The present work embodies a detailed investigation of the population structure, reproductive biology, karyology and pollen mother cell meiosis of three rare and threatened medicinal plants of Kashmir Himalayas namely: *Podophyllum hexandrum*, *Aconitum heterophyllum* and *Saussurea lappa*. The following aspects have been worked out:

1. Distribution
2. Morphology and phenotypic variability
3. Flowering phenology
4. Breeding system:
   4a. Pollen emission and stigma receptivity
   4b. Pollen viability and pollen ovule ratio
   4c. Pollination system
   4d. Breeding behaviour
   4e. Modes of propagation
5. Reproductive effort and resource partitioning in sex organs
Distribution:

A look at the world wide distribution of these taxa depicts that they are restricted to a narrow geographical region of the world. *P. hexandrum* is found in the Himalayas, Afghanistan and parts of south west China. *A. heterophyllum* and *S. lappa* on the other hand are endemic to western Himalayas, the latter being restricted only to Kashmir and Pakistan.

In Kashmir Himalayas these taxa obtain sporadic representation and are confined exclusively to the high altitude montane habitats.

**Morphology and phenotypic variability:**

Several natural populations have been scanned for variability in the morphological traits. The characters analysed include: the dimensions of the subterranean organs, plant height, number of leaves per shoot, lobing pattern of the leaves, leaf area, foliar, floral, and fruit dimensions and flower, floret and capitula production per plant.

The investigations reveal a high body of variability in all the three taxa. The magnitude of this variability is, however, considerably narrowed down when plants from diverse natural sources are cultured in
a uniform environment. The mean values of most of the characters of the natural and transplant populations depict statistically significant differences. The results of the transplant experiments reveal that the plant to plant and population to population variability in the morphological characters is partly environmentally induced and partly germinal in origin. In order to assess the variability of various quantitative traits in relation to each other, coefficients of correlation have been computed. The results obtained indicate that a large number of the quantitative characters are positively correlated with each other and exhibit parallel variations, while some others show no correlation and vary independent of each other.

**Flowering phenology:**

These studies include analysis of various phenological events such as the initiation and duration of sprouting of the plants, floral bud formation, anthesis, petal fall and senescence.

Of the three taxa, *P. hexandrum* is a spring flowering herb, *A. heterophyllum* and *S. lappa* on the other hand initiate their life cycles in the later part of the spring months and flower during summer. While *P. hexandrum* produces single flowered shoots, the remaining two taxa bear multiflowered inflorescences. Anthesis occurs acropetally in *A. heterophyllum* and basipetally in
The peak blooming seasons are from March through May in *P. hexandrum* and June through August in the other two taxa.

The data generated reveal a remarkable temporal variability in various phenophases from plant to plant and population to population. The transplant experiments demonstrate that these differences are largely environmental rather than genetic in origin.

**BREEDING SYSTEM:**

*Pollen emission and Stigma Receptivity:*

All the three taxa produce bisexual flowers. In *P. hexandrum*, the development of male and female phases in a flower proceed almost simultaneously. This homogamy provides good chances for selfing within a flower. On the contrary, in *A. heterophyllum*, the stigmas of a flower become receptive only after the anthers have shed their pollen completely. There is thus a perfect isolation of the male and female phases at the level of an individual flower which creates "temporal dioecism" and prevents selfing. However, these phases overlap to some extent when the entire inflorescence is taken as a unit. This provides opportunities for geitonogamy within an individual. The male-male and female-female phases of different individuals in a population develop by
and large asynchronously. There is, however, a significant overlap of male and female phases among these individuals which creates enough chance for plant to plant pollen flow in a population.

Yet another system is operative in the third taxon - *S. lappa*. In this species, the pollen availability coincides with the receptive phase of the stigma in a floret. However, the pollen grains of a floret fail to germinate on the stigmas of the same floret. The species therefore seems to be strictly self-incompatible. Since there is a considerable asynchrony from floret to floret in a capitulum, capitulum to capitulum in a plant and plant to plant in a population, the system provides ample opportunities for pollen flow between different individuals of a population.

**Pollen viability and Pollen-Ovule Ratio:**

Pollen are emitted as tetrads in *P. hexandrum* and singly in the other two taxa. In the former, individual tetrads exhibit differential staining with one, two, three or all the cells of a tetrad non-staining. On an average all the three species display fairly large percentage of pollen viability (> 90%).

An important factor affecting the breeding system of a species is the ratio in which the male and female gametes are produced by an individual. Low pollen -
ratio is considered to be characteristic of the autogamous taxa while higher ratio reflects the allogamous nature of the breeding system. The average pollen-ovule ratio of the three taxa presently investigated works to 3056.11, 11798.34 and 13631.27 for *P. hexandrum*, *A. heterophyllum*, and *S. lappa* respectively. The higher pollen-ovule ratio indicates that outcrossing must be the predominant mode of breeding system operative in these taxa.

**Pollination System:**

The pollination systems investigated now, clearly indicate that the sexual reproduction in *A. heterophyllum* and *S. lappa* is insect mediated. The transfer of pollen to the receptive female tissues is manipulated by large number of insects belonging mainly to two orders, Hymenoptera (families: Bombidae and Bremidae) and Diptera (family: Syrphidae). Bumblebees (*Bombus* spp.) seem to be the primary pollinators in whose absence these species fail to produce seed. No pollen vector could, however, be detected for *P. hexandrum* during the present investigations. The species seems to have adopted autogamy as an alternative and produces three types of flowers designated "A", "B", and "C". In the flowers of type A, the anthers are placed in level with stigma and can touch the receptive surface of the latter with ease. Such homogamous flowers, therefore, provide ample chance for selfing. In the flowers of types
B and C, however, the essential organs being positioned at different levels, are unable to touch each other and depend upon some external agency for pollination. The production of such flowers fulfills the predictions made on grounds of pollen-ovule ratio that the species may be outbreeding. Due to lack of insects, however, pollination in these flowers is not realised and they drop precociously. This loss is offset by producing type A flowers.

Breeding behaviour:

The breeding behaviour of the taxa investigated now was unravelled by several bagging experiments. These experiments reveal that *P. hexandrum* can reproduce both autogamously as well as through outcrossing. This is demonstrated by the fact that the flowers produced seed both when pollinated with pollen from a different source and when forced to self-pollinate. *A. heterophyllum* although exclusively cross-pollinating in nature can reproduce geitonogamously as well. On the contrary *S. lappa* is self-incompatible and predominantly cross-pollinating. Therefore capitula bagged and allowed to self-pollinate failed to produce achenes. In no case does any of the three taxa show evidences of apomixis.

Modes of Propagation:

All these taxa have two reproductive options -
the sexual (via seeds) and the asexual (via rhizomes/tubers). The average number of seeds produced per individual works to 55.62, 180.52, and 550.58 in *P. hexandrum*, *S. lepapp* and *A. heterophyllum* respectively. The two systems of reproduction impose a selective advantage over these species. The variability generated by the sexual system for natural selection to operate is fixed by the vegetative system.

Reproductive effort and resource partitioning in the sex organs:

Of the total above ground resource budget in a plant, maximum proportion is allocated towards the leaves in *P. hexandrum* and towards the stem tissues in the remaining two taxa. Reproductive effort is 38.59% in *P. hexandrum* and slightly lesser (i.e. 34.34%) in *S. leppa*. In case of *A. heterophyllum*, the vegetative reproductive effort is more than the sexual reproductive effort. Thus the % VRE and SRE in the species amount to 20.66 and 13.68 respectively.

Analysis of resource partitioning in the floral organs conducted in *P. hexandrum* and *A. heterophyllum* indicates that maximum proportion of dry biomass is found in the perianth and only a small amount utilised in the development of reproductive units before fertilization. The partitioning of resources among the male and female sex organs is more or less equal (male : 30.89% and female : 31.13%) with a slight tilt towards the female side in...
P. hexandrum. Conversely, the resource allocation towards the male and female functions is in the ratio of 3 : 1 in A. heterophyllum. These results are quite commensurate with those obtained from the bagging experiments and suggest both selfing as well as outcrossing in P. hexandrum and predominant outcrossing in A. heterophyllum.

Karyology and pollen mother cell meiosis:

The detailed karyological studies have been conducted for the first time on P. hexandrum and S. lappa. These studies reveal that the taxa under reference are diploid having $2n = 2x = 12$ (P. hexandrum), $2n = 2x = 16$ (A. heterophyllum) and $2n = 2x = 36$ (S. lappa). Although S. lappa is known to have $x = 13$ as the base number, the present count of $x = 18$ is a new addition to this list which suggests polybasic nature of the species.

In P. hexandrum and A. heterophyllum, the somatic complement comprises three types of chromosomes namely metacentric, submetacentric and acrocentric in the ratio of $1 : 3 : 2$ and $f : 3 : 4$ respectively. However, the chromosome complement in S. lappa is constituted by only two types namely submetacentric and acrocentric in the ratio of $1 : 2$. The number of nucleolar chromosomes is 4 in P. hexandrum as revealed by the nucleolar studies.

Pollen mother cell meiosis proceeds normally in
all these taxa. This leads to high pollen fertility. However, abnormalities such as precocious separation of bivalents, chromosome fragments and clump formation is also observed, though very rarely. Presence of 5 nucleolar bivalents in S. lappa indicates that the species possesses 10 nucleolar chromosomes.

The convergence of evidence from various aspects of reproductive biology of the three taxa investigated now reveal that they are fairly stable diploids with normal gamete differentiation, efficient pollination and profuse seed production. The sexual reproduction is assisted by vegetative reproduction in the maintenance of their populations. What then makes these taxa rare and threatened in nature? The answer to this question is afforded by several factors which pose a threat to the very existence of these species. Some of the most prominent ones are:

- floral abortion,
- fruit predation,
- inadequate seed dispersal,
- prolonged seed dormancy,
- slow germination,
- stiff competition of seedlings with already established plants,
- high seedling mortality,
- endemic nature and restricted distribution,
- habitat specificity and destruction,
- non-judicious exploitation of their vegetative propagules for medicinal purposes and indiscriminate grazing etc.

In order to salvage this valuable germplasm, the following conservation measure have been proposed:
i) Mass awareness about the relevance of these species to human life and effects of their indiscriminate exploitation be ensured.

ii) Appropriate conservation strategies be planned. This should also include provision of legislative protection to such species.

iii) Raising of germplasm banks in the protected areas such as the national parks and biosphere reserves be undertaken.

(iv) Identification and conservation of vulnerable habitats be taken up.

v) Developmental programmes be planned with due cognizance to the possible threats they can pose to such species.

vi) Adequately funded action plans be launched for their mass cultivation. This should also include subjecting these species to tissue culture techniques.

vii) Breeding programmes be initiated for their genetic improvement.