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Farming and Environmental Conservation in Asian Cold Deserts: A Review

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ABSTRACT

Asian cold desert, which includes Gobi desert, Iranian desert, Takla Makan desert, Turkestan desert and Trans-Himalayan desert, has an extremely inhospitable climate and terrain. It has been neglected both by the scientists and development practitioners for a long time. The region is highly heterogeneous in terms of farming practices, biodiversity, ecosystem services and livelihoods. Efforts for understanding the dynamics of climate, land use-land cover, biodiversity and livelihoods, by and large, focus on macro-scale, with serious gaps in knowledge and understanding about local environmental, economic and social processes. Unlike many other areas, this region has escaped extensive transformation of natural ecosystems and loss of biodiversity. The studies reviewed here provide insights into the ways and means of avoiding environmental degradation and promoting environmental conservation and sustainable livelihoods. There is a need for further enhancing and consolidating scientific knowledge on multiple dimensions of farming, food security and environmental conservation through national and international interdisciplinary endeavours to maximize global benefits from this unique ecoregion which is highly sensitive to global climate change. Research is needed to demonstrate the potential of biodiversity/environmental conservation for sustainable agriculture and food security and vice-versa.

Key Words: Biodiversity; Livelihoods; Crop Husbandry; Animal Husbandry; Climate Change; Indigenous Knowledge

INTRODUCTION

Arid regions have rarely been on the forefront of biodiversity and sustainability research and management agenda. Nonetheless, the Palearctic Desert covering arid North Africa, the Middle East and Central Asia is the cradle of Old World civilization that has given the mankind many domestic animals and food crops (McNeely 2003). Centuries ago, pastoralists in the eastern Tibetan highlands succeeded in transforming natural ecosystems to the ones more useful for grazing (Miehe et al. 2009). Asia has the largest contiguous area of cold desert, which includes Gobi desert (northern China and southern Mongolia), Iranian desert (Iran, Afghanistan, and Pakistan), Takla Makan desert (western China), Turkestan desert (parts of the Middle East and Southwestern Russia) and Trans-Himalayan desert (parts of Afghanistan, China, India and Pakistan). The world's largest glaciers in highlands (viz., Siachen), the largest expanse of the highest tableland (Changthang and Tibet:

the 'Roof of the world') and the highest permanent settlements (4000-4500 m altitude) are located in this region. Asian cold desert region deserves urgent attention for conservation/enhancement of biodiversity and ecosystem services as it:

- harbors many endemic, rare and threatened wildlife (e.g., snow leopard, Marco Polo sheep, wild yak) and economically useful but 'lesser-known' plants and animals (e.g., extreme-cold adapted and disease resistant cultivars of wheat, barley and pea, several wild medicinal plants, yak) (Kala 2000, Ballabh et al. 2007, Shrestha and Jha 2009, Wiener et al. 2003),
- is home to cultural landscapes rich in wildlife without any legal protection and thus a storehouse of indigenous knowledge and institutions fostering conservation linked sustainable livelihoods (Goldstein 1981, Fox et al. 1994),
- maintains water flows in Indus, Ganga, Brahmaputra, Salween, Mekong, Yangtze, Yellow, Tarim, Syr Darya, Amu Darya and many other rivers, the basis of livelihoods of several millions of people (Badenkov 1992, Breu and Hurni 2003, Immerzeel et al. 2008),
- regulates the atmospheric circulation and monsoon (Liu et al. 2002); is the most sensitive part of the planet to climate change as it is located at the highest elevation distinguished by intense insolation, low carbon dioxide partial pressure and huge ice mass (100,000 km^2 area of glaciers) next to the two poles (Liu and Chen 2000, Yu et al. 2002, Holland and Bitz 2003, Yao et al. 2012); global warming provides new economic opportunities to local communities (e.g., agricultural extensification/ intensification as a result of moderation of cold-stress coupled with better irrigation capacity from faster snow melt under warmer climate) as well as new threats , e.g., overgrazing (Yan and Wu 2005, Wang et al. 2012, Gao et al. 2013, Li et al. 2013), changes in permafrost region (Zhang et al. 2010), shifting of species dominance/ranges (Song et al. 2004, Mong and Vetaas 2006, Harsch et al. 2012), glacial lake outburst floods (Liu et al. 2013) and water shortage in lowlands following reduction in base flow of rivers (Yao et al. 2012),
- has been functioning as a net carbon sink since last few years (Zhuang et al. 2010),
- will have advantage of sustaining higher crop yields in the face of global warming (Sommer et al. 2013),
- has undergone socio-political upheavals in the recent past causing land degradation, food insecurity and malnutrition (Hoek et al. 2007, Azzari and Zezza 2011), poverty (Zhong et al. 2004) and limited capacity to meet the challenge of conserving/enhancing biodiversity and ecosystem services in the face of global changes (Giam et al. 2010).

Despite immense importance from both environmental and developmental perspectives, there are only a few research efforts on understanding the trends, driving factors and implications of land use changes in Asian cold desert. Linkages between environmental conservation, sustainable agriculture and food security are theoretically well established but are poorly articulated in the policies. Building on our earlier efforts (Saxena et al. 2011), this article presents a review of the available scientific knowledge and policies on different facets of crop husbandry, animal husbandry and biodiversity conservation in Asian cold desert, identifying knowledge gaps and needed research efforts.

ASIAN COLD DESERT: SOCIO-ECOLOGICAL CONDITIONS AND RESOURCES

Climate and Climate Change

The entire Asian cold desert is weakly influenced by monsoon, with westerlies accounting for most precipitation. Snowfall occurs in winter (October-March) and rainfall in summer months (July-August). Physico-chemical characteristics of snow deposition suggest transport of huge amount of particulate matter from far off oceans and central Asia affecting the rate of snow melt and chemical characteristics of snowmelt water (Dong et al. 2011). Climate regimes enormously vary depending on latitude, longitude, elevation and orographic conditions. The areas used by humans for grazing or cultivation experience mean annual temperature in the range of <1-8 ºC and annual rainfall of 20-620 mm (Table 1). Day time maximum temperatures in summers may be as high as 35ºC, with 40-60 km h^{-1} wind speed, and night time minimum in winters as low as −40ºC (Sharma and Sharma 2011, Julka and Paliwal 2011). Annual rainfall is more uncertain in the trans-Himalayan cold desert (coefficient variation of 49%: Paudel and Andersen 2010) compared to the other regions (coefficient variation of 30%: Robinson et al. 2003).

Table 1. Range of mean annual temperature and rainfall in different geographical regions of the Asian cold desert (NA, data not available; sources of data given in footnote)

Geographical region	Mean annual temperature (°C)	Mean annual rainfall (mm)
Qinghai-Tibetan plateau, China [1]	-1.3-5.2	230-530
Eastern Tibetan plateau, China 2	1.2	620
Central Tibetan higlands, China [3]	NA	21-504
North Tibet Plateau [4]	<1.0	73-412
Inner Mangolia, China [5]	1.7-7.7	130-370
Baltistan, Karakorum, Pakistan [6]	NA	30
Indian cold desert, India [7]	< 8	100-500
Pamir, Tajikistan [8]	5 to 7	70-120
Manang, Nepal [9]	NA	400
Mustang, Nepal [10]	NA	153
Karakum and Kyzylkum, Kyrgyzstan [11]	NA	100-15

[1] Long et al. (2011), Xue et al. (2011), Genxu et al. (2006), Wang et al. (2007); [2] Ma et al. (2010); 3 Miehe et al. (2011); [4] Yuxiang (2004), Cao et al. (2013); [5] Ni (2003), Yong-Zong et al. (2005), Tong et al. (2004), Pie et al. (2008), Zhao et al. (2007); [6] MacDonald (1998); [7] Sehgal et al. (1990), Rawat et al. (2011), Chandrasekhar et al. (2011), Vishwakarma et al. (2011); [8] Saidov (2011); [9] Aase (2011), Shrestha and Jha (2009); [10] Paudel and Andresen (2010); [11] Gintzburger et al. (2005)

Conclusions about nature and magnitude of climate change vary enormously partly because of the variation in methodology (viz., modeling, trend analysis of long term instrumental records, dendrochronology and dynamics of wetlands and glaciers) and spatial/temporal scale of change characterization (Table 2). While warming is widely reported, there have been cooling events too in Qinghai-Xizang Plateau and Karakorum (Li and Tang 1986, Hewitt 2005, Fowler and Archer 2006). The reported warming rates vary from 0.16 to 0.5 °C per decade, with summers getting warmer than the winters. Precipitation has received much less attention compared to temperature in climate change studies. In Qinghai-Tibetan Plateau, growing season seems to have become drier and the remaining period of the year more wet, with average increase in annual precipitation by 5 mm per decade during 1970-2000 period. Warming over the last few decades is also supported by species level changes in phenology deduced by herbarium collections from Tibetan Autonomous Region (Li et al. 2013). Studies have revealed that herders in Mongolia (Venable et al. 2012) and northern Pakistan (Joshi et al. 2013) perceived warming in recent years and changed the herding routes and camping sites to escape from the likely adverse effects on livestock productivity.

Soils

Cold desert soils are coarse (gravelly loamy sand) to fine (silty clay loam), shallow to deep and with moderate nutrient contents. Clay content, pH and organic carbon content varied in the ranges of 4-43%, 6.1-8.9 and 0.18 – 5.3%, respectively, in Indian cold desert (Bagchi and Ritchie 2010, Parmar and Jamwal 2011, Sharma and Sharma 2011, Chandrasekhar et al. 2011), Tibet (Yuxiang 2004, Yang et al. 2008) and Mongolia (Yong-Zhong et al. 2005, Zhao et al. 2007, Han et al. 2008, Pei et al. 2008, Li et al. 2008). Shrestha and Jha (2009) recorded 7.9% organic carbon in Manang in Nepalese cold desert. Shi et al. (2012) reported soil organic carbon values in the range of 0.3-26.2% covering a wide range of Tibetan and Mongolian grasslands, with Tibetan soils having 3-fold higher organic carbon than the Mongolian soils. Highly erodible soils, such as limestone deposits, lacustrine muds and tills, vulnerable to mass movements are widespread. Much of cold desert of Asia is covered under land capability classes VII and VIII (of the United States Department of Agriculture Land Capability Classification System), with soil erosion as a major threat and factor limiting productivity. Soil physico-chemical properties however are highly variable due to huge variation in terrain attributes and land use-land cover (Sharma and Sharma 2011).

People

The region is home to many indigenous communities/ ethnic minorities. The culture of only one son in a family passing married life (others becoming priests/lamas), polyandry (brothers sharing wife) and joint family systems restraining population growth in ancient times started collapsing under the influence of migrants and the mainstream society. The number of households increased by 29% annually following settlement of Tibetan refugees in some villages in Ladakh, India. Further, public health services introduced in 1970s also contri-buted to higher population growth (Bhatnagar and Singh 2011). Similarly, the Pamir-Altai mountain region experienced high rates of population growth (Pachova et al. 2011). In China, people faced with overpopulation/ resource scarcity are migrating from south-east Tibet to the thinly populated/resource rich central region where

Table 2. Climate change scenarios in Asian cold desert

Geographical area	Reported climate change trend and methodology of change analysis
Karakorum	Increase in precipitation, decline in summer temperature, diminishing trend of glaciers during 1920-70, short term advances and surges during 1970s and again expanding trend in 1990s; analysis of climate station records of the period 1920-2000 [1]
Karakorum	Decrease in summer mean temperature by 0.04-0.99 °C per decade, increase in winter mean temperature at four stations by 0.07- 0.38°C and decrease at two stations by 0.03-0.07°C per decade, and increase in mean annual temperature by 0.01-0.21°C at two stations and decrease by 0.08-0.52 °C per decade at four stations; trend analysis of instrumental records of the period 1961-1999 [2]
Lahaul and Spiti, Himachal Pradesh, India	20-year-mean rainfall from 534 mm to 781 mm, with the driest episode during the mid-19th century and distinct wet periods during the late 13th, 14th and 18th centuries; reconstruction of climate based on dendrochronology [3]
Ladakh, India	Increase in monsoon, winter and annual temperature by 0.09, 0.17 and 0.11°C per decade, respectively; insignificant changes in monsoon, winter and annual precipitation; trend analysis of instrumental records of the period 1901-1989 [4]
Manang, Nepal	Warming by 0.5 °C per decade; retreat of glaciers at a rate of 40-50 m annually; deductions from repeat photography and country-level reported trends [5]
Lancang river valley, China	Increase in mean temperature by 0.1 to 0.4 °C per year, increase in precipitation by 5.77-7.44 mm per year at two stations and decrease by 2.86-5.29 mm per year at 3 stations, lower reaches experienced higher rates of increase in temperature and decrease in precipitation; trend analysis of instrumental records of 19 stations over 1960-2000 period [6]
Qinghai-Xizang Plateau, China	Cooling during 1950-70 and, warming thereafter; trend analysis of instrumental records of 1950-1980 [7]
Qinghai region, China	Warming by 0.2 °C per decade; ice core analysis [8]
Qinghai-Tibetan plateau	Increase in mean temperature by 0.29 °C per year at Pulan, 0.23 °C at Shiquanhe and 0.12 °C per year at Gaize during 1980-1990 period; trend analysis of instrumental records [9]
Maduo county in Qinghai Tibetan plateau	Increase in mean temperature at a rate of 0.02 ° C per year during 1953-2005 and 0.05 °C per year during 1979-2005 period; trend analysis of instrumental records [10]
Tibetan plateau	Warming during the period 1955–1996 by 0.16 °C per decade for the annual mean and 0.32°C/decade for the winter mean; trend analysis of instrumental records [11]

[1] Hewitt (2005); [2] Fowler and Archer (2006); [3] Yadav (2011); [4] Bhutiyani et al. (2010); [5] Aase (2011) ; [6] Yunling and Yiping (2005); [7] Li and Tang (1986); [8] Thompson et al. (2000); [9] Long et al. (2011) ; [10] Xue et al. (2011); [11] Liu and Chen (2000)

global warming has made the climate more hospitable (Long et al. 2011). Such resource scarcity/climate change driven shifting of people have not been observed elsewhere. At present, human population density within Asian cold desert varies enormously from 0.44 individuals km^{-2} in Inner Mongolia to 8 individuals km^{-2} in Ladakh (India). Social groups like Manangees (Nepal) and Lahaulis (India) have set examples of achieving prosperity without any external support.

Biodiversity

Natural vegetation of cold desert has been variously described as alpine arid pastures, desert steppe and alpine arid rangelands. With 33% of all economically valuable species being endemic/near-endemic and 37% used in local health care being rare/endangered in Spiti catchment of India, sustainable utilization of biological resources is crucial for biodiversity conservation (Khan et al. 2013). The cold desert biome is one of the least legally protected regions but supports a large number of rare, endangered and endemic species (Shrestha and Jha 2009, Kala 2011, Rawat et al. 2011, Samant et al. 2011, Rawat and Everson 2012). Within cold desert biome, species richness may vary tremendously. Aswal and Mehrotra (1994) recorded 977 plant species in floristic survey of Lahaul and Spiti region compared to 611-647 species in the adjacent Ladakh region of Indian cold desert (Kachroo et al. 1977). In ecological studies, which cover smaller areas compared to floristic surveys, local species richness varied from 18 to 87 species in the Indian cold desert (Bagchi et al. 2004 and 2006, Gavali 2003, Chandrasekhar 2003) and 31-69 in Chinese cold desert region (Zhang and Skarpe 1995, Ma et al. 2010).

Though not as species rich as tropical rain forests, cold desert is endowed with many endemic species (e.g., *Meconopsis bikramii* Aswal, *Microsisymbrium axillare* ssp. *brevipedicellatum* Jafrie, *Pseudomertensia lahulensis* (Brand) Aswal and *Ranunculus bikramii* Aswal & Mehrotra endemic to Lahaul and Spiti, Himachal Pradesh, India), botanical curiosities (e.g., *Saxifraga flagellaris* Willd. with surculi radiating from the basal rosettes of leaves enabling extreme cold adaptation) (Aswal and Mehrotra 1994) and less-exploited but high value medicinal and aromatic species like *Lycium ruthenicum* Murray (Dhar et al. 2011) and *Artemisia absinthium* L. (Sharopov et al. 2012). Asian cold desert is home to many important wildlife (Bhatnagar and Singh 2011, Saidov 2011, Ito et al. 2011). Because of poor infrastructure and extremely inhospitable terrain and climate, cold desert remains a poorly explored area and hence is likely to be home to several new species.

FARMING IN THE ASIAN COLD DESERTS

Crop Husbandry

Crop husbandry is crucial to food security in the region where settlements are small, dispersed and poorly connected. Harsh climate, poor soil quality and limited locations where irrigation is manageable delimit arable area. In typical cold desert, irrigation is essential for crop cultivation and only one crop can be harvested in a year. Although crop husbandry is confined to <5% area of Asian cold desert, shortage of irrigation water limits crop productivity in many instances (Tashmatov et al. 2000; Kreutzmann 2011). In Indian cold desert region, barley and wheat are widespread while potato, hog millet, kidney bean, hops, pea and medicinal and aromatic crops are confined to specific locations. Barley is represented by two species with divergent values: *Hordeum himalayense* Schult. (naked barley) valued as human food and *Hordeum vulgare* L. (typical common barley) as animal feed. Centuries-old traditional irrigation system and use of night soil and livestock excreta as manure persist (Chandrasekhar et al. 2011, Nautiyal et al. 2011, Vishvakarma et al. 2011, Farooquee et al. 2011). Wheat and naked barley are common crops in Eastern Tibet (Yang et al. 2008) as is maize in Manang in Nepal (Aase 2011), Eastern Hindukush and Nanga Parbat in Pakistan (Nusser 2000 and 2001) and Inner Mongolia in China (Zhao et al. 2007). Black pea (*Pisum arvense* L.) valued as human food and also livestock feed is grown only in Indian cold desert region. Though the region is not as rich in crop species diversity as the humid tropics, the region is unique in that naked barley, black pea and wheat/barley cultivars highly adapted to low temperatures, water stress and soils with high pH are confined to it. Systematic comparisons of performance of different cultivars are lacking. Frequent exchange of seeds among farmers without any monetary considera-tion is testified by huge genetic diversity within a small area and poor distinction of landraces (Usubaliev et al. 2013).

As a result of physical stresses (low temperature and shortage of irrigation water during crop growth season), poor soil structure and fertility, limited farm labor and lack of means of farm mechanization or commercialization, agricultural systems are characterized by large livestock holdings, extensive pasturing and crop husbandry in small land holdings. In extreme cold-dry areas, people depend exclusively on livestock for livelihood. Land holding size varies in the range of 0.35 to 2.6 ha and livestock holding of 14-654 animals in Indian cold desert (Osmaston 1994, Fox et al. 1994, Mishra 1997, Chandrasekhar et al. 2007, Nautiyal et al. 2011, Bhatnagar and Singh 2011, Vishvakarma et al. 2011) and 1.0-1.3 ha of cropland and 59-93 livestock in cold desert villages in Pakistan (Kreutzmann 1993, Nusser and Clemens 1996, MacDonald 1998), Nepal (Ikeda 2004, Shreshtha and Wegge 2008) and China (Yin 2011). Livestock holdings in many Tajik and Kyrgyz villages in Pamir cold desert are quite small (average 18 goat/sheep units) (Pachova et al. 2011).

Historically, local production in Manang (Nepal) could meet food requirements for only eight months in a year and in Nanda Devi Biopshere Reserve (India) for 6 months in a year (Nautiyal et al. 2011, Aase 2011). Differing from this widespread food-deficiency scenario (Tashmatov et al. 2000), there are isolated examples of food-secured settlements. Because of high insolation and absence of crop pests and pathogens, crop yields may be very high in cold deserts if farmers are able to develop an efficient irrigation system and properly manage traditional crops. Yields of wheat/ barley may be as high as 5000-8000 kg ha^{-1} in traditional organic agro-ecosytems in Spiti and Ladakh, India (Osmaston 1994, Chandrasekhar et al. 2011) and Eastern Tibet, China (Terjung et al. 1984) and maize yields as high as 14150 kg ha^{-1} (aboveground biomass: 23420-30000 kg ha^{-1}) in Inner Mongolia (Zhao et al. 2006 and 2007). Nonetheless, fairly lower yields (1300-2790 kg ha^{-1}) have also been reported (Tashmatov et al. 2000, Yang et al. 2008, Vishvakarma et al. 2011) from these regions.

Agricultural land use changes are evident in terms of its abandonment or expansion and changes in the

Table 3. Land use-land cover changes, driving factors, ecological/socio-economic implications in Asian cold desert

Type of land use-land cover change and geographical location	Identified cause(s) of the change	Outcomes and Implications of the change for biodiversity, ecosystem services and local livelihoods
Abandonment/expansion of crop husbandry		
Abandonment of agricultural land use in Manang, Nepal after 1970s (Aase et al. 2009, Aase 2011).	• Outmigration for wage earning in urban centers • Implementation of Land Reform Act, 1997 with a provision of transfer of land rights of absentee landlords to share croppers • Lack of policies encouraging optimal land use or discouraging agricultural abandonment • Emergence of new income opportunities: demand of *Cordyceps sinesnsis* in China	• Loss of crop genetic diversity: almost extinction of barley cultivar '*ne*' • Increase in wild biodiversity in abandoned lands • Social ban on collection of *Cordyceps sinesnsis* after people realized deterioration of livestock (particularly yak) health due to low intake of this species during grazing
Agricultural land use expansion after 1990s in Spiti valley, India (Chandrasekhar et al. 2011)	• Policy of allotting land to the landless in the 1990s • Household fragmentation partly deriving from lack of appreciation or incentives for joint families/the tradition of only the eldest son inheriting land and getting married and the younger siblings becoming Lamas	• Allotted land parcels are at higher elevations where human food crops do not grow • The magnitude of expansion is still negligible (<2%)
Agricultural land use expansion during 1930-1990 around Nanga Parbat, northern Pakistan and Chitral, eastern Hindukush, Pakistan (Nusser 2000 and 2001)	• Improved accessibility • Increase in population • Development of community managed irrigation systems	• Increase in hygrophilous trees and thickets along water channels • Symptoms of "ecological disaster" not yet visible
Agricultural land use expansion in Northeast Qinghai-Tibetan plateau during 1987-1996 period (Yongnian et al. 2003, Wang et al. 2008)	• Policy of 'reclaiming wasteland' for crops	• This followed overgrazing, land degradation and loss of soil organic carbon and hence amplification of global warming
Changes in crop diversity		
Cultivation of new crops (Aase et al. 2009, Aase 2011)	• Expansion of tourism and environmental potential of growing crops demanded by tourists but not part of local food habit	• Loss of indigenous crop genetic diversity
Replacement of traditional food crops (barley, wheat, maize, buckwheat, black pea and medicinal plants [*Saussurea costus* and *Inula racemosa*]) by cash crops (sweat pea, potato and hops) over the last 40-50 years in Lahaul valley, Himachal Pradesh, India (Kuniyal et al. 2004 and 2005, Oinam et al. 2008, Vishwakarma et al. 2011, Chandrasekhar et al. 2011)	• Socio-cultural transformation from subsistence to market economy • Policy of supplying staple food at subsidized price • Policy interventions encouraging cash crops or discouraging/neutral to cultivation of traditional crops	• Changes in cropping systems are such that fodder production from croplands has reduced and irrigation intensity has increased, implying more intensive grazing and risks of inadequate recharge of irrigation water sources. • Farmers are unaware of the policy, market and environmental risks of cash crops and ensuing vulnerability.
Expansion of cultivation of apple and apricots, more so in 2000-3200 m elevation zone (Sharma and Chauhan 2008)	• Climate change and financial support for apple cultivation, value addition and marketing by government	• Apple cultivation may induce encroachment in pasture lands. • Abandonment of food crop cultivation would reduce fodder (crop residues) availability from cropland, increase livestock grazing pressure on pastures, intensify competition between livestock and wild herbivores, increase frequency of livestock depredation by carnivores and make farmers dependent on market based food system

Table 3. Continued/

Replacement of barley by wheat in Manang (Aase et al. 2009)	• Male outmigration for income and women finding threshing of barley more exhaustive compared to wheat	• Wheat cultivation may not be sustainable in the face of global change as it is more water demanding and less resilient than barley (Chandrasekhar et al. 2003 and 2011, Singh et al. 2008)
Replacement of barley, buckwheat and millet by potato, wheat and maize in Rupal Velley Northern Pakistan (Nusser and Clemens 1996)	• Improvement in accessibility	• Improvement in income but new risks if people completely switch over to cash crops.
Changes in alpine meadows/grazing lands		
Degradation of pastures/overgrazing in the vicinity of settlements and decline in pasturage in distiant locations around Hunza, Pakistan (Kreutzmann 1993)	• Emergence of new livelihood means following construction of the Karakoram Highway • Subsidy on inputs and market demand of seed potato drawing people away from pastoralism	• Indicators of overgrazing/pasture degradation are not so precise.
Patchy land degradation in Changthang, India (Bhatnagar and Singh 2011).	• Immigration of Tibetans alongwith their huge livestock holdings, with little appreciation for rotational grazing and population control measures valued by the indigenous people • Policy incentives for sedentary life leading to confinement of livestock around homestays/camping sites/settlements	• Degradation of habitats of black necked crane. • Intrusion of livestock grazing in protected areas and increased risks of livestock depredation by wildlife.
Conversion of landscapes quite homogenous in grazing pressure to mosaics of patches differing in grazing pressure in Ladakh, India (Fox et al. 1994)	• Introduction of new livestock breeds • Development of irrigation systems and concentration of grazing pressure around them • Impacts of tourism/tertiary sector development	• Optimal grazing pressure/carrying capacity remains poorly understood.
Vegetation degradation in terms of decline in graminoid biomass in Spiti valley, India (Mishra et al. 2004)	• Centuries of intensive livestock grazing and water harvest for agriculture	• Long term grazing may result in stable systems adapted to this disturbance.
Land degradation/desertification (e.g.; conversion of swamps to meadows) during 1986-2000 in Qinghai-Tibetan plateau (Genxu et al. 2006, Wang et al. 2007)	• Climate change	• Loss of soil organic carbon and thereby amplification of global warming/climate change • Impacts of climate change cannot be isolated from those due to policy interventions and human population dynamics
Overgrazing in alpine pastures during 1984-1991 in Himachal Pradesh (Chakravarty-Kaul 1998)	• Low precipitation	• Low precipitation alone may not be the sole driving factor.
Rangeland degradation in Kazakhastan (Robinson et al. 2003)	• Increase in livestock population • Establishment of State Farms in pastures used by migratory graziers	• Indicators of degradation are not articulated in quantitative terms.
Degradation of alpine pastures (increase in woody elements) in Yunnan, China (Shaoliang et al. 2007)	• Intensive grazing at places due to decline in rotational pasture area	• Specificities of healthy pastures are poorly understood.
Degradation of pastures in Northeast Qinghai Tibetan Plateau during 1987-1996 period (Yongnian et al. 2003)	• Overgrazing	• Indicators of degradation/overgrazing are not articulated in quantitative terms.

cropping patterns and management practices, with enormous variation in rates, driving factors and implications of changes (Table 3). In Manang (Nepal), cropped area has decreased partly due to labour shortage arising from out-migration and partly to the threat of losing rights by absentee-farmers if their lands were cultivated with traditional informal share cropping arrangements following adoption of Land Reform Act, 1997. Labour shortage resulted in poor management of irrigation system and scarcity of irrigation water. Land degradation followed by reduction in cropping intensity but increase in local biodiversity (Aase 2011). Suspension of technical and financial support from Soviet Union from 1990s resulted in abandonment of cultivation of food crops (which required green houses) and barley as fodder crop (which required sufficient irrigation but could survive in open) in areas like Murgab in Tajikistan. Locally managed irrigation system could sustain only hay regrowth with enrichment by broadcasting seeds of *Ulmus* sp. (2-3 Mg ha^{-1} yr^{-1} of hay). Farmers compensated the losses from crop husbandry by giving more stress to livestock husbandry. The Pamir Biological Institute developed cost-effective greenhouses using geothermal energy/hotspring water enabling cultivation of tomato, cucumber and ornamental plants. However, this technology would benefit only a small population around hot springs. Crops can grow only upto 2700-2900 m in Tajik territory compared to 4500 m in Indian cold desert.

It is common to observe abandoned agricultural lands functioning as refugia of invasive alien species in the tropics (Ramakrishanan 1992) but such instances are not reported from cold desert. In contrast, agricultural land use area has marginally increased in Indian trans-Himalaya (Oinam et al. 2005, Chandrasekhar et al. 2011) as a result of the policy of allotment of land to the landless families introduced in 1990s, lack of outmigration and financial support for cultivation provided by the government (Table 4).

In Deqin county in China, buckwheat and highland barley were replaced by wheat, corn, potato and vegetables long ago under the influence of Han Chinese (Yin 2011). In Manang (Nepal), barley was replaced by wheat in recent times when male workforce outmigrated in mass and women found its threshing quite exhaustive compared to wheat (Aase 2011). The farmers replaced the staple food crops (barley, naked barley, wheat, buckwheat and black pea) and medicinal plants (*Saussurea costus* (Falc.) Lipsch. and *Inula racemosa* Hk.f.) with cash crops having higher land and labour productivity such as sweet/green pea, potato and hops (*Humulus lupulus* Linn. because the government policies supported them to get integrated with the mainstream market economy by supplying food grains and inputs required for crop production at subsidized prices (Table 4) since 1990s (Vishvakarma et al. 2011, Chandrasekhar et al. 2011, Farooquee et al. 2011). Such transformation of agriculture discouraged the traditional compost use. A huge uncultivated area was legally protected with varied degrees of exclusion of consumptive resource uses. Such restrictions and lack of modern health facilities motivated farmers to innovate domestication of medicinal plants. Farmers around core zone of Nanda Devi Biosphere Reserve succeeded in cultivating medicinal and aromatic plants viz., *Allium humile* Kunth, *A. stracheyi* Baker, *Angelica glauca* Edgew., *Pleurospermum angelicoides* (Wall. ex C.B. Clarke, *Saussurea costus* L., *Carum carvi* L., *Megacarpaea polyandra* Benth. and *Dactylorhiza hatageria* (D.Don) Soo. Thus, legal protection could catalyse farmers' innovations serving their economic interests simultaneously with conservation of wild biodiversity and associated ecosystem services (Nautiyal et al. 2011). Cultivation of *Bidens pilosa* L. was innovated by farmers in Ladakh (Bhatt et al. 2009). These innovations however remained confined to isolated locations. Low crop productivity due to depredation by wild herbivores, manure shortage and insect pests and pathogens widespread in the humid tropics are uncommon in cold desert. The crops introduced recently like sweat/green pea, however, are more susceptible to diseases (Kumar and Sugha 2006) compared to the traditional crops and cultivars (Chandrasekhar et al. 2011).

Unlike Indian and Chinese territories of cold desert where traditional agriculture persists in various modified forms, land ownership and related reforms brought drastic changes in Tajikistan and Kyrgyzstan which remained parts of the Soviet Union for a long time and became independent Republics during 1990s. State and collective farms that existed in Soviet time ceased following privatization of farm lands after independence. This change was followed by 1.5-fold reduction in cultivation costs, 1.2-1.3-fold increase in yields and 10-15-fold increase in income from farming in Kyrgyz Repubic (Tashmatov et al. 2000).

Despite smaller holdings (<0.5 ha) in Spiti valley in India (Chandrasekhar et al. 2011) than in Kyrgyz Republic (>1 ha) (Tashmatov et al. 2000), the former area was self-sufficient in food as a result of higher yields. Conclusions about food sufficiency may vary depending on spatial scale of observation: river-side villages being food-deficient, hillside villages food-

Table 4. Salient features of the policies in place since 1990s in the Indian cold desert region

Agriculture
- Supply of seeds of green pea, mustard, radish, carrot and saplings of apple at subsidized price
- Supply of chemical fertilizers at subsidized price
- Subsidy on water tanks, canal etc
- Subsidy on polyhouse (farmer pays only Rs 10000 to the company and the balance is paid by the government)
- Vaccination and all other livestock health care free of cost
- Supply of livestock feed concentrate @ Rs 500 for 50 animal units

State owned/regulated commodity distribution system
- Supply of 150 kg rice @ Rs 2 for *Antyodaya* (the ones with no source of income), Rs 7 (marginal families) and Rs 10 (other families)
- Supply of 150 kg wheat @Re 1 only for Antyodaya members
- Supply of 12 kg vegetable oil @ Rs 35 for all
- Supply of wheat flour @Rs 8/kg (50% of market price) -unrestricted
- Supply of 12 kg pulse @ Rs 40 (50% of market price)
- Supply of 16 kg sugar @Rs 26 (75% of market price)
- Supply of 240 liter kerosene oil @ Rs 16 (not available in open market)
- Supply of cooking gas at subsidized price

Environmental conservation and Wildlife
- Plantation of *Salix, Betula* and *Populus*
- Supply of propagules of medicinal plants
- Grant of cash compensation for livestock depredation
- Promotion of ecotourism (through village-level self-help groups)

Social security, population control, human health and economic upliftment
- Old age pension @ Rs 200 per month
- Free primary health care within village
- Free vasectomy operations together with some funds for child and mother care
- 100 days of guaranteed employment in village development works to 1 or 2 members of a family in Mahatma Gandhi National Rural Employment Guarantee Scheme
- A quota of government jobs and seats in educational institutions reserved for ethnic minorities
- Grant of funds for construction of houses to poor families and to village institutions for constructions promoting community assembly and discussion for micro-scale participatory management

surplus and the two considered together, with supplementary/complementary exchanges between them enforced by socio-cultural norms, as food-sufficient units (Chandrasekhar et al. 2011). Food shortage may force poor and marginal people to intensively utilize wild edibles which would be detrimental to conservation of biodiversity and ecosystem services (Pachova et al. 2011). To overcome the food production shortfalls, the food deficient countries have resorted to increasing the production of food grains at the expense of high value cash crops (Tashmatov et al. 2000).

Agrobiodiversity could be enhanced if farmers grow new crops to satisfy the demand of tourists. However, local communities would become more vulnerable if they completely abandon traditional staple food crops, trade conditions become unfavourable to them, tourist inflow is reduced and the new crops fail to perform in the changing environmental conditions (Aase 2011).

Animal Husbandry

The region has a long evolutionary history of livestock grazing, with livestock products meeting as much as 50% of diet for many groups (Ikeda 2004). Yaks (*Bos grunniens* L.), traditional yak-cow crossbreeds and Pashmina goats (*Capra hircus aegagrus* Erxleben) are the livestock confined to cold desert (Wiener et al. 2003, Qi et al. 2010, McGregor et al. 2011). The region is characterized by huge spatio-temporal variation in livestock holding size, composition and management. The responsibility of summer grazing in high pastures far away from permanent settlements shifted from men to women in Hushe valley, Karakorum, northern Pakistan under the influence of modernization (Azhar-Hewitt 1999). In Spiti region of Indian cold desert, socio-economically weaker families (who do not have any arable land) have social sanction of summer grazing in distant pastures. These families are further divided into two categories: the Tarjias who are specialized for herding horses and Dogpas for other animals and women alone never carryout this task (Chandrasekhar et al. 2003).

Mixed trends of change in livestock population are evident. Livestock population declined by 30% over the last 40-50 years due to natural degradation of pastures in Qinghai-Tibetan plateau (Xue et al. 2011) and due to development of tourism in Deqin County, Yunnan, China (Shaoling et al. 2007). In some locations in Inner Mongolia, people reduced sheep/goat population by 38% during 2001-2005 period after they realized these animals as the primary cause of pasture degradation (Jiang et al. 2011). Many farmers in Manang, Nepal abandoned yak husbandry (Aase 2011) and in Deqin county (Yunnan, China) all kinds of livestock (Yin 2011). Over 1982-2002 period, livestock population declined in Nanda Devi Biosphere Reserve due to termination of rights of grazing in vast pasture area following its legal protection coupled with new opportunities of income to local people provided by the government (Nautiyal et al. 2011). In contrast, livestock population increased by 83-1600% when population grew but new livelihood opportunities did not emerge (Tong et al. 2004), people treated livestock as capital/wealth (Bai et al. 2002, Schoch et al. 2010), individual family-managed husbandry systems changed to collective systems guided by distant government agencies (Robinson et al. 2003), fodder became available close to dwellings as a result of changes in cropping patterns (Kreutzmann 1989, Nusser and Clemens 1996), local communities accepted migrants with their livestock and adopted their monogamous family culture, abandoned traditional polygamous family culture, and the government provided free veterinary services (Bhatnagar and Singh 2011). In some cases, changes in livestock composition were more drastic than livestock holding size. Sheep: goat ratio changed from 100:67 in the 1980s to 100:300 in 2005 as a result of expanding market of pashmina wool and incentives for raising its production (Bhatnagar and Singh 2011). Livestock population was quite high in Kyrgyz Pamir-Alai ranges until 1990s as Soviet Union targeted this area for 'maximization of sheep production' maintaining huge state or collective farms. Conversion of state and collective farms to private farms and agricultural enterprises resulted in drastic decline in livestock population and production, more so of wool, replacement of fodder crops by cash crops and concentration of grazing around settlements. Grazing in distant pastures was abandoned because of suspension of government services to maintain water points and low net returns from small scale household/private livestock husbandry if distant pastures were used. The net result has been rangeland degradation around settlements (Suleimenov and Oram 2000). In Indian and Pakistan cold desert regions which did not pass through such agro-political reforms, indigenous systems of regulated grazing have been quite successful in avoiding ecosystem degradation while advancing on the path of modernization (Bhasin 2000, Schmidt 2004, Fazlur-Rahman 2009). Diverse temporal trends and driving factors (Tables 3 and 4) warrant generalizations based on small-area studies.

Overstocking and overgrazing are often put forward as the cause of pasture degradation evident in terms of short height of vegetation, high proportions of bare area, low aboveground biomass, low livestock productivity, and abundance of unpalatable species. Reported above-ground biomass values range from 102 to 250 g m^{-2} in Afghanistan (Casimir et al. 1980), 142 to 433 g m^{-2} in Spiti (Mishra et al. 2004, Chandrasekhar et al. 2007, Gavali 2003) and 27 to 215 g m^{-2} in Changthang regions of India (Saxena et al. 2011), 14 to 193 g m^{-2} in Inner Mongolia (Yong-Zhoung et al. 2005, Pie et al. 2008, Han et al. 2008), 161 to 351 g m^{-2} in Tibet (Zhang and Welker 1996, Lu et al. 2011) and 7 to 440 g m^{-2} in Kazakhastan (Robinson et al. 2003). While some areas in Kazakhastan with above-ground biomass <40 g m^{-2} are extensively and severely degraded, pastoral landscapes are mosaics of high and low biomass patches in other countries. Farmers' under-standing about carrying capacity and indicators of over-grazing drawn from their experiences over generations differ from those based on simplified scientific models and short term experimental measurements. Pastoralists considered grazing pressure of two sheep per ha for achieving optimal livestock productivity (Zhou et al. 1995) which is 8-times higher than the carrying capacity (0.25 sheep per ha) worked out by scientists (Pie et al. 2008). Chandrasekhar et al. (2007) did not conclude overstocking/overgrazing in a traditional systematically well herded and grazing-stall feeding mixed livestock system with a grazing pressure of 2 sheep per ha. On the other hand, Rawat et al. (2001), Bhatnagar et al. (2006) and Mishra et al. (2004) concluded overstocking/ overgrazing under much lower grazing pressure of 0.1-0.7 sheep ha^{-1}. In the absence of precise knowledge on carrying capacity or indicators of healthy pastures, conclusions about pasture degradation suffer from subjective biases and should be treated with caution (Figure 1).

ENVIRONMENTAL CONSERVATION AND ITS LINKAGES WITH FARMING AND RURAL DEVELOPMENT

Policy interest and interventions for conservation of biodiversity and ecosystem services pitched in long after those related to farming. Sustainable utilization of natural resources and conservation together constituted an integrated goal of management of cultural landscapes. Local communities remained neutral to legal protection as long as it did not adversely affect their livelihoods and aspirations. Negative attitudes to conservation develop when (i) people feel that they are not properly compensated for resources denied to them (e.g., exclusion of grazing in protected areas) or they perceive new threats originating from conservation policies/ programmes, e.g., prohibition of killing carnivores attacking them and their livestock, (ii) authorities fail to demonstrate the benefits from conservation unknown to people (e.g., recharge of sources of potable and irrigation water, development of improved crop varieties and livestock breeds, effective pollination and pest/pathogen control, climate change mitigation/adaptation), (iii) people are denied access or required to pay entry fee even to visit areas they conserved for generations after they get a status of national park and income from park is not shared with them, and (iv) policy interventions based on a weak scientific foundation, often assuming indigenous resource users to be the sole cause of ecological degradation (Nautiyal et al. 1998, Rao et al. 2003, Chandraekhar et al. 2007). A review of available knowledge reveals that many a times threats to conservation arise from misplaced knowledge and policy interventions themselves.

Figure 1. Systematic herding, hay making, use of crop residue as animal feed and stall feeding maintain pasture quality and high food crop yields in Indian cold desert

Rangeland degradation is widespread in the region though opinions about extents and magnitudes of degradation diverge (Harris 2010). The collapse of Soviet Union followed termination of supply of coal and petroleum at subsidized price. Tajik people met their energy demand by utilizing both roots and shoots of *Ceratoides* sps. (locally called Terskeen) as fuelwood and burning dung cakes (Figure 2). Kyrgyz people started protecting natural regeneration of Junipers and planting *Salix* to meet fuel demand (Figure 3). In both cases, forage production in rangelands was reduced. Degradation in Tajik territory derived from over-exploiation of one shrub species and in Kyrgyz territory from monopolization of habitat by the two tree species and intensive utilization of their biomass. Though live tock population on regional level declined with dissolution of state/ collective farms, grazing pressure intensified in rangelands close to settlements due to labor shortage

Figure 2. Overexploitation of Terskeen (*Certaoides* sp.) degrades range lands and reduced livestock productivity while use of dung for cooking reduces soil fertility in crop lands in Tajikistan cold desert region

Figure 3. Increase in tree cover in cold desert territory of Kyrgyz Republic following protection of natural regeneration of junipers and planting of Salix to meet the fuelwood demands when supply of coal/petroleum at subsidized price was suspended after the collapse of Soviet Union in 1990s

(arising from outmigration to city centers within as well as outside the country), increasing preference to sedentary life, investment of income to create livestock capital and replacement of food crops by fodder crops (Tashmatov et al. 2000, Suleimenov and Oram 2000, Azzari and Zezza 2011). Thus, here the root cause of rangeland degradation was termination of the policy of supply of fuel at subsidized price by the government.

In Tibet-Mongolia region, researchers differ in their conclusions about the cause of degradation: inherently harsh climate, climate change, high population of small wild mammals and overstocking. However, mean pasture area of 5-40 ha per livestock unit suggest that overstocking is confined to isolated pockets rather than a uniform feature of the whole area. There is also a view that government policies during the Great Leap induced people to enlarge livestock holdings. Here, an inefficient livestock husbandry system seemingly coupled with climate change is the root cause of degradation (Gintzburger et al. 2005, Harris 2010). Overlap in forage of livestock and wild herbivores and complementary effects of livestock and marmots on spatial heterogeneity (Yoshihara et al. 2008 and 2010) suggest more detailed studies on livestock-biodiversity-ecosystem functioning linkages. Ecosystem degradation is indeed widespread when livestock density is high, biomass is continuously used through grazing or hay making, livestock are poorly herded, summer temperatures increase but precipitation decreases and snowstorms are frequent (Miller 2000, Tong et al. 2004, Young-Zhong et al. 2005).

In Indian cold desert, conclusions about livestock as a threat to conservation are based on observations on decline in large/medium wild mammal populations and increase in livestock population over the past few decades, overlap in the habitats of wild herbivores/carnivores and the ones grazed by livestock, similarity in forage intake of wild herbivores and livestock and competitive superiority of livestock over wild herbivores under controlled grazing (Namgail et al. 2007, Mishra et al. 2004), retaliatory killings of carnivores (Oli et al. 1994, Mishra et al. 2003a) and from lower soil organic carbon stock in areas grazed by livestock compared to the ungrazed ones (Bagchi and Ritchie 2010). Diverging from this view, Mallon (1991), based on frequent sighting of large (bharal, ibex and urial) as well as medium sized herbivores (hares and marmots) concluded that coexistence of wild and domestic animals was possible. Most studies on livestock-wildlife interactions have ignored the role of traditional systematic herding, transhumance and stall feeding which reduce negative interactions between different animals and strike a balance in utilization and regeneration of forage (Duncan et al. 2006, Chandrasekhara et al. 2007, Gavali et al. 2011) and of climate change driven changes in forage availability (Wang et al. 2007). Village community pastures in Spiti Valley is divided into areas (i) close to settlements grazed exclusively by the livestock of the village owning the territory and (b) away from settlements (called Doksa) grazed by a cluster of pasture-surplus/-deficient villages under supervision of local herders (Dokpas and Tarjias). Access to pastures outside village territories is regulated by village clusters. Migratory herders bringing livestock from far-off lowlands were allowed to graze during summer in pastures outside village territories by local communities for two reasons: (i) the herders from lowlands would exchange commodities not available locally (e.g., rice, sugar and kerosene oil, with local products like wool), saving time and energy of local people, and (ii) livestock with migratory herders would shield local livestock from depredation by carnivores. Increasing influence of cash economy together with legal protection of vast pasture area and grant of grazing permits to migratory herders on payment of fee inculcates an attitude of maximization of profits causing ecosystem degradation (Rawat et al. 2011, Farooquee et al. 2011, Gavali et al. 2011). Policies promoting sedentary life also contribute to concentration of grazing pressure and thereby land degradation around settlements. Changpas of Indian Changthang region converted their nomadic winter camps into tourist homestays. This followed intensive grazing by pack animals as well as waste disposal around such sites, located invariably close to lakes and marshy meadows visited by threatened black necked crane, and intrusion of livestock grazing in protected areas. Under the influence of outsiders, local people start looking down their traditional nomadic/ transhumant life style adding to the risks of overgrazing (Bhatnagar et al. 2011). Rural development policies target directly the enhancement of local incomes and livelihoods without properly ascertaining their ecological implications. Natural processes are inadequate to recover degraded ecosystems (Jiang et al. 2003 and 2011).

Sparse population, cultural-religious restraints on hunting wildlife and utilization of natural resources in subsistence economy contributed to wildlife abundance in cold desert for a long time (Mallon 1991, Fox et al. 1994, Chakravarty-Kaul 1998). Local people in Indian cold desert did view snow leopard and wolf with hostility for depredation of livestock by them. Yet, retaliatory killings of the snow leopard have been rare while wolf pubs were trapped but only in the vicinity of settlements (Fox et al. 1991a,b, Mallon 1991). Widespread Buddhist faith is a major factor restraining hunting in Indian and Chinese cold desert territories unlike frequent killing of wolf (taming eagle to kill wolf) and marmots for income in Kyrgyzstan. Wild boar is more protected in a country like Tajikistan compared to Kyrgyzstan as Muslim faith in the former country prohibits its killing. Nevertheless, trophy hunting permitted by the state/government to earn revenue has equally been harmful to wildlife. The frequency and composition of hunted animals varied from country to country. All ungulates except wild ass were hunted for trophies only during 1850-1940 period in Indian cold desert region but largely by the British sportsmen (Mallon 1991). Trophy hunting has been more prevalent in countries like Tajikistan and Kyrgyzstan. Tajikistan suffered a 7-fold decline in Morco Polo sheep population during 1960-2002 period (Saidov 2011).

While livestock depredation by carnivores is an age-old process, people feel it to be more frequent after introduction of conservation programmes. Losses to livestock caused by diseases may be as significant as depredation by legally protected carnivores (Li et al. 2013). Though people may exaggerate losses to stake greater claims for compensation provided by conservation agencies, the losses are significant irrespective of the increase or decrease in populations of livestock, wild herbivores and carnivores. Marmots are preferred preys of wolves. Local Kyrgyz people captured and supplied them/their products to Russia. With abandonment of this trade following collapse of Soviet Union, Marmota population is likely to have increased. With improved availability of wild preys, frequency of predation of livestock should have decreased. Yet, people feel increased frequency of livestock killings by wolves revealing the complexities in complex prey-predator dynamics.

Figure 4. Traditionally trained eagles are used to check wolves which depredate livestock. Limited hunting is perhaps essential for food security and sustainable agriculture without any threat to biodiversity.

There may be several reasons for an increase in livestock depredation perceived by local people (Hussain 2003, Suryawanshi et al. 2013):

(i) ban on hunting carnivores in India or complex procedure laid down for hunting, e.g., issuance of hunter ticket, hunting license and firearms and the economic benefits from the killed animals being dismal compared to expenditure in securing permits and decline in traditional practices of checking wolf population in Kyrgyzstan (Figure 4),

(ii) carnivores finding it easier to prey livestock around settlements as a result of decline in populations of their wild preys (due to trophy hunting), abandonment of traditional practices of protecting livestock (e.g., capturing wolf pubs and using them to train Taigon dogs to protect livestock) and herding/stall-feeding of live-stock, minimizing overlap of carnivore habitats with grazing areas and construction of roads/bridges eliminating the restrictions to movement of carnivores posed by rivers/streams,

(iii) increase in the population of carnivores and,

(iv) in trophy hunting of herbivores many animals are injured and these injured animals are easily predated by carnivores; abandonment of hunting of protected herbivores increased dependence of carnivores on livestock

(v) displacement of carnivores towards cultural landscapes induced by direct or indirect effects of climate change.

Unlike snow leopard producing 1-2 pubs once in two years, wolves breed every year with 4-6 pubs at a time. Thus, reduced hunting follows faster increase in population of wolves than snow leopard.

OPTIONS FOR COUPLING SUSTAINABLE FARMING AND ENVIRONMENTAL CONSERVATION

Table 5 gives a summary of problems and recommended solutions related to farming and environmental conservation identified by different workers.

Achieving Food Sufficiency

Raising crop yields along with conservation of biodiversity and natural ecosystem services is a challenge which could be met by two parallel actions (i) facilitation of exchange of knowledge and experiences between food-sufficient and food-deficient communities, mobilizing the latter to learn lessons from the former, and (ii) promotion of new agrotechnologies. Integrated use of chemical fertilizers, organic manure and beneficial microbes could raise productivity and profitability of cash crops by 31-99% in Indian cold desert (Parmar and Jamwal 2011). Farmers must be made aware of the risks of market dependency while pushing interventions/ technologies altogether new to them. Increased use of water in a region like Tibetan plateau might reduce water available for agriculture in downstream areas of India, Bangladesh and China in future. If economic loss to farmers from water conservation in Asian cold desert (e.g., by not cultivating crops or not expanding agricultural land use) is lower than the gain from economic gain to downstream farmers from availability of water, policies favouring payment for ecosystem services need to be urgently evolved and implemented (Immerzeel et al. 2008). As several countries are part of and influenced by Asian cold desert, international cooperation is needed to address these issues.

Changing Food Habit: Promoting Fishery

Though fish-based meal is more nutritious than cattle meat-based meal, many Indian communities do not eat fish for religious reasons. Fishery, apart from improving

Table 5. Problems, recommended solutions and additional considerations for improving the state of farming and environmental conservation in cold desert

Identified problem(s), geographical location and authors	Solution(s) recommended by the authors	Additional considerations
Food shortage, low productivity and profitability of traditional low input crop husbandry system in Indian cold desert region (Parmar and Jamwal 2011)	Application of chemical fertilizers alongwith farm yard manure	• Highly productive traditional organic crop systems do exist [5000-8000 kg ha^{-1} wheat/barley yields (Terjung et al. 1984, Osmaston 1994, Chandrasekhar et al. 2011)].
Overstocking and degradation of rangelands, decline in wild herbivore populations, livestock depredation by large carnivores and retaliatory killings threatening their conservation in Spiti valley, and lowering of soil carbon levels by livestock compared to wild herbivores exerting similar grazing pressure (Mishra et al. 2002, 2003, 2004, Bagchi et al. 2004, Namgail et al. 2007b, 2009, 2010, Yoshihara et al. 2008, Bagchi and Ritchie 2010, Wingard et al. 2011)	• Supplemental feeding of wild herbivores • Reduction in livestock population and creation of livestock-free conservation areas • Physical measures of protection and systematic herding of livestock. • Rotational grazing, hay making and supplement feeding of grazing animals • Establishing Communal Insurance Programme (people-NGO-government partnership) in place of the present exclusive government operated compensation mechanisms • Creating Reserves free from livestock grazing for restoring wild herbivores like Tibetan argali	• Specificities of a "perfect" landscape management system serving multiple functions are not precisely defined. • Conclusions on impacts of livestock and wildlife on soil organic carbon would depend on the grazing/management history of the site and temporal scale of observation in livestock exclusion experiments. • High soil organic carbon stocks can be maintained under light grazing by livestock (Liu et al. 2012). • Communities in dry habitats may be grazing-adapted and the ones in moist habitats to desiccation as well as grazing (Miehe et al. 2011). • Livestock and wildlife may have complementary functions (Yoshihara et al. 2010). • Participatory research and demonstration unraveling the contributions of conservation to crop and livestock productivity and human health (Chen et al. 2012, Chakravarty-Kaul 1998) could foster conservation leading to sustainable livelihoods.
Threats to conservation of snow leopard and their preys in Mangolia (Mishra et al. 2003b)	• Capacity building of pastoralists to enhance income from wood by adding value to it	• Empowering local communities to realize fine from the poachers • Incentives to local communities based on their contribution to conservation
Competitive edge of wild donkeys (*Equus kiang*) over livestock in sedge-rich habitats (Bhatnagar et al. 2006)	• Herder-centered sustainable solution for livelihoods together with conservation	• Specificities of sustainable solutions need to be worked out.
Livestock depredation by snow leopard (Ikeda 2004, Hussain 2000)	• Special care of owners of small and medium-sized herds in compensation schemes • Recognizing herders' rights to remove individual carnivore frequently depredating their livestock • Involving herders in ecotourism activities	• Developing livestock husbandry systems such that frequency of livestock depredation is reduced.

human health and nutrition, could raise income, reduce pressure on alpine meadows and thus contribute to the goal of environmental conservation. Government agencies have been successful in introducing Rainbow trout (*Onchynchus mykiss* Walbaum), Brown trout (*Salmo trutta fario* Linn.) and exotic carps, viz. C*yprinus carpio communis* Linn., *Cyprinus carpio specularis* Lacepede, *Cyprinus carpio nudus* Bloch in their experimental ponds in Indian cold desert. Effective education and awareness programmes are needed to convince people to come out of religious beliefs and faiths lacking any scientific rationale (Sharma and Mehta 2011).

Promoting Ecotourism

Ecotourism programmes need to be designed such that both local people and tourists become conservation conscious. A win-win situation is achieved when objects of conservation attract tourists. As tourists valued sightings of snow leopard, blue sheep, brown bear and a wide range of rare medicinal plants in a stunning landscape around Manang, local people readily accepted the proposal for the establishment of Annapurna Conservation Area (ACA) in 1980s (Aase 2011). There is a need of disseminating, adapting and building on such participatory conservation–economic development coupled approaches across the region.

Encouraging Fodder Crops and Increasing Carrying Capacity of Pastures Outside Protected Areas

The threat of overgrazing/overstocking could be reduced by cultivating fodder crops. Indeed, replacement of food crops by fodder crops shall not be a sustainable option because of tiny holdings, widespread food deficiency and low levels of income. There is a need of identifying fodder crops which would not interfere with food crops or could grow when crop fields are fallowed. Legume fodder species viz., *Cicer microphyllum* Benth., *Pisum arvense* L. and *Thermopsis inflata* Cambess. naturally proliferating in the region could be evaluated for feasibility of their cultivation (Chandrasekhar et al. 2011). Trials on raising fodder production by irrigating natural pastures have so far met a very low level of success in India (Rawat et al. 2011, Bhatnagar et al. 2011), while keystone species approach has not been tried so far (Saxena et al. 2005). Comprehensive research programmes are needed to identify sustainable technologies for raising carrying capacity of natural pastures. The threats of overstocking can be reduced if income from cash crops is significant (Duncan et al. 2006).

Capitalizing on Economic Potential of Lesser Known Biodiversity

Many biological products used by local communities are lesser-known to the wider global community, while the potential benefits of value addition are lesser-known to the local communities. Getting cues from indigenous knowledge, it has been possible to develop value-added products from seabuckthorn (*Hippophae rhamnoides* L.) as a source of income to local people in India (Maikhuri et al. 2004, Singh et al. 2012). Cold desert varieties of apricot (*Prunus armeniaca* L.) are far superior to those from other ecoregions, but 40-60% production is wasted due to limited storage, value addition and marketing capacity. Yield enhancement by genetic selection, cultivation and value addition of such species can bring in vital changes in rural economy (Yadav et al. 2011). Introduction of poultry birds feeding on grasshoppers offers a win-win solution in Qilian mountain of Qinghai-Tibetan plateau: reducing input costs of husbandry and production of 'green food' from natural ecosystems (Long et al. 2011). Such systems would indeed need proper care so as to minimize the risks of depredation of poultry birds by wild animals.

Lesser known unique local food can widen the scope of ecotourism in unique picturesque landscapes. The area has always comparative advantage for supply of organic food. Reorientation of local cuisines may be required to meet preferences of tourists. Local communities in Indian cold desert are not aware of use of horse milk for maintaining health in general and curing tuberculosis and liver disorders in particular in Kyrgyz Republic (Figure 5) and of medicinal uses of hot spring water in Jalaundi Deh Sanitorium in Tajikistan. Exchange of indigenous knowledge between different communities within cold desert isolated because of terrain and linguistic barriers can enhance local livelihoods together with environmental conservation and indigenous knowledge.

Though biodiversity is causally related to ecosystem services, this relationship is complex and necessarily not positive (Tallis et al. 2008, Carpenter et al. 2009). Restoration or conservation of biodiversity may not increase the provision of ecosystem services and vice-versa (Bullock et al. 2007, Nehring and Hesse 2008, Cao et al. 2009, Ren et al. 2009, Fulford et al. 2010). Often biodiversity is manipulated/managed to increase the provisioning of a specific service and this may be associated with the loss of other services (e.g., tree planting in arid lands may sequester carbon but at the cost of excessive depletion of water resources). The degraded ecosystems need to be transformed into "novel ecosystems and landscapes" which may not resemble the historical ones but have the potential to enhance biodiversity and ecosystem services, offering sustainable solution(s) to multiple problems faced by the mankind (Putz and Redford 2009, Jackson and Hobs 2009, Bullock et al. 2011, Montoya et al. 2012).

Figure 5. Lesser known dimensions of agrobiodiversity: Kyrgyz people use horse-milk for maintaining health and curing liver and kidney disorders that is not practised in the Indian cold desert.

Building on Indigenous Knowledge and Social Capital

There are several traditions among local communities fostering sustainable and equitable use of resources :

(i) social sanction of collection of rare and endangered medicinal species only to local healers so as to avoid overharvesting (Kala 2011),

(ii) obligation of local healers to charge only a nominal fee ensuring flow of benefits to wider community (Kala 2011),

(iii) cattle milking only twice a day sanctioned to migratory graziers so as to maintain animal health and avoid overgrazing (Gavali et al. 2011),

(iv) social sanction to only landless or marginal farmers to become herders and healers so as to protect equity (Gavali et al. 2011),

(v) cultural-religious beliefs fostering watershed protection and equitable access to scarce resources (Yin 2011),

(vi) religious controls on extraction of highly profitable rare wild products like *Cordyceps sinensis* (Berk.) Sacc. [recently renamed as *Ophiocordyceps sinensis* (Berk.) Sacc.)] (Aase 2011),

(vii) collection of medicinal plants only after cessation of livestock grazing so as to avoid high intensity disturbances (Farooquee et al. 2011),

(viii) mixed herding so as to minimize negative interactions between different livestock and between wild herbivores and livestock (Chandrasekhar et al. 2007, Gavali et al. 2011), and

(ix) institutional mechanisms promoting sustainable development (Goldstein and Bell 1991, Chakravarty-Kaul 1998, Bhasin 2004, Schmidt 2004, Fuzlur-Rahman 2009, Aase 2011).

Cold desert pockets in Sikkim (India) where external interventions could not penetrate, have been found to be exceptionally rich in biodiversity (Lalchungpa 2009, Chanchani et al. 2010). Nevertheless, there are also many deficiencies in the indigenous knowledge system. Some Ladakhi people (India) dislike conservation of wild donkeys as they believe that this animal competes with pashmina goats, which may not be true (Bhatnagar et al. 2011, Fox et al. 1991, Shah and Qureshi 2002). Yaks and horses are left unattended in distant pastures, making them more susceptible to depredation by carnivores (Gavali et al. 2011). Manangees (Nepal) are not concerned about reduction in population size of wild medicinal plant *Aconitum naviculare* (Bruhl) Stapf. likely from its collection before seed dispersal and inefficient use of agricultural land by share-croppers (Aase 2011). Changpas of Ladakh (India) failed to check overgrazing by migrants (Bhatnagar et al. 2011). Communities differ in terms of strengths and weaknesses of indigenous knowledge. It will be more appropriate to build on indigenous systems by retaining their strengths and overcoming their weaknesses with appropriate scientific and institutional inputs rather than replacing them with altogether new systems.

Promoting New Technologies

Technologies like hydroelectricity production altogether new to people could run small scale industries adding value to local products, reduce use of biomass burning for energy and foster water conservation. Greenhouse technologies and solar driers could reduce pressure on natural ecosystems along with significant economic benefits to local people. Indeed, technologies altogether new to local people will require investments, but the quantum of investment could be reduced by 40-50% by securing people's participation (Singh 2011, Thapa 2011).

Coping Global Changes

Rapid melting of glaciers under warm atmosphere would increase the amount of water available for irrigation and inducing agricultural extensification or intensification. However, expansion of agricultural land use has so far been negligible possibly because of institutional arrangements inhibiting such a land use change, scarcity of farm inputs (e.g., manure and human labour), lack of any severe food insecurity and declining preferences to crop/livestock centered livelihood (Farooquee et al. 2011). However, prospects of cultivation in distant future would be gloomy if one accepts the prediction of disappearance of glaciers after 50 years (Aase 2011). Signals of aggravating water stress have already surfaced in some part of Tibetan plateau (Xue et al. 2011).

Globalisation shall drive drastic changes in the production and consumption patterns. Tourists and immigrants in Spiti valley opened demand for goat meat that was considered poor quality meat by local people (Gavali et al. 2011). Traditional staple, viz., barley and buckwheat, are rarely liked by tourists. Preference for wheat among tourists has induced a trend of decline in barley production and consumption. Parallel to this change, is an increase in production/consumption of vegetable crops demanded by tourists as well as far off lowland people. Easy accessibility/connectivity is viewed as a prerequisite for economic development/ growth to take off, leading to huge investments for expansion of road and rail network in all developing countries. However, an ill-conceived transport network may be a threat to biodiversity conservation (Ito et al. 2011).

Increase in tree cover to meet the domestic fuel demands following suspension of coal/petroleum supply during Soviet Union time reduces forage production but increases carbon stocks. Local people can claim compensation for carbon sequestration from this land use change under the United Nations programme on Reducing Emissions from Deforestation and Forest Degradation (REDD) in developing countries launched in 2008. However, as water requirements of trees are quite high, increase in tree cover may aggravate water stress to crops and add to preexisting threats to local food security. There is a need of developing integrated landscape management plans taking into account the present and future opportunities as well as constraints to sustainable livelihoods and environmental conservation (Hayes and Persha 2010, Semwal et al. 2013).

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