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Alien squirrels introduced into Italy and conservation of the native red squirrel (*Sciurus vulgaris*) in Alpine forests

The introduction of species outside their native range is considered one of the most important threats to biodiversity. A well documented case of competition by an invasive alien species is the replacement of the native Eurasian red squirrel (*Sciurus vulgaris*) by the introduced American grey squirrel (*Sciurus carolinensis*) in the British Isles and in parts of northern Italy. Model-based simulations suggest that, after the spread of grey squirrels throughout Europe, red squirrels will persist only in large tracts of coniferous forest.
The research for my PhD thesis was oriented towards two main topics: management of alien squirrels introduced to Italy and conservation of the red squirrel in Alpine coniferous forests. The results have been presented in 6 articles published in international journals and in 2 submitted papers.
The grey squirrel has adapted very well to European habitats, invading the areas where it was introduced. According to modelling scenarios, the species will manage to cross the Italian border to enter France and Switzerland in a few decades. The colonization of vast areas of Eurasia will then be only a matter of time and will represent a serious threat to the survival of the red squirrel throughout its range. An application of the European strategy on invasive alien species to squirrels showed that non-indigenous squirrel species introduced into Italy easily established new populations. This success is probably related to their broad ecological amplitude and high reproductive rate.
The study on the red squirrel in Alpine coniferous forests was based on a trapping programme in two areas of the Gran Paradiso National Park. This project provided information about the life history and space-use pattern of the species. Differences in body size and mass among red squirrel populations were explained by habitat-related differences and variability of seed-crops, suggesting differential selection for smaller squirrels in spruce-larch forests and for larger, heavier animals in mixed forests. The probability of reproduction by females varied strongly among habitats and years, with more females reproducing in years with rich seed-crops. In both sexes, body mass positively affected probability of settlement and length of residency. Our results suggest that in temporally variable environments that differ in overall amount of food resources, individual variation of body mass is related to habitat type, and that, within each population, having a relatively high body mass positively affects male and female settlement success and local survival, as well as female reproductive success.
Red squirrels responded to spruce seed-crop failure by strongly increasing their home ranges in the following year. They also moved to patches with other food resources and abandoned the spacing pattern of reduced core-area overlap among males and nearly exclusive core-areas among females found in less variable habitats. These results are consistent with a space-use model for vertebrates, which predicts large and strongly overlapping home ranges and absence of territorial behaviour in habitats with poor food availability. Spacing behaviour in red squirrels was a plastic, conditional strategy, with individuals adapting the size and/or location of their home ranges in relation to local distribution and abundance of food resources.
The red squirrel is considered a key species in forest ecosystems because of its role in seed dispersal. We also suggest that it helps disseminate spores of mycorrhizal fungi that are important in maintaining a high level of inoculation in tree roots within the forest. Spores of mycorrhizal

hypogeous fungi were found in the squirrel faeces. This confirms the use of fungi by squirrels as a secondary food resource and suggests a role of the animals in the maintenance and diffusion of the mycorrhizal system, which is important for the growth of coniferous forests. This hypothesis will be investigated further by comparison of the use of fungi by squirrels with fungal availability over many years.

A technique to obtain population indices for red squirrels using hair-tubes was tested by comparison of these indices with population estimates obtained by live-trapping. A combined model derived from areas monitored for five years had a high predictive value both locally (a model derived with data from 2000-2002 correctly predicted 89% of density values from hair-tube indices in 2003-2004) and when applied to an English data set (73% of 11 density values were correctly predicted using the model developed in the Alps). Hence, this method could be used to monitor squirrel populations with a low field effort.

The information about the ecology of the red squirrel in coniferous forests acquired during this research helps to better understand the adaptation of the species to these Alpine habitats, and will probably be useful for conservation of the species when the grey squirrel has colonized the mountain areas of southern Europe.