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Forest management, restoration, and designer ecosystems: Integrating strategies for a crowded planet[1]

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Abstract: As the global human population increases, the demand to conserve, restore, create, and sustainably manage ecosystems will increase as well. Forested ecosystems are of particular interest because of the biodiversity they support and their diverse values to people. Developments in conservation, restoration forestry, and in the study of designer ecosystems provide a diverse set of tools with which to pursue sustainable forestry goals. Nonetheless, we suggest that sustainable forestry can only be achieved by fully considering ecological, economic, and social needs in landscapes. This will require a clear realization of the trade-offs in site-specific management approaches and a multifaceted, landscape-scale perspective for evaluation of sustainability criteria. We propose collaborative creation of Sustainable Forestry Portfolios as a means to encourage the breadth of thinking required to guide sustainable forest management. We discuss 3 examples of Sustainable Forestry Portfolios with relevance to different settings in the future: 1) the Triad Approach, 2) Forest Landscape Restoration, and 3) Urban Forestry. In all settings, sustainable forestry is not solely a technical problem, but a challenge that must be met through a multidimensional perspective, interdisciplinary collaboration, and with active engagement of the people that live and work in the landscape.
Keywords: designer ecosystems, restoration, Sustainable Forestry Portfolios.

Résumé : Avec l’accroissement de la population mondiale, la demande pour conserver, restaurer, créer et aménager les écosystèmes de façon durable va aller en augmentant. Les écosystèmes forestiers sont d’un intérêt particulier à cause de leur biodiversité et de leurs valeurs diversifiées pour la population. Les développements dans la conservation, la restauration forestière et l’ingénierie écologique procurent un ensemble d’outils divers grâce auxquels des objectifs d’aménagement forestier durable peuvent être poursuivis. Néanmoins, nous suggérons que l’aménagement forestier durable ne peut être atteint qu’en tenant compte au sein d’un paysage de l’ensemble des besoins écologiques, économiques et sociaux. Cela requerra une vision claire des compromis liés aux approches d’aménagement spécifiques à chaque site et une perspective à l’échelle du paysage des différents aspects sera nécessaire afin d’évaluer les critères de durabilité. Nous proposons la création de portfolios collaboratifs en aménagement forestier durable comme moyen d’encourager l’ampleur de vision requise pour guider l’aménagement forestier durable. Nous discutons de trois exemples de portfolios d’aménagement forestier durable qui peuvent être pertinents à différents contextes futurs : 1) l’approche de la triade, 2) la restauration de paysages forestiers et 3) la foresterie urbaine. Dans tous les contextes, la foresterie durable n’est pas seulement une question technique mais un défi qui doit être envisagé dans une perspective multidimensionnelle, une collaboration interdisciplinaire et avec l’engagement actif des personnes qui vivent et travaillent dans le paysage.
Mots clés : ingénierie écologique, portfolios d’aménagement forestier durable, restauration.

Forests in the Future

Increasingly, ecologists are being confronted with two intellectual frontiers: the ongoing study of pristine natural systems and the exploration of ecological processes where people live and work. Although we know that many native species and processes still remain to be described in remote or untouched areas of the globe, it is becoming clear that human-dominated landscapes hold rigorous and compelling questions for ecological science (Roy, Hill & Rothery, 1999; Grimm *et al.,* 2000; Savard, Clergeau & Mennechez, 2000; Fernández-Juricic, 2004). The global human population continues to grow, leading to an increasingly desperate need for understanding how to conserve native forest ecosystems, restore those we can, and effectively design others to provide a host of services where human presence constrains natural ecological processes (Bazzaz, 2001). Consequently, forest and restoration scientists and other applied ecologists must expand their focus from intrinsic ecological phenomena to include studies of sustainability in a diversity of human-dominated landscapes (Palmer *et al.,* 2004).

Forests have long been flashpoints for societal conflicts between utilitarian and aesthetic values and biodiversity conservation (Cohen, 2004). Humans have used trees for fibre, fuel, shelter, and beauty since the earliest societies (Perlin, 2005) and will continue to do so. The loss of native forests has been a recurring chapter in human ecological history, yet there is little doubt that trees hold a special place in the heart of most people, evoking diverse and deep-seated convictions about ecological health and wholeness (Cohen, 2004). We now know that forestlands function as the great nurseries of the earth’s continents, providing habitat for

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the majority of terrestrial species (Gaston, 2000) and a host of ecological services to humans (Daily, 1997). Although increasing numbers of people depend upon these services, deforestation, land conversion, and a variety of alterations have endangered ecological processes over large parts of the globe. For example, deforestation and geomorphic changes along the coastline of the southern USA decreased the protective capacities of bayou forests precisely when greater numbers of people needed them (Tidwell, 2004). Conservation and restoration of indigenous forests are activities with broad international support. Yet in the world of the future, these efforts likely will not be sufficient to accommodate human demands. Forests of many types and in many places will be needed to maintain global biodiversity and other crucial ecological services through time.

In this article, we discuss developments in the conceptual basis of sustainable forestry, the current challenges that need to be surmounted to achieve sustainability goals, and the roles that forest management, restoration, and designer ecosystems can play in future forest landscapes.

Forestry in the future

The paradigm of sustainable forestry

The Brundtland Report (WCED, 1987) provided a definition of sustainable development that has implications for the sustainability of forest landscapes: "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

This broad international mandate assumes that needs for development and conservation are both essential and need to be integrated in landscapes, although it does not provide guidance on how such an integration might be obtained. We believe a sustainable forestry must start with a commitment to harness all relevant knowledge and proceed beyond narrow values and goals to careful consideration of trade-offs in real landscapes.

The scientific and operational principles that are needed to guide sustainable forestry have been developed in different disciplines with largely distinctive histories and goals. For example, ecologists have long been concerned with sustainability of species and ecosystems (Leopold, 1949; Carson, 1962), and some have sought to explicitly connect the economic and ecological arenas (Mäler, 1974; Constanza & Daly, 1987), but ecological research has historically focused more on understanding and conserving native forests than on meeting social and economic concerns (Costanza *et al.,* 2000; Di Castri, 2000; Alberti *et al.,* 2003). Indeed, efforts to define ecological integrity have sometimes emphasized a need for exclusion of human impacts (Angermeier & Karr, 1994). Not surprisingly, ecological contributions to sustainable forest management have often emphasized the value of forest reserves or intrinsic ecosystem processes with only minor consideration of human dynamics and needs (Groves, 2003). Forestry, in contrast, has traditionally aimed to meet human needs through resource management and utilization, with ecological goals as a secondary consideration (Kimmins, 1992). Nonetheless, the need for a stable and predictable revenue source compelled foresters to engage early in discussions of sustainable resource use (von Carlowitz, 1713) as well as of the broader dimensions of sustainability (Toman & Ashton, 1996; Floyd, Vonhof & Seyfang, 2001). Initially the sustainable forestry concept was limited to ensuring a sustainable wood supply, with an inherent assumption that a forest capable of providing a high volume of timber would also satisfy other human demands (Mantel, 1990). Modern views of sustainable forest management reflect shifts in human values and in perceptions of forests, as societies have transitioned from rural and agrarian to urban and industrial (Bliss, 2003). Ecologists have further expanded the discussion of sustainability by tying it to ecosystem functions and processes and through concepts such as resistance and resilience (Ludwig, Walker & Holling, 1997).

In recent years, the disciplines of ecology and forestry have begun to converge upon a common goal of landscape sustainability that builds upon both their respective strengths. For example, ecological science has developed conceptual models that can be used to guide forest management (Bormann & Likens, 1979; Huston, 1979; Holling, 1992; Odion & Sarr, 2007). Ecological scientists have also recognized the importance of including human needs and values along with existing ecological principles in a broader ecosystem concept (Naveh, 2005). Existing forestry disciplines bring an impressive array of techniques and planning approaches to the practical ecological and economic problems of sustainable forest management (Kohm & Franklin, 1997; Hunter, 1999; Lindenmayer & Franklin, 2003). In addition, other applied ecological disciplines, such as restoration ecology, are pioneering new management techniques (Frelich & Puettmann, 1999; Temperton *et al.,* 2004). Finally, sociological research plays a critical role in linking land use choices with human needs and perceptions (Perz, 2001; Bliss, 2000; 2003). Sustainable forestry needs to use contributions from all these disciplines to achieve a conscious integration of ecological, economic, and social goals. That integration may be pursued by incorporating these 3 goals at a local scale (centripetal management model) or by allocating uses at particular sites to the different goals and evaluating sustainability at a landscape scale (centrifugal management model; Figure 1).

Forest conservation, restoration, and design

Sustainable forestry tools have expanded rapidly in recent years due to improved ecological knowledge, management innovations, and new challenges, as evident in the blossoming of restoration ecology (Frelich & Puettmann, 1999; Sarr *et al.,* 2004; Temperton *et al.,* 2004). Strategies include reserve-based management (reviewed in Noss & Cooperrider, 1994; Groves, 2003) as well as active management approaches, such as conservation and restoration forestry (Drengson & Taylor, 1997; Seymour & Hunter, 1999; Floyd, Vonhof & Seyfang, 2001), and even forests "designed" for specific ecological purposes, such as home gardens, hedgerows, and urban forests (Lamb, 1998). The application of conservation forestry, derived from discussions around the concept of ecosystem management, has been the topic of a number of books in recent years (Kohm & Franklin, 1997; Hunter, 1999; Lindenmayer & Franklin, 2003). These sources have emphasized the roles of natu-

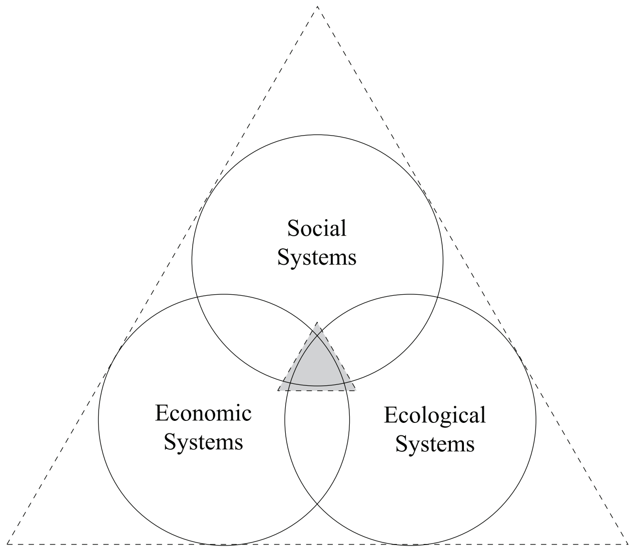


FIGURE 1. Sustainable forestry triad. Sustainable forestry requires the integration of ecological, economic, and social goals in the landscape of interest. This can be achieved by either a centripetal approach that involves integration at the local scale (small triangle in centre of diagram where the circles overlap), a centrifugal approach that emphasizes complementary allocations at the landscape scale (large triangle bounding all 3 circles), or a combination of the 2 approaches.

ral variability, structural and compositional heterogeneity, varied silvicultural techniques, and a multiscale perspective for conserving biological diversity in managed forests. Discussions about and guidance for restoration forestry have also grown rapidly in the last 2 decades (Pilarski, 1994; Frelich & Puettmann, 1999; Sarr *et al.,* 2004). Restoration forestry has usually involved re-creation of a set of specific ecological conditions that were believed to be present in the past or that exist in remaining reference areas (Pilarski, 1994; Keddy & Drummond, 1996).

Designer ecosystems (Palmer *et al.,* 2004) have recently been proposed as another set of tools to apply to the sustainable forestry challenge. The concept, as defined by Palmer *et al.* (2004), has a goal of "creating a well-functioning community of organisms that optimizes the ecological services available from coupled natural–human ecosystems." Most "designed" forests to date have been intensively managed tree plantations with narrow goals of maximizing timber and/or pulp volume (Messier, Bigue & Bernier, 2003), with notable exceptions such as protection forests on steep slopes (Schönenberger, 1987; 2001). Such plantations only fulfilled a narrow subset of the goals listed by Palmer *et al.* (2004), as forest plantations are not likely to provide the same diversity of habitat, aesthetic beauty, and other values of native forests (Hayes *et al.*, 2005). However, their high yield potential has been proposed as a means to ease pressure on primary forests at the global scale (Binkley, 1997; Sedjo & Botkin, 1997). These compensation arguments have been used to justify the value of forest plantations for preservation of biodiversity and other ecological benefits (Norton & Miller, 2000; Hartley, 2002; Sayer & Elliott, 2005). However, designed forests can certainly provide greater ecological services than they do presently (Sayer, Chokkalingam & Poulsen, 2004). A broader set of goals for plantations, for example, could be accomplished through retention and or restoration of native understory species and legacy elements (snags, downed logs), management of horizontal and vertical structure to better support wildlife use, and maintenance of connectivity with native forest remnants (Sayer, Chokkalingam & Poulsen, 2004; Sayer & Elliott, 2005). Challenges include devising ways to measure and increase their ecological functions (Hartley, 2002; Dudley, 2005) or to create forests with ecological functions as the primary objective (Palmer *et al.,* 2004). Increased understanding of other "designer ecosystems" such as windbreaks, hedgerows, and wooded streets has demonstrated the importance of a diverse set of forest conditions for maintaining ecological functions in human-dominated ecosystems (McCollin, 2000; Fernandez-Juricic, 2000; 2004).

Taken together, these advancements in forestry management, restoration, and design provide a valuable tool set for sustainable forestry. Refinement and collaborative application of these and related conservation techniques by a variety of applied ecology practitioners will be needed to pursue the elusive goal of sustainability. To do this will require closer consideration of the obstacles that limit such broad-based and synthetic forestry programs.

Challenges in implementing sustainable forestry

The goal of simultaneously meeting ecological, economic, and social goals through forest management is not new (Floyd, Vonhof & Seyfang, 2001). Any assessment of this topic would be incomplete without discussing some of the challenges in implementing this vision. Sustainable forestry, as with any form of land management, involves tradeoffs in values and goals, as well as practical concerns about the compatibility of particular management actions.

Many people have a particularly strong connection with forests, and this often leads to strong feelings about forest management options (Bliss, 2000; Hunter, 2001). Despite notable progress in developing robust principles for conservation of species and other ecological values in managed landscapes in recent years (reviewed in Kohm & Franklin, 1997; Hunter, 1999; Lindenmayer & Franklin, 2003), public apprehensions about forest management are still pronounced. Therefore, any form of active forest management (*e.g.,* harvest) has to deal with the ecological consequences and public perceptions of the proposed practices (Bliss, 2000; Shindler, Brunson & Stankey, 2002; Shepard, Creighton & Duzan, 2004). Also, distinctions between tree cutting for restoration and for timber production goals are easily blurred, sometimes intentionally, as evidenced by recent controversies over restoration efforts to encourage more fire-resistant ecosystems in the western US (DellaSala *et al.,* 2003; Brunson & Shindler, 2004).

At the same time, landowners and forest users are often justifiably concerned about additional costs, lowered efficiency, and loss of ownership rights caused by added management restrictions inherent in some sustainability criteria (Raedeke, Rikoon & Nilon, 2001). When such restrictions are applied without consideration to their economic or other impacts, they will be resisted. Indeed, a history of adversarial relations between economic and ecologically oriented stakeholders has created a culture of mistrust that can pose a very real obstacle to collaboration by all concerned parties (Hillier, 2003). Cultivation of goodwill, trust, and confidence among all affected parties is perhaps the most immediate requirement for implementing any broad-base program, such as sustainable forestry initiatives (Munton, 1997).

Another major challenge stems from conflicts between local land-use desires and larger-scale sustainability issues. For example, in relatively affluent regions with productive forestlands the "not in my backyard" (NIMBY) perspective with respect to forestry has been documented (Berlik, Kittredge & Foster, 2002). In such cases, utilization of forest productivity is opposed locally in the name of environmental protection, while continued high *per capita* wood consumption encourages resource extraction and ecological damage in other regions. In a similar vein, unregulated exploitation of forests for fuel and timber supplies has led to overcutting in many regions (Kimmins, 1992). In these cases, landowners "exported" environmental costs of operations to the larger land base and surrounding populations (Coats & Miller, 1981), while internalizing profits. There are important parallels on temporal scales. The primacy of short-term needs over longer-term concerns is a major source of unsustainable land use worldwide (WCED, 1987).

Other challenges for implementation of sustainable forestry are derived from urgent and ongoing needs of resource-dependent communities. Especially in developing regions, immediate shelter, fuel, and economic needs of human populations often limit restoration options that ecologists or foresters could hope to implement. Any forest restoration approaches that further diminish the suite of benefits local populations gain from degraded forests (*e.g.,* replacement of Eucalypt monocultures with lower yielding mixed species woodlands or establishing long-term livestock exclusion) are unlikely to gain lasting support (Maginnis & Jackson, 2005). Indeed, Geist and Galatowitsch (1999) developed a "reciprocal ecosystem restoration model" to describe the synergistic linkages between investments in human capital and ecological functions. They argue that the development of human capacity is a natural precursor to the commitment and investment required for enduring restoration or sustainable management. Especially in urban and suburban landscapes, a host of human concerns will affect the selection of restoration or other forest management options. Local effects on neighbourhood aesthetics, water resources, crime, recreation, sound levels, and even perceived impacts on property values will need consideration (Hunter, 2001).

Given the challenges to implementing sustainable forestry in landscapes with diverse sets of human constraints and goals, ecologists, foresters, and restorationists will need to give careful thought to these and other challenges. Together they need to provide leadership in creating integrative, multidimensional, and multiscale approaches for sustainable forestry.

Building Sustainable Forestry Portfolios

A wealth of knowledge and techniques for implementing restoration and sustainable forestry practices already exist. However, the challenges discussed above indicate that not all components of sustainable forestry, as defined in Figure 1, can be easily accomplished at every location and all management practices involve weighing trade-offs in ecological, economic, and social values. When viewed as different elements of a landscape portfolio, apparently conflicting land-use practices can actually be complementary. We therefore propose a general approach, the "Sustainable Forestry Portfolio", as a useful framework to organize and illustrate relationships among types of natural and human-designed ecosystems and to ensure diverse perspectives are included. The portfolio approach is widely used for conservation planning and reserve design at landscape (Groves, 2003; Davis *et al.,* 2003) and regional (Jongman, Külvik & Kristiansen, 2003) scales. It has only recently been applied in human- or commodity-oriented landscapes (Costanza *et al.,* 2000; Machado *et al.,* 2006). In addition, we suggest that participation in all aspects of development and implementation of the Sustainable Forestry Portfolio will challenge scientists from various disciplines to work together. It will force all stakeholders to put their specific needs and constraints into the larger ecological, economic, and social context necessary to attain sustainability goals (Figure 1).

Below we discuss 3 approaches for assembling Sustainable Forestry Portfolios. Each approach is presented in the context of particular landscapes and the social or historical settings where it has been developed. However, these approaches should not be viewed as rigid prescriptions, but as examples of the array of tools that may be appropriate to develop Sustainable Forestry Portfolios across a wide range of future forest landscapes.

The Triad Approach

Forest sustainability is a major concern, even when population density is low and there are large expanses of forested lands (Kohm & Franklin, 1997; Lindenmayer & Franklin, 2003). In order to translate the sustainable forestry concept into management, Seymour and Hunter (1992) developed the "Triad Approach" (Figure 2). This strategy employs a portfolio approach in that it allows different areas in a landscape to be assigned to one of 3 management classes with clearly defined purposes: 1) Protected areas, 2) Extensive forestry, and 3) Intensive forestry. Protected areas are intended to conserve biodiversity. Extensive areas, where the economic and ecological values are blended, are managed with largely open forest access, allowing the social needs for recreation, aesthetics, and other uses to be met. The third component includes plantations or naturally regenerated forests that are intensively managed for commodity production. The different elements of the triad approach overlap crudely with the sustainable forestry concept (Figure 1), but it minimizes conflict at specific locations by explicitly assigning a priority use to one of the sustainability elements (Figure 2). For discussion purposes, this type of model can be labelled a centrifugal model, as specific locations within a landscape are pushed from general, multipurpose use into specialty categories. A centrifugal land use model provides the simplest means to minimize conflict within a portfolio, but it requires that assessment of the sustainability of management is done at a scale large enough that all 3 dimensions of the sustainable forestry triad (Figure 1) can be satisfied.

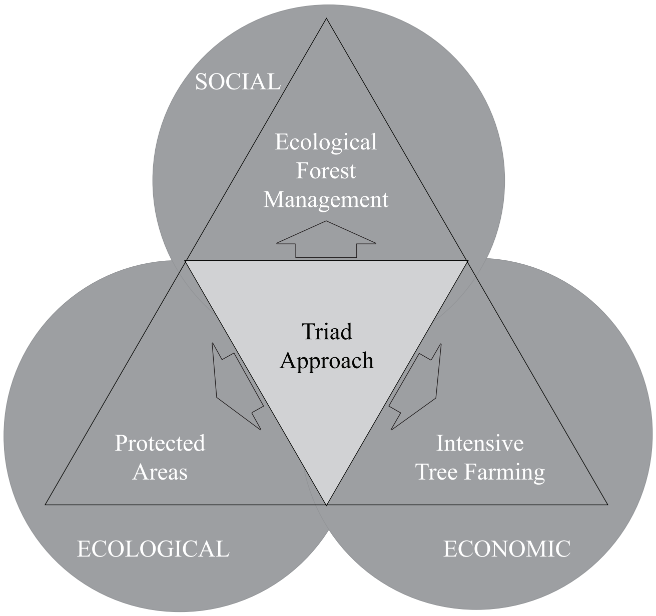


FIGURE 2. The Triad Approach overlaid on the elements of sustainable forestry. Block arrows illustrate the centrifugal model of assigning land management to discrete elements.

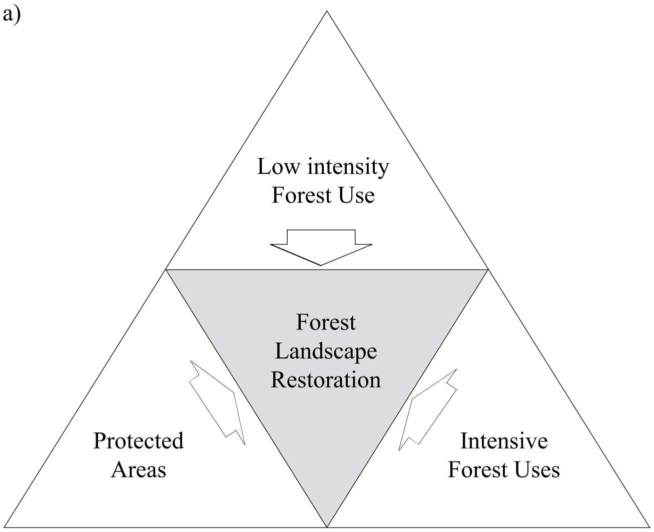
The first formal applications of the triad approach are being implemented in Canada. For example, the 5.5-million-ha Forest Stewardship Council (FSC)–certified area of public land managed by Alberta-Pacific (Al-Pac) is managed by the triad approach. Within the triad, Al-Pac manages among others fast-growing hybrid poplar (*Populus*) tree plantations on short, even-aged rotations, usually on leased private farmland. By growing trees in a tightly controlled environment, local mills are guaranteed a long-term, economically viable fibre source. Extensive forestry sites, which provide the greatest challenge of the 3 approaches (Seymour & Hunter, 1999), are applied to the majority of the land base. The challenge of extensive forest management is to maintain biodiversity and ecosystem functions while sustainably extracting wood fibre. To accomplish this, the foresters attempt to match forestry operations to natural disturbance patterns at the stand and landscape scale (Bergeron & Harvey, 1997). The protected areas are managed as reference areas where natural disturbances and associated biodiversity can be monitored. This approach has broad-based support among the participating industry, First Nations, and the environmental communities in the region. With other related approaches, such as the QUAD Approach (Messier & Kneeshaw, 1999), the triad is being explored as a conservation approach for the boreal forest region of Canada (Messier, Bigue & Bernier, 2003). It may also provide elements of a framework for sustainable development in regions with large areas of natural forest and rural poverty (*e.g.,* parts of Amazonia).

For successful application, the triad approach requires ownership control or cooperation for the entire landscape and/or flexibility in assigning land allocations to any of the 3 uses. Consequently, the approach works best in settings with abundant old forest and a dominance of large ownerships. In settings where forest landscapes are too small or are already fragmented (*e.g.,* all private forestland in Croatia or Poland is in ownerships < 5 ha), political and ownership boundaries and constraints may prohibit management under a single centralized plan (Ohmann, Gregory & Spies, 2007). Instead, incentives or policies may encourage different landowners to provide different portions of the triad (Spies *et al.,* 2007). Aligning ownership patterns with different sides of the triad is less effective where ownership patterns are determined by biophysical gradients with different ownerships having different potential for productivity, biodiversity, and other ecological processes. For example, in parts of the western United States private land is typically at low elevation and biologically rich, whereas federally protected areas are typically high-elevation landscapes with less biodiversity potential (Hansen & Rotella, 2002). Nonetheless, the triad approach provides a conceptual basis for developing management strategies for future forests in a variety of ownership settings where population densities are low to moderate and land tenure is secure.

Forest landscape restoration

In areas with high human population densities and growth rates, the above-described requirements for successful application of the triad approach are likely not fulfilled. Especially in landscapes with high rural population densities and rural poverty, large coherently managed landscape units are not available because much of the landscape has likely been converted to secondary forest or pasture (Maginnis & Jackson, 2005). In addition, histories of exploitation by centralized governments or external corporations have frequently disrupted the human ecology of many traditional agricultural systems (Lamb & Gilmour, 2003), leading to a call for community or bio-cultural restoration in conjunction with ecological restoration efforts (Janzen, 1988; DellaSala *et al.,* 2003). In these settings, a spatially integrated approach may be more appropriate, where ecological, social, and economic goals are pursued in smaller portfolio elements in close proximity or with multiple uses. The high population pressure necessitates a centripetal model (*i.e.,* no area can be exclusively assigned to a single use; Figure 3a). Instead, multiple sustainability elements have to be pursued together, where relative weights of each component likely differ in close proximity. Obviously, in such situations conflicts among land uses are more likely and the range of management options is narrower. It is also crucial for long-term sustainability that local residents are continuously involved in management decisions (Lamb & Gilmour, 2003).

Parallel to the triad approach in forestry, Forest Landscape Restoration (FLR) focuses on assessment of restoration efforts on ecosystem functions at the landscape rather than site scale (Maginnis & Jackson, 2005). FLR is a portfolio-based approach that is gaining strength as a process for collaborative forest planning in such settings (Barrow *et al.,* 2002). It emphasizes consideration of landscape context while at the same time considering human well-being, recognition of local needs and involvement, and land-use trade-offs (Maginnis & Jackson, 2005). Necessarily the restoration approaches must extend beyond technical aspects of ecosystem restoration such as tree establishment. It needs to include collaborative or formal policy mechanisms to ensure a)



b)

Figure 3. a) Forest Landscape Restoration as a centripetal (spatially integrated) model for developing a Sustainable Forestry Portfolio. b) Landscape dominated by agroforestry near Dilla, Ethiopia, including enclosed homesteads with home gardens. Enset (*Ensete ventricosum*) is the major food source, with a large variety of staple food crops, vegetables, and tree crops, including *Eucalyptus* trees planted around fields or building sites for building material or sale. Coffee (*Coffea* spp.) trees planted under large shade trees (*e.g., Ficus*) provide the major cash crop. Population density in the region ranges from 200 up to 900 people per square kilometre (photo credit: Klaus Puettmann).

that all stakeholders understand and agree to the local trade-offs proposed to achieve landscape sustainability.

In many regions, traditional ecological knowledge and agroforestry systems provide a rich reservoir of strategies for meeting ecological and social needs within the FLR framework (Folke, 2004). For instance, home gardens are already meeting a number of ecological and human needs in some rural communities (Jose & Shanmugaratnam, 1993; Das & Das, 2005; Figure 3b). Home gardens can provide relatively stable food and fuel sources, domestic animal forage, and fibre and fruit for household income, while providing ecological services such nutrient cycling, soil stabilization, and high plant and animal diversity (Méndez, Lok & Somarriba, 2001; Das & Das, 2005). Also, forests traditionally managed for other purposes, such as sacred groves (Bhagwat & Rutte, 2006), may provide opportunities for the beginnings of conservation networks. Foresters and restoration ecologists may need to be opportunistic and incorporate such site-specific approaches and resources within larger-scale Sustainable Forestry Portfolios.

Forests in the city

Living conditions for humans are becoming increasingly dominated by urban settings (Bolund & Hunhammar, 1999; Palmer *et al.,* 2004), yet urban ecology remains in its infancy (Grimm *et al.,* 2000; Alberti *et al.,* 2003). Although more people are likely to live in an urban or suburban setting than in native forests (close to 50% of humans now live in cities), people remain as dependent on nature as ever. Ecological services from urban and community forestlands are of direct value to many people in cities (Bolund & Hunhammar, 1999; Bray *et al.,* 2003; Daley, 2006), providing air purification, climate modification, and wildlife habitat as well as distinctly social benefits, such as noise reduction, recreation, and beauty. The ecological integrity and biodiversity of urban forest environments depends upon current land uses as well as spatial and historical factors (Fernandez-Juricic, 2004; Cadenasso, Pickett & Schwarz, 2007). Management approaches in urban settings range from simple preservation to restoration or even creation of forested ecosystems. The ecological benefits of these efforts are far from trivial. A recent assessment estimated that metropolitan areas across the United States averaged 33.4 percent tree cover, an area equivalent to the size of the state of Texas, USA (Dwyer *et al.,* 2000).

Many human needs are met from landscapes surrounding cities, but a significant and growing number can only be met directly within the human-dominated landscape (Bolund & Hunhammar, 1999). The current portfolio of forested urban environments typically includes tree-shaded streets, parks, urban and community forests, municipal watersheds, and wooded semi-natural areas along streams. Because of limited space and high population pressures in urban settings, a Sustainable Forestry Portfolio will require that land uses be closely juxtaposed and integrated (Figure 4). In urban settings the 3 dimensions of the sustainable forestry triad are commonly broken down into narrow objectives built around social or ecological services, such as visual quality, noise reduction, recreation, or wildlife habitat for specific sets of species. The economic services may be expressed through enhanced real estate values near urban forests. In many parts of the world, especially in developing

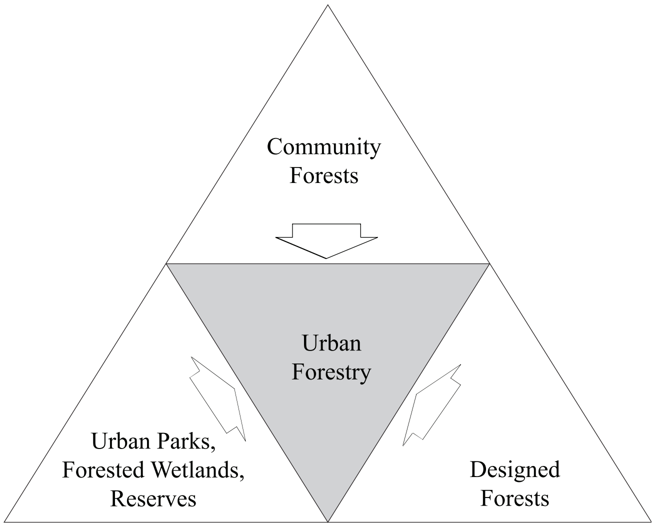


FIGURE 4. Elements of a centripetal Sustainable Forestry Portfolio for an urban forestry setting.

countries, this portfolio might be expanded to include provision of some consumptive uses such as fibre, fuel, or food. Due to the high visibility of any urban forest uses and their direct effects on many people, careful selection of compatible uses will be necessary.

The options for more intensive forest uses will likely be considerably constrained in most urban settings because of safety and environmental quality concerns, but such settings may prove to be particularly fertile experimental grounds for novel investigations and applications of ecology, such as explorations of effects of urban forests on ecosystem properties (*e.g.,* macro- and microclimate dynamics, carbon and nitrogen retention and cycling rates) in the city and surrounding regions, studies of metapopulation dynamics of native and non-native plant and animal species, and development of urban and suburban forest habitat models. A particularly relevant and underexplored realm concerns how traditional forest dynamics affect and are affected by the surrounding developed landscape.

Urban areas are the sources of the great majority of global emissions and resource use (Grimm *et al.,* 2000), yet their inhabitants are often the most isolated from the ecological consequences of their actions. Therefore, urban ecosystems may pose the most urgent and innovative settings in which to pursue sustainable forestry goals. We see great benefits from a function-driven approach, such as designer ecosystems to provide critical ecological services of direct benefit to humans (Bolund & Hunhammar, 1999) and at the same time to foster the ecological awareness of the population. Urban forests can be created and managed to provide fibre, local food sources, altered microclimates, sediment retention, fuel, or other resources beyond simply aesthetic goals. The ecological, economic, and especially social contributions of such novel ecosystems will be of increasing value in the future.

Designed urban forests are also ideally situated to serve as educational ecosystems. Scientists have repeatedly stressed that an ecologically literate population is a prerequisite to sustainability (Lubchenco *et al.,* 1991; Orr, 1992; Louv, 2005). A key to attaining ecological literacy is to provide opportunities for people with a variety of ages, backgrounds, and interests to engage with nature. At the same time, urban forests can become a focus for cultural "restoration" and social interactions. School gardens and arboreta constructed to teach students about ecology and production of resources are valuable teaching tools that can encourage local traditions. There are and will continue to be many interesting questions to consider in the ecology of such ecosystems both on-site and with respect to their influences on larger cultural landscapes.

Sustainable Forestry Portfolios and the larger landscape

The design of Sustainable Forestry Portfolios needs to incorporate aspects of the different approaches described above. It requires an explicit acceptance of the premises that 1) ecological, economic, and social dimensions are all of high value in forests, 2) not every goal can be achieved on every part of the landscape, and 3) sustainability can only be adequately evaluated in terms of ecosystem processes and functions at the landscape scale. In areas with lower population pressures, centrifugal, spatially assigned portfolios, such as the triad approach, are already demonstrating ways to achieve sustainable forestry goals. FLR and the larger field of ecological restoration are also beginning to move towards integration of all 3 dimensions of sustainability (Higgs, 1997; Maginnis & Jackson, 2005). Given the unique pressures often present in densely populated areas where FLR is practiced, spatial assignments to narrow objectives must be replaced by a centripetal portfolio of services provided together in the most harmonious ways possible. In urban settings, space limitations require an even wider portfolio of goals to be pursued together. We are only beginning to understand the ecological services that can be provided in urban forest landscapes and how they will integrate with existing and future economic and social goals. Therefore, the portfolio concept must be extended beyond strict spatial land-planning approaches towards the development of integrated planning and management processes that emphasize representation of ecological, economic, and social goals in landscapes over time.

The specific design and effectiveness of Sustainable Forestry Portfolios will also depend upon how they fit into larger regional or global conservation frameworks. In densely settled regions, such as Europe, urban forests and other restored or designed ecosystems have the potential to contribute to larger conservation portfolios, such as Econets (Jongman, Külvik & Kristiansen, 2003), which propose land allocations for biodiversity conservation. For instance, hedgerows in Europe provide a number of ecological and aesthetic services to agricultural landscapes in which they occur, including increasing insect and bird diversity and increasing connectivity (Lewis, 1969; Parish, Lakhani & Sparks, 1994; McCollin, 2000). Urban parks and wooded streets are also known to provide habitat for many bird species in urban and suburban environments (Fernandez-Juricic, 2000; 2004). While the design and management of Sustainable Forestry Portfolios will be of primary concern to local communities they support, the larger ecological and conservation communities may play an important role in assessing contributions of such portfolios to regional, continental, and global conservation goals.

In all settings described above, the Sustainable Forestry Portfolio concept needs to include a suite of ecological, economic, and social goals. However, the relative importance of each goal, as well as the degree of spatial differentiation among and mixture of portfolio elements must fit the realities on the ground. This leads to a need to apply multidisciplinary analysis to compare the efficacy of different portfolio designs in meeting sustainability goals. Moreover, Sustainable Forestry Portfolios must develop an inclusive and collaborative environment that builds trust and engagement if they are to succeed and endure (Mosely & KenCairn, 2001; Rangan & Lane, 2001). Such collaborative efforts can themselves be challenging (Wondolleck & Jaffee, 2000), but there is little question that they will increase in the future as previously ignored participants and values are fully and equitably recognized in forest landscapes.

We conclude that the pursuit of sustainability in future forest landscapes will require synthesis of knowledge and skills from a number of established ecological and social disciplines. Advances in forest management, restoration, and ecosystem design will be particularly valuable. However, meeting challenges of sustainability will require not only applications of specific techniques but their creative integration in landscape-scale Sustainable Forestry Portfolios. It will also require involvement with and investment in the humans who will undoubtedly also play an important role in the forest landscapes of the future.

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