecology study can also help us to formulate effective species conservation and management plan (Manly *et al.* 2002).

Volumes of literature exists related to on habitat and behavioural ecology of various wildlife species (Lubin *et al.* 1993; Welham and Ydenberg 1993; Abrams 1994), but studies related to alpine mammal's ecology are relatively rare, possibly due to climatic and topographic constrains. The contemporary climate change scenario creates increase concern about the persistence of the species which live in mountain top environment (Pounds *et al.* 1999; Walther *et al.* 2005; Sekercioglu *et al.* 2008). But, scarcity of ecological information about of alpine mammals hampers our understanding about how they will respond if their habitats become altered due to anthropogenic or natural disturbances.

Lagomorphs, especially pikas attains a district position among alpine mammal community. Lagomorphs in general are small (100g) to medium sized (1-5kg) herbivores considered to be most closely related to rodents (Li *et al.* 1987). They can be

distinguished from rodents and other mammals by presence of small peg-like teeth immediately behind the incisors. There are also recognizable fossils of both pikas and rabbits dating back to before the Oligocene (Smith 1990). The order Lagomorpha is represented by two families, viz., Ochotonidae (pikas) and Leporidae (hare and rabbits). The Ochotonidae or pikas, is represented by one living genus *Ochotona* and have hind legs not much longer than the forelegs. They are very small, have rounded ears and a skull with no supraorbital bones and a relatively short nasal region. The Leporidae, on the other hand, comprise of ten or eleven genera (depending on taxonomic status of the pygmy rabbit) are larger, with hind legs longer than the forelegs, have long ears and a skull with prominent supraorbital bones and long nasal region.

Pikas (genus *Ochotona*) now occurs only alpine mountainous terrain in the Northern Hemisphere. Systematically the pikas or *Ochotona* were clearly differentiated from the other lagomorphs as early as the Oligocene (Wilson 1960; Dawson 1967). Though pikas, play significant ecological role in alpine ecosystem, they are also a very poorly known group of mammals as they live in remote and rugged terrain which is difficult to access (Smith *et al.* 1990).

1.2 Ecological importance of pikas

Pikas play significant ecological role at high altitude ecosystem in terms of occupying a special niche in the food chain. Generalist herbivores such as pikas are important prey base to many carnivorous birds and mammals. Pikas do not hibernate, thus they are the only winter prey available to middle-sized mustelid, felid or canid carnivores (Formozov 1966). Pikas are reported to comprise the following percentages of the diet of avian predators: steppe eagle (*Aquila nipalensis*), 62%; upland buzzard (*Buteo hemilasius*), 17%; eagle owl (*Bubo bubo*), 73%; and saker falcon (*Falco cherrug*), 22% (Peshkov 1957, 1967). Similarly, alpine (*O. alpina*) and northern (*O. hyperborean*) pikas are the most important prey for Mustelids such as weasels (*Mustela ermine*) and sables (*Martes zibellina*; Khlebnikov 1977). Roberts (1977) reported that Afghan pikas were the primary prey of the stone marten (*Martes foina*) and booted eagle (*Hieraaetus pennatus*) in

Pakistan, whereas in southwestern Turkmenia, the levantine viper (*Viper lebitina*) appears dependent upon this pika (Danov 1985).

Pikas also found to be strongly influence plant community composition and micro-habitats. It has been observed that the plant species richness was higher near the small mammal colonies than away from such colonies in the Indian trans-Himalaya and also due to activity in soil by small mammals led to higher plant diversity without significant decline in the total vegetation cover (Bagchi *et al.* 2006). Selective foraging of low and moderate populations of black-lipped pikas on the Qinghai and Xizang steppes reported to play an important role in the stabilization of the alpine meadow vegetation community (Jiang and Xia 1985, 1987). The burrowing activity of Daurian pikas loosens and improves the soil, and the accumulation of their excrement and left over stores in the burrow system yields high levels of organic materials which increase local floral diversity (Dmitriev 1985; Tsendzhav 1985). On the other hand, the heavy grazing by pikas in the meadows at the edge of the talus may profoundly alter the composition and diversity of plant communities found there (Khlebnikova 1978; Huntly *et. al.* 1986; Huntly 1987).

The winter food hoarding behaviour in pikas may also influence directly or indirectly the population dynamics of other sympatric herbivores such as hares (*Lepus timidus* and *Lepus. capensis*), marmots (*Marmota camtschatica*), voles (*Clethrionomys* spp.) and Shrews lives in alpine areas. Density of voles and shrews were reported to be is four times higher in the vicinity of alpine pikas than in the surrounding forest (Naumov 1974). Pika burrows are often shared with other species of birds and small mammals. The burrows of Afghan pikas are shared with rock-dwelling Persian jird (*Meriones persicus*), Libyan jird (*Meriones libycus*), Great gerbil (*Rhombomy sopimus*), mouse-like hamster (*Calomyscus mystax*), Gray hamster (*Cricetulus migratorius*) and white-toothed shrews (*Crocidura* spp.; Sapargeldyev 1987).

1.3 Phylogeny and evolution of pikas

Similarity in general morphology in pikas makes it difficult to determine exact number of recognized species and the phylogenetic relationships among them. The number of recorded species varies from 18 to 30 (Feng and Zheng 1985; Smith *et al.* 1990; Wilson and Reeder 1993; Gong *et al.* 2000; Wang 2003). The phylogeny of genus *Ochotona* first described by Luo and Feng 1981 by using fossil data but it could not resolve interspecies relationships. Afterwards, Weston (1982); Yu *et al.* (1992, 1996, 1997) made some effort to effort to examine the relationship of the genus *Ochotona*, but either small number of species or sampling bias makes those studies incomplete. Yu *et al.* (2000) recommended that the genus *Ochotona* could be divided into 3 subgenera using mt DNA sequences study. But they worked on only 19 species and many known species were not examined in their study which makes the study incomprehensive. However, sequence data inferred from cytochrome b and ND 4 genes did not agree with the previous subgeneric classification of two subgenera – *Ochotona* and *Pika*, but they have been accepted by many authors (Ellerman and Morrison-Scott 1951; Luo and Feng 1981; Feng and Zheng 1985; Niu *et al.* 2001). The basic characters of subgenus *Pika* are incisive and palatal foramina separated from each other whereas the basic character of *Ochotona* is incisive and palatal foramina form a pear-shaped or triangle opening. Niu *et al.* (2004) studied a 402 base-pair region of the cytochrome b protein coding gene of 27 species, compared and analyzed. This study suggests about five groups *viz*, Northern, Surrounding Qinghai-Tibet Plateau, Qinghai-Tibet Plateau, Huanghe and Central Asia (Table 1.1). Northern and Surrounding Qinghai-Tibet Plateau group pikas generally found to be talus dwelling or live in intermediate type of habitat i.e, talus and steppe. *Pika* species belong to Qinghai-Tibet Plateau, Huanghe and Central Asia either steppe or shrub habitat.

The evolution of pikas is greatly influenced by the habitat adaptability in different environment condition (Yu 1997; Yu *et al.* 1992, 1996, 1997, 2000). Irwin *et al.* (1991) estimated that the divergence rate of cytochrome b gene of mammalian species is of 2-5%/Myr (mean 3%/Myr). If it is true for pikas, then it can be suggest that during the early Pleistocene which is approx. 2.8 Myr ago, five major splits took place. Huntley and

Webb (1989) suggested that environmental changes may be a cause of rapid morphological diversification.

Table 1.1 Description of various pika phylogenetic group and their habitat characteristics adopted from Niu *et. al.* 2004.

Phylogenetic Group	Species	Subgenus		Habitat Characteristics
		<i>Ochotona</i>	<i>Pika</i>	
Northern	<i>O. pallasi</i>		√	Intermediate (Talus and steppe)
	<i>O. alpina</i>		√	Rock-talus
	<i>O. hyperborea</i>		√	
	<i>O. princeps</i>		√	
	<i>O. collaris</i>		√	
Surrounding Qinghai-Tibet Plateau	<i>O. macrotis</i>	√		Rock-talus
	<i>O. roylei</i>	√		
	<i>O. iliensis</i>	√		
	<i>O. himalayana</i>	√		
	<i>O. erythrotis</i>		√	
	<i>O. gloveri</i>		√	
	<i>O. brookei</i>		√	
	<i>O. muliensis</i>		√	
	<i>O. rutila</i>		√	Intermediate (Talus and steppe)
	<i>O. koslowi</i>	√		
	<i>O. forresti</i>	√		
	<i>O. rufescens</i>	√		
	<i>O. ladacensis</i>		√	
Qinghai-Tibet Plateau	<i>O. curzoniae</i>	√		Steppe
	<i>O. annectens</i>	√		Shrub
	<i>O. daurica</i>	√		
	<i>O. thibetana</i>	√		
	<i>O. cansus</i>	√		
	<i>O. nubrica</i>	√		
	<i>O. thomasi</i>	√		
Huanghe	<i>O. huangensis</i>	√		Shrub
Central Asia	<i>O. pusilla</i>	√		Steppe, shrub

The Beringian Bridge, a proposed land bridge from Asia to the America considered as a possible migratory route of pikas from Asia to North America during the Pliocene (Kurten and Anderson 1980). The Wisconsinan glaciation (about 75,000 - 10,000 years ago) which engulf most of northern North America separated *O. princeps* in the south and *O. collaris* in the north (Guthrie 1973). Different post-Pleistocene events act as isolating factors which results the formation of numerous subspecies *O. princeps* (Guilday 1979; Hall 1981; Smith and Weston 1990).

Three strong and frequent large-scale uplifting of the Qinghai-Tibet Plateau about 3.4 Myr ago to 1.6 Myr ago causes differentiation of genus *Ochotona* in the Palearctic region (Yu *et al.* 1992b, 1996, 1997, 2000). The surrounding Qinghai-Tibet Plateau group pikas has experienced rapid multi-diverse radiation since the early Pleistocene (about 2.2 Myr ago) and adapted to high altitude as well as plateau habitat. The Qinghai-Tibet Plateau group pikas are comparatively young and inhabitants on the plateau. The high molecular sequence divergence between the steppe dwellers and shrub dwellers suggests the divergence event between the two dwellers may have happened recently by convergent evolution.

1.4 Need of pika research in Himalaya

There are altogether 31 living species in the world, of which 27 are found in Asia including 7 in the Indian Himalaya. Pikas found in the Indian Himalaya are: Plateau pika (*Ochotona curzoniae*), Forrest's pika (*Ochotona forresti*), Ladak pika (*Ochotona ladacensis*), Large-eared pika (*Ochotona macrotis*), Nubra pika (*Ochotona nubrica*), Royle's pika (*Ochotona roylei*) and Moupin pika (*Ochotona thibetana*). Though Himalaya is a home of seven different pika species but studies on pikas are scanty. Some preliminary study on the distribution pattern, winter behaviour and social organization of *O. macrotis* and *O. roylei*, was conducted by Kawamichi (1968, 1971) at Khumbu region in, Nepal. Khanal and Shrestha 2000 as well as Shrestha *et al.* 1999 reported some natural history information about habitat and foraging behaviour of Royle's pika in Nepal Himalaya. But all studies were conducted for very short periods (a week to three months) and lacks quantitative ecological information. Pikas are occasionally reported from the

Indian Himalaya but baseline ecological information generated from long term studies are completely lacking.

A study on the habitat ecology of American pika (*Ochotona princeps*) by Beever (2003) suggests that rapid changes in climate caused local extinction of the American pika in the Western United States during later part of the 20th century. Pikas are highly active above ground surface during the hottest months of the year. During these months, they collect vegetation for winter as they remain active round the year. Earlier senescence of vegetation may increase nutritional stress for pikas, and hotter temperatures during high activity periods can create direct thermal stress on the animals. Pikas are densely furred, and thus cannot dissipate heat easily. Earlier, it has been hypothesized that all mountain dwelling animal will migrate to higher altitudes in the event of increase in ambient temperature caused due to global warming (Walther *et al.* 2002). But talus dwelling pikas are confined to small pockets throughout their life-span and seem to be unable to migrate long distances. As the Himalayan region is extremely sensitive to global warming, it is obvious that several habitats, micro-habitats and dependent native flora and fauna would also be affected. However, in the absence of any empirical evidence and long term monitoring it is difficult to draw any strong conclusion. Since, small mammals in the Himalaya are likely to be more vulnerable to climate change; studies on their basic ecology, foraging behaviour and dependence on special micro-habitat parameters are urgently needed.

Keeping the above research gaps in view, the present study addresses the habitat ecology and foraging behaviour of Royle's pika along an altitudinal gradient in a part of Kedarnath Wildlife Sanctuary, Western Himalaya. Royle's pika is quite common throughout the Himalayan region (Hoffmann and Smith 2005). It is reddish brown in colour, having a pale band over the nape, head 7cm in diameter and body length is 15-20cm and weighing about 100-150g (Alfred *et al.* 2006). They occur up from 2400m to 5000m in the Western Himalaya inhabiting open rocky ground and *Rhododendron* forest. The Lower range of their distribution is 2500m (Tak and Lamba 1985; Chakraborty *et al.*

2005). Like other pika species, Roylei's pika is highly specialized to live in the subalpine and alpine areas. Their existence is directly related with the quality of their habitat including the availability of foraging plant species (Kawamichi 1968). Royle's pikas are reported to be an important prey base for several carnivore species such as marten, stoat, weasel, snow leopard and red fox in alpine and subalpine ecosystems (Roberts 1977; Oli *et al.* 1994; Aryal *et al.* 2010).

Table 1.2 Distribution and conservation status of various pika species found in Himalaya (adopted from Smith *et al.*1990)

Name of species	Scientific name	Distribution	Conservation status
Moupin Pika	<i>Ochotona thibetana</i>	Shanxi, Shaanxi, W Hubei, Yunnan, Sichuan, S Tibet (China); N Burma; Sikkim (India); perhaps adjacent Bhutan and India	Lower Risk
Royle's Pika	<i>Ochotona roylei</i>	Himalayan Mtns in NW Pakistan and India to Nepal; adjacent Tibet (China)	Lower Risk
Nubra Pika	<i>Ochotona rubrica</i>	Southern edge of Tibetan Plateau from Ladak (India) through Nepal to E Tibet (China)	Lower Risk
Large-eared Pika.	<i>Ochotona macrotis</i>	Mountainous regions including the Himalayas (Nepal, India) from Bhutan through Tibet, Kunlun (Qinghai, Xinjiang, Sichuan and Yunnan [China]), Karakorum (Pakistan), Hindu Kush (Afghanistan), Pamir, and W Tien Shan Mtns (Kyrgyzstan, Tajikistan, SE Kazakhstan).	Lower Risk
Ladak Pika	<i>Ochotona ladacensis</i>	SW Xinjiang, Qinghai, E Tibet (China); Kashmir (India); Pakistan.	Lower Risk
Forrest's Pika.	<i>Ochotona forresti</i>	NW Yunnan, SE Tibet (China); N Burma ;Assam, Sikkim (India); Bhutan	Lower Risk
Plateau Pika	<i>Ochotona curzoniae</i>	Tibetan Plateau; adjacent Gansu, Qinghai, Sichuan (China), Sikkim (India) and E Nepal.	Lower Risk

This study attempts to unveil the basic ecological information about the relationship of habitat characteristics and occurrence, distribution, abundance, behavioural pattern and food selection in Royle's pika.

1.5 Objectives

The present study addresses the habitat ecology and foraging behaviour of Royle's pika in Western Himalaya with following objectives:

1. To characterize micro-habitat features associated with Royle's pika along a subalpine – alpine ecotone and identify the factors which governs its occurrence.
2. To study the topographical and bioclimatic factors affecting Royle's pika's landscape level distribution.
3. To understand factors which govern abundance of Royle's pika
4. To document behavioural repertoire of Royle's pika in various season.
5. To study the influence of habitat microclimatic condition on activity of Royle's pika.
6. To identify the factors which govern the food selection decision of Royle's pika.

1.6 Organization of the thesis

This thesis is organized in 9 chapters. The Chapter 1 describes the basic information about pikas and background, objectives of the study. The Chapter 2 describes the study area in Kedarnath Wildlife Sanctuary with a focus on its location, climate, flora and fauna, people. Chapter 3 provides a detailed description of different pika habitats in the study area and how habitat characteristics affects occurrence of Royle's pika (Objective 1). Chapter 4 provides information about factors which governs distribution pattern of Royle's pika in large landscape (Objective 2). Chapter 5 deals with various factors affecting abundance of Royle's pika (Objective 3). Chapter 6 is focused on seasonal variation activity pattern and budget (Objective 4) whereas habitat microclimatic factors effects on pika activity was discussed in chapter 7 (Objective 5). The foraging behaviour and food selection criteria of Royle's pika was discussed in Chapter 8 (Objective 6). Chapter 9 is general discussion which summarizes the key findings of the study and conservation implications.

2.1 Introduction

The study was carried out in part of the Kedarnath Wildlife Sanctuary (*ca.* 975 km²), situated in the upper catchments of the Alaknanda River at Chamoli district, Uttarakhand in Garhwal Himalaya (Fig. 2.1). It is one of the largest protected areas within Indian Himalaya, notified as Wildlife Sanctuary (WLS) on 21st January 1973 and comes under IUCN management category IV, Managed Nature Reserve (IUCN 1993). This sanctuary covers 70% of the Kedarnath Forest Division (1393 km²). The sanctuary is bounded by Mandakini and Uttarkashi district boundaries in the West, great mountain peaks (Kedarnath- 6940m; Mandani- 6193m and Chaukhamba- 7068m) in the North, the Gopeshwar - Mandal - Chopta - Okhimath motor road in the South, and Urgam Reserve Forest in the East. The altitude ranges from 1160m (near Phata) to peak of Chaukhamba - 7068m. The sanctuary was named after the famous Hindu shrine at Kedarnath, an eighth century temple situated at 3562m altitude, outside the northern border of the sanctuary.

2.2 The Intensive Study Area

An intensive study area (ISA) of 10 sq km was selected in the sanctuary encompassing the area from Chopta to Tungnath (30°30'-31°29'N and 78°12'-79°13'E). This area was selected due to the accessible elevation range (2600-3680m a.s.l.) and availability of Royle's pika habitat types. This area, marked by the Hindu shrine Tungnath (3550m), is famous as a place of Hindu pilgrimage for centuries and also for its scenic beauty. The local inhabitants are traditionally agro-pastoralists settled in scattered villages along lower fringes of the sanctuary. The altitude of the intensive study area varies between 2600m to 3680m (Fig. 2.1B). Majority of the study area has North West and South West aspects (Fig. 2.1D) with medium (21°-40°) to very steep slope (> 40°, Fig. 2.1C).

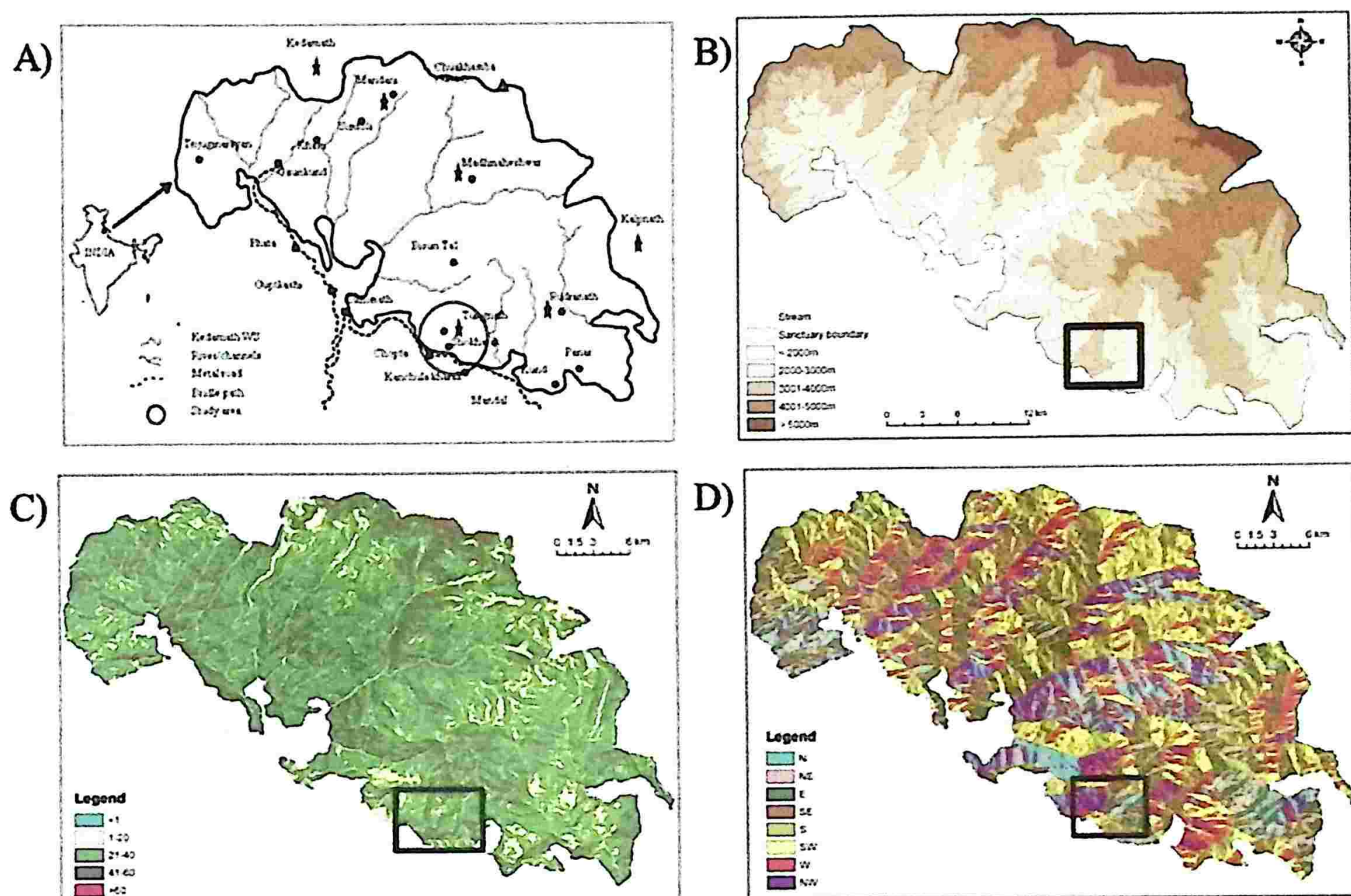


Figure 2. 1 Location (A), elevation (B), slope (C), aspects (D) of the intensive study area (in circle or square) in Kedarnath Wildlife Sanctuary, India

2.3 Geology and soil

The rocks around Tungnath are mainly types of metamorphic rocks such as mylonitized gneisses, augen gneisses, schists and granites (Agrawala 1973). Majority of schists are highly interleaved biotite, mica, quartz and feldspar. The gneisses, schists and granites form a light, sandy and micaceous, mineral rich soil which is excellent for tree growth on favorable aspects through pedogenesis process (Agrawala 1973). Soils are in general sandy loam in texture with high proportion of sand and silt, and acidic in nature (Bisht 2005). Soil within forests is rich in humus whereas the traditional practice of burning the pastures for better grass production enriches soils in meadows and grassy slopes with minerals (Green 1985).

2.4 Climate

Both the South-West monsoon in summer and westerly disturbances in winter influences the climate of the study area (Mani 1981). The study area generally experience 5 seasons, a short spring (March-April) and summer (typically lasts from May to June), monsoon (from end of June to September), a very short autumn (October-November) and long winter December to February). There is some precipitation as it snows during winter. Temperature is highest during summer (May-June) and lowest in December-January. The snow starts to melt during March first week in subalpine areas whereas the alpine areas are not completely snow free until mid-April. Meteorological data of the intensive study area reveals that during 3 years of study period there was much fluctuation in the inter-annual climate. Extreme events in the weather were more pronounced. The mean annual temperature was 6.9°C in 2008, 5.8°C in 2009 and 7.1°C in 2010, whereas maximum temperature in was 22°C (July), 21.3°C (June) and 25.6°C (May), respectively. Figure 2.2 indicates daily average temperature at the timberline zone (Adhikari *et al.* 2012). Precipitation pattern also varied considerably during 2008-10. Highest precipitation was recorded in 2010 with prolonged monsoon and heavy rainfall in the months of August-September, and good snowfall at the end of year ((Adhikari *et al.* 2012; Figure 2.3).

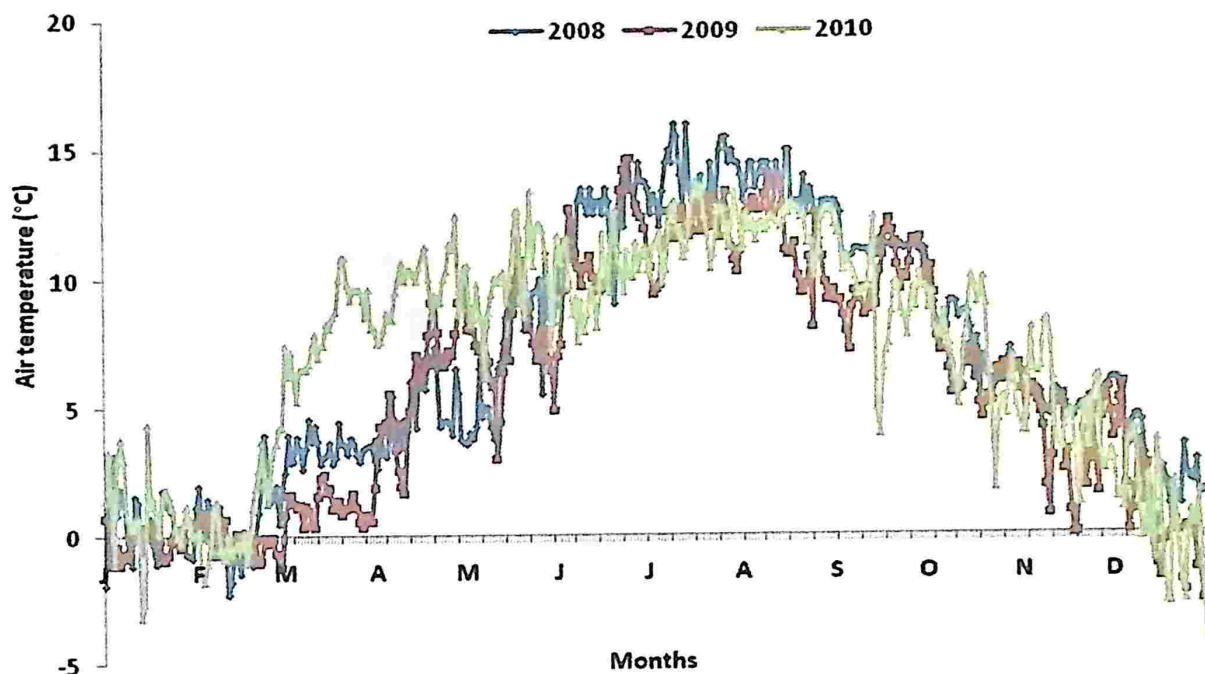


Figure 2.2 Daily average temperature at the timberline zone (3300m) from 2008-2010

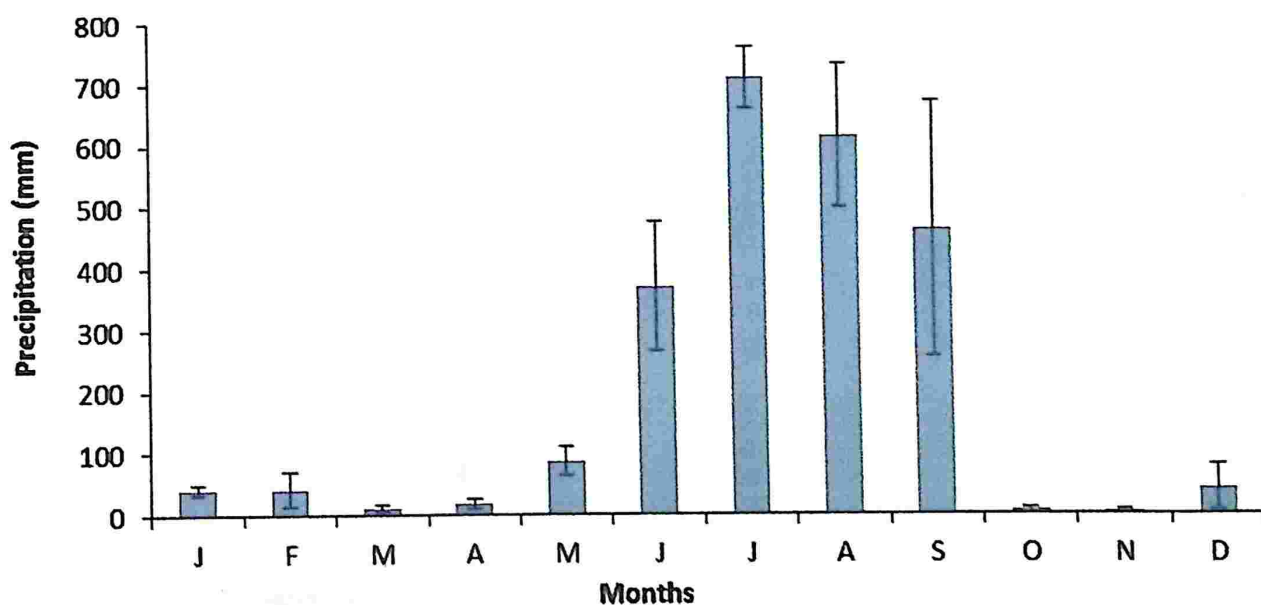


Figure 2.3 Mean monthly precipitation in study area during 2008-2011 (October to May is in the form of snowfall).

2.5 Flora and Fauna

The subalpine vegetation (2700-3300m) comprises mostly of broadleaved sclerophyllous communities of *Quercus semecarpifolia*, *Rhododendron arboreum*, *R. campanulatum*, *Abies pindrow*, *A. spectabilis* and *Sorbus* sp. whereas the alpine meadows (above 3300m) at and around Tungnath are dominated by various grass and herbaceous communities (Sundriyal *et al.* 1987). The major shrub species in the alpine zone are *Rhododendron campanulatum*, *R. anthopogon*, *Salix elegans*, *Lonicera myrtillus* and *Cotoneaster microphyllus* whereas *Danthonia cachemyriana*, *Agrostis pilosula*, *Trisetum spicatum*, are the common grasses and *Kobresia royleana*, and *Carex nubigena* are the major sedges. Some prominent species forming the herbaceous communities in the alpine zone are *Potentilla atosanguinea*, *Geranium wallichianum*, *Primula denticulata*, *Epilobium royleanum*, *Ranunculus hirtellus*, *Impatiens sulcata*, *Bistorta affinis*, *Fritillaria roylei* and *Satyrium nepalense*.

The study area is very rich in wild mammals and bird diversity. A total of 30 mammalian species (excluding bats) are known to occur in Kedarnath WLS of which 25 species have been reported from the intensive study area (Green 1985). Seven species of ungulates viz, Himalayan musk deer (*Moschus chrysogaster*), Himalayan tahr (*Hemitragus jemhalicus*), Serow (*Nemorhedus sumatraensis*), Himalayan goral (*Nemorhedus goral*), Sambar (*Cervus unicolor*), Barking deer (*Muntiacus muntjak*) and Wild pig (*Sus scrofa*), and 2 species of primates, Rhesus macaque (*Macaca mullata*) and Common langur (*Semnopithecus himalayanus*) are reported from the study area. Jackal (*Canis aureus*), red fox (*Vulpes vulpes*), yellow throated marten (*Martes flavigula*), Himalayan weasel (*Mustela sibirica*) and common leopard (*Panthera pardus*) are potential predators of pikas in the study area (Green 1985). A total of 210 species of birds including 3 pheasants viz., Himalayan monal (*Lophophorus impejanus*), Khaleej (*Lophura leucomelana*) and Koklass (*Pucrasia macrolopa*) are reported from the intensive study area (Sathyakumar unpublished). Notable species of reptiles include Himalayan pit viper (*Ancistrodon himalayensis*) and Boulenger's keelback (*Amphiesma parallela*).

2.5 Land use practices

The Kedarnath WLS is surrounded by 182 villages of which 50 are located in the fringe areas of the sanctuary (Rawat 2007). Practicing agriculture and utilization of forest resources are the principle source of livelihood for the local people. Trees are lopped for fodder and fuel wood. Also, since the area is a pilgrim and tourist site, consumption of firewood is very high around tree line and sub-alpine zones. These anthropogenic pressures (regular camping and removal of woody vegetation) are considered a driving force for lowering the natural tree line in various parts of the Western Himalaya (Rawat and Uniyal 1993). The migratory families and shops at intensive study area (Chopta-Tungnath) create extreme pressure in subalpine – alpine zone from high fuel wood collection and grazing from April to November. They mainly exploit *Quercus semecarpifolia*, *Betula utilis*, *Rhododendron campanulatum*, *R. anthopogon* and *R. lepidotum* for fuel wood (Rawat 2007).

2.6 People and their cultural history

The population of Garhwal Himalaya can be grouped into 3 major ethnicities: i) Bhotias who are mixed Tibetan in origin, have mongoloid countenance and live in high trans Himalayan valleys (2400m-3600m), ii) the aboriginal “Austic” or “pre-Dravidian”, represented by the Koltas, Doms and other artisan castes, and iii) the Rajputs of the Cis-Himalaya known as Khasas who share similar origin and culture with Brahmins (Nityaanand and Kumar 1989).

The cultural history of the study area as well as entire Garhwal Himalaya has been under waves of external influences in different periods of history. Many moved across the main valley routes. The religious structure of this region as a substratum of nature’s worship has successive layers of cults of Shivism, Shaktism, Buddhism and Vaishnavism. Thus, the fabric of the cultural landscape of Garhwal Himalaya is woven with multi tribal and racial elements of culture (Atkinson 1973). The religion of people who live near intensive study area is principally Hinduism and they belong to either “pre-Dravidians” or “Khasas” ethnic group.

Influence of habitat characteristics on occurrence of Royle's pika

3.1 Introduction

Species-habitat relationships are central to autecological studies and can be addressed from various perspectives. One of them is to identify habitat characteristics that influence species occurrence by comparing presence versus absence sites. Such habitat models can shed light on the distributional range (Wikle 2003; Engler *et al.* 2004), habitat selection (Bradford *et al.* 2003; Gibson *et al.* 2004) and meta population dynamics (Hanski 1994 1999) of species. This information may in turn help in designing effective conservation programs (Zielinski and Stauffer 1996; Trenham *et al.* 2003; Weber *et al.* 2004) for species, particularly the threatened and sparsely known ones.

A multitude of literature exists on habitat selection and occupancy patterns of various wildlife species (e.g. Lubin *et al.* 1993; Welham and Ydenberg 1993; Abrams 1994), but studies related to habitat occupancy in alpine mammals are relatively rare due to harsh climatic conditions (even during summer), the short snow free period every year and inaccessibility. Absence of information about habitat occupancy patterns and requirements hamper our understanding about how alpine mammals will respond if their habitats become altered due to anthropogenic or natural disturbances. This study investigates the relationship of the habitat characteristics and occupancy of a high altitude small mammal, Royle's pika (*Ochotona roylei*), in the Western Himalaya. Royle's Pikas are small herbivorous rock talus dwelling lagomorphs (100-150g; Alfred *et al.* 2006). They are diurnal, highly detectable, limited to a single narrowly defined accessible (survey able) habitat, talus or piles of broken rock adjacent to suitable vegetation and leave unmistakable indirect evidence i.e., piles of typical small round droppings. Hence, they are ideal small mammals for field observation (Beever *et al.* 2010). Royle's Pikas are reported to be an important prey base for several carnivore species (such as marten, stoat, weasel, snow leopard, red fox) in alpine and subalpine ecosystems (Roberts 1977; Oli *et al.* 1994; Aryal *et al.* 2010). Pikas do not possess any physiological armor to defend themselves against predators. Therefore, when threatened they take shelter in the interstices of talus habitat patch to escape from the predator. Habitat quality and the

connectivity of these patches were found to be the best predictors regarding the extinction of other talus dwelling pika, the Collared Pika (Franken and Hik 2004). Royle's Pika is currently in the "least concern" category in the IUCN red list of threatened species (Smith and Boyer 2008). Rapid change in climatic regime is reported in the Himalaya (Singh and Bengtsson 2004). Li and Smith (2005) suggested that there might be a link between dramatic decline of another Asian pika species, Ili Pika (*Ochotona iliensis*) and global warming in China. Hence, these incidents compel conservationists and ecologists to reassess the status and generate basic ecological information like factors governing occupancy of Himalayan pika species such as Royle's pika to design effective future conservation management plans.

Royle's pika is distributed in the Himalayan region from North-West Pakistan to India, Nepal and adjacent Tibet (China; Hoffmann and Smith 2005). In the Western Himalaya, Royle's pika occurs mostly in open rocky grounds and rhododendron forests from 2400m a.s.l. up to 5000m a.s.l. (Chakraborty *et al.* 2005). Most pika species show a marked food hoarding behaviour (Smith *et al.* 1990), while surprisingly Royle's pikas are reported to show very weak hoarding behavior, i.e., presence of very small haypiles that consisted of only few individuals of plants in front of their nest opening (Kawamichi 1968). It is also comparatively less vocal than other pika species (Kawamichi 1968). The fecundity of Royle's pika is low; litter size varies from 1-3 and usually occurs in low densities like other talus dwelling pikas (Smith *et al.* 1990; Bhattacharyya *et al.* 2009). They are highly active in early morning and late afternoon and evening.

An animal's decision to occupy a site is often hierarchical in nature, operating from geographical range to micro habitats within individual home range (Manly *et al.* 2002). In this study, information on habitat characteristics associated with Royle's pika occurrence was collected at its home range scale (80-82 m²; Kawamichi, 1968). Royle's pika does not make burrows and therefore, it is evident that they would prefer to occupy broken rock habitats. The talus connectivity, rock structures was found to be a significant factor which governs the abundance and habitat use pattern in talus dwelling pikas such as the Collared pika (Holmes 1991; Morrison *et al.* 2004; Franken and Hik 2004) and the

American pika (Roach *et al.* 2001; Tyser 1980). As Royle's pika also lives in an area with rock boulders we hypothesize that the distribution pattern of rocks in a talus and fine scale habitat characteristics such as availability of different size crevices would influence its habitat occupancy. We compare the characteristics of currently occupied pika habitats with neighboring potentially unoccupied similar habitats (putative plots) with the help of discrete choice analysis, infer about the relationship of Royle's pika habitat structure and its occupancy in Western Himalaya.

3.2 Methodology

3.2.1 Pika habitat occupancy survey

The habitat of Royle's pika was surveyed at 50m×50 m plots in the study area. Design I as proposed by Manly *et al.* 2002 was selected in which presence and absence resources were sampled at randomly located plots for the entire study area and no individual animals were marked. During the survey for each occupied plot, another putative but unoccupied plot was selected horizontally within a 100m distance in the same aspect either left or right to the presence plot and treated as a pair (N=20 pairs) to evaluate selection during subsequent statistical analysis. The putative unoccupied plot was selected within a 100m radius of occupied plot as rock cover and characteristics, topographical aspect as well as vegetation might differ beyond this range. Within each survey plot 30 minutes were spent to record direct sightings and after that a thorough search was carried out for indirect evidence (pellets) of pika presence (Beever *et al.* 2003, 2010). A putative plot was considered as unoccupied when neither direct nor indirect evidence of pika presence was recorded. Royle's pikas actively use crevices or fissures to make nest like other talus dwelling pikas (Smith *et al.* 1990). Therefore, the amount of rock cover as well as the availability of different size crevices could be considered as a potential important variable and was hence quantified. Each survey plot was divided into one hundred large 5m×5m grids to record data on various habitat related variables (rock cover, crevices size etc.). Each of these 5m×5m grids was divided further into four smaller equal size (2.5m×2.5m) grids to establish the frequency of occurrence of rocks and crevices (Fig. 2.1). Three representative grids shown in Fig. 2.1 were having frequency of rock occurrence (f) equal to, 0 when none of the smaller grids covers any

rock, 4 when all grids cover rocks, 1 when only one grid cover rocks. Rocks were categorized into two major categories, either with crevices present or not. If crevices were present, then rocks were further categorized in two categories, viz., small (≤ 10 -15cm) and medium (≤ 15 cm). Measurement of crevices width was taken at the widest part as well as narrowest part with the help of a measuring tape and mean crevices width was calculated. The ratio of the variance to the mean was used to determine whether the rock distribution pattern at each survey plot was uniform, random or clumped, and is referred to as the index of dispersion (Krebs 1999). As pikas actively used crevices in rocks it can be assumed that pika habitat occupancy could arise from an interactive or additive effects of rock cover and crevices size or index of dispersion. We calculate the uniformity in rocks as total rock cover of a survey plot $\times$ dispersion of rocks. Previous field observations show that pikas use rocks with small crevices more frequently than medium and large ones. Therefore, the availability of the effective rock cover was calculated as the amount of rocks with small crevices in a plot $\times$ dispersion of rocks. The amount of rocks with small crevices / rocks with large or no crevices was also used as index of crevices amount available to make nest. Percent area cover, i.e., how much of the ground area is covered by herbs, scrubs (*Rhododendron anthopogon* and/or *Rhododendron campanulatum*) and trees (*Quercus semecarpifolia*, *Rhododendron arboretum*, *Abies pindrow*, *A. spectabilis* and *Sorbus* sp.) was recorded with the ocular cover estimation method within each large grid (5m $\times$ 5m) and finally, expressed as the average ground cover percentage at each survey plot (Van Hees and Mead 2000).

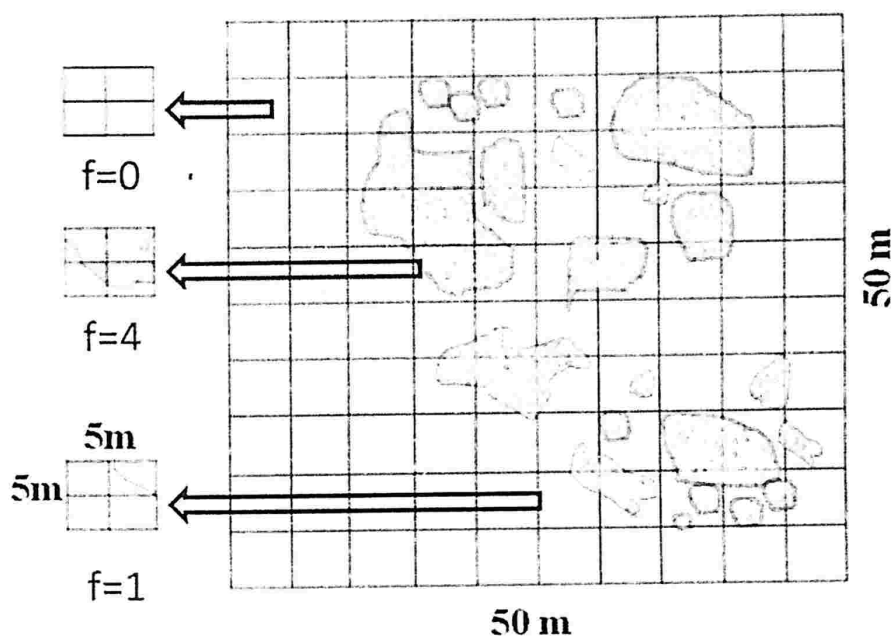


Figure 3.1 Schematic representation of methodology for collecting frequency of occurrence and dispersion of different habitat variables such as rock cover(shaded areas), crevices type data from 100 large grid (5m×5m) and further into 2.5m × 2.5m smaller grids at each survey plot (50m× 50m).

3.2.2 Data analysis

Distribution of variables (e.g. effective rock cover, percent ground cover of different vegetation type) were compared between pika occupied and unoccupied putative plots using box and whisker graphs in SPSS16.0 (SPSS for Windows, Rel. 16.0.0. 2008. Chicago: SPSS Inc). Earlier mentioned ecological hypotheses about the influence of habitat characteristics on Royle's pika occurrence were tested using discrete choice analysis. Some of the explanatory variables were the availability of rock cover, crevices of different width or different types of vegetation cover (herbs, shrubs and trees) and the response variable was pika occupancy. Discrete-choice models are a powerful and flexible method that can be used to understand habitat occupancy in pikas as it allows us to incorporate resource availability to change at every survey plot (Cooper and Millspaugh 1999). Discrete choice models are frequently applied in economics, marketing, and health science and are gradually becoming common in wildlife science to understand resource selection criteria in animals (Manly *et al.* 2002; Train 2003;

MacDonald *et al.* 2006). The basic assumption of discrete choice models in wildlife resource selection studies is that animals make multiple selections from finite sets of discrete habitat units, commonly known as choice sets (MacDonald *et al.* 2006). This choice is assumed to be a function of the attributes of various resource types. Therefore, when an individual animal has a set of resources, it will choose the resource which maximizes its fitness and survival (Cooper and Millspaugh 1999). Though other resource selection analysis methods (like logistic regression) also assume that choice of used and unused units are made from a set of available resources. But the discrete choice models, unlike logistic regression (or other resource selection analysis methods), control the variation between choice sets which can influence the future selection and consider the probability of a unit with certain characteristics being selected during first choice, rather once after multiple choices. The discrete choice model was performed by maximizing the multinomial log likelihood (Manly *et al.* 2002). This was achieved using the stratified Cox proportional hazards likelihood maximization routine available in the Software Package SPSS 16.0 (SPSS for Windows, Rel. 16.0.0. 2008. Chicago: SPSS Inc). Candidate models were formulated based on additive or interactive effects of one or multiple habitat variables mentioned earlier. We used an information theoretic approach of testing a priori models by Akaike's information criterion (AIC) and ranked candidate models using Δ AIC (Burnham and Anderson 2002). Log likelihood, number of modeled parameter (K), Akaike's information criterion (AIC), difference in Akaike's information criterion (Δ AIC) and likelihood test statistics (χ^2 stat) were reported for each model. A Receiver Operating Characteristics (ROC) curve was generated from fitted pika occupancy probabilities versus observed pika occupancy to assess the predictive accuracy of the best-fit model (Baasch *et al.* 2010).

3.3 Results

The lowest distribution limit of Royle's pikas in the study area was a talus habitat in an Oak-*Rhododendron* mixed forest opening at 2650m whereas the highest distribution limit was talus habitat in alpine meadow at 3680m. They were found to inhabit various types of habitats in different altitudes viz., a. habitats with rocky boulder or broken slopes in

Oak-*Rhododendron* mixed forest gaps, **b.** rocky talus habitat in oak-conifer mixed forest edge, **c.** herbaceous meadows with embedded rocks in soil, **d.** rock talus in alpine meadow, **e.** rocky talus in scrub (*Rhododendron anthopogon*) meadow, **f.** rubble walls or human made rocky structures (Fig. 3.2). The highest amount of rock cover (54.5%) was observed in rubble wall habitats followed by rocky talus in herbaceous meadow (46.5%) and oak- conifer mixed forest edge habitats (33.25%, Table 3.1). Major herbaceous species recorded in different pika habitats were *Trachydium roylei*, *Ranunculus hirtellus*, *Carex setigera*, *Oxygraphis polypetala*, *Parnassia nubicola* and *Geum elatum*. Herbaceous cover was highest (64%) in the meadow with embedded rock habitat and lowest (30.5%) in rocky talus in scrub meadow habitat. *Quercus semecarpifolia* and *Rhododendron arboreum* were two major tree species encountered in forest gap with boulder habitats whereas *Abies pindrow*, *A. spectabilis* and *Sorbus sp.* were prominent tree species recorded in oak-conifer forest edge habitats. *Rhododendron campanulatum* forms the major shrub cover in most of the pika habitats and recorded highest in the meadow with embedded rock habitats. *Rhododendron anthopogon*, an alpine scrub species, was recorded only in rocky scrub meadow habitat. *Rhododendron anthopogon* is generally less than 1m tall, forms a very dense ground cover in alpine meadows and leaves very few gaps for grass and other herbaceous communities to grow (Tambe and Rawat 2010). The rubble walls or human made rocky structure habitats were active as well as abandoned human settlements mainly used by seasonal pastoral grazers, rocky walls beside roads. These rocky structures were often found to be covered by mosses and lichens.



Figure 3.2 Different Royle's Pika habitats in Tungnath region of Kedarnath WLS
 (a. Rocky boulder in Oak-*Rhododendron* mixed forest gaps, b. Rocky talus in oak-conifer mixed forest edge, c. herbaceous meadows with embedded rock, d. Rock talus in alpine herbaceous meadow, e. Rocky talus in scrub (*Rhododendron anthopogon*) meadow, f. Rubble walls or human made rocky structures).

Table 1. Number of paired survey plots, AR= Altitudinal range) in study area

Habitat type	Rock (%)	Herb (%)	Shrub (%)	Scrub (%)	Tree (%)
Rocky boulders in oak- <i>Rhododendron</i> mixed forest gaps (N = 3, AR= 2650m - 3000m)	25.5 (25-26.5)	37.66 (35-40)	12.0 (10-15)	0	24.83 (22-27.5)
Rocky talus in oak-conifer mixed forest edge (N=4, AR= 3000m-3200m)	33.25 (25-48)	41.75 (27-50)	11.25 (10-15)	0	13.75 (5-20)
Herbaceous meadows with rocks mostly embedded in soil (N = 2, AR= 3200m-3300m)	16.0 (14- 18)	64.0 (57-71)	20.0 (15 - 25)	0	0
Rock talus in alpine meadow (N = 7, AR= 3300m-3550m)	46.57 (42-50)	48.42 (43 - 56)	5.0 (3 - 15)	0	0
Rocky talus in scrub meadow (N = 2, AR= 3500m-3680m)	20.0 (17 -23)	30.5 (27 - 34)	0	49.5 (49-50)	0
Rubble walls or human made rocky structures (N = 2, AR= 2750m-3500m)	54.5 (54 - 55)	42.0 (44 -40)	3.5 (2- 5)	0	0

The amount of rock cover, rock uniformity, effective rock cover and availability of effective crevices for nests were comparatively higher in the pika occupied plots than unoccupied plots (Fig. 3.3). The amount of various types of vegetation covers like herb, shrub or trees was similar in both occupied and unoccupied plots. The estimated best fit discrete choice model suggested effective rock cover was the most important factor which positively influenced the habitat selection decision in pikas at the scale of investigation (Table 3.2 and Table 3.3). The best fit model also had satisfactory predictive accuracy (area under ROC curve $0.94_{\text{Mean} \pm 0.03_{\text{SE}}}$, $p < 0.001$, Fig. 3.4). The proportion of small and large crevices along with total rock cover as well as dispersion of rocks in a habitat plot were also found to be important factors which had positive influence over pika occupancy (Table 3.3). Results of discrete choice models also show that the amount of rock cover or rock dispersion pattern in a plot alone might not be a determining factor for habitat occupancy. For habitat occupancy, summed Akaike weights ranked the relative importance of habitat variables as: effective rock cover > crevices availability, rock cover and its dispersion > rock uniformity >> vegetation cover (Table 3.2). The amount of various types of vegetation covers had least impact on habitat occupancy criteria at the scale of the investigation.

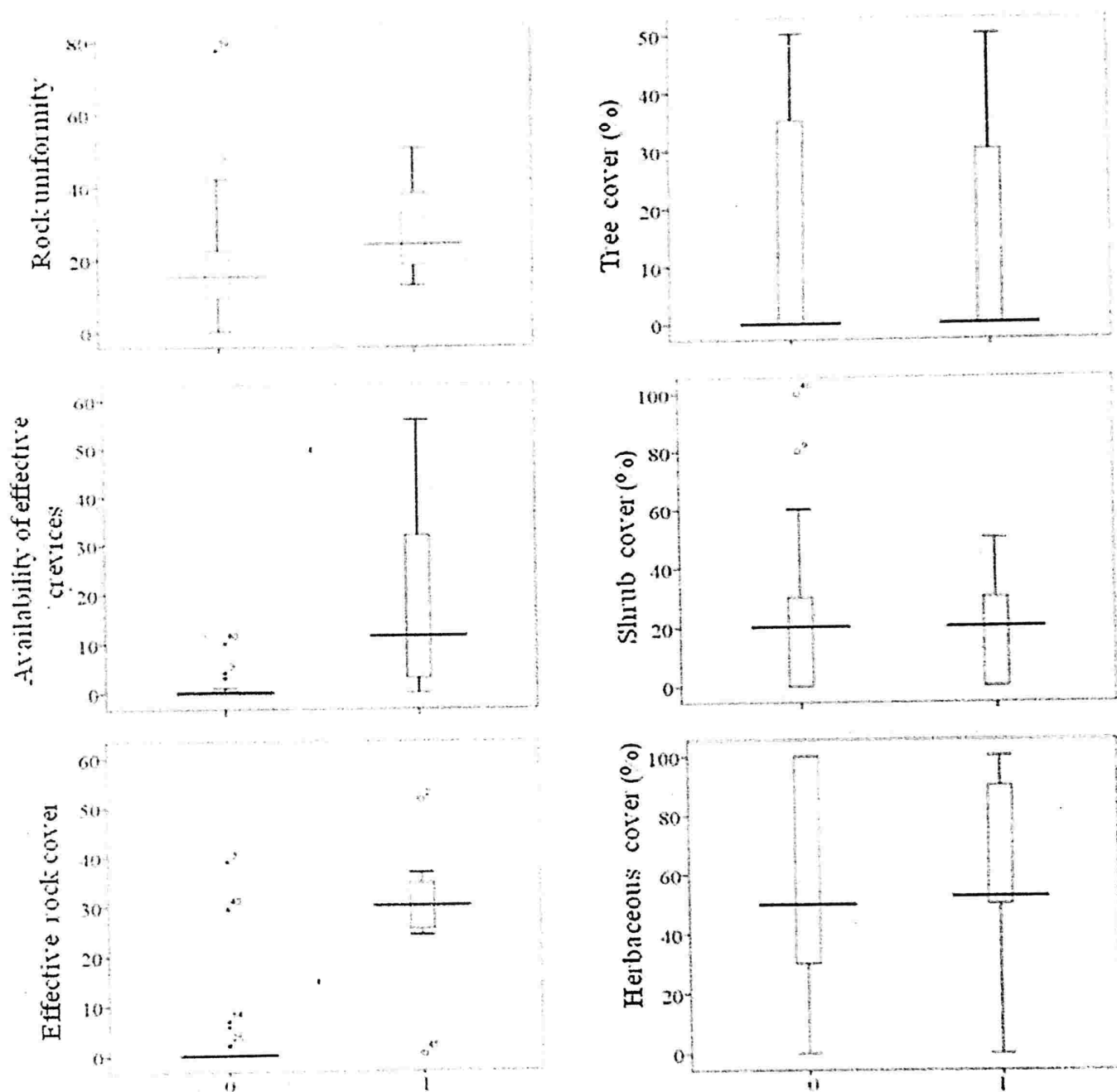


Figure 3.3 Data distribution of different variables (Effective rock cover = small crevices $\times$ dispersion of rock, Rock uniformity = total rock $\times$ dispersion of rock cover, Availability of effective crevices = amount of small crevices/ amount of large crevices, Tree, shrub and scrub cover) in survey plots (0 = pika absence, 1 = pika occupied or presence) in study area.

selection criteria of Royle's pika, using information theoretic criteria (minimum AIC) in study area

Model (Predictors)	-2 ×Log(L)	k	AIC	ΔAIC	χ ² Stat.	p-value
Small crevices× dispersion of rocks	18.30	3.00	24.30	0.00	18.47	0.00
(Small crevices/ Rest)+total Rock cover	18.90	4.00	26.90	2.60	16.97	0.00
(Small crevices /Rest)×total Rock cover	21.42	3.00	27.42	3.13	11.47	0.00
(Small crevices /Rest)×total Rock cover× dispersion of rocks	21.74	3.00	27.74	3.45	19.79	0.00
(Small crevices /Rest)+total Rock cover +dispersion of rocks	18.88	5.00	28.88	4.59	16.97	0.00
Rock cover	26.08	3.00	32.08	7.79	11.49	0.00
Rock cover+ dispersion of rocks	25.94	4.00	33.94	9.65	11.53	0.00
Total rock cover × dispersion of rocks	34.97	3.00	40.97	16.68	5.00	0.02
Shrub cover	39.72	3.00	45.72	21.42	0.49	0.49
Tree cover	39.93	3.00	45.93	21.63	0.30	0.58
Herb cover	40.00	3.00	46.00	21.71	0.23	0.63

Table 3.1 Estimated influence of parameter (Effective rock cover) on Royle's pika habitat selection measured by the best fit discrete choice model (minimum Akaike information criterion)

Parameter	Beta	SE	Wald	P-value	Odd's ratio
Effective Rock cover (Small crevices × dispersion of rocks)	1.70	0.57	8.99	0.003	5.47

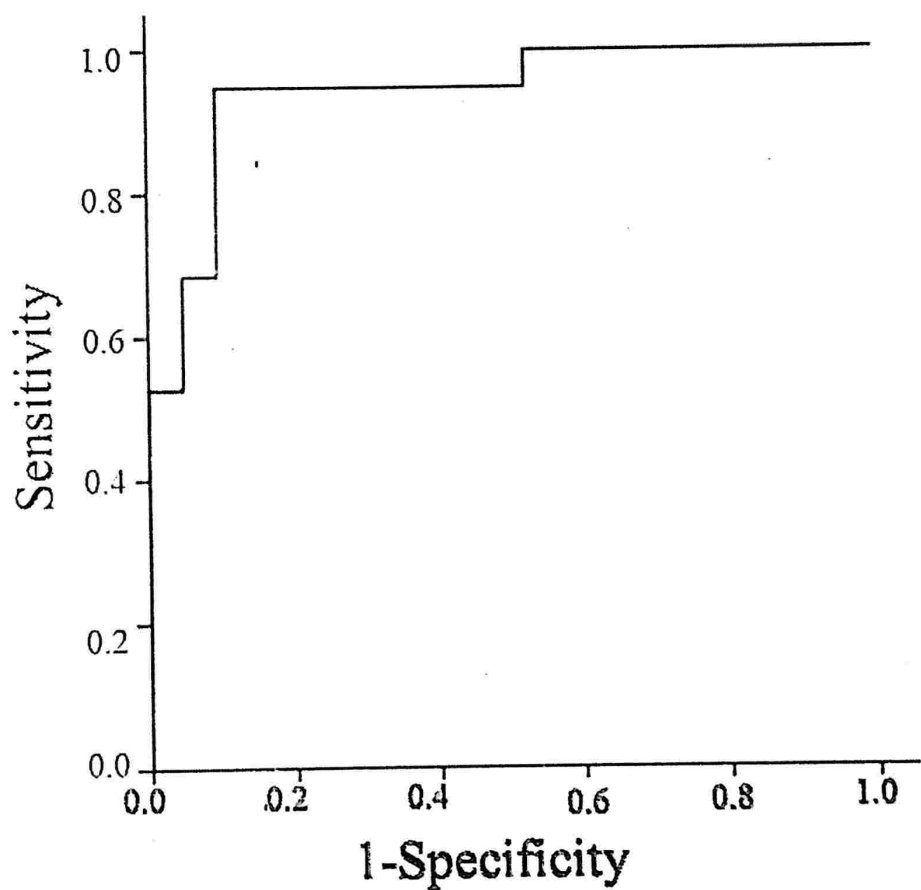


Figure 3. 1 Receiver Operating Characteristics (ROC) curve of best fit discrete choice model.

3.4 Discussion

Availability of a suitable habitat is considered to be one of the most important factor that influences small mammal abundance and distribution within their geographical range (Baker 1968; Vaughan 1972). Some small mammal species are very specific about habitat requirements that limit their distribution where as others can inhabit in a range of habitats (Kaufman and Fleharty 1974; Briese and Smith 1975; Miller and Getz 1976). The result showed that Royle's pika probably belongs to the first group as it cannot make burrow therefore significantly depends on available habitat structures.

Our finding also supports the results of earlier studies on American pika (*Ochotona princeps*) which shows the pika density is high in insular, disperse and smaller rockslides than clumped and larger rock slides (Broadbook 1965). The talus rock size and accessibility to its periphery is also considered as an important factor which limits colony size in American pika (Sheppe 1959; Bunnell *et al.* 1974). Similar trends were observed in Collored pika (*Ochotona collaris*) where its occupancy probability in talus was also found to be significantly governed by connectivity between talus patches and their size (Franken and Hik 2004). The amount of rock cover in habitat also has significant influence over abundance of Royle's pika in western Himalaya (Bhattacharyya *et al.* 2009).

Pikas are central place foragers, they venture out from their nests for foraging and return after each bout (Orians and Pearson 1979; Huntley *et al.* 1986). Apart from the food quality, quantity and travel time, predation risk is one important cost associated with each foraging bout for central place foragers (Jenkins 1980; Krebs 1980; Chase 1998). To cope with conflicting need of efficient foraging and avoid predation, animals select habitats which minimize predation while maximize available forage (Pulliam 1989). Earlier studies in other talus dwelling pikas (Collared pikas) showed that in the absence of effective talus escape cover, they tend to forage within close vicinity of the rock talus even though high nutritive plants were available in the open alpine meadows (Holmes 1991; Morrison *et al.* 2004). Roach *et al.* (2001) reported similar observation in American pikas where they venture out far in to the open meadows for foraging only when the talus is well connected. Tyser (1980) reported that American pika prefer

medium-sized boulders (0.20-0.99 m diameter) for most of its surveillance activity. The results of the current study support our hypothesis which demonstrated that the availability of small crevices and its dispersion pattern is the most important factors which govern the habitat occupancy decision in Royle's pika. Highly dispersed small crevices provide more effective escape cover to Royle's pikas from its predators than clumped and medium or large size crevices. If rocks are highly dispersed and connected then pikas can venture more into surrounding meadows to feed, move quickly within rock talus to take shelter into small crevices if face any threat from predators. Therefore, pika presence was comparatively higher in those habitats which had highly dispersed small crevices than habitat with medium or large crevices.

Earlier research reveals behavioral thermoregulation is an important aspect of talus dwelling American pika physiology, as this species has a high normal body temperature (40°C) and relatively low lethal maximum body temperature (approx. 43°C; Smith and Weston 1990). Temperature restriction influences the species distribution because acute heat stress can occur after exposure to ambient temperatures greater than 25.5°C in summer as well as acute cold stress upon exposure to ambient temperature below 0 to -5°C in winter (Smith 1974; Beever *et al.* 2010). Therefore, change in climatic regime during last ten year in Great Basin eco region observed to increase the rate of American pika population local extinction (fivefold) and upslope retraction (eleven fold) of than previous century (Beever *et al.* 2011). Rocky talus habitat was also found to provide a cool and moist refuge to talus dwelling pikas in summer months and thermal insulation from cold in winter months (Beever *et al.* 2003; Manning and Hager 2011). Therefore, there is a possibility that being talus dwelling, Royle's Pika probably prefer to occupy habitats which could increase their foraging efficiency by providing more effective escape cover, allowing them to access larger area to forage and take shelter during hottest time of the day to avoid heat stress. Royle's pikas are reported to be synanthropic in nature (Kawamichi 1968) and observed to be actively occupying several anthropogenic habitats during this study.. Similar observations about American pikas utilizing various anthropogenic habitats such as mine tailings and man-made rock structures such as quarries, road fill, railroad riprap and lumber piles (Smith 1974; Lutton 1975; Millar and Westfall 2010; Manning and Hager 2011) were also reported. Earlier research indicates

various types of disturbances (realignment of stream channel, clear cutting, fire, and mining) can alter small mammal population and community composition (Possardt and Dodge 1978; Martell and Radvanyi 1977; Fala 1975; DeCapita and Bookhout 1975). Though there were no direct anthropogenic threats exists for the pikas in the study area. But on several occasions during this study as well as in earlier studies (Bhattacharyya *et al.* 2009), it has been observed that some of the pika habitat sites were severally destroyed to extracts rocks for various developmental activities (making road or house, Fig. 3.5). The rock structures in those habitats were completely altered and most of the area was left with completely embedded rocks in soil without any crevices in them. None of those altered habitat were observed to be recolonized by pikas since the last three year. The entire affected area become devoid of Royle's pika population. As our results suggested that the Royle's pika will show more affinity to a habitat with small crevices than large one. Hence, probability of a successful re colonization event will be possibly



Figure 3.5 Extraction of rock from Royle's pika habitat to perform different developmental activities in Tungnath region of Kedarnath WLS

governed by habitat rock structures. Royle's pika do not make haypile like other pika species and feed extensively on lichens and moss available on crevices during winter. Therefore, alternation of habitat rock structures may not only increase predation risk but can also lead to significant decline in winter food since moss and lichens takes years to cover rocks. Hence, unplanned rock extraction for developmental activities might lead to decrease in habitat availability and reduce the fitness of the Royle's pika population.

4.1 Introduction

One central theme in ecology is the patterns and processes of species distribution at spatio-temporal scales. Of late, species distribution models have become increasingly popular not only for predicting occurrence of the species but also to explain trends in ecology, biogeography, evolution, conservation biology and more recently, in climate change research (Elith *et al.* 2006). The species distribution models, if prepared based on empirical data; provide important information about relationship of species occurrence ecology, and biophysical conditions through statistical and theoretical response framework (Guisan and Zimmermann 2000).

The contemporary climate change predictions have led to increasing concern about the persistence of the species which live around mountain top environments (Pounds *et al.* 1999; Walther *et al.* 2005; Sekercioglu *et al.* 2008). Mountain environments also show significant variation in climate (both seasonal and diurnal) which includes pronounced fluctuation in orographic precipitation, snowfall, UV radiation, wind speed, ambient temperature and atmospheric pressure. Therefore, mountain-dwelling species also exhibit high phenological, reproductive and behavioural plasticity (Inouye *et al.* 2000). However, the species which are obligate to mountain top environments may not be able to adapt to rapid changes in climate (Inouye *et al.* 2000; Walther *et al.* 2002; Menendez *et al.* 2006). Thus, Species distribution models can be used as excellent tools to understand how different environmental parameters shape the distribution of species.

Recent studies have revealed that alpine small mammals have contracted their distribution range while low elevation species have extended their ranges upwards (Moritz *et al.* 2008). Beever (2003) reported that rapid change in climate during later part of 20th century has resulted in local extinction of American pika (*O. princeps*), a high altitude obligate lagomorph. s. Earlier paleontological research illustrated that American pika experienced expansion and contraction in response to climatic fluctuation across

geologic time (Hafner 1983). They were also found to be highly vulnerable to acute-heat stress, when they could not perform behavioural thermoregulation efficiently (Smith 1974). Increase in temperature (up to 6°C) by mid-21st century might result in range constrictions (extirpation in lower altitude) led by various mechanisms (Ray *et al.* 2010; Beever *et al.* 2010).

Though, Himalaya is the home for seven different pika species, limited ecological information is available on them (Smith 1990). Himalaya is also affected by climate change (Singh and Bengtsson 2004), but due to lack of scientific knowledge, it is often difficult to understand how small mammals such as pikas who play important ecological role in the region, will respond to changing climate. Hence, in this study Royle's pika (*Ochotona roylei*), a rock talus dwelling lagomorphs (100-150g; Alfred *et al.* 2006) was selected to understand how various climatic and habitat characteristics influence its geographical distribution in western Himalaya.

Royle's pikas are distributed from North-West Pakistan to India, Nepal and adjacent Tibet (China; Chakraborty *et al.* 2005). It is reported to be an important prey base for several carnivore species (such as marten, stoat, weasel, snow leopard, and red fox) in alpine and subalpine ecosystems (Roberts 1977; Oli *et al.* 1994; Aryal *et al.* 2010). Pikas are considered to be ideal small mammals for field observation as they are diurnal, highly detectable and leave unmistakable indirect evidence i.e., piles of typical small round droppings (Beever *et al.* 2010). The objectives of the study were to: (i) predict suitable distribution range for Royle's pika in western Himalaya using occurrence records collected through landscape level survey, and (ii) identify the environmental factors associated with Roylei's pika distribution. The species occurrence records along with geographical information system (GIS) environmental layers (bioclimatic and topographic), and the maximum entropy distribution modeling approach (Phillips *et al.* 2006) was used to predict potential suitable distribution range in Western Himalaya.

4.2 Methodology

4.2.1 Pika presence data

The current occupancy (presence) data (N=56) of Royle's pika were collected through survey from various locations in Kedarnath Wildlife Sanctuary (Tungnath, Rudranath, Madmaheswar), Valley of flowers National Park; Nanada Devi Biosphere Reserve (Lata Kharak, Bedni-Ali, Malari) in Chamoli district, Gangotri National park (Chirbasa) in Uttarkashi district. Two locations (Dharansi Pass, Ramni) within Nanda Devi National Park were collected from literature (Uniyal 2002). Altogether 27 locations were used as input for distribution modeling. During a survey the presence data of Royle's pika was collected from direct (sighting) or indirect evidence (pellets) and geographical co-ordinates of each presence location were collected using a Garmin-72 GPS.

4.2.2 Selection of environmental layers

A rectangular boundary was drawn which covers the total sampling area (Uttarkashi, Chamoli in Uttarakhand). This rectangular boundary was further modeled as a raster map based on Universal Transverse Mercator (UTM WGS 84 Zone 30N) coordinate system. Geo-referenced satellite images (Landsat ETM) were collected from Global Land Cover Facility (GLCF) website and processed ERDAS Imagine 9.3 and finally the study area was exclusively extracted from the entire large landscape map. Normalized Difference Vegetation Index (NDVI) for peak alpine vegetation growth period (May to August) was created by ERDAS Imagine 9.3 software from these images. Various topographical variables such as elevation, slope, aspect and ruggedness were prepared from Digital elevation model using SRTM data of that region. The high resolution (1km) BioClim environmental dataset (Hijmans *et al.* 2005; available at <http://www.worldclim.org>) were used to create environmental layers or variables. In general these datasets provide a high resolution monthly maximum, minimum, and mean temperatures, and monthly precipitation data for current and future scenarios. Based on these data a set of 19 bioclimatic variables can be generated (Busby 1991). For the present study a set of 12 bioclimatic variables was based on earlier pika research information (Table 4.1).

Table 4. 1 Selection of bioclimatic and topographic variables based on literature available on pika ecology and distribution

Variables	Description	Source	Resolution	Reference
Bioclimatic				
BIO1	Annual mean temperature	BioClim	1km	Calkin <i>et al.</i> 2012; Loire <i>et al.</i> <i>in press</i> ; Ray <i>et al.</i> 2010
BIO2	Mean diurnal range (max temp - min temp)	BioClim	1km	Calkin <i>et al.</i> 2012
BIO5	Max temperature of warmest month	BioClim	1km	Beever <i>et al.</i> 2010; Calkin <i>et al.</i> 2012; Wilkening <i>et al.</i> 2010
BIO6	Min temperature of coldest month	BioClim	1km	Beever <i>et al.</i> 2010; Wilkening <i>et al.</i> 2010; Loire <i>et al.</i> <i>in press</i>
BIO8	Mean temperature of wettest quarter.	BioClim	1km	Calkin <i>et al.</i> 2012
BIO10	Mean temperature of warmest quarter	BioClim	1km	Beever <i>et al.</i> 2010; Calkin <i>et al.</i> 2012; Wilkening <i>et al.</i> 2010
BIO11	Mean temperature of coldest quarter	BioClim	1km	Loire <i>et al.</i> <i>in press</i>
BIO12	Annual precipitation	BioClim	1km	Erb <i>et al.</i> 2011; Calkin <i>et al.</i> 2012; Loire <i>et al.</i> <i>in press</i>
BIO18	Precipitation of warmest quarter	BioClim	1km	Calkin <i>et al.</i> 2012
BIO19	Precipitation of coldest quarter	BioClim	1km	Loire <i>et al.</i> <i>in press</i>
Topographic				
DEM	Elevation, Slope, Ruggedness	SRTM	30m	Rodhouse <i>et al.</i> 2010
NDVI	Vegetation	MODIS	1km	Wilkening <i>et al.</i> 2010; Rodhouse <i>et al.</i> 2010

4.2.2 Modeling process

Habitat suitability and distribution of a species can be calculated as measure of similarity to the presence location of the species by using environmental variables. Though there are different modelling algorithms available to understand how species distribution might be influenced by different bio-climatic variables, the maximum entropy algorithms (Maxent, Phillips *et al.* 2006; <http://www.cs.princeton.edu/~schapire/maxent/>) are widely used for developing ecological niche models due to its high accuracy (Elith and Leathwick 2009; Rota *et al.* 2011). In general, one can define “Maxent” as software and statistical method which can be used to develop species distribution models (SDMs) when presence-only species occurrence data are available (Phillips *et al.* 2006). It estimates the species distribution by species presence specific environmental covariate density. Finally, it provides logistic output that estimates species occurrence probability at each site (Phillips and Dudik 2008). Maxent version 3.3.3.e was used to run the model (Linear, Quadratic, Hinge, and Threshold) with product features for convergence threshold, maximum iterations (5) and background points (10,000). Jackknife variable importance features was used to assess the relative importance of environmental predictors. This generates an estimate of probability of presence of the species which varies from 0 to 1 (lowest to Highest).

4.3 Results

Royle's pikas were distributed between 2650m to 4554m in the study area. In Kedarnath Wildlife Sanctuary, they were found to inhabit six different habitat types viz., a. habitats with rocky boulder or broken slopes in oak-rhododendron mixed forest gaps, b. rocky talus habitat in oak-conifer mixed forest edge, c. herbaceous meadows with embedded rocks in soil, d. rock talus in alpine meadow, e. rocky talus in scrub (*Rhododendron anthopogon*) covered meadow in alpine, f. rubble walls or human made rocky structures from 2650m (Kachula-kharak) to 3752m (Rudranath). In Valley of Flowers National park, Royle's pika inhabit open rocky talus habitat close to water stream. In Nanda Devi

Biosphere reserve, they occupy rocky boulder in oak-rhododendron mixed forest gaps, rubble walls or human made rocky structures and open talus in alpine along 2850m to 4554m altitudinal gradient. Pika habitats in Gangotri National park were both rubble walls (3300m) and rock talus in conifer forest gap (3345m).

The pika distribution model produced through maxent gave an estimate between 0 (very low) and 1 (very high) of probability of presence (Fig. 4.1) in the study area. Majority of high probability of pika occurrence locations were found to be in glaciated valleys with ridge slope which receives high precipitation during monsoon (Kedarnath Wildlife Sanctuary, Valley of Flowers National park and Nanda Devi Biosphere Reserve) whereas dry alpine areas (Gangotri National Park) found to have medium to low Royle's pika presence probability .

Mean Temperature of warmest quarter, elevation and precipitation of warmest quarter were found to be the important contributors which govern Royle's pika distribution in western Himalaya (Table 4.2). Other important factors were Normalized Difference Vegetation Index (NDVI) of monsoon (July and August) and the amount of precipitation in coldest quarter. The probability of pika presence found to be decrease with high mean temperature of warmest quarter and very high NDVI value (Fig 4.2). Pika presence probability was increased with elevation but precision of parameter estimates were very low in higher elevation (>6000m). Most suitable elevation was observed between 3500m to 4000m (Fig 4.2). The probability of pika presence also increased with high precipitation during coldest quarter. The area under the receiver operating curve (AUC) was 0.91 with standard deviation 0.02 which suggested that maxent models produced reasonable results.

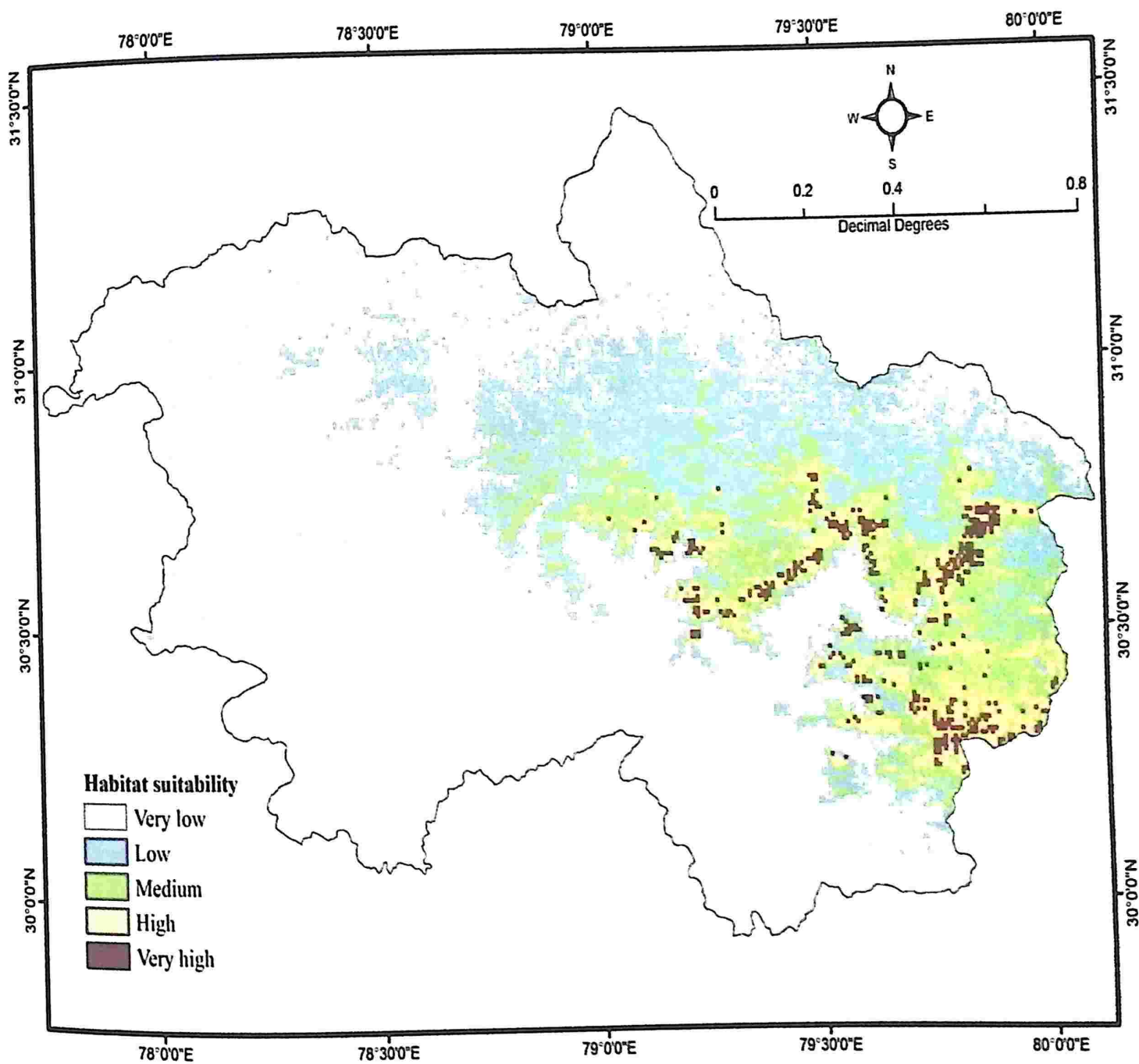


Figure 4.1 Potential distribution map of Royle's pika in study area.

Table 4.2 Major contributor environmental factors for predicted distribution

Variable	Percent contribution
Mean Temperature of Warmest Quarter	19.2
Elevation	17.6
Precipitation of Warmest Quarter	16.2
NDVI for month of August	9.4
NDVI for month of July	8.2
Precipitation of Coldest Quarter	6
Mean Diurnal Range	5.7
Slope	3.9
Ruggedness	3.3
Min Temperature of Coldest Month	2.9
Max Temperature of Warmest Month	2.2
NDVI for month of May	2.2
Mean Temperature of Wettest Quarter	1.9
Aspect	0.9
Annual Precipitation	0.4

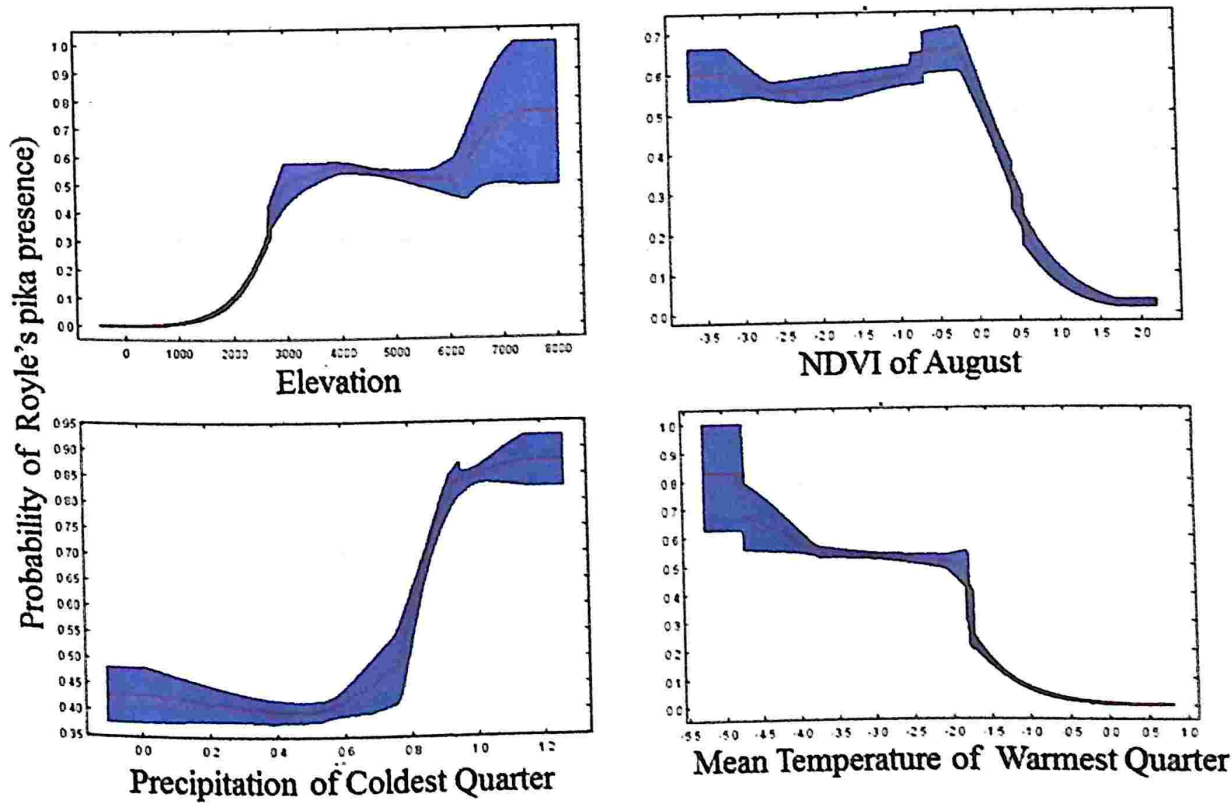


Figure 4.2 Response curve of Royle's pika presence probability and various climatic and habitat parameters.

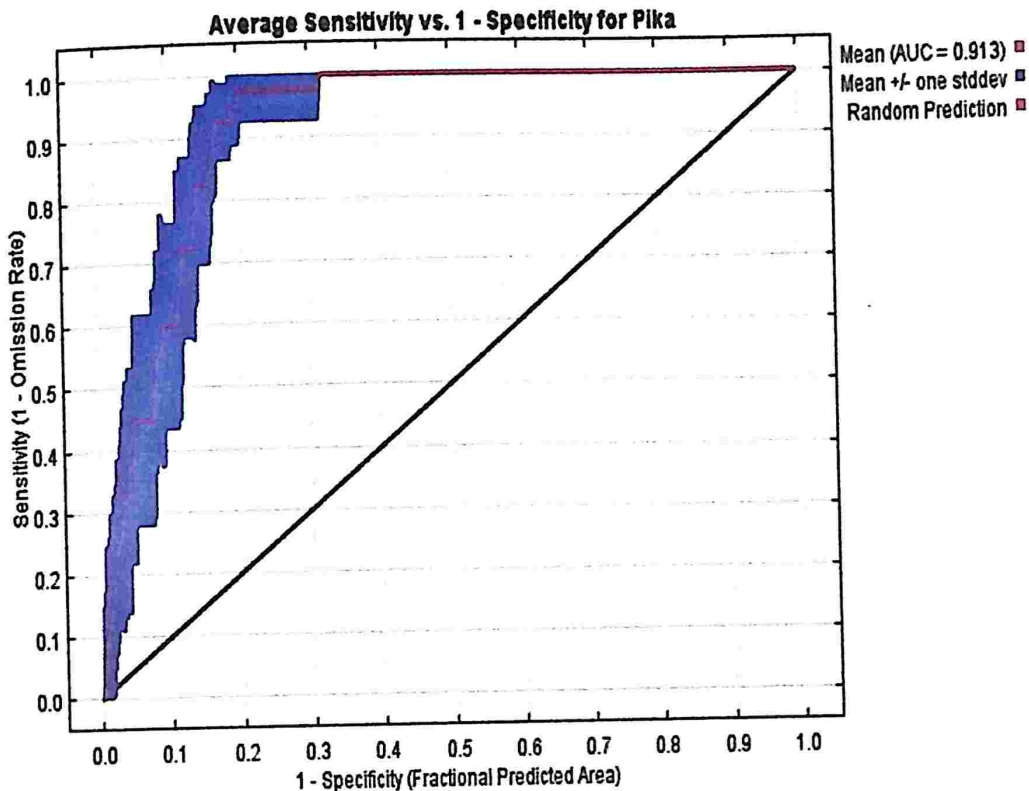


Figure 4.3 Receiver operating characteristic (ROC) curve for Royle's pika distribution predicting model

4.4 Discussion

Montane species distribution has been known to be significantly governed by climate (Grinnell 1917) especially by precipitation, temperature as well as other topographical factor such as latitude, elevation (Koerner 2007). This study also indicated that temperature (summer), precipitation (monsoon and winter), elevation and openness in habitat (low NDVI) as principal factor which governs the distribution of Royle's pika in study area. Often distribution limits of a species found to be determined by various physiological constrains (Gaston and Spicer 1998; Chown and Gaston 2000). Thermoregulatory mechanisms in pikas generally said to be more behavioural rather than physiological (Smith 1974). Pikas restrict their diurnal activity more in high temperature. Thick fur layer as well as micro-organism's activity (bacteria) in gut which aid in digestion results comparatively high ($2-3^{\circ}\text{C}$) body temperature than other rock talus dwelling small mammals (MacArthur and Wang 1973). Other pika species (*O. princeps*) with similar ecological requirements of Royle's pika showed high tendency of hyperthermia which even leads to death at brief direct exposure to medium ambient

temperatures (25.5-29.4°C) and intense solar radiation (MacArthur and Wang 1973, 1974; Smith 1974). High core body temperature (40.1°C) as well as a low upper lethal temperature (43.1°C) in pikas reflects their poor capability to prevent heat stress (MacArthur and Wang 1973). Therefore, all pika population is sensitive to high temperature. Because of this high sensitivity researchers consider temperature as primary factors which governs the geographical distribution of various pika species (Grinnell 1917; Smith 1974; Hafner 1993; Beever *et al.* 2003; Grayson 2005) Temperature is also found to be one of primary environmental factors which govern juvenile pika dispersal (Smith 1974). American pika (*O. princeps*) becomes inactive during early day time at lower altitude and remains active throughout the day at higher altitude (Hall 1946; Smith 1974). In winter large eared pika (*O. macrotis*) remains active all day as it inhabits comparatively higher altitude than Royle's pika (*O. roylei*) which remain active only during dawn and dusk (Kawamichi 1971). The microclimate of talus habitat acts as thermal refuge for pika which helps them in behavioral thermoregulation (Rodhouse *et al.* 2010). Various micro topographical features such as rock-ice features or cool crevices even help them to persists beyond the limits of their bioclimatic envelope (Millar and Westfall 2010; Simpson 2009).

The climate was considered to be the primary force which results local extirpation of American pika (*Ochotona princeps*) in Great basin (Beever *et al.* 2003, 2011; Calkin *et al.* 2012). The microclimates of pika extirpated locations were comparatively hotter during summer and very cold during winter than locations which contain persisting pika population (Beever *et al.* 2010). Calkin *et al.* 2012 found that the future distribution predicting models for American pika under various degree of temperature increase showed significant distribution shrinkage. The current distribution of various traditional sub species of American pika (*O. p. clamosa*, *O. p. utahensis*, *O. p. nigrescens* and *O. p. schisticeps*) found to be collapse 100% even prior to a 5°C increase (Calkin *et al.* 2012). As Royle's pika is also a talus dwelling species, thus it can possible that they will also be very sensitive towards the high temperature. Thus, the temperature during the warmest quarter (summer and monsoon) found to be major factor which shapes Royle's pika distribution in the study area.

Winter precipitation i.e., snow acts as insulation for both pikas and their food plants. Pika remain active throughout the winter, therefore thick snow cover works as a protective layer allowing pikas to survive high diurnal temperature fluctuation during winter and early spring (Morrison and Hik 2007). Thus, winter precipitation in the form of snow reduces energy expenditure for thermoregulation (Smith *et al.* 2004; Morrison and Hik 2007). The snow melting pattern also found to have significant influence on American pika (*O. p. princeps*) population demography (Kreuzer and Huntly 2003). Beever 2010 found that acute cold stress due to short duration of snow cover or a thin snowpack results pika extirpation in the Great Basin. Snow-cover period and depth are critical to maintain soil-nutrient quality, and thus have a profound effect on alpine food plant growth (Walker *et al.* 1993, 1995; Brooks and Williams 1999). Thick snow cover results slow snowmelt, which delays the beginning of the growing season, and reduces frost mortality in herbaceous plants buds (Inouye 2008). Thus, high winter precipitation also helps pikas food plants to survive in extreme low and fluctuating temperatures during winter and finally maintain availability of food plants for pikas (Marchand 1996).

The amount of precipitation is generally high in mountains, thus most of the alpine plant community generally prefer moist environment (Billings and Mooney 1968). Majority of pika food plants follow C₃ photosynthetic pathway thus has high nitrogen and more dependence on water than C₄ plants (Billings and Mooney 1968; Ge *et al.* 2012). Therefore, water availability greatly affects the photosynthesis and thus also productivity. A recent study by Ge *et al.* 2012 also revealed that expansion of C₄ plants might have cause significant range constriction and extinction during late Miocene. Unlike other talus dwelling pikas, Royle's pika does not make hay-piles for winter food (Kawamichi 1968). Therefore, availability of food plants during growing period plays crucial role in Royle's pikas by fulfilling its nutritional demands for successful survival and reproduction. Hence, precipitation either during growing period or during winter plays a significant role in distribution of alpine generalist herbivores such as Royle's pika. The Royle's pika distribution map generated during this current study also indicated similar trends as all the highly potential habitats were located in those areas in Kedarnath wildlife sanctuary or Nanda Devi Biosphere Reserve which receive comparatively more rains

during growing periods than those areas in north and northwest which are in rain shadow areas. Royle's pika generally prefer open habitats (Smith *et al.* 1990), thus probability of its distribution decreases with increase amount of canopy cover. The elevation generally determines the climatic regime as well as alpine plant community structure. Therefore, Royle's pika distribution found to be significantly governed by elevation.

Hafner (1993) showed that climatic fluctuation influenced the range expansion and contraction in American pika across geological time scale. Though, the pika distribution was found to be significantly governed by its bioclimatic niche. Recently some low elevation pika populations were also reported which still persists beyond the limits of earlier mentioned bioclimatic niche (Simpson 2009; Rodhouse *et al.* 2010). Royle's pika is distributed across the entire Hindukush-Himalayan arc. Thus, this current study just identified some potential climatic and habitat variables which can significantly govern Royle's pika distribution at a landscape in western Himalaya only. Hence, to get more accurate information about how various factors actually influence this species distribution, more data on its presence as well as habitat should be collected from its entire geographic range.

Influence of snow and habitat characteristics on Royle's pika abundance

5.1 Introduction

Environmental variability can influence the evolution and life history of a species (Boyce 1988). Short-term variability in the environment can affect a species directly by changing both its annual population size and its evolution of life history (Yoccoz and Rolf 1999). A few empirical studies have addressed the effects of environmental variability and its impact on species abundance, but these were mostly in plants (Benton and Grant 1996; Gaillard *et al.* 1997). All cold regions experience marked seasonality, which include a short growing period for vegetation during summer, a prolonged winter and considerable snow cover. In contrast to high latitudes, climate at high altitude mountains shows remarkable diurnal and seasonal variability (Barry 1992). Species adapted to cold climate are sensitive to changes in ambient temperature and precipitation (Grinnell 1917; Heatwole and Taylor 1987; Körner 2007). This may explain why several animal species in the alpine and arctic environment experienced range expansion and high gene flow during the last glacial period (Hewitt 2000). Current global climate change might prove to be greater threat to such species than those faced in past periods of climate cooling (Sala *et al.* 2000; Holt 2003; Wiens and Graham 2005). The velocity of climate change is higher in alpine regions than in regions of lower altitude (Naftz *et al.* 2002); thus, species adapted to cold climates are more vulnerable to global warming (Hughes 2000; Moritz *et al.* 2008). Significant change in climatic conditions may therefore induce extirpation in species with low adaptive capability and a fixed bioclimatic niche across the distribution range (Beever 2010).

Pikas (*Ochotona* spp.) are alpine small mammals (121-176g; Smith and Weston 1990). In the western United States, the distribution of these herbivorous lagomorphs has moved 153 m upslope (~17 m/decade) during the course of several decades (~90 years, Moritz *et al.* 2008). Recent studies (Beever *et al.* 2003, 2010; Calkin 2012) have indicated that, in the United States, the distribution and abundance of pikas is significantly governed by climatic drivers.

Pikas and voles strongly influence the composition of the local plant community through their ecological engineering activity, leading to increased diversity of plant species (Bagchi *et al.* 2006). Pikaš may also be an important prey base for several endangered lesser carnivores (Roberts 1977; Oli *et al.* 1994; Aryal *et al.* 2010), and their positive impacts on soil nutrients and moisture gradient influence habitat quality for several avian and mammalian species (Smith *et al.* 1999). Hence, pika extinction due to climate change could have a significant negative impact on the functioning of alpine ecosystems.

Himalaya is home to seven different pika species (Smith *et al.* 1990), but there have been only few scientific studies on pikas. One of the most widely distributed but least studied alpine lagomorphs in the Himalaya is Royle's pika (*Ochotona roylei*), which belongs to the talus dwelling pikas (100-150g; Alfred *et al.* 2006). Royle's pika is distributed from north-west Pakistan to India, Nepal and the adjacent region of the Tibetan Plateau in China (Hoffmann and Smith 2005), occupying open rocky slopes between 2400m and 5000m above sea level (asl) (Chakraborty *et al.* 2005). Previous studies of Royle's pika dealt mainly with behavioural aspects (Kawamichi 1968, 1970). Bhattacharyya *et al.* (2009) suggested that the seasonal variation in relative abundance of Royle's pika is mainly influenced by rock cover. The species is diurnal, clearly visible and relatively easy to observe. Hence, they are ideal small mammals for field observation (Beever *et al.* 2010).

The objective of present study was to collect baseline ecological information, to understand which factors influence the relative abundance of Royle's pika. Using pika population monitoring studies at permanently marked plots and a set of regression models based on a priori ecological knowledge, competing models which incorporate various logical combinations of snow attributes (snow cover period, snow depth), habitat characteristics (rock cover, food availability) were selected. Winter precipitation and habitat structure are important parameters governing the abundance of similar pika species (Franken and Hik 2004; Morrison and Hik 2007). Therefore, it can be hypothesized that abundance of Royle's pika will be governed by snow attributes (e.g. snow cover period and depth of snow pack during winter and spring), and habitat characteristics (e.g. food availability or amount of rock cover). An information theoretic

framework was used to construct and evaluate competing regression models to test this hypothesis.

5.2 Methodology

5.2.1 Estimation of pika abundance

Ten permanently marked plots (50m×50m) were used to record the abundance of Royle's pika in various habitat types along a 750 m altitude gradient, starting at 2900m. All sites were further categorized into two altitudinal zones: an alpine zone (3400–3650 m, N = 5) and a timberline to subalpine zone (2900–3300 m, N = 5). Each plot was surveyed for pikas once a month during the pre-dispersal period (May–August), from 2008 to 2011 (except for July–August in 2010 and May in 2011), yielding a total of 390 sampling occasions. At each sampling occasion for a plot, there were three sampling sessions of four hours each (morning: 6–10 am; day: 10 am–2 pm; evening: 2–6 pm). Royle's pikas were also categorized into three distinct groups: juvenile, sub-adult and adult. Individual animals were identified based on morphological features (body size, coat colour, location and pattern of molting marks, and scar marks on ears). Since pika abundance was studied during the pre-dispersal months only, pikas were categorized in two groups: juvenile (the new born litter) and adults (adults and sub-adults). The pika abundance index was calculated by taking the average individual count of three observation sessions in a day, and then pooled to obtain monthly and annual estimates (Bhattacharyya *et al.* 2009). The detection probability of pikas in study sites is influenced only by the richness of herbaceous species (Bhattacharyya *et al.* 2009). Therefore, other habitat variables (e.g. food availability, rock cover or altitude zone) were used as predictors of pika abundance in a linear regression model, as discussed below.

The location and altitude of the plots was recorded through a global positioning system (GPS, Garmin 72), and the percentage of rock cover was estimated visually. Pika food plants were identified by direct focal sampling (Altmann 1974). Royle's pika reported to forage on 26 different plant species in the study area (Bhattacharyya *et al.* 2009). Therefore, a standard quadrat method (Rawat and Adhikari 2005) was followed to

estimate the density of food plant species. Ten, 1m x1 m quadrats were laid randomly within each permanent plot at monthly intervals. The availability of food plants (individuals per sq.m) in a study plot was calculated after pooling the abundance of all food plants for that site. Snow depth was recorded at ten fixed points in each study plot over four years (2007–2011) on a monthly basis during winter and spring, with the results pooled to obtain annual average snow depth, and average spring snow depth. The snow cover period was estimated as the number of days, in which at least five of ten snow-depth measuring points in a study plot were covered by snow. The day of first sighting of a juvenile at a permanent site was used as the index of juvenile pika emergence time.

5.2.2 Data analysis

All data were tested for normality through the Kolmogorov-Smirnov test, and square root transformation was applied to achieve normality (Zar 1999). Adult population data were log-transformed before regression analyses, to reduce skewness. Data were also tested through Pearson's correlation test; predictor variables with a Pearson's $r > 0.4$ are considered to be highly correlated. Therefore, those correlated variables appear as separate models or as an interaction affects in linear regression models.

Linear mixed models (LMM) were used with year as predictors to test whether abundance of pikas (adult and juvenile), snow-cover period, annual snow depth, spring snow depth and food availability varied significantly in 2009, 2010 and 2011 compared with 2008, using different sites as random effect. Logistic regression was used to model pika abundance as a function of various predictor variables. Based on the research literature on pikas, a set of predictor variables was selected (Table 5.1).

Table 5.1 Potential predictor variables for modeling pika abundance during the years 2008 to 2011 among various sites (N = 10) in the western Himalaya. Each variable was selected based on a priori ecological information available on pika from the sources presented here

Predictor variables	Rationale	Source
Snow cover duration	Increase snow duration, depth in winter and spring will reduce cold stress in pikas and its food plants and increase winter survival	1,2,3
Snow depth in Winter		1,3
Snow depth in spring		2,3
Rock cover	High rock cover reduce predation risk	4,5, 6,7
Food availability	High food availability will positively influence the fecundity of pika population	7

Source reference: 1. Kreuzer and Huntly 2003, 2. Franken and Hik 2004, 3.Morrison and Hik 2007, 4.Bunnell and Johnson 1974, 5. Smith 1974, 6. Roach *et al.* 2001, 7. Bhattacharyya *et al.* 2009.

Although pika observations were separated by different sites for independence of observations, the nesting of pika observation within sites might lead to a different kind of dependence, which would violate assumptions related to independence of regression technique (Zar 1999). To rule out this problem, we used generalized linear mixed effect models, with different sites as random intercept. This method helps to identify the natural grouping of observations and would also explicitly account for random variations in the odds of activity between sites that might arise from within the site, if other factors remain constant (Zuur *et al.* 2009). Following Zuur *et al.* (2009), candidate models were designed by Laplace approximation and maximum likelihood parameter estimation using the “lmer” function of the lme4 package in program R. Each candidate model was formulated based on one or more predictor variables. The relative support for each model, as well as each predictor, was compared in an information-theoretic framework using Akaike Information Criteria (AIC, adjusted for small sample size-AICc, Burnham and Anderson 2002). The best fit model was selected (lowest AICc), and final parameter estimates were obtained by the restricted maximum likelihood method. All analysis and plots were executed through R 3.2 (the R Foundation for Statistical Computing, <http://www.rproject.org/>).

Initially, linear mixed effects models were used, in which the abundance of both adult and juvenile pika was used as a function of the predictor variables mentioned in Table 5.1, using different sites as random effect. Simple linear regression was followed to test various candidate models. It was expected that the pika abundance would have a positive influence if snow cover period and annual mean snow depth increased and a negative influence if spring snow depth, food availability and rock cover decreased during the study period. To address these hypotheses, a set of logistic-regression models were constructed, each based on the predictors mentioned above. Additive effects as well as interactive effects of one, two or three predictor variables on pika abundance were also estimated. For example, it was predicted adult pika abundance would be influenced by snow cover period or average snow depth, and interactive effects of snow cover period or annual mean snow depth and altitude zone. In contrast, juvenile pika abundance would be influenced by additive effects of spring snow depth and food availability or rock cover, and food availability or rock cover or spring snow depth. In total, five models for adult and six for juvenile pikas were compared to support various hypotheses including a null (intercept-only) model for each adult and juvenile abundance analysis. The best candidate model was selected with the lowest AIC. Multi model averaging was performed, if two or more models $\Delta AIC < 2$. To identify the factors that govern the emergence of juvenile pika at each permanent site, the emergence was modeled with logical alternate combinations of snow cover period, spring snow depth, food availability of the month when emergence were recorded and altitude zone, following the statistical modelling protocol described above.

5.3 Results

In the alpine zone, five distinct habitats were identified (rocky alpine meadow, alpine scrub meadow, rubble wall, broken slope and *Danthonia* grassland) as well as a timberline–subalpine zone (mixed herbaceous meadow, rocky slope, rocky forest edge, broken slope in subalpine and forest gap with boulder). The rock cover was highest (72%) in broken slope in the subalpine habitat, and lowest (10%) in mixed herbaceous meadow. The highest adult pika abundance (4.43 ± 0.60) was recorded during 2008 at rubble wall in the alpine zone, followed by broken slope (3.78 ± 0.34) in the timberline–

subalpine zone. The lowest adult abundance (1.22 ± 0.21) was observed at forest gap with boulders in the timberline–subalpine zone during 2009. Royle’s pika found to give birth only one litter per annually. In juvenile pikas, the highest abundance was recorded in broken slope (3.11 ± 0.15) during 2009 and in rocky slope (2.33 ± 0.19) during 2011 in the timberline–subalpine zone (Fig.5.1). Overall, both adult and juvenile abundance was y higher in alpine zone habitats than in timberline–subalpine zone habitats throughout the study period.

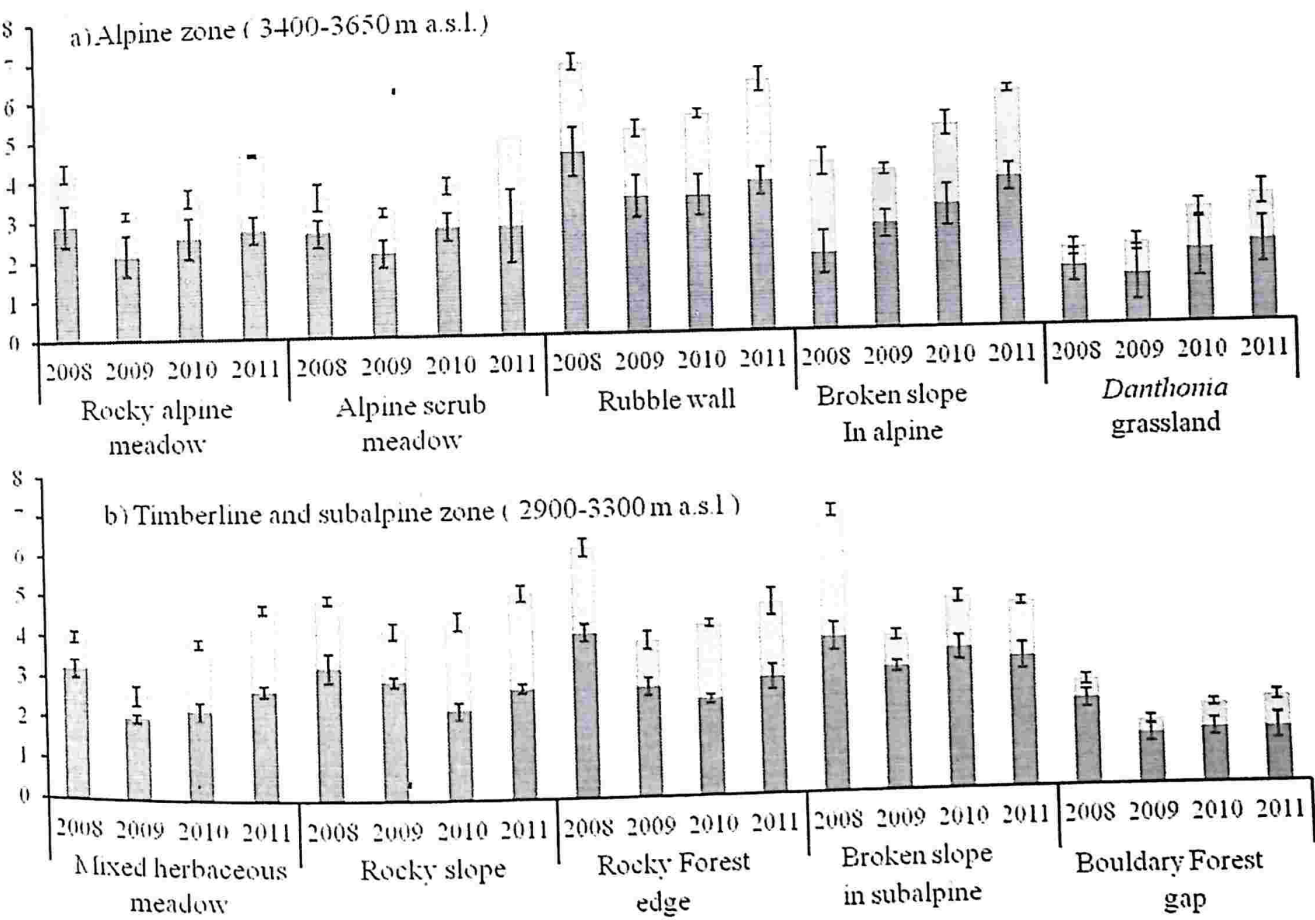


Figure 5.1 Abundance of Royle’s pika in different habitat types of the alpine zone and timberline- sub alpine zones during study period (light colored bar represent juvenile pika and dark color bar represent adult pika abundance).

The adult and juvenile pika abundance was significantly lower in 2009, and no significant change was observed in 2010 and 2011 compared to 2008 in the study area. During 2008–2009, all snow-related predictors (snow cover period and snow depth in annual and spring season) were significantly lower than in 2007–2008. Significant increases in snow-cover duration and annual snow depth were observed in 2010–2011 (Table 5.2). The study area experienced the highest mean snow-cover period (111.9 ± 4.45 days) during 2010–2011, with an average annual snow depth of 59.59 ± 4.48 cm and food availability of 503.0 ± 14.43 individual m^{-2} . The shortest snow-cover period (71 ± 3.81 days) with average annual snow depth of 23.18 ± 1.12 and food availability of 214.11 ± 11.15 was observed in 2008–2009. The spring snow depth was highest (44.13 ± 1.06 cm) in 2007–2008 and lowest (18.33 ± 3.06 cm) in 2008–2009.

The possible relationship of different predictor variables (snow-cover period, spring snow depth and food availability) and pika abundance in alpine and timberline-subalpine zone was explored through a scatter plot (Fig.5.2). The adult and juvenile populations in alpine zone showed a positive trend with increase in snow-cover period and spring snow depth, whereas no distinct trend was observed in the timberline–subalpine zone. No trends were observed between food availability and pika abundance (adult and juvenile) in both altitudinal zones.

Table 5. 2 Summary statistics of linear mixed effects models to test significant inter-annual variations (2008 Vs. 2009, 2010, 2011) in adult and juvenile pika population abundance, snow cover period, annual mean snow depth, spring snow depth, food availability in the study area (N = 10). * indicate significant change.

Parameters		Beta	SE	t-value
Adult abundance	Intercept	2.87	0.16	17.21
	Year 2009	-0.58	0.21	-2.66*
	Year2010	0.04	0.24	0.20
	Year2011	-0.29	0.24	-1.20
Juvenile abundance	Intercept	1.57	0.18	8.40
	Year 2009	-0.41	0.19	-2.09*
	Year2010	0.12	0.21	0.57
	Year2011	-0.20	0.21	-0.94
Snow cover period	Intercept	95.80	3.93	24.34
	Year 2009	-24.80	0.68	-36.05*
	Year2010	0.10	0.76	0.13
	Year2011	16.10	0.76	20.93*
Annual mean snow depth	Intercept	35.46	4.70	7.54
	Year 2009	-12.28	0.92	-13.30*
	Year2010	-6.06	1.03	-5.88*
	Year2011	24.13	1.03	23.37*
Spring snow depth	Intercept	44.18	3.68	12.02
	Year 2009	-20.65	1.23	-16.78*
	Year2010	-25.68	1.37	-18.66*
	Year2011	-25.85	1.37	-18.79*
Food availability	Intercept	258.74	46.67	5.54
	Year 2009	-44.63	39.35	-1.13
	Year2010	76.60	44.00	1.74
	Year2011	244.27	44.00	5.55*

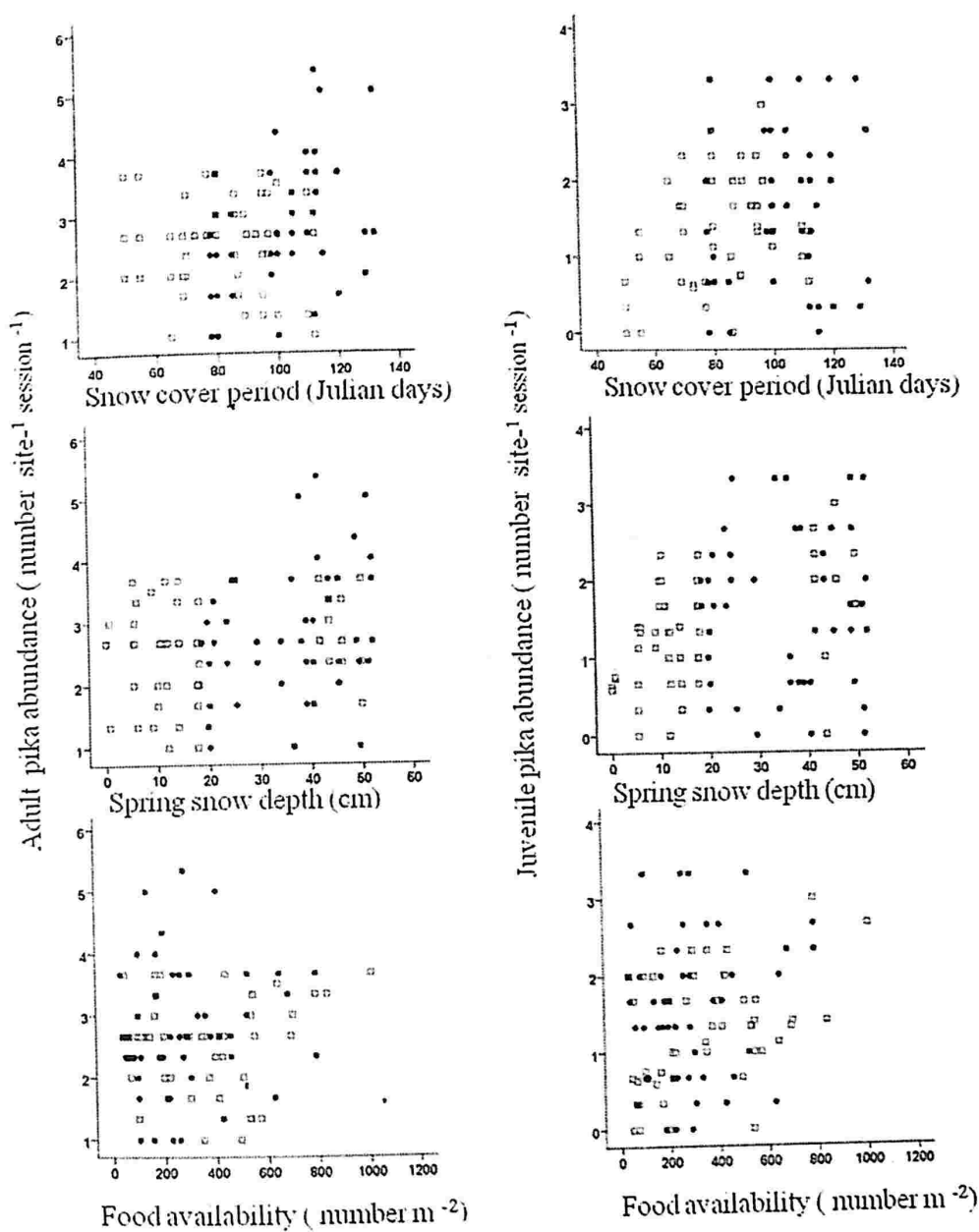


Figure 5.2 The relationship of pika abundance (adult and juvenile) and different environmental factors (snow cover period, spring snow depth, food availability) in alpine (●) and timberline-subalpine zone (□).

Most of the potential predictor variables (Table 5.1) were found to have a high correlation. Food availability had a weak but significant correlation with annual snow depth ($r = 0.235$, $p < 0.05$) and snow cover period ($r = 0.291$, $p < 0.05$). All snow-related predictors were correlated with one another (snow-cover period and spring snow depth: $r = 0.408$, $p < 0.001$; snow-cover period and annual mean snow depth: $r = 0.899$, $p < 0.001$; spring snow depth and annual mean snow depth: $r = 0.419$, $p < 0.001$), as well as with altitude zone (spring snow depth: $r = 0.536$, $p < 0.001$; annual mean snow depth: $r =$

0.607, $p < 0.001$, snow-cover period: $r = 0.514$, $p < 0.001$). Therefore, they appeared as separate model or interaction effects with altitudinal zone.

The best model of adult pika abundance (Table 5.3, Fig 5.3) received far more support than that of the null model ($\Delta AIC = 7.10$); no other model received similar support (all ΔAIC values were > 2). In the best model, the interactive effect of predictors (snow-cover period and altitudinal zone) had a significant positive influence over adult pika abundance (Table 5.4). For juvenile pika abundance, only two models received more support than that of the null model. The food availability, amount of rock cover and spring snow depth formed the best model as predictor, and positively influenced the abundance of juvenile pika (Table 5.3). Food availability and rock cover had more influence on juvenile abundance than the spring snow depth (Table 5.5).

The timing of emergence of juvenile pika varied significantly between different sites across the year ($F = 10111.35$, $df = 1, 56$, $p < 0.001$). The juvenile pikas were encountered earlier (4.13 days) in the timberline–subalpine zone than in the alpine zone (Fig. 5.4). The earliest emergence of juvenile pika was recorded at broken slope in the subalpine zone and at bouldary forest gap habitats in the timberline–subalpine zone on 8 May 2010, whereas the latest emergence was recorded at rocky alpine meadow and alpine scrub meadow in the alpine zone on 8 June 2009. The best candidate model to explain the relationship of juvenile pika emergence time with snow-cover period, spring snow depth and food availability received more support than the null model ($\Delta AICc = 204.85$); no other model received similar support (all ΔAIC values were > 2). The standard deviation of random effects of site was 4.658, implying that much of the variation in emergence time was due to random variation between sites. In the best model, juvenile pika emergence time was found to be governed by interactive effects of snow-cover period and altitude zone. The best fit model's β -coefficients estimates suggest that a short snow-cover period ($\beta = -0.337 \pm 0.11$, $t = -2.963$, mean $\pm$ SE) delayed the pika emergence date. Both altitude ($\beta = -4.712 \pm 7.11$, $t = -0.662$, mean $\pm$ SE) and the interactive influence of altitude and snow-cover period ($\beta = 0.1032 \pm 0.073$, $t = -1.409$, mean $\pm$ SE) also had a negative influence over emergence timing.

Table 5.3 Relative support to various candidate models explaining competing ecological hypothesis about factors affecting abundance of Royle’s pika, using information theoretic criteria at different study plots (N =10 ;AICc values = Akaike’s information criterion, Log(L) Log= likelihood, K= number of modeled parameter, ΔAICc= the difference between the indicated model and the best model (the model with lowest AIC).

Model (predictor)	-2×Log(L)	K	AICc	ΔAICc	Akaike weight
Adult pika abundance					
Snow cover period* Altitude zone	-35.97	3	81.95	0.00	
Annual mean snow depth* Altitude zone	-38.38	3	86.76	4.80	
Snow cover period	-40.71	3	87.42	5.46	
Rock cover+ Snow cover‡ period	-39.97	4	87.95	5.99	
Null model	-42.52	2	89.05	7.10	
Food availability	-42.11	3	90.22	8.26	
Rock cover	-42.14	3	90.29	8.33	
Juvenile pika abundance					
Food availability + spring snow depth	-40.02	4	88.04	0.00	0.39
Rock cover+ spring snow depth	-40.19	4	88.39	0.34	0.33
Null model	-42.52	2	89.05	1.01	0.28
Food availability	-42.11	3	90.22	2.17	
Rock cover	-42.14	3	90.29	2.24	
Food availability * altitude zone	-42.46	3	92.93	4.88	

Table 5.4 Estimated influence of parameter (Snow cover period and altitude zone) on adult Royle’s pika abundance measured by the best fit general linear model (minimum Akaike information criterion)

Parameter	Beta	Std. Error	t value	p-value
Intercept	0.852	0.050	14.610	0.000
Snow cover period	-0.053	0.058	-0.906	0.367
Altitude zone	-0.016	0.083	-0.189	0.851
Snow covered period × altitude zone	0.256	0.083	3.083	0.003

Residual standard error: 0.3539 on 96 degrees of freedom, Multiple R-squared: 0.1228, Adjusted R- squared: 0.09537 ,F-statistic: 4.479 on 3 and 96 DF, p-value: 0.005481

Table 5.5 Estimated influence of parameter (food availability, rock cover, spring snow depth) on juvenile Royle's pika abundance measured by the best fit general linear model (minimum Akaike information criterion and multi model averaging)

Parameter	Average Beta	Confidence Interval		Relative Variable importance
		Lower	Upper	
Intercept	0.910	0.837	0.983	
Food availability	0.045	-0.028	-0.120	0.72
Rock cover	0.040	-0.033	0.144	0.39
Spring snow depth	0.074	-0.0006	0.148	0.33

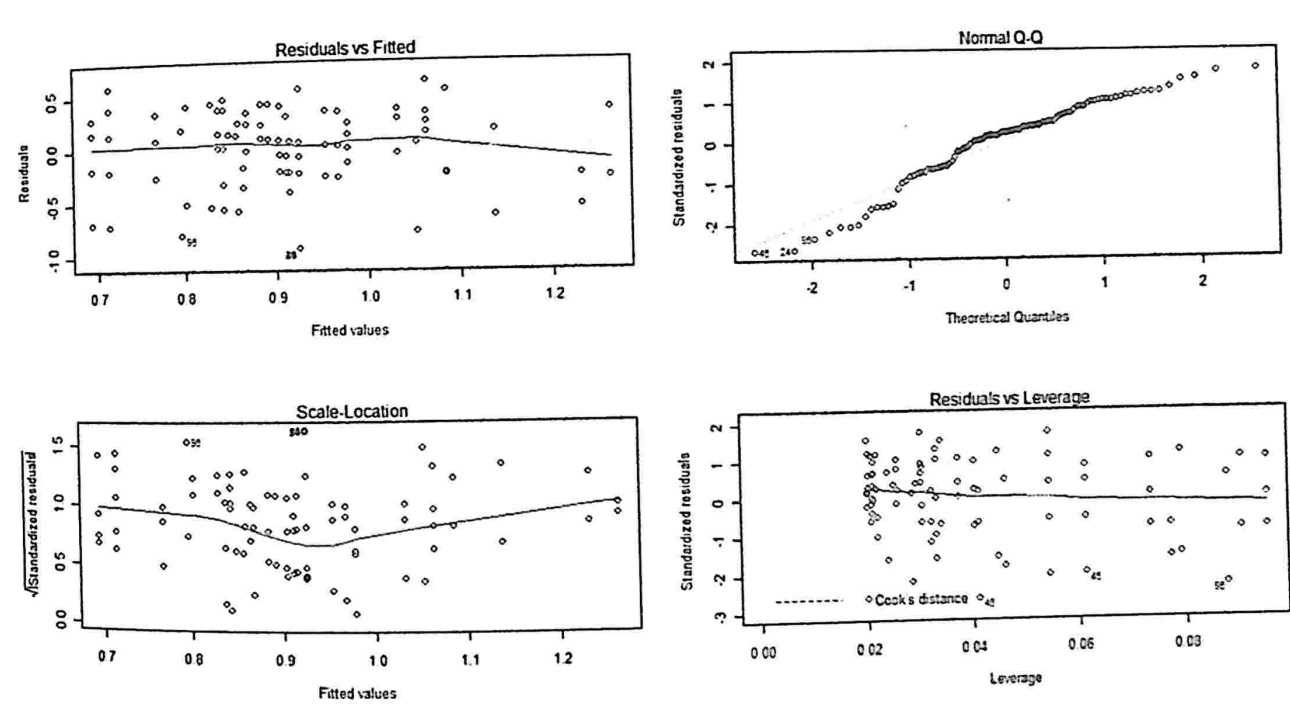


Figure 5.3 Diagnosis of best fit adult pika abundance candidate model.

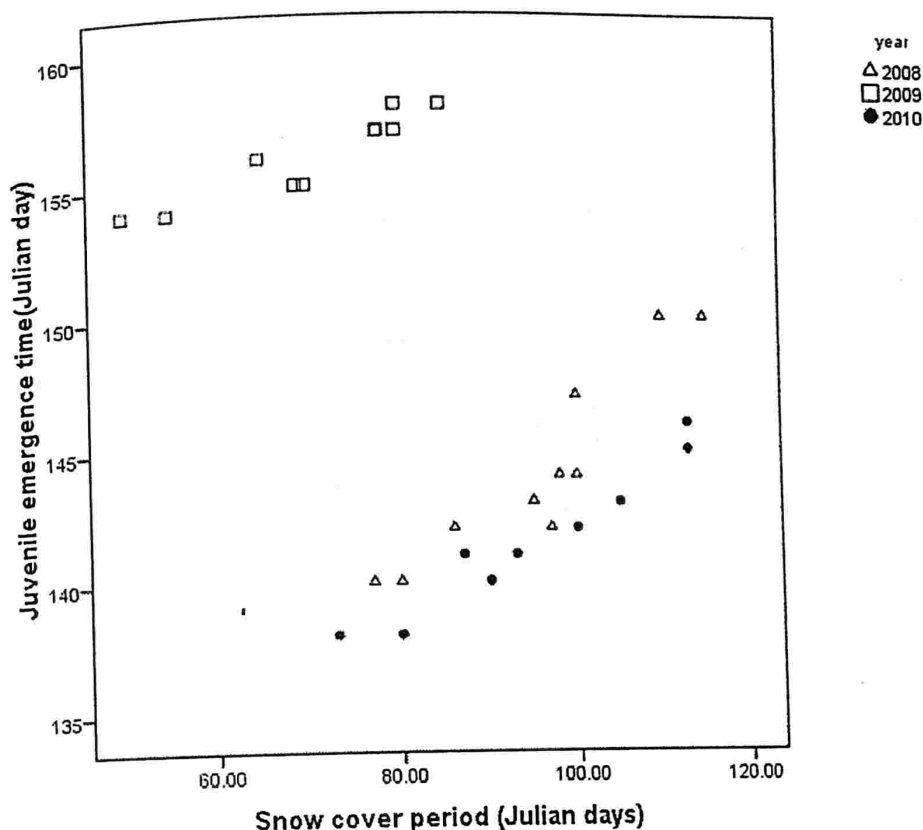


Figure 5. 4 Influence of snow cover on emergence time of juvenile Royle's pika.

5.4 Discussion

Snow acts as insulation for pikas during winter; a thick snow cover works as a protective layer, allowing pikas to survive high diurnal temperature fluctuation during winter and early spring (Morrison and Hik 2007). The results of this study support the hypothesis that pika abundance is significantly affected by total snow-cover period and snow depth in spring. Royle's pika does not hibernate in winter, and does not make hay-piles for winter food (Kawamichi 1968). Thus, adult pikas face harsh climatic conditions during winter (in contrast to juvenile pikas, which are usually born in early summer). This explains why snow attributes were more important governing factors for abundance of adult pikas than other habitat characteristics, such as amount of rock cover or food availability. During the winter of 2008–2009, a short snow-cover period may have caused high adult pika mortality due to cold stress, which in turn resulted in low pika abundance in the summer of 2009. Kreuzer and Huntly (2003) found that the snow melting pattern and its duration has a significant impact on the demography of the American pika. Acute cold stress (due to short duration of snow cover or a thin snowpack) was also found to be

an important reason for pika extirpation in the Great Basin (Beever 2010). Royle's pika become ready to reproduce during spring, and the gestation period in similar talus-dwelling pika is reported to be about 30 days (Severaid 1950; Smith and Weston 1990). The thermal insulation provided by a thick snow pack during spring reduces cold stress; it also creates within burrows an environment that favours successful reproduction in adult pika. Hence, spring snow increases the abundance of juvenile pika. Snow distribution in the alpine environment is mainly governed by the interaction of wind and topography. Snow generally falls evenly, but strong winds usually remove snow from ridges and deposit it in drifts and other protected (unexposed) places. Hence, variation in snow cover duration, as well as depth across the sites or the years, may have led to the variation in the abundance of adult and juvenile pika seen in the present study.

Winter snow cover works as thermal insulation for plants, as it does for pikas, protecting alpine plants from extreme low temperatures and fluctuating temperatures (Marchand 1996). Snow-cover period and depth are critical to soil-nutrient quality, and thus have a profound effect on alpine food plant growth (Walker *et al* 1993, 1995; Brooks and Williams 1999). Although the alpine soils are frozen and snow covered for much of the year, soil particles are reported to be surrounded by water films even at -10°C (Romanovsky and Osterkamp 2000), allowing microbial activity to continue (Coxson and Parkinson 1987; Rivkina *et al.* 2000; Mikan *et al.* 2002). Therefore, deep snow during winter and early spring may alter the soil microbial community by increasing their nutrient pool, leading to more nutrients (e.g. nitrogen) becoming available to plants for following growing season (Buckeridge and Grogan 2008). In alpine and tundra ecosystems, soil nitrogen supply is limited; thus, a change in nitrogen supply can significantly influence phenology and biomass of alpine food plants (Shaver and Kummerow 1992; Schimel *et al.* 1996). Thick snow cover results in later snowmelt, which delays the beginning of the growing season, and reduces frost mortality in herbaceous plants buds (Inouye 2008). These facts support the findings of present study, which indicate that long snow cover period and thick snow pack results in high availability of food plants, which possibly, improve pikas's health by increasing nutritional intake during following breeding season in spring and also for rest of the summer. These results supports the second hypothesis that indicate high food availability

directly influences the pika abundance (juvenile) through providing optimum nutrition and indirectly by improving fecundity of adult pikas.

Pikas venture out from their burrows to forage and return back after each bout (Orians and Pearson 1979; Roach *et al.* 2001). Therefore, predation risk is an important cost associated with each forage bout, and to minimize predation while maximizing available forage, pikas take advantage of rock cover. This was confirmed in the present study, which identified rock cover as important factor governing juvenile pika abundance, supporting the third and final hypothesis. The results also aligned with earlier research on American pika that suggested a positive linear relationship between pika abundance and talus rock size (Bunnell and Johnson 1974). The amount of rock cover in a habitat has also been shown to have significant influence over seasonal abundance of Royle's pika in western Himalaya (Bhattacharyya *et al.* 2009).

In spite of high variation in alpine environment, especially in terms of precipitation and snow pack, the talus-dwelling pika population is reported to be remarkably stable (Southwick *et al.* 1986). Pikas, especially those that are talus dwelling, share several characteristics that make them vulnerable to climate change; these characteristics include poor ability to disperse, close association with patchy habitat in mountain sky islands, high sensitivity towards temperature fluctuation and low fecundity (Smith and Weston 1990; Walther *et al.* 2002; Beever *et al.* 2011). American pika, which are widely distributed across a high-altitude talus habitat in the Great Basin–Greater Yellowstone ecosystem, are reported to be extirpated at 9 of 25 locations of historical records in the Great Basin, and functionally from another site (Beever *et al.* 2003, 2010). Climate warming is predicted to dramatically alter this species's distribution of genetic diversity (Galbreath 2009). Even the Ili pika (*O. iliensis*) in China has experienced recent and drastic range retractions, putatively due to increased temperature, possibly due to global warming (Li and Smith 2005). The Himalayan region is reported to be affected by global warming (Singh and Bengtsson 2004). However, the absence of basic ecological information derived from long-term information about Himalayan pika species hampers understanding of how they will respond to future climate change.

The present study uncovered the basic relationship between pika abundance and the environment. The findings can be used as baseline information for a future long-term pika research and population monitoring programme, with the aim of tracing and quantifying the effects of climate change in alpine Himalaya.

Seasonal variation in time activity budget of Royle's pika

6.1 Introduction

Information on activity budget has significant ecological importance as natural selection often favor individuals who can effectively utilize time within space (Caraco 1979). Understanding of activity budget can also provide us information about how an animal divide up its activity throughout the day as well as different seasons which are important to understand the mechanism through which animals cope with varying energy demand, environmental and habitat changes and allocate time and energy for successful survival (Defler 1995). Therefore, time activity budget reflects animal's physical condition, social structure which is extremely helpful to understand their ecological needs (Paulus 1988). Hence, activity budget can provide insight on the functional role of a habitat to its inhabitants and this information can also be very useful for effective conservation and management planning (Barros and Baldassarre 1989).

Activity budget studies were often used to better understand the ecology of variety of animals such as birds (Stock and Hofeditz 1996), small mammals like squirrels (Wauters *et al.* 1992) and bats (Charle-Dominique 1991), ungulates like moose (Miquelle 1990) and bighorn sheep (Goodson *et al.* 1991). Activity budgets are also very popular in primatology studies as they are excellent tools to understand effects of variation in habitat structure (Isbell and Young 1993; Watts 1988; Defler 1996), predation risk (van Schaik *et al.* 1983), food availability (Adeyemo 1997) as well as social structure on an individual or group of animals. It is also recognized as an important tool to understand habitat use, community structure and niche separation (Rave and Baldassarre 1989; Hepworth and Hamilton 2001).

High altitude ecosystems experience marked seasonality, thus animal lives in such ecosystem has short and restricted period to gain energy and perform successful reproduction. High variation in climatic condition also impose additional energetic burden over alpine mammals which has relatively small body size. Therefore, we select Royle's pika (*Ochotona roylei*) a high altitude small (100-150g; Alfred *et al.* 2006)

lagomorph as our study species to understand how alpine small mammals like pikas perform optimal allocation of time-activity budget under such highly seasonal and rigorous climatic condition. Additionally, pikas are excellent model systems for behavioural ecology studies as they are diurnal, highly detectable and easy to observe in their rocky talus habitat and have high tolerance for human observer presence. Pikas are also reported to play significant ecological role in alpine-subalpine ecosystem as they are prey base for several endangered carnivores (Roberts 1977; Oli *et al.* 1994; Aryal *et al.* 2010).

Royle's pika is distributed in Himalayan region from north-west Pakistan to India, Nepal and adjacent Tibet (China; Hoffmann and Smith 2005) and highly adapted to sub-alpine and alpine habitats in Himalaya. Its distribution varies from 2400m a.s.l. up to 5000m a.s.l. and mostly in open rocky grounds and Rhododendron forests (Chakraborty *et al.* 2005). Although Himalaya is home for seven different pika species (Smith *et al.* 1990), but studies on Royle's pika as well as other pika species inhabit in Himalaya are scanty. Earlier research was conducted on Royle's pika by Kawamichi (1968, 1971) at Khumbu region in Nepal were mainly focused on the distribution pattern, winter behaviour and social organization of *O. macrotis* and *O. roylei*. Though these studies provide a detail account for winter behaviour of Royle's pika, but all earlier studies were conducted for very short term (four months or less) and only during winter months. Therefore, these studies did not provide any information about Royle's pika behavioural ecology during their peak activity period.

This research is aims to collect ecological information to understand the time activity budget of Royle's pika in a spatio-temporal scale. Major objectives of the study were i) to document different behavioural states of Royle's pika, ii) to calculate time activity budget for different altitude as well as season, iii) to understand how habitat characteristics like amount of rock cover or food availability might influence pika behaviour, especially vigilance behaviour iv) to understand the behaviour sequences in activity budget.

6.2 Methodology

6.2.1 Behavioural observations

The pika behaviours were observed for two year (2008-2009) on monthly basis. The entire study period were divided into three season viz. summer (May-June), monsoon (July-September) and autumn (October-November) while no observations were recorded during September due to heavy rain or during winter due to inaccessibility. The entire study area was divided into three altitudinal zones: sub-alpine (2900-3150m), timberline (3200-3350m) and alpine (3350-3680m). In each altitudinal zone, one 50×50 m permanent plots were delineated to record the behaviour. Each permanent study plot was at a minimum 200 m distance from its neighboring plot and has similar aspect and slope. Pikas were observed using focal sampling methods by a 10× 40mm Nikon binocular from high vantage point on a rock from where entire study plot is visible (Altman 1974). As Royle's pikas are synanthropic in nature, hence, presence of observer didn't seem to influence their natural activity (Kawamichi 1968). Individual animals were identified based on size, moulting sign in body and scar marks in ear. Juvenile pikas was monitored only during summer and monsoon as after this period they attained same body size of one year old adult, therefore, it was difficult to separate them from adults. Juveniles were also very less active than adults, especially during summer which results a low amount of observation. Hence, Juvenile pika data were only used to describe their activity budget not in any further statistical analysis. Food plants were identified during behaviour observation session and 1×1m traditional quadrat were performed to estimate food plant density in each study plot. Percentages of rock cover at each study plots were recorded by ocular estimation (Van Hees and Mead 2000).

The behaviour of Royle's pika was monitored from 0600hrs to 1900hrs and categorized further in five observation sessions as early morning (0600-0800hrs), late morning (0800-1100hrs), day (1100-1500hrs), afternoon (1500-1700hrs) and evening (1700-1900hrs). Time spends for different behaviour were estimated by a stopwatch and recorded in pre structured data sheet. Each observation occasion lasted for ten min and followed by a five minute recess.

Total six behavioural states were selected for behavioural observation based on earlier studies (Kawamichi *et al.* 1968, 1971), such as-

1. Foraging- feeding in sitting posture or carrying food to refuge,
2. Locomotion- includes running and leaping,
3. Musing- spending time in sedentary sitting condition and depend on the duration further divided into two groups, a) Long musing- The duration varies from few minutes to several minutes, they sit at a particular location known as musing points and do not move their head or ear, fore paws are not visible, b) Short musing- The duration of this musing varies from few seconds to one or two minutes, though pika sits motionlessly but always seems to be very alert,
4. Grooming- rubbing chicks by fore paws and scratching body by hind paws (this behaviour was mentioned as "washing and scratching" by Kawamichi, 1969, He also mentioned "trembling behaviour" which has similar function like washing and scratching, thus trembling and washing, scratching observation were pooled together under grooming behaviour category),
5. Vigilance- moving head in different directions and observing habitat, possibly to understand predation risk (Kawamichi 1968,1971 called this behaviour as "inspection"),
6. Vocalization- low pitched call. Kawamichi 1968 reported very weak vocalization in Royle's pika, most vocalizations reported to be very low pitched and hardly audible from few meter distance.

Some behavioural states were considered as rare behaviour if they were observed only one or two observation occasions during whole two year study period and contribute less than one percent in overall activity budget. Those rare behavioural observations were not included in activity budget calculations and reported separately in results.

During the study, pikas were often out of view within their burrows for considerable amount of observation hours. As it is difficult to predict their activity state while they are within burrow, therefore, pika were considered as "active" (all behaviour data pooled together) only when they were visible above ground and "inactive" if they were out of

view. Activity pattern often also defined as ratio of activity and inactivity. Hence, the ratio of activity and inactivity in adult pikas were plotted in bar graph to get preliminary idea about spatio-temporal pattern of pika activity. While estimating the activity budget, time spent in inactive condition were not incorporated.

6.2.2 Data analysis

The activity budget data were tested for normality by the Kolmogorov-Smirnov test and, whenever necessary, applied the arcsin and square root transformation to achieve normality (Zar 1999). As the data were not normally distributed even after transformation, therefore, Kruskal Wallis tests (Zar 1999) were performed to determine if the amount of time spent in different behaviours significantly varies across different seasons as well as in different observation hours in SPSS 16.0 (SPSS for Windows, Rel. 16.0.0. 2008. Chicago: SPSS Inc).

Behaviour often considered as time sequence of different behavioural states in an animal or a group of animal. For solitary or less social animals behaviour likely to be triggered by internal factors like hunger or external factors like climatic condition, presence of predator (Slooten 1994). Earlier research indicates behaviour of an individual might be influenced by preceding behaviour (Bakeman and Gottman 1986). Therefore, analyzing behavioural sequence or behavioral transition (a preceding-following relationship of two behaviors) can be useful to identify and understand the rules which influence the order of occurrence of several behaviours together (Berridge 1990; Meyer and Guillot 1990; Waas 1991; Wolffgramm 1990). To understand behavioural sequence in a particular season, representative subsamples from entire observation of a plot were chosen for analysis. The entire observation hours were divided into morning (0600-0900hrs), day (1100-1400hrs) and evening (1400-1900hrs). Data were pooled from different altitude zone together for a particular season as the variance present in data was quite low (<15%). Z-scores were used to understand the power of sequential dependence of two behaviours. Z-scores were calculated following the formula adopted from Slooten 1994 and references there in: Allison and Liker 1982; Bakeman and Gottman 1986; Gottman 1980. The difference between observed and expected frequency were divided by their standard deviation (Bakeman and Gottman 1986). Hence, Z-score can be helpful to estimate if a particular

behaviour sequence occurs significantly often or less than expected by chance. As Z-score > 1.96 or < -1.96 are considered as statistically significant at the 0.05 probability level, therefore in our results, we demonstrate only the Z-scores of behaviour sequences which are statistically significant (Bakeman and Gottman 1986). Behaviour sequence with negative z-score value indicate the probability of occurrence of behaviour in sequence is less than random chances whereas behaviour with positive values indicates the probability of two behaviour occur in a sequence is more than only random chances.

6.3 Results

Pika observation plot in alpine zone and subalpine zone was broken slope talus habitat where as it was a mixed herbaceous meadow in timberline zone. The talus rocks were quite abundant and dispersed in alpine and subalpine zone habitat whereas most of rocks were embedded in soil with crevices in timberline zone habitat. Highest (72%) rock cover was recorded in broken slope in subalpine followed by broken slope (55%) in alpine and mixed herbaceous meadow (20%) in timberline. As the study area receives high rainfall during monsoon as well as summer and post monsoon seasons. Thus, most of the talus rocks were covered by moss and lichens. Royle's pikas showed bimodal activity pattern in all seasons and altitude. Total observation hours were 464 for adult and 312 for juvenile pikas. Adult pikas found to be highly active during early morning and late evening hours whereas comparatively less active during midday hours (Fig.6.1).

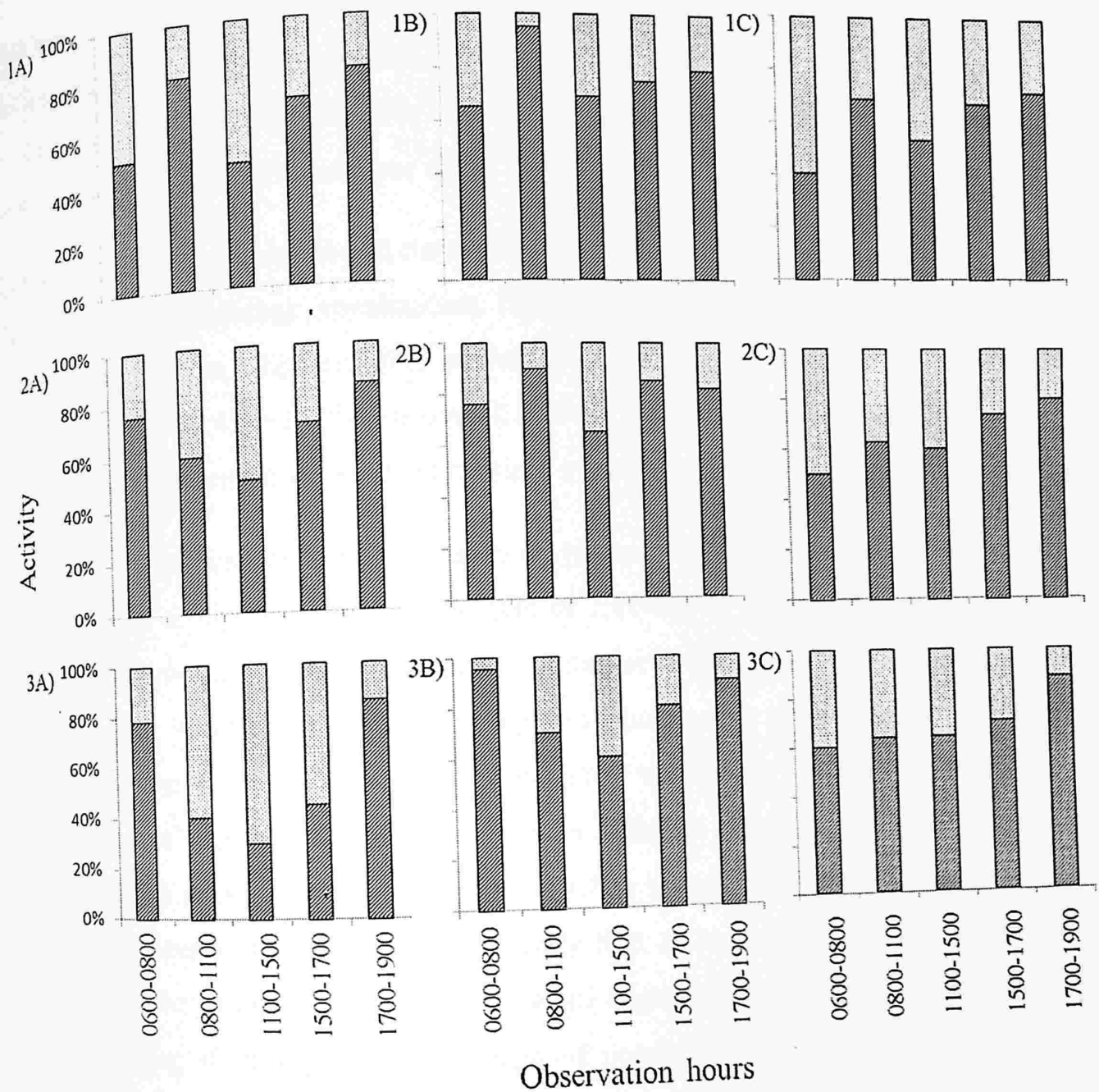


Figure 6.1 The percent time spent in activity state vs. inactivity state by adult Royle's pika in different altitude (activity = dark bar, inactivity = light colored bar, 1= alpine, 2= timberline, 3= subalpine) and seasons (A= summer, B=monsoon, C=autumn)

During entire study period lowest activity ($30.00 \pm 0.12\%$) was observed in summer during 1200-1300hrs in subalpine whereas it was comparatively higher (16-19%) in timberline and alpine zone (Fig. 6.1). During summer the length of midday low activity hours was also comparatively longer in subalpine zone (0800hrs-1600hrs) than alpine or timberline zone (1100-1400hrs). Similar midday activity pattern were observed during monsoon and autumn but activity was comparatively higher ($>50\%$) than summer and it

was almost equal in all altitude zone. The highest activity ($95.02 \pm 0.14\%$) was recorded during early morning hours (0600-0700hrs) during monsoon in subalpine zone. Food availability were highest (732.35 ± 2.34 individuals per sq m) during monsoon whereas lowest (35.07 ± 1.23 individuals per sq m) during autumn at alpine study plot.

Total seven different behavioural states (foraging, locomotion, vigilance, grooming, short musing and long musing, vocalization, Fig.6.2) were recorded in adult pikas. Royle's pikas spent highest ($42.0 \pm 1.29\%$) amount of time in foraging whereas vocalization contribute least ($1.49 \pm 0.10\%$) in overall activity budget across all season and altitude (Table 6.1). Here are the detailed descriptions of each behaviours.

Foraging: while foraging on long leaves or grasses, Royle's pikas usually eat the leaf from the root to tip (Fig 2-A). Collection or carrying of food is always found to be performed by mouth not using fore paws. During several occasions pikas were observed to stretch their body or jump to get food plants which one is seemed to be out of reach. Majority of the foraging activity were centered within few meters of talus crevices opening. Royle's pika reported to feed on 26 different plant species in the study area (Bhattacharyya *et al.* 2009). During autumn when majority of herbaceous plant species undergo senescence, they found to be actively feed on moss and lichens on rocks. They also found to be in highly alert condition while engage in foraging activity. Pikas found to stop feeding if they presume any sign of possible threat and enter into vigilance behaviour. Most often after such condition they retrieve themselves within their burrows and again show up after few minutes. Foraging is comparatively higher in all altitude during monsoon ($45.01-44.6\%$) than summer or autumn (Table 6.1) and it was also high in early morning and afternoon and evening hours than midday (Fig.6.3). No significant seasonal difference during different observation hours were observed at alpine or timberline zone whereas in subalpine zone during late morning, day and evening hours pikas found to spend more time in feeding during monsoon than summer or autumn (Table 6.2).

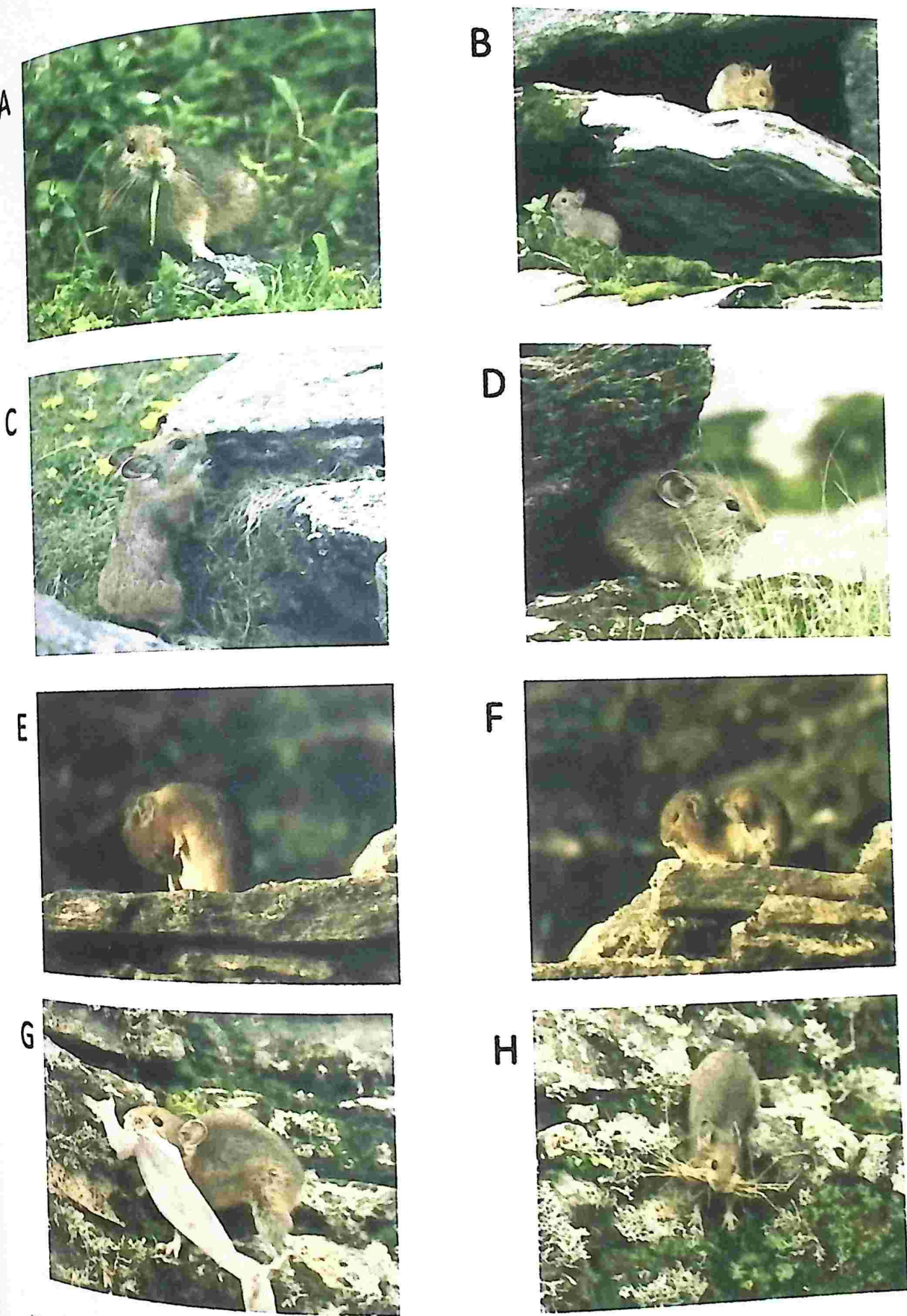


Figure 6.2 Photographical representation of different behaviour of Royle's pika (A= foraging, B=adult and juvenile active in same location but not interacting, C= vigilance, D= musing, E-F= auto grooming by washing and scratching, G-H= nest building by dry grass and plastic)

Table 6.1 Average percent time spent by adult Royle's pika in various activities in different season and altitude zone

Season	Altitude Zone	Foraging	Locomotion	Long Musing	Short Musing	Vigilance	Grooming	Vocalization
All season	All altitude	42.0±1.2	22.0±1.1	11.68±1.5	8.42±0.4	10.65±0.9	3.78±0.3	1.49±0.1
	Alpine	44.0±3.1	20.06±2.2	8.00±0.6	12.00±3.4	12.3±2.6	3.37±0.6	1.00±0.3
	Timberline	43.3±3.8	19.6±2.4	11.5±0.9	9.00±0.9	11.31±0.9	3.24±0.6	1.99±0.0
Summer	Subalpine	40.12±4.0	33.63±4.3	9.44±0.6	9.89±0.9	7.68±0.5	3.49±0.0	0.85±0.0
	Alpine	44.6±2.7	22.97±1.5	11.02±0.6	7.77±2.6	9.90±0.1	3.00±0.5	0.8±0.0
	Timberline	45.51±4.2	25.11±2.0	7.10±0.9	7.3±0.8	9.52±0.7	4.6±0.5	0.86±0.1
Monsoon	Subalpine	45.00±1.7	33.01±0.9	4.20±0.1	6.59±0.7	9.00±0.1	2.50±0.8	0.17±0.0
	Alpine	41.30±4.6	26.97±3.2	10.73±0.8	3.01±0.7	11.51±0.7	6.08±0.0	0.50±0.0
	Timberline	30.00±4.2	28.9±1.7	22.09±2.9	4.01±1.0	10.73±0.5	3.77±0.7	0.50±0.0
Autumn	Subalpine	32.0±3.7	35.00±1.4	18.00±1.7	4.71±0.0	6.00±0.8	4.42±0.5	0

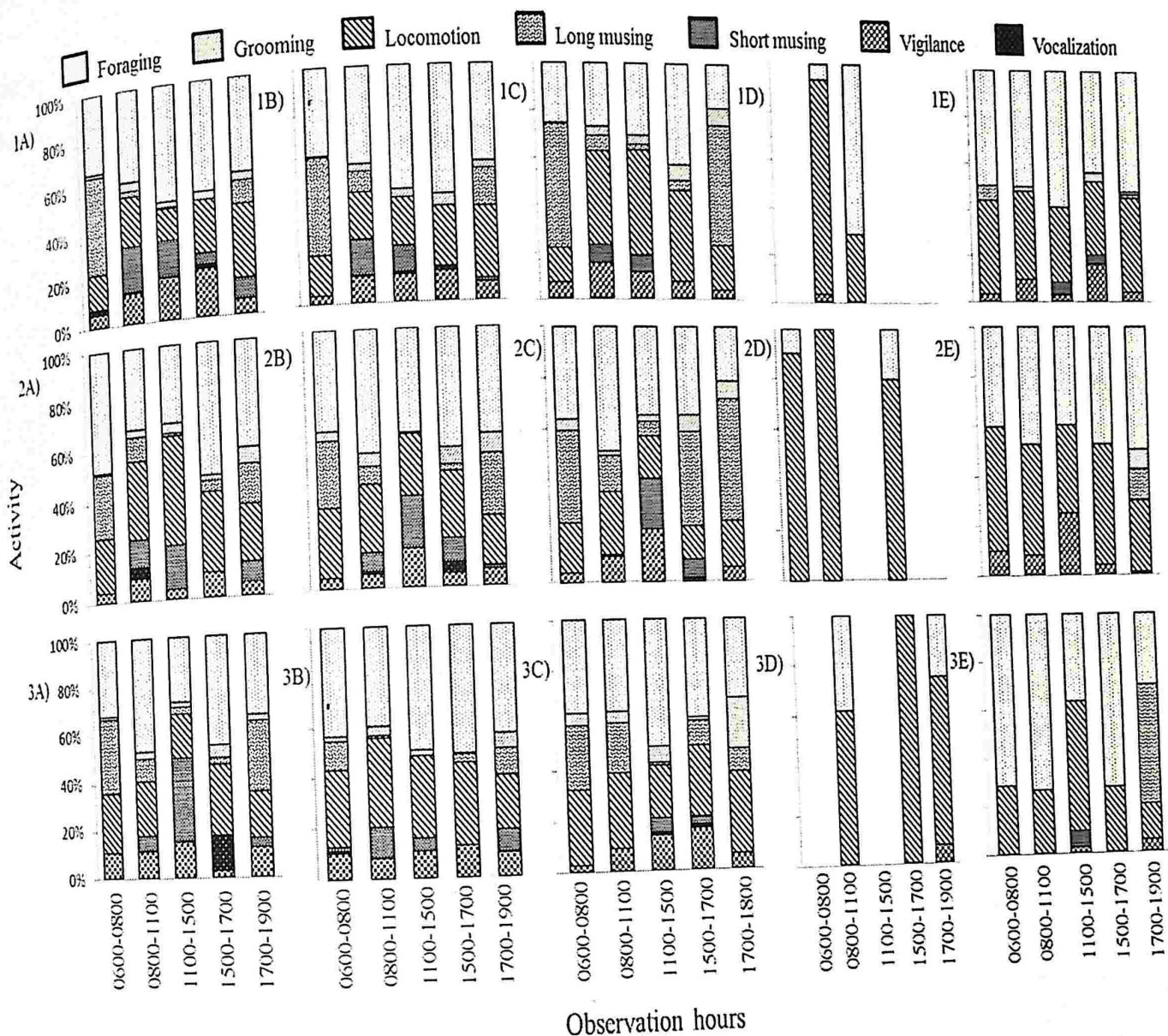


Figure 6.3 The time activity budget of adult Royle's pika (A-C) and Juvenile pika (D-E) in different altitude (1= alpine,2=timberline,3=subalpine) and seasons (for adult, A= summer, B=monsoon, C=autumn; for juvenile, D= summer, E= monsoon)

Locomotion: Royle's pikas found to follow specific paths to move between rock talus. They were found to access more area through locomotion if the rocks were dispersed widely. On several occasions individuals pikas were observed to move more than 80m among talus interstices within a minute. To escape from immediate threats they also found to jump back to their nests within the talus. Some time they were found to jump more than 2m at once. Average time spent for locomotion was higher in autumn (35.00-26.97%) than summer or monsoon (Table 6.1). Time spent for locomotion significantly increased from summer to autumn during early morning hours in alpine and day hours in subalpine whereas showed opposite trend were observed at timberline during afternoon

hours (Table 6.2). Royle's pikas found to spend less (approx. 10-13%) time in locomotion when food availability is high (Fig.6.4).

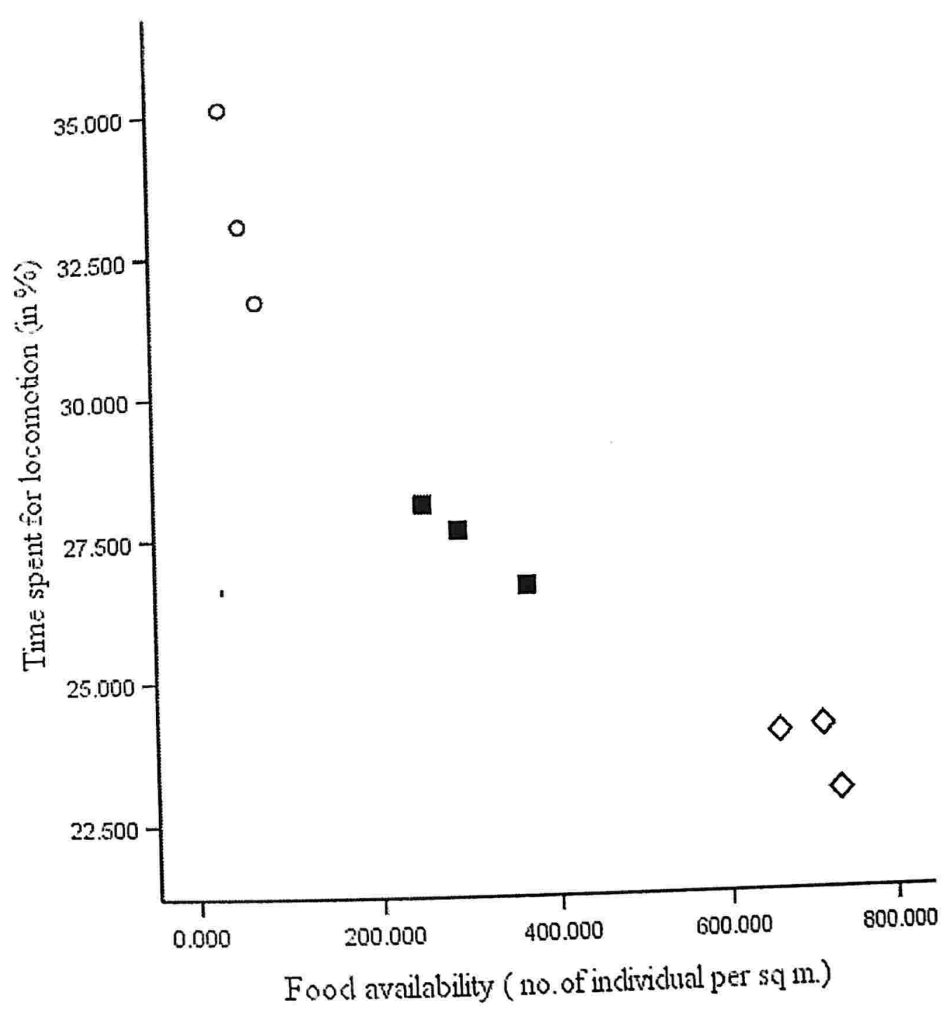


Figure 6.4 The relationship of food availability and time spent in locomotion by adult Royle's pika during summer (■), monsoon (◇) and autumn (○)

Musing: Royle's pikas also found to have typical musing points like other pika species (Kawamichi 1969) within one meter's distance near to talus interstices opening. Musing points were typically tip of a rock occasionally situated little higher than surrounding rocks with good escape cover from predators. All musing points were used for long musing whereas short musing often found to occur outside of musing points too. Long musing usually observed only morning and late evening hours in all seasons and altitude zone (Fig. 6.2-D). Short musing were observed during late morning to late afternoon hours only and found often in summer than monsoon or autumn (Fig. 6.3). Pikas found to

spend more time in long musing during autumn (22.00-10.73%) specially in subalpine zone where as time spend for short musing was higher in summer (12.00-9.00%, Table 6.1). Significant seasonal variation in long musing duration were observed during early morning, afternoon and evening hours at timberline and subalpine zone. The long musing activity found to be decreased in monsoon than summer and again increased in autumn where as it showed gradual increasing trend from summer to autumn during afternoon hours (Table 6.2). For short musing, significant seasonal variation was observed at alpine zone only during late morning hours and the time spend in short musing decreased from summer to autumn.

Grooming: It was found to be a common behaviour among adult animals than juveniles. Though grooming did not performed at specific place but it was often observed that pikas perform grooming at musing points. Pikas found to lick their fur and scratch body by hind paw (Fig. 6.2 E-F). They spend $3.78 \pm 0.36\%$ time of their overall activity budget in grooming behaviour. The amount of grooming behaviour is comparatively higher in autumn (6.08-3.77%) than summer or monsoon (Table 6.1). Significant seasonal difference were observed in early morning and evening hours in alpine, late morning hours in timberline and afternoon hours in subalpine zone (Table 6.2).

Vigilance: Pikas generally found to perform this behaviour while foraging, before locomotion or musing (Fig. 6.2-C). Vigilance found to be consisted of $10.65 \pm 0.92\%$ of overall activity budget. Time spent for vigilance was comparatively higher during midday hours than early morning, afternoon or evening hours (Fig. 6.3). Pikas found to spend comparatively more time in vigilance in summer and monsoon than autumn (Table 1). Significant seasonal differences were observed in amount of vigilance at timberline zone during late morning hours only (Table 6.2). Pikas always found to spent more in vigilance in the habitat with less amount of rock cover (Fig. 6.5)

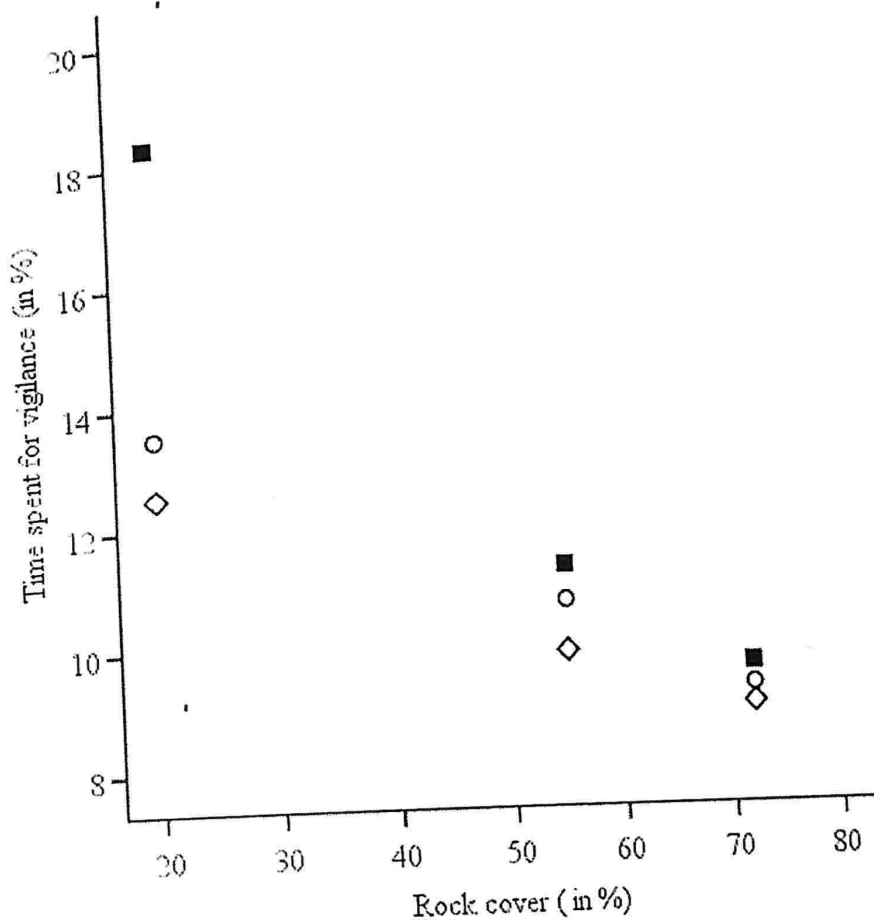


Figure 6.5 The relationship of amount of habitat rock cover and time spent in vigilance by adult Royle's pika during summer (■), monsoon (◇) and autumn (○)

Vocalization: Pikas occasionally found to call if found any unusual movement in surrounding environment. Calls were very weak, short and no variation was observed. No seasonal variations were observed in time spent for vocalization at any altitude zone. It contributed comparatively high in activity budget during summer (1.99-0.85%) than other seasons (Table 6.2)

Behavioural sequences analysis results were summarized in Table 6.3. The results showed during summer morning hours, foraging as well as vocalization was followed by locomotion whereas no prominent behavioural sequences were observed during day hours. During summer evening hours foraging, long musing and grooming were followed by locomotion. During monsoon majority of behavioural states were succeeded by grooming or vocalization, while in some cases foraging was followed by locomotion, locomotion was followed by long musing, long musing were followed by vigilance.

Autumn behavioural sequence results indicated that most behavioural states were either succeeded by foraging or 'locomotion. Though there are some observations which also showed foraging was followed by long musing or locomotion, long musing was followed by grooming and grooming was followed by vigilance.

Unlike adult pikas, juvenile pikas exhibit only six behavioural states. No juvenile pikas found to exhibit long musing behaviour. Juvenile were first encountered in summer between mid-May to early June. In lower altitude (subalpine) juveniles were encountered earlier than higher altitude. They were half of the size of their adult counterpart with very smooth light brown coat color, no mounting or scar marks. Majority of their summer activity budget were consisted of movement (100-28%) followed by foraging (71-60%) and vocalization (9-7%, Fig.3). During first two week all juveniles move at around the burrows and gradually start to venture comparatively larger area. Often adult pikas were found to govern juvenile pika activity during first two weeks. During monsoon juvenile pikas were observed to spend more time in feeding (73-40%), than locomotion (40-26%). Apart from these two behaviour, they also observed to become more vocal (15-2%) and vigilant (25-5%) as well as spend time in maintenance behaviour like grooming (7-4%) during monsoon.

Rare behaviours

Nest building: on 21st July 2009, one adult pika was observed to collect dry grass and herbs as well as plastic wrapper which were windblown to the study site from nearby tourist place at alpine observations site (Fig 6.2 G-H). It made seven trips within six minute observation period. The distance travelled during each collection trip was approximately seven meter. The pika maximizes the effort by collecting multiple numbers of grass or herbs during each collection trip. For each trip it follows same pathway.

Intra-specific interaction: Royle's pikas were found to be asocial in nature. But during some observation occasion two kind of intraspecific interaction were observed. The first was chasing a juvenile or adult by another adult and second was sharing same musing point by two adult) individuals. They were sitting very close but never observed to

interacting with each other (Fig 2-B). Though scar marks were observed on the pika ears which were generally results of aggression but very few such observation of aggression were recorded.

Hoarding behaviour: Though pikas generally show distinct food hoarding behaviour to collect winter food but no such behaviour as well as evidence of older haypile was observed during this study. During monsoon, in some habitat like mixed herbaceous meadow in timberline, Royle's pikas gathered five to six leaf or flower twigs of herbaceous food plants in front of talus interstices opening and ate them afterwards.

Table 6.2 Kruskal Wallis test statistics for significant difference in time spent for various activity (in percentage) during different observation hours (only significant results are shown)

Behavioural state	Altitude	Observation hours	Time spent (in percentage)			KW test statistics		
			Summer	Monsoon	Autumn	Chi	df	p
Foraging	A	No significant seasonal difference during any observation hours						
	T	late morning	32.0±1.13	42.0±2.32	28.32±2.66	12.51	2	0.002
	S	Day	32.56±1.07	51.58±2.63	31.73±1.34	12.53	2	0.002
		Evening	44.6±1.37	46.0±2.4	18.63±1.56	9.29	2	0.01
Locomotion	A	Early morning	15.08±2.21	17.01±2.50	29.91±2.06	9.37	2	0.01
	T	Afternoon	29.7±1.13	28.2±1.33	13.05±0.09	6.39	2	0.04
	S	Day	10.06±0.07	33.46±1.03	46.95±1.33	6.24	2	0.04
Long musing	A	No significant seasonal difference during any observation hours						
	T	Early morning	31.34±1.11	25.67±1.15	36.32±2.01	6.38	2	0.05
		Afternoon	2.54±1.12	26.2±1.09	37.0±1.17	11.48	2	0.01
	S	Early morning	25.5±2.1	11.36±1.02	52.66±1.1	7.42	2	0.02
		Evening	16.49±0.98	11.3±0.67	51.06±2.33	7.09	2	0.02
Grooming	A	Early morning	1.86±0.009	0.85±0.008	4.98±0.01	6.36	2	0.04
		Evening	4.02±0.30	3.01±0.07	20.38±1.33	16.18	2	0.001
	T	late morning	2.14±0.23	5.22±0.27	3.38±0.39	5.68	2	0.05
	S	Afternoon	6.66±0.44	0.24±0.01	1.92±0.19	5.77	2	0.05
Short musing	A	late morning	21.19±1.16	15.19±1.03	6.31±0.25	11	2	0.01
	T	No significant seasonal difference during any observation hours						
	S	No significant seasonal difference during any observation hours						
Vigilance	A	No significant seasonal difference during any observation hours						
	T	late morning	12.93±1.09	5.55±1.14	0.18±0.01	8.14	2	0.01
	S	No significant seasonal difference during any observation hours						
Vocalization	A	No significant seasonal difference during any observation hours						
	T	No significant seasonal difference during any observation hours						
	S	No significant seasonal difference during any observation hours						

Table 6.3 Summary of behavioural sequence or transition (a preceding [pre]- successive relationship of two behaviors [Beh]) occurrence of several behaviours together. Z- Scores (The difference between observed and expected frequency of two behaviour occurred in a sequence divided by their standard deviation) used to understand the power of sequential dependence of two behaviours. Z-score between -1.96 and +1.96 were considered as statistically significant hence not reported. (F= foraging, LM=long musing, L=locomotion, G= grooming, SM=short musing, VG=Vigilance, VOC=vocalization).

Season	Monitoring hours	Pre. Beh.	Successive Beh.						
			F	LM	L	G	SM	VG	VOC
Summer	Morning	F		-10.5	8.61				-2.18
		LM	-9.93		-7.04		-2.03	-2.8	-2.34
		L		-7.92			-2.02		-2.33
		G		-2.01					
		SM		-2.03		-3			
		VG							
		VOC	-3.52	-2.34	2.53				
	Day	F		-2.64			-4.43	-4.4	
		LM					-2.52		
		L					-4.73	-2.8	
		G	-2.29						
		SM							
		VG	-2.08						
		VOC							
	Evening	F		-7.74	5.18		-5.07		
		LM			6.38		-3.34		
		L		-4.69			-3.6	-2.1	
		G	-3.98		4.49			-2.1	
		SM			-4.16				
		VG	-3.88	-2.77	-2.04				
		VOC							
Monsoon	Morning	F		-12.7	11.93	1.96	-3.07	-2	
		LM	-9.04		-9.32	-3.4	-2.14	-3.6	
		L		2.64		4.24	-2.04	-2.7	2.53
		G	-3.7				3.07		-22.52

Autumn		SM				2.33			8.26
		VG			-4.81	2.75			9.57
		VOC							
	Day	F		0	-5.42	5.05	-6.7	-9.5	
		LM							
		L				-2.6	-5.85	-4.6	
		G	-4.04					-2.1	
		SM	-5.8					6.45	
		VG	-2.55			3.12	-3.21		5.24
		VOC				3.99			
	Evening	F		-10.4	5.25		-4.48		
		LM	-8.59		-6.89	-2.7		-3.2	
		L	-3.38	-3.79			-2.69		
		P	-3.54						
		SM	-2.08	-2.16	-3.21				
		VG	-3.13		-3.31	4.64			
		VOC							
	Morning	F		-12.2	9.9				
		LM	-7.85		-8.31	6.23		-4.6	
		L	8.21	-8.16					
		G		-2.95	3.03			3.93	
		SM							
		VG	3.24	-2.79	-2.77				
		VOC							
	Day	F		15.06	3.86	-4.5	-2.57	-5.3	
		LM	-3.69						
		L	8.28	5.64		-4.1	-4.1	-4	
		G	-2.34		2.85				
		SM							
		VG	1.98		-7.04				
		VOC							
	Evening	F		-11.7	12.53		-4.04	-5.9	
		LM	-7.7		-10.1	-4.3	-4.35	-4.8	
		L	5.46	-12.2			-3.45	-2.6	
		G	-2.4	-4.28	4.68				
		SM	3.9	-4.35	-3.45			5.04	
		VG	6.22	-5.83	-5.01				
		VOC							

6.4 Discussion

Activity is considered as one of the most important factor which governs the variability of physiological condition among small mammals (McNab and Morrison 1963; Hart 1971). Earlier research showed food, predation risk and weather condition such as temperature were important factors which affects activity budget (Nakagawa 2000; Chiarello 1993; Harrison 1985; Iwamoto and Dunbar 1983). Most of the pika species generally avoid midday heat during summer. Some pika species, like Japanese pika (*O. hyperborea*) is found to be active during early morning and late evening during most part of the year, excepting the monsoons when it remains active throughout the day (Broadbooks 1965; Kawamichi 1969). American pika (*O. princeps*) reported to be inactive during early day time at lower altitude and remains active throughout the day at higher altitude (Hall 1946; Smith 1974) whereas Collared pika (*O. collaris*) in Canada remains active throughout the day. In winter large eared pika (*O. macrotis*) remains active all day as it inhabits comparatively higher altitude than Royle's pika (*O. roylei*) which remains active only during dawn and dusk in winter in Nepal (Kawamichi 1971). The results of present study also indicate that Royle's pikas showed the tendency to avoid the midday heat during summer. As the high temperature periods were comparatively longer in lower altitude therefore, periods with low activity was also longer in lower altitude (Subalpine) than its higher counterparts (alpine and timberline). High relative humidity during monsoon probably nullify some impacts of high temperature and allow pikas to remain comparatively more active than summer even during midday hours.

Physiological constraints are also considered as important determinants of the distributional limits of species and populations (Gaston and Spicer 1998; Chown and Gaston 2000). Pikas are reported to have comparatively higher (2-3°C) body temperature than other small mammals who reside in talus areas, due to a thick fur layer and the presence of micro-organisms such as bacteria which aid in digestion (MacArthur and Wang 1973). Earlier studies focused on behaviour and physiology of American pikas (*Ochotona princeps*), a similar talus dwelling species like Royle's pika indicated that the thermoregulation process in pikas are mainly behavioural rather than physiological; a

brief exposure to medium ambient temperatures (25.5-29.4°C) and intense solar radiation can cause death in pikas (MacArthur and Wang 1973, 1974; Smith 1974). The American pika also has limited capability to prevent heat stress due to relatively constant high body core temperature (40.1°C), and a low upper lethal temperature (43.1°C, MacArthur and Wang 1973). They effectively use their talus habitat for thermoregulation since the talus habitat provides a cool and moist refuge in summer months and insulation from cold in winter months (Beever *et al.* 2010). During this study, the Royle's pikas also showed take shelter within their talus habitat during warm midday hours to avoid heat stress. Pikas also found to have comparatively less developed visual and motor system than auditory system (Seki *et al.* 1983). But the mid brain rubro-cerebellar system closely associated with extra-pyramidal motor functions found to be markedly well developed than other lagomorphs (house rabbit) or rodents (rat) which allows them to remain active during low day light hours and escape from mid-day heat stress (dawn and dusk hours, Seki *et al.*, 1983).

No evidence of hoarding behaviour was observed in Royle's pika during this current study. Kawamichi 1968 also reported absence of typical hoarding behaviour in Royle's pika in Nepal. Pika habitats in Himalaya generally completely covered by snow only for short period of times (especially in lower altitude) and often pikas do have access to moss, dry grasses and lichens during winter. Therefore, Royle's pikas in the study area did not show any typical hoarding behaviour. American pika is especially famous for their hoarding behaviour, but even they did not show strong hoarding behaviour in some area where they have access to vegetation during winter (Simpson 2009). After the long scarce severe winter, short growing period (summer and monsoon) is the only time for them to acquire adequate energy through feeding. However, high diurnal temperature during summer forces them to remain inactive for a significant amount of day light hours. The juveniles were also born in late summer and lactating females also spend more energy to raise the juveniles. Therefore, during monsoon when herbaceous plant growth and availability were highest, pikas spend highest time in foraging behaviour which probably results gradual increase in foraging time from summer to monsoon and decrease from monsoon to autumn. Earlier research in burrowing pikas such as plateau pika showed high activity during pre-breeding seasons (Yin *et al.* 2006) where as our study

showed Royle's pikas which is a talus dwelling pika, were more active during post breeding season when food availability was highest. Earlier research (Smith 1977; Miltion 1980) also indicates animals tend to spend more in foraging than other behaviour when food availability is high. Therefore, increased time allocation for energy consuming process like foraging during monsoon possibly also reduced the time budget for other behaviour like long musing or grooming.

During autumn majority of herbaceous plant were under go senescence. Thus, pikas spend more time in locomotion to access larger area to forage. Low food availability also might increase time budget for other behaviour like long musing or grooming. Kawamichi (1969) reported that pikas wash and scratched their body to get rid of parasites. High post monsoon parasitic load and access larger area to forage during autumn probably made pikas more susceptible to ecto-parasite infection. Therefore, pikas probably spend more time in grooming to clean their hair form dirt and parasites during autumn than summer or monsoon.

Being a central place forager pikas venture out from their nest with in the talus and return after each bout (Orians and Pearson 1979; Roach *et al* 2001). Therefore, predation risk is one important cost associated with each foraging bout for pikas as well as other central place foragers (Krebs 1980; Chase 1998). Earlier studies in other talus dwelling pikas (Collared pikas) showed that in the absence of effective talus escape cover, they tend to forage within close vicinity of the rock talus even though high nutritive plants were available in the open alpine meadows (Holmes 1991; Morrison *et al.* 2004). Roach *et al.* (2001) reported similar observation in American pikas where they venture out far in to the open meadows for foraging only when the talus is well connected. This study also showed that talus rocks provides pikas escape cover from small (Himalayan weasel) and medium sized (Himalayan yellow throated marten and red fox). Thus, pikas spend more time in vigilance in all season at the study plot which has less rock cover.

The acoustic information (vocalization) often considered as an important way to understand surrounding environment. Vocalization is prominent behaviour among pikas. Various type of vocalizations were reported for Japanese pikas (Oestrous call, diestrous

call, juvenile call, winter call; Kawamichi 1971) as well as American pika (short and long calls; Conner and Whitworth 1985) which were related to different other behaviour such as vigilance, nursing, aggression. Pika's ability to scan its habitat frequently as well as excellent escape cover provided by its talus habitat might reduce the effectiveness of vocalization in many occasions. Ivins and Smith 1983 reported that pika's respond differently to various predators. They called less frequently in response to a weasel which is comparatively more effective predator than marten. This asymmetric behaviour help them to reduce individual predation risk and also indicate that pikas are less depend on vocalization. Similar to other small mammals, pikas probably use contextual information collected from a limited number of signals for communication with other individuals as well as escape from predators (Conner 1982). Thus, in spite of weak vocalization, Royle's pika can effectively communicate with others as well as reduce predation risk. As pikas spend least amount of time in vocalization therefore, there was no seasonal variation observed. But surprisingly behavioural sequence results suggested vocalization was closely associated with other behaviours.

Royle's pika raised their juveniles in summer though typical maternal care system reported to be absent in similar talus dwelling pikas like American pika (Whitworth 1984) and most of the small carnivores like Himalayan weasel, Himalayan yellow throated marten were encountered in high rate at pika habitats during summer months only (Adhikari *et al* 2011). Therefore, pikas spend more time in vigilance and vocalization was more frequent during summer than monsoon or autumn. During summer as adult female lactates, thus, juvenile pikas spend more time in locomotion than energy acquiring behaviour like feeding. While during monsoon juvenile pika become two month old, more experienced with their habitat, therefore spend more time in foraging than locomotion.

Due to recent change in temperature-precipitation regime American pika was found to be dramatically contracted its range in North America (Beever 2003). Galbreath (2009) predicted that global warming might also dramatically alter this species' genetic diversity distribution. Even the Ili pika (*O. iliensis*) in China has experienced recent and drastic range retractions, putatively due to increased temperature, possibly due to global

warming (Li and Smith 2005). The Himalayan region also reported to be highly susceptible to global warming (Singh and Bengtsson 2004). But absence of scientific studies focused on basic ecological information about important prey species such as pikas that play significant ecological role in alpine ecosystem; it is difficult to make predictions about how they will respond to future climate change in Himalaya. The present study uncovers basic information about seasonal time-activity budget of Royle's pika in different altitude which can be used as baseline information for future long term pika research specially focused on behavioural ecology and energy budget to understand effects of climate change in alpine Himalaya.

7.1 Introduction

The interaction of an organism with its environment is often considered as a key to understand species traits (Parmesan and Yohe 2003). Species adapted to cold regions (high altitude or high latitude) experience marked seasonality due to short growing period for vegetation as well as long winter with thick snow cover. Therefore, species existence and distribution in mountain ecosystem have long known to be strongly influenced by ambient temperature and precipitation (Grinnell 1917; Heatwole and Taylor 1987; Körner 2007). Hewitt (2000) showed that animals adapted to cold in alpine and arctic environment experienced range expansion as well as high gene flow during last glacial periods. Hence, change in climatic regime (increased temperature and change in precipitation) might result in high niche conservatism (Holt 2003; Wiens and Graham 2005) which can create greater threat to these highly sensitive species than they faced in past climate cooling (Sala *et al.* 2000). The cold adapted alpine species have already been identified more vulnerable to climate change compared to the tropical or temperate species and alpine habitats are much more sensitive to global warming as the warming may occur more rapidly at high altitudes (Naftz *et al.* 2002; Moritz *et al.* 2008). However, species specific responses to climate change have not been documented from most of the alpine areas. Hence, detailed quantitative baseline ecological studies are needed to understand the direct and indirect effects of climate change on alpine species.

Several small mammals have shown range fluctuations regionally as well as globally in response to climate fluctuation during late quaternary (Beever *et al.* 2003; Grayson *et al.* 2006). In particular, high altitude small mammals have contracted their ranges while low elevation species have extended their ranges upwards (Moritz *et al.* 2008). A study on the ecology of American pika *O. princeps* (Beever 2003) suggests that rapid changes in climate during later part of 20th century has resulted in local extinction of this species from many parts of western United States. The American pika is an extraordinary example of how a species distribution can be altered drastically by climate

change alone, where other factors like hunting is negligible (Lyons 2003). Their low elevation range boundary was found to move upslope with rate of 145m per decade at Great basin in United States (Beever 2011). It has been hypothesized that many mountain species will migrate towards higher altitude in the event of increased ambient temperatures due to global warming (Walther *et al.* 2002). However, some species such as talus dwelling pikas (*Ochotona* spp.) are confined to small pockets of talus habitat throughout their life-span and have limited capability to migrate long distances (Smith and Weston 1990; Peacock 1997). Moreover, pikas are already confined to the higher elevations that limit their chances to disperse at higher slopes and shifts in range.

Pikas are reported to be an important keystone species in alpine –subalpine ecosystem, prey base for several endangered carnivores and strongly influence plant community composition (Bagchi *et al.* 2006; Smith *et al.* 1999). Pikas do not hibernate in winter, so they are sole winter food source for several endangered high altitude carnivores. Pikas are very much prone to heat stroke as they are densely fur coated, has high normal body temperature and relatively low lethal maximum body temperature, thus cannot dissipate heat easily (MacAurthur and Wang 1973, 1974; Smith 1974). Hence, they are easily affected by climatic fluctuation as compared to larger mammals (Adolph 1947). Extirpation of pikas due to climate change may collapse entire food web. Although Himalaya is home for seven different pika species (Smith *et al.* 1990), only few short term studies have been conducted on them so far (Kawamichi 1968, 1971). Hence, studies on various aspect of pika ecology and dependence on are urgently required. The alpine region of Himalaya is extremely vulnerable to global warming (Singh and Bengtsson 2004). It has been observed that during last two decades seasonal mean temperature in western Himalaya has increased by $\sim 2^{\circ}\text{C}$ whereas maximum temperature has increased by $\sim 2.8^{\circ}\text{C}$ (Shekhar *et al.* 2010). This implies that several habitats, micro-habitats and dependent native flora and fauna might be affected. However, without basic ecological information it is difficult to assess the possible impact of climate change on native animals in the Himalayan region.

Pikas are central-place foragers and generally philopatric (Smith and Weston 1990). High detection probability, accessible habitat, simple movement pattern and high sensitivity towards climatic variation which determines pika survival and its sub-surface

habitat usage makes pika an excellent species to carry out studies on influences of habitat microclimate on animals (MacAurthur and Wang 1973, 1974; Smith 1974). A study by Ray *et al.* (in press) also shows that the persistence of American pika is affected by micro-climatic condition as well as availability of proper habitat at higher elevation which can act as climatic refuge. Thus, studies on species – environment interaction have become significant tool for conservation biology and gaining high importance in understanding the impact of global climate change on an ecosystem (Elith and Leathwick 2009). Understanding the micro-habitat condition can help us identify the probable response of species to change in temperature or precipitation regime or factors altering the bioclimatic niche of the species (Beayer *et al.* 2011). This approach is especially useful when baseline data or historical data, essential for change detection is completely absent for a species which is highly vulnerable to climate change.

Royle's pika (*Ochotona roylei*), selected for the study, is distributed in the Himalayan region from north-west Pakistan to India, Nepal and adjacent Tibetan plateau (Hoffmann and Smith 2005), and highly adapted to sub-alpine and alpine habitats in Himalaya. In western Himalaya, Royle's pika occurs mostly in open rocky grounds and Rhododendron forests from 2500m a.s.l. up to 5000m a.s.l. (Tak and Lamba 1985). Studies on Royle's pika are scanty (Kawamichi 1968, 1969, 1971; Bhattacharyya *et al.* 2009). Some preliminary study on the distribution pattern, winter behaviour and social organization of *O. macrotis* and *O. roylei*, have been conducted by Kawamichi (1968, 1971) at Khumbu region in Nepal. All earlier studies have been conducted for a very short period and influence of microclimatic conditions on Royle's pika behavioural response has not been documented so far.

Major objective of the study was to describe daily activity pattern of Royle's pika at different altitudes and examine how these factors affect their activity patterns. Pikas show behavioural thermoregulation to cope up with micro-climatic variations, especially temperature (Smith 1974), thus prior ecological hypothesis were: i. Royle's pika activity rate would be principally influenced by habitat microclimate such as ambient temperature and moisture ii. The talus habitat will be thermally favourable and serve as thermal refuge for pikas.

7.2 Methodology

7.2.1 Behavioural observation and microclimate data collection

This study was conducted for four year (May –August in 2008, 2009; May-June 2010; June-July 2011) on monthly basis. The study area was divided into three altitudinal zones: sub-alpine (2900-3150m), timberline (3200-3350m) and alpine (3350-3680m). In each altitudinal zone, two 50×50 m² permanent plots were delineated to record the activity of Royle's pika and the microclimatic features of the habitat. Each permanent study plot was located at a minimum distance of 100 m from its neighbouring plot have similar aspect and slope. This distance was greater than the mean home range radius (82-83m²) of the species (Kawamichi 1968), to avoid overlap of individuals from adjoining plots. Pikas were observed by a 10× 40 mm Nikon binocular from high vantage point on a rock from where entire study plot is visible. Individual animals were identified based on size, moulting sign in body and scar marks in ear. The activity pattern of Royle's pika was studied through direct observation from 0600hrs to 1900hrs categorised on an hourly interval basis, thereby giving a total of 13 hours per observation session in a plot. The proportion of individual active (hereafter denoted as "activity") was indexed as percentage of individuals observed in an interval relative to the maximum number of individuals sighted on that particular day in that plot. The habitat microclimatic parameters recorded during this study were pika burrow soil temperature and humidity, habitat soil temperature and humidity and atmospheric temperature. The atmospheric temperature was recorded by automatic HOBO data loggers TM. Data loggers were programmed to record temperature reading every ten minutes, and were placed in secure place away from direct sunlight. Temperature data was downloaded and analysed to yield hourly average temperature. Pika burrows are on the talus slopes or slide rocks in natural crevices formed between the rocks. Burrow temperature and humidity of pika burrows were recorded using a soil thermometer (Reotemp Inst. Corp. San Diego, California, USA) and hygrometer (Huger, Germany), by placing them about 80-100cm within the burrow during each observation interval. Similarly, soil temperature and humidity were also measured at a random open ground location within the site.

7.2.2 Data analysis

Post hoc Student-Newman-Keuls test was used to detect significant difference in activity rate during different time intervals. The multi-collinearity present among different microclimatic variables (air temperature, soil temperature in open area, burrow temperature, burrow humidity and ambient humidity) was examined through Pearson's correlation in SPSS 16 (SPSS Inc. 1989-2007). Temperature related variables were correlated with one another ($r > 0.4$) and humidity related variables were correlated with one another. Therefore, generalised linear regression was used to model activity (binary response: the number of individual active versus inactive) as a function of predictor variables (temperature related: ambient temperature, burrow temperature, open area soil temperature; humidity related: ambient humidity, burrow humidity) in an information-theoretic (I-T) framework. Relative support for each model and each predictor was compared (AIC, Burnham and Anderson 2002) and most important temperature and humidity related variable (ambient temperature and humidity, see results below) were used in further analysis to predict their relationship with pika activity. The diurnal ambient temperature and humidity might be influenced by altitude zone as well as time of the day. Therefore, ambient temperature was first regressed with altitude zone and the un-standardised residuals were saved. Furthermore, these un-standardised residuals were regressed against time of the day to get residuals of ambient temperature which was neither influenced by altitude zone nor time. Same procedure was followed for ambient humidity.

Pika activity was (binary response) modelled as the number of individual active versus inactive with logical alternate combinations of ambient temperature, ambient humidity residual values, altitude zone, time group. Although pika observation were separated by different site as well as time interval for independence of observations, the nesting of pika observation within site might lead to a different kind of dependence which would violate assumptions related to independence of regression technique (Zar 1999). To rule out this problem, generalized linear mixed effect models (logit link and binomial errors) were used with different site as random intercept and year as slope. This method helps to

identify the natural grouping of observations and would also explicitly accounted for random variations in the odds of activity between sites as well as year that might arise from intra-site or year correlations, with other factors remaining constant (Zuur *et al.* 2009). Following Zuur *et al.* (2009), candidate models were designed by Laplace approximation and Maximum Likelihood parameter estimation using lmer function of lme4 package in program R (The R Foundation for Statistical Computing, <http://www.rproject.org/>). Each candidate model was formulated based on one or more predictor variables. It was predicted that pika activity rate would be- i. influenced by additive as well as interactive effect of ambient temperature and humidity and ii. depend on interactive as well as additive effects of altitude zone, time of the day, ambient temperature and humidity. In total, seven models for pika activity and microclimate were compared for support of various hypotheses including a null (intercept-only) model. Information theoretic approach (AIC) were used for selection of the best fit model (lowest AIC), and obtained final parameter estimates by Restricted Maximum Likelihood method. Paired t test was used to examine if the microclimatic conditions (ambient temperature and humidity) within pika burrows were significantly different from the outside environment during midday hours. This would help us to understand if burrows act as thermal refuge for pikas or not.

7.3 Results

In the sub-alpine zone the pika habitat included forest gap with big rocks (2900m) and broken slope (3150m) with big as well as medium sized rocks. The pika habitat in the timberline zone was found in broken slope (3280m) with rolling boulders and embedded rocks interspersed with mixed herbaceous meadows (3300m). The pika habitat in the alpine zone was mostly confined to the areas having medium sized rocks found in the broken slopes (3444m) and rubble walls (3520m). The range of maximum individuals detected in any site over year across all visits of a year was 0-2 individuals, showing that our assumption of maximum number of individual observed during each observation sessions can be a reasonable surrogate of population size of that plot.

Royle's pika showed a bimodal activity pattern during a total 936 hrs of observation in different altitudinal zone (Fig.7.1). The post hoc ANOVA test detected three groups viz., morning, day and evening, of activity based on time (Table 7.1). Maximum activity was observed in early morning and evening while activity pattern dipped to its lowest during the midday time. The year 2009 was the warmest and driest during the whole study period. During May- June 2009, pika activity completely ceased from 1200 to 1400hrs in alpine zone and from 1100hrs to 1400hrs in the sub-alpine zone. However, in timberline zone the activity was lower but did not stop altogether. No such complete cessation of activity was recorded during 2008, 2010, and 2011. Pika activity was highest at Timberline zone during morning ($73.73 \pm 2.61\%$) and evening ($80.00 \pm 2.46\%$) whereas it was highest ($34.98 \pm 2.04\%$) during day at alpine zone. Low pika activity was recorded at subalpine during all time groups and lowest activity was observed during midday ($19.22 \pm 1.69\%$).

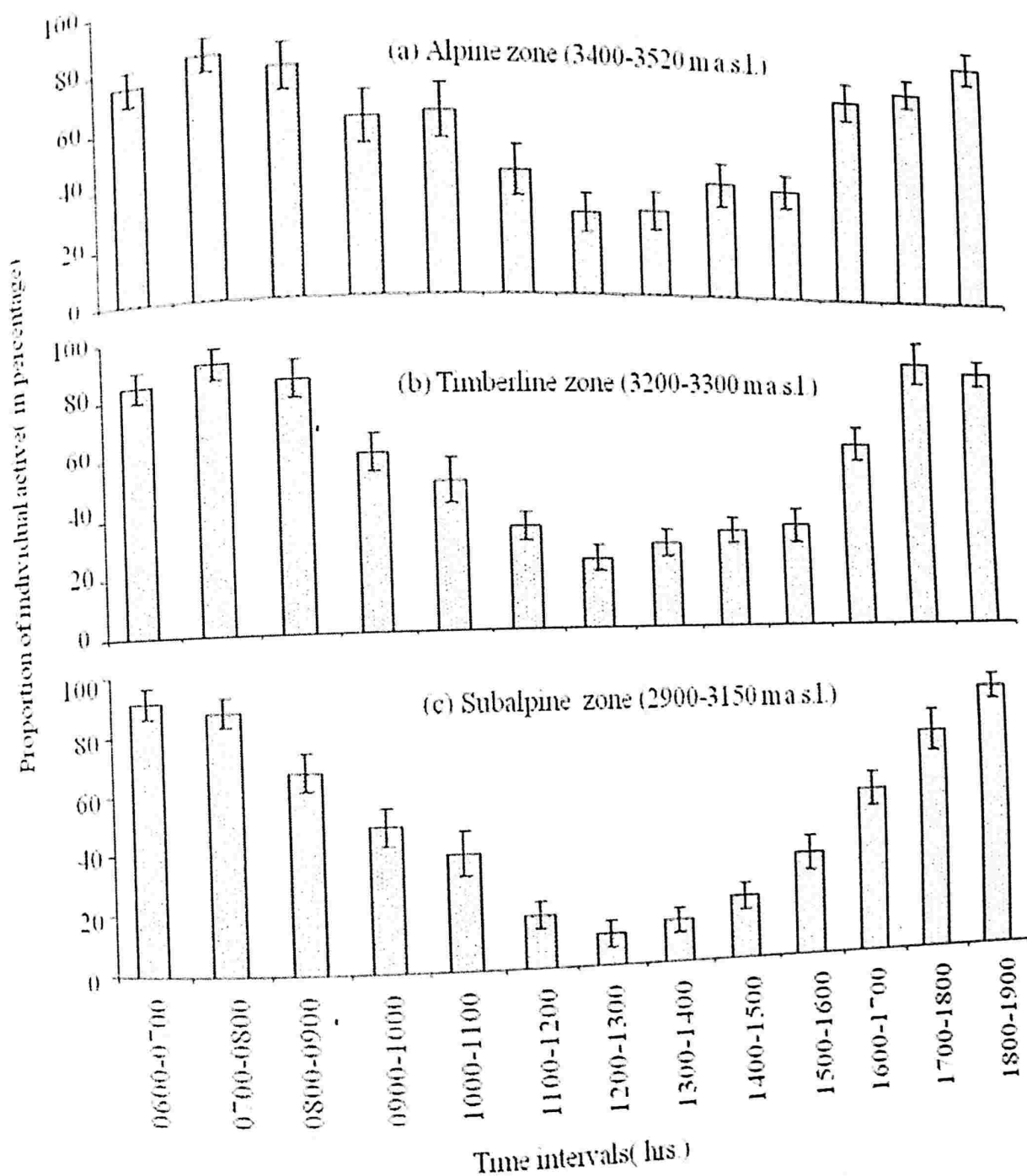


Figure 7.1 Royle's pika activity at different altitude zone during various time intervals in a day at Tungnath region of Kedarnath Wildlife Sanctuary during May to August (2008-2011)

Table 7.1 Summary statistics of Post hoc Student-Newman-Keuls test for significant difference in activity rate during different time group. The time interval was reclassified into time classes which have similar activity rate and also with contiguity with each other. This way three time classes were obtained.

Observation Hours	Reclassified Time group	Activity rate subset for alpha = 0.05		
		1	2	3
1200-1300	1100-1600hrs	20.11 $\pm$ 2.26		
1300-1400		23.34 $\pm$ 2.29		
1100-1200		28.27 $\pm$ 2.86		
1400-1500		28.95 $\pm$ 2.41		
1500-1600		34.94 $\pm$ 2.08		
0700-0800	0600-1100hrs		41.70 $\pm$ 3.89	
1000-1100			43.5 $\pm$ 3.11	
0600-0700			44.15 $\pm$ 3.70	
0900-1000			46.90 $\pm$ 2.84	
0800-0900			48.77 $\pm$ 3.56	
1700-1800	1600-1900hrs			51.06 $\pm$ 3.63
1600-1700				52.31 $\pm$ 2.61
1800-1900				39.90 $\pm$ 3.83

The microclimatic condition of pika habitat suggested that pika burrows were generally cooler and moist than the outer environment (Fig. 7.2). During warm midday hours when outside environment was hot and dry, pika burrows were found to be significantly cooler (burrow temperature: 10.0 ± 0.01 °C, ambient temperature: 12.40 ± 0.14 °C; paired t test: $t = -18.22$, $df=359$, $p<0.001$) and moist (burrow humidity: 62.62 ± 0.08 %, ambient humidity : 60.43 ± 0.96 %; paired t test: $t = 3.11$, $df=359$, $p<0.01$). But during early morning (0600-0800 hrs) and late evening (1800-1900 hrs) pika burrows were found to be significantly warmer (Early morning hours- burrow: 8.59 ± 0.25 °C, ambient: 7.32 ± 0.27 °C, paired t test- $t= 12.12$, $df =143$, $p<0.001$; late evening hours- burrow: 9.66 ± 0.20 °C, ambient: 8.40 ± 0.21 °C, paired t test, $t= 9.39$, $df=73$, $p<0.001$) than outside environment.

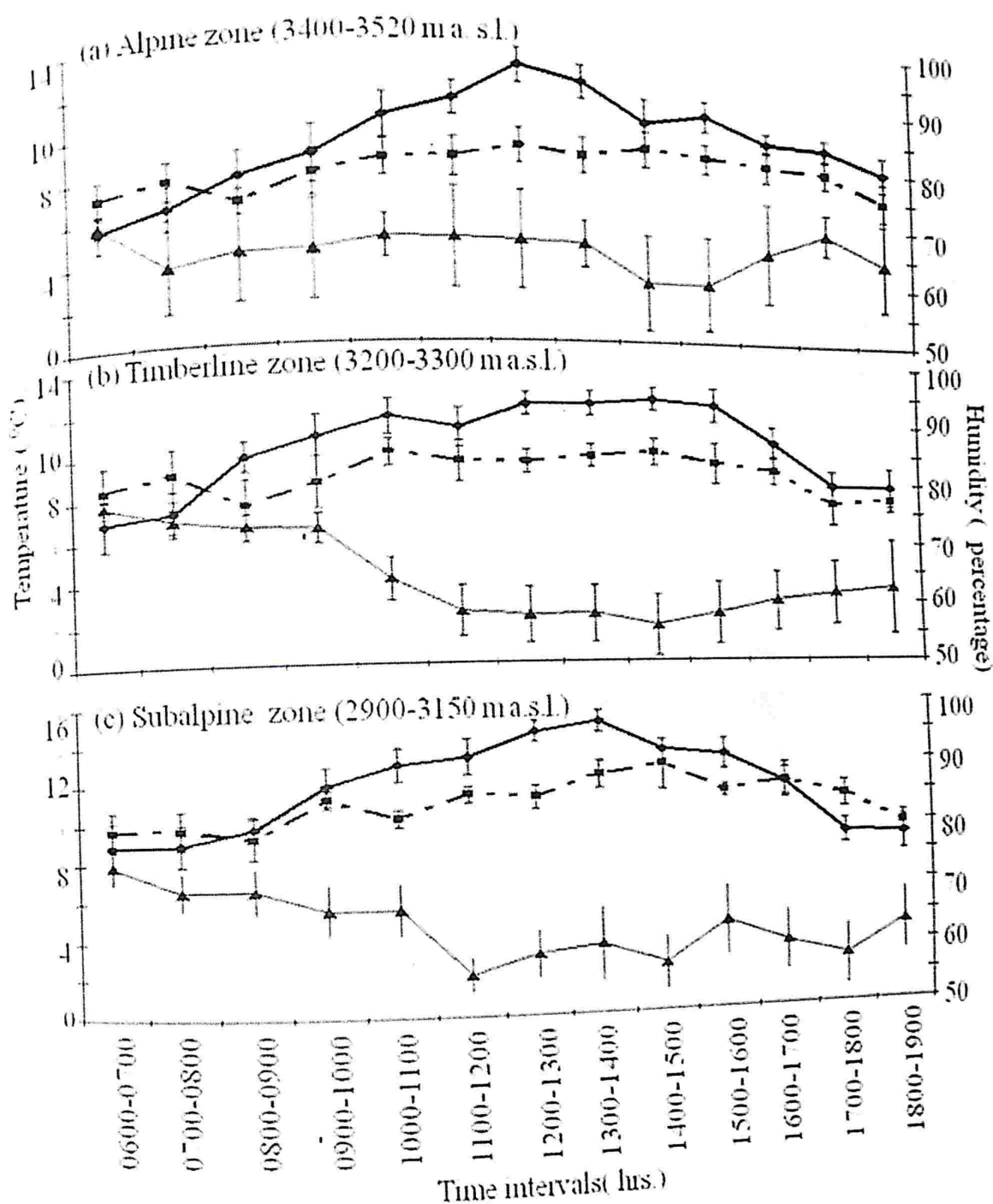


Figure 7.2 Royle's pika habitat microclimatic parameters in different altitude zone and time intervals (ambient temperature =——, burrow temperature =----, ambient humidity =.....) at Tungnath region of Kedarnath Wildlife Sanctuary during May to August (2008-2011)

Ambient temperature and humidity received more support ($\Delta AIC > 2$) than null model as well as other temperature related variables (burrow soil temperature, open area soil temperature) and humidity related variable (burrow humidity) to explain pika relationship of activity and microclimate. Therefore, ambient temperature and humidity were used for

further analysis to identify how pika activity was governed by direct or interactive influence of habitat microclimatic conditions as well as altitude and time of day.

The best candidate model to explain relationship of pika activity and habitat micro climate received more support than the null model ($\Delta AIC = 1263.83$) and no other model received similar support (all ΔAIC values were greater than 2, Table 7.2). The standard deviation of random effects of site was negligible ($SD=10^{-13}$), but standard deviation for year across site was large (Year 2009, Std. Dev. = 0.034; Year 2010, Std. Dev. = 0.052; Year 2011, Std. Dev. = 0.076). This implies that much of the variation in activity were random variation between site year combination. In the best model, proportion of pika activity was found to be governed by additive effects of ambient humidity, time of day and interactive effects of ambient air temperature and altitude zone. The best fit model's β -coefficients estimates suggest a negative influence of ambient temperature ($\beta = -0.143 \pm 0.01$, $p < 0.001$, mean $\pm$ SE) and a positive influence of ambient humidity ($\beta = 0.017 \pm 0.001$, $p < 0.001$, mean $\pm$ SE) on pika activity (Table 7.3). It also suggests pika activity was significantly low in subalpine zone ($\beta = -0.433 \pm 0.08$, $p < 0.001$, mean $\pm$ SE) in comparison to alpine zone. The pika activity was significantly low ($\beta = -1.48 \pm 0.074$, $p < 0.001$, mean $\pm$ SE) during day time hours than early morning or evening hours. The interactive influence of ambient temperature and altitude zone suggests if ambient temperature increases then the pika activity will significantly reduce ($\beta = -0.069 \pm 0.02$, $p < 0.05$) in subalpine zone than alpine or timberline zone. The random effect of the best fit candidate model indicates all different sites have very low influence.

Table 7.2 Relative support to various candidate models explaining competing ecological hypothesis about factors affecting activity of Royle's pika using information theoretic criteria (minimum AIC). Log-likelihood (L), degrees of freedom (df), Akaike's information criterion (AIC), difference in Akaike's information criterion (Δ AIC) were reported for each model.

Model (predictor)	-2×Log(L)	df	AIC	Δ AIC
Ambient temp.*altitude + ambient humidity+ time	-638.39	19	1314.79	0
Ambient temp.+ ambient humidity+ altitude + time	-643.46	17	1320.94	6.14
Ambient temp.*ambient humidity+ time	-645.4	16	1322.81	8.01
Ambient temp.+ time	-681.25	14	1390.5	75.7
Ambient temp.	-965.9	12	1955.81	641.01
Ambient humidity	-1239.3	12	2502.52	1187.72
Null model	-1278.3	11	2578.62	1263.83

Table 7.3 Estimated influence of parameters (Intercept, ambient temperature, ambient humidity, altitude zone, time group) on pika activity estimated by the best fit linear mixed effect model (minimum Akaike information criterion).

Parameter	Beta $\pm$ S.E	Z value	P value
Intercept	0.891 $\pm$ 0.067	13.84	0.001
Ambient temperature	-0.143 $\pm$ 0.017	-8.042	0.001
Ambient humidity	0.017 $\pm$ 0.001	8.699	0.001
Timberline zone	-0.004 $\pm$ 0.083	-0.052	0.958
Subalpine zone	-0.433 $\pm$ 0.08	-5.394	0.001
Midday time group	-1.486 $\pm$ 0.076	-19.5	0.001
Evening time group	0.037 $\pm$ 0.089	0.421	0.673
Ambient temperature* timberline zone	-0.033 $\pm$ 0.027	-1.193	0.232
Ambient temperature* subalpine zone	-0.069 $\pm$ 0.026	2.61	0.001

7.4 Discussion

Activity is considered to be the most significant factor which contributes to the variability of physiological states especially to body temperature among small mammals (McNab and Morrison 1963; Hart 1971). All pika population generally avoid midday heat during summer. American pika (*O. princeps*) becomes inactive during early day time at lower altitude and remains active throughout the day at higher altitude (Hall 1946; Smith 1974). Collared pika (*O. collaris*) in Canada remains active throughout the day whereas Japanese pika (*O. hyperborea*) is found to be active during early morning and late evening during most part of the year, excepting the monsoons when it remains active throughout the day (Broadbooks 1965; Kawamichi 1969). In winter large eared pika (*O. macrotis*) remains active all day as it inhabits comparatively higher altitude than Royle's pika (*O. roylei*) which remain active only during dawn and dusk in winter in Nepal (Kawamichi 1971).

In the present study, daily activity pattern of Royle's pika suggests the tendency to avoid the day time warm temperature, being highly active during early morning and late evening hours. Increase in activity was observed with increase in altitude. This observation supports the fact that, like other talus dwelling pikas (American pika), thermoregulation by Royle's pika might be behavioural rather than physiological. When stressed under high temperature they seem to be restricting their diurnal activity more in lower altitude (Smith 1974). The best fit regression model also shows the negative impact of temperature and positive impact of humidity on Royle's pika activity rate. It can be inferred from the observation that pikas prefer low temperature, but at times they can be active if the humidity is higher. This observation supports the first ecological hypothesis that predict temperature and humidity as a key components which control the behaviour of pikas and this impact is stronger at lower altitude than that of other altitudes.

Pikas spend 25-55% of their surface activity in foraging (Smith and Ivins 1983). The results show that the daytime activity in subalpine zone is significantly lower than alpine

zone. The low activity (below 40%) hours was also found to be comparatively long (five hours) in subalpine than alpine (two hours). Our result also show that reduction in activity due to increase in ambient temperature was significantly higher in lower altitude habitat (subalpine) than higher altitude (alpine). Thus, Royle's pika shows difference in activity at different altitude due to variation in ambient temperature. Royle's pika does not hoard winter hay pile (Kawamichi 1968). Hence, after the long scarce severe winter, summer-monsoon is the only time for them to acquire proper energy through feeding. However, high diurnal temperature might force them to remain less active for large amount of day light hours. Hence, pikas might get less opportunity to feed. High midday temperature might also force pikas to restrict their activity in day. Hence, become more active in twilight hours which might lead to an increased predation risk.

Different types of physiological constraints can be important determinants of the distributional limits of species and populations (Gaston and Spicer 1998; Chown and Gaston 2000). Generally pikas have a comparatively higher ($2-3^{\circ}\text{C}$) body temperature than other small mammals who reside in talus areas, due to a thick fur layer and the presence of micro-organisms such as bacteria which aid in digestion (MacArthur and Wang 1973). Earlier studies on the behaviour and physiology of American pika which has similar ecological requirements like Royle's pika, showed that they become hyperthermic and die at even a brief exposure to medium ambient temperatures ($25.5-29.4^{\circ}\text{C}$) and intense solar radiation (MacArthur and Wang 1973, 1974; Smith 1974). They have a relatively constant high body core temperature (40.1°C), and a low upper lethal temperature (43.1°C), which reflects in their poor capability to prevent heat stress (MacArthur and Wang 1973). Grinnel (1917) also suggested that temperature acts as a key factor which governs American pika distribution. Temperature is also found to be one of primary environmental factors which govern juvenile pika dispersal (Smith 1974) and most plausible predictors for most of the American pika extirpation and distribution change model (Wilkenning *et. al.* 2011).

This study also supports the facts that like other talus dwelling pikas, Royle's pika activity is also influenced by habitat microclimatic conditions specifically ambient

temperature. American pika uses the talus for thermoregulation since the talus habitat provides a cool and moist refuge in summer months and insulation from cold in winter months (Beever *et al.* 2010). Our observation of Royle's pika burrows microclimatic condition supports our second hypothesis which predicts pika burrows as thermal refuge. Results indicate that pika's burrow microclimate is significantly cooler and stable than the outer environment, especially during midday. Hence, pikas reduce their surface activity and remain in their burrows during warmest time of the day to avoid heat stress. Besides direct effects of warm temperature, there may be several ecological processes such as diseases which can spread rapidly in warmer temperature in an already heat stressed susceptible pika population. Pikas serve as host for several parasites some of which may be vector for various diseases (Severaid 1955). It has been reported that Ili pika (*Ochotona iliensis*) populations are closely linked with Sylvatic plague, a flea-vectored bacterial disease endemic to Asia and possibly causes dramatic population decline (Biggins and Kosoy 2001; Li and Smith 2005). Mechanism through which climate stress acts need to be studied properly in order to understand how and why biotas are affected by climate change as well as for a wider application in information, monitoring, management and conservation strategies (Hallett *et al.* 2004; Ray *et al.* in press). An understanding of factors influencing Royle's pika activity is a prerequisite for evaluating the long-term viability of the species in Himalaya. If climate in the lower altitude becomes inhospitable due to change in climatic regime for Royle's pikas, they are likely to move upslope like other alpine mammalian species (Guralnick 2007). Though this upslope range shift might help them to cope with warming climate, but it may not improve connectivity between habitats which in the long run will reduce resilience capacity of pika population towards any threat including climate change (Gilpin and Soulé 1986; Sekercioglu *et al.* 2008) and finally could lead to local extinction of the species.

8.1 Introduction

The dynamics and complexity of forage quality, accessibility and abundance influence food selection in herbivores (Stephens and Krebs 1986; McNaughton and Banyikwa 1995). Herbivores have evolved to forage on a particular phenophase of select food plants that meets their nutritional requirements (Belovsky 1978; Robbins 1983; Stephens and Krebs 1986; Belovsky and Schmitz 1991). Moore and Foley (2005) stated that an individual selects its forage from a complex nutritional environment. Thus, it is desirable to know how herbivores evaluate and select their forage based on nutritional characteristics, given plant chemical and physical defense mechanisms (Robbins 1983). During 1960's, the theory of optimal foraging emphasized that the food selection is governed by the energy value per unit cost which is often considered as the time and distance travelled to obtain the diet. But during 1970's, nutrient balancing and minimization of toxic materials in food plants obtained more attention (Westoby 1974; Pulliam 1975). In general, foraging theory indicates the tendency of herbivores to maximize foraging efficiency by consuming highly nutritive forage or by avoidance of toxins or indigestible materials (Stephens and Krebs 1986). Nevertheless, mechanism through which a herbivore maximizes its foraging efficiency remains a key area of research in nutritional ecology.

Nutritional ecology involves study of organic (e.g. fiber, carbohydrates, nitrogen or protein) as well as mineral (e.g. calcium, phosphorus, potassium, sodium, magnesium) contents. Macro-minerals form important structural components of various tissues and bones, maintain acid-base balance and membrane electric potential in animals (MacDowell 1992; NRC 2001). Lignin and fiber also play important roles in herbivore food selection (Calvert 1985).

Pika, a small lagomorph and generalist forager at high altitudes, provide an excellent opportunity to study food selection. The influence of various intrinsic and extrinsic predictors of forage selection has been well studied in North American pikas, while

comparatively fewer studies have documented these behaviours in talus dwelling pikas of Asia (Millar and Zwickel 1972; Smith 1974; Dearing 1996; Morrison *et al.* 2004; Gliwicz *et al.* 2006; Morrison and Hik 2008). Pikas generally forage on standing vegetation around their talus habitat. Most pikas actively forage during early summer and start to collect and hoard food plants during late summer in hay piles for winter consumption (Dearing 1997). The hay piles play crucial role in winter survival and maintaining fecundity in early spring (Huntly *et al.* 1986; Morrison 2007). Unlike other talus dwelling pikas, Himalayan pika species have not been studied in terms of food selection and ecology (Kawamichi 1968, 1971). For the present study, Royle's pika, a widely distributed species in the western Himalaya, was selected to understand how this generalist forager selects its food plants in a highly seasonal environment. This is a relatively easy species to observe, allowing for the study of various ecological hypotheses in both field as well as experimental conditions.

Royle's pika (100-150g; Alfred *et al.* 2006) is distributed in open rocky grounds and rhododendron forests from 2400m a.s.l. up to 5000m a.s.l. in the Himalayan region from North-West Pakistan to India (Jammu and Kashmir, Himachal Pradesh and Uttarakhand), Nepal and adjacent Tibet (China; Hoffmann and Smith 2005; Chakraborty *et al.* 2005). They play an important ecological role in alpine Himalaya, as they are reported to be an important prey base for several carnivore species such as marten, stoat, weasel, and red fox (Roberts 1977; Oli *et al.* 1994; Aryal *et al.* 2010).

Three different hypotheses have been used to explain diet selection (caching for winter consumption) in talus dwelling pikas. Millar and Zwickel (1972) proposed that pikas use nutritional quality or plant morphology (also Huntley *et al.* 1986) as a cue for diet selection whereas Dearing (1996, 1997a, 1997b) proposed that pikas select plants based on plant secondary compounds. Millar and Zwickel 1972 and Huntly *et al.* 1986 also suggested being central place forager pikas should show preference towards larger forage in order to efficiently manage energy gained and effort invested to gain that energy. Royle's pika live in a similar habitat in alpine environment, thus it can be predicted that Royle's pika will show a response consistent with plant morphology hypothesis. Plant species consumed by herbivores can vary significantly in their nutritional value, for example, plant species with high concentrations of crude protein and mineral or moisture

indicate high nutritional value whereas high fiber or phenolics concentration reduce digestibility, hence have low nutritional values. Thus, it can be predicted that pikas should prefer forage plants with high nitrogen and moisture while avoiding forage with high phenolics and fiber content. Descriptive as well as experimental methodologies, combined with statistical modelling techniques, were used to enhance the knowledge of plant-herbivore interaction and its influence on herbivores forage selection decision, using Royle's pika (*Ochotona roylei*), as study species in Kedarnath Wildlife Sanctuary, India.

8.2 Methodology

8.2.1 Data collection for field observation

Pika foraging behaviour was observed for two years (2008-2009) on a monthly basis during their peak activity period i.e., summer (May-June) and monsoon (July-August). The entire study area was divided into three altitudinal zones: sub-alpine (2900-3150m), timberline (3200-3350m) and alpine (3350-3680m). In each altitudinal zone, one 50×50 m permanent plot was delineated to record pika behaviour. Each permanent study plot was at a minimum 200 m distance from its neighboring plot and has similar topographical aspect and slope. Pikas were observed by focal sampling methods from morning 0600-1000hrs and evening 1500-1800hrs using a 10× 40 mm Nikon binocular from high vantage point on a rock from where entire study plot is visible (Altman 1974). As Royle's pikas are synanthropic in nature, presence of observer didn't seem to influence their natural activity (Kawamichi 1968). During each observation, food plant species specific bite counts were recorded. The relative bite counts were calculated with the help of following formula (Krebs 1999): $\text{Relative bite count} = (\text{Number of bites of a particular species in a site} / \text{total number of bite sampled in that site during observation session}) \times 100$. It gave us the percentage of bite count. Only food plants which contributed a minimum 5 percent of total bite count observations in a plot were considered for further cafeteria experiments and nutritional analysis. Plants which were highly abundant in environments but never selected by pikas (N=4) were also considered for both cafeteria and nutritional analysis as they could provide more insight on food selection.

Fourteen 1m×1m traditional quadrats were surveyed to estimate food plant (identified during observation sessions) density in each study plot. Leaf area cover was measured by tracing leaf (N=10) of each species on a 1mm x 1mm graduated the graph paper (Pandey and Singh 2011). After removal of the leaf, the numbers of whole as well as $\frac{3}{4}$ filled square occupied by the leaf were counted. Numbers of half-filled square were also counted and this total was divided by two. The total leaf area was obtained after combining all numbers of squares together.

Selectivity occurs when a feeder consumes available and co-occurring edible resources at different rates (Jacob 1974). Earlier research has suggested many measures of preference such as forage ratio (Savage 1931) or Ivlev's selectivity index (Ivlev 1961). Both of the previously mentioned indices depend not only on the selection but also on relative abundance of the food resource in environment. Therefore, they are less applicable in field ecological research where relative abundance of different food resources varies significantly in the environment or in studies which aim to understand the relation between selection and relative abundance (Jacob 1974). Thus, Jacob's selection index was used to understand plant selection preference.

Jacob's selection index (D ; Jacob 1974) = $a - b / (a + b - 2ab)$, where, a = Bite count of a food plant species, b = availability (percent cover per m^2) of food species in environment.

8.2.2 Data collection for Cafeteria experiments

The food preference of generalist herbivores (pikas) was also studied in standardized conditions using a cafeteria-style arrangement or feeding trials. Pikas are allowed to feed selectively on various combinations of food plants placed in front of their nest opening (Krebs 1989). All food plants in this cafeteria experiment were provided with equal biomass. Each experiment lasted for one complete foraging bout of a pika, starting when it came out from its nest, throughout its consumption of feeding trial plants, and concluding when the individual went back to its nest. After a complete bout, change in biomass for each species was recorded using a digital field weighing balance. The difference in initial and final biomass of each species provided in the experiment was expressed as a percentage and further used in calculating Jacob's selection index for those species. Food

plants used in cafeteria experiment generally lost their moisture content very fast. Thus, if a cafeteria experiment set was not visited by a pika for more than one hour, then the entire set was replaced by fresh food plant species.

8.2.3 Nutritional analysis of food plants

Forage plant species samples (350g) were collected from adjacent areas near pika habitat within permanently marked plots for nutritional analysis. Earlier observation indicated that the majority of pika food items were leaves, thus analysis of chemical composition was mainly focused on leaves of food plants (except *Geum elatum* where both flower and leaf were used for chemical composition separately). The dry matter of food plant species was determined by overnight oven drying of sub samples at 105°C. As most of the nutritional components in plant leaf usually breakdown at 105°C, thus for other nutritional analysis, separate set of samples were dried below 50°C for 24 hrs and ground in a Wiley mill. All ground samples were further tested for their uniformity in size by passing through a 1mm mesh sieve. Moisture content was determined by oven drying, whereas percentage of nitrogen (N) content was measured by the Kjeldhal method in a Kjeltac[™] 2000 (AOAC 1990). The Neutral Detergent Fiber (NDF) for fiber content (Goering and Vansoest 1970), Acid detergent Fiber (ADF) for lignocelluloses and silica content (Vansoest 1963), Acid detergent Lignin (ADL) for lignin content (Morais and Nascimento 1991) was determined by FOSS-Fibertech[™] 2010 machine. Macro mineral elements such as phosphorus (P) were estimated by UV Spectrophotometer (Cary 100 Bio-UV visible Spectrophotometer), while calcium (Ca) and magnesium (Mg) by atomic absorption spectrophotometer (AAnalyst 700, Perkin Elmer). Potassium (K) and sodium (Na) content were estimated by flame photometer (Systronics flame photometer 128^μC; Jackson 1958) and total carbohydrates in "Anthone" method (Brummer and Cui 2005). The condensed tannin present in food plants were analyzed by Vaniline assay using catechine as standard following Hagerman (2002).

8.2.4 Data analysis

Pearson's correlation tests were used to understand the relationship of the pika food selectivity index with food plant leaf area cover as well as other nutritional components. A

relationship was considered strong when the Pearson's correlation coefficient (r) > 0.4 . All correlated variables appeared together each other in further regression models only to test for their interactive effects. Because different variables are measured in different scales, before performing further modeling, all variables were rescaled to 0 to 1.

Linear regression was used to determine if the pika food selection index as well as amount of various nutrients significantly varies across plots. Since food selection index values did not vary significantly across plots, different linear regression candidate models were formulated based on one or more predictor variables selected from *a priori* ecological knowledge available on pikas or other small mammals. Additive effects as well as interactive effects of one, two or three predictor variables on pika food selection (Jacob's Index) were also estimated. It was expected that the pika would prefer a plant if it had larger leaf area size (Millar and Zwickel 1972; Huntly *et al.* 1986) or contained high moisture, nitrogen, total carbohydrate and other macronutrient elements (Na, Ca, Mg, P, K). Similarly, pikas were expected to avoid food plants with high fiber content (NDF, ADF, and ADL) or high secondary metabolite content (e.g. Tannin; Dearing 1996). Apart from the above mentioned hypotheses, new variables were synthesized from the previously mentioned plant nutritional parameters. For example, it was predicted that pika food selection (Jacob's selection index) would be influenced by i) palatability of the food plant, which was synthesized as the ratio of positive nutrient index (moisture, nitrogen, carbohydrate, Na, Ca, Mg, P, K) and avoided substance index 1 (NDF, ADF, ADL, Tannin), or ii) positive nutrient index or avoided substance index separately, iii) the interactive effect of leaf area and palatability or leaf area and avoided substance index 1, iv) the additive influence of leaf area and amount of nitrogen, moisture, or palatability, avoided substance index 2 (ADF + ADL + tannin) or avoided substance index 3 (ADL + ADF) which is only lignin and hemicellulose content. In total, 15 models were formulated and compared to support various hypotheses. The relative support for each model as well as each predictor was compared in an information-theoretic framework using Akaike Information Criteria (AIC, Burnham and Anderson 2002). The best fit models were selected (lowest AIC i.e., that models with $\Delta AIC < 2$ considered equivalent), and final parameter estimates of best fit models were reported. All analyses and model diagnostic plots were executed through R 3.2 (the R Foundation for Statistical

Computing, [http:// www. rproject.org/](http://www.rproject.org/)). Food plant-specific Jacobs selection index values from wild and cafeteria experiments were compared (Pearson's correlation) to understand how pika food selection in the field matched cafeteria experiments. Based on the results, factors affecting food plant selection in cafeteria experiments were studied through similar hypothesis and modeling methodology mentioned earlier.

8.3 Results

Royle's pikas were reported to feed on 26 plant species (Bhattacharyya *et al.* 2009). But during this study only 17 plant species (Total bite count = 3153) were identified as major food plants for this species (Table 8.1). Pika food selection (Jacob's selection index) was highest for *Jurinea dolomiaea* (0.83 ± 0.09), *Taraxacum officinale* (0.53 ± 0.06), *Tanacetum longifolium* (0.54 ± 0.05) and lowest for *Prunella vulgaris* (-0.735 ± 0.03). The largest food plant leaf area was observed in Fern ($128 \pm 10.5 \text{ cm}^2$) and lowest in Moss ($0.1 \pm 0.007 \text{ cm}^2$). All the nonfood plants were found to contain 4 to 12 times more condensed tannin than any pika food plants (Table 8.2). Highest palatability (ratio of positive vs. negative nutritional indices) was observed in *Taraxacum officinale* (86.76 ± 1.94) followed by *Polygonum macrophylla* (83.56 ± 1.02) whereas lowest palatability was observed in *Sibbaldia cuneata* (23.61 ± 1.78 ; Table 2). Among the potential predictor variables, moisture ($r = -0.466$, $p < 0.001$), amount of calcium ($r = 0.43$, $p < 0.05$), and nitrogen ($r = 0.451$, $p < 0.05$) of food plants were found to have significant high positive correlation whereas fiber content such as ADF ($r = -0.447$, $p < 0.001$), ADL ($r = -0.475$, $p < 0.001$), and secondary metabolites such as condensed tannin ($r = -0.598$, $p < 0.001$) had significant negative correlations with food selection (Jacobs selection index; Table 8.3).

Food selection (Jacob's Index) did not vary significantly across sites in timberline ($\beta = -0.023_{\text{mean}} \pm 0.17_{\text{SE}}$, $t = -0.138$) or subalpine ($\beta = -0.055_{\text{mean}} \pm 0.18_{\text{SE}}$, $t = -0.299$) zones in comparison to alpine. The best fitting model of pika food selection in the field (Table 8.4) received far more support than that of the null model ($\Delta \text{AIC} = 42.592$) and no other model received similar support (all ΔAIC values were > 2). In the best model, the interactive effect of predictors (plant leaf surface area and avoided substance index) was found to have significant negative influence over pika food selection in the field (Table 8.5). The top model's β -coefficient estimates suggest large plant leaf positively influences

food selection ($\beta = 1.55_{\text{mean}} \pm 0.38_{\text{S.E.}}$, $t=4.023$) whereas avoided substance index (NDF, ADF, ADL, tannin) negatively ($\beta = -0.54_{\text{mean}} \pm 0.24_{\text{S.E.}}$, $t=-2.239$) influences food selection. The interactive influence of leaf surface area and amount of avoidable nutrients ($\beta = -3.16_{\text{mean}} \pm 0.63_{\text{S.E.}}$, $t= -4.97$) also had a negative influence on food selection (Table 8.5). Food selection (Jacob's selection index) in the field and in experiments was found to be highly correlated ($r = 0.742$, $p<0.001$). The best fit model in cafeteria experiments had similar results to that for field observations (Table 8.4). The trends in β -coefficient estimates in cafeteria experiments were also similar to the β -coefficient estimates of field-based observation models (Table 8.4). In cafeteria experiments, the β -coefficients estimates for leaf surface area ($\beta = 0.87_{\text{mean}} \pm 0.26_{\text{SE}}$, $t = 3.28$) and interactive influence of leaf surface area and avoided substances index ($\beta = -1.51_{\text{mean}} \pm 0.44_{\text{SE}}$, $t = -3.44$) were comparatively lower whereas for avoided substance index was higher ($\beta = -0.86_{\text{mean}} \pm 0.23_{\text{SE}}$, $t = -3.77$) than field-based analyses (Table 8.5). The diagnostic features of best fit models for field as well as experimental observations indicated satisfactory validation (Fig8.2 and Fig8.3)

Table 8.1 Nutrient profile of Royle's pika food and nonfood plants (JCI=Jacobs' selection Index, values are in percentage for moisture, nitrogen and in other are in mg g⁻¹ sample)

Plant species	JCI	Moisture	Nitrogen	Phosphorus	Carbohydrate	Magnesium	Calcium	Sodium	Potassium
<i>Taraxacum officinale</i>	0.534±0.06	85.72±1.97	3.33±0.05	0.050±0.003	0.038±0.003	0.038±0.004	0.137±0.002	0.054±0.009	3.929±0.010
<i>Polygonum macrophylla</i>	0.285±0.01	82.39±1.01	3.25±0.06	0.032±0.002	0.035±0.005	0.045±0.003	0.080±0.002	0.047±0.002	2.979±0.010
<i>Asplenium</i> sp.	0.375±0.13	80.43±1.32	2.45±0.26	0.053±0.003	0.025±0.007	0.024±0.005	0.023±0.004	0.047±0.006	2.859±0.045
<i>Plantago brachyphylla</i>	0.481±0.018	79.86±3.15	2.14±0.2	0.035±0.002	0.031±0.003	0.037±0.002	0.223±0.006	0.051±0.005	2.007±0.026
<i>Trachydium roylei</i>	0.357±0.03	79.18±3.45	2.62±0.09	0.030±0.009	0.030±0.011	0.020±0.001	0.122±0.001	0.065±0.003	2.823±0.031
<i>Jurinea dolomiaea</i>	0.836±0.097	77.47±3.84	1.78±0.08	0.023±0.001	0.021±0.008	0.042±0.005	0.910±0.010	0.100±0.008	1.555±0.010
<i>Carex setigera</i>	0.069±0.02	74.20±4.06	1.81±0.20	0.035±0.002	0.039±0.001	0.014±0.001	-0.031±0.002	0.041±0.001	2.079±0.078
<i>Geum elatum</i>	0.386±0.006	73.65±0.57	2.06±0.06	0.032±0.002	0.033±0.001	0.031±0.001	0.148±0.010	0.058±0.003	1.758±0.023
<i>Tanacetum longifolium</i>	0.541±0.05	71.72±4.32	2.36±0.11	0.030±0.002	0.034±0.009	0.021±0.005	0.115±0.003	0.057±0.007	2.890±0.021
<i>Sibbaldia micropetala</i>	-0.020±0.003	68.72±3.53	2.41±0.12	0.040±0.003	0.039±0.011	0.028±0.001	0.058±0.001	0.052±0.003	1.132±0.029
<i>Viola biflora</i>	0.267±0.02	61.53±2.31	1.11±0.04	0.040±0.011	0.066±0.010	0.044±0.003	0.127±0.001	0.020±0.001	1.916±0.037
<i>Potentilla atrosanguinea</i>	0.475±0.08	60.40±2.34	1.50±0.23	0.014±0.001	0.034±0.007	0.030±0.007	0.153±0.010	0.045±0.002	1.393±0.004
<i>Danthonia cachemyriana</i>	-0.191±0.04	54.81±1.15	1.53±0.09	0.029±0.004	0.041±0.008	0.013±0.001	0.040±0.003	0.042±0.002	1.122±0.039
<i>Polygonum polystachyum</i>	-1±0.00	54.49±3.90	2.85±0.02	0.035±0.004	0.024±0.008	0.026±0.001	0.123±0.024	0.054±0.005	1.613±0.037
Moss	-0.515±0.018	43.53±0.54	1.22±0.07	0.030±0.001	0.053±0.001	0.035±0.002	0.056±0.021	0.087±0.001	0.480±0.001
<i>Rhododendron campanulatum</i>	-1±0.00	42.58±2.32	1.04±0.004	0.008±0.001	0.035±0.004	0.020±0.012	0.204±0.011	0.081±0.007	0.143±0.008
<i>Rhododendron anthopogon</i>	-1±0.00	41.83±3.42	1.06±0.01	0.031±0.001	0.029±0.007	0.019±0.004	0.072±0.003	0.063±0.006	0.400±0.003
<i>Anaphalis royleana</i>	-0.185±0.93	40.09±8.10	1.69±0.22	0.031±0.004	0.045±0.001	0.025±0.001	0.092±0.007	0.060±0.003	2.362±0.049
<i>Viburnum</i> sp.	-1±0.00	31.76±5.43	2.18±0.05	0.020±0.002	0.033±0.005	0.046±0.011	0.053±0.002	0.097±0.002	5.806±0.067
<i>Prunella vulgaris</i>	-0.735±0.03	29.41±3.23	2.25±0.34	0.010±0.001	0.059±0.005	0.026±0.010	0.045±0.009	0.042±0.003	2.778±0.006
<i>Sibbaldia cuneata</i>	-0.244±0.08	23.34±1.43	1.86±0.08	0.010±0.001	0.052±0.013	0.022±0.011	0.120±0.003	0.051±0.003	2.114±0.010

Table 8.2 Description of Royle's pika food selection (JCI= Jacobs selection index), leaf morphology(in cm²), profile of avoided substances and palatability(NDF=Neutral detergent fiber, ADF=Acid detergent fiber, ADL= Acid detergent lignin, all expressed in percentage and tannin in g/100g catechine equivalent)

Plant species	JCI	Leaf area	NDF	ADF	ADL	Tannin	Palatability
<i>Taraxacum officinale</i>	0.534±0.06	2.4±0.76	51.24±2.56	23.50±2.18	7.57±0.06	6.45±0.043	86.76±1.94
<i>Polygonum macrophylla</i>	0.285±0.01	25.77±0.80	44.23±0.815	16.68±0.34	6.13±0.23	10.74±0.10	83.56±1.02
<i>Asplenium</i> sp.	0.375±0.13	128±10.5	58.01±1.38	29.84±0.90	4.77±0.42	5.22±0.02	81.30±1.30
<i>Plantago brachyphylla</i>	0.481±0.018	6.21±0.069	41.29±2.04	21.44±1.01	6.40±0.71	6.53±0.04	80.97±3.22
<i>Trachydium roylei</i>	0.357±0.03	3.75±0.34	47.39±0.32	19.68±1.003	6.34±0.03	5.22±0.02	80.26±2.31
<i>Jurinea dolomiaea</i>	0.836±0.097	67±4.34	46.89±1.80	20.26±1.18	5.76±0.63	7.40±0.02	78.49±3.90
<i>Carex setigera</i>	0.069±0.02	2.63±0.03	50.78±1.93	24.63±0.55	6.92±1.01	5.84±0.08	75.09±4.11
<i>Geum elatum</i>	0.386±0.006	51.72±1.15	43.36±1.44	21.56±0.39	7.58±0.10	5.75±0.06	74.64±0.59
<i>Tanacetum longifolium</i>	0.541±0.05	13.93±2.89	43.40±1.23	21.26±0.10	7.11±0.03	6.10±0.23	72.71±2.32
<i>Sibbaldia micropetala</i>	-0.020±0.003	21.6±1.24	53.19±2.05	30.25±0.90	14.24±0.64	6.39±0.03	69.42±3.55
<i>Viola biflora</i>	0.267±0.02	1.5±0.23	39.48±1.31	17.59±1.003	3.3020.04	2.61±0.06	62.56±4.10
<i>Potentilla atrosanguinea</i>	0.475±0.08	5.44±0.23	45.03±0.01	23.83±1.003	8.62 ±0.03	3.62±0.02	61.19±2.31
<i>Danthonia cachemyriana</i>	-0.191±0.04	10.16±0.38	58.48±1.01	27.96±0.72	12.97±0.67	4.37±0.50	55.36±1.13
<i>Polygonum polystachyum</i>	-1±0.00	115.6±11.2	55.45±0.98	26.20±0.35	12.04±1.05	73.17±2.02	54.85±3.937
Moss	-0.515±0.018	0.1±0.007	41.13±2.40	24.48±1.48	6.64±0.19	1.79±0.02	44.14±0.569
<i>Rhododendron campanulatum</i>	-1±0.00	135±11.36	49.37±0.34	26.47±0.23	13.08±0.32	42.31±0.02	42.89±3.021
<i>Rhododendron anthopogon</i>	-1±0.00	8.00±1.34	54.08±2.80	32.31±1.14	13.68±0.87	45.63±0.02	42.13±1.03
<i>Anaphalis royleana</i>	-0.185±0.93	1.73±0.22	53.26±2.35	30.57±1.01	13.62±0.71	4.88±0.01	40.53±2.321
<i>Viburnum</i> sp.	-1±0.00	38.7±3.67	50.11±1.32	29.88±2.003	14.50±1.23	19.32±0.002	32.11±0.034
<i>Prunella vulgaris</i>	-0.735±0.03	2.6±0.11	48.99±0.03	28.48±0.67	9.24±0.03	6.97±0.021	29.77±3.302
<i>Sibbaldia cuneata</i>	-0.244±0.08	1.11±0.06	52.28±3.006	28.09±0.73	12.72±1.56	6.3±0.082	23.61±1.788

Table 8.3 Pearson correlation estimates between pika food selection (Jacobs selection index) and its nutritional profile, plant leaf morphology.

Variables	Pearson's Correlation coefficient	p-value
Nitrogen	0.451(*)	0.038
Phosphorus	0.12	0.356
Carbohydrate	-0.105	0.449
Magnesium	0.249	0.068
Calcium	0.338(*)	0.012
Sodium	-0.079	0.565
Potassium	0.197	0.151
Neutral Detergent Fiber(NDF)	-0.247	0.071
Acid Detergent Fiber(ADF)	-0.447(**)	0.0007
Acid Detergent Lignin(ADL)	-0.475(**)	0.0002
Tannin	-0.598(**)	0.0000
Moisture	0.466(**)	0.0003
Leaf surface area	0.248	0.0696

Table 8.4 Relative support to various candidate models explaining competing ecological hypothesis about forage selection criteria of Royle's pika in field observation and cafeteria experiments, using information theoretic criteria (minimum AIC).

Model description	Design	LogLik	df	AIC	ΔAIC
Leaf surface area * avoided substance index 1(NDF, ADF, ADL, Tannin)	Field	-17.73	5	45.467	0
	Experimental	-28.09	5	66.196	0
Avoided substance index 2 (ADF, ADL, Tannin)	Field	-24.71	3	55.439	9.97
	Experimental	-46.55	3	99.107	32.91
Avoided substance index 1 (NDF, ADF, ADL, Tannin)	Field	-29.03	3	64.06	18.6
	Experimental	-34.1	3	74.21	8.02
Tannin	Field	-29.03	3	62.34	16.87
	Experimental	-49.07	3	104.15	37.95
Leaf surface area + Avoided substance index 3 (ADF, ADL) + Nitrogen	Field	-32.18	5	74.37	28.9
	Experimental	-56.44	5	122.89	56.94
Leaf surface area+ Palatability	Field	-33.3	4	74.61	31.39
	Experimental	-60.169	4	128.33	62.14
Palatability	Field	-35.42	3	76.85	31.39
	Experimental	-64.96	3	135.92	69.72
Positive nutrient index (N, Ca, Mg, Na, K, carbohydrate, moisture)	Field	-37.36	3	80.73	35.26
	Experimental	-62.12	3	130.25	64.05
Moisture	Field	-35.43	3	76.87	31.4
	Experimental	-64.96	3	135.93	69.73
Leaf surface area	Field	-40.31	3	86.6	41.14
	Experimental	-67.93	3	141.87	75.68
Nitrogen	Field	-41.99	3	89.98	44.51
	Experimental	-72.75	3	151.5	85.3
Carbohydrate	Field	-41.72	3	89.45	43.99
	Experimental	-72.75	3	151.5	85.3

Table 8.5. Estimated influence of parameter on Royle's forage selection during field and experimental observation measured by the best fit candidate regression model (minimum AIC)

Parameter	Design	Beta $\pm$ S.E	t value	p value
Intercept	Field	0.12 $\pm$ 0.10	1.81	0.24
	Experimental	0.11 $\pm$ 0.08	1.31	0.19
Leaf surface area	Field	1.55 $\pm$ 0.38	4.02	0.001
	Experimental	0.87 $\pm$ 0.26	3.28	0.001
Avoided substance index 1	Field	-0.54 $\pm$ 0.24	-2.39	0.029
	Experimental	-0.86 $\pm$ 0.23	-3.77	0.001
Leaf surface area*avoided substance index1	Field	-3.16 $\pm$ 0.63	-4.97	0.001
	Experimental	-1.51 $\pm$ 0.44	-3.44	0.001

Figure 8.1 Diagnosis of best fit pika food plant selection candidate model for field observation.

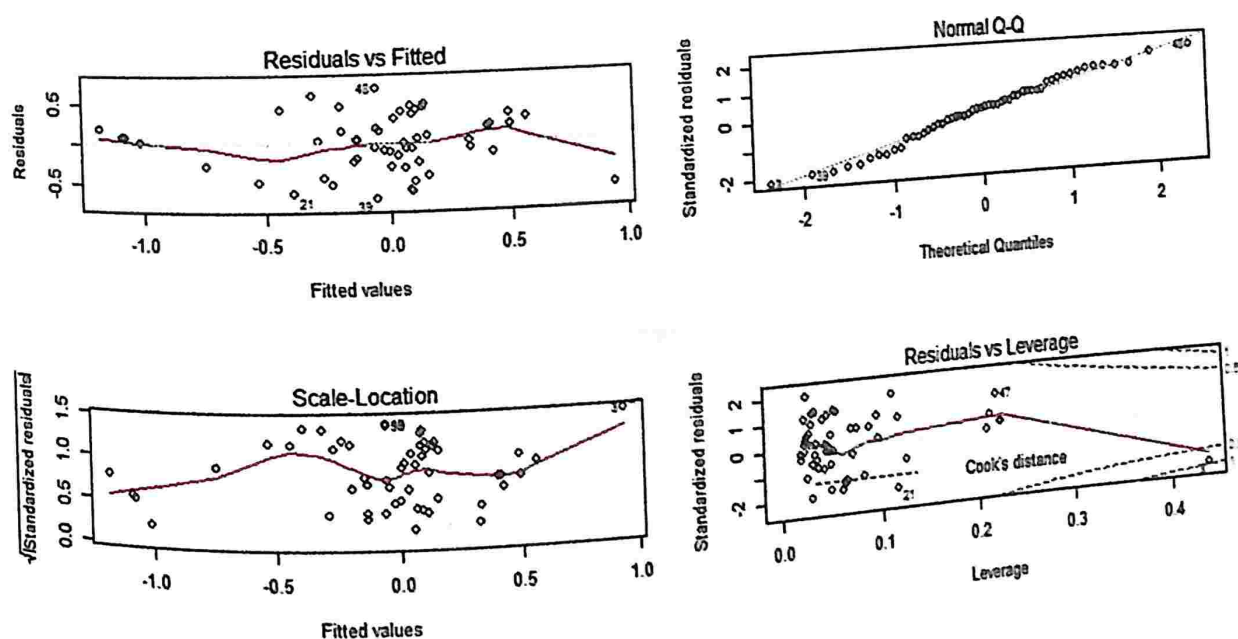
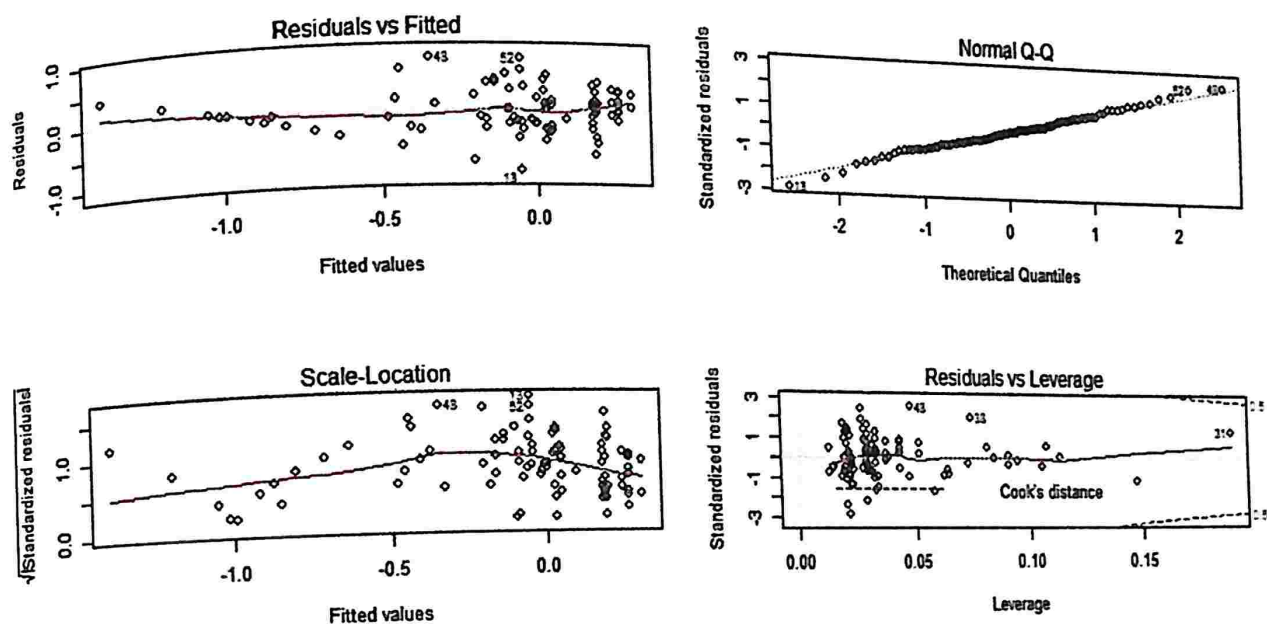


Figure 8.2 Diagnosis of best fit pika food plant selection candidate model for cafeteria experiment



8.4 Discussion

Foraging decisions in herbivores are influenced by various constraints, such as energy or nutritional demand (Stephens and Krebs 1986) or predation risk (Lima and Dill 1990). Thus, the foraging ability of an herbivore is governed by these constraints and explains the need of diet selectivity in herbivores. Demment and Van Soest (1985) states that due to comparatively high energy demand and similar gut capacity like large mammals, small mammal are specifically challenged to survive on low digestibility foods, thus they must select highly digestible food. Asian rock dwelling pikas are considered to be opportunistic herbivores which show very weak selectivity in forage selection (Krivosheyev 1971; Khlebnikova 1976; Yudin *et al.* 1976; Revin and Boeskorov 1990). They tend to feed on or collect the plants which are common and highly abundant in the environment (Cherniavski 1984; Voronov and Basarukin 1992). Despite of these tendencies, Travina *et al.* (2000) documented some degree of forage preference in Asian pika species. Food selection in *O. hyperborean* was found to depend on site and local composition of vegetation structure (Gliwicz *et al.* 2006). Earlier studies of the American pika also indicated low food plant selectivity but recent studies reveal significant selectivity (Millar and Zwickel 1972; Dearing 1996; Roach *et al.* 2001).

The present study tested three hypotheses explaining diet selection in talus dwelling pikas. Nutritional quality, plant morphology, and secondary compounds were all tested as possible predictors of Royle's pika food selection. Our results indicate that Royle's pika use leaf size and amount of avoided substances (fiber and plant secondary compound such as tannin) as principle cue to select its food plants. Therefore, this study provides strong support for both the plant morphology hypothesis (Huntley *et al.* 1986), which says central place foragers should feed on larger leaf to achieve energy efficient foraging strategy, as well as support for the plant chemical defense (Dearing 1996, 1997a, 1997b) hypothesis, which says pikas should select plants with fewer plant secondary metabolites. Additionally, this study reveals that pikas prefer forage with low fiber and lignin content (NDF, ADF, and ADL). Similar to results of this study, Hudson *et al.* (2008) indicated collared pika (*O. collaris*)' preference towards larger leaves for their winter diet in field observation as well as cafeteria trials.

Our finding of larger leaf size as a positive correlate for pika selectivity possibly enables pikas to achieve energetically as well as nutritionally efficient foraging strategies to survive in periods of food scarcity season. In contrast, the negative relationship between plant defenses and selectivity is likely due to the toxicity of many plant secondary metabolites. Plant secondary metabolites such as tannins are reported to reduce digestibility and food intake, slow down growth, and hamper functioning of kidneys, liver or intestines in mammals (Butler *et al.* 1986; Kumar and Singh 1984; Price and Butler 1980; Thomas *et al.* 1988; Zucker 1983). The effects of tannins on herbivores depend on the characteristics of the specific tannins present as well as adaptation capability to neutralize or metabolize those tannins. Therefore, tannins are always considered to be key elements in plant-animal interaction. Plant secondary metabolites have also been found to play a more significant role in American pika food selection than nutrients (Dearing 1996; Gliwicz *et al.* 2006). For example, *Acomastylis rossii*, a forb which comprises 60-77% of winter diet of American pika in Colorado, is reported to have high plant secondary metabolite content (Dearing 1996, 1997b), and yet American pikas consume those forbs only during winter when secondary metabolites have decayed to low levels. Similar trends were observed in collared pikas, which prefer to collect winter food plants with low phenolic contents (Hudson *et al.* 2008).

Apart from chemical composition of food plants, endophyte infection in food plants is also found to influence food selection in pikas (Koh and Hik 2007). Dietary fiber constitutes the heaviest portion of herbivore diets and yet is comparatively less digestible than other nutrients (Mertens 2002). NDF and ADF represent cellulose and hemicellulose content of feed whereas ADL represent the lignin and cutin content of plant cell (Jung *et al.* 1993). High fiber content (NDF, ADF, and ADL) is considered an important reason for low forage digestibility. Therefore, Royle's pika prefers forage with low fiber and lignin content.

Royle's pika prefers forage plants with larger leaf area and low fiber (NDF, ADF, ADL) as well as low tannin content. But the interaction of leaf size and concentration of non-digestible or avoided substances (fiber or tannin) indicated that selectivity for large leaf area was reduced if a large leaf plant contained high levels of avoided substances. This result is supported by the observation that plant species (*Polygonum polystachyum*, *Rhododendron campanulatum*, *Rhododendron anthopogon*, *Viburnum* sp.) with larger leaf area than any typical pika food plant which are also abundant in environment were never selected as food plants due to their high condensed tannin and fiber content. Hence, Royle's pika prefer *Prunella vulgaris*, a plant low in nitrogen, moisture content and palatability over plants such as *Polygonum polystachyum*, *Viburnum* sp. which contain three to ten times more condensed tannin.

Often prey populations are affected by predators either directly due to mortality or indirectly due to change in behaviour and physiology (Lima and Dill 1990; Sinclair and Arcese 1995). These effects are found to have significant impacts on prey populations, which are often influenced by actual predation (Lima 1998; Schmitz *et al.* 1997). Pikas are considered a classical example of central place foragers as they venture out from their nest location for foraging and return to the same location after completion of the foraging bout (Huntley 1986). Therefore, they need to balance of the predation risk associated with each foraging bout and nutritional quality of food plants. In general, central place foragers are reported to be more selective for their forage when predation risk increases (Morrison 2006). Earlier studies in other talus dwelling pikas (Collared pikas) showed that in the absence of effective talus escape cover, they tend to forage within close

vicinity of the rock talus even though high nutritive plants were available in the open alpine meadows (Holmes 1991; Morrison *et al.* 2004). Roach *et al.* (2001) reported similar observation in American pikas where they venture far into open meadows for foraging only when the talus is well connected. The comparison between field observation and cafeteria results of the current study revealed that Royle's pikas are more selective for leaf size when grazing away from the talus in areas of presumably higher predation risk. But when presented with food plants within their talus habitat during cafeteria experiments, a presumed low predation risk environment, they showed less selectivity toward leaf size and more towards digestibility or secondary metabolite content of the food plants. Thus, a trade off mechanism of energy/ effort is likely to dictate Royle's pika food selection.

Nitrogen content is found to play important role in governing the abundance of small mammalian herbivores (Grant *et al.* 1977; Boutin 1990; Boonstra *et al.* 2001), as it is the principle constituent of amino acids which are essential for growth and reproduction (Robbins 1983; Schetter *et al.* 1998). Alpine ecosystems are highly limited by nitrogen availability, (Bowman *et al.* 1993; Chapin *et al.* 1995; Nilsson *et al.* 2002), therefore the amount of nitrogen or protein available in forage plants might have immense impact on food selection in alpine herbivores. Earlier research (Millar and Zwickel 1972; Smith 1974; Dearing 1996) indicates pika preference towards nitrogen rich forage for winter diet. The results of the present study also showed that nitrogen content of food plants has a positive correlation with Royle's pika food plant selection. Calcium, an important mineral nutrient, was also found to have a positive correlation with pika food selection. Pikas prefer plants high in calcium, as it is essential to maintain skeletal tissue, transmission of nerve impulse, important component of milk (NRC 2001). Moisture or water content of forage is also considered as an important constraint on herbivore food selection decisions (Belovsky 1984; Belovsky and Schmitz 1991; Schmitz *et al.* 1992). Previous studies suggested that moisture content of food plants influence forage selection in pikas (Millar 1971; Smith 1974; Dearing 1996). Pikas might use moisture content as a cue for forage selection, as high moisture content leads to increased digestibility of forage as well as availability of highly nutritive cytoplasmic contents (Robbins 1983). This study also indicated a positive correlation of pika food selection and plant moisture

content, but food selection in Royle's pika seems to be influenced more by leaf size and amount of different fiber and tannin than other nutrient such as nitrogen, calcium or moisture. Unlike other talus dwelling pikas such as American pika (*O. princeps*) or collared pika (*O. collaris*), Royle's pika do not store winter food in haypiles (Kawamichi 1968). Thus, Royle's pikas have few opportunities to manipulate plant toxin or fiber content, unlike other haypile forming pika species. As a result, they show strong preference towards plants with low fiber and tannin content.

Adequate nutrition facilitates successful reproduction in mammals. A large amount of food is generally used for body maintenance and other activity and rest in reproduction (Studier 1979). Small mammals are not able to efficiently store large amounts of energy, which would help sustain both in gestation and lactation periods. Therefore, they require a continuous supply of highly nutritive food throughout the reproductive period (Miller 1977). Alpine plant communities are considered to be more vulnerable to climate change than plants in lower altitude as they were more influence by abiotic factors (temperature, precipitation) than biotic (competition) factors (Pauli *et al.* 2003). Recent climate change (temperature and precipitation regime) in Europe predicted to cause disproportionate loss (more than 60%) of alpine plant species in near future (Thuiller *et al.* 2005). Often herbivore and vegetation were associated in reciprocal relationship that is abundance of one though times significantly influence abundance of other (Caughley 1976). Therefore, change in alpine food plant community structure and composition might have strong impact on mammalian herbivores, especially small herbivores such as pikas which exclusively live in alpine ecosystem. Hence, to understand, predict and monitor changes in these highly vulnerable small mammalian herbivore species, more reference data are required to collect through intense ecological studies. As rapid change in climatic regime is also reported in the Himalaya (Singh and Bengtsson 2004), therefore, the knowledge generated through this current study about food selection by an generalist alpine herbivore (Royle's pika) which play significant ecological role in alpine Himalaya, can be used for future climate change monitoring studies to track effect and magnitude of change more efficiently.

Introduction

Recent research trends indicate increase of global mean surface temperature (0.6°C since late 1800s) which affected worldwide species distribution, phenology and physiology (Hughes 2000; Walther *et al.* 2002; IPCC 2007). General-circulation models (GCMs) also predicted a potential increase in the average global temperature by 2.4°C to 6.4°C by 2100 (IPCC 2007). Hence, climate change is now considered as the greatest threat to global ecosystem and biodiversity (Glick and Van Putten 2002). The climate change especially threatens the survivals of many organisms whose distribution is restricted to fragmented habitats (Peters and Darling 1985). Species with narrow ecological requirements are predicted to be highly affected and even might be extinct due to climate change mediated habitat alteration (Murphy and Weiss 1992). As the velocity of climate change is high in alpine regions (Naftz *et al.* 2002) than lower altitudes regions, the species adapted to cold climatic conditions are more vulnerable to global warming (Hughes 2000; Moritz *et al.* 2008). Furthermore, change in environment might also exceed the adaptation capacity of several species to cope with altered climate (Barnosky and Kraatz 2007). Therefore, significant change in climatic conditions might induce extirpation in species with low adaptive capability and fixed bioclimatic niche across its distribution range (Beever 2010). Several studies indicate disproportionate loss of species which results change in altitudinal (e.g., Walther *et al.* 2005; Wilson *et al.* 2005) and latitudinal distributional range (Guralnick 2007). Species with poor dispersal capability and broad distribution might also show local adaptation to highly variable and physiologically stressful environments based on their phenotypic plasticity (Lema 2008; Re'ale *et al.* 2003). Hence, understanding the basic ecology about climate sensitive species is extremely important not only to identify the mechanism through which climate change might affect them but also for developing effective informing monitoring, management, and conservation strategies (Root and Schneider 2006). Alpine small mammal lives in isolated mountain sky islands might be more vulnerable to contemporary climate change due to their high energy demands, limited dispersal

capability and sensitivity towards climatic variation than other larger species or species which lives in tropical and temperate environment. Among alpine small mammals pikas attain distinct position due to its high ecological importance. In spite of high number pika species reported from Himalaya, information about their basic ecology is very scanty. Hence, this study reveals baseline ecological information about a widely distributed alpine small mammal, Royle's pika (*Ochotona roylei*) in western Himalaya.

Influence of habitat characteristics on Royle's pika occurrence

The distribution pattern of rocks and available crevices size were found to be most important in explaining Royle's pika occurrence. Royle's pika prefer habitats with uniformly distributed rocks with small crevices as it allows them to access and feed on a larger area by providing an escape cover from predators. As Royle's pikas are talus dwelling pikas cannot make burrows thus, they use small crevices as their nests. Royle's pikas are also reported to be synanthropic in nature (Kawamichi 1968) and observed to be actively occupying several anthropogenic habitats during this study. Earlier research indicates various types of disturbances (realignment of stream channel, clear cutting, fire and mining) can alter small mammal population and community composition (Possardt and Dodge 1978; Martell and Radvanyi 1977; Fala 1975; DeCapita and Bookhout 1975). Through there was no direct anthropogenic threats exists for the pikas in the study area. But on several occasions during this study as well as in earlier studies (Bhattacharyya *et al.* 2009), it has been observed that some of the pika habitat sites were severally destroyed to extract rocks for various developmental activities (making road or house). The habitat structures especially the crevices in rocks in those altered habitats were completely changed. None of those altered habitat were observed to be recolonized by pikas since last three year. The entire affected area become devoid of Royle's pika population. Thus, larger scale pika habitat alternation might lead significant amount of habitat loss to the species. This study reveals that the Royle's pika will show more affinity to a habitat with small crevices than large one. Hence, the rocks structure is the key component which can maintain viable Royle's pika population in the study area. Royle's Pika do not make haypile like other pika species and feed extensively on lichens and moss available on crevices during winter. Therefore, alternation of habitat rock

structures may not only increase in predation risk but can also lead to significant decline in winter food as moss and lichens takes years to cover rocks. Therefore, any large scale development activities which involve extraction of rock structure from pika habitat should be avoided as these might lead to decrease in habitat availability to the species and reduce the fitness of the Royle's pika population.

Factors influence Royle's pika distribution

The distribution of montane species has been known to be significantly governed by various climatic parameters such as climate precipitation, temperature as well as other topographical factor such as latitude, elevation (Grinnell 1917; Körner 2007). Earlier paleontological research illustrated that pikas (*O. princeps*) distribution range in North American experienced expansion and contraction in response to climatic fluctuation across geologic time (Hafner 1983). They were also found to be highly vulnerable to acute-heat stress, when they could not perform behavioural thermoregulation efficiently (Smith 1974). Because of this high sensitivity researchers consider temperature as primary factor which governs the geographical distribution of various pika species (Grinnell 1917; Smith 1974; Hafner 1993; Beever *et al.* 2003; Grayson 2005).

The present study reveals that the mean temperature of warmest quarter, elevation and precipitation of warmest quarter were the most important contributors which govern Royle's pika distribution in western Himalaya. The probability of pika presence found to be decrease with high mean temperature of warmest quarter as increase temperature also increase the probability of increase of heat stroke in pikas. Similarly, precipitation of warmest quarter (summer and monsoon) also influence the abundance of pika food plants, thus also govern the distribution of Royle's pika. Snow acts as thermal insulation for pikas which thus high precipitation during coldest quarter protects them from high diurnal temperature and severe cold.

The climate change was considered to be the primary force which results local extirpation of American pika (*Ochotona princeps*) in Great basin (Beever *et al.* 2003, 2011; Calkin *et al.* 2012). The microclimates of pika extirpated locations were comparatively hotter during summer and very cold during winter than locations which contain persisting pika

population (Beever *et al.* 2010). Though, Royle's pika is distributed across the entire Hindukush-Himalayan arc, but contemporary climate change might also affect its distribution. This current study identified some potential climatic and habitat variables which can significantly govern Royle's pika distribution at a landscape in western Himalaya. This information further can be used in future predictive modeling for the species.

Influence of snow and habitat characteristics on the abundance of Royle's pika

Thick snow cover works as a protective thermal insulation layer, allowing pikas to survive high diurnal temperature fluctuation during winter and early spring (Morrison and Hik 2007). Kreuzer and Huntly (2003) found that the snow melting pattern and its duration has a significant impact on the demography of the American pika. Acute cold stress (due to short duration of snow cover or a thin snowpack) was also found to be an important reason for pika extirpation in the Great Basin (Beever 2010). This present study also reveals that the adult pika abundance was significantly governed by the interactive effects of snow-cover period and altitude, whereas juvenile pika abundance was governed by food availability, amount of rock cover and spring snow depth. Juvenile pika emergence time was influenced by the interactive effects of snow cover period and altitude. During the winter of 2008-2009, a short snow-cover period may have caused high adult pika mortality due to cold stress, which in turn resulted in low pika abundance in the summer of 2009. The thermal insulation provided by a thick snow pack during spring reduces cold stress; it also creates an environment within crevices that favours successful reproduction in adult pika. Hence, spring snow increases the abundance of juvenile pika.

Winter snow also protects alpine plants from extreme low and fluctuating temperatures (Marchand 1996). Snow-cover period and depth are critical for alpine soil-nutrient quality and thus have a profound effect on alpine food plant growth (Walker *et al* 1993, 1995; Brooks and Williams 1999). Long snow cover period and thick snow pack reported to result in high availability of pika food plants during the present study. High food availability possibly, improves pikas' health by increasing nutritional intake during

following breeding season in spring and also for rest of the summer. Thus, change in winter precipitation (snow) pattern not only increase pika mortality due to loss of protective thermal insulation but might also reduce the food availability for pikas. This, phenomenon might reduce the survival of Royle's pika population in western Himalaya.

Seasonal variation in time activity budget of Royle's pika

High altitude ecosystems experience marked seasonality, thus animal lives in such ecosystem has short and restricted period to gain energy and perform successful reproduction. High variation in climatic condition also impose additional energetic burden over alpine mammals which has relatively small body size such as pikas. Royle's pika shows bimodal activity pattern during this study. Adult pikas were found to spend highest amount of their activity budget in foraging and least amount in vocalization. Due to high food availability pikas spend comparatively more time for foraging in monsoon than other seasons. Pikas spend more time in locomotion and long musing during autumn. The time spent in locomotion in pikas was found to be inversely related to availability of food plants. They explored larger area during autumn when most of its food plants under do senescence. Vigilance was high during summer as well as in the habitats with low escape cover, possibly due to high predation risk. This baseline information about how Royle's pika allocate its time for various activity in different season can be used further in applied ecological studies such as in bio energetics.

Influence of microclimate on Royle's pika activity

The present study reported high pika activity during morning and evening hours where as low activity during midday hours. Physiological constraints generally considered as an important determinants of the distributional limits of species and populations (Gaston and Spicer 1998; Chown and Gaston 2000). Pikas are reported to have comparatively higher (2-3°C) body temperature than other small mammals who reside in talus areas, due to a thick fur layer and the presence of micro-organisms such as bacteria which aid in digestion (MacArthur and Wang 1973). Earlier studies focused on behaviour and physiology of American pikas (*Ochotona princeps*), a similar talus dwelling species like

Royle's pika indicated that the thermoregulation process in pikas are mainly behavioural rather than physiological; a brief exposure to medium ambient temperatures (25.5-29.4°C) and intense solar radiation can cause death in pikas (MacArthur and Wang 1973, 1974; Smith 1974). Therefore, Royle's pikas also avoid midday heat stress by taking shelter in micro-climatically favorable crevices in talus rock habitat. If the diurnal temperature becomes higher in future then it might significantly reduce the pika foraging time, especially during midday hours which might results nutritional deficiency.

Factors influence food selection in Royle's pika

The foraging decision in herbivore reported to be influenced by various constrains, such as energy or nutritional demand (Stephens and Krebs 1986) or predation risk (Lima and Dill 1990). Thus, the foraging ability of an herbivore is govern by these constrains and explain the need of diet selectivity in herbivores. Various food selection hypotheses viz, plant morphology (Millar and Zwickel 1972; Huntley *et al.* 1986), Nutritional quality (Millar and Zwickel 1972) and plant secondary compounds (Dearing 1996, 1997a, 1997b) from earlier research in talus dwelling pikas were tested to understand food selection in Royle's pika. The results indicated that food selection decision in Royle's pika was positively governed by leaf area size and negatively by amount of avoided substance (NDF, ADF, ADL and tannin) in food plants. The interaction of leaf size and avoided substance indicates that a plant with larger leaves will be selected only if it contains low avoided substance. This study also reported that magnitude of predation risk might also influence the importance of leaf size or amount of avoided substance on pika food selection decision. Often herbivore and vegetation were associated in reciprocal relationship that is abundance of one though times significantly influence abundance of other (Caughley 1976). Therefore, change in alpine food plant community structure and composition might have strong impact on mammalian herbivores, especially small herbivores such as pikas which exclusively live in alpine ecosystem. Hence, to understand, predict and monitor changes in these highly vulnerable small mammalian herbivore species, more reference data are required to collect through intense ecological studies.

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ABUNDANCE OF ROYLE'S PIKA (*OCHOTONA ROYLEI*) ALONG AN ALTITUDINAL GRADIENT IN UTTARAKHAND, WESTERN HIMALAYA

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ABSTRACT - The relative abundance of Royle's pika (*Ochotona roylei*) was studied in a part of the Kedarnath Wildlife Sanctuary, Uttarakhand, West Himalaya along an altitudinal gradient from 2900 to 3650 m a.s.l. Pikas' detection probability and relative abundance per month and habitat were recorded by monthly surveys consisting of three sampling sessions of four hours each. Food plant species were identified by visual observation and quantified by a standard quadrat method. The highest relative abundance was observed at man-made walls and surroundings in the alpine zone and on broken slopes in the sub-alpine one, whereas alpine meadows showed the lowest abundance. A total of 26 plant species were found to be consumed by pikas. The proportion of forage plants was the highest (77.4%) on the rocky slopes of the timberline zone. The results of multiple regressions suggest that rock cover is the main factor affecting the relative abundance of Royle's pika. Rocky areas probably offer both nest-sites and temporary refuges to escape from predators.

Key words: Royle's pika, relative abundance, Kedarnath, Western Himalaya, India

RIASSUNTO - *Abbondanza relativa del pika di Royle (Ochotona roylei) lungo un gradiente altitudinale in Uttarakhand, Himalaya occidentale.* In un'area del Kedarnath Wildlife Sanctuary (Uttarakhand, Himalaya occidentale), è stata stimata l'abbondanza relativa del pika di Royle (*Ochotona roylei*) lungo un gradiente altitudinale compreso tra 2900 e 3650 m. Sono stati identificate tre fasce altitudinali e 10 habitat complessivi. La probabilità di osservazione e l'abbondanza relativa dei pika per ciascun mese e habitat sono state stimate tramite censimenti mensili consistenti in tre periodi di 4 ore ciascuno. Le specie vegetali consumate sono state identificate tramite osservazione diretta; la disponibilità è stata quantificata tramite rilievo fitosociologico standard. L'abbondanza relativa maggiore è stata riscontrata nella zona alpina, in aree caratterizzate dalla presenza di muri in pietra, e sui pendii della zona sub-alpina, mentre l'abbondanza minore è stata rilevata nelle praterie alpine. I pika sono stati osservati consumare 26 specie di vegetali. La maggiore percentuale di piante utilizzate è stata rilevata lungo i pendii rocciosi al limite della vegetazione arborea. Tramite regressione multipla si è evidenziato che la copertura rocciosa è il fattore che più influenza l'abbondanza della specie. Le aree rocciose offrono probabilmente sia aree idonee per la tana, sia riparo dai predatori.

Parole chiave: pika di Royle, abbondanza relativa, Kedarnath, Himalaya occidentale, India

INTRODUCTION

Small mammals strongly influence the composition of plant communities and micro-habitats (Smith and Foggin, 1999). Accordingly, in the Indian Trans-Himalaya, plant species richness and diversity have been reported to be higher in the presence of small mammal colonies (Bagchi *et al.*, 2006). Pikas seem to be relatively primitive animals, having passed their evolutionary zenith (Thenius, 1972). The only living genus, *Ochotona*, includes a few species adapted to sub-alpine and alpine habitats of Asia and North America. Ochotonids reached their greatest diversity and widest distribution in the Miocene when they spread throughout Europe, Asia, Africa and North America (Dawson, 1967). It is believed that, in the past, nearly 16 species of *Ochotona* inhabited Europe and Africa (Thenius, 1972). Currently there are altogether 30 living species in the world, of which 27 are found in Asia, including 7 in the Indian Himalaya (Hoffmann and Smith, 2005). Royle's pika (*Ochotona roylei*) is quite common throughout the Himalayan region (Hoffmann and Smith, 2005). Its fur is reddish brown with a pale band over the nape. Body length ranges from 15 to 20 cm and the diameter of the head is ca. 7 cm; it weighs 100-150 g (Alfred *et al.*, 2006). In the western Himalaya, pikas occur from 2500 m a.s.l. up to 5000 m a.s.l., inhabiting open rocky ground and *Rhododendron* forests (Tak and Lamba, 1985). Their distribution depends directly on the availability of forage plant species (Kawamichi, 1968). The bulk of the pikas' diet includes fresh grass, fallen leaves, mosses and the leaves of dwarf bam-

boo. Most species show a marked food hoarding behaviour, whilst, surprisingly, Royle's pikas hoard only a few plant species in their burrows (Kawamichi, 1968).

Few studies have been conducted on Royle's pikas, as they prefer rugged high altitude environments. Kawamichi (1968) suggested that Royle's pika is less vocal than other pikas and does not hibernate in winter. A preliminary study on the distribution pattern, behavior and social organization of *O. macrotis* and *O. roylei* was conducted by Kawamichi (1970) at Mt. Everest. In 1990, Smith *et al.* revised the data of Kawamichi (1968) and found a density of 12.5 pikas ha⁻¹ in Nepal Himalaya. However the study of Kawamichi covered only a brief period and there is no long term study on the seasonal variation in the abundance of Royle's pika.

The present study is an attempt to assess the status and distribution of Royle's pika in relation to habitat use in the Indian Himalaya. The main aims were i) to assess the relative abundance of Royle's pika along an altitudinal gradient and ii) to identify the environmental factors which govern the relative abundance of pikas in different habitat types.

STUDY AREA

The study was carried out in a part of the Kedarnath Wildlife Sanctuary, which is situated in the district of Chamoli, Uttarakhand state (Fig. 1). The total area of Kedarnath WS, which coincides with the upper catchment of the River Alaknanda, is ca. 975 km² and altitude ranges from 1160 m a.s.l. to 7068 m a.s.l. The intensive study area (ca. 10 km²) is located in the southern fringe of Kedarnath WS around Chopta and Tungnath (30°29' N, 79°12' E). This area

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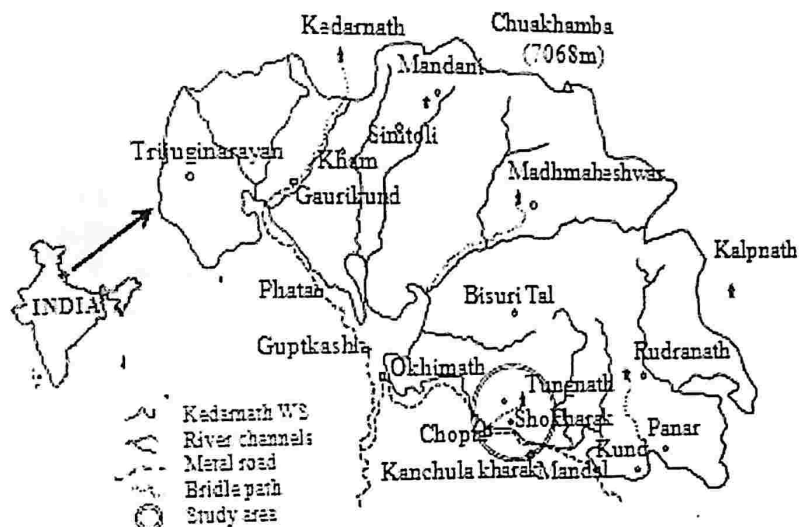


Figure 1 - Location of the study area in Kedarnath Wildlife Sanctuary.

was selected due to its suitable altitudinal range (2900-3680 m a.s.l.), variety of micro-habitat types and accessibility throughout the year.

The forests around Chopta are dominated by broadleaved sclerophyllous communities of *Quercus semecarpifolia*, *Rhododendron arboreum*, *R. campanulatum*, *Abies pindrow*, *A. spectabilis* and *Sorbus vestita*. The alpine meadows at and around Tungnath are dominated by herbaceous plant communities and *Danthonia* grassland (Sundriyal *et al.*, 1987). The main potential predators of pikas in the study area are red fox *Vulpes vulpes*, yellow-throated marten *Martes flavigula*, Himalayan weasel *Mustela sibirica* and common leopard *Panthera pardus* (Green, 1985).

The climate of the area is influenced by a south-west monsoon in summer and westerly disturbances in winters (Mani, 1981). In particular, the intensive study area is characterized by a rainy season lasting from mid-June to September and a long severe winter from October to April.

METHODS

The study area was divided into three zones along an altitudinal gradient, viz. sub-alpine, timberline and alpine zone. In each

zone, a permanent plot (50×50m) was marked within each available habitat type (N = 10). The location of the plots was recorded through a Global Positioning System (GPS, Garmin72); at each plot aspect and slope were determined through a compass and the percentage of rock cover was visually estimated. In each plot, pikas were searched for once a month from November 2007 to November 2008, except during heavy rains (September 2008) and winter (December 2007 - March 2008), yielding a total of 70 sampling sessions. Each survey lasted 12 hours, subdivided into 3 sampling sessions of 4 hours each. According to morphological features, we could distinguish three groups of individuals, corresponding to juvenile, sub-adult and adult pikas. The juveniles showed a regular light brown fur coat; medium sized sub-adults had very small black patches or moulting marks in the dorsal portion of their bodies and scar marks on one or both ears; adults showed prominent ear scar marks with blackish molting marks on their dorsal body surface. To facilitate the identification of the individuals, during each survey the location of each animal was recorded and photographs were taken from different angles for comparison. In this way we could identify individual pikas and then assess population size with reasonable care.

We estimated site and survey probabilities of detection of the pika by the ratio: $p_{kij} = n_{kij}/N_j$, where k is the sampling occasion ($k = 1, 2, 3$) during survey i in site j , n_{kij} is the number of observed individuals and N_j is the total number of pikas in site j over the study time. The average number of individuals seen in each survey ($\sum p_k/3 \pm SD$) was considered as an index of relative abundance. Mean relative abundances were compared by Kruskal-Wallis' test.

We tested our data for normality by the Kolmogorov-Smirnov test and, whenever necessary, applied the square root transformation to achieve normality (Zar, 1999). Data were also tested for autocorrelation by the Durbin-Watson test (Zar, 1999). We used general linear models (GLM) to test for the effects of site and survey covariates on detection probability and relative abundance of pikas. Detection probability was regressed against rock cover, altitude, food availability and herbaceous species richness. According to our results (see below) pika relative abundance was modeled against three covariates - rock cover, altitude and food availability - using a step-wise forward computation method in a multiple regression framework (SPSS version 15.0). The significance of the models was assessed by ANOVA. The plants eaten by pikas were identified by direct focal sampling (Altmann, 1974). For assessing the density of plant species by the standard quadrat method (Rawat and Adhikari, 2005), ten 1x1 m random quadrates were laid monthly within each plot; the availability of food plants (individuals m^{-2}) was assessed from total herbaceous vegetation cover. The chi-square (χ^2) test was performed to compare plant densities across different habitat types and altitudinal zones. The diversity of herbaceous species (Shannon-Wiener index) was calculated by the software EstimateS 7.51.

RESULTS

Five different habitats were identified

in the alpine zone (i.e., rocky alpine meadows, alpine meadows, man-made walls and surroundings, broken slopes in alpine and *Danthonia* grassland), three in the timberline zone (mixed herbaceous meadows, rocky slopes and rocky forest edges) and two in the sub-alpine zone (broken slopes and forest gaps with boulders).

In both alpine and sub-alpine zones plant density was the highest (710 and 521 individuals m^{-2} , respectively) in broken slopes (respectively: $\chi^2 = 668.7$, d.f. = 4, $P = 0.05$ and $\chi^2 = 110.9$, d.f. = 1, $P = 0.05$), while no difference emerged among the habitats of the timberline zone ($\chi^2 = 0.10$, d.f.=2, N.S.). The proportion of forage plants was the highest (77.4%) on rocky slopes - timberline zone ($\chi^2 = 16.92$, d.f. = 9, $P = 0.05$; Table 1). A total of 26 plant species were consumed by pikas, of which 18 were herbs, 5 grasses, 2 shrubs and one fern (Table 2). Royle's pikas mainly ate leaves (18 species), or both leaves and flowers (7 species; Table 2). The Shannon-Wiener diversity index was the highest (2.95) at forest gaps with boulders during the monsoon (August) and the lowest (1.99) in rocky alpine meadows.

Mean density of royle's pika was 15.3 individuals ha^{-1} . Throughout the study period pikas were relatively more abundant at man-made walls in the alpine zone and on broken slopes in the sub-alpine zone ($\chi^2 = 52.1$, d.f. = 9, $P < 0.0001$; Table 3). The highest relative abundance (7.67 ± 0.33) was recorded around the man-made walls in June and on broken slopes in May. The lowest relative abundance (1.44 ± 0.56) was found in alpine meadows in October and November 2008. In *Danthonia* grassland and forest gaps with boulders

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Table 1 - Density of plant species in different habitat types. Values in parentheses indicate the percent contribution of each species in the habitat.

Zone	Habitat	Density (plants m ⁻²)	% of forage plants	Dominant species
Alpine	Rocky alpine meadow	197.0	53.1	<i>Salix elegans</i> (36%) <i>Danthonia cachemyriana</i> (15%) <i>Viola biflora</i> (15%)
	Alpine meadow	116.8	45.8	<i>Salix elegans</i> (34%) <i>R. anthopogon</i> (26%) <i>Danthonia cachemyriana</i> (20%)
	Man-made walls	279.5	61.9	<i>Trachydium roylei</i> (29%) <i>Ranunculus hirtellus</i> (24%) <i>Parnassia nubicola</i> (23%)
	Broken slope	710.4	59.3	<i>Trachydium roylei</i> (39%) <i>Oxygraphis polypetala</i> (19%) <i>Ranunculus hirtellus</i> (7%)
	<i>Danthonia</i> grassland	281.0	60.7	<i>Oxygraphis polypetala</i> (17%) <i>Ranunculus hirtellus</i> (17%) <i>Danthonia cachemyriana</i> (13%)
Timberline	Mixed herbaceous meadow	482.0	58.8	<i>Trachydium roylei</i> (31%) <i>Ranunculus hirtellus</i> (23%) <i>Oxygraphis polypetala</i> (16%)
	Rocky slope	479.1	77.4	<i>Trachydium roylei</i> (22%) <i>Ranunculus hirtellus</i> (19%) <i>Viola biflora</i> (12%)
	Rocky forest edge	472.3	71.1	<i>Trachydium roylei</i> (38%) <i>Sibbaldia micropetala</i> (32%) <i>Oxygraphis polypetala</i> (20%)
Sub-alpine	Broken slope	520.6	66.9	<i>Trachydium roylei</i> (53%) <i>Ranunculus hirtellus</i> (33%) <i>Viola biflora</i> (11%)
	Forest gap with boulders	231.7	36.5	<i>Potentilla atosanguinea</i> (35%) <i>Ranunculus hirtellus</i> (14%) <i>Fragaria nubicola</i> (13%)

the relative abundance of pikas was rather low throughout the study period. Juveniles were observed from May to August. The highest relative abundance of juveniles (3.33 ± 0.33), was found at sub-alpine broken slopes, while the

lowest (0.33 ± 0.33) at forest gaps with boulders in June and rocky alpine meadows in May (Fig. 2). In November 2007 and October-November 2008 no juveniles were reported. Detection probability (Table 4) was found to be

Table 2 - Main food plants and parts consumed by Royle's pika.

Family	Species	Parts consumed
Aspleniaceae	<i>Asplenium</i> sp.	leaf
Asteraceae	<i>Anaphalis royleana</i>	leaf
	<i>Anaphalis triplinervis</i>	leaf
	<i>Jurinea dolomiaea</i>	leaf
	<i>Saussurea nepalensis</i>	leaf
	<i>Tanacetum longifolium</i>	leaf and flower
	<i>Taraxacum officinale</i>	leaf and flower
Apiaceae	<i>Trachydium roylei</i>	leaf
Cyperaceae	<i>Carex setigera</i>	leaf
Ericaceae	<i>Rhododendron anthopogon</i>	leaf
	<i>Rhododendron campanulatum</i>	leaf
Lamiaceae	<i>Prunella vulgaris</i>	leaf
Plantaginaceae	<i>Plantago brachyphylla</i>	leaf
Poaceae	<i>Danthonia cachemyriana</i>	leaf
	<i>Poa</i> sp.	leaf
Polygonaceae	<i>Polygonum macrophylla</i>	leaf and petiole
Primulaceae	<i>Primula denticulata</i>	leaf and flower
Ranunculaceae	<i>Oxygraphis polypetala</i>	leaf and flower
	<i>Ranunculus hirtellus</i>	leaf
Rosaceae	<i>Geum elatum</i>	leaf and flower
	<i>Potentilla atrosanguinea</i>	leaf
	<i>Potentilla fulgens</i>	leaf
	<i>Sibbaldia micropetala</i>	leaf and flower
	<i>Sibbaldia cuneata</i>	leaf
	<i>Pedicularis pectinata</i>	leaf
Scrophulariaceae		leaf and flower
Violaceae	<i>Viola biflora</i>	

influenced only by herbaceous species richness ($R^2 = 0.180$, $F = 10.516$, d.f. = 1, $P < 0.002$). Therefore, in each site the number of sightings during a survey (relative abundance) can be a reasonable surrogate of population abundance in a general linear (multiple regression) model that incorporates as site covariates: (a) rock cover, (b) altitude and c)

food availability.

We found a strong linear relationship between pika relative abundance and rock cover ($R^2 = 0.327$, $F = 23.29$, d.f. = 1, $P < 0.001$), estimated by the following equation: $Y = 1.73 \pm 0.54 + 0.05 \pm 0.01 \times$ rock cover. No serial auto-correlation was found among data/variables by the Durbin-Watson test (1.07).

Royle's pika in Western Himalaya

Table 3 - Mean relative abundance of Royle's pika in different habitat types and altitudinal zones.

Zone	Habitat	m a.s.l.	Mean relative abundance $\pm$ SD
Alpine	Rocky alpine meadow	3650	3.52 $\pm$ 1.34
	Alpine meadow	3633	2.89 $\pm$ 1.26
	Man-made walls	3520	5.57 $\pm$ 1.58
	Broken slope	3444	3.52 $\pm$ 0.97
	<i>Danthonia</i> grassland	3400	2.00 $\pm$ 0.43
Timberline	Mixed herbaceous meadow	3300	3.62 $\pm$ 0.70
	Rocky slope	3280	4.24 $\pm$ 0.76
	Rocky forest edge	3200	4.67 $\pm$ 1.46
Sub-alpine	Broken slope	3150	6.05 $\pm$ 1.29
	Forest gap with boulders	2900	2.29 $\pm$ 0.48

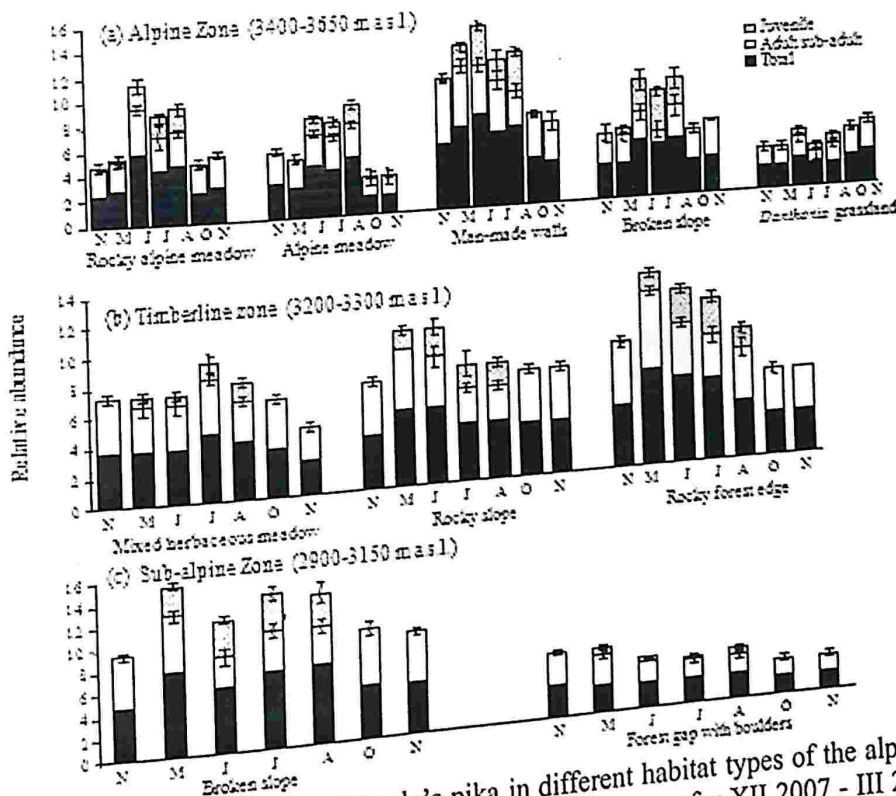


Figure 2 - Relative abundance of Royle's pika in different habitat types of the alpine, timberline and sub-alpine zones from XI 2007 to XI 2008 (except for XII 2007 - III 2008 and IX 2008).

Table 4 - Average detection probability (P) of Royle's pika across different habitat types.

Habitat types	P
Rocky alpine meadow	0.571
Alpine meadow	0.640
Man-made walls	0.750
Broken slope	0.644
<i>Danthonia</i> grassland	0.667
Mixed herbaceous meadow	0.644
Rocky slope	0.744
Rocky forest edge	0.714
Broken slope	0.741
Forest gap with boulders	0.480

DISCUSSION

Royle's pika density in the study area was markedly higher than that in Nepal Himalaya (12.5 ha^{-1} ; Smith *et al.*, 1990). There may be several factors which possibly affect on the distribution and abundance of pika populations. Bunnell *et al.* (1974) reported that the physical characteristics of rock slides – mainly the size of the rocks – and accessibility of their periphery affect both the density and dispersal of the American pika (*O. princeps*). Our results suggest that both the amount of rock cover and food availability are main factors shaping the relative abundance of Royle's pika populations. Pikas use rocky areas as both nest-sites and temporary refuges to escape from predators (Bunnell *et al.*, 1974). Accordingly, pika relative abundance was higher in man-made walls and broken slopes in sub-alpine habitats, the latter offering cover and higher accessibility to food resources than alpine meadows.

In the alpine area the growth season is limited and as soon as the monsoon ends most of the herbaceous plants become senescent. Therefore, pikas have to get an adequate amount of food in a relatively short time, as they do not hibernate to compensate for the prolonged winter food scarcity.

Royle's pika is a generalist herbivore, relying on a wide variety of herbs and grasses. Accordingly, its probability of detection was found to be influenced by the relative richness of herbaceous species.

Our study suggests that Royle's pika reproduces only once in a year, as other talus dwelling pikas.

This preliminary study represents a basis for further research aiming to estimate the seasonal and habitat variation of pika abundance, which will allow us to better understand the population dynamics of these high-altitude small mammals.

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