Toward a Research Agenda for Water Policy Implementation: Knowledge about Beaver (*Castor fiber*) as a Tool for Water Management with a Catchment Perspective

JOHAN TÖRNBLOM[1], PER ANGELSTAM[1], GÖRAN HARTMAN[2], LENNART HENRIKSON[3] AND GÖRAN SJÖBERG[4]

[1]*School for Forest Management, SLU, Box 43, SE-739 21 Skinnskatteberg, Sweden; johan.tornblom@smsk.slu.se; per.angelstam@smsk.slu.se*

[2]*Dept. of Ecology, SLU, Box 7044, SE-75007 Uppsala, Sweden; goran.hartman@ekol.slu.se*

[3]*WWF, Ulriksdals Slott SE-170 81 Solna, Sweden; lennart.henrikson@wwf.se*

[4]*Dept. of Wildlife, Fish and Environmental Studies, SLU, SE-90183 Umeå, Sweden; goran.sjoberg@adm.slu.se Tel: +46-90-786 82 96*

Baltic Forestry 17(1): 154–161.

Abstract

The EU Water Framework Directive (WFD) was adopted in 2000 and is now being implemented in national legislations in the Member States. According to this directive, all waters should have good ecological and chemical status. Good ecological status signifies only a slight departure from the biological community which would be expected in conditions of minimal anthropogenic impact. To achieve this goal, knowledge about historical reference conditions for different ecoregions is urgently needed. The aim of this paper is to present a research agenda for acquiring knowledge about the beaver's role in natural ecosystems as a tool for WFD implementation. The beaver is an ecological engineer for both aquatic and terrestrial ecosystems. As the species was once common in large parts of Europe, reference conditions in terms of the historic natural range of variability in riverine landscapes were to a great extent created by its activities. Thus, "good ecological status" of small to medium sized streams should include compositional, structural and functional characteristics created by beavers. First we define these characteristics and how they relate to the concept of ecological status. Second we describe how viable beaver populations may contribute to the ecological status in different parts of the continent, and conclude that the re-establishment of the beaver on the European continent is a way to approach good ecological status. However, increased knowledge is needed in terms of studies of (1) the historical beaver distribution in different types of catchments using both modelling, and studies in reference landscapes where beavers are still present; (2) the present density and ecosystem effects of beaver in the landscape; (3) interactions between aquatic and terrestrial ecosystems; (4) analysis of economic and ecological trade-offs, especially in areas with high beaver or human population densities. Finally, (5) stakeholders' attitudes and understanding related to the WFD and beavers in areas with differing history and density of beavers will need to be studied as a base for governance and management of catchments.

Key words: Beaver, landscape planning, catchment perspective, sustainable landscapes, biodiversity, water management, governance

Introduction

The EU Water Framework Directive (WFD) was adopted in 2000 (Directive 2000/60/EC…2000) and is now being implemented in national legislations in the Member States (see EU WFD website: Ecological status and intercalibration 2010). The purpose of this Directive is to establish a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater, which prevents further deterioration and protects and enhances the status of aquatic ecosystems. It is also intended to promote sustainable water use, and aims at enhanced protection and improvement of the aquatic environment. Finally it should ensure the progressive reduction of pollution of groundwater, and mitigate the effects of floods and droughts (Article 1; (Directive 2000/60/EC…2000). One important aim is to maintain or improve the ecological status of the streams and lakes within the European Union. National and local administrations will thus need to make trade-offs and compromises, so they can find a balance before habitats are lost and species are extirpated, but at the same time allow certain impacts linked to use of natural resources without damage becoming irreversible.

According to the WFD directive, all waters should have good ecological and chemical status. Ecological status is "an expression of the quality of the structure and functioning of aquatic ecosystems associated with surface waters" (Article 2; (Directive 2000/60/EC…2000). Good ecological status signifies only a slight departure from the biological community which would be expected in conditions of minimal anthropogenic impact ("high status"; EU WFD website: Ecological status and intercalibration 2010). To achieve this goal, knowledge about historical reference conditions in terms of natural range of variability (Egan and Howell 2001) of both aquatic and terrestrial systems for different ecoregions is urgently needed (Degerman et al. 2004, Törnblom 2008, Angelstam and Kuuluvainen 2004).

The beaver (*Castor fiber*) influences ecosystems and the biotic community in a number of ways in both aquatic and terrestrial environments (see e.g., Danilov et al. 2007, Krylov and Bobrov 2007, Naiman et al. 1994, Rosell et al. 2005, Zav'yalov et al. 2005). It has been described as a keystone species and an ecological engineering species (Jones et al. 1994, cf. Johnston 1994). Beavers may create a mosaic-type landscape composition by creating open water surfaces that can develop into marshes, wetland forests, and beaver meadows in wetland successions (Ives 1942, Johnston and Naiman 1987, 1990a,b, Naiman et al. 1988, Remillard et al. 1987, Ruedemann and Schoonmaker 1938).

In lower (i.e. 1–4) stream orders (Horton 1945), the beaver often builds dams across streams, which affect instream sediment patterns and erosion processes that influence stream morphology and macroinvertebrate distribution (Collen and Gibson 2001, Naiman and Melillo 1984). The dams also affect several ecosystem functions, occurrence and densities of insect (Naiman et al. 1984, Clifford et al. 1993), fish (Gard 1961, Hanson and Campbell 1963, Hägglund and Sjöberg 1999, Keast and Fox 1990, McRae and Edwards 1994), bird (Beard 1953, Brown and Parsons 1979, Knudsen 1962, Nummi 1992), mammal (Knudsen 1962, Naiman 1988, Newman and Griffin 1994), and plant species (Coleman and Dahm 1990, Mitchell and Wiering 1993, Rutherford 1964), as well as water quality (McRae and Edwards 1994, Naiman et al. 1991, Smith et al. 1991). The beaver further fells trees for foraging, thus adding physical structure to terrestrial and aquatic ecosystems, and transferring nutrients and energy to the aquatic ecosystem (Collen and Gibson 2001). The felling of trees also strongly influences the composition, density and age structure of various tree and shrub species (Hyvönen and Nummi 2008, cf. Johnston and Naiman 1990c, Pastor and Naiman 1992). Finally, beavers build nest cavities or free-standing huts that may persist for long time (Fries 1960, Rosell and Pedersen 1999).

The beaver was common in large parts of Europe in historic times (Fries 1960), and the landscape that we now regard as a near-natural reference was to a great extent created by its activities affecting the composition, structure and function of aquatic as well as terrestrial ecosystems. Following the re-colonisation of forests and woodlands after deglaciation the beaver was an important factor in the forming of the forest landscape, in particular in lower-order streams (cf. Naiman et al. 1988). Subsequently, the beaver was decimated by habitat change and hunting. Regional extirpation of beavers began in Southern and Western Europe, and ultimately by the mid 19th century, only two small populations with a couple of hundred individuals remained in what are today's 27 EU nations (Halley and Rosell 2003). In the late 19th and early 20th century, the conservation value of beaver and other wildlife was recognized, and the restoration of beaver populations began. Currently, about 350,000 – 400,000 beavers are present within the 27 EU nations (Halley and Rosell 2003). The restoration process still continues and restoration measures have been taken in most European countries where beavers once existed.

The aim of this paper is to present a research agenda for EU Water Framework Directive implementation on the ground using the beaver as a tool. First, a set of criteria for "good water status" is derived from what can be deemed as historical reference conditions. These criteria also need to be adapted for different regions of Europe. Second, to re-establish beaver as a keystone species in riverine landscapes, science-based norms to be met to assure good ecological and chemical status need to be defined. Third, the knowledge accomplished in this research must be transformed into governance and management practices on the ground with a catchment perspective that includes both aquatic and terrestrial systems, and includes stakeholders from different sectors at multiple levels.

From policy to research and practice

The beaver as a tool for management of water and riverine landscapes

The objectives of the Water Framework Directive pronounce that both the water quality and the water environment as a whole should reach "good water status" at the latest by 2015. "Reference conditions" are used in the judgment of the status or quality of a water body. This allows for assessment of how far the water body is from the objective of "good water status". The more the water deviates from the reference condition (i.e. high status), the lower its quality or status will be. "Good ecological status" signifies that the surface water's fauna and flora, the stream channel and its flow variations, the streambed and the shoreline, and the physical and chemical characteristics are not allowed to deviate from what can be deemed as natural reference characteristics of a type of waters in a certain area (EU WFD web site: Introduction to the new EU Water Framework Directive 2010). The biological quality factors are to be given most weight for judgment of "ecological quality conditions".

However, do we really know the reference conditions from an historical perspective considering the beaver abundance and distribution? The occurrence of beaver in the landscape could have had a great importance for the reference conditions and how managed landscapes deviate from those (Figure 1 and 2).

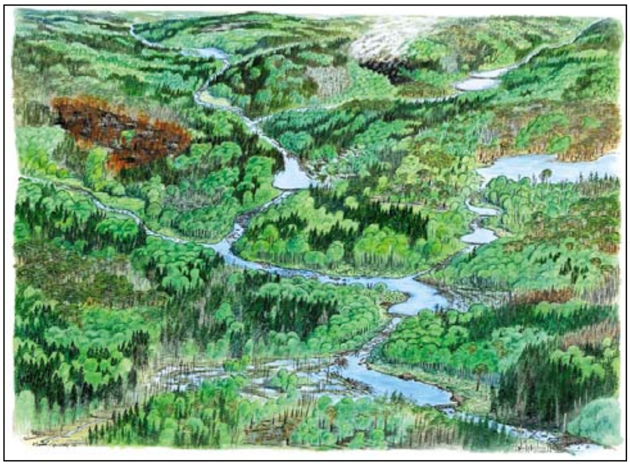

Figure 1. Drainage basin in a pre-industrial forest landscape in northern Europe. Is this the type of landscape that should be used as a reference for today's forest and water managers? Illustration by Martin Holmer

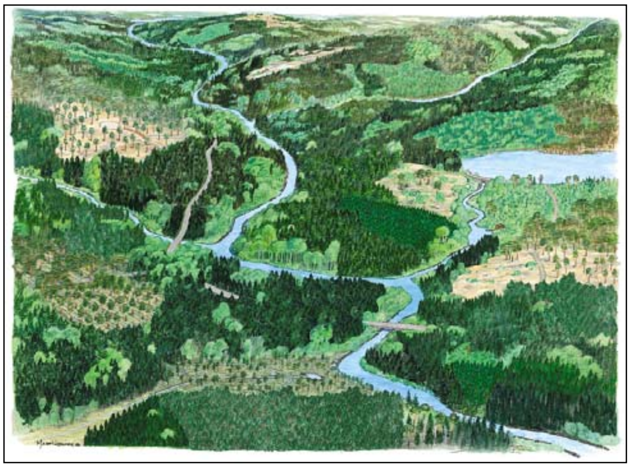

Figure 2. The same landscape as in Fig. 1, today. Can the production landscape fulfil the environmental ambitions of the EU Water Framework Directive, and how much of natural structures and processes are enough? Illustration by Martin Holmer

Many signs point to the beaver as having had a crucial impact on the streams in natural conditions (see Introduction).

We argue that:

1. The re-establishment of viable beaver populations, which now is accomplished in parts of the European continent, is a way to approach good ecological status.

2. The condition of "good ecological status" of small – medium sized (stream orders 1–4; Horton 1945) streams in many cases would need to include characteristics created by beavers.

3. The characteristics can be transformed into a set of criteria, indicators, and norms (sensu Lammerts van Bueren and Blom 1997) for use in running waters in the EU member states. The list can be seen as a way to apply the quality elements listed in Annex V of the WFD and its Table 1.2.1 (Table 1), which will need to be further developed into indicators and norms to assess the status of streams, and adapted to differing local and regional conditions and size of streams.

- Physical structure in the streams – occurrence of dead wood in and close to streams
- Ability to retain sediments and nutrients
- Ability to process organic material
- Ability to even out flow fluctuations - mitigate high flows and counteract draught conditions
- Habitat variation along stream – fast and slow current, with characteristic biota
- Biodiversity of various aquatic and riparian organism groups
- Occurrence of patches in temporal transition between terrestrial and aquatic environments

Toward a research agenda

Forest landscape disturbance regimes range from succession following stand-replacing disturbances, such as severe fires and wind-storms, to small-scale dynamics associated with gaps in the canopy created by the loss of individual trees due abiotic disturbance such as flooding, and biotic disturbances (Angelstam and Kuuluvainen 2004). A good deal of knowledge about the role of beaver for terrestrial and aquatic ecosystems is already available, and this knowledge can already today be used in water management. However, the status of beaver populations over Europe varies strongly, some being viable and even subject to harvesting, while others are only becoming re-established (Halley and Rosell 2001, 2003). This means that the beaver's contribution to the ecological status varies strongly among different parts of the EU. However, increased knowledge is needed about the role of the beaver as a keystone species for water management with a riverine landscape perspective (cf. Malanson 1993).

Table 1. Quality elements for the classification of ecological status of rivers. From Annex V of the WFD (Directive 2000/60/EC… 2000)

Biological elements
Composition and abundance of aquatic flora
Composition and abundance of benthic invertebrate fauna
Composition, abundance and age structure of fish fauna
Hydromorphological elements supporting the biological elements
Hydrological regime
quantity and dynamics of water flow
connection to groundwater bodies
River continuity
Morphological conditions
river depth and width variation
structure and substrate of the river bed
structure of the riparian zone
Chemical and physico-chemical elements supporting the biological elements
General
Thermal conditions
Oxygenation conditions
Salinity
Acidification status
Nutrient conditions
Specific pollutants
Pollution by all priority substances identified as being discharged into the body of water
Pollution by other substances identified as being discharged in significant quantities into the body of water

Knowledge needs to define norms for assessments of ecological status, for use of the beaver as a tool to approach reference conditions, include the following issues:

• The historical beaver distribution in different types of ecoregions and catchments should be modelled, and studies in reference landscapes where beavers are still present are needed.

More knowledge is needed about the historical conditions for the beaver as well as its densities and effects in the European forest landscape. There is a need for studies of a dose-response-type (Törnblom 2008, Roberge and Angelstam 2009), i.e. for example using GIS analysis of the landscape composition of the catchments, along with an historical and archaeological documentation of the beaver's earlier distribution and its importance for humans (Danilov et al. 2007).

• Present distribution, density and impact of beaver in the landscape

Today's situation concerning the present density and influence of beavers on European landscapes and streams needs to be mapped. Estimates of densities for beaver ponds are generally lacking for EU countries. Estimates of beaver population size should be made using aerial photos quantified by GIS methods (Kaczka et al. 2001, cf. Johnston and Naiman 1990a). Using interpretation of aerial photos, the extent of damming for areas with known densities of beaver can be estimated.

• Interactions with terrestrial ecosystems

Beaver browsing strongly influences species and age-class composition of riverine forests, and thus indirectly also other flora and fauna (cf. Johnston and Naiman 1990c). The historical aspects of these conditions are poorly known. It is also little known to what extent the late succession stages of beaver ponds, such as "beaver meadows", have formed stream valley landscapes (Terwilliger and Pastor 1999).

• Analysis of economic and ecological trade-offs, especially in areas with high beaver or human population densities

Analyses of beaver populations of high densities should be made along with economic trade-offs between ecological benefits and levels of damage. Using questionnaires and in-depth interviews, a greater understanding can be reached about how the beaver activities can lead to economic or ecological problems such as forest damage, impounding, flooding, cramming of road drains, migration obstacles etc. (Härkönen 1999, cf. McKinstry and Anderson 1999).

• The current attitudes and understanding related to beavers in areas with differing history and density of beavers will need to be studied as a base for governance and management of catchments.

Attitudes to beaver among the general public and various stakeholder groups, depend on the history and the present state of the beaver populations in each country. We suggest that the development of attitudes may follow certain paths that to some extent may be predicted (Ajzen 1991, Eagly and Chaiken 1993, Gardner and Stern 2002). Attitudes in different groups of people should therefore be studied in selected countries (cf. McKinstry and Anderson 1999). Cross-country comparisons may be used for improving governance practices and management advice.

Governance and management of beaver landscapes

Restoration of viable beaver populations may cause conflicts with other interests. Economic production losses in certain types of land and water management, or social needs of human communities, will need to be weighed against the values of undisturbed waterways and fish migration, or riverine landscape biodiversity. Knowledge among managers and planners will be crucial for how to satisfy the living conditions simultaneously for aquatic and terrestrial species, without creating unreasonable negative consequences for human interests or other endangered species or habitats.

The beaver can be a controversial species primarily when they come into conflict with human interests (e.g., urban and production forests, outdoor recreation), or in conflict with other species (Rosell and Pedersen 1999). Therefore knowledge is needed of how to process ecological knowledge into practical management of terrestrial and aquatic natural resources and desired ecological outcomes, and to involve stakeholders into governance at different levels (see Rauschmayer et al. 2009). To promote learning and legitimacy, it is important to understand what knowledge, understanding, perceived needs and attitudes the stakeholders have.

To implement the Water Framework Directive there is a need to include the understanding of these stakeholders of management principles and interests as well as their capacity and interest to implement this policy. With this in mind it will be easier to judge how large a geographical area will be needed for managing various landscape values. For example, to plan for sustained yield wood production, knowledge about the spatial distribution of forests of varying age and tree species composition at the landscape scale is not crucial. However, to preserve, manage or recreate functioning green and blue infrastructures – i.e., habitat networks that will function in a landscape perspective, for terrestrial and aquatic environments, respectively– for a number of species, as well as ecological integrity (Karr 1981), a landscape approach that encompasses both the social and ecological systems is crucial (e.g., World Forestry Congress XIII 2009).

This means that apart from science-based knowledge about the role of beavers in different ecosystems as outline above, both top-down hierarchical strategic, tactical and operational planning (Sundberg and Silversides 1996) on the one hand, and collaborative and communicative bottom-up participatory approaches on the other (Törnblom 2008) are needed to support the implementation of policies about good ecological status of catchments in riverine landscapes. This is consistent with proactive adaptive governance and management cycle approaches (Pahl-Wostl 2007) that link policy, management, monitoring and assessment in iterated cycles within entire catchments (e.g., Angelstam et al. 2003, Lazdinis and Angelstam 2004). At the first strategic level, regional quantitative gap analysis (Scott et al. 1993) is a tool for assessing the extent to which ecological integrity is maintained by appropriate combination of protection, management and restoration of representative habitat types in an ecoregion. A second tactical level tool is Habitat Suitability Index (HSI) spatial modelling (Angelstam et al. 2004) that combines quantitative knowledge about focal species' requirements and the spatial distribution of resources into maps for visualization and scenario building. This allows both for assessment and subsequent spatial planning at different scales and time horizons. These two steps guide the management operations needed for the protection, maintenance and restoration at instream, riparian, catchment and landscape scales. There is, however, a scale mismatch between the need for this kind of systematic approach and reality. Thus monitoring programs and performance target need to be assessed, and tools for proper assessment, governance and management towards ecological integrity by various formal and informal organizations be developed.

Finally, adaptive governance and management need to be developed using participatory approaches (Angelstam and Törnblom 2004) that include relevant actors and stakeholders to become understood and accepted. This requires enhanced communication and collaboration. To fill knowledge gaps about performance targets and tools for governance, applied interdisciplinary research is needed, which must become systematic in two dimensions. First, comparisons of reference landscapes with ecological integrity should be compared with altered systems to determine how much are enough of different structures and processes to secure viable populations of species used as indicators, and thus operationalise the terms "good ecological status" and "ecological integrity". Second, the idea that analytic deliberation, nested institutions and institutional variety open up for continuous experimentation, learning and change in society needs to be evaluated by studies of local and regional governance arrangements' ability to deliver good ecological status, even if it is difficult, time consuming and sometimes unrewarding (Törnblom and Angelstam 2008).

However, there is limited knowledge about how much beavers influence ecological systems, and more research is need to fully understand beavers' influence on ecological water status and conservation status. There is also a need to study social systems in terms of the understanding, ability to act and attitudes among stakeholders, governors, planners and managers at multiple levels. Ultimately, such a landscape approach that considers both the ecological and social systems will be needed to implement the WFD.

Conclusions

There is much evidence that the activities of beavers have been decisive for the function of landscapes and catchments and thus for forest streams. Therefore it is important to consider beavers' role in ecosystems when setting up criteria, indicators and norms for good ecological status. To handle potential conflicts and economic losses related to beavers, there is a need for adaptive management (Lee 1993) of the European beaver population.

Acknowledgements

Funding for this work was provided by Marcus och Amalia Wallenbergs Minnesfond and Sveaskog Co. to Per Angelstam. We thank Marine Elbakidze for comments on the manuscript and translation of the abstract into Russian, and two anonymous reviewers for their suggestions.

References

Ajzen, I. 1991. The theory of planned behavior. *Organizational Behavior and Human Decision Processes* 50: 179-211.

Angelstam, P. and Kuuluvainen, T. 2004. Boreal forest disturbance regimes, successional dynamics and landscape structures – a European perspective. *Ecological Bulletins* 51: 117-136.

Angelstam, P., Mikusinski, G., Rönnbäck, B.-I., Östman, A., Lazdinis, M., Roberge, J.-M., Arnberg, W. and Olsson, J. 2003. Two-dimensional gap analysis: a tool for efficient conservation planning and biodiversity policy implementation. *Ambio* 33, 527-534.

Angelstam, P., Roberge, J.-M., Lõhmus, A., Bergmanis, M., Brazaitis, G., Dönz-Breuss, M., Edenius, L., Kosinski, Z., Kurlavicius, P., Lārmanis, V., Lūkins, M., Mikusinski, G., Račinskis, E., Strazds, M. and Tryjanowski, P. 2004. Habitat modelling as a tool for landscape-scale conservation – a review of parameters for focal forest birds. *Ecological Bulletins* 51: 427–453.

Angelstam, P., and Törnblom, J. 2004. Maintaining forest biodiversity in actual landscapes – European gradients in history and governance systems as a "landscape lab". In: Marchetti, M. (ed). Monitoring and indicators of forest biodiversity in Europe – from ideas to operationality. EFI symposium No. 51: 299-313.

Beard, E.B. 1953. The importance of beaver in waterfowl management at the Seney National Wildlife Refuge. *Journal of Wildlife Management* 17:398-436.

Brown, M.K. and Parsons, G.R. 1979. Waterfowl production on beaver flowages in a part of northern New York. N*ewYork Fish and Game Journal* 26:143-153.

Clifford, H.F., Wiley, G.M. and Casey, R.J. 1993. Macroinvertebrates of a beaver-altered boreal stream of Alberta, Canada, with special reference to the fauna of the dams. *Canadian Journal of Zoology* 71:1439-1447.

Coleman, R.L. and Dahm, C. N. 1990. Strem geomorphology: effects on periphyton standing crop and primary production. *Journal of the North American Benthological Society* 9:293-302.

Collen, P. and Gibson, R.J. 2001. The general ecology of beavers (*Castor* spp.), as related to their influence on stream ecosystems and riparian habitats, and their subsequent effects on fish – a review. *Reviews in Fish Biology and Fisheries* 10: 439-461.

Danilov, P.I., Kanshiev, V.Ya. and Fyodorov, F.V. 2007. Beavers of the Russian European North. Nauka, Moskva. 199 pp. In Russian.

Degerman, E., Sers, B., Törnblom, J. and Angelstam, P. 2004. Large woody debris and brown trout in small forest streams – towards targets for assessment and management of riparian landscapes. *Ecological Bulletins* 51: 233-239.

Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. 2000. Official Journal of the European Communities L 327 1-72. 22.12.2000.

Also: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2000:327:0001:0072:EN:PDF Accessed Nov 29, 2010

Eagly, A.H. and Chaiken, S. 1993. The Psychology of Attitudes. Orlando, Harcourt Brace & Company.

Egan, D. and Howell, E. A. 2001. The historical ecology handbook. Island Press.

EU WFD web site: Ecological status and intercalibration. 2010. http://ec.europa.eu/environment/water/water-framework/info/intro_en.htm. Accessed Nov 29, 2010.

EU WFD web site: Introduction to the new EU Water Framework Directive. 2010. http://ec.europa.eu/environment/water/water-framework/objectives/status_en.htm. Accessed Nov 29, 2010.

Fries, C. 1960. Beaverland. A book about the beaver and his work. Nordisk Rotogravyr, Stockholm. 188 pp. (In Swedish).

Gard, R. 1961. Effects of beaver on trout in Sagehen Creek, California. *Journal of Wildlife Management* 25:221-242.

Gardner, G.T. and Stern P.C. 2002. Environmental Problems and Human Behavior. Needham Heights, Allyn and Bacon.

Halley, D.J. and Rosell, F. 2001. Current distribution, status and pattern of spread of the Eurasian beaver Castor fiber, and the implications for management. In: Czech, A. and Schwab, G. (Eds.). The European beaver in a new millennium. Proc. 2nd European Beaver Symposium. Carpatian Heritage Society, Kraków: p. 15-24

Halley, D.J. and Rosell, F. 2003. Population and distribution of European beavers (*Castor fiber*). *Lutra* 46: 91-102.

Hanson, W.D. and Campbell, R.S. 1963. The effects of pool size and beaver activity on distribution and abundance of warm-water fishes in a north Missouri stream. *American Midland Naturalist* 69:136-149.

Horton, R. E. 1945. Erosional development of streams and their drainage basins: hydro-physical approach to quantitative morphology. *Geological Society of America Bulletin* 56 (3): 275–370.

Hyvönen, T. and Nummi, P. 2008. Habitat dynamics of beaver (*Castor canadensis*) at two spatial scales. *Wildlife Biology* 14: 302-308.

Hägglund, Å. and Sjöberg, G. 1999. Effects of beaver dams on the fish fauna of forest streams. *Forest Ecology and Management* 115: 259–266.

Härkönen, S. 1999. Forest damage caused by the Canadian beaver (*Castor canadensis*) in South Savo, Finland. *Silva Fennica* 33(4): 247–259.

Ives, R.L. 1942. The beaver meadow complex. *Journal of Geomorphology* 5: 191-203.

Johnston, C.A. 1994. Ecological engineering of wetlands by beavers. In: Mitsch, W.J. (Ed). Global Wetlands: Old World and New. Elsevier, p. 379-384.

Johnston, C.A. and Naiman, R.J. 1987. Boundary dynamics at the aquatic-terrestrial interface: The influence of beaver and geomorphology: *Landscape Ecology* 1:45-57.

Johnston, C.A. and Naiman, R.J. 1990a. The use of a geographic information system to analyze long-term landscape alteration by beaver. *Landscape Ecology* 4: 5-19.

Johnston, C.A. and Naiman, R.J. 1990b. Aquatic patch creation in relation to beaverpopulation trends. *Ecology* 71:1617-1621.

Johnston, C.A. and Naiman, R.J. 1990c. Browse selection by beaver: effects on riparian forest composition. *Canadian Journal of Forest Research* 20: 1036-1043.

Jones, C.G., Lawton, J.H. and Shachak, M. 1994. Organisms as ecosystem engineers. *Oikos* 69: 373-386.

Kaczka, R., Czech, A. and Derwich, A. 2001. Using a global positioning system for mapping beaver-created wetlands. P 173-175 In: Czech, A. and Schwab, G. (Eds.) The European beaver in a new millennium. Proc. 2nd European Beaver Symposium. Carpatian Heritage Society, Kraków.

Karr, J. 1981. Assessment of biotic integrity using fish communities. *Fisheries* 6 (6): 21-27.

Keast, A. and Fox, M.G. 1990. Fish community structure, spatial distribution and feeding ecology in a beaver pond. *Environmental Biology of Fishes* 27:201-214.

Knudsen, G.J. 1962. Relationship of beaver to forest, trout and wildlife in Wisconsin. *Wisconsin Conservation Department, Technical Bulletin.* No. 25: 51 pp.

Krylov, A.V. and Bobrov, A.A. (Eds.) 2007. Succession changes in the small river ecosystems. KMK Scientific press, Moskva. 372 pp.(In Russian).

Lammerts van Bueren, E. and Blom, E. 1997. Hierarchical framework for the formulation of sustainable forest management standards. Principles, criteria, indicators. Tropenbos Foundation, Backhuys Publishers, AH Leiden, The Netherlands. 82 pp.

Lazdinis, M. and Angelstam, P. 2004. Connecting social and ecological systems: an integrated toolbox for hierarchical evaluation of biodiversity policy implementation. *Ecological Bulletins* 51: 385-400.

Lee, K. 1993. Compass and gyroscope: integrating science and politics for the environment. Washington, D.C., Island Press.

Malanson, G.P. 1993. Riparian landscapes. Cambridge University Press.

McKinstry, M.C and Anderson, S.H. 1999. Attitudes of private- and public-land managers in Wyoming, USA, toward beaver. *Environmental Management* 23:95-101.

McRae, G. and Edwards, C. J. 1994. Thermal characteristics of Wisconsin headwater streams occupied by beaver: Implications for brook trout habitat. T*ransactions of the American Fisheries Society* 123:641-656.

Mitchell, C.C. and Wiering, W.A. 1993. Vegetation in a topogenic bog following beaver flooding. *Bulletin of the Torrey Botanical Club.* 120:136-147.

Naiman, R.J., Johnston, C.A. and Kelley, J.C. 1988. Alteration of North American Streams by Beaver. *BioScience* 38: 753-762.

Naiman, R.J., MacDowell, D.M. and Farr, B.S. 1984. The influence of beaver on the production dynamics of aquatic insects. *Verhandlungen der Internationalen Vereinigung für Theoretische und Angewandte Limnologie* 22: 1801-1810.

Naiman, R.J., Manning, T. and Johnston, C.A. 1991. Beaver population fluctuations and tropospheric methane emissions in boreal wetlands. *Biogeochemistry* 12:1-15.

Naiman, R.J. and Melillo, J.M. 1984. Nitrogen budget of a subarctic stream altered by beaver. *Oecologia* 62:150-155.

Naiman, R.J., Pinay, G., Johnston, C.A. and Pastor, J. 1994. Beaver influences on the long-term biogeochemical characteristics of boreal forest drainage networks. *Ecology* 75:905-921.

Newman, D.G. and Griffin, C.R. 1994. Wetland use by river otters in Massachussetts. *Journal of Wildlife Management* 58:18-23.

Nummi, P. 1992. The importance of beaver ponds to waterfowl broods: an experiment and natural tests. *Annales Zoologici Fennici* 29:47-55.

Pahl-Wostl, C. 2007. Transition towards adaptive management of water facing climate and global change. *Water Resources Management.* 21: 49-62.

Pastor, J. and Naiman, R.J. 1992. Selective foraging and ecosystem processes in boreal forests. *American Naturalist* 139: 690-705.

Rauschmayer, F., Berghöfer, A. Omann, I., and Zikos, D. 2009. Examining processes or/and outcomes? Evaluation concepts in European governance of natural resources. E*nvironmental Policy and Governance* 19: 159-173.

Remillard, M.M., Gruendling, G.K. and Bogucki, D.J. 1987. Disturbance by beaver and increased landscape heterogeneity. In: Goigel Turner, M. (ed), Ecological studies, Landscape, heterogeneity, and disturbance. 64 Springer Verlag. NJ, USA.

Roberge, J.-M. and Angelstam, P. 2009. Selecting species to be used as tools in the development of forest conservation targets. In: André, M.-A., Jonsson, B.G. (eds) Setting conservation targets for managed forest landscapes. Cambridge University Press, p. 109-128.

Rosell, F. and Pedersen, K.V. 1999. Beaver. Landbruksforlaget.272 pp. (In Norwegian).

Rosell, F., Bozsér, O., Collen, P. and Parker, H. 2005. Ecological impact of beavers *Castor fiber* and *Castor canadensis* and their ability to modify ecosystems. *Mammal Review* 35: 248-276.

Ruedemann, R. and Schoonmaker, W. J. 1938. Beaver-dams as geologic agents. *Science* 88:523-525.

Rutherford, W.H. 1964. Beaver influence on plant growth and succession. Colorado Game, Fish and Park Dept. Techn. Bull. No. 17.

Scott, J.M., Davis, F., Csuti, B., Noss, R., Butterfield, B., Groves, C., Anderson, J., Caicco, S., D'Erchia, F., Edwards, T.C., Ulliman, J. and Wright, R.G. 1993. Gap analysis: A geographical approach to protection of biological diversity. *Wildlife Monographs* 123, 1-41.

Smith, M.E., Driscoll,C.T., Wyskowski, B.J., Brooks, C.M. and Cosentini, C.C. 1991. Modification of stream ecosystem structure and function by beaver in the Adirondack Mountains, New York. *Canadian Journal of Zoology* 69:55-61.

Sundberg, U. and Silversides, C.R. (eds.) 1996. Operational efficiency in forestry. Kluwer Academic Publishers, AH Dordrecht, The Netherlands.

Terwilliger, J. and Pastor, J. 1999. Small mammals, ectomycorrhizae, and conifer succession in beaver meadows. *Oikos* 85: 83-94.

Törnblom, J. 2008. A landscape approach towards ecological integrity of catchments and streams. Doctoral Thesis No.2008:70. Faculty of Forest Sciences, SLU.

Törnblom, J. and Angelstam, P. 2008. Assessment, planning and management of ecological sustainability in riverine landscapes: Towards an integrated tool-box and adaptive governance. In: Frostell, B., Danielsson, Å., Hagberg, L., Linnér, B.-O. and Lisberg Jensen E. (Eds.) Science for sustainable development - The social challenge with emphasis on the conditions for change. VHU, Uppsala, p. 247-254.

World Forestry Congress XIII. 2009, Buenos Aires, Argentina. Forest Development: A Vital Balance, Findings and Strategic Actions. Findings and Strategic Actions, se: http://foris.fao.org/meetings/download/_2009/xiii_th_world_forestry_congress/misc_documents/wfc_declaration.pdf

Zav'yalov, N.A., Krylov, A.V., Bobrov, A.A., Ivanov, V.K and Dgebuadze, Yu.Yu. 2005. Impact of the European Beaver on small river ecosystems. Moskva *Nauka*, 186 pp. (In Russian)

Received 12 September 2009
Accepted 05 April 2011

ПО НАПРАВЛЕНИЮ К ИЗУЧЕНИЮ ВНЕДРЕНИЯ ВОДНОЙ ПОЛИТИКИ: ПОЗНАНИЕ БОБРА (*CASTOR FIBER*) КАК СРЕДСТВА ВОДОУСТРОЙСТВА НА ЛАНДШАФТНОМ УРОВНЕ

J. Tцrnblom, P. Angelstam, G. Hartman, L. Henrikson и G. Sjцberg

Резюме

Водная рамочная директива Европейского Союза (ВРД) была принята в 2000 году и в настоящее время адаптируется в национальных законодательствах в государствах-членах ЕС. Согласно этой директиве, все воды должны иметь хороший экологический и химический статус. Хороший экологический статус означает лишь небольшое отклонение от биологического сообщества, которое можно было бы ожидать в условиях минимального антропогенного воздействия. Для достижения этой цели, необходимы знания об исторических эталонных условиях различных экорегионов. Цель данной статьи – представить программу исследований для получения необходимых знаний о роли бобра в природных экосистемах, которые необходимы для внедрения ВРД, Бобр – экологический инженер водных и наземных экосистем. Как вид, бобр был широко распространен во многих регионах Европы, и природные условия, необходимые для его существования, были созданы в прошлом в результате его жизнедеятельности. Таким образом, "хороший экологический статус" малых и средних водотоков должен включать в себя композиционные, структурные и функциональные характеристики, созданные бобрами. В данной статье мы сначала определяем эти особенности и как они могут быть соотнесены с концепцией экологического статуса вод Европы. Во-вторых, мы описываем, как жизнеспособные популяции бобра в Европе могут способствовать улучшению экологического статуса вод в различных частях континента, и делаем вывод о том, что восстановление популяции бобра на европейском континенте, является подходом к внедрению концепции хорошего экологического статуса. Тем не менее, необходимо улучшать знания относительно (1) распространения бобра в историческом прошлом различных типах водосборов с использованием методов моделирования, так и в результате проведения исследования в ландшафтах, где бобры все еще существуют; (2) плотности распространения вида и экосистемных последствий для ландшафтов в результате деятельности бобра; (3) взаимодействия между водными и наземными экосистемами; (4) экономических и экологических компромиссов, особенно в районах с высокой плотностью населения и популяции бобра. И наконец, необходимо изучать как основу для принятия решения и управления водосборами (5) отношение заинтересованных сторон и их понимание, касающиеся бобров и РВД в районах с различной историей и плотностью популяции бобров.

Ключевые слова: бобр, ландшафтное планирование, водосбор с точки зрения устойчивого ландшафтов, биоразнообразие, водные ресурсы, управление