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Forest carbon projects in the Ukrainian carpathians: An assessment of potential community impacts and benefits

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Sustainable Forest Management Alternatives for the Carpathian Mountains with a Focus on Ukraine

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Abstract Sustainable forest management (SFM) has been challenging in the Carpathian Mountain region of Europe. We explore emerging models and innovative practices that offer guidance on implementing SFM, based on recommendations developed through a scientific atelier held in western Ukraine. Information was gathered through technical presentations, site visits, unstructured interviews with stakeholders, and literature review. The contribution of SFM to biodiversity conservation depends on the establishment of fully representative and sufficiently extensive reserve systems. On managed forestlands, providing a better balance of stand ages and recently developed silvicultural practices, such as "close to-nature" and disturbance-based forestry, will help maintain ecosystem functions while providing a range of economic uses. Restoration of native species composition in areas dominated by spruce plantations will both enhance forest health and promote biodiversity conservation. Broader use of contemporary watershed management approaches is recommended, including delineation of riparian buffers, riparian forest restoration, ecologically informed design of transportation infrastructure, and investment in modernized harvesting machinery. Expanding forest sector participation in forest certification and carbon markets offer new opportunities and challenges. Certification of forestlands is expanding but has been limited by non-conformities. Ukrainian afforestation goals have the potential to sequester large quantities of carbon and generate substantial economic benefits as international carbon markets develop. The relatively long rotations currently required under Ukrainian forest code offer significant carbon storage benefits, as would conservation of high biomass, old-growth Carpathian beech and spruce–fir forests. A variety of stresses are predicted to increase with climate change, requiring adaptive responses. The challenge facing Ukraine and other Carpathian nations is to merge these ideas into a holistic, landscape approach adapted to the context of transitional, post-socialist economies.

1 Introduction

In the Carpathian Mountain region of Europe translating principles of sustainable forest management (SFM) into meaningful change and management strategies has proven challenging in transitional, post-socialist economies. Yet this context also provides a window of opportunity for experimentation, innovation, and adaptation. These are needed to transform general principles and theory into practical guidance for multi-functional forestry that is administratively and operationally feasible.

This review explores emerging models and innovative practices in forestry and economics that offer guidance on implementing SFM criteria in the Carpathians, with a focus on western Ukraine. Western Ukraine is representative of many of the complex forest management issues at play throughout the broader region. We discuss three (of several, Table 1) international SFM principles: (1) conservation of biological diversity, (2) maintenance of water resources, and (3) contribution to

Table 1 SFM criteria under the Montreal Process (12 non-European temperate and boreal forested nations) and Helsinki Initiative (38 European temperate and boreal forested nations, including Russia). These have been standardized using terminology shared by the two systems. Note that while the Helsinki process does not explicitly address legal systems at the criterion level, the importance of legal frameworks for SFM is manifest in a number of specific indicators

Criteria	Montreal process (1994)	Helsinki process (1994)
Conservation of biological diversity	Yes	Yes
Maintenance of soil and water resources	Yes	Yes
Contribution to global carbon cycles	Yes	Yes
Maintenance of ecosystem health	Yes	Yes
Maintenance of ecosystem productivity (wood and non-wood)	Yes	Yes
Provision of multiple, long-term socio-economic benefits	Yes	Yes
Legislative, institutional, and economic frameworks	Yes	No[a]

[a] In the Helsinki process, there are indicators for this theme associated with the other six criteria

global carbon cycles. Our recommendations are based on a synthesis of information and literature collected in a scientific atelier (or problem solving workshop) on integrating ecological economics and SFM in the Carpathian ecoregion, held in Lviv, Ukraine in the fall of 2007. The atelier brought together over 100 participants from Carpathian nations, elsewhere in Europe, and the U S, including scientists, economists, resource managers, and stakeholders from academia, governmental agencies, funding institutions, local communities, and non-governmental organizations. An initial set of challenges and opportunities for SFM were identified through technical presentations, brainstorming sessions, and literature review, conducted in preparation for and at the outset of the atelier. These were explored further through field visits to forestry operations and protected areas, and on-site meetings with forest managers and local stakeholders in the Ukrainian Carpathians. Qualitative data were collected through unstructured interviews with key informants and additional data were collected through programmatic document review. We integrated the data using triangulation (Flick 2009), allowing identification of cross-cutting themes, such as opportunities for SFM expressed by multiple experts and stakeholders (Table 2). The atelier method and process are described in Farley et al. (2009).

About 10 % of the Carpathian range lie in western Ukraine and contain 16.7 % of the nation's total forest area. Two million ha or 56 % of the Ukrainian Carpathians are forested, representing a resource of high economic, biological, and cultural value. In Ukraine there is a long history of well-trained, professional forest management within the State Forestry Enterprises (Nordberg 2007). However, forest management remains highly regimented, with most policy emanating from centralized planning at the ministerial level (Soloviy and Cubbage 2007). This contrasts with Romania, for instance, where forest administration has decentralized but involved substantial post-socialist land restitution and privatization

Table 2 Recommendations for SFM in the Carpathian Mountain region developed by participants in the Atelier on ecological economics and sustainable forest management, held in Lviv, Ukraine in September 2007

Topic	Recommendation
Watershed management	Implement watershed restoration programs, including riparian forest restoration on main floodplains
	Relocate logging roads away from streams and rivers
Forest health	Expand restoration of genetically non-endemic *Picea abies* plantations to native forest composition
	Utilize Carpathian Convention to reduce deposition of airborne pollutants
Ecological forestry	Expand experimentation with and use of ecologically-based silvicultural systems, such as "close to nature" and "natural disturbance-based" silviculture
Conservation and protected areas	Conserve remaining old-growth and high conservation value forests
	Expand protected areas system to encompass adequate representation of biological diversity
Management planning	Coordinate forest management planning at landscape scales (i.e. "matrix management")
	Maintain connectivity and habitat representation on managed forestlands
Certification	Expand participation in SFM certification; address non-conformity issues such as illegal logging
	Maintain high forest management standards over long-term to avoid certification suspension
Illegal logging	Improve socio-economic conditions at the community level, including employment opportunities
	Introduce effective legal regulation and enforcement
Payments for ecosystem services	Incentivize SFM by participating in international carbon markets and other "payment for ecosystem services" opportunities
Non-timber forest uses	Incorporate non-timber forest uses, such as ecologically sound recreation and non-timber forest products, into forest management planning
Infrastructure: roads and equipment	Increase investment in the forest sector to modernize forest infrastructure and harvesting machinery
Community participation	Promote community-based SFM initiatives, including projects designed by NGOs and public participation in forest governance
	Maintain and promote community-based forest management, such as traditional village systems
Sustainable development	Address increasing development pressures through land-use planning and promotion of ecologically-sensitive tourism
	Evaluate forest privatization proposals based on sustainability criteria

(Sikor 2003). Centralized forest governance and overall declines in forest sector investment since the collapse of the Soviet Union have limited innovation and policy reform at local, district, and regional administrative scales (Nordberg 2007). The Ukrainian forest code was amended in 2006 to address some of these constraints (see below). However, illegal logging continues to hinder forest management efforts, remaining prevalent both within and outside of protected areas in Ukraine (Kuemmerle et al. 2007, 2009). By one estimate using remotely sensed data, the area affected by illegal logging during this period was roughly equal in size to the total area of government sanctioned logging (Kuemmerle et al. 2009), though this estimate is contested within Ukraine. Bureaucratic inefficiency, inadequate public involvement processes, and a poorly developed non-governmental sector have also limited broader adoption of SFM principles in forest planning and governance (Soloviy and Cubbage 2007). These factors inhibit the ability of forest managers to respond effectively to new demands and economic opportunities, such as certification and payments for ecosystem services including carbon markets.

On the positive side, accords established by the Carpathian Convention (2003), expanding enrolment in SFM certification schemes, and international non-governmental organization initiatives (Björnsen-Gurung et al. 2009) are bringing new attention to this region. Yet certification projects are frequently challenged by non-compliance, including illegal logging, insufficient transparency in forest planning, lack of public involvement, violations of worker safety standards, inadequate attention to High Conservation Value forests, weak monitoring of rare, threatened, and endangered species, and the poor condition of forest road systems (Kovalyshyn and Pecher 2009). There may be opportunities for application of new SFM approaches, for instance building on existing social capital in traditional village systems (Elbakidze and Angelstam 2007), but this will require access and openness to new information, collaborative planning among actors from different sectors, investment in the forest sector, and experimentation with alternative silvicultural systems, including restorative approaches.

2 Integrating Ecological and Socio-Economic Objectives

In difficult economic circumstances sustainable development initiatives that build the social capital necessary for a long-term commitment to environmental protection become as important as the technical and scientific basis for forest management decisions. SFM begins with an understanding of the capacity of an ecosystem to produce a full range of ecosystem goods and services. However, initiatives must also support economic opportunities and social capital in communities striving to meet the basic necessities of life (Elbakidze and Angelstam 2007), and requires an economic system that rewards the provision of both market and non-market goods and services (Farley 2008, 2009).

The Carpathian region is struggling economically (Palang 2006) and yet subject to development pressures including growing tourism interest (Turnock 1999). The latter includes expanding transport infrastructure and sprawl, especially near tourism developments like ski areas. Some remote areas of the Carpathians retain traditional, village-based forest management systems that promote community engagement (Angelstam 2006; Elbakidze and Angelstam 2007). These cultural traditions were mostly superseded by the government controlled State Forest Enterprises established during the socialist period; subsequent political upheavals further disconnected communities from a shared, cultural connection to the landscape in some regions (Palang et al. 2006). However, in recent years innovative projects have helped re-establish a limited degree of public participation in SFM decision making at the community and regional levels (Foellmi and Schwitter 2009).

Carpathian forests bear the legacy of a long history of utilization within traditional village systems (Elbakidze and Angelstam 2007), intensive production-driven management dating to the Austro-Hungarian period in the nineteenth century, and more recent forest management systems introduced during the Soviet period. While most of the lowland temperate forests were cleared during the Austro-Hungarian period, much of the native beech (*Fagus sylvatica*) and mixed species forests were converted to Norway spruce (*Picea abies*), a species native to the Carpathians but planted ubiquitously on non-endemic sites and using non-local genetic varieties (e.g. Austrian genomes). This, together with even-aged, plantation style forest management practices, resulted in homogenized and simplified forest structure and composition at both stand and landscape scales, especially in areas not protected under the Soviet system (Stoyko 1998). This situation is not unique globally, bearing a striking resemblance to landscape scale changes occurring in southern Sweden during the nineteenth century (Björse and Bradshaw 1998) and the U S Pacific Northwest during the twentieth century for instance (Swanson and Franklin 1992). Now with conversion of some areas back to uneven-aged stand structures and mixed species composition underway in the Carpathians (Chernyavskyy 2009), SFM principles stressing restoration of ecological complexity are particularly germane.

There are strong economic incentives reinforcing the status quo, such as the financial efficiency of even-aged management, support from central budgets, and increasing demand for raw timber exports. Thus adoption of SFM principles by state forestry enterprises will depend on clear evidence of economic feasibility. This is no small challenge for advocates of major transformation within the forest sector. Market-based approaches providing economic incentives for SFM, such as certification, payments for ecosystem services, non-timber forest products, and value-added production, become particularly important in this context.

3 Conserving Biodiversity: Reserves and “Matrix Management”

The Carpathian Mountain complex is the largest in Europe, stretching 1,500 km from Serbia and Romania in the southeast, arching through western Ukraine, Poland, Hungary, and Slovakia, reaching the Czech Republic and Austria in the northwest (Fig. 1). It encompasses over 10 million ha of forestland dominated by spruce (*Picea abies*) and beech (*Fagus sylvatica*) cover types, with smaller proportions of fir (*Abies*

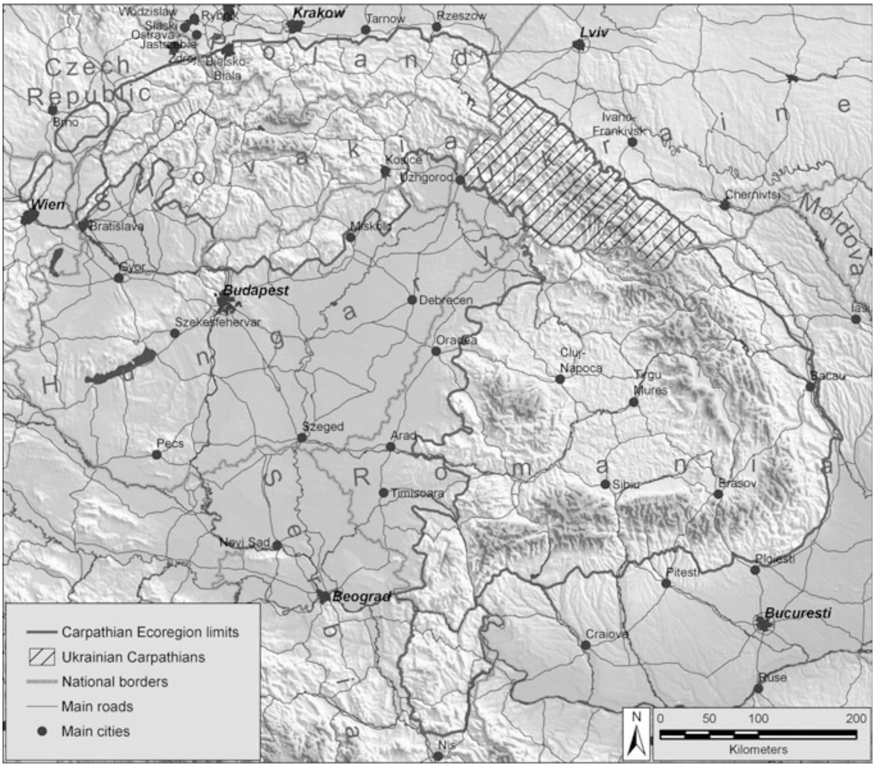

Fig. 1 Map of the Carpathian ecoregion, including political boundaries, cities, and major roads

alba), low elevation oak (*Quercus* sp.), and high elevation pines (*Pinus* sp.). The region is a focus of international attention due to its unique biological and cultural resources, now recognized as of global significance by UNESCO. The Carpathians harbour a full compliment of large European mammal species, including lynx (*Lynx lynx*), wildcat (*Felis silvestris*), river otter (*Lutra lutra*), gray wolf (*Canis lupus*), woodland bison (*Bison bonasus*), red deer (*Cervus elaphus*), and brown bear (*Ursus arctos*). Over 200 species of plants are endemic to this region, and stands of old-growth European beech larger than 10,000 ha are found only here, such as within the Uholka World Heritage Site in Ukraine.

Current conservation efforts in the Carpathians generally fit into three groups. The first focuses on establishment and better management of protected forest areas. The second includes those interested in SFM practices outside of core protected areas, and the third involves maintenance of traditional village systems providing high conservation value cultural woodlands. The tri-lateral East Carpathian Biosphere Reserve and bi-lateral Carpathian Biosphere Reserve, incorporate elements of all three approaches (Fall 1999), but suffer from lack of formalized transboundary cooperation mechanisms and insufficient institutional resources (Elbakidze and Angelstam 2009).

A topic of debate in Europe has been how to optimally allocate land among a mix of protected areas and actively managed areas to secure both natural and cultural biodiversity (Angelstam 2006). However, it is now generally recognized that reserves and SFM applied within a landscape approach are, in fact, complementary, and that both are required to achieve biodiversity conservation across large landscapes (Keeton 2007). Many conservation biologists argue that the first step is to design a functional reserve system containing the most complete and spatially redundant ecological representation possible (Noss and Scott 1997). Protected areas create greater flexibility for active forest management because they minimize risk associated with over reliance on any one approach (Lindenmayer and Franklin 2002). Thus protected areas and SFM are mutually advantageous and self-reinforcing at the landscape scale.

Sustainable management of semi-natural forest and cultural woodlands surrounding reserves is essential to meet conservation objectives. An emerging approach to landscape scale planning, called “matrix management”, focuses on maintaining connectivity among reserves, watershed functionality, and habitat representation on actively managed timberlands (Lindenmayer and Franklin 2002; Keeton 2007). The Carpathian landscape, comprised of a mix of forestlands assigned to different levels of protection, intermingled human settlements, cultural areas and agricultural lands, is in many ways amenable to matrix management. The need to maintain corridors and ecological connectivity is important for maintaining viable populations of species with large area requirements, including the region’s increasingly rare and geographically isolated large mammal populations.

The Ukrainian state-owned forest system (~97 % of forestland as of 2007) already provides the administrative foundation needed to design a comprehensive and complementary system of protected areas and SFM areas. Under recent (2006) forest code revisions state forests are allocated to four main groups. These are “protected forests” (~15 %) set aside for primarily for watershed protection; “recreation forests” (~10 %) managed for recreational uses and tourism; “protective forests” (~25 %) conserved for a variety of ecological, cultural, scientific, and aesthetic reasons; and “economic forests” (~50 %) managed primarily for commercial timber production (Anfodillo et al. 2008). These categories encompass a range of more specific designations, including strictly protected nature preserves (*zapovidniks*, IUCN category I), national nature parks and regional landscape parks (both similar to IUCN category V protected landscapes), and state forestry enterprises (comparable to the U S National Forest System). Since Ukrainian independence in 1991 the area of protected forest has more than doubled nationwide (Nordberg 2007). However, protected areas management remains constrained by lack of funding. Nevertheless, these land allocations provide the building blocks necessary for matrix management, particularly if illegal logging can be curbed.

In the Carpathians as in many regions of the world, there are important questions about how to design the most fully representative and sufficiently extensive system with the greatest likelihood of maintaining viable populations. Currently approximately 16 % of forests in the Carpathian bioregion (Anfodillo et al. 2008) and 17.6 % of the Ukrainian Carpathians specifically (Budyakova et al. 2005) are protected within core reserves (IUCN categories I–III). This is significantly higher than the 5 % average for European countries. An effort by the World Wide Fund for Nature is mapping the distribution of biodiversity and "High Conservation Value" forests throughout the Carpathian Range. This, together with on-going Gap Analyses, will allow more robust prioritization of areas for reserve status or special management consideration. There is also a need to develop mechanisms through which beneficiaries—at regional and larger scales—share the costs of provision (Farley 2009).

4 Silviculural Alternatives for the Carpathians: Providing a Broader Mix of Ecosystem Goods and Services

To complement a functional protected area network, matrix management requires planning and silvicultural practices in actively managed forests and woodlands that will sustain production of a broad range of ecosystem goods and services (Keeton 2007). An emerging approach in SFM internationally, termed "disturbance-based forestry", is particularly relevant to the Carpathians. The concepts are similar to European "natural dynamics forestry" (Angelstam and Kuuluvainen 2004) and "close to nature silviculture" (Chernyavskyy 2009). A paramount objective of disturbance-based forestry is to better conserve biological diversity by emulating the landscape dynamics and disturbance regimes to which organisms are adapted (North and Keeton 2008). The Carpathians have a natural disturbance regime dominated by wind events, ranging from frequent low intensity wind throw (e.g. gap creating disturbances) to moderate intensity and stand-replacing windstorms (Lavnyy and Lässig 2003; Nagel et al. 2006). Thus, innovative silvicultural systems emulating, at the landscape scale, a combination of gap dynamics and moderate intensity disturbances are directly applicable to this region. Examples include "the expanding gap" system first developed in Germany and now utilized in the northeastern U S (Seymour et al. 2005); the "structural complexity enhancement system" first tested in Vermont, U S (Keeton 2006); multi-cohort management systems that emulate the multi-aged stand structure associated with moderate intensity wind regimes (Hanson and Lorimer 2007); and variable retention harvest systems developed in the Pacific Northwest, U S (Franklin et al. 1997). Each of these helps achieve matrix management objectives by maintaining landscape heterogeneity and connectivity across managed forestlands, while also providing opportunities for timber revenue generation and a range of other economic uses.

However, more than three quarters of Ukraine's Carpathian forests are plantations (i.e. regenerated by planting) or regulated even-aged stands (Anfodillo 2008). About 72 % of the harvesting is clearcutting, 24 % is two and occasionally three-stage shelterwood cutting, and only 4 % of stands are managed using selection systems (Mahura et al. 2009). Variable retention systems or irregular shelterwoods (i.e. with retention of reserve trees over multiple rotations) are generally not employed in the Ukrainian Carpathian region, though they are actively used in the Polish Carpathians. Stand structure is less diverse in the resulting even-aged stands compared to multi-aged and natural forests. This holds true for the Norway spruce (*Picea abies*) plantations as well as younger beech and mixed species stands typical of the Carpathians. Compared to uneven-aged primary forests (Fig. 2), even-aged plantations typically have less vertical differentiation of the canopy (i.e. they are single layered), less horizontal complexity (e.g. gap structure), and lower densities of other important habitat characteristics, such as large trees and downed logs (Chernyavskyy 2005; Parpan et al. 2005). Thus, disturbance-based silviculture promoting redevelopment of complex stand structures provides a broader representation of habitat characteristics in managed stands (Franklin et al. 2002). If planned as an element of matrix management, together with reserves and careful scheduling and placement of harvest units, disturbance-based forestry accommodates both timber harvesting and production of non-timber forest products, as well as sustained ecosystem functioning. Disturbance-based forestry is not mutually exclusive of conventional harvesting methods; these of course would be part of the mix at landscape scales.

Mono-cultured plantations in the Carpathians have been particularly susceptible to mortality agents, such as root rots (e.g. *Armillaria* sp.; *Heterobasidion annosum*) and spruce bark beetle (*Ips typographus*), and have been stressed by airborne pollution, including acid deposition and heavy metals. Collectively these factors have contributed to extensive spruce dieback (Badea et al. 2004; Grodzki et al. 2004; Shparyk and Parpan 2004). Although dieback in Ukraine has been less severe than in other Carpathian countries, region wide about 40–50 % of both spruce and fir (*Abies alba*) has been damaged by heavy defoliation (Badea et al. 2004). Hence, there is a pressing need for broader adoption of restorative silvicultural practices, such as systems that convert stand structure from even to uneven-aged and reintroduce mixed species composition. These include sequential partial cutting approaches that promote development of multi-cohort, mixed species stands over time (e.g. Seidl et al. 2008). In Ukraine there are on-going trials of an approach termed "close to nature" silviculture that can be used for conversion purposes (Chernyavskyy 2009). This method employs group selection techniques, with small canopy openings placed around areas of desirable advanced regeneration. Ukrainian foresters have also developed a rapid restoration system involving clearcutting of dead and dying spruce (termed "sanitation cutting") followed by replanting with site-endemic species (Fig. 3). However, recent evidence suggests sanitation cutting often has been used for commercial purposes rather than strictly restorative objectives, exploiting an exemption from limitations on cutting unit size in the Ukrainian Forest Code (Kuemmerle et al. 2007, 2009). Moreover, it is important for restoration treatments to be planned strategically so as to restore high priority sites while minimizing fragmentation and watershed impacts.

Another concern pertains to the current age class distribution of Carpathian forests (Fig. 4), which is heavily skewed towards young to early mature (0–80 year old) plantations (Strochinskii et al. 2001; Anfodillo et al. 2008). This reflects a history of over-cutting during the socialist period, especially during the

Fig. 2 Examples of forest stand structure in relation to age. *Top left* young, managed beech forest in the Austrian Alps. *Top right* old-growth beech forest in the Ukrainian Carpathians. *Lower left* mature Norway spruce plantation in the Ukrainian Carpathians, with some evidence of spruce decline. *Lower right* old-growth Norway spruce-silver fir forest in the Ukrainian Carpathians. Note the higher degree of structural complexity in the older forests, including vertically complex canopies, larger trees, and large woody debris both standing and downed. *Photo credits* W.S. Keeton

Fig. 3 Spruce decline and restoration in the Skole District of the Ukrainian Carpathians. *Left* declining Norway spruce stand with heavy mortality. *Top right* sanitation cut followed by replanting species endemic to the site. *Lower right* foreground shows a young, mixed species stand restored following sanitation cutting of declining spruce. This figure represents a forest restoration pathway, though there is evidence that sanitation cutting is being over-used as a way to circumvent regulations limiting clearcutting size. *Photo credits* W.S. Keeton

1950s (Nijnik 2004), resulting in conversion of landscapes from old to young forest dominated. Some have argued that the current forest age distribution will result in future timber supply limitations if harvest levels are not increased during the near term (Nijnik and van Kooten 2000). In our view, however, this argument discounts the current deficit of harvestable stands (100–120 year old) relative to sub-merchantable stands. Rather, the solution is to allow the merchantable growing stock to build up both passively and through stand improvement treatments, such as intermediate thinnings. Others have drawn similar conclusions, arguing that "harvest potential will increase in the future" and pointing out that the area of mature stands almost doubled from the late 1980s to late 1990s (Polyakova and Sydor 2006). Whereas in the 1990s more than 80 % of gross annual increment was harvested each year, currently legal harvest rates are 50–60 % of annual forest growth in the Ukrainian Carpathians (Anfodillo et al. 2008), suggesting that timber stocks are increasing, not decreasing. Far from limiting future timber availability, the current distribution provides an abundant source from which merchantable timber will recruit over the next several decades.

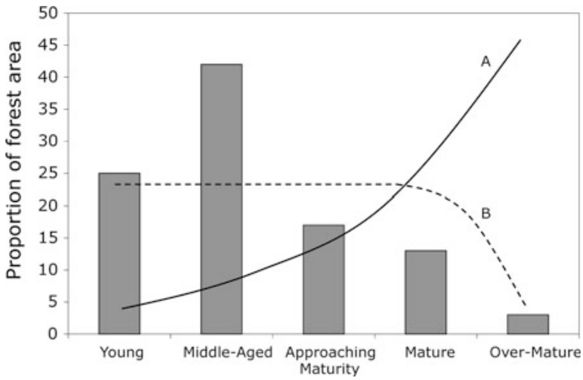

Fig. 4 The bars show the current age class distribution of commercial forests ("economic" group) in the Ukrainian Carpathians using data and classes from Anfodillo et al. (2008). The *solid line* (**A**) represents the probable age class distribution that would develop over time in the absence of human disturbances, and provides a benchmark for understanding the associated changes in forest biodiversity. The *dotted line* (**B**) represents a distribution that would favor sustained timber yield, but would not necessarily provide sufficient representation of late-successional forests. Age ranges for the dominant forest types are as follows: young, 0–40; middle-aged, 41–80; approaching maturity, 81–100; mature, 101–120; and over-mature, >120

Once sufficient merchantable stocking is achieved, careful stewardship to maintain a desired distribution (either balanced across age classes or tilted toward mature and late-successional forests) will sustain timber yields while maintaining a broader mix of ecosystem services (Fig. 4). Polyakova and Sydor (2006) argue that active management will be vital because so much of the forested landscape is in plantations or has developed from afforestation or forest regrowth on abandoned agricultural lands. Forest cover expanded at an annual rate of 0.1 % during the 1990s for the Carpathian region overall; forested area increased by 54,000 ha in the Ukrainian Carpathians from 1988–2004 (Anfodillo et al. 2008). Moreover, given the strong association between biodiversity and forest developmental stages (Stoyko 1998), shifting the landscape towards a better balance of stand ages would both provide a stable timber supply and ensure adequate representation of late-successional habitats. In addition, maintaining a margin of unharvested net growth provides numerous ecosystem services, such as development of stand structural complexity, riparian functionality, and carbon storage. There is unlikely to be a deficit of early successional forest habitat in the future due to forest regrowth on abandoned agricultural lands, which has increased markedly during the post-socialist period (Kuemmerle et al. 2006, 2008).

5 Conserving Freshwater Ecosystems and Watershed Functioning

The need to develop new approaches for integrated watershed management has been recognized internationally as a key element of SFM. The Carpathians have experienced several severe flooding events over the last decade, including particularly destructive floods in 1998, 2001 and 2008. While extreme precipitation is considered the primary cause, the magnitude of flooding has also been attributed to logging and land cover change in some cases (Shulyarenko 2002). For example, Dezso et al. (2005) concluded that recent floods in eastern catchments (Ukraine) of the Tisza river were not caused solely by heavy precipitation, but may also have been influenced by the 10–20 % forest cover loss that occurred from 1993–2001, although these linkages are debated in Ukraine. Thus, an important issue for SFM in the Carpathians is the application of integrated watershed management approaches designed to reduce flooding hazards, such as cumulative effects analysis, spatially-explicit planning, and collaborative governance including local community input (Naiman et al. 1997; Sabatier et al. 2005).

Emerging science describing forest ecosystem regulation of hydrologic and watershed functions is directly relevant to the Carpathian region. Scientists have documented important ecological interactions between entire catchments, riparian forests, and aquatic ecosystems (Naiman et al. 2005; Keeton et al. 2007). In many regions improved scientific understanding has led to regulations and changes in management practices designed to better protect freshwater ecosystems. For instance, delineation of riparian buffers and riparian forest restoration are now frequently employed as central elements of SFM (Gregory et al. 1997). Riparian buffers take different forms depending on context (Lazdinis and Angelstam 2005). Some are entirely off limits to logging or road construction, while others allow limited entry if deemed appropriate (Lee et al. 2004). Many regions employ zonations with varying intensity of permissible management, often including a strictly protected buffer zone immediately adjacent to the stream channel. Broader adoption and enforcement of similar approaches would help safeguard aquatic resources in the Carpathian Mountains. For example, lack of consistent riparian protections is frequently cited as a non-conformity impeding forest certification projects in Ukraine (Kovalyshyn and Pecher 2009). Reforestation and improved riparian protection is needed especially on cutover and degraded main floodplains, which are ubiquitous throughout the Carpathians.

Recently calls have been made throughout the Ukrainian forest sector for increased construction of logging roads (Mahura et al. 2009). This reflects the general disrepair and lack of investment in the existing forest infrastructure and limited forest access, particularly away from valley bottoms. Decommissioning deteriorating, poorly designed roads close to stream channels is an imperative, and the desire for greater access for forest management, fire control, and recreation are also understandable. A year 2000 law required the expansion of the hard-surface forest road network in the Ukrainian Carpathians to 10 km per 1,000 ha by 2010, but this target was not met despite some new construction. The road density today is ~3–5 km per 1000 ha. In our view, forest managers in the Carpathians should proceed cautiously with plans for new road construction. This is vital to minimize road system extent and landscape fragmentation, design well engineered roads with minimal erosive and hydrologic impacts, make use of temporary logging roads whenever possible, and avoid negative impacts to aquatic ecosystems, for instance by minimizing the number of stream crossings.

Much of the harvesting machinery in use in the Carpathians is obsolete by contemporary standards, such as decades-old tracked skidders that cause significant rutting, erosion, and damage to advanced regeneration. For example, by one estimate 60–85 % of harvest units in Ukraine experience significant soil damage due to current skidding practices (Mahura et al. 2009). Beginning in 2005, timber harvesting in mountain forests is permitted only with the use of low impact skidding systems and renovation of the Austro-Hungarian era narrow-gauge railway network. But implementing this policy will require substantial new investment in harvesting and transportation technology, such as mobile cable systems, wheeled skidders, and harvester/forwarder systems.

6 Forest Carbon Management: Opportunities and Incentives for SFM in the Carpathians

Rapidly developing international carbon markets have potential to incentivize aspects of SFM, though they are also fraught with challenges (Ruddell et. al. 2007). Under the Kyoto Protocol's Joint Implementation (J.I.) mechanism, developed countries (Annex I) can purchase credits from nations with transitional economies, including former socialist republics, to offset their greenhouse gas emissions above the cap set by the Protocol. Initially afforestation and reforestation were the primary forest sector opportunities for earning credits. Recent developments in carbon markets outside the Kyoto framework (primarily voluntary markets) have introduced credits for "avoided deforestation" (often termed REDD, or reduced emissions from deforestation and degradation) and "improved forest management" (IFM). The latter requires participants to substantiate that additional carbon will be stored with some measure of "permanence" over a baseline or "business as usual" scenario. There are the added difficulties of accounting for carbon stored in wood products, the "offsets" achieved by substituting wood for more energy intensive building materials, and "leakage" or the emissions from geographically displaced harvesting (Ray et al. 2009). Significant advances in voluntary markets have been made in the last several years to resolve these technical issues.

Ukraine and other Carpathian nations are positioned to immediately benefit from credits awarded for afforestation under existing carbon market mechanisms. In 2002 Ukraine launched a program called "Forests of Ukraine", with the objective of increasing forest cover from 15.6 % (10.9 million ha) to 16.1 % (11.3 million ha) of its total land area by 2015 (Soloviy and Cubbage 2007). According to Nijnik (2001) there are 2.3 million ha available for afforestation in Ukraine alone based on an analysis of current land use, terrain, and soils. This number declines to 1.7 million ha when areas requiring unacceptably high afforestation costs are excluded. Currently Ukrainian forests sequester about 180 million Mg of CO_2 annually through growth in existing forests (Soloviy and Yaremchuk 2001). Areas available for afforestation have the potential to store (i.e. in new forest biomass) an additional 200 million Mg of carbon after 40 years, and would be cost effective for earning carbon credits based either on in situ carbon storage or emissions offset by biomass fuel production (Nijnik 2001).

Ukraine has been signatory to the Kyoto Protocol since 2004, and emitted less greenhouse gas than permitted (by so-called “Assigned Amount Units”), a trend like to continue for some time under most scenarios of economic growth and energy efficiency (Victor et al. 2001). Consequently, forest sector participation in carbon markets would only supplement the already substantial market opportunity Ukraine is likely to enjoy under a successor to the Kyoto framework. Ukraine has been eligible to participate in J.I. sequestration projects, however, no J.I. projects have been conducted in the Ukrainian forest sector to date. Ukraine worked with the World Bank on a trial carbon management project involving afforestation on 15,000 ha of abandoned agricultural land near Chernobyl (World Bank 2006). However, the project was cancelled in 2007 due to contractual, land tenure, and ministerial disputes. Thus, Ukrainian participation in carbon markets remains fraught with challenges, many of them institutional, yet considerable potential remains, particularly under rapidly growing international voluntary market systems. Community support and benefit at the local level also will be important for the success of forest carbon projects in the Carpathians.

There may be opportunities for earning carbon credits through avoided deforestation in areas of the Carpathians experiencing land use pressures, such as recently privatized forests facing subdivision and development in Romania. These opportunities may increase if a $REDD^{++}$ program is adopted by a successor to the Kyoto Protocol and expanded outside of the tropics. Recent research suggests that structurally complex, old-growth Carpathian beech and spruce–fir forests store very large amounts of carbon (Szwagrzyk and Gazda 2007; Keeton et al. 2010a), 50 % more than mature stands and higher than the average reported for temperate old-growth forests globally (Keeton et al. 2010b). By one estimate there are over 322,000 ha of primary (or “virgin”) forest left in the Carpathians (Anfodillo et al. 2008), though it is unknown how much of this remains outside of reserves. Thus, conservation of unprotected old-growth and primary forests would carry significant carbon benefits. A key challenge will be ensuring that a portion of the carbon revenue is returned directly to local administrative units for investment in projects that also benefit local communities.

While still evolving, IFM may add further potential for carbon market participation in the Carpathians. Innovative silvicultural options, including extended rotations and retention forestry, have been developed to enhance carbon storage in managed temperate forests (Nunery and Keeton 2010). These may provide economic incentives for SFM in the future. The relatively long rotations (e.g. 80–140 years) currently required under Ukrainian forest code already offer significant carbon storage benefits, but limit opportunities to create additionality (enhanced storage) over baseline levels. A concern with long rotations, however, is the increasing susceptibility to decline and dieback as spruce plantations age; indeed, some spruce stands have almost complete tree mortality by the time rotations periods are reached (Kovalyshyn and Pecher 2009). Thus, in the Carpathians there may be limitations to the carbon storage benefits typically associated with extended rotations, and restoration of endemic forest composition will be an important element of a comprehensive forest carbon management strategy.

Alternative silvicultural systems specifically intended to promote development of structurally complex, high biomass forests offer additional carbon sequestration opportunities, while also providing economically and ecologically sustainable timber harvests (Keeton 2006; Bauhus et al. 2009). These are most applicable to site-endemic beach, mixed hardwood-conifer, and native spruce-fir stands. Group selection (e.g. "close to nature silviculture") techniques designed to release advanced regeneration and restore native species composition in non-endemic spruce stands are an important element of this strategy (Chernyavskyy 2009).

7 Adapting to Climate Change

A major source of uncertainty for forest managers in the Carpathian region is how to anticipate and adapt to climate change. Regional-scale climate models for the Carpathians predict increases in mean annual temperature, concurrent with increased and decreased winter and summer precipitation respectively (Bartholy et al. 2007). Also predicted is greater irregularity of precipitation patterns, including increased frequency of extreme events (Bartholy and Pongracz 2007). A combination of summer drought and warmer winters may exacerbate insect pest risks and localized species extirpations, particularly for species already suffering geographic isolation and low genetic diversity (Levinsky et al. 2007). Interaction between climate impacts and other ecosystem stressors, such as airborne pollution, invasive species, and land-use change, has the potential to accelerate ecosystem shifts (Aber et al. 2001), and yet this topic appears poorly studied in the Carpathian region.

Adaptation science generally stresses management for ecosystem properties that increase resilience and reduce vulnerability, such as restoration and management for native species diversity and continuous forest cover. Another approach is to expand the representation of geophysical diversity within protected areas, thereby providing potential for difficult-to-predict species range shifts and formation of new assemblages, as occurred with past climate changes (Hunter et al. 1988). A universal challenge will be operationalizing and down-scaling the generalized adaptive strategies developed to date. We recommend this as a topic worthy of further investigation.

8 Conclusion

There is a long history of professional forest management in the Carpathians, but the region is facing new opportunities and challenges. International criteria provide a basic framework for SFM, but implementation approaches need to be adapted to the Carpathian context. Concepts such as matrix management and disturbance-based forestry, as well as multi-level governance incorporating local community involvement in planning and decision making processes, are readily adaptable to the Carpathian landscape. They would help provide a broader array of ecosystem goods and services, including biodiversity conservation and timber revenue, if employed in conjunction with regional level design and establishment of functional reserve networks. An adaptive approach to SFM will be essential due to the anticipated effects of climate change on Carpathian flora and fauna (Björnsen-Gurung et al. 2009). Recent research advances in the fields of watershed management, riparian forest conservation, and logging road system design and development of collaborative planning will help inform improved protections for aquatic ecosystems in the Carpathians. Market based approaches, such as forest certification, carbon markets, and payments for ecosystem services, may help incentivize sustainable forest management for a broad array of ecosystem goods and services. These represent significant opportunities for the Carpathian region. The challenge facing Ukraine and other Carpathian nations is to merge these ideas into a holistic, landscape approach that can be implemented within existing or reformed administrative frameworks.

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