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METHODOLOGICAL ISSUES IN IMPLEMENTING A SUSTAINABLE FOREST MANAGEMENT PLAN IN REMOTE MOUNTAIN AREAS

The Karakorum (Pakistan)

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SUMMARY

Based on a practical case-study, the Central Karakorum National Park - Gilgit-Baltistan - Pakistan, the aim of the thesis is to present a methodological framework for promoting the sustainable forest management in mountain areas characterized by remoteness, difficulties of access and where few data are available.

Forest resources of Karakorum Mountains assume an essential role for the livelihoods of local communities, heavily dependent on wood for heating, cooking and construction purposes. However, uncontrolled and long lasting anthropogenic pressures (as grazing, high firewood necessities, increase in population) have slowly but continuously degraded forest resources, posing threats to their conservation. Paradoxically, this has been exacerbated by mismanagement, lack of forest inventories and lack of community involvement, consequence of a strong top-down and centralized governance of natural resources.

The development of a sustainable and participatory forest management plan based on sound scientific data can be therefore considered both a priority and an innovative approach. Even if the whole work was completed in a single protected area, the issues under investigation, the problems encountered and the methodologies applied to solve them are similar in many other mountains of developing countries.

To reach this objective, the research has been divided into three main areas of investigation.

The first relates to the spatial quantification of resources availability and involved the development of a land cover map of the Park area and an assessment of Park's forests in terms of above ground biomass and current annual increment. This was achieved using satellite images and field plots.

The second investigation included activities aimed at assessing local communities' livelihood options and their use of forest resources. We organized focus groups in 24 villages of 9 valleys with the double objective of collecting information and stimulate discussion about management plan issues.

Finally, to increase locals' capacity in forest management related activities, two reforestation initiatives, which included all steps from seeds collection to seeding and seedlings protection from browsing, were organized.

In the last chapter of the thesis the preliminary Central Karakorum National Park management indications are summarized.

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خلاصہ

ایک عملی مطالعہ کی بنیاد پر، مرکزی قراقرم نیشنل پارک، گلگت بلتستان، پاکستان پر مبنی مقالہ کا مقصد دور دراز، رسائی کی مشکلات اور جہاں چند معلومات دستیاب ہیں، پہاڑی علاقوں میں جنگلات کے پائیدار انتظام کو فروغ دینے کیلئے ایک با ضابطہ فریم ورک پیش کرنا ہے ۔

قراقرم پہاڑوں کے جنگل کے وسائل مقامی کمیونٹیز کیلئے ہیٹنگ، کھانا پکانے، تعمیری مقاصد اور روزگار کے مقاصد کے لئے ایک لازمی کردار ادا کرتے ہیں. تاہم بے لگام اور دیر پا انسانی دباو (چرنے کے طور پر ، جلانے کیلئے لکڑی کی زیادہ ضرروریات، آبادی میں اضافہ) نے آہستہ آہستہ لیکن مسلسل جنگل کے وسائل اور ان کے تحفظ کیلئے خطرات پیدا کر دئیے ہیں۔ اس کے علاوہ یہ بد انتظامی ، جنگل کے وسائل کے ریکارڈ / فہرست کا نہ ہونا اور مقامی لوگوں کی جنگل کے انتظام میں بہت کم شمولیت کی وجہ سے مزید متاثر ہو گیا ہے۔

اعلیٰ سائنسی معلومات کی بنیاد پر جنگلات کے پائیدار اور اشتراکی منصوبہ بندی پلان کی تیاری کو ترجیحی اور جدید نقطہ نظر پر لیا جا سکتا ہے۔ اگرچہ منصوبہ ایک مخصوص علاقے کیلئے تیار کیا جاتا ہے تو اس تحقیق کے مطابق، درپیش مسائل اور ان کے حل کیلئے دیئے گئے طریقہ کار جو کہ بہت سے ترقی پذیر ممالک کے پہاڑی علاقوں سے ملتے جلتے ہیں اور اسی لیے یہ منصوبہ عالمی تناظر میں بھی مفید ہو سکتا ہے۔

اس مقصد تک پہنچنے کیلئے تحقیق کو تین اہم حصوں میں تقسیم کیا گیا ہے۔

پہلا حصہ وسائل کی دستیابی کے فضائی تعین سے متعلق ہے جو پارک ایریا کے لئے زمینی نقشہ کی تیاری اور پارک کے سطحی جنگلی حیات کے طور پر موجودہ سالانہ افزائش کی جانکاری پر مبنی ہے۔ یہ سیٹیلائٹ تصاویر اور فیلڈ پلاٹس کو استعمال کرتے ہوئے حاصل کیا گیا تھا۔

دوسری تحقیق میں شامل سرگرمیوں کا مقصد مقامی سماجی گروہوں کے معیار زندگی اور ان کے جنگل کے وسائل کے استعمال کا تعین کرنا ہے۔ ہم نے 9 وادیوں کے 24 دیہاتوں میں توجہ مرکوز گروپ بحثوں سے دو مقاصد؛ معلومات کا اکٹھا کرنا اور منصوبہ بندی کے پلان بارےمعاملات پر بحث کی حوصلہ افزائی کا اہتمام کیا گیا ۔

آخرمیں مقامی لوگوں کی جنگل کے انتظام اور اس سے متعلقہ سرگرمیوں میں صلاحیت بڑھانے کیلئے جنگل کی بحالی کےدو اقدامات اُٹھائے گئے جن میں بیج جمع کرنے سے پودوں کی نرسری تک ،اور پودوں کی مال مویشیوں سے تحفظ شامل ہیں۔

مقالے کے آخری باب میں مرکزی قراقرم نیشنل پارک کے انتظام کی ابتدائی نشاندہی کا خلاصہ کیا گیا ہے۔

SOMMARIO

Questa tesi, partendo da un caso studio focalizzato sul Parco Nazionale del Karakorum Centrale – Provincia del Gilgit Baltistan – Pakistan, è finalizzata all'individuazione di un quadro metodologico per promuovere la gestione forestale sostenibile in aree montane remote, caratterizzate da un estremo isolamento imputabile a difficoltà di accesso e comunicazione, e da mancanza di informazioni su stato e disponibilità delle risorse forestali.

Le foreste montane del Karakorum rivestono un ruolo essenziale nel garantire la sopravvivenza delle comunità locali, fortemente dipendenti dal legname sia per fini energetici (riscaldamento, cucina) che strutturali (ponti, edifici). Inoltre, la persistente ed incontrollata pressione antropica, esacerbata dall'aumento demografico, il pascolo indiscriminato ed alti consumi pro-capite, hanno provocato una forte degradazione degli ecosistemi forestali, fino a renderne la conservazione precaria.

Paradossalmente, questi processi sono stati ulteriormente aggravati dalla mancanza di una gestione selvicolturale razionale, dalla mancanza di inventari quantitativi e qualitativi e da un generale scarso coinvolgimento delle comunità locali nella gestione. Il quadro normativo forestale, infatti, prevede tutt'ora un forte controllo, centralizzato, dell'amministrazione pubblica, con ridotta partecipazione delle comunità sia a livello di pianificazione che di gestione.

In un contesto siffatto, quindi, lo sviluppo di una gestione forestale sostenibile e partecipativa, basata su concreti dati scientifici, rappresenta sia una priorità che un approccio innovativo. E, pur consapevoli che questo studio è riferito esclusivamente ad una ben specifica area protetta, le tematiche affrontate, le problematiche riscontrate e le soluzioni metodologiche prospettate possono costituire argomento di interesse e di riflessione per molte altre realtà montane di paesi in via di sviluppo.

Per evidenziare l'aspetto metodologico del progetto, lo svolgimento della ricerca è stato ripartito in tre distinti filoni tematici di investigazione.

Il primo riguarda le attività mirate ad ottenere una stima quantitativa e spaziale della disponibilità di risorse forestali: a tal fine, è stata tratta da immagini satellitari una cartografia di uso del suolo con

particolare attenzione alla componente forestale. Inoltre, sempre utilizzando tecniche di telerilevamento, si è stimata la biomassa epigea e l'incremento corrente.

Il secondo tema di indagine è focalizzato sulle comunità locali, con particolare attenzione all'utilizzo da parte loro delle risorse forestali e naturali. Tramite l'organizzazione di focus groups in 24 villaggi di 9 valli, sono state analizzate le pratiche di gestione ed i consumi di legna pro-capite.

Infine in due valli campione sono state realizzate due riforestazioni, per esemplificare in concreto una prassi di buona gestione forestale. In entrambe le occasioni tutti i passaggi necessari al loro corretto svolgimento, dalla raccolta del seme alla protezione dei semenzali tramite recinzioni elettrificate, sono stati svolti con la determinante collaborazione delle comunità locali. Occasione preziosa e significativa per stimolare il coinvolgimento dei locali anche in merito a tematiche riguardanti la pianificazione gestionale.

L'ultimo capitolo della tesi contiene un riassunto delle prime linee di gestione forestale individuate per il Parco Nazionale del Karakorum Centrale. Indicazioni queste che possono essere considerate le conclusioni dello studio.

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CHAPTER 1

CONCEPTUAL FRAMEWORK

Conservation of forest resources and sustainable development are ambitious objectives arisen from numerous global environmental debates since more than 20 years (UN, 1992a; UN, 1992b; UNCED, 1992; UNDP, 2000). It was at the United Nation Conference on Environment and Development held in Rio de Janeiro, in 1992, that a process towards definition of best management practices and protection of biodiversity rich-areas was prioritized to achieve an ecologically sound sustainable development.

During this meeting two important documents related to forest conservation and good management were ratified: one specifically focused on the forest sector, the "Principles for a global consensus on the management, conservation and sustainable development of all types of forests" the second, which includes different issues and thematic is the Agenda 21[1]. In both documents, reducing deforestation is a core aspect to guarantee a sustainable future to biodiversity, society and to ensure future's human well-being (McShane et al., 2011).

Few years later, in 1997, during the UNFCCC Conference of Parties held in Kyoto, forests resources gained even more attention for their potential role in combating climate change. On the one side photosynthesis (i.e. plant Co2 uptake) is seen as a relatively low-cost measure to reduce total global GHG emissions, on the other deforestation alone accounts for as much as 17% of all annual anthropogenic greenhouse gas emissions (DeFries et al., 2006; van der Werf et al., 2009). Policies aimed at reducing deforestation are nowadays a central points of a strategy to decrease carbon emissions, reflected in pending international discussions.

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[1] Both documents are available respectively at: http://www.un.org/documents/ga/conf151/aconf15126-3annex3.htm and http://www.un.org/esa/dsd/agenda21/res_agenda21_11.shtml. Agenda 21, Section II, Chapter 11 specifically deal with deforestation by identifying measures and techniques to combat it.

Finally, in the last decade, the objective of combating poverty and improving living conditions of local communities in remote areas, clearly stated in the Millennium Development Goals (MDG[2]) ratified by 191 governments at the Millennium Summit in early 2000, has been increasingly linked with forests and forest management issues. Consequently, the importance of sustainable harvesting rate of wood and non-wood forest products as a base-line to guarantee sufficient living standards, the preservation of traditional knowledge, the crucial importance of involving local communities in community-based forest management (CBM) programs have been deeply explored (Sam and Shepherd, 2011).

More recently, the United Nation Conference on Sustainable Development, Rio +20, held in Rio de Janeiro, Brazil, in June 2012, confirmed further the strong link between sustainable development and conservation of forest resources[3].

As a result, it has been internationally recognized that sustainable forest management can promote local communities living conditions while conserving forest resources. This is especially true if the management of forests is done by or with the involvement of local communities (Ostrom, 1990). Since 2005, almost 75% of the world forest resources were covered by a national forest program (i.e. participatory forest management schemes) (FAO, 2011a).

Contextually, to actively protect and conserve highly valuable and representative biomes, species and natural ecosystems worldwide, an increasing number of protected areas have been established throughout the world (Margules and Pressey, 2000). Especially in developing countries where those areas have often been inhabited since long time, they have the additional role to improve local communities welfare and to become examples of sustainability (Adam, 2006; Naughton-Treves et al., 2005). However, the most recent estimates on the state of the world's forests still deliver a different picture, as deforestation and forest degradation are still threatening biodiversity, livelihoods of communities and, in general, ecosystem functioning. Additionally, protected areas are in many cases ineffective despite international funds and strong commitment from donors countries (Leverington et al., 2010).

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[2] Available at: http://www.un.org/millenniumgoals/bkgd.shtml.

3 This is clearly stated in principles n° 193, 194, 195 on forests, and 210, 211 and 212 on mountains.

State of the world's forests

According to FAO "State of the World's Forests 2011" (2011b), "the overall rate of deforestation in the world remained alarmingly high, although the rate was slowing". Globally, deforestation rate decreased from 16 million hectares per year during the 1990s to around 13 million hectares per year during the last decades. During the same time span, afforestation with fast growing plantation and natural expansion of forest areas (concentrated mainly in developed countries) reduced the overall loss of forest area at global level from -8.3 million hectares per year to -5.2 million hectares/year (FAO, 2011b).

However, large discrepancies have been recorded across the globe with highest deforestation rate in South America and the Caribbean and net-reforestation in Europe.

Asia showed a particular behavior during the last 20 years: from being an area with high forest losses (during the '90s estimated to be 0.7 million hectares per year), in the last decade the trend reversed mainly thanks to large scale plantations resulting in a net increase of 1.4 million hectares per year. On a regional perspective, South Asia reversed the annual change trend from a negative growth until 2000 (-7000 hectares per year in the period 1990-2000) to a gain in the last 10 years (221000 hectares per year during 2000-2010, or +0.19%) (FAO, 2012).

The Pakistan case

Fig. 1 Pakistan and its provinces.

Pakistan (Fig. 1) spreads over more than 800,000 km2 between latitudes 24 and 37°N and longitudes 61 and 77°E. Encompassing an exceptionally broad geo-morphological variability, from the arid shores of the Arabian sea to the 8000 meters high peaks of the Karakorum mountains, it inherits very high levels of biodiversity and endemic species. With a population of more than 180 million people, and a total forest area of less than 1.7 million hectares (FAO, 2010), Pakistan is one of the country with the

lowest forest area per inhabitants in the world (below 0.1 square km every 1000 inhabitants), one of the highest population growth rate in the region, currently at 1.59% per year (2011 Census[4]) and the highest deforestation rate in Asia region. This shows no sign of reduction: according to the FAO Global Forest Resources Assessment (2011), forest area shrunk from 2.527 million hectares in 1990 to 1.687 million hectares in 2010. Deforestation rate passed in the same time span from -1.76% per year to -2.37% in 2010. Also the growing stock of living forests is decreasing at an alarmingly high rate and it's already much lower compared to similar country like Nepal or Bhutan. Interestingly, in opposition to global and regional tendency, forest plantations trend in the last 20 years is showing no clear increasing trend (currently set at +4000 hectares/year from >6000 hectares/year 10 years before).

Accordingly to FAO and other studies, much of the current pressure on Pakistan forest resources is consequence of the high woodfuel necessities rather than on industrial roundwood consumptions (Ali et al., 2005; FAO, 2010; Gohar, 2002; IUCN, 2003a; IUCN, 2003c; Qasim et al., 2011; Schickhoff, 1998; Shahbaz et al., 2011; Shahbaz et al., 2007; World Bank, 2010). In the last 20 years in example, due to a constantly high population growth, woodfuel removals increased from an estimated 24.7 million m^3year^{-1} to more than 31.6 million m^3year^{-1} while timber consumptions remained stable around 2.3/2.4 million m^3year^{-1}.

Forest resources, in addition, are not evenly distributed in the whole country: aridity in the southern and westernmost regions (Sindh and Balochistan) and intensive agriculture in the irrigated flat areas of Punjab, result in a jeopardized forest presence (Tab. 1)[5] mainly located along the mountain regions of Himalaya, Karakorum and Hindu-Kush, in the north and north west portion of the country (Government of Pakistan, 2001).

Table 1: Forest area per Province: in bold northern mountain regions.

Province	Total Area ('000 ha)	Forest Area ('000 ha)	Percentage
Northern Areas	1330	360	27.0
Azad Kashmir	7040	770	11
Khyber Pakthunkhwa	10170	1410	13.9
Balochistan	34720	720	2.1
Sindh	14090	680	4.8
Punjab	20630	630	3.1
Total	87980	4570	5.2

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[4] http://www.census.gov.pk/

[5]: official national statistics do not include the whole portion of Gilgit-Baltistan province as this area is still disputed with India.

The strong human pressure which the country's forest resources are facing, therefore, calls for immediate international efforts.

This study focuses on the Central Karakorum National Park, Pakistan. This is a highly remote mountainous area entirely included in its northernmost province, Gilgit – Baltistan. Its mountain forests, as other types of forests, are essential to guarantee a large amount of ecosystem services important for local wellbeing. However, their importance is not limited for people residing in mountain areas: even those living in the flat portion of the country are heavily affected by their presence, diffusion and management. In example, Karakorum-Hindu Kush mountain forests protects watersheds which are supplying freshwater, food through irrigation and energy security to more than 215 million people residing in Punjab and nearby areas (Karki et al., 2011). Additionally to timber and firewood, those forests are often an essential source of food, fodder and medicines especially for poor households (ICIMOD, 2011). For those people, heavily dependent on the entire forest ecosystem, specific mountain forest policies and management practices acknowledging first the needs of local communities are essential. As was previously revealed in other investigations, however, local forest policies (as the Northern Areas Forest Rules, 1983[6]) still rely on a strictly top-down governance, with poor consideration of local uses needs (Ali and Nyborg, 2010; Geiser and Steimann, 2004; Knudsen, 2011; Shahbaz et al., 2011; Shahbaz et al., 2007).

Many R&D centers have been founded and financed internationally in the last decades to encourage the development of guidelines and tools to help local policy makers in taking into consideration local communities necessities and, at the same time, reduce deforestation rate. However, the sharing of know-how, scientific findings and practical management techniques alone is not sufficient in such areas characterized by complex environment, culture and society (Rasul and Karki, 2007).

The aim of this thesis work is to develop a sustainable and participatory forest management plan for the Central Karakoram National Park. The terms sustainable and participatory are closely connected one to each other, however they refers to different area of interest. If sustainability is often measured in ecological, economical and, social terms, participatory processes refer directly to the governance system, in which a participatory approach can be seen as the first step to develop "social sustainability".

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[6] https://cmsdata.iucn.org/downloads/northern_areas_forest_rules_1983.pdf

Sustainable Forest Management

Countless definition of sustainable management has been proposed, not only for the forest sector in the last decades (Adam, 2006; Irland, 2010). However, this concept had in forestry a long and precious tradition. The following description, which has been extracted by the 2008 United Nation resolution 62/98 "Non-legally binding instrument on all types of forests" defines "Sustainable forest management as a dynamic and evolving concept aiming at maintain and enhance the economic, social and environmental value of all types of forests, for the benefit of present and future generations."[7]

Seven themes are considered fundamentals:

- *Extent of forest resources*: extent and amount of forest shall be preserved.
- *Forest biological diversity*: The conservation and preservation of biological diversity at the landscape, species and genetic levels.
- *Forest health and vitality*: Management of forest resources aimed at reducing the impact on the ecosystems and its functioning.
- *Productive functions of forest resources*: Sustainable forest management shall concentrate on the maintenance of a continuous flow of timber and also other non-wood forest products essential.
- *Protective functions of forest resources*: The protective role of forests shall be maintained and where possible enhanced to moderate soil, hydrological and aquatic systems in both quality and quantity.
- *Socio-economic functions of forests*: Sustainable forest management shall address the contribution of forest resources to the overall economy as well as to tradition, spiritual and recreational values.
- *Legal, policy and institutional framework*: This framework shall support the above six themes including participation in decision making and governance of local communities.

As can be appreciated in the seven themes considered, social aspects are marginally mentioned. While working in a rural and remote area it's fundamental, if not mandatory, to involve and work in tight relationships with the local communities. In this cases, indeed, to develop and apply concrete

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[7] The resolution is available at: http://daccess-dds-ny.un.org/doc/UNDOC/GEN/N07/469/65/PDF/N0746965.pdf

participatory initiatives to raise awareness and involve local communities is a necessity, rather than an option (Tambe et al., 2011).

Participatory forest management

Defined "as the management of forest lands and forest resources by or with local people, whether for commercial or non-commercial purposes"(Sam and Shepherd, 2011), PFM is not either a single guideline or a set of principles, it's more a concept aiming at increasing awareness and participation of local communities in the decision making process (Dhakal et al., 2012). Essential component of the PFM are:

- **use** of forest by local people on individual or group basis and
- the community **management** of forest: a collaborative organization led by local people with or without the support of external organization who manage the forest for the provision of goods and services (Rasul and Karki, 2007).

PFM is seen as a consequence of two main global policy trends: one side forest devolution, the process for which forest control goes in the hand of local communities rather than at government level, on the other side government decentralization, for which the planning start at local level instead of being imposed from central authorities (Dellasala et al., 2012; Hammi et al., 2010). Both those policies are the result of three decades of experience in combating deforestation and promoting local and rural livelihoods. Until the '70s, indeed, Government and/or large scale private companies were setting the regulation of forest management and local communities were addressed as one of the main cause of deforestation (Nagendra et al., 2005). Continuously increasing rate of deforestation and lack of applicable regulation, however, enhanced the idea for which environmental conservation and rural development where not contradictory and that local communities must be involved at all levels to allow a sustainable forest management (Angelstam et al., 2004). During the '80s the firsts examples of PFM in South Asia (Nepal, 1978) and Brazil (1980s in the Amazon) gave promising results and the concept was finally ratify at the 1992 Rio de Janeiro conference in the "Principle for a global consensus on the management, conservation and sustainable development of all types of forest"(Sam and Shepherd, 2011).

The complexity of the Karakorum area, both in ecological and social terms, has shaped the following research: "global" results, covering the whole park, have been reached for what concern the development of the National Park landcover, the assessment of forest area and its productivity.

The estimate of forest products uses by local communities was performed in 24 villages from 8 valleys covering almost half of the Park area (10000 km^2) while capacity building activities for local communities were implemented in 2 selected case studies (Bagrote valley – in the western part of the Park and Astak valley in its eastern portion).

CHAPTER 2

OBJECTIVE AND STRUCTURE OF THE THESIS

Conservation of natural ecosystems and sustainable development are ambitious objectives arisen from numerous global environmental debates in the last two decades. Among the themes under discussion, specific attention was dedicated to forest resources and a process towards the definition of best management practices for the conservation of biodiversity, reduction of deforestation and forest degradation and improvement of local communities living conditions has been prioritized.

Forests role, indeed, is not limited to the production of timber and firewood. They are host of biodiversity, sink for carbon sequestration and essential to guarantee a large amount of ecosystem services important for human wellbeing. This is especially true for the 28 percent of world's forests located in mountain areas. Directly or indirectly, indeed, their presence is fundamental also for people living outside mountain regions. However, unregulated firewood extraction and timber logging, a constant population growth, mismanagement and unregulated/illegal felling, are leading to widespread and unprecedented degradation of those ecosystems, posing threats to their ability to fulfill needs and secure wellbeing of human population. Urgent measures are needed to secure sustainability in the management of those precious resources, worldwide. A sustainability as respectful of nature and its components as of local communities and their needs.

Based on a practical case-study, the aim of the thesis is to present a methodological framework for the promotion of sustainable forest management in mountain areas characterized by remoteness, difficulties of access and where little to none former information are available. Even if the whole work was completed in a single protected area, the issues under investigation, the problems encountered and the methodologies applied to solve them are similar in many other mountains of developing countries.

The Central Karakoram National Park (CKNP), Gilgit-Baltistan, Pakistan, is a recently established protected area, where little information on forests resources are available and where local community are still heavily dependent on them. Lack of information on forests distribution and quantity, lack of effective management guidelines and little consideration of local communities

needs are the ingredients that have exacerbated forest degradation to an alarmingly high rate. Forests here are essential not only for securing livelihoods of local communities, but also to prevent soil erosion and landslides. This is particular important in an area characterized by frequent natural disasters as debris-flow, earthquakes, floods and where a large rural population is depending on the water coming from those mountains to sustain their agricultural production.

To partially alleviate those negative effects, the Park decided to initiate the process for the adoption of a sustainable forest management plan as a first step towards sustainable development. This represents the final objective of the thesis work.

The gathering of information for the development of a rational and concrete management plan represent the pillars on which the thesis has been shaped. Following a brief introduction to the study area and a qualitative description of its vegetation (*Chapter 3*), three issues, different for thematic, approaches and methodologies involved will be considered, all of them equally necessary to fund a management plan.

- The assessment of forest resources in terms of types and quantity.
- The assessment of dependents local communities' wood needs.
- The involvement of those communities (capacity building activities) and the development of the firsts management guidelines.

First pillar: Inventory of forest resources (Chapter 4 and 5)

The inventory of forest resources, in terms of types, spatial extent, location, biomass and increment is a major step to define sustainable harvesting rates. According to the size of the study area (more than 10.000 km^2), the remoteness of its valleys, the difficulties of access and the limited economical and temporal resources available, we applied remote sensing techniques to spread over the entire study area the results from local field surveys.

The methodological approach implemented involves firstly the construction of a **database on land cover** (with particular emphasis on forest cover) **and land use** *(Chapter 5)*. This, was necessary to create a knowledge system useful at different stages of management of the Park: in the programming phase, when this is the basis for knowledge of the environment dynamics and of the distribution of resources and during subsequent monitoring activities.

Secondly, we estimated the Central Karakorum National Park's **Above Ground Biomass (AGB)** and **Current Annual Increment (CAI)**, *(Chapter 6)*. We examine the distribution of those two

parameters in the Park area and, with a particular detail, in 24 case study villages. These data forms the base on which forest management plan prescriptions are based and represent the first large-scale forest inventory for the Gilgit-Baltistan region.

Second pillar: Assessment of local communities wood needs

Limited information were formerly available on **needs of forest products by local communities** in terms of timber, firewood and Non Wood Forest Products (NWFP). Additionally, the in between village land-ownership and the **livelihood options** in the Park area were not clear. It was therefore important to assess and evaluate which are the important assets for local communities, which and how much are their uses of forests, and how the harvesting is traditionally organized. For this reason, and to increase locals acknowledgment of our researches, we conducted focus groups interviews in 24 villages of 9 valleys (*Chapter 4 and Chapter 6*). While in Chapter 4 the main general results relatives to livelihood options in the study area will be presented, in chapter 6, the focus will be specifically on the quantification of timber and firewood needs in the selected villages. From the survey, it emerged that local households are dependent on forest resources and, realized that most of them are under pressure, have tried with different degrees of success to limit their exploitation through the creation of specific forest committee. The average per household harvesting rates and per valley forest resources availability, have been used to assess the per village and per valley wood needs.

Third pillar: Development of management plan guidelines and mitigation measures to increase local communities capacity building.

The information obtained from the inventory of forest resources and the local communities amounts of yearly wood needs allowed us to assess, at valley level, which are the communities depleting most their forests and to prioritize the mitigation interventions (Chapter 6). As economic and technical constraints are limiting the capabilities of CKNP to directly intervene in all the Park area, this result is of uttermost importance. The management plan guidelines developed are, therefore, spatially prioritized accordingly (Chapter 7). In this thesis's last chapter, additionally, the results from experimental mitigation measures carried out in the last three years are presented. In particular, two forest tree species seeds harvesting have been organized and three sites have been reforested in two valleys. All those works were organized with the collaboration of local communities and CKNP officer to increase awareness and develop capacity building.

STUDY AREA: CENTRAL KARAKORUM NATIONAL PARK

The Central Karakoram National Park is located in Northern Eastern Pakistan in proximity to the border with China and India cease fire control–line (specifically between 36° 29'N and 35° 15'S while spreading longitudinally from 74° 19'W and 76° 49'E) (Fig. 2). It was declared a National Park in 1993 to protect this "mountain area endowed with rich biodiversity and natural beauty clearly exceptional on a world scale" (IUCN, 1993).

Covering an area of 12.400 km^2, CKNP includes the Central - Western portion of the Karakorum mountain range, 4 peaks above 8000 m a.s.l., and several of the longest glaciers in the world. Around 40% of the National Park surface is covered by snow and ice (Minora et al., 2013). CKNP displays an extremely high altitude range, from the 8611 m a.s.l. of K2 to 1300 m a.s.l., resulting in exceptionally steep slopes. The whole area is characterized by extremely high relief, difficult of accessibility and widespread poverty.
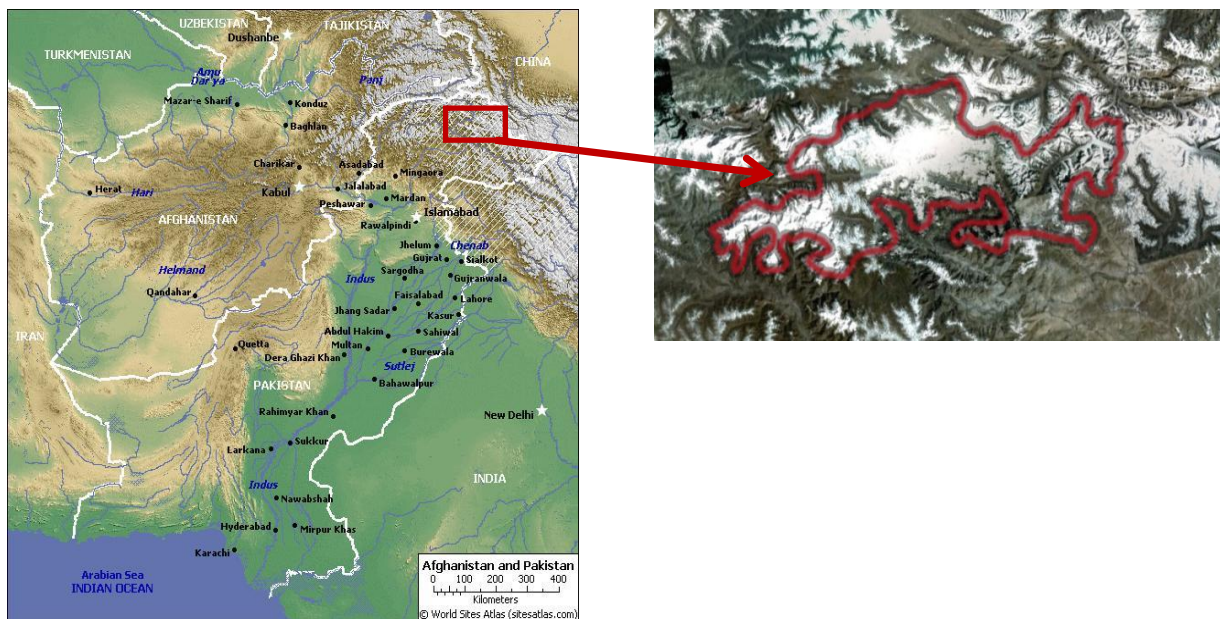
Fig. 2: Location of CKNP in Pakistan (left image) and border of the National Park area in the Karakoram range.

Geology

The Karakoram mountain range is built on Peri – Godwanian continental crust rifted away from Gondwana during Late Paleozoic and accreted to the Southern Eurasian margin during the Upper Mesozoic (Desio, 1974). It is bounded to the South by the Shyok suture whereas to the North, the limit lies along the Tas Kupruk zone. To the east its limit may represent the Paleo-Tethyan suture separating Karakoram from Hindu Kush – Pamir ranges (CKNP, 2012). Following the classification proposed by Gansser, the Karakoram unit is usually divided into three main parallel sub-units from north to south (Gansser, 1964):

1) The northern sedimentary belt, made up of a pile of thrust sheets

2) The Karakoram batholiths, or central plutonic belt, which covers around 30% of the range

3) The southern metamorphic belt, composed by sedimentary series where the metamorphism reaches the amphibolites facies (Desio, 1974; Rolland et al., 2001).

Most of the study areas fells inside the southern metamorphic belt, whereas the Karakoram batholiths is present in few valleys of the North-Eastern park sector (Hushey valley in particular).

Climatology

The Central Karakoram National Park area is falling in the transitional zone between the arid and continental Central Asia climate and the semi-humid subtropics climate of South Asia (CKNP, 2012). In general local climate is characterized by dry condition especially at the lowest elevation: precipitation usually falls during winter and spring while summer is relatively arid until the onsets of cold weather in early autumn. As a general rule, a decreasing humidity and an increasing significance of continental elements can be observed from south to north and from west to east. In addition, a strong rain shadow effect is evident, with dry conditions at lower elevation and precipitation mostly occurring during winter and spring.

Precipitation is strongly affected by the extreme topography, resulting in evident "rain-shadow" effects: it increases considerably with altitude (a precondition for the large glacial masses present above 5500 meters) where it occurs mainly as snowfall while in the lower valleys bottom, surrounded by high peaks, aridity prevails with an average annual precipitation between 100 and 300 mm mostly felling during winter and early spring months (Archer and Fowler, 2004).

Vegetation

Ecological setting

The vegetation of Central Karakoram National Park grows only in a small percentage of the park area. This is a consequence of different abiotic factors which constraints plants growth: the high average elevation which reduces temperature and the length of the growing season, the rough relief and large glacial masses which restrict the area suitable for plants establishment, the continental climate and rain-shadow caused by the mountain massifs and their impact on precipitation distribution along altitudinal gradient. In particular, temperature is a limiting factor at higher elevations (above 4500 m) while insufficient water availability during the growing season is impeding plants growth at lower altitudes (below 2000 m, where natural vegetation is mainly found around water bodies as streams or lakes). Additionally, natural floristic composition has been affected by the millennium-old human presence that impacted and modified the vegetation components both directly (i.e. clearings of forest for pastureland and cultivated areas) and indirectly (i.e. prolonged grazing by livestock). Nevertheless, different vegetation types grow in the CKNP and they are of major importance both for ecological reasons (e.g. as habitat for wildlife, biodiversity conservation, etc) and for the sustainment of local communities (e.g. for the provision of grazing ground, firewood, timber, etc). Additionally environmental services like protection from soil erosion, regulation of water quantity and quality, nutrient recycling are being provided.

The plant communities present in Central Karakoram National Park are of particularly interest since the park location in the transition zone between sub-tropical humid condition to the south and continental dry climate of northern areas. Indeed, inside the CKNP borders, this transition is evident moving from southwest towards northeast. CKNP can therefore ideally be divided into two main ecological zones: a southwest part, around Gilgit district, which is relatively warmer and partially influenced by the summer monsoon and the northeast part, felling mostly in Skardu district which is characterized by a more continental climate (Treydte et al., 2006). This climate patterns have a major influence on vegetation characteristics and distribution: it is of particularly interest to deeply evaluate the effect of climate transition on the CKNP forest resources, especially for their importance in the livelihoods of local communities. Overall, the South-Western sector is characterized by a forest composition and structure which is richer both in area, biomass and species. Most of the largest forests of CKNP are located in the Southern lateral valleys of the main Gilgit river valley (with few exceptions on the southern border of CKNP along Indus River). Good examples of those rich forest

ecosystems can be found in Haramosh, Khaltaro, Bagrote, Jaglot Gor and Astak valleys among others. On the contrary, in the North-Eastern valleys, mainly plant adapted to cold and xeric environment can be found. Forest cover is more fragmented and sparse with lower densities, stand biomass and increments. Forests areas here are therefore more scattered.
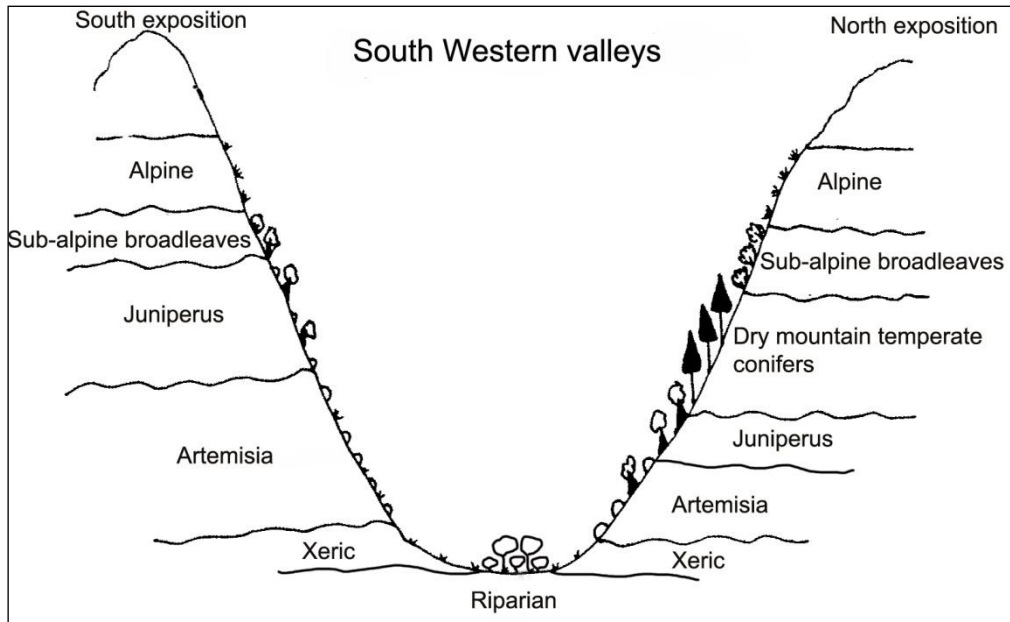
Fig. 3: Vegetation distribution in SW valleys (modified from Miehe and Miehe, 1998)
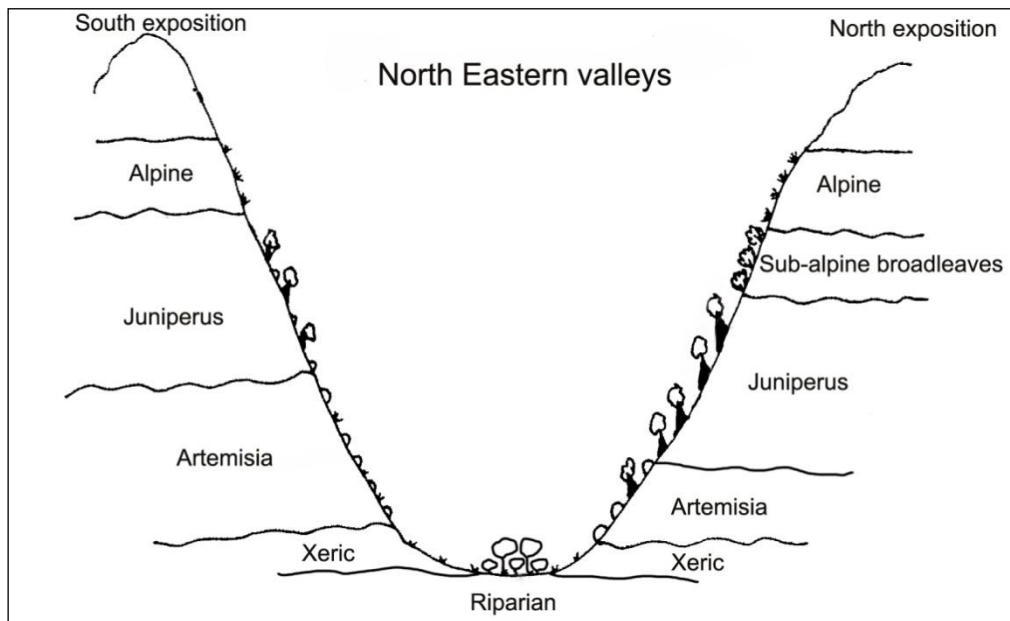
Fig. 4: Vegetation distribution in NE valleys (modified from Miehe & Miehe, 1998)

Vegetation types

Vegetation types, which partially follow the classification proposed by Champion et al. (1965), have been formulated according to the species composition and, therefore, as a consequence of the most prominent ecological processes shaping their geographic distribution (Ahmed et al., 2006; Akbar et al., 2010; Akbar et al., 2011; Champion et al., 1965; Du, 1998; Eberhardt et al., 2007). Overall, inside the CKNP limits 4 forests and 3 shrub-lands types can be recognized.

Climate (especially temperature and water availability) is the main driver which influence species distribution in the park area (Miehe and Miehe, 1998). At valley level, instead, aspect and morphology leads to a series of common distribution patterns although with differences from valley to valley (Fig.3 and Fig 4).

To describe CKNP vegetation we will follow an ideal transect, starting from the valley bottom and gradually increasing altitude until we will reach the snowline.

In close proximity to river/streams, in all CKNP valleys, a plant community adapted to this seasonally humid but disturbed environment, characterized by frequent floods, draughts, and landslides is common: riparian vegetation. Broadleaved species as willows (*Salix* spp.), poplars (*Populus* spp.), sea-buckthorns (*Hippophae rhamnoides* ssp. *Turkestanica*) and Tamarisk (*Tamarix ramosissima*) are the prominent species. Unlike the other vegetation belts, the distribution of this community is not altitude driven (it can be found from 1800 up to 3000 m) but its limited by air and soil moisture derived from water bodies. For this reason it can be described as an "azonal" vegetation which usually has a linear shape, few tens of meters large. The closeness to villages and fields has an effect on riparian vegetation, which is often managed by local communities. Poplar is mainly managed for timber production, while sea-buckthorns and willows for firewood. Fruit trees are also diffuse.

Where the river moisture effect ends, as the humidity derived by the presence of stream decreases exponentially with distance, the dry environment is hampering the growth to most plants. Only the most drought resistant species with particular physiological adaptation to couple with this harsh environment, like *Capparis himalayensis*, *Ephedra* spp and *Cardus* spp can develop, but their cover is sparse and fragmented. Xeric vegetation is frequent in all valleys, starting from 1600 m. At lower elevation those communities develop mainly in shaded, north-exposed areas, while at higher elevation they are mainly confined in the most dry and sunny locations (2000/2200 m a.s.l.).

Moving at higher elevations (above 2200 m), precipitation and water availability gradually increase, allowing the development of a steppe-like community of perennial shrubs adapted to xeric environment. Among the most representative species, Artemisia (*Artemisia brevifolia, Artemisia wellby, Artemisia fragrans, Artemisia brevifolia*) is common all over the CKNP boundaries and characterizes this vegetation belt (Artemisia shrub-land). Other species include *Agrostis* spp, *Astragalus* spp. few tree species, adapted to grow in xeric locations as Junipers can be found in protected location. Artemisia shrub-land is often grazed during autumn and winter months by livestock. In the coldest and driest valleys of CKNP (like Braldu) the stems and roots of those bushes are collected and used as firewood (Flury, 2012). Additionally, Artemisia shrub-land can be the result of a persistent and long-lasting degradation of more fertile vegetation belt (as Juniperus shrub-land/forest).

As altitude increase, from approximately 2600 m, stands of Junipers (*Juniperus* spp.) are frequent (Juniperus shrub/forest). The ecological plasticity of those species is remarkable: often isolated trees are found in inaccessible locations on very steep mountain sides where just a small pocket of soil might be available. The stands biomass and increment is correlated to water availability: at higher altitude, or where water availability is more abundant, Juniperus become denser and taller (>5 m in height). In those areas, Juniperus can be classified as forests according to FAO definition (UN-ECE and FAO, 2000). At lower elevation or in the drier sites instead, sparse individuals are growing in between Artemisia shrubs (Juniperus shrub-land). Three species of Juniperus have been recorded by far in the CKNP (*Juniperus excelsa* ssp *polycarpos*, *Juniperus semiglobosa* and *Juniperus pseudosabina*). Other shrub species are usually available: Berberis spp., Caragana gerardiana, Rosa webbiana among others. Juniperus trees are the preferred species for firewood thanks to their dry and fragrant wood. Consequently a long lasting harvesting resulted in degradation of stands located in proximity to villages and a reduction of their spatial diffusion. Nevertheless, inside CKNP borders, Juniperus are still very common and diffuse in most of the valleys: generally, in northern exposed location, they can be found at lower elevation, compared to the drier and warmer southern exposed sides. However, while in the North-Eastern sector of the park they are the only forest biomes to be found up to the sub-alpine broadleaved forests, in the more humid sides of the South-Western part, from around 3000 m, this community is substituted by the mountain dry temperate forests. Here Junipers stands above 3000 m are confined in steep and dry southern exposed mountain sides.

The above mentioned differences in climate between SW and NE sector of CKNP, affect heavily the diffusion of species inside the CKNP. This is particularly evident for the typical mountain dry temperate forest vegetation belt of the Western Himalayan/Karakoram range (IUCN, 2003b),

characterized by tall conifer trees as *Pinus wallichiana* and *Picea smithiana* mixed or in purity. This community, living in areas characterized by a strong relief, high precipitation (for CKNP standard) mostly felling during the winter months and a strong continental climate, is naturally scarce, occurring mainly at an altitude between 2800 and 3800 m a.s.l.. The most forest rich areas are generally located on the shaded Northern and Eastern slopes (due to higher water availability) or on the frontal and lateral glacier moraine (deeper soils). In general, trees growth is strongly favored in areas where snow accumulation and melting can guarantee sufficient water availability during the growing season. Those conditions are mainly met in the South-Western valleys. Few stands of those species are present in the valleys north of the Rakaposhi-Diran-Spantik ridge and east of the Shigar valley: Pinus wallichiana has been recorded in Shaghar Logma, Doko and Besil valleys (in Basha) and Baumaharel (Shigar). Moreover, *Picea smithiana* mixed with *Pinus wallichiana* is still present in some lateral valleys of Nagar like Nilt, Minapin and Sumayar among others. Traditionally, mountain dry temperate forest has been managed for the production of timber. Initially, this activity was limited to fulfill local household needs but, following roads constructions in the Indus-Gilgit river lateral valleys8, timber has been and occasionally is felled for the market in Gilgit or Skardu. Illegal harvesting, lack of proper management guidelines and lack of regeneration is often threatening those forests, which today appear often degraded (low stand densities, lack of small diameters).

The last forest belt, diffuse in the entire CKNP, to be found before the alpine meadows and shrub-land is sub-alpine broadleaved forests. This is composed mainly by stand of *Betula utilis* and *Salix* spp., located at high elevation (above 3500 m) where snow accumulation and avalanche guarantee water availability throughout the short growing season (June-September). As a direct consequence most of the stands are located on shaded north or northeast exposed mountain side. The largest birch forests are found in the more humid southwest valleys. Traditionally, birch trees are used by the shepherds: the outer white portion of the stem is peeled to obtain "paper" mainly used to pack the local butter. This vegetation is often in a good conservation status since timber or firewood is rarely harvested.

Above 3800-4000 m, the short growing season and the low temperatures do not allow the growth of trees. Here herbs and few shrubs are abundant, identifying the Alpine meadows and shrubs-land belt. Thanks to the relatively high summer rainfall, alpine meadows have a good fertility and are a key-asset for the sustainment of local communities which relies heavily on this belt for the grazing of

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[8] Most of the lateral valleys of Indus and Gilgit river where reached by roads at the end of the 1980s – beginning of the 1990s.

livestock (during summer) (Miehe and Miehe, 1998). Through the centuries, alpine meadows lower altitudinal limit have often been increased in size by local communities through clearings of sub-alpine broadleaved forest, mountain dry temperate forest and Juniperus shrub-land/forest. Poa and Carex genus are the most common plant members (CKNP IMP, 2009), but many other species are present such as *Kobresia* spp, *Bistorta* spp, *Polygonum* spp.

These areas provide ideal habitats for many important mammalian species like Marcopolo sheep, Blue sheep, ibex and marmots (EV-K2-CNR, 2009).

Table 2: Summary of CKNP Vegetation types

Vegetation type	Altitude	Description
Riparian vegetation	Azonal distribution	Next to mountain streams and rivers, along a wide altitudinal gradient (azonal). Species as Willow (*Salix* spp.), Poplars (*Populus* spp.) and Sea-Buckthorns (*Hippophae* spp.) are common, often cultivated for the production of timber and firewood.
Xeric vegetation	< 2200 m	On extremely dry sites. Presence of xeric tolerant species, as *Capparis*, *Ephedra* and *Carduus*, protected by rocks or in favorable niche. Grazed by livestock in winter months.
Artemisia shrub land	< 2600 m	Occasionally presence of scattered Junipers. Can be the result of a long lasting and heavy degradation of former forests. This vegetation is common all-over the CKNP. Important grazing ground in the autumn-winter months.
Juniperus shrubs/forest	SW CKNP: < 3000 m (3800 m*) NE CKNP: 2800 – 3800 m	Stands of Juniperus are distributed all over CKNP. In the South-West valleys, the stands are located mainly at low elevation (at altitude below 3000 m) or on the dry, southern exposed mountain sides (up to treeline, 3800 m*). Moving North-East their abundance increase and Juniperus stands are located an altitude between 3000 and 3800 m. Usually stand density is low and stand dynamic is slow (scatter regeneration). The Juniperus forests are the main source of firewood for local communities inside the CKNP.
Mountain dry temperate coniferous forest	3000 – 3800 m	Stands of Himalayan Blue Pine (*Pinus wallichiana*, Kail) and Morinda spruce (*Picea smithiana*, Kutwal) with marginal presence of *Juniperus* spp are frequent in the south-western valleys of the CKNP. Those forests are located on moist and fertile sites, at an average altitude between 3000 and 3800 m usually on North/North-East exposed mountain sides. In the recent past most of them have been heavily managed for timber production. The livestock grazing which reduce trees regeneration and the lack of proper management guidelines makes temperate mixed forest types often degraded.
Sub-alpine broadleaved forest	3300 – 3800 m	Stand composed by birch (*Betula utilis*) and/or willow (*Salix* sp.) are scattered at high altitude mainly on northern exposed valley sides. Relying heavily on snow accumulation and avalanche for water availability, those species are usually composing the upper tree-line. Harvesting of firewood is low, mainly used for "paper" production.
Alpine meadows and shrubs	> 3900	The alpine pasture zone lies above the timberline that fluctuates from 3,800 m a.s.l to 4,000 m a.s.l. At this altitude the temperature does not allow the growth of trees, however, alpine pastures shows good levels of growth and fertility(Miehe and Miehe, 1998). *Poa* and *Carex* genus are the most common plant members (EV-K2-CNR, 2009). These areas provide ideal habitats for many important mammalian species.

Table 3: Broad distribution of Vegetation types according to the two "ecological zones" of CKNP. Based on field observations.

Vegetation types	SW valleys	NE valleys
Riparian	Frequent	Present
Xeric vegetation	Present	Present
Artemisia shrub land	Frequent	Frequent
Juniperus shrub/forest	Frequent	Frequent
Mountain dry temperate coniferous	Present	Absent
Sub-alpine broadleaved	Frequent	Present
Alpine meadows and shrubs	Frequent	Frequent

CHAPTER 4

LIVELIHOODS IN THE CENTRAL KARAKORUM NATIONAL PARK: A SURVEY

4.1 Introduction

Degradation of ecosystems and loss of biodiversity in mountain areas has lead to the creation of numerous protected areas in developing countries and specific prescriptions aimed at the conservation of their natural heritage were established (Leverington et al., 2010). Often, the conventional management strategies applied involved top-down approaches, such as "fences and fines" system, for which prohibition in access or use is a precondition for preservation of the natural capital (Masozera et al., 2006). Those, however, led to widespread conflicts between authorities and local communities, particularly evident where the latter are dependent on natural resources for their subsistence (Maikhuri et al., 2000; Wells et al., 1992). A paradigm shift towards decentralization and devolution has been promoted to counteract and mitigate those negative effects: the responsibility for protection has been gradually held back to communities, paving the way for what today is commonly called Community Based Management (CBM) (Fisher, 1999). In CBM, communities are the target for assessing natural resource uses, problems, trends and opportunities. By incorporating them in the management system, their experiences, values and capacity are preserved, resulting in higher level of acceptance and sense of ownership both positively correlated with natural resource conservation (Ellis and Porter-Bolland, 2008; Sam and Shepherd, 2011).

However, CBM can be achieved if communities gain the knowledge and abilities to manage actively the resources, as unsuccessful stories are common, Pakistan included (Geiser and Steimann, 2004; Gohar, 2002; Hasan, 2007; Knudsen, 1999; Knudsen, 2011). The present study, conducted in 9 valleys, aims to set the basis for developing CBM in the Central Karakorum National Park.

According to the regulation applied in the Protected Areas of Pakistan Northern Areas province[9], indeed, the use of natural resources, forest included, is strictly controlled by government which holds all the use rights in a classic "Top-down" system (Ali et al., 2006; Khan and Khan, 2009; Shahbaz et al., 2007). Communities, on the contrary, are left with secondary usufruct (i.e. grazing right in forest, firewood collection from dead or diseased trees) (IUCN, 2003b). Therefore, before proceeding towards a relaxation of the existing regulations, we intended to deeply investigate how local communities are actually managing natural resources with a specific focus on forests and grazing land. We organized a set of focus groups in selected valleys to obtain a comprehensive overview of CKNP livelihoods, to raise community involvement in forest related decisions and increase their participation.

4.2 Materials and methods

4.2.1 Study area

The study area is located in the Central Karakorum National Park, Gilgit-Baltistan province, Pakistan (75°43' E 35°51' N). Approximately 100.000 inhabitants are living along the Park valleys. Those are mostly self-sufficient farmers heavily relying on locally produced agriculture products and sheep/goat breeding. They are dependent on wood for fire (cooking, heating) and construction purposes. Three ethnics groups are living in the Park valleys: *Baltì* in the eastern valleys (Skardu area), *Shinaa* in the south western (Gilgit area), *Burushaski* in the north western (Hunza area).

Access rights, rules and uses of natural resources, mainly forests and pastures, are typically managed by the Tsarmas/Jirga at village-level. Those are the traditional council of elders (in Baltistan and Gilgit area, respectively) which are also holding the knowledge of the area (borders, property rights etc). Due to economic and time constraints the research on livelihoods was conducted in 24 villages of 9 valleys (Fig. 5).

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[9] The Northern Areas Wildlife Preservation Act (1975) describe all the activities which are allowed within the boundary of a Park. The fifth rule states that no person shall "Cause any bush or grass fire (except at designated places) or cut, destroy, injure or damage in any way any tree or other vegetation in a National Park;

4.2.2 Focus groups

The 24 focus groups, one per each village, were organized in collaboration with the CKNP game-watchers. The main objective was to gather information about livelihood opportunities and natural resource uses in the different CKNP villages. Additionally, it was a precious opportunity to inform locals about CKNP management plan and main forest management guidelines. The presence of at least one representative from each community, in the form of *nambardar* (chairman of local community organization) has been strongly encouraged.

A specific questionnaire was developed to gather information about the uses of forest resources and was translated in *Urdu/Shinaa/Baltì* or *Burushaski* according to local community linguistic preferences (Annex 1).
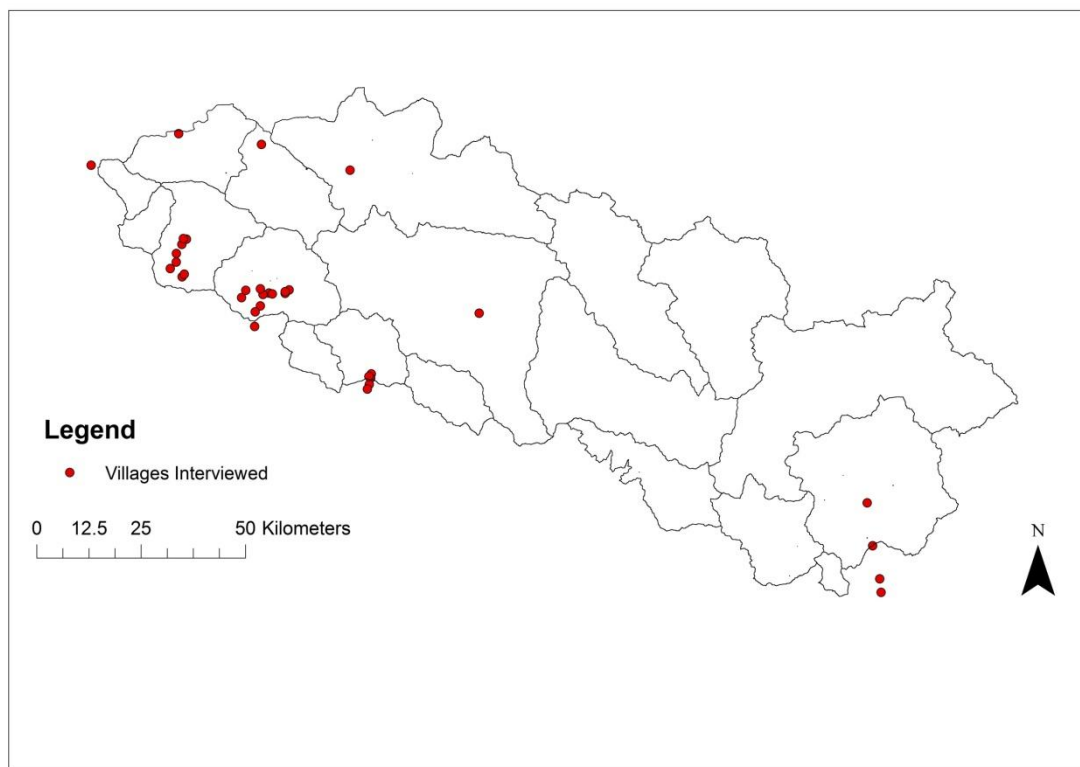
Fig. 5: Location of the villages where focus groups were conducted.

4.3 Results

4.3.1 Utilization of natural resources

The communities living around CKNP are heavily dependent on natural resources located inside and around the park boundary. The livelihoods opportunities are strongly tied with the availability of resources, the location of the villages (i.e. altitude), climate, availability of water and easiness of road connections. Comprehensively, all community but one (Minapin Nagar) are mainly relying on goods (*output*) produced from local activity (*input*): i.e. food (agriculture), fruits (orchards), dairy and meat (livestock), timber (forest), non-wood forest products (forest). Mining, as tourism, are important natural assets only for few villages and not all the household are usually involved in such activities. Thus, benefit sharing is not equally distributed.

Generally the livelihood in the research area can be defined as "*Combined-mountain-agriculture*" following Kreutzmann definition (Kreutzmann, 2004). This is a typically mountainous livelihood scheme in which livestock, agriculture and horticulture, and forest harvesting and non-wood forest products collection are fundamental activities performed at different times of the year in a cycle, along altitudinal gradients. The timing of the cycle is decided by the climate of the area and might vary from village to village and in between valleys. Here we will define the main steps, similar through all the study area. During springs, the fields are ploughed and grains are sowed. Consequently, household's livestock is moved out of villages to the lower pastures, free of snow, to protect cultivated areas from animal browsing. As the season advance, livestock is gradually moved at higher elevation to the summer pasture (July-August) above the timberline (4500 m a.s.l.). In the mean time, crops are grown and finally harvested. Therefore, livestock can gradually returns to lower pastures and to stables at village levels (November). There, they will stay during all winter (November – March) until successive spring, feeding on the crop residuals and hay collected during summer stored and dried by the households. From summer to early autumn, orchards production is collected and dried, eventually being sold to the nearest city market. In the villages where productivity is higher (lower elevation), fruits is an important component of the households economic portfolio.

During summer and autumn months, firewood and timber, where available, are harvested from local forests and used for construction or as firewood reserve for the following winter. In few valley timber and more rarely firewood is illegally sold to the market.

The overall livelihood scheme is constant over the study area, although timing and relative importance of each output may vary according to village location. The main difference is the availability of forest resources (Fig. 6 and 7), almost absent in the eastern valleys of CKNP.
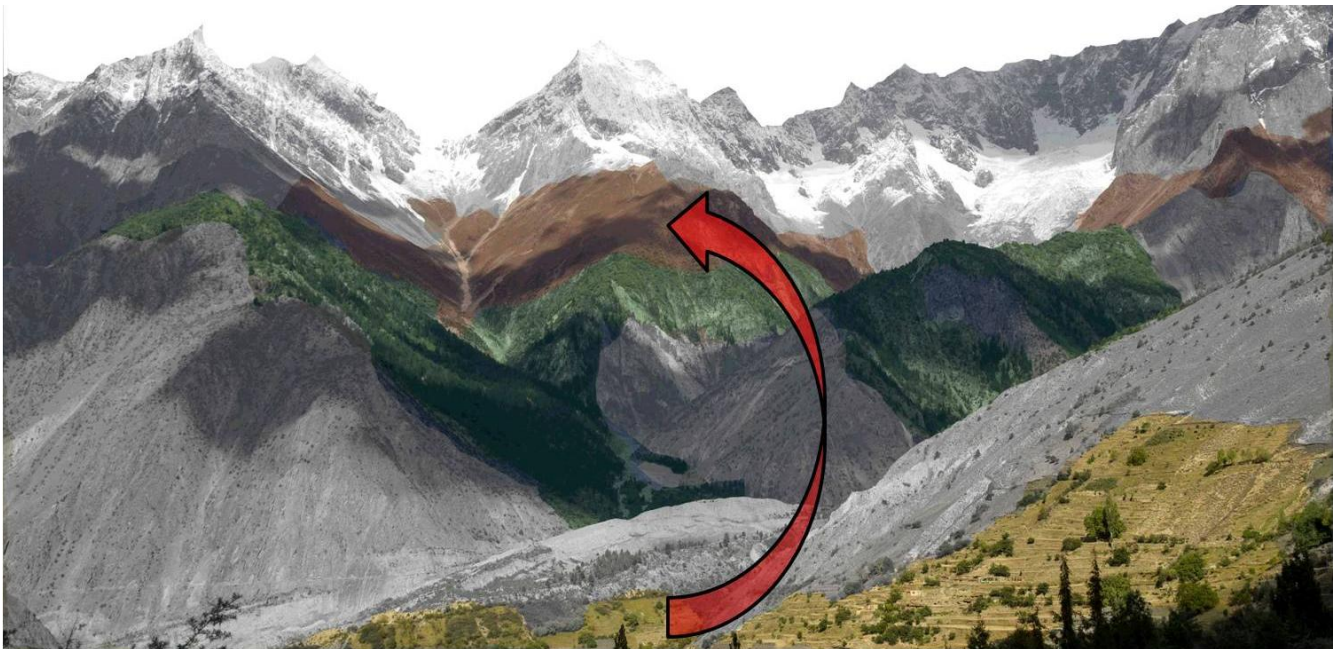
Fig. 6: Combined mountain – agriculture in Western CKNP valleys: fields, yellow shaded, forest, green shaded and pasture, red shaded are all major component of the subsistence livelihood of local communities. Livestock is gradually moved from spring to early autumn months out of villages gradually up to summer pastures, located well-above the treeline (4000 m a.s.l.).

Fig. 7 Combined mountain – agriculture in Eastern CKNP valleys: fields, yellow shaded, and pasture, red shaded. Note the absence of forest areas.

4.3.2 Land Tenure

Houses, arable lands and livestock are property of each households while pastures, forests and irrigation systems (fundamental as rain-fed agriculture is not possible due to aridity) are collectively managed at village or households level.

4.3.2 Agriculture

In the research area, agriculture is forcedly restricted to irrigated terraces, due to extreme slope steepness and summer aridity. Predominant crops are grains as wheat, barley and buckwheat. Additional crops as legumes are seldom grown as catch crop while potatoes are the main cash crop. Those productions hardly met household yearly needs and often a large amount of the yearly income is spent on purchasing additional requirements from the market. This is especially true for high altitude villages (above 2500 m a.s.l.) located in the single cropping zone while lower villages, located in the double cropping zone, usually are able to satisfy their own requirements (Tab. 4). Most of crop derivates are dried and stocked during the good season and used as winter fodder for livestock. For those cultivations, manure from household's livestock is the main fertilizer.

Limitation

The main limitations to the improvement of agriculture output lies in the scarce irrigation system and complex topography which hampered the land surface available for cultivation and the low soil fertility and limited cultivated varieties which reduced the single-field productivity.

4.3.3 Orchards

Household living in villages located at lower elevation (below 2500 m a.s.l.) maintain a great variety of fruit trees as apricot, walnut, apple, cherry and pears. Most of the fruits are simply collected and dried on house roof. Then, villages located in proximity of market city as Gilgit or Skardu and with sufficiently good road connection sell them directly there. This is an important asset as productivity and quality is relatively high. Orchards leaves are collected in the autumn months and used as additional fodder for livestock. Similarly, all pruning residuals are used as firewood. For lower altitude villages, where quality and productivity are higher, orchards can constitute both an important revenue and a large source of firewood.

Limitation

Orchards diffusion is limited by both environmental factors as land availability and water scarcity, as well as limited productive capacity and infrastructure (fruit procession facility).

4.3.4 Agro-forestry

Poplars (*Populus* spp.) and willows (*Salix* spp.) are the predominant plantation grown around fields and villages. Poplars can be successfully grown in villages up to 3000 m a.s.l. however, as growing rate decrease sharply with elevation, they are more diffuse at lower elevation where they assume an important role in timber production. Similarly to orchards, pruning residuals and leaves are used as firewood and fodder respectively. Poplar became relatively abundant in the last 20 years following large scale supporting campaign by NGOs. No coppice plantation system is used specifically for firewood production. To protect fields from livestock browsing during early spring, when animals are not yet moved to higher elevation pastures, linear hedge of Russian olives (Seabuckthorn, *Hippophae* spp.) are common. Those are seldom used as firewood, especially in drier areas.

Limitation

Main limitation in higher diffusion in agro-forestry is the lack of land and specific species.

4.3.5 Livestock

Goats, sheep, cattle, yak and crossbreed of cow and yak are common all over the study area. Goat and sheep share in total household livestock are particularly large in lower altitude villages, whereas cows, yaks, and crossbreed, tend to be more common in higher altitude villages, probably as a consequence of larger and more fertile grasslands (Tab. 4). While goat, sheep and cows are grazing in managed pastures, yaks are free roamers: during summer in high altitude pastures (> 4500 m a.s.l.) as well as in winter (around forest or in intermediate pastures (3500 m a.s.l.)). The amount of livestock is variable from village to village, according to pasture size and fertility, and among household within a village (Tab. 4). However, through all the study area, livestock represent the most valuable asset for households, thanks to relatively high prices of selling animals in the market and the good value of the dairy products (mainly butter). Just to mention, one goat average price is

between 10 and 15.000 Rps (between 70 and 100 €[10]). Moreover, animals can be readily sell in case of economic shortages.

The alpine pastures, in the framework of combined-mountain-agriculture, constitute a key resource for households, which organize the grazing mainly according to two schemes:

1) The household leave most of its animals to a shepherd, which will have the responsibility to move the animals in the different pastures until autumn months (Nov).The shepherd keeps all the dairy products as a payment or exchange the 50% for a certain amount of grains (usually 1 kg of butter equals to 5 kg of grains). In this case, few huts are usually available in the largest pastures.

2) Each family moves his own livestock during the spring and summer months to the upper pastures. In villages where amount of animals is not very large, several families might join together their livestock, each keeping them for one/two weeks. Usually several huts are located in pasture zones.

Rather than a single upward movement to summer pastures, the grazing is organized in a cycle where each single intermediate pasture is used for several weeks both on the upward and downward movement to/from summer higher pastures (Fig. 8). Regulation in the grazing-land uses are mainly adopted at village level, through a specific commission. Those decides the timing at which livestock should be moved out of the village and the use rights of all the village pastures.

Limitation

Key limiting factor for the livestock size is represented by scarcity of fodder during the winter season, between November and March, when animals are kept and fed in households houses. At that time, all the available fodder collected in summer is used and often additional reserves are purchased from the market or from other households. Diseases and predations negatively affect household livestock size even if usually to a lesser extent.

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[10] Considering January 2014 exchange rate (1 € = 144 Pakistan Rupees).
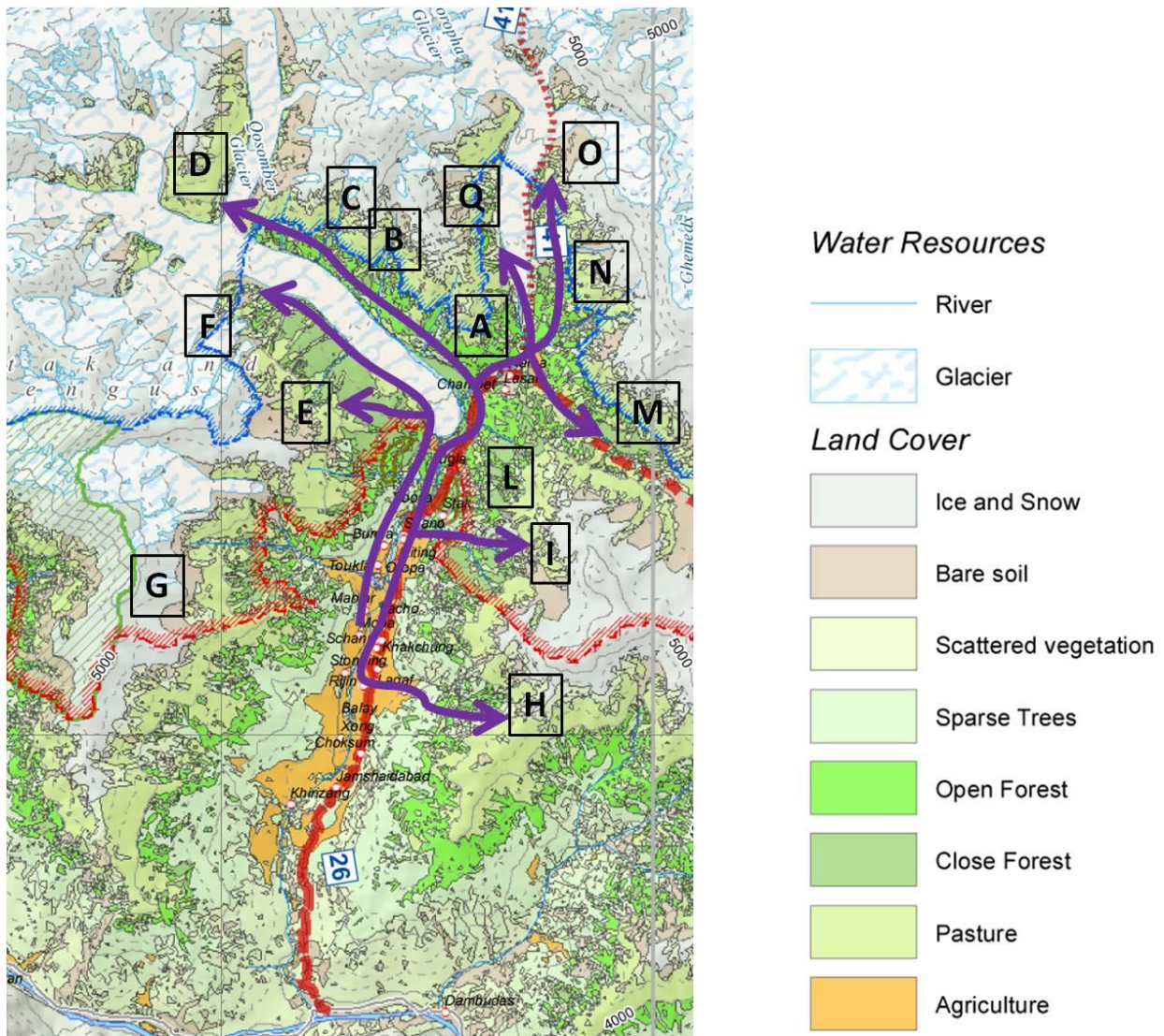
Fig. 8: Pastures of Astak valley and movement of livestock during the season: A) Chambet (April/May->Sept/Oct), B) Morpholuma (June/August), C) Seralpa (June-August), D) Chaspolo (August); E) Kutja (May/September), F) Schango Luma (June/August); G) Tuglamo (June/August); H) Servogir (July/August); I) Matumbur (July/August); L) Lassar (June/August); M) Lahamosh (June/August); N) Drumaso (June/August) O) Hlarzing (July/August), Q) Liglidlmo (June/August).

4.3.6 Forests

Forests are essential for providing grazing ground for the livestock, for covering the firewood necessities (heating and cooking) and for the supplement of timber for construction. Additionally, non-wood forest products as mushrooms (*morels*) and other plants are widely collected for personal use as well as, in some cases, for selling. From an economical point of view, communities which can entirely rely on self-collection of forest products (timber and especially firewood), even if it is a time consuming activity, save large amounts of money. The different forest conditions among the Gilgit and Skardu district have historically brought some differences in forest use: the forest of Skardu district are mainly used for communities subsistence due to the lack of high-value timber, while the

richest forest in the south-eastern sector of Gilgit district have been (and in some cases are still) illegally felled for selling timber in the local markets (Ali et al., 2005; Ali et al., 2006).

A large majority of the communities, realized that most of forest are under pressure, have tried with different degrees of success to limit their exploitation through the creation of specific forest committees. Those in some areas have been successful in reducing the forest degradation (as in Bagrote and Khaltaro) while in other areas like Haramosh and Jaglot Gor were unable to effectively tackle deforestation and corruption which today are still very common.

Timber

Most of the high value timber (mainly Pine and Spruce) is located in the southern valleys of Gilgit district. Consequently, villages with little access to high forests or located in forest scarce areas, organized private/common poplar plantations for obtaining construction wood and firewood is the only product harvested from natural forests. In those realities accessibility to the forest has not been regulated or restricted yet and average annual timber wood needs per household, obtained from the plantation, has been estimated to be 500 Mg per household per year.

On the contrary, in forest rich villages timber harvesting is usually regulated and represent an important share in total household livelihood revenues. All the timber harvested in those valleys shall be considered illegal, as local laws allow the cutting of trees only if previously marked and signed by forest officials. However, in practice, this is hardly happening and locals decide by themselves where and how much to cut. Usually a commission is setting a certain amount (in n° of logs) harvestable for each household. It is important noting that use rights are maintained even by households now residing in nearby villages/cities. Those are allowed to cut the same amount of local residents. The usual amount harvestable is around 100/200 logs per household per year. From a large tree, locals usually obtain around 50 logs. The value of a large tree harvested, divided into logs and transported to the nearest city (Gilgit or Skardu), can vary between 100.000 Rps (*Picea*) and 125.000 (*Pinus*)[11]. It is evident, therefore, the high importance that forest harvesting represent in the livelihood of forest-rich communities.

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[11] In between 700 and 900 € considering January 2014 exchange rate. Transport from Barchi/Dassu forest (Haramosh) to Gilgit city can be up to 200 € per tree.

Firewood

Firewood is by far the most important wood products harvested from CKNP forests, covering more than 75% of the total forest utilization, as organic carbon is used for heating and cooking and not feasible alternative are found at the moment. This is a consequence both of the cold climate and the high cost of purchasing firewood from local markets (700 Rps per 40 kg in Skardu[12]). The preferred firewood is Juniperus, a very common but slow growing species, followed by shrubs, Artemisia roots, dung and riparian vegetation (as Seabuckthorn) all important component of household fuel portfolio. Additionally, fruit trees pruning residuals are often being used and their relative importance increases in those villages where orchards, being an important income source, are diffuse. Only Minapin Nagar, thanks to its location along Karakorum Highway and the higher revenues related to other economic sources, shifted to gas/LPG cooking systems.

In most of the villages there is no restriction/indication on firewood harvestable amounts and locations, but there are exceptions like Hushey village (where a ban has been imposed on some degraded forests close to the village) or few location in Astak valley. What is usually put in practice is a ban on selling of firewood to nearby villages or cities, at the moment heavily regulated in most villages.

Considering wood consumptions, the amount of firewood yearly used obviously decreases from the higher villages (apr. 4000 kg/household/year) to the lower one (2000 kg/household/year). Similarly the share of firewood collected from natural forests decreases from 100% for the villages in proximity of forested areas (higher altitude) to almost 0 of the ones far away from them or located the valleys with scarce forest resources. These villages are mainly using dry livestock dung or orchards residuals to overcome their firewood needs.

Non-wood Forest product

Few non-wood forest product assume an economical significance for local communities. In particular, morels mushroom represent the most important one. Collected in spruce and pine forests from late spring until early autumn, they are dried and sold in Skardu or Gilgit market city. The average price for a kg of good quality dry mushroom can reach 11000/12000 Rps13. No large scale

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[12] Equals to 5€ per 40 kg transport included (Skardu). In Astak, firewood is sold locally at 2€ per 40 kg.

[13] 70-80€ per kg dry.

processing or drying facility is available and usually only few households (mainly shepherd or young people) is actively searching for them during most of the season.

Table 4: Livelihood strategies in the 24 villages surveyed. n° HH: Number of Household, Alt: Altitude (m a.s.l.), Agriculture: double/single cropping zone, Orchards: only fruits sold to market have been highlighted (Apr: Apricot, Wal: walnut, App: apple, Cher: Cherry, Pear), Livestock: n° of animals per HH (G: goat, S: sheep, C: cow and crossbreed, Y: yak); Livestock product: only products sold to market are highlighted; Pasture organization: how is, at village level, organized the grazing of livestock; NWFP: only products sold to market are highlighted.

Valley	Village	N° HH.	Alt.	Agriculture	Orchards*	Livestock				Livestock products*	Pasture organization	NWFP*
						G	S	C	Y			
Astak	Astak E	600	2500	double	Apr	15	10	4	1	Meat, butter	Shepherd	
	Astak O	700	2450	double	Apr	15	10	4	1	Meat, butter	Shepherd	Morel
Bagrote	Bilchar	250	2610	-	Wal	-	-	-	-	-	Shepherd	
	Bulchi	250	2406	single	Wal	10	8	2	-	Meat, butter	Shepherd	Morel
	Chirah	100	2416	single	-	15	10	4	-	Meat, butter	Shepherd	Morel
	Farfoo	250	2332	double	Apr	15	10	5	-	-	Shepherd	
	Hopey	140	2196	double	Apr, Wal, App, Cher	10	10	4	-	-	Shepherd	Morel
	Datuchi	150	2231	double	Apr, Wal, App, pear	5	10	3	-	-	Shepherd	Morel
	Sinaker	130	2137	double	Apr, Wal, App, Cher	10	2	3	-	-	Shepherd	Morel
	Taysote	150	2450	-	Wal	-	-	-	-	-	Shepherd	
Basha	Arandu	100	2736	single	-	30	20	15	30	Meat, butter, wool	Family	
Haramosh	Barchi	200	2036	double	Apr	50	20	15	-	-	Family	
	Dassu	300	1846	double	Apr, Cher	20	10	5	-	-	Family	Morel
	Hanuchal	250	1475	double	-	5	1	1	-	-	Family	
	Jutial	45	2044	single	-	40	10	10	-	Meat, butter, wool	Family	Morel
	Khaltaro	150	2601	single	-	50	30	5	30	Meat, butter, wool	Shepherd	Morel
Hushey	Hushey	300	3075	single	-	30	20	5	10	Meat, butter, wool	Family	
	Marzigond	75	2649	double	Apr, Wal	15	10	2	1	-	Family	
	Talis	300	2642	double	Apr, Wal	10	10	1	1	-	Family	
	Kande	200	2877	single	Wal	15	10	5	5	Meat, butter	Family	
Minapin	Minapin	140	2026	double	Wal, Apr, Cher	2	2	1	-	-	Shepherd	Morel
Jaglot	Jaglot	150	1950	double	Apr, Cher	15	5	1	-	-	Shepherd	Morel
Hopar	Hopar	600	2700	double	Wal, Apr, App, pear	20	33	3	1	Meat, butter	Shepherd	
Hispar	Hispar	200	3003	single	-	20	10	2	3	Butter, wool	Shepherd	

4.4 Conclusion

Local communities living in the Central Karakorum National Park valleys are heavily dependent on natural resources and their livelihoods were traditionally shaped over a fragile equilibrium with natural resources availability. Increase in population and change in traditional living conditions, have recently modify this equilibrium which today seems to be lost, as their use of natural resources have probably reached, in many areas, an unsustainable rate. Specifically, the possibilities to control or limit their exploitation rate for forest products and their use of grazing lands is limited if no alternative measures are being provided. However, the diffuse mismanagement and the limited knowledge in restoring degraded ecosystem leave space for mitigation measures which might partially counteract the predominant trend. Working in collaboration with the community, acknowledging first their problems and solving them with a capacity building perspective, are to be considered the only feasible options for reducing the degradation processes.

Annex 1: Questionnaire

Village name: **Date**:

Household N°:
Forest area (on the map):
Pasture area (on the map):

- **Forest commission**:   YES ☐   No ☐

- **Forest history**: Is forest area changed in the last 50/100 years? If it's so, how?

- **Forest uses**:

    - *Firewood*: amount per household per year (% from natural forest):

        Which species are collected?
        Where are the commonest harvesting area?
        Any regulation in collection of firewood?

    - *Timber*: amount per household per year (% from natural forest):

        Which species are collected?
        Where are the commonest harvesting area?
        Any regulation in collection of firewood?

    - Any regeneration problem has being recorded?
    - Cutting of green trees is accepted?   Yes ☐   No ☐

- **Pasture**

    - Where are them?
    - When are used?
    - Is grazing in the forest allowed?
    - Do they recorded damages to seedlings? If it's so, on which species?
    - Is it allowed litter collection?
    - Amount of livestock (and trend in last 10/20 years):   Sheep
                                                                        Goat

                                                                        Cattle

                                                                        Horses

                                                                        Yak

- **Non-Wood Forest Product**: Any collection of resin/mushroom/Medicinal plant?

- **Skills**:

    - Any experience with reforestation?
    - Any area available for new plantation?
    - Any experience in seed harvesting?
    - Improved cooking stove(efficient stoves): someone willing to try them?

<div align="right"># CHAPTER 5</div>

LAND-COVER OF CKNP

The methodological approach implemented involves the construction of a database on the land cover (with particular emphasis on forest cover) and land use. Successively, the results obtained will be used to assess the forest Above Ground Biomass (AGB) and increment. This objective can be achieved by processing data from the analysis of remotely sensed images and field-acquired data. The data from different sources contribute to create a knowledge system that can be used in the different stages of management of the Park: in the programming phase when they are the basis for knowledge of the environment dynamics and of the distribution of resources and during subsequent monitoring activities. In this way, it becomes mandatory to follow a replicable methodology in time and in space based on data calibrated to the ground.

The classification schema utilized in land use mapping includes the main components of the landscape:

- Vegetation features: forest, herbaceous cover, crops
- Mineral features: water, rock and soil
- Human component: villages, roads and other artifacts.

In this project it was decided to work in an integrated way in the GIS environment, acquiring information from different sources populating the geographical database.

5.1 Introduction

Land cover is defined as the layer of soil and biomass, including natural vegetation, crops and human structures that cover the land surface. Land use refers to the purposes for which humans exploit the land cover (Veldkamp and Fresco, 1996). Land cover change is the complete replacement of one cover type by another, while land use changes also include the modification of land cover types, e.g., intensification of agricultural use, without changing its

overall classification. A better understanding of land cover and land use change are essential to assess and predict its effects on ecosystem and society.

Land use and land cover are the result of many interacting processes. Each of these processes operates over a range of scales in time and in space. With the term of scale we refer to the spatial, temporal, quantitative, or analytic dimensions used by specialists to measure and study objects and processes (Gibson et al., 2000).

Scales that we use in the cartographic processes have extent and resolution. Extent refers to the magnitude of a dimension used in measuring (e.g., area covered on a map), whereas resolution refers to the precision used in this measurement (e.g., grain size). For each process important to land use and land cover mapping a range of scales may be defined over which it has significant influence on the land use pattern.

In this project the implementation of a land cover/ land use classification is focused on these goals:

- distribution of forest resources and human activities

- evaluation of the resources in quantitative terms (extent)

These objectives meet the general focus of the management of the natural resource in the park. In particular, the distribution and extent of forests inside Central Karakoram National Park is of uttermost importance since no data about forest typology, forest extent and biomass were previously available.

Remote sensing techniques have long been successfully adopted in developing land cover and vegetation maps at a local (Bayarsaikhan et al., 2009) as well as regional (Avitabile et al., 2012; Brown de Colstoun et al., 2003; Kozak et al., 2008) and global scale (Friedl et al., 2002). The ability to cover a broad spatial extent and the possibility to gather a long time series of data are two of the key features related to their success and diffusion. Since the 1970s, a wide array of sensors became available with different spatial resolutions, frequency of flight and costs of image purchasing. Similarly, many classification techniques have been developed, from vegetation indices, as NDVI (Ali et al., 2013), to classic parametric and non parametric classifiers as Maximum Likelihood or Support Vector Machines (Aguirre-Gutiérrez et al., 2012; Kahya et al., 2010; Lu, 2006; Paneque-Gálvez et al., 2013; Vanonckelen et al., 2013).

A comprehensive and synoptic overview of the Park vegetation distribution, has been considered a priority for the management and future monitoring of the Park. This study aims at: i) define vegetation landcover classes, meaningful for the Park management, ii) evaluate best methodology to obtain a spatial reliable vegetation map of the entire CKNP, iii) describe the essential land cover characteristics of the park area. Moreover, the map will serve as a basis for the development of above ground biomass and increment assessment, two key parameters to achieve sustainable forest management. Essential characteristic of the output were: i) clarity and easiness of the defined classes (i.e. to be understood and used by local communities and meaningful for managing the Park), ii) simple and robust methodology (i.e. to be easily replicable in future monitoring of vegetation cover change), iii) to form the basis for above ground biomass and increment assessment and, above all, iv) economically and temporally cost-effective.

Following this rational, and considering the difficulties related to vegetation mapping in steep mountain areas (Dorren et al., 2003; Gartzia et al., 2013; Hantson and Chuvieco, 2011; Vanonckelen et al., 2013), we evaluated which methodology performed better between a classic per-pixel classification involving the use of supervised classification algorithms (Mahalanobis Distance, Minimum Distance, Maximum Likelihood, Support Vector Machines) and a combined approach of vegetation index (NDVI), ancillary data (Dem) and supervised classification implemented through a Decision Tree. Both classifications were based on Landsat images due to their large and long lasting dataset, freely available and on field collected training datasets.

5.2 Methods

5.2.1 Vegetation classes

The land cover classes, presented in the next sub-chapter, were delineated through a consultative process with CKNP directorate and are shaped on natural vegetation belts, uses by local communities and management necessities. We opted for a classification of forest stands by density rather than by composition of species, to increase easiness of use and significance for management and to facilitate the future assessment of Park's forest above ground biomass.

5.2.2 Digital Elevation Model and its derivatives

The unavailability of topographic maps in appropriate scale has led to the use of a DEM as a source for the extraction of the necessary morphological parameters. A DEM derived from the high-spatial-resolution multispectral images of ASTER was used. The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) on NASA's Terra spacecraft collects in-track stereo using nadir- and aft looking near infrared cameras. Since 2000, these stereo pairs have been used to produce single-scene (60 x 60 km) digital elevation models having vertical (root-mean-squared-error) accuracies generally between 10 m and 25 m. The GDEM2 used in this research was acquired from http://reverb.echo.nasa.gov/reverb. This grid presents some artefacts visible as a regular grid which, in the derived maps, appear as irregular data. The minimization of this noise was resolved with the application of a neighbourhood operation, for which the final cell value is function of the values of all the cells that are in a specified neighbourhood around that cell. A kernel of 5x5 was chosen and the mean was calculated for the output pixel (Calligaris et al., 2013). These data were used to delineate the watersheds of the park on the basis of the drainage network extracted from DEM. Two kinds of pour points were used to calculate the contributing area: the confluence of rivers classified with the Strahler order and the position of the villages on the bottom of the valleys. Main and secondary valleys were defined and discussed with the local communities for the sharing of their right definition.

Moreover, the GDEM was used in order to improve the land cover classification and evaluate if additional orthorectification was needed. After a visual inspection of the mosaic image we concluded that no additional transformation was needed to match the adjacent paths. From the DEM, values of slope and aspect were derived.

5.2.3 Satellite Dataset

To cover the entire CKNP area, three Landsat 5 Thematic Mapper (TM) images with 30x30 m spatial resolution were used (Tab. 5). The images, acquired at product level 1T (radiometrically and geometrically terrain corrected) from the GLOVIS web-portal (*http://glovis.usgs.gov/*), were chosen specifically from the month of August to capture full vegetation development along all possible altitudes. The most cloud free images were selected (cloud cover < 6% with the only exception of image 148/35, only marginally used).Throughout the paper, all the analyses were performed on the 6 non-thermal bands of

the composite (three visible and three infrared). Conversion of reflective band data (Digital Number) into at-sensor reflectance was performed using the specific ENVI ® toolkit separately for the 6 bands of each Landsat image.

Table 5: The Landsat images, and their property, used for this study.

Path/Row	Acquisition Date	Data type	Cloud cover (%)	Quality	Sun elevation (°)	Sun azimuth (°)
149/035	11 August 2009	L1T	6	9	59.3	126.6
148/035	04 August 2009	L1T	5.6	9	60.8	123.5
148/036	04 August 2009	L1T	26.5	9	61.3	120.9

5.2.4 Training and Validation datasets

Three separate datasets were used to produce and evaluate the final classification: one for calibrate NDVI with vegetation classes, one as training sample for the classification algorithm and one for the validation and accuracy assessment.

NDVI Training dataset

During summer 2008 a campaign was conducted to collect 69 sampling plots from vegetated areas from Bagrote valley. The location of each point was defined according to a stratified system. To ensure vegetation presence only pixel with a NDVI > 0 were selected. We opted for round sampling plots with 20 m radius (surface area 1256 m^2) where we measured vegetation cover (visual estimate %), diameters at breast height (DBH) for every shrub/tree species present (H>1.3 m), the height of the 5 tallest individuals (with a TruPulse laser hypsometer) and coordinates of the plot centroide. Those plots were used to set the NDVI limits of each vegetation class.

Supervised classification training datasets

Training datasets were collected in various CKNP valleys in the period between April 2011 and May 2013. These, were composed by 47 georeferenced digital photographs collected with a high resolution/definition camera from favorable locations in 8 different valleys (see Brown de Colstoun et al., 2003). This is an efficient methodology to gather large number of training points from different locations in a short time period.

A first dataset, based on land cover/land use classes defined in Tab. 1, was used for the supervised classification (thereafter LC training). This was composed by a total of 1891 pixels clustered in 107 polygons, as previous studies revealed that for spatially heterogeneous

classes, box of training pixels perform better than single pixels (Chen and Stown, 2002). Each polygon was located sufficiently far away from the other to reduce spatial autocorrelation (Foody and Mathur, 2004; Vanonckelen et al., 2013). For each vegetation class, at least 210 pixels were used as training dataset as is commonly suggested to collect a number of training pixels equals to $30p$ per class where p is the number of spectral bands used (Mather and Koch, 2011).

A second dataset, for the training of the supervised classification of the Decision Tree, was developed from the same images. Instead of selecting the pixels representative of the vegetation classes, we selected pixel representative of the main vegetation species: Bare soil, Artemisia, Juniperus, Conifers, Broadleaves, Grassland (thereafter, SP training dataset).

Validation dataset

A specific validation dataset, composed by 334 ground control points gathered in 10 valleys was used to validate the final map and assess its accuracy. The points were collected on field, using a GPS device. Mean tree height of the 5 tallest trees (measured with a TruPulse hypsometer), visual estimation of vegetation cover, vegetation land cover class definition, location (X,Y), altitude and date of collection were recorded for each point.

5.2.5 Satellite data processing

The project objectives required the mapping process to be relatively simple, based on a robust methodology, cost-effective and a starting point for the future development of above ground biomass and increment estimates. Following data acquisition, images have been pre-processed through topographic correction and snow and clouds masking.

We evaluated two different classification methodologies using the two datasets previously described. The first was based on well-known and long adopted parametric (Minimum Distance, MD and Maximum Likelihood, ML) and non-parametric classification algorithms (Support Vector Machines, SVM). The second, instead, combined in a Decision Tree an NDVI-based class's identification with supervised classifications (MD, ML and SVM) and ancillary data.

Pre-processing

The Karakorum strong relief implies large variation in illumination between areas directly hit by sunlight and areas deeply shaded by orography (i.e. North exposed slopes). Topographic correction algorithms are widely adopted to reduce those effects, resulting in higher classification accuracies (Dorren et al., 2003; Hantson and Chuvieco, 2011; Teillet et al., 1982). We opted for the classic C-Correction firstly introduced by Teillet et al. (1982) because of its simplicity and its effective improvement of image quality (see Hantson and Chuvieco, 2011; Vanonckelen et al., 2013 for further details). This is a wavelength dependent correction method used to calculate new values of corrected reflectances for each pixel. The first step was to calculate the illumination angle:

$$\cos \gamma_i = \cos \theta_s \cos \eta_i + \sin \theta_s \sin \eta_i \cos(\phi_a - \phi_0)$$

Where, γ_i represents the incidence angle, θ_s the solar zenith angle, η_i slope angle, ϕ_a the solar azimuth angle and ϕ_0 the slope aspect.

New pixels values of corrected reflectances are then computed for each band:

$$\rho_{\lambda,h,i} = \rho_{\lambda,i} \left(\frac{\cos \theta_s + c_\lambda}{\cos \lambda_i + c_\lambda} \right)$$

Where $\rho_{\lambda,h,i}$ is the terrain corrected reflectance, $\rho_{\lambda,i}$ the uncorrected reflectance and c is a band dependent constant derived from the regression coefficient between illumination angle and each band reflectances:

$$c_\lambda = \left(\frac{b_\lambda}{m_\lambda} \right)$$

$$\rho_{\lambda,i} = b_\lambda + m_\lambda \cos \gamma_i$$

The corrected bands were stacked together and a mosaic of the three corrected Landsat images was created to cover the entire study area. Atmospheric correction, performed on at sensor radiance and computed through the ENVI Flaash module, was not applied because of reduced scattering over the image (i.e., high mean elevation, low air moisture and aerosols) and no improvement on classification accuracy.

The Normalize Difference Vegetation Index, calculated as $NDVI = (B4 - B3)/(B4 + B3)$, was used as an additional band to the 6 Landsat non-thermal bands to increase classification accuracies (Heinl et al., 2009).

Masking

To reduce classification errors and ease visual image analyses, clouds, snow and ice were identified and masked. For cloud identification we used Band 1 while for snow and ice we used NDSI index (Tang et al., 2013): $NDSI = (B2 - B5)/(B2 + B5)$. After visual images inspection, threshold values of 0.23 and 0.3 were respectively applied to develop a snow and cloud mask.

5.2.6 Classifications

Supervised classification

Supervised classification algorithms have long been adopted to developed land cover maps and have been widely covered in the literature (Lu and Weng, 2007). We evaluated the use of both parametric (MD, ML) and non-parametric classifiers (SVM). The former are based on statistical assumptions derived from the training dataset: all unclassified pixels are attributed to the nearest class centroid according to Euclidean distance (as in MD) or taking into consideration means and covariance (ML) (Jones and Vaughan, 2010; Mather and Koch, 2011). Non-parametric classifiers, on the contrary, are directly trained by the training sample without assuming normal distribution of data. SVM, in particular, relies on between class spectral boundary rather than class centroid values and distances and have often been found to be more accurate than parametric classifiers (Heinl et al., 2009; Otukei and Blaschke, 2010; Paneque-Gálvez et al., 2013). To train the classifier, the LC training dataset was adopted to directly detect the vegetation classes of Tab. 1.

Decision Tree

A different approach was followed for the second classification. In this case we aimed at evaluate the feasibility of using a simple vegetation index, with the additional use of ancillary data (mask and DEM), to separate the land cover classes hierarchically developed according to vegetation cover (i.e. from bare soil to close forest). NDVI (Rouse et al., 1974) has been extensively adopted to quantitatively assess vegetation density due to the simple and direct calculation process, the ability to distinguish between vegetation and soil, the proportionality

with chlorophyll content (and therefore LAI and vegetation amount) and the low sensitivity towards irradiance and other atmospheric disturbances (Jones and Vaughan, 2010; Lu, 2006). Additionally, where partially vegetated areas are diffuse, NDVI was shown to be more affected by changes in vegetation cover than by changes in canopy thickness (Solans Vila and Barbosa, 2010). One of the main limitation in the use of NDVI as a proxy for vegetation cover is its saturation at high canopy density (Kolios and Stylios, 2013). The low mean density of CKNP forests (Akbar et al., 2010; Akbar et al., 2011; Hussain et al., 2013) and the ample vegetation classes adopted in the CKNP land cover partially overcome this problem. Another limit inherent the use of a vegetation index is that NDVI alone does not differentiate between various types of land cover classes. For our purposes, instead, it was necessary to separate the signal of dense vegetation as grassland, agriculture and close forests classes. We used a mix of supervised classification and ancillary data to separate those classes: an altitudinal limit, based on field observations and data from the literature (Du, 1998; Eberhardt et al., 2007; Miehe and Miehe, 1998), was used to set a treeline elevation. Pixels with high NDVI values lying above 4000 m a.s.l. were automatically classified as grassland. The actual treeline of close and open forests in CKNP is located at 3800/3900 m a.s.l.. We set higher altitudinal limit to allow some resolution errors in between the GDEM and the satellite images. Additionally, we performed a supervised classification with the algorithms (MD, ML and SVM) trained on the species training dataset. This was used to extract grasslands and agriculture pixels lying at lower elevation (<4000 m). However, spectral differences between grassland and agriculture areas are often scarce (i.e. due to the similarity of vegetation growth form and density) making class detection difficult and reducing final accuracy (Heinl et al., 2009). We therefore developed an agriculture mask to identify and separate agriculture class.

In CKNP area, fields are mainly located at low elevation along valleys bottom, surrounded by bare soil. Grasslands, on the contrary, are located above tree line (>4000 m a.s.l.) or in between patches of forests (Du, 1998). This spatial difference makes the recognition of agriculture areas relatively simple. The mask was based on the 3000 m contour line, manually modified on a GIS using a FCC image of the terrain corrected Landsat images. The final classification was developed through a decision tree (Fig.2). NDVI value thresholds were set to distinguish bare soil/scattered vegetation/sparse vegetation/open forest/close forest classes while the supervised classification image and the agriculture mask, were used to extract, and then separate, agriculture and grassland classes.

5.2.7 Validation & Accuracy assessment

The specific validation dataset was used to evaluate the maps accuracy. We performed error matrix to obtain overall accuracy, producer's and user's accuracies, and K coefficient of agreement (total and per class) through a specific R package (Rossiter, 2004).

5.2.8 Vegetation pattern analyses

Distribution patterns of land cover classes were further evaluated using Standard Deviation Ellipses through ArcGis ® Spatial Statistics package. This is an efficient methodology to visually assess the spatial trends of land cover within the study area by looking at the ellipse centered in the mean geographical center of each class distribution. Standard distances, separating the classes areas from the mean center for both the x and y directions are computed and are used to define the length of the two ellipse's axes (Lefever, 1926). We adopted one standard deviation ellipse which includes approximately 68% of the total pixels classified in that particular land cover class. Finally, we evaluated the results of each species distribution according to elevation and aspect using the Aster DEM.

5.3 Results

5.3.1 Land-cover classes definition

The number of classes and their definitions is a tradeoff between the need to precisely assess ecosystems distribution inside the Park borders and the limits imposed by the satellite images classification procedure. Additionally, being the land-cover mapping an important management tool for Park staff, clarity and reduced redundancy are essential characteristic. Therefore, 8 classes have been developed, enough general to encompass a wide variety of similar environments and enough different each other to simplify their recognition and maximize their management usefulness (Tab. 6).

The classes are: Bare soil, scattered vegetation, sparse trees, open forest, closed forest, grassland, agriculture and snow-ice.

Table 6: Land cover classes identified for the Central Karakorum National Park, their definition and the main species present.

Class	Definition	Main Species
Bare soil	Nude soil, bare rock, debris covered by isolated plants	*Capparis, Ephedra, Cardus*
Scattered vegetation	Scattered and fragmented *chamaephytes* vegetation.	*Artemisia, Juniperus*
Sparse trees	Tall shrubs or single trees. C.c. < 10% and height < 5 m.	*Juniperus, Rosa, Artemisia*
Open forest	Partially forested. 10% < C.c. < 50%. 5m < mean height < 15m	*Juniperus, Pinus, Picea, Salix*
Close forest	Dense forests. C.c. > 50 %. Mean height > 15m	*Jun., Picea, Pinus, Betula, Salix*
Agriculture	Fields/orchards/plantations/villages.	*Populus, Salix,* crops
Grassland	Dense grassland & meadows	*Carex, Poa*
Snow & Ice	Snow covered land/ice	

Each class has been coupled to specific spectral values. Additionally, the classes composed by vegetation are matched to on-field measurable parameters: the ground vegetation cover (for bare soil/scattered vegetation/sparse vegetation/open forest/close forest) and the mean heights of tallest trees (for sparse trees/open forest and close forest). Specifically, mean heights of trees was used to distinguish, with precise and rapid analyses, the different classes representing arboreal vegetation.

Vegetation cover

The vegetation cover is defined as the ratio between the horizontal projection of trees/shrubs canopy on the soil and the total soil surface, in percent (Tab. 2). The green dots represent the area occupied by the plant canopy while the larger black circle is the surface of the study area. The vegetation cover therefore is given by the ratio between green and white.

Mean height of tallest trees

As mean height of tallest trees we intend the mean heights of the 4-5 tallest trees, if present, on the area.

Bare soil

A class representing predominantly unvegetated surfaces (bare rock, nude soil), or surfaces with reduced vegetation cover in the form of single, isolated plants normally of xeric species as *Capparis*, *Ephedra* or *Cardus*. Also glacial masses covered by debris (rocks) are indicated as bare soil (Fig. 9).

Fig. 9: Steep slopes, scarcely vegetated, are represented by Bare soil class. (Hispar valley)

Scattered vegetation

A class composed mainly by herbaceous/shrub *Chamaephytes,* of which *Artemisia* shrubs are the most common. Few isolated scattered Junipers or others shrub/trees might be present (Fig. 10).

Fig. 10: Artemisia shrubs are covering large section of the CKNP, forming the Scattered vegetation community.

(Bagrote valley)

Sparse trees

It's a class with a reduced tree canopy cover (<10%) which therefore cannot be classified as a forest according to FAO standards. The tree individuals present are sparse and small (less

than 5 meters high). Usually Junipers are the dominant tree species, together with *Rosaceae* and *Artemisia* in the shrub/herbaceous layer respectively (Fig. 11)

.
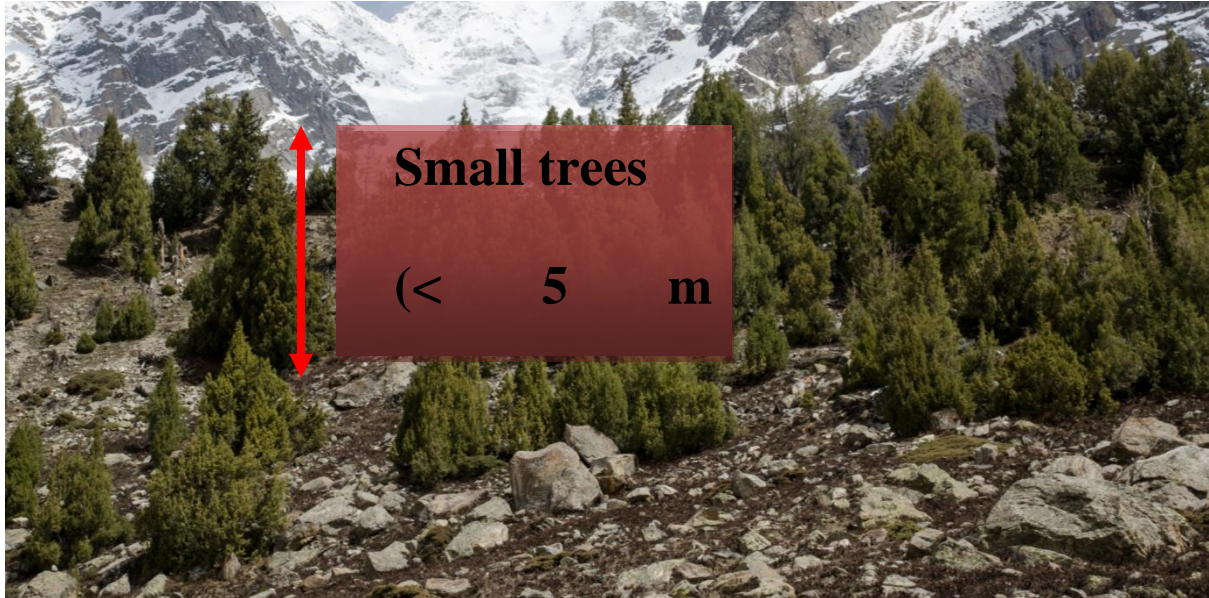
Fig. 11: Sparse trees class. *Juniperus turkestanica,* in this case, is not forming a forest (according to FAO standard).

(Astak valley)

Open Forest

It's the first vegetation class which can be classified as forest according to FAO standards. The vegetation cover is between 10 and 50% and the mean height of tallest trees is between 5 and 15 meters.

Usually, open forests are the result of long lasting degradation of previously closed forest or forest growing on poor, rocky or dry soils. In this category are included the forest which should actively be managed and in which once degradation drivers are reduced, reforestation is suggested. The species composition of this class can be various, from degraded spruce (*Picea smithiana*) and Pine (*Pinus wallichiana*) to dense Juniperus woodland (Fig. 12).

Fig. 12: Open forest class, in this case as a result of large forest degradation (Jaglot valley).

Close forest

It's the land-cover class including the most productive forests. The vegetation cover is above 50% and the mean height of tallest trees it's above 15 meters.

The sustainable forest management will be applied mostly to this category. Usually this class is composed by dense forests of spruce (Picea smithiana), pine (Pinus wallichiana) and/or birch (Betula utilis). Most of the CKNP increment and biomass is found within this class.

Fig. 13: Close forest of Birch (*Betula utilis*) and spruce (*Picea smithiana*), Bagrote valley.

Grassland

The class representing most productive pastureland, usually located in between 4000 m and 5500 m a.s.l.., grassland can be found also in between patches of forest. The vast alpine grasslands of CKNP are mainly composed by *Poa* and *Carex* species (Du, 1998). The abundant winter snowfall covers them from mid-October until June. Transhumance of local livestock population to this high-altitude area is a common practice all over the study area during the summer months (Fig. 14).

Fig. 14: Grassland. (Hispar valley)

Agriculture

Agriculture areas, in the forms of fields, orchards or poplar/willow plantations are common along the valley floor up to an elevation of 3000 m a.s.l..The vast majority of those are irrigated through water channel since precipitation are scarce, especially during summer months (Fig. 15).

Fig. 15: Marzigond village, lower Hushey valley.

Snow – Ice

Glacial masses and snow covered surfaces are covering large sections of CKNP. Only "white" glacier without surface debris are classified as snow-ice.

Fig. 16: Barpu glacier, Hopar valley.

5.3.2 Land cover of the Central Karakorum National Park

For the development of the CKNP landcover map, two methodologies were tested and compared. The first one is based on supervised classification algorithms. Those have long been adopted to developed land cover maps and have been widely covered in the literature (Lu and Weng, 2007). We evaluated the use of both parametric (MD, ML) and non-

parametric classifiers (SVM). A different approach was followed for the second classification. In this case we aimed at evaluate the feasibility of using a simple vegetation index, with the additional use of ancillary data (mask and DEM) to separate the land cover classes hierarchically developed according to vegetation cover (i.e. from bare soil to close forest) through a decision tree.

5.3.3 Accuracy assessment

Six land cover maps of the CKNP area were obtained. Three using supervised classification alone (one for each algorithm, MD, ML and SVM) and three using the Decision Tree (one per algorithm, MD, ML and SVM). Supervised classifications resulted in low to very low levels of overall accuracies (between 57.58% in SVM and 48.18% in MD) and kappa statistic (0.505 and 0.3992) (Tab. 7).

Table 7: Overall accuracy and Kappa statistic for: a) Supervised classification with LC dataset (MD: Minimum Distance, ML: Maximum Likelihood, SVM: Support Vector Machine) b) Decision Tree with species dataset (MD: Minimum Distance, ML: Maximum Likelihood, SVM: Support Vector Machine)

	Supervised classification			Decision Tree		
Method	MD	ML	SVM	MD	ML	SVM
Overall accuracy	48.18%	57.27%	57.58%	80.24%	79.04%	76.65%
Kappa statistic	0.3992	0.504	0.505	0.7691	0.755	0.7277

Extremely low levels of producer's and user's accuracies were recorded for grassland (0.33) and agriculture (0.193) classes and grassland (0.294) and open forest (0.375) classes, respectively, in MD; in grassland (0.289) and agriculture (0.386) and grassland (0.25) and open forest (0.469) classes respectively in ML; and in agriculture (0.15) and bare soil (0.56) and grassland (0.337) and open forest (0.58) classes in SVM.

The combined use through the decision tree of NDVI index and supervised classification with species training dataset, on the contrary, resulted in acceptable level of accuracies (between 80.24% in MD and 78.24% in SVM) and kappa statistic (0.7691 and 0.7517, respectively, for MD and SVM). Open forest resulted the class with the lowest producer's and user's accuracies (0.7 and 0.65) in MD, grassland (0.66) and open forest (0.64), respectively, in ML and open forest (0.65) and grassland (0.62), in SVM. Agriculture class shows the highest proportional increase in classification accuracies compared to classic supervised classification both for producer's and user's accuracies (0.87 and 0.92 in MD). Similar results have been obtained for the extremes classes, bare soil and close forest, with

producer's and user's accuracies close to or above 0.90. Acceptable accuracies were obtained also for the intermediate classes, as scattered vegetation/sparse vegetation classes (0.72 and 0.75, respectively in MD). Further analyses are based on the MD decision tree land cover since it provided the highest accuracy also after visual inspections by experts of the area (the entire landcover map of the CKNP is available in Annex 2).

5.3.4 Land cover characteristic of the study area

The land cover map developed for the Central Karakorum National Park revealed important information regarding vegetation distribution inside the study area. Grasslands cover the 11% (1350 km^2) of the total surface (11862 km^2), followed by scattered vegetation (7.9%) and sparse vegetation (4.2%). Open and close forests represent the 2.6% and 2% respectively (310 and 230 km^2), while agriculture the 1.2%. Un-vegetated surfaces are the large majority, 70.6%, with 16.3% of the area being bare rock and 54.3% covered by snow or ice. Large differences are evident between the different valleys (Tab. 8), both in grassland and forest cover.

Table 8: Land cover (in % of total valley area) for the different valley and total valley surface (in ha). (AG: agriculture, GR: grassland, SV: scattered vegetation, SP: sparse vegetation, OF: Open forest, CF: Close forest, SN: Snow and Ice, BR: bare rock).

Valley	AG	GR	SV	SP	OF	CF	SN	BR	TOT
Astak	0.7	14.5	5.5	3.7	5.7	4.5	45.5	19.9	26948.64
Bagrote	3.0	16.3	8.6	8.0	7.8	9.1	28.1	19.1	43245.7
Baltoro	0.0	1.6	5.2	0.1	0.0	0.0	78.7	14.5	170940.5
Basha	1.7	14.2	6.4	5.8	4.0	2.0	46.3	19.5	166826.7
Biafo	0.0	4.9	3.6	0.4	0.2	0.1	74.6	16.2	82837.37
Braldu	2.0	16.8	14.8	10.0	3.5	1.6	37.7	13.7	106888.1
Danyore	1.0	15.3	9.5	8.8	8.1	8.8	32.9	15.6	11609.64
Dumordo	0.0	5.4	6.2	0.9	0.2	0.0	74.2	13.1	84726.04
Haramosh	2.1	19.1	6.7	6.7	6.8	12.9	29.5	16.1	48623.05
HIsper	0.1	6.3	7.3	1.9	0.5	0.1	62.6	21.1	130567.4
Hoper	1.9	10.4	6.7	5.4	2.9	1.7	47.9	23.0	42585.02
Hushey	0.4	10.8	8.6	3.7	1.2	0.1	64.2	11.0	103918.8
Jutal/Jaglot	0.9	12.2	12.7	9.6	7.7	6.4	32.6	17.9	10168.2
Kharku	0.0	28.3	24.1	1.2	0.1	0.0	38.3	8.0	4987.26
Minapin	8.8	10.6	9.9	9.9	5.7	5.0	24.8	25.4	37383.84
Shengus	0.2	20.3	8.8	5.2	6.7	4.4	44.1	10.3	13390.11
Shigar	0.1	23.7	15.1	5.1	2.3	1.4	34.8	17.5	38884.37
Thalley	2.6	24.4	12.6	6.3	4.6	0.5	42.5	6.5	39524.31
Tormik	3.2	36.1	5.5	6.5	7.6	4.4	24.8	11.8	22099.41

In general, surface covered by vegetation is lower in the valleys lying north of the main Karakorum ridge. In example (Fig. 17), Hispar valley, located in the Northern area of the Park, have 16% of the total valley area covered by vegetation (7.35% scattered vegetation, 6% grassland, 0.64% for open and close forest) while in Haramosh valley, located in the more humid south-west area, vegetation cover is 52% (19% grasslands, 13% close forest, 6.8% open forests, 6.7% for both scattered and sparse vegetation).
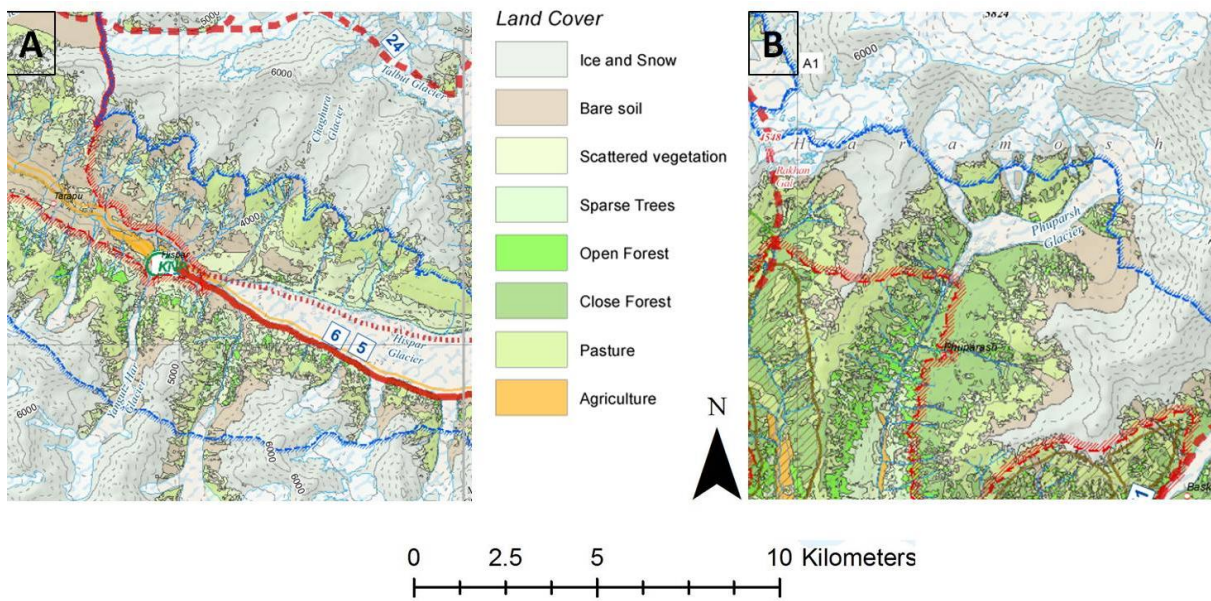
Fig. 17: Example of land cover map for A) Hispar valley (North of Karakorum main ridge) and B) Haramosh valley (South West of Karakorum main ridge). The two valleys are separated by less than 10 km large mountain ridge, however, their land cover appear very different.

We further evaluated class distribution with directional distribution ellipsoids. Through this technique, the overall pattern of classes distribution can be summarized (Fig. 18). Classes representing less or unvegetated land covers, as bare soil and scattered vegetation, show a central, balanced distribution. Specifically, bare rock is the northernmost ellipse, while scattered vegetation the easternmost. Sparse vegetation ellipse, instead, is more Southerly and Westerly located even if maintaining an overall balanced distribution. Open forest and mostly close forest, on the contrary, are heavily squeezed on the South - West portion of the Park and the Y axis is much shorter compared to other classes, denoting a comparably lower penetration of those two land cover types inside the Park northern areas. Finally, grassland class is again more centrally located and more balanced, denoting a wider and equal distribution within all Park valleys.
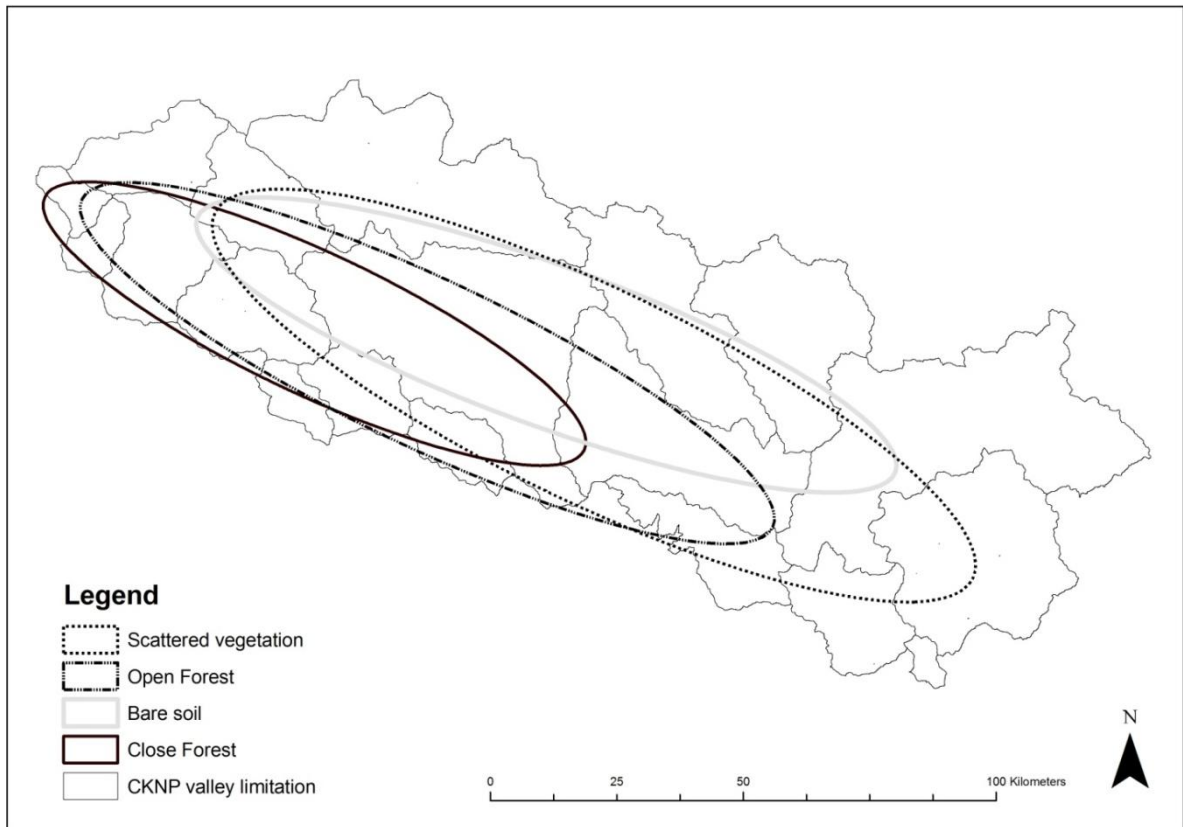
Fig. 18: Directional distribution ellipses for Bare soil (grey line), Scattered vegetation (dots), Open forest (Dots and lines), Close forest (thick black line) in CKNP. One st.dev ellipse..

The results of the MD classification, used for the DT, allowed us to evaluate how the three main forest categories (Juniperus, Conifers and High altitude Broadleaves) in the Open and Close Forest classes are distributed within Park valleys (Tab. 9) and along altitudinal and exposition gradients (Fig. 19 and Fig. 20). Conifer forests are relatively abundant in the Western valley, south of the main Karakorum ridge around the Rakaposhi massif. Haramosh (26.9%), Danyore (20.9%) and Bagrote (14.9%) are the richest valley in terms of conifer forests (Picea smithiana and Pinus wallichiana). On the contrary, in Baltoro/Dumordo/Hushey and Kharku valley, located in the Eastern area, conifers are absent. Broadleaves species distributions show similar trends even if less pronounced: Haramosh (18.7%) and Minapin (16.8%) are the valley with the highest proportion compared to Baltoro/Hushey (2.6%) and Thalley (2.4%) having the lowest. Even if less abundant, both Betula utilis and Salix spp are diffuse in all the CKNP valleys.

Table 9: Species composition (in percentage of total open and close forest class) in the different CKNP valleys.

Valley	Broadleaves	Conifers	Junipers
Astak	13.8	5.7	80.5
Bagrote	11.1	14.9	74.1
Baltoro	0.5	0.0	99.5
Basha	13.0	4.9	82.1
Biafo	11.5	5.1	83.3
Braldu	11.2	5.3	83.5
Danyore	11.2	20.9	67.9
Dumordo	2.4	0.1	97.5
Haramosh	18.7	26.9	54.4
HIsper	5.1	3.1	91.8
Hoper	8.9	5.7	85.3
Hushey	2.6	0.1	97.3
Jutal/Jaglot	10.5	12.8	76.7
Kharku	6.4	0.0	93.6
Minapin	16.8	11.9	71.3
Shengus	10.9	11.6	77.5
Shigar	6.1	8.8	85.1
Thalley	2.4	4.5	93.0
Tormik	15.1	7.2	77.6

Regarding altitudinal and aspect distribution, the results of the analyses highlight the different ecological needs of each species: birch and other high altitude broadleaves are mainly located on North and North East exposed slopes, in a narrow altitudinal range (3300-3900 m a.s.l.).
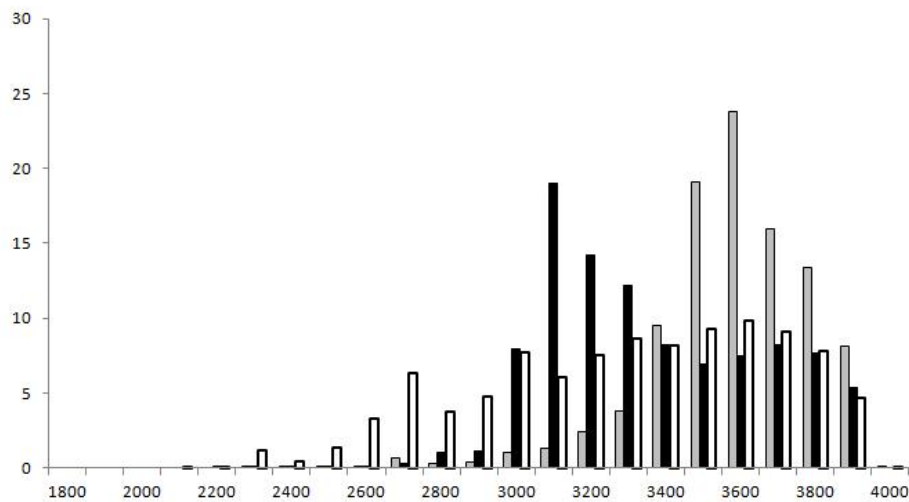
Fig. 19: Altitudinal distribution (m a.s.l.) for the main forest types (relative percentage). Full black bars: conifers, grey bars: broadleaves, white bars: Junipers).

Conifers, are widespread on North and West slopes in between 3000 and 3900 m a.s.l.. Junipers are less influenced by slope orientation and similarly, show the highest plasticity, with a very broad altitudinal range (2800 m a.s.l. – 3900 m a.s.l.).
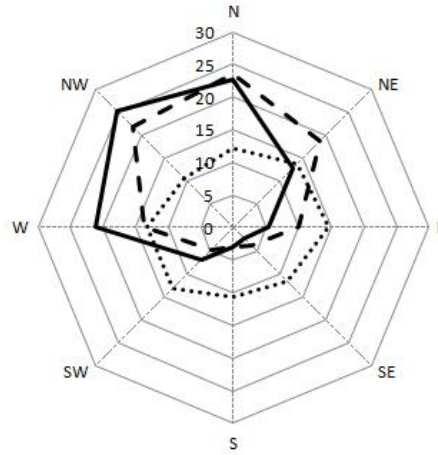
Fig. 20: Topographic distribution (relative percentage) for the main forest types. Full line: conifers, broken line: broadleaves, dotted: Junipers).

5.4 Discussion & conclusion

5.4.1 Accuracy and methodology

The combined classification, implemented through a decision tree, gave an acceptable overall accuracy through a relatively simple and straightforward methodology. The accuracy is comparable to other land cover/land use studies in similar rough mountain areas (Heinl et al., 2009; Munsi et al., 2012; Vanonckelen et al., 2013). The use of hybrid or combined approaches compared to standard classification techniques, were previously reported to be more effective: a mixture of pixel and object based classifications (Aguirre-Gutiérrez et al., 2012) and of supervised and unsupervised classifications (Bakr et al., 2010) offered indeed higher accuracy and reliability. However, combining NDVI and supervised classification was not previously tested. Even though some limitations in its use exist, NDVI can be a simple, efficient and effective index in classifying vegetation cover. Its applicability has been long recognized: as an ancillary data in addition to the standard Landsat bands, it proved to enhance class separability and increase overall classification accuracy (Gartzia et al., 2013; Heinl et al., 2009). Moreover, its direct use as a classifier provided evidence of its relationship to biomass and vegetation cover, producing accurate mapping of vegetation gradients (Ali et al., 2013; Kolios and Stylios, 2013; Solans Vila and Barbosa, 2010; Wang et

al., 2009). According to our results, NDVI can be profitably used as a classifier, especially in dry environments where land cover/land use classes can be differentiated according to vegetation cover. In those conditions, NDVI proved to be more reliable than standards classifications. This is consequence of the difficulties of those algorithms to correctly classify geologically different bare rocks/soils in classes where soil background has a large effect. Taking advantage of NDVI ability to distinguish between vegetated and unvegetated areas can increase considerably land cover accuracy. With the combined use of supervised classification to detect different types of vegetation, moreover, even the limitation imposed by NDVI saturation and its inability to spectrally distinguish different vegetation types (Jones and Vaughan, 2010; Mather and Koch, 2011) can be overcome. The results obtained demonstrate that this is a feasible and robust approach. Some general suggestions before its use shall be noted: first, selection of good quality satellite images with reduced cloud and haze cover is critical to avoid interference with NDVI calculation even if this index is more stable than standard classification algorithm alone (Jones and Vaughan, 2010; Kozak et al., 2008). Secondly, knowledge of study area's flora ecology is an essential precondition to ensure the capture of full vegetation development at all altitudes. In mountain areas as CKNP, there might be large differences in seasonality of vegetation growth at different elevations. This might lead to classification errors and, therefore, reduce final accuracy in the case leaf development, and therefore chlorophyll content, is not complete (i.e. WWF (2009) land cover/land use map missing broadleaves forests or, as in Bakr (2010), fallow fields classified as un-vegetated). Thirdly, knowledge of the area is necessary for the development of meaningful land cover classes hierarchically defined according to vegetation cover gradients.

5.4.2 Land cover characteristic

The land cover/land use map developed for CKNP represents a valuable source of information, both for scientists as well as Park managers. It revealed unequally distributed environmental resources among the different Park valleys. Vegetation cover follows a clear longitudinal as well as latitudinal gradient: Western valleys are richer in forests and sparse trees classes compared to the valleys lying in the Eastern sector, where scattered vegetation and bare rock are dominant. Additionally, forest cover is scarce to absent north of the main Karakorum ridge. This distributional pattern is probably consequence of a parallel trend in precipitation in which Western valleys are marginally influenced by summer monsoon and Westerly dominated low pressures (Treydte et al., 2006) contrary to the Eastern Park area

which, hidden by the high ridges of Himalayan range (Nanga Parbat massif), are in a rain shadow zone.

The distribution patterns observed for single species gives insights about their ecological needs. Conifers and high altitude broadleaves in open and close forest classes, revealed clear altitudinal as well as topographical trends depicted in other land cover studies from central Asian countries (i.e. Mongolia, Bayarsaikhan et al., 2009; Indian Himalaya, Sharma et al., 2010). The most water exigent species (i.e. Birch) are mainly located on North or East exposed slopes and at high elevation, where late season snow melting represents an important additional water reservoir during growing season. Pinaceae are following a similar pattern, contrary to Junipers which are exhibiting typical character of frugal species as the broad altitudinal and topographical distribution suggest. The altitudinal distribution of those forest classes confirms previous findings from the area (Du, 1998; Miehe and Miehe, 1998).

5.4.3 Consequence for Park management

The vegetation map produced provides the Park managers with valuable data to develop management guidelines. The results clearly suggest that rather than general indications valid for the whole Park, valley based management approach should be promoted. The establishment of plantations, often recommended by many governmental and non-governmental organizations, as a measure to reduce pressure on natural forests, shall be prioritized according to per valley forest availability, starting from those who revealed a chronic lack/degradation of wood resources. The distribution of natural forest trees, additionally, suggests to carefully plan reforestation and enriching seeding according to the elevation and exposition revealed in this study.

Pakistan faces several problems related to natural resource management, among which over-exploitation and degradation of forests is one of the main issue (UN, 2012). UN estimates suggest that the yearly costs related to environmental degradation account for nearly three per cent of country GDP. Vulnerable populations, living in the valleys of CKNP, might benefit from improved sustainable environmental management practices, including livestock and forest management.

CHAPTER 6

LYING THE FUNDATION FOR SUSTAINABLE FOREST MANAGEMENT IN THE REMOTE VALLEYS OF THE CENTRAL KARAKORUM NATIONAL PARK

6.1 Introduction

Pakistan is a country with scarce forest cover, a large and increasing population and the highest deforestation rate in Asia (FAO, 2010). Scattered forests, mainly concentrated in its northern mountain ranges, Himalaya, Karakorum and Hindu Kush, are increasingly disappearing due to direct and indirect drivers among which firewood consumptions (Nüsser, 2000), high harvesting rates and mismanagement (Ali et al., 2005; Ali et al., 2006), reclamation of forest land for agriculture (Qasim et al., 2011). This is resulting in large emission of greenhouse gases, major threat for biodiversity and scarce resilience of poor local communities, heavily relying on them (Busch et al., 2011; Shahbaz et al., 2007; van der Werf et al., 2009). To reduce those adverse human effects, sustainable forest management (SFM) has long been recognized as one of the key priority (FAO, 2012; UN, 1992a; UN, 1992b). Many definitions of SFM have been proposed based on broad concepts involving social economical and environmental issues (Angelstam et al., 2004; Kennedy et al., 2001). However, from a simplistic and strictly management oriented point of view, SFM can be summarized as the need to ensure that, over a certain area and in a defined time frame, wood felling are not overtopping forest yield (Davis et al., 2001; Irland, 2010). This, together with rational management practices, would ensure the long-term retention of forest stock, without further reductions in the total amount of wood. In Pakistan northern mountain ranges, however, lack of forest inventories (Gohar, 2002) make the precise assessment of forest biomass (AGB) and current annual increment (CAI) particularly difficult. This is especially

true in remote locations, where large scale on-ground inventories are time-consuming and considerably expensive. Thus, remote sensing can be considered the only cost-effective and appropriate methodology to obtain spatially explicit and comprehensive information about these two important biophysical forest parameters (Ji et al., 2012; Langner et al., 2012; Lu, 2006). The use of satellite images for AGB estimate has received increasing attentions in the last decades, especially to evaluate forest carbon stock and its fluxes as a consequence of recently developed REDD schemes and a wide array of methodologies have been developed (Avitabile et al., 2012; Dong et al., 2003). Mapping of forest stock, even over large areas, can today be considered reliable if appropriate techniques are developed (Goetz et al., 2009). This study focuses on the Central Karakorum National Park (CKNP), Gilgit – Baltistan Province, Pakistan, a protected area created in 1994 for the protection of valuable communities of animals and plants. Here, the development of a SFM is considered a priority, in an area where local communities are heavily dependent on woody biomass for construction (bridges, houses) and energy (cooking, heating) purposes (IUCN, 2003c; IUCN, 2009) and where forest degradation is mainly consequence of mismanagement and increased firewood demand (Ali et al., 2005; Schickhoff, 1998). Additionally, at the moment, there are no feasible alternative for those living around the Park borders to uncouple their livelihood from forest products, particularly firewood (Khan and Khan, 2009). Conservation of forests, therefore, can only be met through a management as respectful of local communities living needs as of forest reproductive capacity.

This study aims to provide forest managers working in remote mountain areas with scarce a priori information a methodological framework for the promotion of SFM. In particular, we aimed at gather information about the basic parameters needed to define appropriate management guidelines and to prioritize interventions (i.e. efficient wood-stoves and specific plantation) in the most forest deficient areas. To reach the objective we divided our study in two main investigations: i) assessment of forest biomass and yield through remote sensing and field data and ii) assessment of local communities wood needs. The comparison of those data will reveal how to better iii) prioritize intervention at a village level. Indeed, large differences exists regarding forest resources availability and uses among valleys and between villages as previous studies called for village based approaches (Shahbaz et al., 2011). The work presents the results from case study villages located in 9 valleys of the Central Karakorum National Park.

6.2 Study area

The study area is located in the Central Karakorum National Park, Gilgit-Baltistan province, Pakistan (75°43'16.255"E 35°51'4.439"N) (Fig.21). This is an entirely mountainous protected area of 10.000 km2 which includes the highest peaks of the Karakorum range (K2, 8611 m a.s.l.) and several among the longest glacier of the world. Climate is cold, dry continental, typical of Central Asian mountain ranges as Indian Summer Monsoon is only marginally influencing Park south western valleys. Forests, mainly composed by Junipers (*Juniperus semiglobosa*, *Juniperus excelsa* sub. *oxycedrus*, *Juniperus turkestanica*), *Pinus wallichiana*, *Picea smithiana* and *Betula utilis* species, are scattered, clearly distributed along altitudinal as well as orographical gradients.
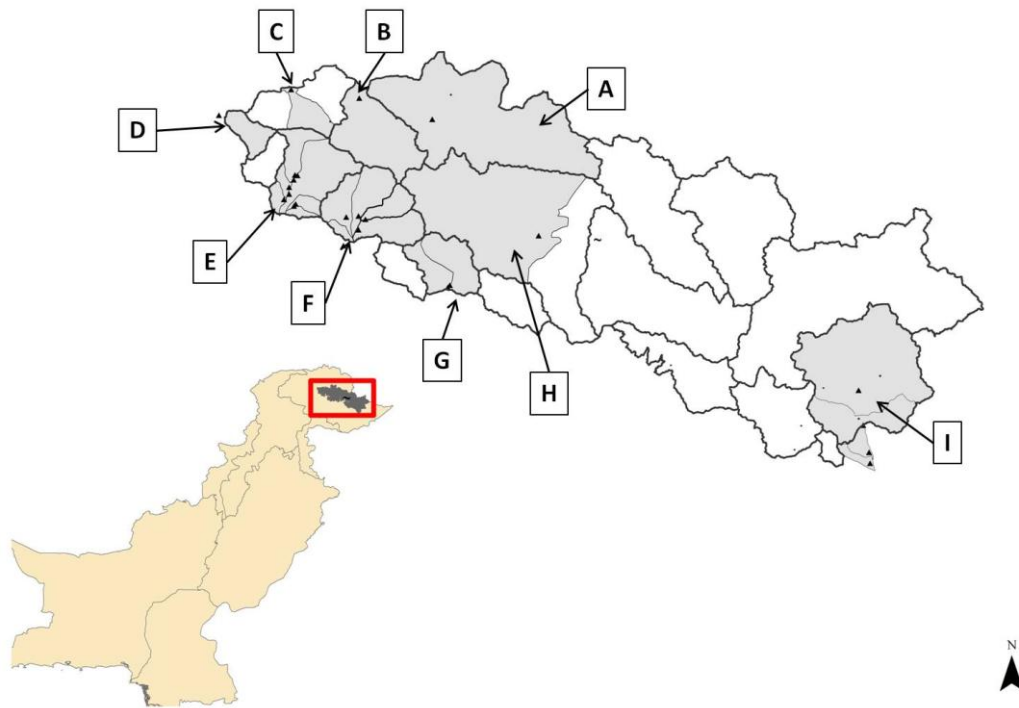
Fig. 21: Central Karakorum National Park location in Pakistan and valley and villages surveyed (grey area and dots represent case studies valley (and villages), respectively): A) Hispar (Hispar village), B) Hopar (Hopar village), C) Minapin (Minapin village),) Jaglot (Jaglot village), E) Bagrote (Sinaker, Hopey, Datuchi, Farfoo, Chirah, Bulchi, Taysote and Bilchar, F) Haramosh (Hanuchal, Dassi, Barchi, Jutial, Khaltaro), G) Astak (Astak E, Astak O), H) Basha (Arandu), I) Hushey (Marzigond, Talis, Kande, Hushey).

Generally, their cover increases moving east to west and north to south. Within the Park area, forest covers a total of 545 km2 whereas around 500 km2 are covered by sparse trees (usually Junipers). Approximately 100.000 inhabitants are living along the Park valleys. Those are mostly self-sufficient farmers relying on locally produced agriculture products and sheep/goat breeding. They are heavily dependent on wood for fire (cooking, heating) and

construction purposes. Access rights, rules and uses of natural resources, mainly forests and pastures, are typically managed by the Tsarmas/Jirga at village-level. Those are the traditional council of elders (in Baltistan and Gilgit area, respectively) which are also holding the knowledge of the area (borders, property rights etc).

Due to the difficulties of covering the whole Park large area, we opted for selecting case study villages as most representative as possible of Park environmental and social variability. We therefore chose 24 villages from 9 valleys located in each of the four districts interested by Park presence (Nagar, Gilgit, Skardu, Ganche) (Fig. 21).

6.3 Methodological framework and dataset

Fig.22 presents the logic of the intervention. A first investigation was organized to assess forest resources availability.
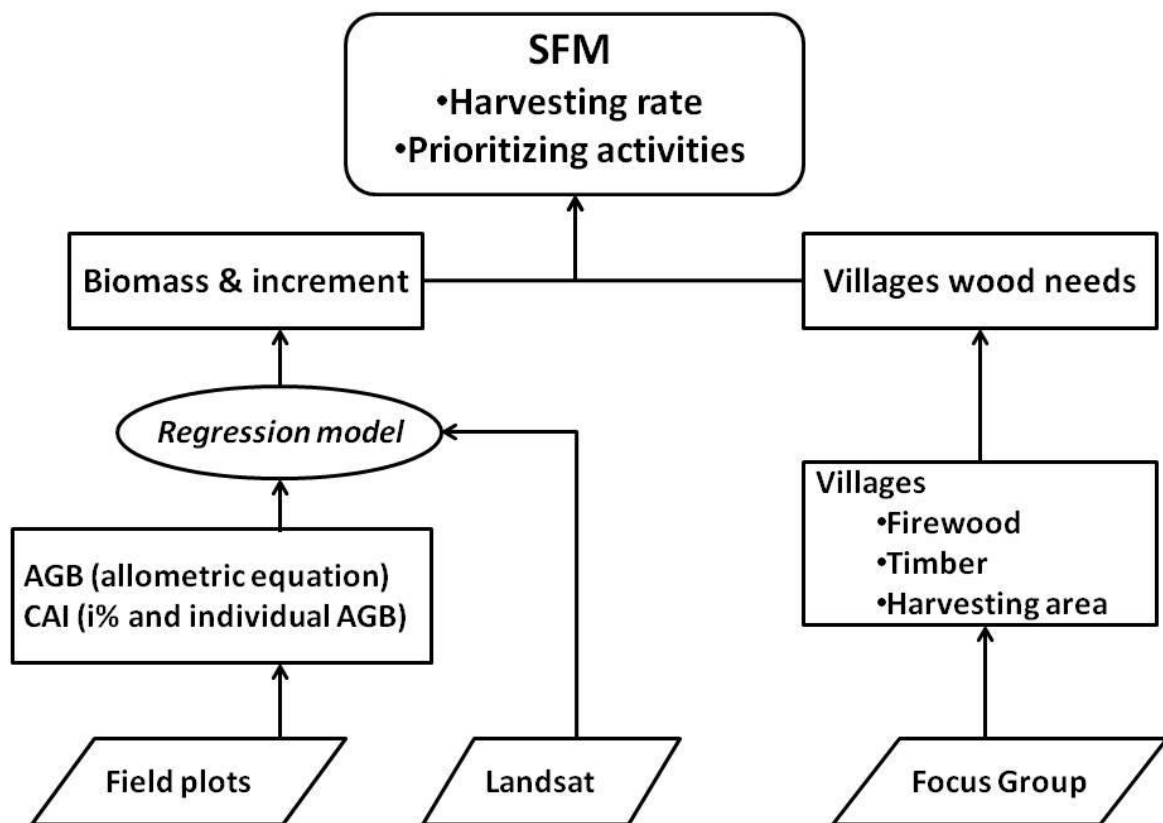

Fig. 22: Logical framework of the study.

Field plot data (DBH, increment) and allometric equations were used to assess plots AGB.

Those were related, through regression models, to Landsat images derived spectral values. After best model selection and validation, we predicted AGB values in un-sampled locations. Subsequently, plot CAI was related to plot AGB through regression and this relation was used to estimate the total CAI of village's forests.

The second investigation aimed at assessing the needs of rural communities in terms of firewood and timber and to define each village use-rights area. Simultaneously this was a precious occasion to raise community awareness and capabilities regarding forest management. For this purpose we organized focus group interviews with the representatives of each village.

6.3.1 Field plots of AGB and CAI measurements

A field campaign was undertaken during summer 2008 in Bagrote valley to examine the relations between remotely sensed data and AGB. The sampling plots location was defined according to stratified system on areas with NDVI > 0 to ensure vegetation presence. A randomly selected sub-sample of 80 plots of 1256 m^2 each (r=20 m) was arranged. Those were located in homogeneous areas (i.e. distant from edges or borders) to reduce errors and disturbances. In each plot we measured: coordinates of plot centroide with GPS, orientation/slope/elevation, specie and DBH of all trees with H>1.3 meters and for one tree every three the height and a 1 cm long increment core. Only plots with trees cover were retained (58 out of 80).

6.3.2 Satellite data

To cover the Park area, three Landsat 5 TM images with a 30x30 m spatial resolution were obtained from the Earth Explorer portal at product level 1T (WRS path: 149-035;148-035 and 148-036). We acquired the most cloud-free images, as closest as possible to field campaign dates, collected in summer months to capture full vegetation development at all elevation ranges. The three images used are all dating from August 2009. Raw digital numbers (DN) of the 6 non thermal bands of the composite were converted to at-sensor reflectance. A DEM derived from the high-spatial-resolution multispectral images of ASTER (GDEM2) was used to correct satellite images for topographic effect using the C-correction algorithm (Teillet et al., 1982). Snow and cloud were masked using NDSI and B1 threshold values empirically set after visual inspection of images composite. We classify the images in vegetation classes by

implementing, in a decision tree, NDVI limits and minimum distance classification as described in Chapter 5. Finally, all the classes uncovered by trees were masked to retain pixels from *sparse trees*, *open forest* and *close forest* classes only. PCA was performed on bands reflectance (1-5, 7) to derive a set of new, uncorrelated variables as it is well known that some of the Landsat bands shows high multicollinearity, resulting in redundancy of information which might affect regression models (Jones and Vaughan, 2010). NDVI (Rouse et al., 1974), additionally, was computed and used thanks to its proportionality with vegetation amount (Dong et al., 2003; Jones and Vaughan, 2010; Lu, 2006) and because local forests low biomass (Akbar et al., 2010; Akbar et al., 2011; Hussain et al., 2013) reduce the risk of saturation which has often been reported at high AGB levels (Anaya et al., 2009; Santin-Janin et al., 2009; Soenen et al., 2010).

6.4 Methods

6.4.1 Plot AGB and CAI assessment

We derived the diameter distribution and species composition of all the sampling plots. Single tree AGB was calculated through allometric equations. As no specie-specific equations exist for the local trees we derived them from the literature, selecting species from the same genus, growing in mountain areas and attending similar sizes and growth forms (for Junipers Grier et al., 1992; for *Betula*, *Pinus* and *Picea* Ter-Mikaelian and Korzukhin, 1997) (Tab. 10).

Table 10: Allometric equations used for estimating single tree biomass.

Equation	Author	Specie
AGB=0.154*(DBH)^2.3753	Ter-Mikaelian and Korzukhin (1997)	*Betula papyrifera*
AGB=0.0696*(DBH)^2.449	Ter-Mikaelian and Korzukhin (1997)	*Pinus strobus*
AGB=0.2722*(DBH)^2.1040	Ter-Mikaelian and Korzukhin (1997)	*Picea abies*
AGB=0.013*DBH^(2.81)	Grier (1992)	*Juniperus monosperma*

After counting for each core the number of rings in the last cm we assessed the percentage annual increment ($I_{\%}$) of the cored trees using the Schneider equation (Marziliano et al., 2012; Phillip, 1994).

$$i_{\%} = \frac{k}{DBH \; x \; n}$$

Where k is a constant (400,600 or 800) and n is the rings number in the last centimeter. In order to be as conservative as possible we used k = 400. Current annual increment (CAI) of cored trees was obtained by multiplying tree AGB with $I_\%$. Successively we developed specie-specific exponential regressions between each specie CAI and DBH to estimate CAI of all trees measured and of each plot (Tab.11).

Table 11: Regression between DBH and CAI to estimate CAI of each tree sampled and fraction of the total variance explained by the regression (R^2) per species.

Species	Regression	R^2
Betula utilis	CAI=0.033910*(DBH)^1.3573	0.933
Juniperus spp	CAI=0.007058*(DBH)^1.6011	0.875
Picea smithiana	CAI=0.004108*(DBH)^1.8857	0.837
Pinus wallichiana	CAI=0.019571*(DBH)^1.6055	0.65

As plot size (1256 m^2) differs from pixel size (900 m^2) we normalized AGB and CAI to match Landsat pixel. Finally, we developed a power regression to match CAI (MGha^{-1}) and AGB (MGha^{-1}) and to predict CAI (MGha^{-1}) at different AGB (MGha^{-1}) levels:

$$CAI = 0.0121 AGB^{0.7514}$$

This had an R^2 of 0.9527 (Fig. 23).
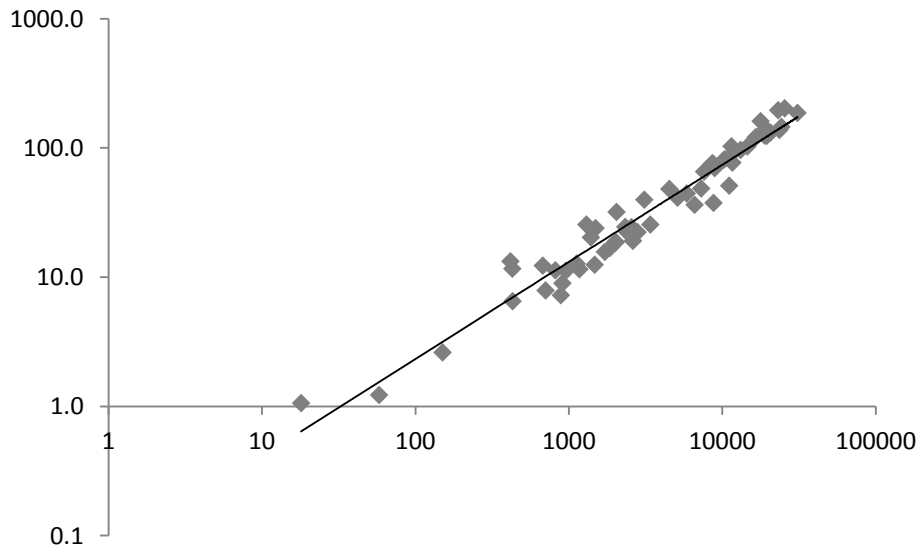
Fig. 23: Regression analyses between plot AGB (Mg*ha^{-1}) and plot increment (Mg*ha^{-1}*yr^{-1})

6.4.2 AGB-spectral values regression model

A 3x3 pixels windows, centered on the plot location, was used to average the spectral values in order to include possible georeferentiation errors. To relate satellite derived spectral

values with AGB (MGpix^{-1}) we evaluated the predictive capacity of multiple regression models composed by different spectral input datasets (Song, 2013). All the models were in the form of AGB = f (spectral values), where AGB is the response variable and PCA / NDVI / PCA + NDVI are the predictor variables we intended to test. As AGB against NDVI tends to assume a non-linear response, we linearized all parameters by logarithmic transformation. The final models were reduced to statistically significant predictor variables following the common variable selection procedure. For all the three resulting models, analyses of variance, normality of residuals (Shapiro-Wilk test) and heteroskedasticity (Breusch-Pagan test) were computed to evaluate models ability to describe the linear relationships between AGB and our explanatory variable and to quantify how much of the total variation in AGB could be explained by the linear relationship with the spectral values/index used.

6.4.3 Validation and AGB model

To evaluate the ability of the model to predict AGB values we performed a K-fold cross validation (K=3) by randomly dividing the original dataset into three folds (Vanwinckelen and Blockeel, 2012). Each fold is then removed, in turn, while the remaining data is used to re-fit the regression model and to predict at the deleted observations.

6.4.4 Forest uses needs

To assess local communities wood needs in terms of firewood and timber and to precisely locate each village use-rights area, several focus groups were conducted, at least one per each village. Those were organized with the CKNP personnel and with the involvement of the local Tsarmas/Jirga in between 2012 and 2013. A specific questionnaire, composed of both open and close questions was developed to fully include the richness and the complexity of the views held by the respondent (Denscombe, 2011; Yin R K, 2009). The questionnaire was translated into the three local languages spoken by the communities: Baltì, Shinaa and Brushashki. As no specific estimates exist on timber and firewood harvesting amount, with the collaboration of the CKNP directorate we derived proxy values to easily calculate wood needs: i.e. to estimate average amount of wood per house built and amount of kg per firewood load (on shoulders and donkey). The questionnaire was divided into three thematic sections: i) village: n° of household, location of village use-rights on a map, presence of regulatory body. ii) firewood: needs (Kg/HH^{-1}yr^{-1}), percentage of firewood coming from

forests (orchards are diffuse and are eventually used for firewood), presence of plantation for firewood. iii) timber: n° of houses built, selling of timber out of the village (if so, importance in % of household income and n° of logs), regulation, presence of plantation. Finally, borders of each village use right area were exported in a GIS environment.

6.5 Results and discussion

6.5.1 Results from the plot survey

In the 60 survey plots, we measured DBH of 2424 trees, mainly Junipers spp. (55%), Picea smithiana (38%), Betula utilis (6.8%) and Pinus wallichiana (6.6%). Also few (<10) individuals of Salix spp and Fraxinus xanthoxyloides were recorded. The DBH distribution of each species was developed (Fig. 24): Junipers show the typical reversed J-shaped curve, with high number of individuals in the smallest classes constantly decreasing towards higher diameter.
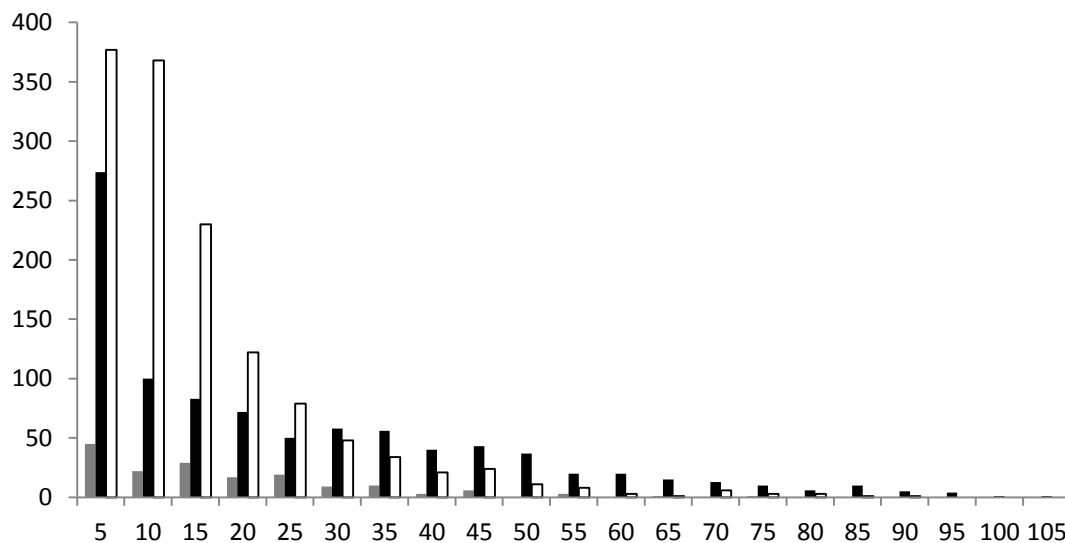
Fig. 24: DBH distribution of the three forest types measured in the plots. Grey: broadleaves, Black: conifers, White: junipers.

Pinus and Picea, on the contrary, show a lower reduction trend, with lack of individuals for the mid (25) and large classes (55), denoting a strong human pressure as a consequence of harvesting. Birch exhibits a quite balanced distribution among different diameter classes. Average DBH, maximum DBH and maximum height are summarized in Tab 12.

Table 12: Maximum (Max) and average (Avg) DBH and maximum height (Max) for study areas species.

	DBH (cm)		H (m)
	Max	Avg	Max
Betula utilis	75	18	21.2
Juniperus	87	13	17
Picea smithiana	117.5	22.6	43
Pinus wallichiana	87.5	22.7	30

Pinus wallichiana and Picea smithiana are the tree species reaching the greatest size both for DBH and height. High average DBH of sampled trees denotes a common lack of regeneration in those stands. This is probably consequence of the heavy livestock browsing pressure, particularly meaningful considering that Picea smithiana is the only shade-tolerant specie which therefore should have a lower mean DBH compared to the others (Schickhoff, 1998). Through allometric equations we estimated the AGB of each tree and consequently of each of the 58 plots. Out of a total of 482 MG, 283 MG are from Picea smithiana, 101 MG from Junipers, 57 MG Pinus wallichiana, and 41 MG from Broadleaves. Plot AGB ranged from 0.4 MGha^{-1} to 343 MGha^{-1} with a mean of 83.9 MGha^{-1}. As expected, however, the frequency distribution of plots AGB reveals generally low levels of biomass: 55% of the plots have less than 40 MGha^{-1} while only 30% have more than 100 MGha^{-1} (Fig. 25). Those data are in line with previous research findings from studies conducted in CKNP forests (Akbar et al., 2010; Akbar et al., 2011; Hussain et al., 2013) as well as from FAO national statistic which estimate an average growing stock of 47.5 MGha^{-1} for Pakistan.
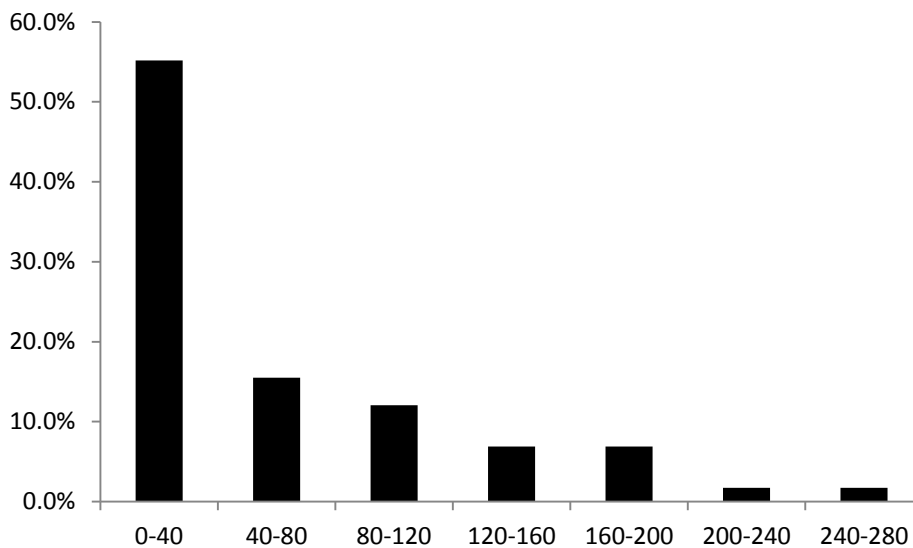
Fig. 25: Frequency distribution of per plot AGB (Mg ha^{-1}).

From the 393 increment cores collected, we assessed the annual percentage increment per tree species. Junipers have the highest mean increment (3.5%), followed by Pinus wallichiana (2.25%), Picea smithiana (2.2%) and Betula (1.1%) (Fig. 26). It's important noting the high dependency of these values on the diameter class of the trees from which are measured.
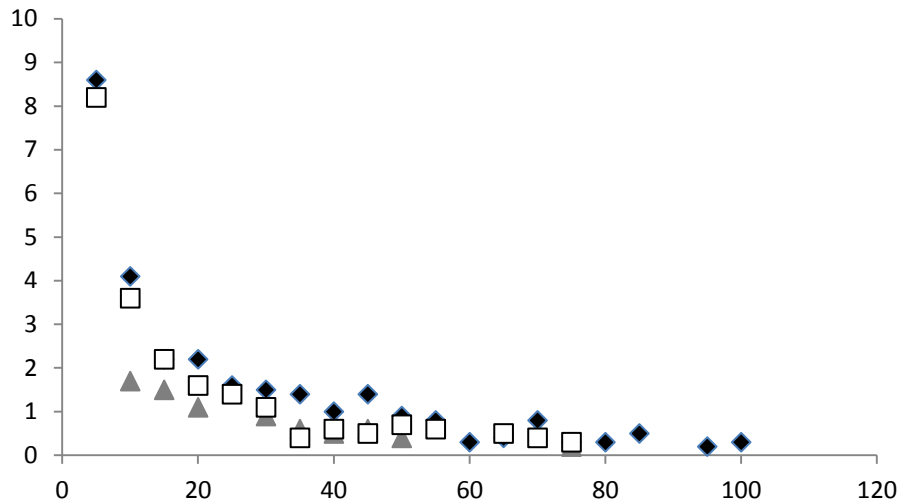
Fig. 26: Annual percentage increment (vertical axe, in percentage) of each tree species according to DBH (horizontal axe, in cm). Conifers (black) Junipers (white square in black line), Broadleaves (grey triangle).

6.5.2 AGB-Landsat model

Three models were tested and evaluated (Tab. 13). NDVI + PCA2 model was selected due to higher fitting to the data. Predictor variables PCA1, PCA3…PCA7 were not significant (p-value>0.05) in the preliminary models and thus were eliminated. The final model, with an adjusted R2=0.799, was significant according to the analyses of variance (F stat: 114.5, p-value:<2.2 e-16). Trough t-test we evaluate the distribution of the average squared residuals which did not differs significantly from 0 (p-value>0.1).

Table 13: Regression model tested for the AGB-Landsat spectral values/indices relation.

AGB f (NDVI, PCA)	log(AGB)=4.6349+3.7979*log(NDVI)-9.1773*(PCA2)	ADJ R^2: 0.799
AGB f (NDVI)	log(AGB)=7.400806+4.933108*log(NDVI)	ADJ R^2: 0.765
AGB f (PCA)	AGB=-1.21-24.6(PCA2)+34.3(PCA3)	ADJ R^2: 0.662

Normality of residuals was tested through Shapiro Test (W=0.9712, p-value=0.1821) while heteroskedasticity was tested with Breusch-Pagan test (BP=8.3, p-value=0.01). The results obtained confirm the ability of NDVI to be used as a proxy of vegetation biomass in dry regions with a reduced tree cover/canopy density. In such areas, stand biomass is directly related to tree cover and NDVI is a powerful index for discerning those vegetation, and

therefore AGB gradients. Nevertheless, its use in high AGB forests should be evaluated carefully, as it would be appropriate to include its saturation effect (Santin-Janin et al., 2009).

To evaluate further the ability of the model to predict AGB values we performed a K-fold cross validation (K=3). The results of cross-validation predictive accuracy are relatively high (0.574) while the absolute error remained high (5.73 MGpixel^{-1}) (Fig. 27).
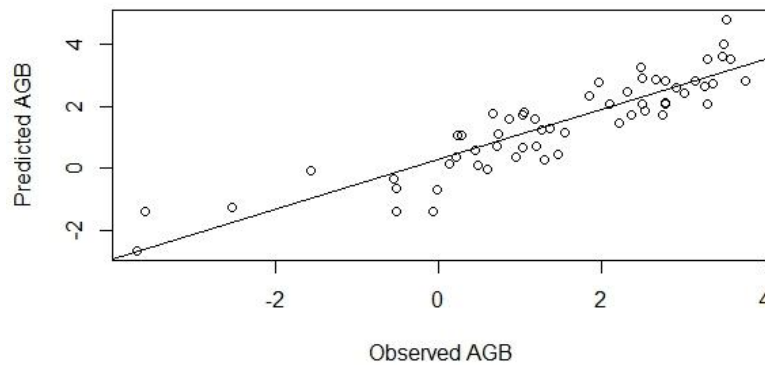
Fig. 27 Predicted vs Observed AGB values.

The accuracy reached by the model was considered sufficient, therefore it was selected for the spatialization of Above Ground Biomass data throughout the Park.

6.5.3 AGB and increment distribution in the Park and in case studies villages.

Following model selection, AGB and CAI of the whole CKNP were estimated (Tab. 14).

Table 14: AGB (Mg) values and CAI (Mgyr-1) in the CKNP valleys.

Valley	Veg. Area (km^2)	Tot AGB (Mg)	TOT CAI (Mgyr^{-1})	AGB/Km^2 (Mgkm^{-2})
Astak	37.5	147255	971.2	3924.8
Bagrote	107.6	434216	2923.4	4033.9
Baltoro	2.1	287	3.4	138.9
Basha	196.5	417418	2865.7	2123.9
Biafo	5.6	8902	63.8	1594.0
Braldu	160.9	229810	1616.5	1428.6
Danyore	29.9	133206	852.7	4460.6
Dumordo	8.7	2069	21.7	237.7
Haramosh	128.5	1005445	6064.7	7827.5
HIsper	33.2	20168	165.4	607.6
Hoper	42.7	72062	533.1	1686.6
Hushey	52.7	22112	196.3	420.0
Jutal/Jaglot	24.1	81642	541.6	3390.0
Kharku	0.7	179	1.6	270.5
Minapin	77.3	234092	1577.6	3029.7
Shengus	21.9	75064	494.9	3421.7
Shigar	34.1	59788	435.6	1755.5
Thalley	44.9	30675	246.8	682.9
Tormik	41.0	139833	902.3	3411.1

Over an area of 11861 km2, we estimated a total AGB of 3114222 MG of which 90% from close forests, 8% from open forests and 1.8% from sparse trees vegetation classes. The total CAI is estimated to be 20478 MGyr-1 (0.67% of AGB). For comparison, we assessed the average AGB of forested areas (according to FAO standards) which equals to 55.6 MG/ha, just slightly above Pakistan average growing stock of 47.5 Mg/ha estimated by FAO (2010). AGB is not equally distributed among the valleys, but show an highly variable distribution, as expected by previous land-cover studies. South-west valleys as Haramosh (32% of total CKNP AGB), Bagrote (14%) and Basha (13%), indeed, represent almost half of total CKNP AGB while eastern valleys, on the contrary, reveal lows levels of AGB. The valley distribution of AGB among the three land-cover classes (sparse trees, open forest and close forest) show a constant longitudinal trend: in western valleys, AGB is mainly concentrated in the close forest class (97% in Haramosh, 97% Bagrote, 92% Jaglot) while in the Eastern valleys open forest and particularly sparse trees becomes predominant (Kharku 68% in SP, Thalley 21% in OF). This is consequence of the gradient in forest cover identifiable moving from forest rich western valleys to forest poorer eastern one. A similar pattern is observed in the CAI availability: the largest increment is clustered in few valleys (28% of total CKNP CAI in Haramosh, 16% in Basha, 13% in Bagrote) while eastern valleys

show relatively low levels of total increment, with the only exception of Braldu (in which high altitude broadleaves forests are quite abundant). The distribution of forest resources in term of biomass and increment, therefore, call for a strictly valley based management approaches, as other studies suggested (Shahbaz et al., 2011).

6.5.4 Local communities' wood needs.

The communities living around CKNP are heavily dependent on forest resources located inside and around the park boundary. Forests are essential for covering firewood necessities (heating and cooking) and for the supplement of timber for construction. Additional they represent an important grazing ground for local livestock. Generally, harvesting from natural forests merely satisfies local needs and only in few valleys firewood and timber are sold to local market cities of Gilgit and Skardu. Firewood consumptions represents almost 75% of total community needs, those figures, however, are variable from valley to valley and from village to village (Tab. 15). In particular some general consideration can be made: forests are managed mostly at village level, and only in two valleys there are examples of co management between villages (in Astak and Bagrote). The dependency of villages from forest resources increases as altitude of villages increase. This is consequence of increased firewood needs, and better accessibility to forest areas. In example, higher villages, located close to 2700/2800 meters consume around 4 $MGHH^{-1}yr^{-1}$ while lower villages (around 2000 meters) consume 2 $MGHH^{-1}yr^{-1}$. Those data are in line with previous estimates from surrounding regions (Ali and Benjaminsen, 2004; Kumar and Sharma, 2009). Just one village, Minapin, uses mostly gasoline or LPG for cooking and heating thanks to its favorable location along Karakorum Highway and the higher income of its inhabitants. For most low altitude villages, additionally, orchards pruning (especially apricot) is an important source of firewood (up to 60%) while in drier valleys where forests are almost absent, as in Hushey or Hispar, yak and cow dung is dried, stored and used for heating and cooking during the winter months. Regarding timber, instead, villagers from eastern valleys rarely use local Juniper woods for construction, as plantation of poplar and willow became relatively abundant in the last two/three decades and are usually enough to satisfy local needs. In western valleys, instead, rich in Pine and Spruce forests, timbers is frequently cut and in most cases strict rules exist at village level to manage those highly valuable resources. Illegal harvesting for timber selling is diffuse in few valleys, as Jaglot/Haramosh/Astak. The logging amount, however, is usually regulated among households but harvesting rate exceeds by far forest yield. Lack of

management guidelines poses additional threats as harvesting is usually on small/medium sized trees, irrespective of regeneration and without considering any rational silvicultural prescription. Illegal timber harvesting is possible only if jeepable roads are connecting villages to the main cities. In example, Khaltaro village, situated in forest-rich Haramosh valley, due to bad road access is not interested by any large scale timber harvesting. As previously revealed, those drivers of deforestation are common also in valleys outside of the national Park: i.e. Basho (Ali et al., 2005; Schickhoff, 1998).

Table 15: Village's population (N° of Household), average firewood needs per Household (Avg HH firewood, MgHH-1yr-1), percentage of firewood collected from natural forest (% forest), total average timber (Avg Timber, Mgyr-1) and firewood (Avg firewood Mgyr-1) needs per village and grand total wood needs (Tot, Mgyr-1), village's forest current annual increment (CAI, MGyr-1) and difference between total CAI and needs (Difference, Mgyr-1, negative values when needs are higher than CAI). Note that Chirah, Farfoo and Hopey villages jointly manage their forest resources.

Valley	Village	Population	Avg HH firewood $(MgHH^{-1}yr^{-1})$	% forest	Avg timber $(Mgyr^{-1})$	Avg firewood $(Mgyr^{-1})$	Tot $(Mgyr^{-1})$	CAI $(Mgyr^{-1})$	Difference $(Mgyr^{-1})$
Astak	*Astak E*	600	2.5	85%	40	1275	1315	498	-817
	Astak O	700	2.5	70%	40	1225	1265	473	-792
Bagrote	*Bilchar*	250	2	100%	6	500	506	265	-241
	Bulchi	250	4	100%	20	1000	1020	474	-546
	Chirah	100	4	100%	6	400	406	1494	-192
	Farfoo	250	4	100%	20	1000	1020		
	Hopey	140	2.4	75%	8	252	260		
	Datuchi	150	3.75	65%	2	366	368	176	-192
	Sinaker	130	3.2	40%	2	166	168	134	-35
	Taysote	150	2	100%	4	300	304	376	72
Basha	*Arandu*	100	3	100%	20	300	320	1481	1161
Haramosh	*Barchi*	200	2.5	100%	1500	500	2000	678	-1322
	Dassu	300	2.5	100%	600	750	1350	1268	-82
	Hanuchal	250	1.5	100%	187.5	375	563	447	-115
	Jutial	45	2	100%	1012.5	90	1103	1654	552
	Khaltaro	150	3	100%	10	450	460	2015	1555
Hushey	*Hushey*	300	3.5	50%	0	525	525	123	-402
	Marzigond	75	1.5	10%	0	11	11	6	-5
	Talis	300	1.5	2%	0	9	9	1	-8
	Kande	200	3	40%	0	240	240	73	-167
Minapin	*Minapin*	140	0.5	20%	10	14	24	511	487
Jaglot	*Jaglot*	150	2.5	100%	100	375	475	542	67
Hopar	*Hopar*	600	1.6	60%	0	576	576	533	-43
Hispar	*Hispar*	200	4	100%	0	800	800	165	-635

6.5.6 SFM promotion

According to the results of forest inventory and local community survey, natural forests at the moment do not have always the potential to support the local's needs. 16 out of 22 villages have unsustainable harvesting rate. In most cases this is consequence of the scarce growth of local forest resources and the high firewood demands of the local communities. Generalizing for the whole study area, it seems to be important to encourage out-of-forest firewood plantation diffusion, through highly productive and easy to maintain short rotation coppice systems. Those interventions shall be prioritize in the villages located in the eastern CKNP where CAI is usually very low and at low elevation villages, where with sufficient watering, production capabilities are higher. Incentives in the adoption of improved cooking stove, whereas possible and accepted by locals, should be encouraged instead in high altitude villages. Timber harvesting shall be managed according to sound silvicultural principles as target diameter, planning of harvesting in time and space, specie-specific treatments for both *Pinus* and *Picea* respectful of the different ecologic needs of those two species. The use of a participatory approach and the implementation of specific courses to train the locals are effective ways of integrating community interest and it is well-known that multi-disciplinary education and training is key to the adoption of a sustainable forest management (Ellis and Porter-Bolland, 2008; Mendoza and Prabhu, 2005). It is also necessary to identify among the locals and the forest department employees, people that will be trained and then made responsible for the implementation and monitoring of all the activities connected with forest management. Additionally, from our visual inspection it seems important to manage and monitor grazing pressure. In particular, regenerating areas shall be protected from grazing and trampling by local livestock (Nüsser, 2000; Schickhoff, 1998). This could be met by concentrating harvesting of trees in few, selected locations and, in collaboration with local Jirga/Tsarmas, implement a grazing ban, wherever possible.

6.6 Conclusion

CKNP faces a high risk of forest degradation. This is mostly consequence of increased firewood demand and mismanagement. Unsustainable forest management leads to further degradation of forests, which affect their ability to deliver products and services to dependent local communities. In an area characterize by rough topography and unstable geology, this means also increased soil erosion, slope instability, as well as reduced carbon sequestration and threat for biodiversity. A co-management between communities and Forest Department shall be prioritized, as a basis to increase local awareness and capabilities in forest management. Simultaneously, specific mitigation measures as coppice plantation and improved cooking stoves shall be adopted to reduce the locals' needs, especially in terms of firewood. This study, moreover, is one of the first forest inventories in the area. The reliability of the data suggests its adoption also in the future monitoring of Park forests resources.

CHAPTER 7

CAPACITY BUILDING AND MANAGEMENT PLAN GUIDELINES

Pakistan is a country which has very little level of participation of local communities in forest management (Shahbaz et al., 2011). Here, forest department is in charge of taking forest related decisions at all levels (planning, monitoring, harvesting, etc) and direct involvement of locals is uncommon (Shahbaz et al., 2007). Communities are being viewed as the source of deforestation and forest degradation rather than an important stakeholder that, with proper involvement, can improve forests conservation and management. If this belief is partially congruent with the observations made in Central Karakorum National Park, the current strict regulations applied to the forest sector did not halt or reduce the deforestation rate anywhere in the country (FAO, 2012).

The top-down, centralized governance system, typical of former British colonies is one of the main reasons behind those unsuccessful attempts, despite large founding and efforts both from the Government and NGOs sectors (Ali and Benjaminsen, 2004; Ali and Nyborg, 2010; Knudsen, 2011).

Contrary to other former colonial countries of South-Asia, as India, Nepal or Bhutan, where participatory forest management is a reality since the 1980s, in Northern Pakistan little improvement towards a less rigid governance system has been made (Rasul and Karki, 2007).

Generally, participation of communities in forest management is considered at three levels (Ostrom, 1990; Rasul and Karki, 2007):

- participation in the programming phase,
- participation in the decision making process and
- participation in the protection/management of forests .

Through the activities implemented in the CKNP during the thesis work, it was our aim to develop awareness about forest importance and to increase communities participation at all three levels. However, the strong rigidity in the local institutions, especially when dealing about forest management in protected areas, heavily limited our "space of maneuver".

This chapter describe the main measures which have been implemented during the last three years to increase locals participation in forest management.

Specifically, the first subchapter (7.1) relates to the capacity building measures aimed at providing skills in reforestation activities among locals and CKNP personnel. Those have been undertaken in 2 valleys.

The last subchapter (7.2), contains the management plan guidelines developed after the consultative process with local communities: in this phase, communities participation to the decision making process was proactive and positive, but to involve them directly in the management a proper legislative framework, of rights and duties, is needed. Regarding this issue, recently, a progress towards a more flexible and comprehensive approach to forest management in protected areas, through a relaxation of existing rules and regulation, gives hope for future's improvement.

This is not to mention that participatory processes are a long and continuous work, which cannot be completed in a short/medium time span of only three years. Results, therefore, are still at their preliminary phase. Indeed, the size of the Park, economic and time constraints has forced us to limit the mitigation actions at just two valleys. However, the involvement of locals and their positive attitude, makes it an important example which we hope might benefit the development of a provincial-based change in governance system.

7.1 Capacity building and mitigation measures

In the Central Karakorum National Park there is large need of forest restoration activities. The few example carried out by the provincial forest department, indeed, had often scarce success since planting materials, species and site selections were poor. Additionally lack of involvement of locals resulted in little acceptance and sense of ownership. This lead to heavy browsing of seedlings by livestock (due to uncontrolled grazing, as in Jaglot valley), destruction by land-owners (as in Haramosh), low survival rate of seedlings.

Seeds and seedlings, additionally, are not produced or grown locally and the great climatic and environmental variability of Pakistan, makes the use of non-local planting materials subjected to an high risk of mortality. Indeed, local seed-banks of forest species are not available and, therefore, to promote reforestation initiatives, seeds must be collected in loci to conserve species genetic variability and adaptability.

Therefore we considered important for the Park to develop skills and knowledge about all the steps necessary to start reforestation using local plants species.

We selected two case study valleys (Bagrote and Astak) where, in collaboration with local representatives, we identified two reforestation areas. In both cases, this was not a straight forward, single meeting decision, but was rather the results of a decision process with local communities where areas of high degradation were identified and mapped and the most favorable site were selected, bearing in mind the results of land cover mapping and species altitudinal and exposition distribution.

The focus of those reforestation activities mainly related to two aspects:

- to evaluate best timing and simplest methodologies for conifers cones collection and storing.
- to evaluate best practiced and techniques for seeding and fencing.

The first reforestation area, located in Bagrote valley, was seeded with *Pinus wallichiana* seeds in Autumn 2012 by the Bagrote local community organization following winter seeding technical guidelines. The reforestation area was visited in late Spring 2013 and revealed good levels of seedlings germinability (>75%) and survival.

The second reforestation, undertaken in Astak valley (Skardu district), was seeded instead with, *Picea smithiana* seeds, collected independently by the local community during autumn 2012. were seeded in Spring 2013.

A reference guide book was produced to be delivered and shared among CKNP officers and other relevant stakeholders (Annex II)

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7.2 Management plan guidelines

The following management indications aim at setting the basis for participatory and sustainable forest management in the Central Karakoram National Park. This is a long lasting and continuous process, where technical skills, community awareness and training of civil society, forest department and park rangers are all necessary ingredients for the delivery of an effective and successful plan. The management plan guidelines can be seen as the conclusion of this thesis work. Three years are not a sufficient amount of time to develop an effective and comprehensive Sustainable Forest Management for the CKNP. However, precious progressions towards its implementation have been made. All those guidelines have been discussed and decided through a consultative process with the representative of each local communities. The time-frame for the adoption of those guidelines through the Park area have been estimated in 5 years. Simultaneously, a

Forest management indication 1 – Constitute forest committees at valley level and community based forest management

Description

In the valleys where they have not been already constituted, CKNP should promote the establishment of forest committees at valley level. The forest committees should become the reference party for the CKNP forest management on the territory, organizing the different actions planned (i.e. reforestation, plantation, etc.) and monitoring the forest threats & degradation drivers. Forest committees, moreover, are the pillars of community based forest management, in which, as the word is suggesting, communities are independently managing their forests with additional assistance by the Forest Department or the CKNP staff.

Additionally forest committees together with CKNP staff should:

Estimate local communities' wood necessities and harvesting areas: precisely, using the questionnaire which has been developed by EV-K2-CNR and University of Padova and locating harvesting areas on the maps developed for the CKNP. A team, composed by the local forest committee members and local CKNP staff will organize open interviews with elders of each village, or, in larger valleys, with a representative sample. This will be a precious occasion also to raise awareness about forest resources conservation and importance.

Report about drivers of forest degradation inside the CKNP buffer area: for each valley a report should clarify if, and in that case, which are the most important factors affecting deforestation and forest degradation (illegal harvesting, firewood necessities, timber harvesting, lack of management guidelines, etc.).

For the SW valleys, where Pinus wallichiana (Kail – Tangshin) or Picea smithiana (Spruce – Katwul – Stak) forests are present: forest committee should be in charge for the collection of cones from those two species. [2.5 kg of Pinus wallichiana (Kail – Tangshin) seeds and/or 1 kg of Picea smithiana (Spruce – Katwul – Stak) seeds - depending on species presence in local forests - would be sufficient to guarantee assisted artificial regeneration in harvested areas (see forest management indication 3).]

Forest management indication 2 –Sustainable Forest Management Plan per valley level (SFMP)

Description

Each forest committee shall prepare a simple Sustainable Forest Management Plan at valley level. This document should include a brief description of the following topics:

- Harvesting area: locate, on a valley map, the areas used by each community to harvest firewood and, eventually, timber.
- Estimation of local community wood necessities: through questionnaire (see management indication 1), the annual wood consumption of local people should be estimated per village (or groups of villages) level.
- Highlight degraded areas: eventually locate on a map the forest areas heavily degraded and the motivation (if possible).
- Regulation already in practice: describe if some regulation have already been set (e.g. limitation on access, ban on harvesting etc) and for which area are valid.
- Forest prescription: in the document all the prescriptions which the forest committee has established should be clearly stated.

The sustainable forest management plan shall be approved, at least, by the forest committee and the CKNP.

Forest management indication 3 – Timber harvesting in mountain dry temperate forest.

Description

According to University of Padova, inside CKNP buffer area some forests is eligible for organized timber harvesting. Those are stands which are classified as "closed forest" of Pinus wallichiana (Kail, Himalayan Blue Pine) and/or Picea smithiana (Katwul, Morinda spruce).

Similarly to what is performed in Europe and North America, harvesting of green trees should be allowed if degradation status is limited (but first a change in Northern Area current forest legislation is needed).

The specific management prescriptions will be defined in the sustainable forest management plan (SFMP).

General guidelines, set by forest committee, should include:

- To adopted a "target diameter" management prescription, for which only the trees which reach or exceed a certain diameter (60/ 80 cm – 23/30 inch, depending on specific site and fertility) can be cut while all the trees smaller than this threshold should be left to grow. These management guidelines (that shall be defined in detail) ensure a correct diameter composition of the forest stands.

- Define the entire forest area eligible for felling and locate it on a map.

- Divide this area into parcel, with an average size of 50 hectares (120 acres) and easily identifiable and understandable borders (ridge, rivers, roads, etc.). Around 10 parcels shall be identified.

- Each year, harvest timber (and eventually firewood) only from a certain parcel, selecting the trees to be cut with the target diameter system: an average cutting cycle of 10 years shall be allowed.

- The area interested by the felling should be left to natural regeneration with additional assisted artificial regeneration (if necessary) provided by the above mentioned seed harvesting (see Forest management indication 1).

- Avoid grazing, as much as possible, in regeneration areas eventually by building fence with thorny shrubs (i.e. sea-buckthorns) to prevent goat and sheep feeding on

young seedlings. In any case, a collaboration with shepherds should be promoted in order to avoid unattended grazing.

- Support a complete utilization of the wood residuals following tree harvesting (e.g. branches, stump,...) also for firewood purposes.

Forest management indication 4 – Firewood collection

Description

Firewood collection, being an essential practice for the community living around the CKNP borders, cannot be limited if alternative energy resources are not found. Moreover, in the short-term-future we do not foresee any feasible possibility for a significant reduction of firewood needs of local communities. Nevertheless, actions raising local communities awareness about the (often) unsustainable long term effects of the current firewood collection practices should be implemented.

Most of firewood necessities are actually met using a wide array of different forest resources according to village location: Juniperus is the most common harvested species, followed by riparian vegetation and other minor shrubs (like Artemisia) in drier and more continental valleys (NE CKNP).

In principle, even the firewood collection activity should be included in the SFMP, with simple prescriptions discussed and approved by the forest committee, local community and CKNP (e.g. reduce collection in heavily degraded areas for a certain time period).

Management indication for firewood collection, which might be considered by the forest committees include:

- Juniperus trees: we recommend to do not harvest complete individuals but rather cut single branches. Juniperus trees, indeed, show a rather strong resilience and are able to sprout new branches the following years.
- Regarding riparian vegetation: for coppice plants like sea-buckthorns or willows we suggest to cut single basal shoots from each plant to preserve its root system. Doing so new shoots can re-grow rapidly producing new biomass to be harvested.

- Shrubs: for coppice plants we suggest to partially cut the basal shoots trying to avoid, if possible, the cutting of whole individuals. In these cases, local knowledge and traditional management system should be emphasized and taken into consideration.

Forest management indication 5 – Firewood plantation

Description

In those areas were firewood from local forests is hardly sufficient to cover the needs of local communities, or where forest degradation have depleted above ground biomass to extremely low amounts, specific actions should be implemented to increase wood availability from non-forest areas. Plantation of trees (poplar, willow, sea buckthorn) to be managed as coppices for the production of firewood, therefore, should be promoted as an effective tool to reduce the pressure on natural forests. Those activities shall be directed particularly to those valleys where forest cover is naturally scarce.

Forest management indication 6 - Training forests

Description

Inside the buffer areas, training forest could be promoted for each valley (if supported by local communities). The objective of training forest is to train local park rangers and members of the forest committees in different forest management practices. Different types of cuttings can be adopted and effect on forest regeneration monitored, in time. Those would be ideal areas also for evaluating the regeneration capabilities of forests in time. One training forest shall be identified for each most common forest typology present in the valley.

Annex II: Reforestation guide book

Seed collection timing:

Table 16: Best timing for *Pinus* and *Picea* cones harvesting.

Species	Timing
Pinus wallichiana	Early October
Picea smithiana	Late September/ Early October

Storing of cones

Once cones of conifers species (*Pinus wallichiana* and/or *Picea smithiana*) have been collected, they should:

- Placed in large sacks
- Fill the sacks with cones only up to one –half to avoid heat buildup
- Ensure that filled sacks are tied at the top to allow for cone expansion
- Store the filled cone sacks on their side not upright.
- Change sacks if they get wet.
- Store the sacks in a dry, cool and ventilated place.

Generally, freshly picked cones are very moist, and is essential to reduce the moisture gradually to prevent fungi spread and mimic, at the same time, the natural maturation process. Try to avoid, if possible, the picking of cones during wet weather. Alternatively, reduce the number of cones per sack to promote uniform and faster drying.

It's important to keep the bags not in direct contact with soil to avoid soil moisture to spread into the sacks. After 2/3 weeks the cones will dry and ultimately they will open, making seeds extraction simpler.

Seeds extraction

First it's important to evaluate if cones dryness is sufficient to allow a complete extraction of the held seeds:

- Check that the cones scales are sufficiently open to allow an easy extraction of seeds on all (or most) of the cones length.
- Check more than one cone per sacks to evaluate the dryings process status.

From each cone a careful extraction of seeds is mandatory to avoid damages. Seeds shall be extracted on a fine knitted towel by gently shaking the cones. Spruce seeds are comparably smaller than pine one and should be handled with more care. In particular:

- Avoid seed's extraction in open environment to prevent seeds dispersion by wind gusts.

If possible, try to clean the seeds from the debris and eventually take the seed wings off by gently pressing it. This will facilitate the seeding process.

Storing of seeds

Once extracted, seeds shall be preserved inside sacks and stored in a dry and cool location (Temperature shall be equal to or below 5°C). Seed can be satisfactorily stored in this condition until the following spring, provided it is kept cool, in sealed sacks. Make particular attention on selecting the location for the seed storing: try to avoid as much as possible places which can be reached by rodents (mice, squirrels, etc). Place barriers or hang the sacks on the roof to make it harder to reach. Ideally, seed storing location should be close to the area selected for reforestation or at least at a similar altitude. This is important to couple local climate with seeds, making them ready to germinate.

Pre-seeding treatment

This section deal with the most important activity to perform before seeding. Seeding can be done in late autumn-early winter (*Winter seeding*) or in spring time when snow melts (*Spring seeding*).

A) *Winter seeding*: winter seeding shall be preferred whenever possible if the following conditions are met:

- reforestation location already chosen
- fence/protection of young seedlings from livestock browsing already built (or in the case if it is not needed).

- Seeds extraction completed before snow accumulation on reforestation ground.

Treatment of seeds: no particular treatment is needed to increase seeds germinability. The seeds dormancy will be naturally broken when warmer temperatures and water availability increase as snow melts in spring time.

B) *Spring seeding*: if winter seeding is not possible, an additional treatment shall be performed:

- Stratification: seeds shall be placed in a box filled with sand and kept wet with cold water (5°C) for at least 4/5 days. This treatment is necessary to break the dormancy and allow a fast germination once the seeds are sowed.

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CHAPTER 8

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