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Arboreal squirrels

As a group among mammals, the 278 species of extant squirrels are known to occupy a variety of ecological niches across different habitats. Squirrels are typically like other small mammals in being diverse and numerous in forest ecosystems and in the key roles that they play, including those of prey, predators, frugivores, pollinators and managers of forests. Despite the fact that they could be model research organisms given their visibility, adaptability and mostly common occurrence, little is known about individual species in this large family. The Third International Tree Squirrel and First International Flying Squirrel Colloquia, hosted by the National Institute of Advanced Studies, Bangalore at the Periyar Tiger Reserve in Kerala between 22 and 29 March 2006, brought together biologists and managers from various countries, and were devoted to developing a more comprehensive understanding of arboreal squirrels. This special section is a collection of papers that emerged as a consequence of this meeting, highlighting important findings as well as the current trends in research on squirrels.

The diversity, conservation status and state of knowledge of squirrels is not uniform worldwide; while arboreal (flying and tree) squirrel diversity is highest in the tropics of Asia, this is also the region containing the most endangered species. John Koprowski and R. Nandini (**page 851**) point out that the skewed pattern of research on squirrels is a cause for concern: most publications on squirrels pertain to species outside the tropics and the bulk of our academic knowledge comes from just ten species. Our knowledge of tree squirrels is much greater than flying squirrels, although again, more flying squirrels are at risk. This study thus highlights the need for more studies on both tree and flying squirrels in tropical forests across the world.

Levels of endangerment and risk are not equally shared by species and could be a function of not just their distributional range but also various other factors, ranging from the phylogenetic history and the position of some species within their families to the specific life-history traits of others. Louise Roth and John Mercer (**page 857**) highlight the importance of accounting for the phylogenetic patterns of species divergence in the context of evolutionary time in assessments of taxa prone to extinction. They draw our attention particularly to the tribe Sciurini as being perhaps the most vulnerable given its high rate of diversification and the current levels of environmental change. Distributed in the South American tropics, this lineage of squirrels has entered and radiated within that continent comparatively recently and is the most rapidly diversifying lineage of squirrels worldwide – factors that make this tribe vulnerable in a phylogenetic context. At a more narrow species-specific level, it is important to identify key life-history characteristics of species to provide a basis for predictive modelling to determine species at risk as well as better focus conservation efforts. Stephen Dobson and Madan Oli (**page 862**) compare the life-histories of rodents with other mammals and find them to be 'fast' (live fast, die young) for their size. Surprisingly, their results show that squirrels exhibit strategies similar to bovids – another herbivore group – though considerably different in body size. They also report considerable variation within squirrels; tree squirrels, for example, exhibit faster life-histories than do ground-dwelling squirrels. More life-history information, however, is needed on most squirrels, especially flying squirrels, before we can effectively use this information for conservation.

Arboreal squirrels are small mammals that comprise an important part of both diurnal and nocturnal communities in forested ecosystems and their occurrence as well as ecology is intricately intertwined with their environment. Apart from arboreal squirrels being more diverse in the tropics, it is also interesting to note that larger species are more distributed in the tropics – presumably as the abundance of resources supports larger and more species of herbivores and frugivores. Renee Borges (**page 866**) points out that vertebrates of larger body size are more common in the Palaeotropics than in the Neotropics and squirrels are no exception to this trend. She suggests viewing this biogeographic pattern of distribution in the light of spatio-temporal availability of resources, productivity of forests and occurrence of competitors and predators. While it is well known that squirrels play an integral role in forest ecosystems by being herbivores and frugivores, it is not so well known that they shape the structure and evolution of forests through these roles by selecting for particular traits in trees. We now know that squirrels are not merely passive users of available resources but instead are architects that actively shape the evolution of trees; this relationship is cyclic, with the squirrels in turn affected by the direction of evolution of the forest stand. In a comprehensive review of tree squirrels and their co-evolutionary relationships with trees and forest ecosystems in the Holarctic region, Michael Steele (**page 871**) pays special attention to the profound roles of squirrels as herbivores and seed predators as well as dispersers. Using three exciting examples of field research, he illustrates how complex interactions between squirrels and pine trees cause selection for traits in the pine as well as in the squirrel populations. The exploitation of these resources by squirrels is not random, and in a study that examines the evolutionary strategy behind food resource utilization, Michael Winterrowd (**page 877**) reveals that flying squirrels use spatial memory cues to retrieve stored caches. These strategies seem to be individual-centric as adult flying squirrels that live in communal nests are unrelated and do not practice any cooperative food hoarding strategy. Squirrels also interact with the forest habitat in their use of trees for nest sites and little is known of the nesting requirements of tropical squirrels. Ravi Shankar Kanoje (**page 882**) describes the nesting trees utilised by the Indian giant squirrel in Sitanadi Wild-

life Sanctuary in central India and lists the current threats to the habitat of the squirrel due to anthropogenic activities.

Anthropogenic threats to animal populations are common throughout the tropics, including south and south-east Asia. While, as pointed out above, the conservation status of squirrels can be examined from phylogenetic or ecological standpoints, translating these theoretical findings into action-based strategies in the field acquires another dimension altogether. Species- and site-specific management plans are required to address conservation issues at the ground level, but several practical challenges lie in the way; for instance, it is imperative to know the basic population descriptors of species before conservation strategies can be outlined. Squirrels, however, are arboreal and often cryptic (and nocturnal in the case of flying squirrels); estimating population parameters for these species is thus a challenge, particularly in the tropics. Using the rigorous and time-tested line-transect (distance sampling) method, Dev Charan Jathanna and his colleagues (**page 885**) estimate densities of the arboreal Indian giant squirrel across a number of sites and habitats, and find that its abundance is driven by habitat structural and compositional features. Another study of giant squirrel abundance that reveals similar occurrence patterns advocates using a different method; V. Srinivas and co-authors (**page 889**) advocate the use of occupancy estimates (proportion of the area occupied by the species) as a surrogate to density estimation, given the practical difficulties of working in mountainous terrain and the accompanying logistic limitations. Their method involves repeated presence/absence surveys and analysis of the data in a capture–recapture framework that could be more applicable for estimating numbers over a larger spatial extent in order to develop broad-scale management plans.

Targeted conservation strategies also need to take into account the ecological nature of the concerned species; they may have different tolerance thresholds and adaptabilities, and react differently to the same threats and external disturbances, consequently requiring different approaches. The degree of arboreality, body size and the dietary and nesting requirements of a species play important roles in the response of species to habitat modification. In measuring the response of four diurnal tree squirrels to logging in northeastern India, Aparajita Datta and S. P. Goyal (**page 895**) illustrate how squirrel species respond differently to disturbance and habitat alteration leading to a drastic reduction or even absence of the species. While the adverse effects of habitat disturbance on species are a challenge for conservation biologists, species that are adaptable pose unique challenges if they out-compete other native species or even develop the potential to cause economic damage in human-dominated landscapes. Sandro Bertolino (**page 903**) discusses the introduced eastern grey squirrel and the threat it poses to the native European red squirrel in Italy, and models the interaction between the two species using knowledge of the behaviour of the introduced grey squirrel in England. In this different approach to conservation, he predicts that the invasive grey squirrel will spread to a few other countries in the short term but to most of Eurasia in the long run, giving cause for concern, and suggests that conservation strategies must transcend international boundaries. While the adaptability of a species to changing habitats clearly determines its long-term persistence, some species, by virtue of this quality, have already come to be regarded as pests in human ecosystems. Some squirrels do cause substantial economic damage and, as a case study, A. K. Chakravarthy and his colleagues (**page 907**) assess the impact of the Indian palm squirrel *Funambulus tristriatus* in commercial cardamom plantations in the Western Ghats. While this species does cause economic damage, the authors maintain that these losses can be mitigated by regular agricultural practices that take the ecology and behaviour of the species into account.

The last two papers in the special section advocate increased research on squirrels, particularly in the tropics, and suggest the use of advanced techniques to acquire more data. D. L. Haughland and co-authors (**page 912**) suggest the use of radio-telemetry and highlight the kinds of data that can be gathered on cryptic animals such as squirrels using this technique. Given the advances in technology and the easy availability of materials, radio-telemetry clearly emerges as a good data-gathering tool. Peter Lurz and his colleagues (**page 918**) review the use of GIS techniques and modelling approaches in the conservation and management of squirrels. Although there is a need to refine techniques and use appropriate data, they specify that models can allow conservation biologists and managers to make informed decisions to better conserve endangered squirrels and other small mammal species as well.

While this special section showcases important and current findings in different areas of squirrel biology, the recurring thread in almost all the papers concerns the lack of adequate knowledge on most species and the critical need for further studies. We hope that this section will serve to encourage more researchers, conservation biologists and managers to turn to their attention to this fascinating group of animals, acquire more scientific knowledge of tree and flying squirrel species, and actively include them in conservation plans, generally in tropical forests across the world, and more particularly in India.

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