Josef Křeček · Martin Haigh
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Catrin Promper *Editors*

Ecosystem Services of Headwater Catchments

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Preface

Changes in headwater and mountain watersheds have major impacts on both the sustainable development of their headwater regions and on those who live downstream. New and effective responses to problems related to upland conservation and mountain watershed management are as necessary today as they were a hundred years ago when the oldest government services for torrent and avalanche control, and forest protection, were created. Water yielded from 'protective lands' cannot be considered as being of a good quality by definition. In addition, the impacts of the over-exploitation of resources, developments related to transport, tourism, forestry, agriculture, water supply, power supply, mining, etc., as well as global climate change and non-point pollution from various sources, can and have seriously degraded many fragile headwater environments.

Headwater control aims to promote grounded, better integrated and more self-sustainable development in headwater environments. It is constructed upon three principles: First, it recognises that headwaters are vulnerable habitats much threatened by environmental change, both climatic and more directly anthropogenic, such as the anthropogenic degradation of forests, biodiversity, ecosystem health, waters and soils and the damaging effects of air pollution, agriculture and economic development. Second, it argues that direct intervention can secure environmental quality in headwater environments through pollution control, forest engineering, water management, soil conservation, torrent control, landslide mitigation, land reclamation, bioengineering, applied environmental education and action-oriented community participation. Finally, it emphasises the practical application of holistic integrated environmental management, both in its biophysical and social components.

Short-term economic criteria are not able to guarantee ecological stability in headwater catchments. This book takes this agenda forward by analysing the environmental benefits of headwaters on a broader scale and by focussing on the problems of evaluating and conserving the ecosystem services they provide.

This volume contains 24 papers selected from contributions to recent meetings of the European Forestry Commission Working Party on the Management of Mountain Watersheds, which is managed by FAO (Food and Agriculture Organization of the

United Nations). The Working Party—its biennial sessions and intersession activities—focusses on the continuous exchange of knowledge and experience between professionals in Europe and other regions of the world confronted with similar issues.

This volume is cosponsored by the International Association for Headwater Control (NGO founded in 1989). It aims to promote inclusive stakeholder dialogue in headwater regions and to bring together the perspectives of applied science practitioners, researchers, policymakers and community groups.

Prague, Czech Republic — Josef Křeček
Oxford, UK — Martin Haigh
Rome, Italy — Thomas Hofer
Oulu, Finland — Eero Kubin
Vienna, Austria — Catrin Promper

Contents

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Martin Haigh, Ph.D. is emeritus professor of geography at Oxford Brookes University, Oxford, UK. Formerly, he was (vice) president of the 'World Association for Soil and Water Conservation'. He is a co-founder of the UNESCO-recognised *International Association for Headwater Control* and co-organiser of most of its international conferences. He is a UK national teaching fellow and a senior fellow of the Higher Education Academy. In 2010, he was awarded the Royal Geographical Society's *Taylor and Francis Award for Excellence in Geography Teaching (Higher Education)*. Martin's current work includes environmental education as well as technical research in landslide prediction and landscape reconstruction in mining and mountainous areas.

Thomas Hofer is forestry officer and leader of the Watershed Management and Mountains Team at the Food and Agriculture Organization of the United Nations (FAO). Since 2006, he served as the secretary of the *EFC/FAO Working Party on the Management of Mountain Watersheds*. He has vast field project experience in Asia, Eastern Europe, Africa and Latin America. He has coordinated the development of a number of flagship publications on watershed management, sustainable mountain development and forest hydrology.

Eero Kubin, Ph.D. is former president of *EFC/FAO Working Party on the Management of Mountain Watersheds* and management committee member of EU COST Action 725. Over 15 years, he served as director of the Muhos Research Unit of the Finnish Forest Research Institute, and he is leader of long-term research projects on phenology and environmental aspects of forestry practices. As docent of Oulu University and Helsinki University, he is lecturer on forest ecology and supervisor of several doctoral thesis.

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Part I
Headwater Environment and Natural Resources

Chapter 1
Headwater Catchments: Foundation Pillars for Ecosystem Services

Elaine Springgay

Recognizing the multi-functionality of landscapes and forested catchments beyond their ability to provide goods, such as timber, non-wood forest products and minerals, is increasingly more important due to continuous land-use and climate changes. Growing populations have led to increased pressure on land, and diminishing natural resources has forced us to face the fact that land and many of its resources are finite, or regenerate significantly slower than they are being utilized. It is not only about the over-consumption of resources, but impacts on the processes that generate these resources. Although the multi-functionality of landscapes is increasingly acknowledged, the inclusion of ecosystem services in policy and practice has been slow, thus moderating the potential for improved integrated landscape approaches.

'Ecosystem services' is a collective term used to describe the plethora of functions provided by ecosystems or landscapes. The Millennium Ecosystem Assessment (MEA 2005) defines ecosystem services as "the functions and products of ecosystems that benefit humans, or yield welfare to society". These include soil fertility, erosion and avalanche control, water regulation and purification, groundwater recharge, carbon storage, wildlife habitat, aesthetic beauty, as well as many others. The term, which gained momentum in the late 1990s, was coined in the mid-1980s (Ehrlich and Mooney 1983) and modified from the term 'environmental services' described by Wilson and Matthews (1970 in Lele et al. 2013). It is often used to encourage integrated landscape management, based on the premise that an ecosystem or landscape that is managed for the conservation of its functions is a healthy one that is resilient to shocks (natural and human-made) and will continue to provide a multitude of goods and services for current and future generations.

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A holistic, integrated landscape approach that includes ecosystem functions is not a new concept. Throughout the first half of the twentieth century, Aldo Leopold argued that the human-centric approach to land management was unsustainable, and therefore, an evolution in ethics was required in order to properly care for land. Leopold (1949) called for a philosophical change in ideals, referred to as the 'land ethic'; it was suggested that by enlarging our sense of community to include soils, waters, plants and animals, an intrinsic value for the environment could be established, resulting in improved conservation and protection. In other words, we should care for our environment the way we care for our neighbours, and society, at large.

Instead of a philosophically based land management approach, a more economic (or market-based) approach evolved. The modern-day concept of including ecosystem function in land management recognizes that the ecosystem or landscape provides services in addition to goods. These services can be valued or monetized, in order to quantify the benefits provided by ecosystems and/or incentivize the mainstreaming of improved landscape management and the inclusion of ecosystem services in practices and policies. However, calculating a market value for these services and determining who pays for such services and to whom, can be complex, which has contributed to the slow adoption of ecosystem services in policy and practice. Similarly, Leopold's 'land ethic', a market-based approach also requires a shift in perspective as traditionally many of these ecosystem services are seen as 'free'. Arguably, many of these services are invaluable.

While ecosystem services are universally important, across all landscapes and at different scales, they are particularly important in headwater catchments: upland areas reputed as the sources of our water supplies, and refuges for biodiversity. As such, it can be said that upland catchments are a main life support, the foundational pillars for our planet. For example, upland areas support approximately one-quarter of terrestrial biological diversity, with half of the world's biodiversity hotspots concentrated in mountain regions (Spehn et al. 2010).

Mountains provide freshwater to over 50% of the world's population (Ariza et al. 2013), which is why they are often referred to as the Earth's "water towers". It is estimated that 75% of water is derived from forested watersheds (MEA 2005), and as much as 90% of a river's flow may originate from the river's headwater catchment (Kirby 1978; Saunders et al. 2002); therefore, headwater catchments are vital for our water supply used for agricultural, domestic, industrial and environmental purposes. As such, these catchments also influence the flow of sediments, nutrients and organic matter downstream, influencing production systems, water quality and energy production.

Due to their altitude and slope, headwater catchments are comparatively fragile ecosystems susceptible to long-term impacts due to natural and/or human-induced shocks, as well as climate change. The remoteness of these areas can also mean they are overlooked, or passively addressed in management and policy, despite their vital role of providing ecosystem services locally and further downstream (Ariza et al. 2013).

The important links between forests and water resources were internationally acknowledged in 2002 by the Shiga Declaration on Forests and Water. However, since then the adoption of integrated policies and practices to address water regulation (quality and quantity), as well as disaster-risk mitigation/management has yet been inadequate to non-existent. Since the signing of the Paris Agreement (2016) by over 190 countries and the adoptions of Agenda 2030 whose Sustainable Development Goals (SDGs) set universal targets, applicable to both developing and developed countries, the push for integrated management and increased recognition of ecosystem services in policy and practice is timely. Agenda 2030 includes forests and mountains in both SDGs 6 (water) and 15 (land), with both goals recognizing the link between forests and mountains to water resources, thus creating renewed momentum and incentives for improved policies and practices.

Collaborative efforts, such as the International Forests and Water Agenda, a process which includes organizations such as the Food and Agriculture Organization of the United Nations (FAO), the International Centre for Integrated Mountain Development (ICIMOD), the World Agroforestry Center (ICRAF), the International Network for Bamboo and Rattan (INBAR) and the International Union for Forest Research Organizations (IUFRO), have strongly advocated for integrative forest-water policies and practices based on sound scientific understanding. The Forests and Water Agenda has been successful at establishing a network of stakeholders representing both forest and water sectors, as well as international organizations, academic institutions, civil society, government and non-government actors, who are actively engaged in sharing knowledge and experiences.

At the XIV World Forestry Congress in Durban, South Africa (September 2015), the Agenda launched *Forests and Water: A five-year action plan* (2016) to guide international concerted efforts in improving forest management for water-related ecosystem services. The launch was a major milestone in the Forest and Water Agenda process as it marked a clear transition from discourse to action.

The Action Plan precipitated the establishment of the Forest and Water programme at FAO, which aims to assist countries in the development and implementation of scientifically-based integrated forest-water policies and practices that will contribute to meeting their Agenda 2030 targets. This will be achieved through advocacy, as well as the sharing of scientific knowledge and the lessons learned regarding policies and practices between regions and countries.

Since 1950, the European Forestry Commission (EFC) has had a group dedicated to addressing upland watershed management, including soil conservation, water management, disaster risk reduction/management and restoration of degraded lands in upland watersheds. The EFC Working Party on the Management of Mountains and Watersheds is tasked to engage EFC member countries in an information exchange on forest and water policies, and watershed and risk management practices, as well as to highlight gaps in research, policy and practice (Hofer and Ceci 2012). The Working Party has remained relevant for over 60 years by continuously engaging in emerging issues of global importance, including the recent issues of climate change and ecosystem services. For example, a Working Group on Forests and Water was established in 2014 to address the water-related ecosystem services provided by mountains and their forests; the Working Group collaborates with the FAO Forest and Water Programme to share scientific knowledge and

European policies and practices with the international community. As such, the EFC Working Party on the Management of Mountains and Watersheds, along with collaborating institutions, organizations and researchers, have contributed to this publication to improve the understanding of ecosystem services in a changing world and the implications this has in practice, policy and society.

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Chapter 2
Technical and Ecological Methods to Control the Water Cycle in Mountain Watersheds

Edward Pierzgalski

1 Introduction

In the Polish part of the Sudeten and Carpathian Mountains, the average annual precipitation ranges from 800 to 1500 mm. Runoff coefficient in mountain catchments there varies from 0.4 to 0.9. Seasonal variation in runoff, and, particularly, extreme events (floods and droughts), cause series problems in the down-hill urban areas, as well as in agriculture and forestry. Namely, heavy rainstorms are harmful, producing devastating surface runoff, soil erosion and stream channel instability. But, in the last years, the periods of water deficit are more frequent.

Nowocień (2008) reported the annual loss of soil in catchments of the Carpathian 280 t/km^2. Mountain streams with slopes of above 40% are very dangerous in forming flash floods by storms exceeding 40 mm of rainfall. The rapid velocities in streams initiate transport of large amounts of debris-flow including boulders and rock blocks. The debris come primarily from the erosion of channel bottoms and banks, but some is derived also by landslides. These processes lead to sedimentation in rivers and water reservoirs (from a few to several tens of centimetres annually). Sheet erosion causes the loss of surface soil layers, particularly, the organic particles, fertilizers and various chemicals. Thus, the soil erosion processes contribute also to the transfer of pollutants and increased risk of flooding. Gully erosion is still a major factor contributing to degradation of the environment in mountain watersheds in Poland. Despite the fact that gully networks in the mountains are already strongly developed, they are still growing due to the forest logging practices.

The aim of this paper is to present results of long-term hydrological studies on forest hydrology conducted by the Polish Forest Research Institute, and to assess the eco-services (technical and ecological measures) adopted in mountain basins by the Coordination Center for Environmental Projects (2010) in 2007–2015. The

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specific objectives of this project were to mitigate environmental damages and to support: water resources recharge, conservation of soil, and control of torrent erosion, stream channels stability of biodiversity.

2 Material and Methods

In general, the project has been implemented in 55 Forest Districts in the mountains. Approx. 3500 different measures were applied, including 130 reconstructed and new ponds, rehabilitation of 53 km of skid-roads, and revitalization of 173 km of streams. The partial tasks were divided into three main groups:

1. To increase the retention capacity
2. To reduce erosion processes (sheet, rill, gully and stream channel erosion)
3. To restore biological corridors in streams

Methods for enhancing the water retention capacity are shown in Fig. 2.1, to reduce erosion processes in Fig. 2.2, and to restore biota in mountain streams and rivers in Fig. 2.3.

Environmentally sound forestry practices were adopted in mountain watersheds to control extreme hydrologic events. The considered interactions between water and forest resources are shown in Table 2.1

The effects of forest harvest on runoff have been studied in two forest catchments located in the Sudeten Mountain and harvested in the 1980s: *Czerniawka*, with only 4% area harvested, and *Ciekoń*, where the clear-cut extended on 40% of the basin area (Pierzgalski et al. 2007, 2009).

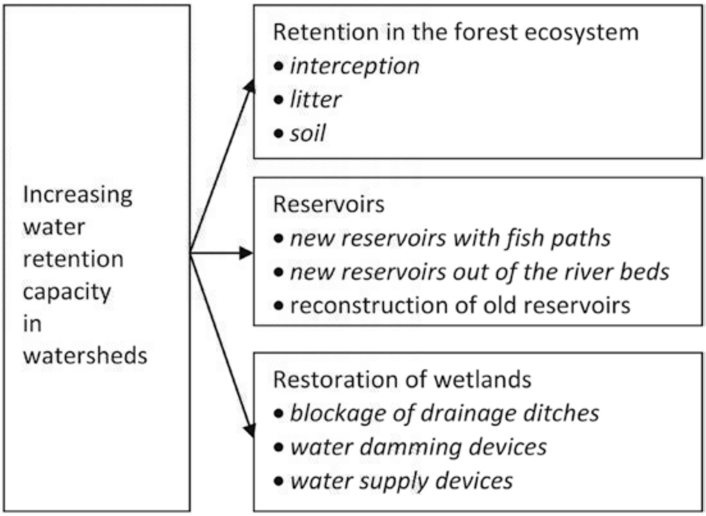

Fig. 2.1 List of measures to increase water retention capacity

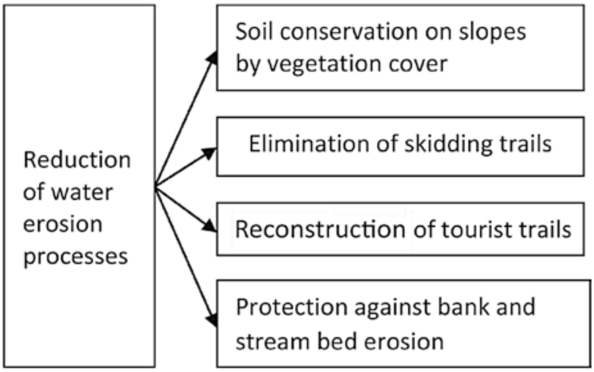

Fig. 2.2 List of measures reducing the erosion

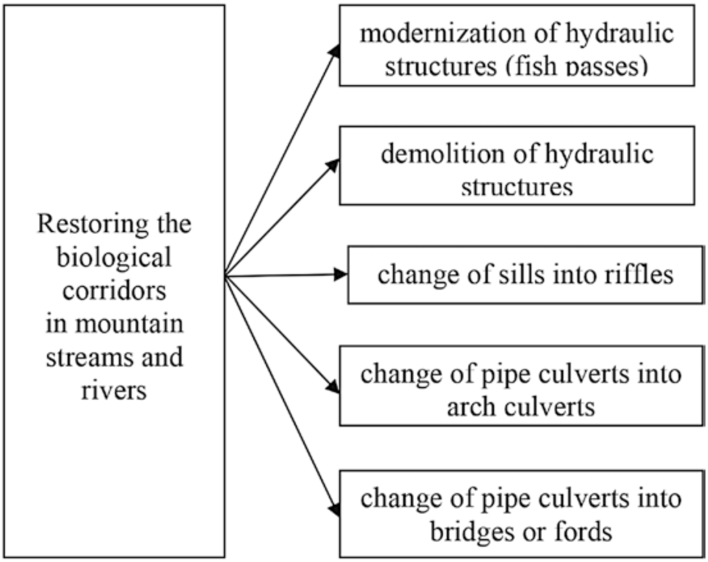

Fig. 2.3 Practices to support revitalization of streams and rivers

Table 2.1 Interaction between forest and water

Influence of forests on water resources	Influence of water on forest resources
Interception	Forest habitat type
Evapotranspiration	Flora and fauna
Retention	Timber growth
Discharge variability	Resistance to disturbances
Erosion and sedimentation	Adaptation to the climate change
Water quality	
Water habitat	Carbon sequestration

3 Results and Discussion

Discharge in streams has been affected by a complex of natural and anthropogenic factors. The runoff from a catchment depends on the area harvested, and also on the position of harvested spots within a watershed. Analyzing the impact of forest stands on water cycle; it has been stated already that, particularly the interception loss ranges from 20 to 40% of precipitation, and plays a significant role in the runoff genesis of a mountain watershed (Lenart et al. 2003). In deciduous forests, the interception loss is generally smaller than in coniferous stands (Osuch 1998). The impact of harvested spruce forests (*Picea abies*) in the Sudeten Mountains on the flood hydrographs is shown in Fig. 2.4: the significantly higher peak and sharper flood hydrograph were found in the Ciekoň basin with more extended intensive forest harvest.

The harvest of forests affected also the seasonal distribution of water yield (Fig. 2.5). Summarizing hydrological observations in Poland (Pierzgalski et al. 2007) the effect of the age of forests on the specific discharge in mountain streams is demonstrated in Fig. 2.6.

To control impacts of extreme hydrological events, at present, the prevailing view prefers ecological oriented measures against the technical approach (Shields et al. 2003). In comparison with commercial forestry, the retention capacity of studied forests was increased by environmental logging technologies, and also by the alternative soil preparation before reforestation. The current environmental forestry includes:

- Restriction of a clear-cut on slopes above 40%,
- Ecological silviculture to produce more stable forest stands with a rich species composition to be resistant against insect or wind damages,

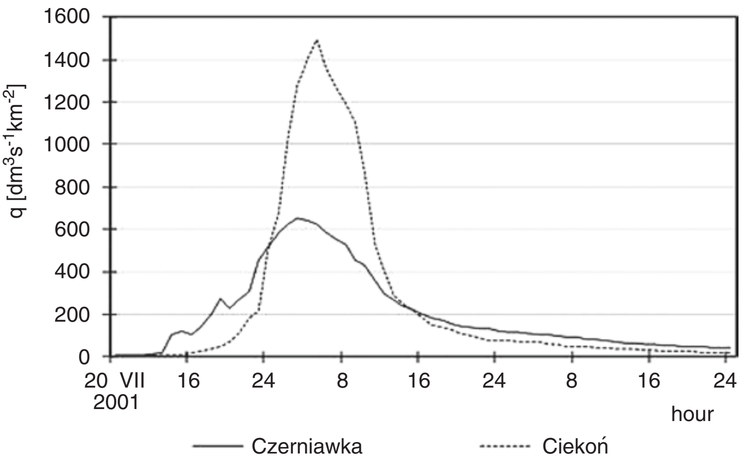

Fig. 2.4 Influence of forest harvest on flood hydrograph (Ciekoň: 40% harvested)

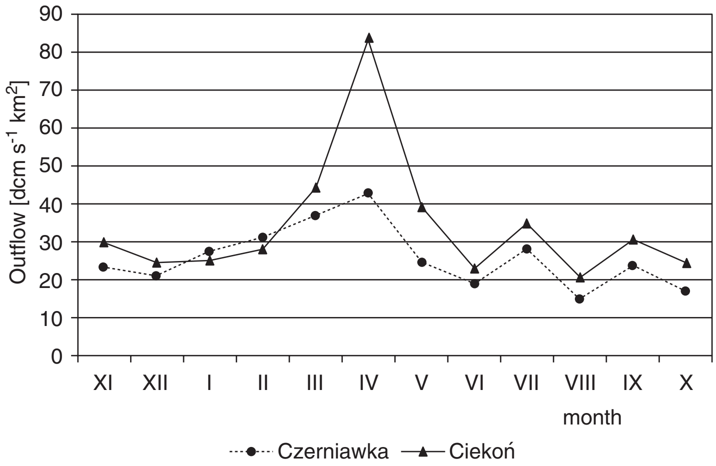

Fig. 2.5 Effect of forest cover on seasonal runoff (Ciekoň: 40% harvested)

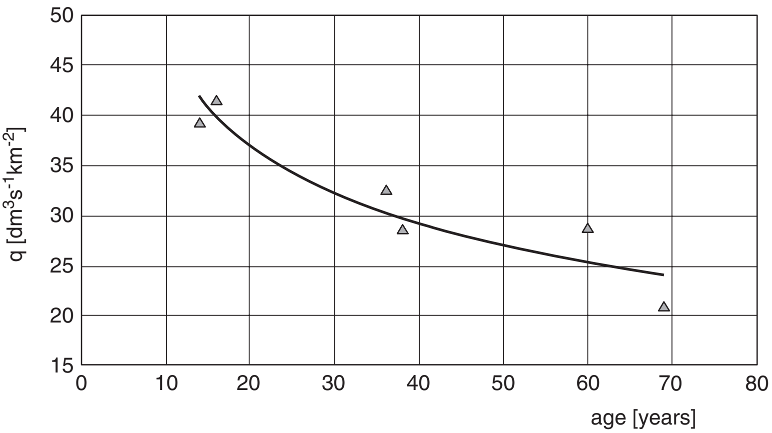

Fig. 2.6 Influence of forest age on specific discharge in mountain streams

- Rehabilitate of skidding roads or trails after the logging, and
- Priority reforestation of slopes above 15%.

In mountain watersheds, all the damages associated with extreme hydrologic events might not be eliminated by adequate forestry practices. The application of traditional technical measures is still important. In the framework of this project, the technical measures included: water reservoirs, hydraulic structures in streams, water damming devices and measures of road protection.

Small water reservoirs represent the primary way to control surface water dynamics. These are usually objects with multiple tasks, clearly defined for their proper design and operation. The reservoirs in mountain forests should be designed comprehensively in terms of catchments despite the fact that they are usually small. Their impact is not determined by size, but by the number of devices in the watershed, which corresponds to the principle of distributed risk. These facilities primarily serve ecological functions, but each project must be assessed for the environmental impact and effective investments. Special environmental impact assessments should be made at the locations protected by Natura 2000 (Coordination Center for Environmental Projects 2010). Small-scale retention structures in forest areas should use the natural and local materials (wood, fascines, stone, sand, cohesive soils). The main goal is to limit the transport of materials, to reduce investment costs and to minimize damages in the forest sector during construction. Devices on the water reservoirs should be durable with a minimum operational service. The philosophy of hydraulic structures in a mountain watershed has been changing. In the past, they were constructed mainly with concrete and rock, blocking the connectivity of the biological corridors. Currently, the biodiversity in stream waters is preferred; therefore, the accepted design has to stabilize stream channels while allowing movement of aquatic organisms (Bojarski et al. 2005). Among the solutions used in this project, stabilization of forest roads by local materials (Fig. 2.7) was used to reduce the risk of sheet erosion and direct flow acceleration.

In the recent period of 1990–2015, the annual amount of direct flood damages in mountain watersheds of Poland ranged from 30 million EUR (2010) to 50 million EUR (1997) (Lenart et al. 2003; Pierzgalski et al. 2011), not including consequent damages (for example reduced timber production, impacts fungal diseases or insect degradation). The hope of the investment in eco-technical services introduced by this project is to reduce significantly those amounts.

Fig. 2.7 Reconstruction of forest roads with local materials (Photo: Edward Pierzgalski)

4 Conclusions

In mountain regions, the control of water resources is essential for the sustainable existence of human society in large downhill areas. Therefore, the proper maintenance of ameliorative infrastructures in forest catchments is urgently needed for enhancing the resilience of forest ecosystems and prevention of their disturbances.

In Poland, hydrological extremes threaten forest catchments, particularly, in the Sudeten and Carpathian Mountains. The most harmful are the effects of soil and stream channel erosion. In 2007–2015, more than 3500 ameliorative measures were realized in the framework of the project “Counteracting the effects of rainwater runoff in mountainous areas”. Both technical and ecological techniques were applied to increase the retention capacity, and to reduce sheet, rill, gully, and stream channel erosion.

The environmental assessment concentrated namely on the landscape stabilization, water retention and retardation, and biodiversity protection. Special attention has been paid to the restoration of biological corridors in mountain streams. Combination of both ecological oriented and technical acquisitions showed a good evaluation in term of eco-services.

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Chapter 3
Ecosystem Services Supporting Water Supply Systems

Özden Görücü

1 Introduction

Forests can provide human societies with series of benefits and services, generally called as ecosystem services. The ecosystem services are in the form of separated or integrated forms. In general, the ecosystem services could be classified as:

- Provisioning services: Materials that ecosystems provide such as food, water, wood, grass, medicinal plants and other raw materials.
- Regulating services: Services that ecosystems provide regulators such as soil and air quality, carbon storage, flood, erosion and disease control.
- Supporting services: Services that ecosystems provide sustained space such as biodiversity of flora and fauna, nutrient cycling.
- Cultural services: Services that ecosystems provide humanity quality such as recreation, aesthetic values, spiritual inspiration and so mental health.

In recent years, there are many efforts and scientific studies to assign economic values to the ecosystem services. This is necessary to reflect the economic values of the ecosystem services to the national account. For this, the theories and application ways of forest economics are being followed (Price 1989). On this topic the crucial question is why to assign economic values to ecosystems? Because there is a failure in environmental management and sustainability to account and to create insource or outsource financing for the full economic values of ecosystems and biodiversity has been a significant factor in their continuing loss and degradation. So, optimal harvest scheduling (Armstrong et al. 1992) and consistent economic value assignment mechanisms to ecosystems (Price 1989) were put forward

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in practice. Therefore, ecosystem valuation approaches are being indicated by Görücü (1998) as:

- Direct market valuation approaches
- Revealed preference approaches
- Stated preference valuation approaches
- Multi criteria analysis

Multi criteria analysis allows formal integration of multiple values of the ecosystems by assigning relative weights to each criterion. On the other hand, this approach has the potential to be extended to cover ecosystem services. The outcomes obtained by multi criteria analysis are a ranking of preferences which supply a basis for taking decisions among various options. In this article, multi criteria analyses were used and operated for the ecosystem services supporting water supply systems.

Turkey has a total area of 78 million hectares; about one quarter is designated as forest. Mountain ranges run generally parallel to the northern and southern coasts, surrounding the central Anatolian Plain, which rises from 500 m elevation in the west to over 2000 m in the east. About 80% of soils in Turkey suffer from moderate to severe sheet and gully erosion and most rivers carry heavy loads of sediment. The mean annual precipitation varies from 250 (central and southeastern plateaus) to 2500 mm (northern coastal plains and mountains). In the western and southern coastal zones, a subtropical Mediterranean climate predominates, with short, mild and wet winters and long, hot, dry summers. Arid and semiarid continental climates prevail in central regions with frequent and heavy snowfall in the higher parts of the Anatolian Plain (Görücü 2009). The extend of forest land has gradually decreased as a result of long-term improper and extensive use, and currently, it has become necessary to take preventive measures for the protection of forests (Görücü 2002). Next to the timber economy, forests have collective benefits that cannot be evaluated monetarily, such as regulations of the climate, controlling the water regime, prevention of erosion, as well as their potential contribution to the defence of the country (Görücü 1998).

The aim of this study is to analyse and evaluate the sectoral relationships between forests and water under the umbrella of ecosystem services. Series of scenarios were designed to investigate the application of multi-criteria analysis in the management of forests. These scenarios are based on the analytical hierarchy process, using weighting and scoring of ecosystems. The output of this study leads to the development of guidelines for the management and practices of the Kahramanmaraş Suçatı forest districts.

2 Material and Methods

This study was carried out in the Ceyhan watershed, located in the upland and semiupland landscapes of the Suçatı Mountains. The altitude alters from 1036 to 2100 m, and forest stands of Turkish pine (*Pinus brutia*) cover 58.6% of the catchment. This study was designed to solve problems of Kahramanmaraş Suçatı Forest Districts, where the management of evenaged forest stands has been discussed, and several levels of clear cutting applied. The management unit of Turkish pine was planned by linear programming with respect of FORPLAN software, as only a timber production forest in one scenario (Görücü 1996). There are 224 compartments in the Suçatı district, but in this study, they were aggregated (according to the criteria of slope, age, exposure, site index etc.) in 95 activity areas. Altogether, the Suçatı forest district of Turkish pine (15,256 ha) consists of productive forests (8183 ha), unproductive forests (3714 ha), and the deforestation area (3359 ha). The data of the selected 95 activity areas were used in the matrix of the FORPLAN software, the linear programming was used for all models in given objectives of the study. These different possible schedules for timber production are based on scenarios:

(a) Four rotation ages: 30, 40, 50 and 60 years
(b) Three different interest rates: 4, 5 and 6%
(c) Long-term sustained yield capacity, present net value as the criterion of efficiency to measure cut and inventory level
(d) Three different objective functions as maximize ending inventory, maximize the sum of cutting and maximize present net value
(e) Three allowable cut levels as 85,000 m^3, 102,000 m^3 and 140,000 m^3

The solutions were produced which test the sensitivity of the harvest schedules to changes in the limit on volume that may be harvested in any of 10 years, and the planning horizon was 100 years (Davis and Johnson 1987). A hundred-year planning period was used with harvesting operations scheduled for each ten-year subperiod within the period 1990–2089. Some constraints which were timber market price, costs of afforestation and road constructions, and administrative expenses had been included in the models. Linear programming was run to get optimal timber production according to present net value of each activity area in the context of multiple constraints on scarce resources. According to the linear programming proposed by Taha (2007):

$$\begin{aligned}
&\text{Objective function:} && maxZ = C_1X_1 + C_2X_2 + \ldots + C_nX_n \\
&\text{Constraints:} && a_{11}X_1 + a_{12}X_2 + \ldots + a_{1n}X_n \le b_1 \\
& && a_{21}X_1 + a_{22}X_2 + \ldots + a_{2n}X_n \le b_2 \\
& && a_{m1}X_n + a_{m2}X_n + \ldots + a_{mn}X_n \le b_m \\
&\text{Positiveness:} && X_1 \ge 0, X_2 \ge 0, \ldots, X_n \ge 0
\end{aligned}$$

In the next step, the ecosystem appropriateness criteria were selected to set up and weightings at forest level as well. For this, on the experimental site, the criteria of the ecosystems were decided as water production, timber production, recreation (and ecotourism) and also carbon storage. According to potentials of the site productivity which was obtained from actual forest management plans, the scores (points) and weightings (percentage) were assigned and included in the model. The cost of water as the ecosystem output must be calculated to reflect the value of the water produced by forest ecosystems to the national income balances. Eker (2005) analysed water economy related to forests in the Darlık Watershed. The costs of general administration, expropriation, maintenance and afforestation were included in this study. To evaluate forest resources, Görücü and Eker (2009) included also the carbon economy in the watershed of Kahramanmaraş Ayvalı Dam. In this study, stands of Turkish pine with site class 3rd in three compartments were analyzed with regard to carbon storage and emission economics such as the monetary value of the carbon content in biomass. The most important parameters used in these calculations were carbon amount in the dry mass of pine forests (amounts of CO_2 fixed in 1 kg of timber) and the default price of carbon per tonne. These parameters were used to calculate the present net value of the carbon storage in the pine biomass.

Subsequently, new evaluation methods on the water economics were tried and made progress in Turkey. The latest one was sophistically carried out and explained here in the Suçatı watershed to measure the ecosystems services which include water as well, by using multi criteria analysis in water centred forest management regime under the analytical hierarchy processing, by weighting and scoring of the selected ecosystem services.

3 Results and Discussion

For only timber production some important scenarios and results were obtained by using clear cutting and thinning-clear cutting, while interest rate was 5%, based on allowable cut level respectively 85,000 m^3, 102,000 m^3 and 140,000 m^3 and also for four different rotation (Görücü 2004). As an example, solution of periodical allowable cut for various rotation ages by clear cutting is given in Table 3.1.

Assuming four ecosystem services (water production, timber production, recreation-ecotourism and carbon storage), the solution is given in Table 3.2. All points and weights were assigned due to the actual forest structure and the watershed landscape, and the multi criteria analysis under the analytical hierarchy process applied.

The derived data according to scenarios 1 and 2, based on the model of Görücü (2011) are in Table 3.3.

In the Suçatı watershed, the forest practices are based on clear cutting and reforestation in ten periods. Both natural and cultivated stands are considered in the schedule (Table 3.1). The growth there is decelerating with the age of a stand. For the 85,000 m^3 of allowable cut the best alternative is the maximum present net value of $16,013 and rotation age 30 years, in the tenth period by long-term sustained yield capacity. For the 102,000 m^3, the best alternative is the maximum present net value of $18,729 and rotation age 40 years, in the nineth period by long-term sustained yield capacity. For the 140,000 m^3 of allowable cut the best alternative is the maximum present net value $19,440 and rotation age 30 years, in the nineth period by long-term sustained yield capacity.

As the next step of this study (Table 3.2), the evaluation of four ecosystem services (water production, timber yield, recreation-ecotourism and carbon storage) was applied. All the used points and weights in the analysis were assigned due to the

Table 3.1 Periodical mean increment for various rotation ages and allowable cut by clear cutting within the Suçatı watershed

Rotation age = 30		Rotation age = 40		Rotation age = 50		Rotation age = 60	
Age (years)	Periodical increment (m^3/ha)	Age (years) (m^3/ha)	Periodical increment	Age (years) (m^3/ha)	Periodical increment	Age (years) (m^3/ha)	Periodical increment
Periodical allowable cut = 85,000 m^3							
25	55	35	54	45	48	55	43
30	63	40	65	50	60	60	40
35	54	45	60	55	52	65	30
40	50	50	58	60	40	70	28
45	48	55	50	65	32		
50	45	60	40	70	30		
55	43	65	35				
60	40	70	33				
65	38						
70	35						
Periodical allowable cut = 102,000 m^3							
25	73	35	72	45	68	55	62
30	76	40	77	50	74	60	60
35	72	45	70	55	65	65	55
40	70	50	66	60	60	70	46
45	68	55	63	65	51		
50	65	60	60	70	47		
55	62	65	55				
60	60	70	50				
65	58						
70	56						
Periodical allowable cut = 140,000 m^3							
25	43	35	50	45	40	55	35
30	52	40	46	50	45	60	33
35	50	45	42	55	40	65	27
40	45	50	40	60	33	70	24
45	40	55	38	65	29		
50	38	60	33	70	27		
55	35	65	30				
60	33	70	28				
65	31						
70	40						

actual forest structure and watershed landscape. The criteria, criterion points (pts) and weightings of the ecosystem services were used in the multi criteria analysis of the Suçatı watershed. Two scenarios were considered in context of the ecosystem services weightings and pointings within the analytical hierarchy process. The scenario 1 means, that by the timber production of 6–10 m^3, recreation (including ecotourism) includes 21 visitors, and the carbon storage is 91–120 tonnes; so, the water

Table 3.2 Multi criteria analysis in water centered forest regime: Analytical hierarchy process, weighting and scoring on ecosystem services in the Suçatı watershed

Water production (1–5 pts)	Wood production (1–5 pts)	Recreation + ecotourism + (1–5 pts)	Carbon storage (1–5 pts)
Ecosystem appropriateness criteria and weightings at forest level (hectare/year)			
Criterion weight: 50%	Criterion weight: 30%	Criterion weight: 10%	Criterion weight: 10%
Criterion lowest point: 0.50	Criterion lowest point: 0.30	Criterion lowest point: 0.10	Criterion lowest point: 0.10
Criterion highest point: 2.50	Criterion highest point: 1.50	Criterion highest point: 0.50	Criterion highest point: 0.50
Criterion average point: 1.50	Criterion average point: 0.90	Criterion average point: 0.30	Criterion average point: 0.30
Subcriteria and points assigned			
1–4000 m3 1	1–5 m3 1	1–5 visitors 1	1–30 tonnes 1
4001–8000 m^3 2	6–10 m^3 2	6–10 visitors 2	31–60 tonnes 2
8001–12,000 m^3 3	11–15 m^3 3	11–15 visitors 3	61–90 tonnes 3
12,001–16,000 m^3 4	16–20 m^3 4	16–20 visitors 4	91–120 tonnes 4
16,001+ m^3 5	21+ m^3 5	20+ visitors 5	121+ tonnes 5
Weighted criterion point (criterion weight × subcriterion point) and criteria total appropriateness point (CTAP)			
1–4000 m^3 $0.50 \times 1 = 0.50$	1–5 m^3 $0.30 \times 1 = 0.30$	1–5 visitors $0.10 \times 1 = 0.10$	1–30 tonnes $0.10 \times 1 = 0.10$
4001–8000 m^3 $0.50 \times 2 = 1.00$	6–10 m^3 $0.30 \times 2 = 0.60$	6–10 visitors $0.10 \times 2 = 0.20$	31–60 tonnes $0.10 \times 2 = 0.20$
8001–12,000 m^3 $0.50 \times 3 = 1.50$	11–15 m^3 $0.30 \times 3 = 0.90$	11–15 visitors $0.10 \times 3 = 0.30$	61–90 tonnes $0.10 \times 3 = 0.30$
12,001–16,000 m^3 $0.50 \times 4 = 2.00$	16–20 m^3 $0.30 \times 4 = 1.20$	16–20 visitors $0.10 \times 4 = 0.40$	91–120 tonnes $0.10 \times 4 = 0.40$
16,001+ m^3 $0.50 \times 5 = 2.50$	21+ m^3 $0.30 \times 5 = 1.50$	21+ visitors $0.10 \times 5 = 0.50$	120+ tonnes $0.10 \times 5 = 0.50$
CTAP 7.50	4.50	1.50	1.50
GTAP (grand total appropriateness point)		15.00 (7.50 + 4.50 + 1.50 + 1.50)	

production is expected between 4001 and 8000 m^3 per hectare. Similarly, the scenario 2 explains that by the water production of 8001–12,000 m^3, the recreation includes 11–15 visitors, and carbon storage is 31–60 tonnes. The solution is based on following conditions: (1) As a correct guide for allocation of the ecosystem services to functions, (2) Capacity building on various goods and services, (3) Costing of the functions according to their weighting and pointing, (4) Estimating the value of the marketable and unmarketable ecosystem services, (5) Handling of the integrated watershed management, (6) Analyzing the watersheds in the holistic manner, and (7) Easier but also analytical valuing of the ecosystem services in the watersheds.

Table 3.3 Scenarios 1 and 2 based on the model by multi criteria analysis for forest related ecosystem services

Scenario 1. Data belong to appropriateness criteria:	*Scenario 2. Data belong to appropriateness criteria:*
Wood production: 6–10 m^3	Water production: 8001–12,000 m^3
Recreation + ecotourism: 21+ visitors	Recreation + ecotourism: 11–15 visitors
Carbon storage: 91–120 tonnes	Carbon storage: 31–60 tonnes
To be found:	*To be found:*
Water production:?	Wood production:?
Points assigned to appropriateness criteria:	*Points assigned to appropriateness criteria:*
Wood production: 2 pts	Water production: 3 pts
Recreation + ecotourism: 5 pts	Recreation + ecotourism: 3 pts
Carbon storage: 4 pts	Carbon storage: 2 pts
Weighted criterion point of appropriateness criteria:	*Weighted criterion point of appropriateness criteria:*
Wood production: 2 × 0.30 = 0.60	Water production: 3 × 0.50 = 1.50
Recreation + ecotourism: 5 × 0.10 = 0.50	Recreation + ecotourism: 3 × 0.10 = 0.30
Carbon storage: 4 × 0.10 = 0.40	Carbon storage: 2 × 0.10 = 0.20
Criteria total appropriateness point (CTAP): 0.60 + 0.50 + 0.40 = 1.50	*Criteria total appropriateness point (CTAP):* 1.50 + 0.30 + 0.20 = 2.00
Grand total appropriateness point (GTAP): 15.00	*Grand total appropriateness point (GTAP):* 15.00
Water production:	*Wood production:*
7.50 × 1.50/15.00 = 0.75 and goes to 4001–8000 m^3	4.50 × 2.00/15.00 = 0.60 and goes to 6–10 m^3

4 Conclusions

Besides the timber production, forests serve in providing human societies with water, erosion control, recreation, game and wildlife shelter, and also reducing carbon emissions and decreasing the negative effects of green house gases and global climate change. To evaluate forest ecosystem services, the optimization methods and quantitative approaches are used worldwide (Görücü and Eker 2009). In forest watersheds with concern of water supply, four ecosystem services should be considered: water production, timber yield, recreation-ecotourism and carbon storage. The scenarios used in the Suçatı watershed confirmed that the applied approach of ecosystem service evaluation is available in the watershed planning worldwide.

In the light of the ecosystem services evaluation processes, the missions to be undertaken about the forest and water agenda in Turkey are being seen in:

- Focusing on wider water cost approach in a catchment (not only water prices).
- Developing integrated resource management concept between forest and water sectors and extending the cooperation portfolio among stakeholders.
- Introducing the Water Framework Directive and International Water Convention to the public compromise towards an integrated watershed management.