Behavioral ecology of the Central Himalayan Langur (*Semnopithecus schistaceus*) in the human dominated landscape: Multi-species interactions and conservation implications Himani Nautiyal

Introduction

Habitats dominated by humans and the concomitant fragmentation and conversion of primate habitats are the driving forces behind human-primate conflict interactions, posing one of the greatest threats to primate survival. One common form of a human-modified landscape is a patch of forest surrounded by agricultural land and settlements. In this thesis, my goal was to investigate the behavioral and ecological adaptability of the understudied Central Himalayan langur (CHL) *Semnopithecus schistaceus*, in its high-altitude human-modified environment, and to contribute useful information for their conservation. To do this, I took a multi-disciplinary approach, combining behavioral, sociological, ecological, and genetic information. While a long-term study has previously been conducted on the species at a low-altitude site, Ramnagar in neighboring Nepal, the current study represents some of the first insights based on long-term research of the species in its high-altitude habitat in the central Himalayas. This study expands on the existing body of information about *Semnopithecus* spp. in the region based on long-term observations of identified individuals and DNA information on kinship. This approach provides new insights about the species that have not previously been possible to address.

I conducted a long-term field study on a fully habituated, individually identified group of langurs to help elucidate four main questions: 1) How do social grooming networks help to maximize individual fitness; 2) What is the source of conflict between CHL and people in a human-modified landscape; 3) What kinds of interactions occur between CHL and their potential predators in an environment not affected by humans; 4) What are the behavioral strategies of CHL in response to predation by dogs in the agricultural fields.

Methodology

In 2014, I habituated and individually identified S group, in the Mandal valley (1500-2500 masl) and initiated a longitudinal study on it between 2016 and 2018. The group lives in an area surrounding five small subsistence agricultural villages in a remote mountainous region of the Garhwal Himalayas. Shorter-term comparative observations were also conducted on neighboring groups and on another population at higher elevations (ranging around 3000 and above masl) to gain some perspective into differences between langurs in close contact with humans and those that experience relativey little interference.

First, the social grooming networks of 34 adult females were investigated to better understand how their distinct patterns of social interactions might help them to survive in this harsh landscape. The grooming network of females was elucidated using social network analysis and mtDNA genotyping to understand the role rank, age, kinship, group membership status (natal, immigrant), mating activity, and the presence/absence of dependent offspring on social organization and their potential impact on individual fitness/survival. I also studied the groups' patterns of interaction with predators and humans in their natural and human-

modified environments. To better understand the human perspective, I conducted structured interviews on the inhabitants of the five villages located along the valley with varying degrees of interactions with langurs, to understand what they perceived as being the sources of conflict between themselves and langurs. From the langurs' perspective I investigated their use of resources in the habitat and the degree of overlap with those of humans. Another source of conflict in the human dominated habitat are domestic dogs, left to roam the area around agricultural fields. Dogs pose a significant threat to langurs, which they attack, kill and sometimes consume. To better understand this threat, I studied the behavioral strategies of 9 male CHL for dealing with predation pressure by dogs. To elucidate the costs and benefits associated with langur anti-predator behavior, I investigated the relationships among the types of anti-predatory behavior displayed (high risk: counterattack, alarm calls; low risk: flee and freeze), adult male attributes (rank, residency duration, genetic relatedness to the group), and potential benefits (mating, grooming). Predatory dog-primate interactions were studied in the 78-member S group. In contrast, in a group of CHL studied far from the village, a feeding association between langurs and a potential predator, the Himalayan black bear, was documented with a systematic survey for bear presence and the feeding ecology of langurs.

Summary of the Results
Central Himalayan langur (CHL) females showed distinct patterns of social interactions in relation to their rank, age, kinship, group membership status (natal, immigrant) and presence or absence of dependent offspring. This study represents an unusually detailed account for any species in the genus *Semnopithecus* (8 species) for the social and genetic structures of females in a group, and the presence of immigrant females forming two distinct haplogroups different from most of the group members. High-ranking females had a greater number of grooming partners, and others groomed females with infants for longer durations. Such strong bonds are known to be beneficial for infant survival. Natal subadult and immigrant (having extra-group haplotype of mtDNA) females formed strong indirect connections, greatly facilitating the overall social connectivity of group members. Immigrant females formed strong grooming relationships with females who themselves had strong bonds, a trait linked in other species to increased fitness. Furthermore, CHL patterns of interactions with humans and predators appeared to be adapted to maximize fitness.

Interactions with local people were complex. When foraging in and around agricultural fields in the village, langurs frequently encountered humans and dogs. Low availability of dense oak (*Quercus leucotricohophora*) patches for sleeping sites by langurs seemed to be one reason for their intense feeding on agricultural crops. This relative lack of suitable sleeping trees is partly attributable to the high dependency of local farmers on this tree species for their livelihood. In contrast, in high-altitude oak forest, CHL formed feeding associations with another potential predator, the Himalayan black bear (*Ursus thibetanus*). The two species shared the alpine habitat only during the peak of the fruiting season of the oak, lasting only a few months before the onset of winter. Both species needed this limited resource to store fats for the winter months. The study group lower down in the village habitat frequently foraged in and around the agricultural fields. This was the context for

encounters with predatory dogs, which frequently harassed and sometimes fatally attacked and ate the langurs in the fields. I found that while high-ranking, newly immigrant males obtained high mating success, they rarely if ever performed high-risk anti-predator behaviors. By contrast, adult males who aggressively interacted with predatory dogs tended to share the same haplotype with group females, had longer tenure in the group, and thus more experience with village dogs. These males also had strong grooming bonds with females. Anti-predatory strategies of adult male CHL were not easily explained by most of the current evolutionary hypothesis on the topic. This high degree of behavioral adaptation to environmental circumstances provides insights into the behavioral flexibility in this species. Further systematic studies on anti-predator behavior in other primate species will be helpful in expanding our understanding of the effects of human impacts on behavioral flexibility and their capability of survival in human- modified environments.

Conservation implications and recommendations

As oak forests appear critical for CHL survival, maintaining sufficient density of oak patches is important for the conservation of this species. Poor regeneration of oak is the biggest challenge facing conservation of oak forests. But, restoration of the oak forest alone is not sufficient for conserving the langurs, because this will not stop people's dependency on oak. For a long-term solution, sustainable livelihood alternatives must be considered. In this study, I showed that the high number of livestock maintained for marketable milk production is the leading cause of villagers' high dependency on the oak forest. Providing alternative income sources through other activities, like ecotourism, cultivation of medicinal plants, and traditional handicraft production could reduce over-exploitation of the surrounding forest.