CHAPTER 1

General Introduction and Review of Literature
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1.1. INTRODUCTION

A number of workers have investigated the impacts of herbivory on ecosystem productivity, diversity, stability and biogeochemical cycling (McNaughton 1983a, McNaughton and Georgadis 1986, Crawley 1983, Milchunas et al. 1988, 1989, Milchunas & Lauenroth 1989, Bonser and Reader 1995, Hiernaux 1988, Biondini et al. 1988, Stohlgren et al. 1999). Three divergent approaches have been adopted to analyze the ecological impacts of grazing: (a) comparison of structure and processes in exclosures where grazing by livestock and large mammals is excluded, with structure and processes in adjacent areas within a given ecosystem type. (b) Comparison of structure and processes of selected ecosystem types subjected to varied grazing disturbance regimes in vast homogenous pastoral landscapes such as savanna, prairies and steppes (c) landscape scale analysis where the landscape is stratified into different ecosystem types and analysis of structure, function and interaction in different ecosystem types forms the basis of elucidating diversity-productivity-environmental function patterns. Attempts along the landscape analysis approach, a more recent development, are not as widely adopted as the other two approaches (Stohlgren et al. 1999, Cingolani et al. 1998).

In highly heterogeneous landscapes, as in the Himalayan alpine region, where physical, edaphic, biological attributes of ecosystem and nature and intensity of grazing often vary over short distances (Puri 1989), a landscape scale analysis assumes importance for managing grazing for direct benefits to the people through animal husbandry on one hand and global environmental benefits (carbon sequestration, biodiversity conservation and hydrological balance) on the other. Within Himalaya, broadly, two zones could be differentiated: (a) the alpine meadow area grazed over a short period of time (during summers) by the migratory livestock of transhumance/nomadic communities (b) forests and pastures around permanent settlements at lower altitudes grazed by the livestock all through the year. There are only a few studies on ecology of grazing in Himalayan alpine region. Past studies have concentrated on effect of grazing in selected Himalayan alpine ecosystems in
Kumaon and Garhwal (Ram et al. 1989, Joshi et al. 1991a, 1991b, Negi et al. 1993a, 1993b, Raizada et al. 1998). These studies provide limited information on ecosystem structure and function variation in the landscape in relation to variation in grazing regime. Further, attempts to understand ecosystem structure, function and management in relation to grazing in the cold desert region of the Himalayas are altogether lacking.

A wider objective of this study is to look at the differentiation of landscape and ecosystem in relation to grazing in upper catchment of Spiti watershed covered in cold desert region and to undertake intensive ecological studies in selected landscape segments.

1.2. LITERATURE REVIEW

1.2.1. High altitude environments

Pastoralism is a common means of subsistence by the humans inhabiting extreme environments where settled agriculture is not a viable livelihood option. The high altitude mountainous areas form one such extreme environments, which supports pastoral activity or/as agropastoralism and where tree component of forests are generally lacking and the landscape, is dominated by Alpine vegetation with montane scrub, meadows and desert vegetation (Ning 1998). Alpine ecosystems of the world are said to be resource limited and seasonally stressed ecosystems (Chapin & Shaver 1985). Soil drought and plant water stress due to low temperatures provides limitation to plant community development and productivity (Sundriyal 1992; Gold & Bliss 1995).

Short growing season and slow nutrient turnover are critical for plant growth, developmental and reproduction (Negi et al. 1992, Walker 1995). Growth and flowering of alpine plants is initiated by snowmelt water in the summer season and plants begin to grow early to complete their growth cycle before the onset of freezing temperatures (Ram et al. 1988, Negi et al. 1992). Most alpine plants at higher attitudes are reported to complete their growth cycle in short period of 2-4 months (Billings and Mooney 1968). In addition to such direct moisture limitations on the vegetation, indirect moisture effects, such as the control of nutrient supply rates by water flux (Chapin et al. 1988) can also be important.

Tropical high elevation areas have been subjected to pastoral land-use since
historical times (Mani 1990, Etter and Villa 2000). The nature and intensity of environmental changes in high mountain areas and their implications taking into consideration of the native flora, elevation, aspect, geology-soil-vegetation complex which determine the ecosystem structure and function (Troll 1972). Such high-elevation ecosystems are characterized by alpine vegetation above the tree line. These areas are wide and diverse: "Paramo" (mesic areas of the northern Andes), "Puna" (drier areas of the central Andes), "Julca" (mesic areas in the transitional zone between the Paramo to the north and the Puna to the south), "Zacatal" in Mexico, "Afroalpine" and "Moorland" in East Africa. Tropical alpine areas have characteristic vegetation physiognomy similar to the Alps vegetation in Central Europe (Whittaker 1975, Smith & Young 1987). High altitude Alpine vegetation is also found in other parts of world as "Rocky Mountains" in North America, 'Pyrenees' in Spain, 'Alps' in Central Europe, Caucasus Mountains' in Central Asia, 'Himalayan and Tibetan plateau' in south-east Asian and high mountainous areas of New Zealand (Walter 1979). These Mountains in tropical and temperate alpine regions differ in many respects. An important difference pertains to higher ratios of above ground to below ground biomass in tropical alpine areas as compared to those in temperate alpine and Arctic areas (Smith and Klinger 1985). Species richness (local, or “alpha” diversity) appears to be similar in tropical alpine and temperate alpine but regional (“gamma”) diversity appears to be greater in tropical alpine than in temperate alpine region. Further, tropical alpine flora shows a higher level of endemism compared to temperate alpine flora (Smith and Young, 1987).

High altitude environment thus supports ecosystems, which have been variously termed as alpine shrub, alpine meadow, alpine steppe, and alpine desert ecosystem, depending upon the variation in microclimatic condition of the area. They form a landscape akin to grassland ecosystem type and are subjected to human disturbances related to grazing. Many of the high altitude tribal people in the Himalayan and Trans-Himalayan areas are still continuing their traditional food production and pastoral activities. To name some, are the Gujjars and Bakrawals of Jammu & Kashmir, Gaddis of Himachal Pradesh and also some Bhotiya tribes in other parts of the Himalaya (Lal 1974). The ecological conditions of high altitude have shaped their lifestyles and culture (Farooque and Saxena 1996), making them to practice sustainable animal husbandry along with agriculture.

Degradation of Himalayan ecosystems due to increasing human disturbances
and the need for its conservation has attracted attention towards the spatio-temporal dynamics of land-use and its implications (Saberwal 1996). While ongoing research has concentrated on the nomadic pastoralism, virtually nothing has been pursued in the context of sedentary and/or sedentary-small scale migratory graziers. Such practices are common in the Trans-Himalayan societies of Spiti-Himalaya. Increasing, human population over the last two decades has also led to over exploitation of natural resources in Spiti (Mishra 1997). The available literature reveals that while flora and landscape of this region have been dealt by some workers (Aswal and Mehrotra 1994, Polunin and Stainton 1997), others have conducted preliminary ecological studies (Singh and Gupta 1990, Rana 1984, Kapadia 1996, Manjerakar 1997, 1998, Mishra 1997, Kala 2000). However, the effects of small scale migratory grazing on ecosystem structure, function and management in cold desert region has not been studied. Meanwhile, long-term research on ecosystem structure and function has been carried in the cold desert region off the Tibetan plateau (Anonymous 1999). Unfortunately, because of language and other constraints very little information has been made available outside China (Tianxiang Lou et al. 2002).

1.2.2. Ecosystem structure in relation to grazing

The role of grazing in influencing the plant population dynamics and community structure has been demonstrated in many studies (reviewed by Huntly 1991, Olff and Ritchie 1998). Grazing animals affect plant communities in several ways example plant defoliation, nutrient removal, and nutrient redistribution through excreta, mechanical impacts on soil and plant material through trampling. Biomass removal can be characterized by its intensity i.e., proportion of biomass removed in each defoliation event and its frequency i.e., how often a plant or a grassland site is defoliated (Turner et al. 1993). Influence of grazing on ecosystem structure depends on its intensity and also, in part on its level of herbivore diet selectivity. Plant community structure can be affected quite differently by generalist high herbivores and by specialist herbivores, depending whether the specialist consumes competitively dominant or competitively inferior species (Lubchenco 1978).

Communities dominated by short-statured prostrate growth forms resulting from repeated heavy grazing by large herbivores in some grasslands is widely
termed as grazing-lawn (McNaughton 1983a, Milchunas & Lauenroth 1989). Herbivores may dramatically alter vegetation structure, influencing habitat adversity and in turn the abundance of small mammals, birds and insects (Milchunas et al. 1988). Grazing has been shown to increase spatial heterogeneity in some grasslands (McNaughton 1986) and decrease heterogeneity in others (Sala et al. 1996, Fuhlendorf and Smeins 1999). In Colorado shortgrass steppe, protection from livestock grazing for 60 years showed that spatial heterogeneity of vegetation increased in comparison to open grazing (Adler and Lauenroth 2001).

McNaughton (1983a) studied vegetation inside and outside 12 year grazing exclosures in several communities of the Serengeti grasslands in Africa and observed that organization and structural properties had changed radically because of protection. In some cases, species composition had changed almost completely. Low-growing prostrate plants dominated heavily grazed areas, whereas protected areas were dominated by tall species capable of eliminating the short species by competition for light.

It is noted that grazing alone cannot induce changes in ecosystem, rather its influences interact with climatic variability and other top-edaphic variables to cause changes in plant communities at various spatial and temporal scales. On a large-scale, precipitation and temperature regulate vegetation dynamics in arid and semiarid systems (Sala et al. 1988). However, most plant communities and landscapes are extremely patchy (Belsky 1983), and broad scale climatic factors cannot be called for the existence of these small-scale patterns. Frequent, small-scale perturbations such as ant mounds, small animal activities, patch grazing, and dung and urine deposition (Coffin and Lauenroth 1988) occur within the context of large scale, less frequent disturbances such as fire and drought to produce a complex disturbance regime. Thus, as spatial and temporal frames of observation are diminished, and resolution increased, edaphic heterogeneity and biotic processes such as grazing assume greater importance in determining vanity structure and function (Archer and Smeins 1991).

In semi-arid short grass steppe of North America, Milchunas et al. (1989) observed increase in cover of the heavily grazed species. Basal cover and density of all species considered together was also greater on grazed sites as compared to the ungrazed. But exclosure to grazing did not show any significant change in canopy structure and species composition and thereby countering the common belief that
grazing by large herbivores creates heterogeneity in plant communities (Milchunas & Lauenroth 1989).

Hiernaux (1998) studied the effects of grazing on plant species composition and spatial distribution in Sahelian a rangeland in Niger, Africa. Short-term protection from grazing accompanied an increase in plant species richness. However, long-term protection resulted in a regular spatial arrangement of highly contrasted, but internally homogenous plant community patches. Heavy grazing resulted in the dominance of few species in contagious patches but also left niches for scattered individual plants of other species to occupy. Moderate grazing enhanced within patch species richness and reduced mosaic heterogeneity of plant community structure.

In semi-arid short grass steppe, the climate and favorable growing season mitigated the effect of grazing. Here grazing can be considered as a disturbance at the level of the individual plants but not at the higher level of organization viz. the community (Milchunas et al. 1989). This suggests that ecosystem responses to grazing depend primarily on the evolutionary history of grazing such as in the Great Plains above, where grazing is accepted by grassland ecologists as a keystone process of the grassland ecosystems (Milchunas et al. 1988, Knapp et al. 1999). Here, moisture stress, climate and soil conditions seem to have stronger control on community structure as compared to controls exerted by the grazing pressure.

1.2.3. Ecosystem diversity and productivity in relation to grazing

Direct effects of grazing on vegetation are associated with alteration of the physiology and morphology resulting from consumption of plant issues and trampling. Grazing also affect plant performance via their affects on nutrient cycling and by disturbances brought in by altering microclimate, soil properties and plant competitive interactions (Crawley 1983). The combination of the above interactions thereby, affects the ecosystem function. In this regard, most of the studies have concentrated on the primary productivity of the grazing system in the grassland. This is primarily because livestock production is the major interest in rangeland management (Walker 1993).

The relationship between biomass species diversity is described as a hump shaped curve, with a peak species diversity at low to intermediate level of biomass (Grime 1973). Several researchers (reviewed by Tillman and Pacala 1993) have
found this pattern, with consistent result being a decrease in species adversity at the highest biomass levels. However, there is little consensus as to the mechanisms involved (Tillman and Pacala 1993, Abrams 1995). Other factors such as disturbance and environmental stress may explain most of the variation in the species diversity in a particular habitat separately from biotic factors such as biomass and competition (Houston 1994).

When productivity and biomass are artificially increased through nutrient additions, species diversity consistently declines in a wide variety of habitats, including arctic to the, old fields, grasslands and other herbaceous communities (Chapin et al. 1995, Gough et al. 1994). This result suggests a direct correlation between these two variables and supports the idea that, with increased biomass competitive exclusion becomes more important in structuring the plant community. In this case, it is essential to know the role of herbivory in affecting in this process. As already explained above herbivores can regulate diversity in various ways (Crawley 1983), but whether the not herbivores function as disturbance agents and maintain higher diversity than would occur without them is debatable (Milchunas et al. 1988, Pacala and Crawley 1992). However, many authors believe that disturbances such as herbivory cause a decline in the importance of competition (Grime 1979, Huston 1994). There is still debate about effect of herbivory on primary productivity (reviewed in Milchunas and Lauenroth 1993) and it would be difficult to draw conclusions on the effect of herbivory on competitive interactions (Gough 1998).

The role of herbivory in affecting the structure and function of ecosystem has been accepted but herbivory cannot be viewed alone but along with other factors controlling the ecosystem processes as the effects differ with differing intensity of each factors and the strength of their interactions.

The disturbance regime of an ecosystem consists of different types of disturbances operating over the range of spatial and temporal scales (Pickket and White 1985). Each disturbance type has its own set off characteristics including size frequency off occurrence, intensity, topography position and grazing intensity by livestock (Peters et al). It is generally noted that moderate intensity of grazing, where around 50% of annual above net primary productivity is grazed (Biondini et al. 1988) maximize ecosystem productivity and diversity and heavy grazing causes decline in it (McNaughton 1994, Huntly 1991). The mechanism underlying is that
certain levels and combinations of grazing or disturbance increases over all plant species diversity by decreasing the capacity of competitive dominance to exclude other species by creating gaps available for occupation by other species (Archer et al. 1987, Collins et al. 1987). This phenomenon of increase in diversity at moderate levels of disturbance has been explained through the intermediate disturbance hypothesis (Grime 1973, Fox 1979) by rangeland ecologists. The magnitude of change depends on the local colonization and extinction rates. Therefore, at intermediate level of disturbances, in the absence or minimum effect of competitive exclusion, the diversity increases. This depicts that along a stress gradient diversity is limited by stress at one end and by competitive exclusion at the other (Milchunas 1988, Huntly 1991, Olff & Ritchie 1998).

Stohlgren et al. (1999) in a long-term study in Rocky Mountain landscapes of North America found that grazing probably has little effect on the native species richness. It was contrary to the earlier hypothesis that grazed sites would have higher native and exotic species compared to ungrazed sites due to disturbance. There was not much difference between the grazed and ungrazed sites. Soil characteristics and climate seemed to have greater effect on plant species diversity and composition than grazing. Therefore, generally grazing may influence ecosystem processes, only on small scales, while at the landscape scale it has little or no effect.

Grazing has traditionally been viewed as having a negative impact on the subsequent rate of energy capture and primary production within grazing systems through a series of direct and indirect affects on plant growth, as explained earlier. However, the grazing intensity necessary to induce a decrease in primary production is difficult to establish definitively (Briske and Heitschmidt 1991). Grazing optimization hypothesis (McNaughton 1983b, 1986, Georgiadis et al. 1989) states that net primary productivity should be maximized at some moderate level of grazing through plant compensatory growth mechanisms. It is observed that removal of plant tissue through grazing in graminoids activates their vigorous growth. This is attained, as plants tend to compensate for tissue loss and due to tillering effect (Coughenour, 1985). A limited amount of evidence exists to support this hypothesis (McNaughton 1979, reviewed by Briske and Heitschmidt 1991), but it does not appear to be a significant ecological process operating on a regular basis in grassland ecosystems (Belsky 1986) Belsky (1986) indicates that the reports in the literature referencing above ground production in response to grazing, 34 reported a decrease
in production, 5 reported no change and 9 reported an increase in production. Much of the data collected in support of grazing optimization hypothesis were derived from grazing systems where humans did not directly regulate herbivore density and movement. In such systems, primary production and herbivore density fluctuate widely in a series of continuous feedback loops in response to climatic variations (Walker et al. 1987). Grazing intensities in many managed systems may frequently exceed the intensity required to consistently stimulate primary production as indicated by this hypothesis (Heitschmidt 1990). Moreover, such compensatory mechanisms are feasible only for a few grasses and resembling species, most likely to be found in grasslands having long evolutionary history of grazing (Mack & Thompson 1982). This type of plant growth compensation response in Savanna ecosystems of Africa, having very long evolutionary history of grazing and its continued high productivity in spite of being grazed, has been viewed as a positive evolutionary response to grazing (McNaughton and Georgadis 1986).

In the mixed-grass prairie Biondini et al. (1998) found that there was no significant difference in the plant species composition and diversity in grazed and areas subjected to 8 years or longer periods of protection. Further, there was no significant linear relationship between net primary productivity and grazing intensity. This led them to conclude that in the mixed-grass prairie ecosystems climatic variations particularly droughts control major trends in species diversity and net primary productivity while grazing has only a minor role.

Another controversy surrounds over the inhibition of root growth due to removal of above ground foliage. Some researchers in their field studies have shown the negative effect of grazing on root biomass (Archer and Tieszen 1983, Milchunas and Lauenroth 1989), other field studies have found positive to non-detectable effects on root biomass (Sims and Singh 1978, Van der Maarel and Titlyanova 1989, McNaughton et al. 1998). Recent evidences suggest that inhibition of root growth cannot be correlated to direct effect of loss to maintain above ground growth (Oesterheld and McNaughton 1991) but could be due to hormonal mechanisms and nutrient shortages (Aiken and Smucker 1996).

1.2.4. Nutrient dynamics in relation to grazing

Nutrient cycling via grazing animals can be important in enhancing or maintaining soil fertility (Detling 1988). Cycling of nutrients through grazers may
help to keep a pool of readily mineralizable organic nutrients near the soil surface where they are more accessible to plants and microbes and also, consumption of vegetation and subsequent defecation could also increase net turnover and availability of various elements that would otherwise remain in organic forms (Archer and Smiens 1991).

As mentioned earlier the relationship between diversity and productivity is shown by the hum-shaped curve and also, they are limited by the nutrient resources (Milchunas et al. 1988, Huston 1994), along with grazing as disturbance (Gough 1988, Olff and Ritchie 1988). Several mechanisms have been put forward to account for beneficial effect of grazing i.e. plant productivity through grazing optimization hypothesis (McNaughton 1979) and among them is the nutrient cycling (de Mazancourt 1988). De Mazancourt (1988) in his model has shown that in the long-term effect off herbivore on plan productivity primarily depends upon the fraction of nutrient lost along the various recycling pathways rather than on the nutrient turnover rate along these pathways and secondarily on the amount of nutrient inputs into the ecosystem and strength of plant nutrient limitation.

Herbivores generate spatial patterns via inputs of excreta to the soil. Ungulates deposit nutrients that they consume from extensive areas into nutrient enriched 20 -100 cm patches (Steinhauer and Collins 1995). In arid ecosystems, grazing by cattle has been linked to increased soil patchiness via effects on grass community composition (Lavado et al. 1995) or shrub encroachment leading to islands of fertility surrounded by barren soil and thereby serving as a potential feedback to grassland desertification (Schlesinger et al. 1996). In Yellowstone, Augustine and Frank (2001) showed that grazers but that the spatial distribution of soil nitrogen proportions at every scale from individual plants (> 10 cm) to plant communities (30 cm) to topographically variable landscapes.

1.2.5. Phenology

Limited resources are available for plant growth in alpine region and these resources are available during a short growing season (Rathcke and Lacey 1985). Phenological studies are important to understand the ecological suitability of species in a given set of environmental conditions and plant-pollinator and plant-herbivore interactions. Phenological patterns are genetically controlled responses but moderated by environmental conditions faced by the species (Crawley 1983, Pors

Walker et al. (1995) studied phenological patterns of two alpine forbs *Acomastylis rossii* and *Bistorta bistortoides* from 1983 to 1988 in five different communities in Colorado alpine sites. Phenological events (initiation of growth, date of maximum leaf length, leaf number, and flower number) were related to snow melt patterns. Arroyo et al. (1981) studied different categories of phenological behaviour along an altitudinal gradient 2320-3550 m in Cordillera de Los Andes, Central Chile. The average length of the flowering period for each species increased with altitude and approximately doubled over 1200 m altitudes. At high elevations, temperature has been considered to be the most important factor for phenology as reported by Holway and Ward (1965). Ram et al. (1988) have correlated phenological development directly with the moisture regimes. Usually, there is low seed production and seedling survival at high altitudes, which is compensated by vegetative propagation to ensure the survival of species even after continuous exposure to unfavourable flowering condition. There is no study on phenology of plant species in cold desert of Himalaya.

1.2.6. Plant defense and resistance to grazing and Plant functional traits

Grazing resistance can be termed as the relative ability of plants to survive grazing. It could be organized into two components viz. avoidance component in which the probability and severity plant defoliation is reduced, while tolerance mechanisms facilitate growth after defoliation i.e. mechanisms of rapid leaf displacement (Briske 1991). Based upon both morphological and physiological considerations, grazing resistance within ecological plant groups may be generally ranked as: herbaceous monocots > herbaceous dicots > deciduous shrubs and trees > Evergreen shrubs and trees (Archer and Tieszen 1986).

Species possessing culmed vegetative shoots are especially susceptible to defoliation because apical meristems are elevated above the soil surface and readily accessible to herbivores (Briske 1991). Mechanical deterrents including spines, awns, and epidermal characteristics (e.g. silica bodies, pubescence and cuticular waxes) directly influence palatability (McNaughton et al. 1985). Long-term grazing has been observed to function as a selection pressure against the tall upright growth-forms in several perennial grasses (Briske 1991). According to Briske (1991) tolerance to grazing by plants may be achieved by several means like rapid leaf
replacement through intercalary meristems, carbon allocation for the above ground production, maintaining carbohydrate reserve, altering plant water status and compensatory growth.

According to Rosenthal and Kotanen (1994), some of the plant traits may reflect selection driven by herbivory, whereas others are merely by-products of other selective factors, e.g. growth forms. Similarly, certain tolerance mechanisms may be involved in defence trade-offs, while others are not. Also, regardless of its evolutionary origin, tolerance may often influence community composition and the evolution of plant defense (Rosenthal & Kotanen 1994). Tolerance to herbivory is also determined by the external growth conditions. Habitats that are rich in resources and characterized by a low level of competition and stress should allow greater tolerance, because herbivory damage could be repaired at a lower cost (Huhta 2001, Rosenthal & Kotanen 1994).

The evidence for importance of evolutionary history of grazing determining ecosystem process has in recent years come from analysis of plant functional traits. Plant functional traits could be a useful tool for predicting and explaining vegetation structure and function under certain environmental conditions (Diaz et al. 1998). Plant traits observed in a community are the consequences of the filtering effect of climate, disturbance and biotic conditions. These filters determine which components of a species pool are assembled into local communities. Thus, the environment acts as a filter removing species, which lack traits for persisting under a particular set of conditions (Keddy 1992). Reader (1988) in a study tested whether differences in species abundance at an infertile site could be explained by differences in plant functional traits. He found significant relationship between species relative abundance and functional traits including shoot mass, mycorhizal association, which explained 69% and 88% of variation in abundance.

Semiarid environments may promote tolerance or avoidance to grazing. Coughenour (1985) due to low basal meristems, small stature, high shoot density, deciduous shoots (high turnover), below ground nutrient reserves, and rapid growth allow grasses to evade or to tolerate both semiarid conditions and grazing. This led Milchunas et al. (1988) to conclude that grazing may not be a disturbance for a plant community depending on its evolutionary history and why some grasslands are more vulnerable to grazing impact by large herbivores.

Difference in ecosystem response to grazing in some ecosystems suggest that
situations for plant compensatory growth are likely to occur in arid ecosystems, where phenological adaptations of plants to moisture stress is similar to that found for tolerance to herbivory (Milchunas et al. 1988, Strauss & Agrawal 1999). Therefore, such selection pressures in semi-arid grasslands that have co-evolved with large herbivores are convergent (Milchunas et al. 1988).

1.2.7. Foraging behaviour

Three divergent approaches have been adopted to understand and predict how grazers interact with the plant community. First, purely an empirical approach in which simple behavioural rules can result in extremely plastic quantitative relationships between plant community characteristics and behavioural patterns. Second, a mechanistic approach by studying the processes that determine intake behaviour and dietary choice (Schoener 1971, Covich 1976). Third one optimal foraging theory (OFT) based on general principles that organize feeding behaviour to produce models that combine understanding of mechanisms and predictive power (Pyke 1984).

Animals usually move faster whilst foraging on food that is either abundant or of a higher quality. In other words, they move faster less search effort is required or they tend to compensate for declining resource availability by reducing movement rates and increasing their feeding time and bite rates (Hanley 1982, Kohlmann and Risenhoover 1994). Selection ratio is an important indicator of the behaviour of an animal to select diet (Van Dyne et al. 1980, Hodgson and Grant 1981).

Grazing animals may or may not be selective feeders. They consume plant species or plant parts non-randomly and so do not ingest an average of the forage on offer (Hodgson 1990). The particular diet selected by herbivore depends on a complex interaction between characteristics of the animal (e.g. dietary requirements, mouth anatomy and grazing behaviour) and characteristics of its food source. Selection occurs across various scales (from plant community to individual species) because animals simultaneously perceive and interact with their feeding environment at different levels of heterogeneity in the food source (Senft et al. 1987). Although selection may occur at multiple spatial and temporal scales, it is convenient to consider selective feeding and its consequences at a number of clearly defined levels. These levels are 1) Habitat selection 2) Patch selection 3) Species
selection 4) Individual plant and plant-part selection 5) selective grazing at various scales.

Sustainable coexistence of different livestock types in a grazing systems could be possible if (a) different livestock use different habitats (b) within habitats different livestock prefer different species because of differences in their digestive systems (ruminant digestive system allows extraction of more digestible matter from medium quality grasses while hind gut digestive system of bovids allows more extraction from grasses with higher fibre content (Janis 1976, Menard et al. 2002). However, a high level of overlap in diet of grazing animals is quite common both in tropical and temperate grazing systems, e.g., a high degree of overlap between cattle and horse diet shown by Menard et al. (2002) and between domestic sheep and wild red deer by Hester et al. (1999). In sheep-goat-horse mixed herd grazing, horses were found to forage as isolated individuals, were slow in changing directions during movement, avoided steep slopes (> 40°) and grazed for longer periods in contrast to sheep and goats grazing in mixed herds, changing directions during movement quickly, reaching slopes as high as 60° and grazing for shorter periods. Goats differed from sheep in that they exhibited a higher bite size, lower bite rate, shorter foraging period and lower dry matter intake but resembled in respect of diet breadth. All the three animals had a far greater intake of forbs than grasses and sedges and comparable response breadth (0.43 to 0.46) (Negi et al. 1993). In sheep-goat mixed herd grazing in cold arid region of Afghanistan, some species like *Peganum harmala* and *Cousinia stockii* were eaten by goats and sheep when they were dried up while *Acantholimon* was seldomly eaten (Casimir et al. 1980). Unlike consumption of *Peganum harmala* and *Cousinia stockii* when dried, young tender stages are foraged in case of other species, e.g., *Nardus stricta* (Fraser and Gordon 1997) and *Juncus sp.* (Bullock 1985). Often community structure is such that architecture of dominant plant restricts access to the highly palatable base layer. Mobile lips and narrow mouths could be advantageous in selecting particular items from structurally heterogeneous and compact communities (Gordon and Illius 1988, Fraser and Gordon 1997). Squires (1982) studied the dietary overlap between sheep, cattle and goats and found a very high degree of similarity in cattle and goat diets. In horse-cattle mixed herd grazing in Europe (Menard et al. 2002), horses were found to use marshes during winter more intensively and spent more time feeding on short
grasses compared to cattle. Both animals used grasslands through out the year and had similar niche breadth with a high overlap. Daily food intake was 63% higher in horses but digestibility of cattle diet was a little higher. This study suggests that horses would out compete cattle if food were limiting. Diet may also change with breed and environmental conditions. In warm-dry arid conditions, goats not only find more food but digest the crude fibre better compared to sheep (El Hag 1976, Devendra 1978) while in cold-moist area daily intake of sheep seems higher than that of goats (Negi et al. 1993).

In European wetlands, cattle and horses showed very similar diets in marshes, but in grasslands cattle ate a wider range of plants than horses. Further, cattle were more constrained by plant height (so were unable to use short grasslands even though they had high quality forage) but less constrained by secondary metabolites (so were able to use dicotyledons to a greater extent) as compared to the horses (Krysl et al. 1984, Menard et al. 2002). As grazing reduces setting of fruits and flowers, diet consists largely of leaves and tender twigs. However, exceptions to this generalization do exist. Sheep and goats consumed only inflorescence of *Aconogonum polystachyum* leading to extremely small biomass of this species (0.7 g m\(^{-2}\) peak biomass) in the community (Negi et al. 1993). Nomads in Afghanistan consider *Stachys trinervis* to be the best forage for sheep and goats while these animals can succumb to saline poisoning by excessive consumption of annual chenopod *Gamanthus gamocarpus* with high salt content (Casimir et al. 1980).

Negi et al (1993) observed that goats preferred forbs growing in drier habitats compared to the moist habitats. Differences in preferences for forage species and habitats between livestock may get reflected in shifts in foraging activity from one community to another community. Such shifts are more marked for more mobile animals like goat and sheep compared to less mobile livestock like horse (Negi et al. 1993).

Diet composition may be significantly influenced by season related changes in community biomass. Though there was no change in actively eating time (33-37% of grazing time) of goats in dry and wet season and average preference index for browse was stable and preference for grass declined with progressive dryness in a semi-humid African rangeland (Becker and Lohramann 1992). Study of Grant et al. (1985) on cattle-sheep mixed grazing in hill grasslands showed that (a) only sheep increased the proportion of certain components (even when the components grew
low in the profile or grew in fine admixture with other components) and reduced the proportion of certain tall components in their diets compared with proportions in the sward (b) sheep and cattle differed significantly for almost all major dietary components (c) sheep diet contained higher proportion of forbs and lower of grass flower stems compared to cattle.

Under free-ranging conditions, seasonal changes in diet selection appear to occur at the community level rather than changes in diet selection within communities (Charles et al. 1977, Gordon 1989, Fraser and Gordon 1997). Herbivores may resemble in dietary composition but may differ in respect of their response to spatio-temporal variation in plant community structure. Hester et al. (1999) observed similar proportion of grass and heather in diet of sheep and red deer but sheep preferred grazing smaller grass patches unlike red deer showing no consistent grass patch size preference in heather moorlands. Fraser and Gordon (1997) analyzed diet composition of goats, red deer and South American camelids grazing on three vegetation types of upland ecosystems in UK viz., a sown sward (Lolium perenne dominated), an indigenous grassland (Nardus stricta dominated) and a dwarf shrub community (Calluna vulgaris) dominated. All the three animals were more selective when grazing the indigenous communities than when grazing the sown sward.

Posse et al. (1996) described seasonal diets of sheep in two landscape types of the Magellanic steppe region of Tierra del Fuego, Argentina. Quaternary landscape, where woody variants of the steppe prevail and in Tertiary landscape, woody plants are absent and short grasses and forbs are abundant. Despite the large proportion of common species, diets differed significantly between landscapes. In the Quaternary landscape, which has a higher botanical diversity, diets were more dissimilar among seasons. The Tertiary landscape, with a low floristic diversity but richer in highly preferred species as Poa spp would be a more risky grazing area in winter, when an ice sheet or a snow cover limits forage of the lower layer of short grasses and forbs.

Diet selection is influenced by familiarity with the environment. In sheep, social factors can override food preferences in a novel environment, but food preferences may be more influential in food selection in a familiar environment (Scott et al. 1996). Experimental studies of Villalba and Provenza (1999) showed that food’s biochemical composition was more important than its structure in
determining preference when sheep’s need for a particular macronutrient was high. Fehmi et al. (2002) determined if known forage of cattle change through season, if feedbacks from previous grazing intensity affect current use, and if resources such as water and salt in combination with shorter forage base increases grazing time compared to previously rested pasture. They found that cattle can rotate themselves among various pasture types if given free choice and season-long grazing may be an effective system if a variety of forage types are available. Observations on grazing behaviour of mixed flocks of sheep and goats in Sahelian rangeland (Ngwa et al. 2000) showed that feed scarcity could not force them to feed on some undesirable forage species, indicating some degree of nutritional wisdom in these small ruminants. Goats spent 75% of their grazing time browsing, while the reverse was true for sheep.

A strategy of flexible selectivity is common to most arid zone herbivores. In food-scarcity situations, as in extreme drought period, larger herbivores rather consume unconventional diets (Noy-Meir 1974). Consumption and dietary habits appear often to be determined by water content of food and water requirement of animals than by energy or protein content and requirements. When food and/or water are saline, a salt balance problem arises that is linked with water, heat and food balances. Water consumption increases with salinity and water (Dawson and Bartholomew 1968, Macfarlane and Howard 1970).

Herbivores having special large chambers called rumen and reticulum containing cellulose-degrading bacteria in their stomach are referred to as ruminants. Non-ruminants (e.g., pig, horse, ass) have lower ability to digest cellulose compared to the ruminants (e.g., cattle, sheep, goat). However, some non-ruminant herbivores are ‘hindgut fermenters’ as they are able to obtain energy from cellulose with the help of bacteria in their caecum. Indeed ability to obtain energy from cellulose in much lower in non-ruminants compared to ruminants (Duncan 1992, Illius and Gordon 1992). Ruminants are able to assimilate more but this is offset by their low intake rate. If food availability is not limited, the hindgut fermenter is predicted to obtain slightly more energy per day whatever the composition of the food. If food is limited, ruminants may have advantage over non-ruminants (Illius and Gordon 1992). There may not be consistent difference in diet between ruminants and non-ruminants.
Based on diet composition, herbivores are classified as grazers (which grasses and other herbaceous plants) and browsers (which eat mainly leaves and other parts of woody plants). There are consistent trends among ungulates relating body size to diet and digestion (Hodgson and Illius 1996, Hanley 1997). Energy need per unit of body mass is inversely related to body size. Smaller species tend to be browsers because browse tends to have a higher percentage of easily digestible cell solubles (though also of lignin), whereas grasses are higher in cellulose. Smaller animals because of smaller mouth are better able to select food on a smaller scale, and therefore be able to choose a more nutritious diet.

Palatability together with stature and location of meristem determine the response of plant species to grazing. Sheep prefer grasses and other herbaceous species to heather. In the absence of grazing, heather can out compete most grasses, while even light grazing can cause significant reduction of apical meristems of heathers, thereby reducing its growth and abundance. In contrast, grasses, sedges and rushes have a meristem at the base of each leaf enabling regrowth following consumption of most of leaf by grazing animal (Marrs et al. 1988).

Noy-Meir (1974) showed that 5 to 75% of total primary production is utilized in arid grazing systems. While light grazing is expected to stimulate production of perennials by increasing reserve utilization and turn-over (Pearson 1965), repeated defoliation may result in decline in productive potential as a result of damage to regenerating buds and exhaustion of reserves (Cook and Child 1971, Trlica and Cook 1971). Negi et al. (1993) studied plant regrowth following selective horse and sheep grazing and clipping in central Himalayan alpine meadow. Sheep grazed deeper and left little tissue to support regrowth, as opposed to horse that left more tissue. This finding supports the prevailing notion that grazing by sheep and goats leads to greater deleterious effects on vegetation than other animals. For forbs, regrowth was better in grazed plants than in clipped plants and for the grass the effect was reverse.

1.2.8. Some high altitude and cold desert studies

Recent productivity studies for the alpine-tundra upland at Colorado show that productivity is limited by water and nutrient stresses (Walker et al. 1994). Phytomass ranged from 97 g m\(^{-2}\) to area 237g m\(^{-2}\) along a moisture gradient in the
landscape, suggesting that climate plays a major role in determining the productivity. International Biological Programme (IBP) in tundra sites indicates the net annual above ground productions for forbs and graminoid dominated tundra communities ranging from 16 to 356 g m\(^{-2}\) (Wielgolaksi et al. 1981).

High altitude ecosystems are predicted to be some of the terrestrial habitats most sensitive and vulnerable to changing climates due to the effect of inter annual climatic changes and changes in growing-season length (Walker et al. 1994, 1995, Galen and Stanton 1995). In Colorado alpine plant community, Walker et al. (1995) found that changes in phenology of plant is related to changes in snowfall and snowmelt pattern, which will cause detectable changes in growth and biomass, and thus showing the sensitivity of alpine communities for short climatic changes.

These high altitude ecosystems consist of slow growing plants and are dominated by soils rich in organic matter (Bowmen et al. 1993). Both plant growth and possibly organic matter decomposition are expected to increase under warmer climates. However, whether these habitats are carbon sink or source for CO\(_2\) are still difficult to predict (Billings 1987, Oechel et al. 1993). In a simulated warming treatment for Tibetan alpine tundra responses to above ground biomass, Zang & Welker (1996) reported that under ambient conditions total aboveground community biomass increased seasonally from 16 g m\(^{-2}\) in July to a maximum of 351 g m\(^{-2}\) in October. However, under warm conditions, peak community biomass was extended to October due to continued growth of grasses and the postponement of senescence. This also indicates that alpine grasses may respond favorably to the altered conditions, but other species may not.

Net Primary Productivity (NPP) in alpine areas from the other parts of the world is reported to vary from 112 to 348 g m\(^{-2}\) in Medicine Bow mountains, Wyoming (Bliss, 1956), 13 to 102 g m\(^{-2}\) in Central Rocky Mountains (Paulsen, 1960.), 180 g m\(^{-2}\) in Sierra Nevada (Klikoff 1965), 176 g m\(^{-2}\) in Mt. Washington (Bliss, 1966), 118 g m\(^{-2}\) to 259 g m\(^{-2}\) in Olympic Mountains, Washington (Kuramoto & Bliss 1970), 145 to 185 g m\(^{-2}\) in Klaune Mountains, Canada (Grier & Ballard, 1981), 164 g m\(^{-2}\) to 196 g m\(^{-2}\) in Niwot ridge, Colorado (May & Webber 1982), 161 to 351 g m\(^{-2}\).

In high elevation desert area of Afghanistan, which is used for winter grazing by Pasthun nomads rearing goats and sheeps, Casimir et al. (1980)
distinguished two biotopes a) moist areas around winter and spring rivers b) drier areas. Both the biotopes had dense dwarf bush cover. *Artemisia siberi, Cousinia stockii* and *Scariola orientalis*, the three Asteraceae members comprised more than 40% of all dwarf bushes. These three Asteraceae members together with *Stachys trinervis, Acantholimon* sp. and *Peganum harmala* accounted for more than 80% of all bushes. Moist biotopes differed from the dry biotope, in that Chenopodiaceae members *Gamanthus gamocarpus* dominate the drier biotope but not the moist biotope. The moist biotope had standing crop of 250 gm⁻² and GPP of 50 g m⁻² yr⁻¹ compared to standing crop of 102 gm⁻² and GPP of 102 g m⁻² yr⁻¹ of the dry biotope. As the field samples were continuously grazed, the productivity values reported in this study are coarse estimate.

In the cold desert of Central Asia, the aboveground yield of phytomass of sub alpine bunchgrasses steppe varies from 0.46 to 1.45 t ha⁻¹. In Alpine Forb steppes, phytomass varies from 0.68 to 1.78 t ha⁻¹ and in alpine shortgrass meadows the yield raise from 0.30 to 1.40 t/ha (Madaminov 1999).

Schaller and Wulin (1996) distinguished three broad plant formation in yak range in Tibetan plateau: a) Alpine meadow characterized by 350-400 mm annual precipitation, occurrence along streams and swamps, 10-40cm thick sod layer and dense short sedge cover (dominated by *Kobresia* sp mixed with various forbs). b) Alpine steppe characterized by 100-350 mm rainfall, poor physical quality of soil, lack of any sod layer, sparse plant cover, dominance of grass *Stipa* sp. with graminoids such as *Poa, Kobresia* and *Carex moorcroftii* and shrubs/legumes viz. *Ajania* sp., *Ceratojides* sp. and *Astragalus, Oxytropis* and *Leontopodium* as co-dominants. c) Desert steppe characterized by 50-100 mm precipitation and vegetation/floristic elements broadly similar to that in alpine steppe except that vegetal cover is very sparse.

Zhao and Zhou (1999) have described producer sub-system of the Tibetan plateau where only fodder crops are cultivated. Based on the species dominance, they identified three types of vegetation a) Alpine meadow dominated by *Kobresia humilis* and various grasses and forbs along valley floor b) *Potentilla fruticosa* (shrub) mixed with *Salix* sp. on the northern slopes c) *Kobresia tibetica* and *Pedicularis longiflora* dominated community in marshy areas. The slope lands in the region are common summer grazing lands whereas meadow vegetation along valley floor is privately owned and grazed during winters. Nutritive value deteriorates
sharply after flowering and senescence. Herbage quality was considered adequate for animal growth and production in the summer, but only, at best, for subsistence during the winter. Because of poor nutritional quality and scarcity of feed, sheep and yak, loose 50% to 80% of the body weight gained during the warm season when good quality (high protein, fat and non-structured carbohydrate) feed is plentiful. At high intensity grazing pressure (4.4-5.35 sheep/ha), aboveground biomass decreased by 22 to 30% after three years of grazing. Low intensity grazing pressure (1.8-2.7 sheep/ha) led to increase in aboveground biomass by 21% to 35%. Dominance of forbs was an indicator of vegetation degradation due to overgrazing by sheep and yaks. Over a period of three years, aboveground net primary productivity (NPP) varied from 1690 kg ha$^{-1}$ to 3076 kg ha$^{-1}$. Fencing increased productivity by 3%, scarification plus reseeding plus fertilizing by 29% and scarification plus reseeding plus fertilizing plus fencing by 78%.

Andren et al. (1994) highlighted vegetation while describing climate and litter decomposition in Inner Mongolia, China. The natural forest steppe consisted of elm (*Ulmus* spp.), maple (*Acer* spp.), hawthorn (*Crataegus* spp.) and a rich variety of grasses and herbs. Human activities, particularly, cultivation and overgrazing leads to almost 80% decline of grass and tree cover resulting in desert like conditions. Only scattered shrubs mainly *Artemisia halodendron* and *Caragana microphylla* were found on dry slopes. *Phragmites communis* was found in moist depressions and ephemeral *Agriophyllum squarrosum* on the top of shifting sand dunes. Hansson et al. (1994) described root growth dynamics of shrubs *Artemisia halodendron* and *Caragana microphylla*. *Caragana microphylla* is a nitrogen-fixing legume species, whereas *Artemisia halodendron* must obtain all of its nitrogen from soil water solution. Normally, *Caragana microphylla* is larger than *Artemisia halodendron* both above and belowground. However, these functional and structural differences apparently had little or no effect on fine root-growth dynamics.

1.2.9. The Himalayan context

Ram et al. (1989) studied plant biomass, species diversity and net primary production in a central Himalayan high altitude grassland located at 3600 m altitude. The biomass of live shoots ranged from 35 to 409 g m$^{-2}$ and increased from April, attained a peak in August and declined rapidly in October. The amount of live shoot biomass was positively related to monthly rainfall. Dead shoot biomass ranged from...
286 to 509 g m\(^{-2}\), declined from May to August, and increased after decline of live shoot biomass. The litter biomass ranged from 188 to 376 g m\(^{-2}\), declined continuously from May to August, and thereafter increased in subsequent months. The root biomass ranged from 307 g m\(^{-2}\) (April-August) to 470 g m\(^{-2}\) (October). The crown biomass, which was part of belowground biomass, ranged from 470-635 g m\(^{-2}\). The total belowground biomass ranged from 777-1105 g m\(^{-2}\) in this grassland. The contribution of grasses and sedges to the total ANP was 73%.

Joshi et al. (1991a) found that variable grazing intensity increased above ground production as compared to complete protection and continuous grazing. Grasses and forbs accumulated the highest concentration of nitrogen at vegetative stage followed by K, Ca, P and Mg. This indicated that grazing induced uptake of N & K and reduced retention and replacement of P in the system (Joshi et al. 1991b).

Ram et al. (1991) observed the effect of nitrogen application on the plant biomass and rate of net aboveground accumulation in alpine grassland of Central Himalaya, dominated by the grass *Danthonia* spp. Their result indicates that this alpine meadow is less nitrogen limited than the grasslands studied elsewhere. Nitrogen fertilization has more effects on the pattern of biomass allocation than on the production. Therefore, because of the favorable moisture, nutrient release from litter of the previous year is adequate for the growing season and plant productivity is not limited by nitrogen in the soil.

Negi et al. (1992) studied phenological features in relation to growth forms and biomass accumulation in Baideni-Ali bugiyal (alpine meadow) grazed during summer (May to September) in central Himalaya located between 3100-3750m amsl elevations. Six natural communities were identified 1) *Trachydium*-forb community 2) *Forb-Danthonia* community 3) *Danthonia*-forb community 4) *Danthonia* community 5) *Kobresia-Danthonia* community 6) *Rhododendron-Cassiope* community. About 8% of species monitored showed short growth cycle, 44% intermediate growth cycle and 48% long growth cycle. Tall forbs and grasses were more abundant in sites with larger community biomass compared to sites with lower biomass. Tall forbs were more frequent in warmer habitats. Most of the grasses showed long growth cycle and length of growth cycle did not vary much with variation in temperature in the elevation gradient sampled. The rate of net biomass accumulation was negatively correlated with rainfall in cushion and sprawling forbs and positively in other life forms.
Rikhari et al. (1992) compared alpine meadows sites differing in terms of length of time of abandonment after grazing. Ordination analysis showed occurrence of two seres: 1) *Trachydium-forb* sere characterized by gentle slopes (10-30°), deeper soil (more than one meter) and *Rumex nepalensis* and *Poa pratensis* as the most dominant species 2) *Forb-Danthonia* sere characterised by steeper slopes (20-40°) and shallower soil (>1 meter) and *Plantago major*, *Trachydium roylei* or *Carex alpina* and *Trachydium roylei* as the most dominant species. They observed that plant size decreased with progression of succession contrary to widely reported trend of increasing plant size with progression of succession (Odum 1971). Total shoot biomass decreased from 357 gm⁻² in meadow abandoned for two years to 146 g m⁻² in meadows abandoned for 30 years in *Trachydium-forb* sere and from 374 g m⁻² to 198 g m⁻² in *Danthonia-forb* sere. In both the seres, diversity peaked during middle age stages and relative importance of tall forbs decreased and that of cushion and sprawling forbs, grasses and sedges increased with increase in the length of fallow period.

Nautiyal et al. (1997) studied biomass, production potential dynamics and turnover rate in an alpine meadow in North-west Himalaya over an elevational gradient 3000-3500 m amsl. The peak belowground biomass values ranged from 708.5 to 2477.8 g m⁻² over two growing seasons. The contribution of grasses and sedges to total shoot biomass were higher during early growth period (May), whereas, forbs contributed maximum biomass during rest of the growing seasons (June to September).

Raizada et al. (1998) described vegetation composition and diversity in alpine grassland in Garhwal Himalaya at an elevation gradient 3800-3950 m amsl, where nomadic grazers grazed their livestock (horses, buffaloes, sheep and goats). Communities in the region were classified as: a) *Carex nubigena-Trachydium roylei* b) *Danthonia cachemyriana-Geum elatum* c) *Carex nubigena-Tanacetum longifolium* d) *Danthonia cachemyriana-Trachydium roylei* e) *Danthonia cachemyriana-Saxifraga androsacea* f) *Carex nubigena-Poa supina* g) *Poa supina-Carex nubigena*. These communities differed in respect of grazing regime. Species richness and diversity was highest in moderately grazed plot and least in the intensively grazed plot. Under continued grazing *Danthonia cachemyriana* and *Saxifraga androsacea* were replaced by *Carex nubigena* and *Trachydium roylei*. 
Moderate grazing increased and continued protection decreased species diversity whereas unchecked grazing led to the disappearance of several species, and their gradual replacement with unpalatable herbs.

Pandey et al. (1999) studied growth form and biological spectrum in an alpine region in North-west Himalaya. The meadow is dominated by grasses viz. *Agrostis, Danthonia, Kobresia, Poa*. Out of total 134 plant species the shrubs and undershrubs contributed 2.2% species, tall forbs 27.4%, short forbs 39.2%, cushion and spreading 25.2% and grasses and sedges 5.9% species. About 2.9% of species completed their growth cycle within 2-4 months period (intermediate growth cycle) and 62.02% species for more than 4 months periods (long growth cycle). In the entire region, there were 25.1% therophytes, 30.37% geophytes, 20% hemicryptophytes and 24.4% chamaephytes, indicating a geotherophytic and geochamaephytic climate.

Mallon (1991) while describing status and conservation of large mammals in Ladakh, highlighted vegetation communities that include species of *Artemisia, Astragalus, Caragana, Aconogonum, Acantholimon, Krascheninnikovia, Ephedra*, and bushes of *Rosa webbiana, Ribes alpestre and Lonicera glauca, Delphinium cashmerianum, Corydalis crassissima* and *Saussurea gnaphaloides* grow above 4700 m altitudes where vegetation cover averages below 1%. *Artemisia, Astragalus* and *Acantholimon* are traditional fuel species and *Aconogonum tortuosum* and *Stachys tibetica* used as winter fodder species.

Osmaston and Crook (1994) described important species in Zangskar region of Ladakh. Kachroo et al. (1977) and Dhar et al. (1994) have elaborately described flora of Ladakh, a cold arid desert of the Trans-Himalayan range. Aswal and Mehrotra (1994) has described flora of Lahaul and Spiti, a part of Indian Trans-Himalaya and recorded 985 species belonging to 353 genera and 79 families. Asteraceae is the most dominant family followed by Poaceae and Brassicaceae. Chauhan et al. (2000) described vegetation in and around Sitikher bog in the upper Spiti while discussing vegetation and climate during late Holocene period.

1.3. CONCLUSION

Review of literature shows that scientific understanding on ecosystem structure, function and interaction in agropastoral landscapes in alpine Himalayas is very limited, more so in respect of Indian cold desert region. It could be noted from
the above studies that the focus is primarily on the plant-herbivore interaction and productivity. A more realistic approach of soil-plant-animal interaction is necessary (Shankar and Singh 1996). Recent work on impacts of herbivory on ecosystem has shifted the question from 'do herbivore have an effect?' to why do the effects differ?' (Olff and Ritchie 1988). The strength of their effects range from weak to strong across a continuum from small to large herbivores. Furthermore, these effects depend on regional variation in major habitat characteristics, such as soil fertility and water availability, which determine herbivore abundance and the number of plant species that have evolved herbivore avoidance or tolerance strategies. Therefore, stocking rate, herbivore body size, grazing behavior and environmental gradients need to be considered together for understanding ecosystem responses to grazing.

1.4. OBJECTIVES

The objectives of the study were:

1. Characterization of ecosystems and microhabitats in pastoral landscape subjected to grazing by migratory graziers.

2. Comparison of community structure, productivity and soil physico-chemical characteristics in different ecosystem types.

3. Comparison of biomass removal and recovery patterns in different ecosystem types.

4. Analysis of strengths and weaknesses of resources uses in traditional migratory pastoral land use.