Beaver pond development and its hydrogeomorphic and sedimentary impact on the Jossa floodplain in Germany

Stefan John* & Andreas Klein#

Institute of Physical Geography, J.W. Goethe University, P.O. Box 11 19 32, D-60054 Frankfurt am Main, Germany, e-mail: geobiber@web.de

Abstract: This paper presents results of a two-year study showing different beaver (*Castor fiber*) induced hydrogeomorphic changes on the floodplain of the small river Jossa (Spessart Uplands, Germany). Using GIS and aerial photography, different stages of river and floodplain morphology were mapped. In addition, length of water courses, areal extent of ponds and wetlands, sediment depths, volumes and sedimentation rates, as well as erosion rates and amounts of eroded material were calculated with the supplementary aid of precise levelling. The results revealed that beaver dams create large wetlands and greatly increase the area of open water surface by damming-up ponds. Moreover, they enhance the total water flow length by diverting water onto the floodplain, resulting in a multi-channeled drainage network. The new diversion channels induced the erosion of 50 m^3 of overbank fines. By reducing flow velocity within the dammed-up channel and by diverting water onto the floodplain, the dams lead to the deposition of a total amount of 1,890 m^3 of sediments within the beaver ponds and on the inundated floodplain.

Keywords: beaver, channel pattern, GIS, geomorphic factor, sedimentation patterns, sediment fluxes.

Introduction

The manifold alterations of upland streams and floodplain areas by beaver (*Castor* spp.) tree felling or dam building activities are described by many authors. But, the majority of investigations on geomorphic effects of beaver dams have concentrated on the natural landscapes of North-America. However, specific data e.g. relating to sedimentation rates in beaver ponds are still rare (cf. e.g. Butler & Malanson 1995, Meentemeyer & Butler 1999, Naiman et al. 1986).

Publications on the European beaver (*Castor fiber*) concentrate on its ethology and morphology, but little is known about the role of the European beaver as a "geomorphic agent" in the cultivated landscapes of central Europe (cf. Butler 1995, Zahner 1997, Gurnell 1998, Harthun 1998). This lack of knowledge is caused by the human extermination of beavers in most regions of Europe.

In the Spessart Uplands, less than 100 km east of Frankfurt/Main (central Germany), beavers remained extinct from the 17th century until reintroduction of 18 beavers (*Castor fiber albicus*) in 1987/1988. Afterwards, the population size increased to more than 260 individuals in 2003.

Especially in the catchment of the 3rd order river Jossa (figure 1), they showed intensive dam-building activity which led to extensive changes on river and floodplain morphology.

In a two-year study at Jossainsel beaver site, several methods were used to visualise and analyse beaver-induced hydrogeomorphic changes of channel pattern, sediment fluxes and erosion processes on the upland valley floor of the Jossa. The results presented in this paper should make a further useful contribution to draw more attention on the dam-building activity of the European species and its hydrogeo-

* Present address: Alt Falkenstein 61, D-61462 Königstein, Germany

Present address: Pfingstbornstraße 27, D-61440 Oberursel, Germany

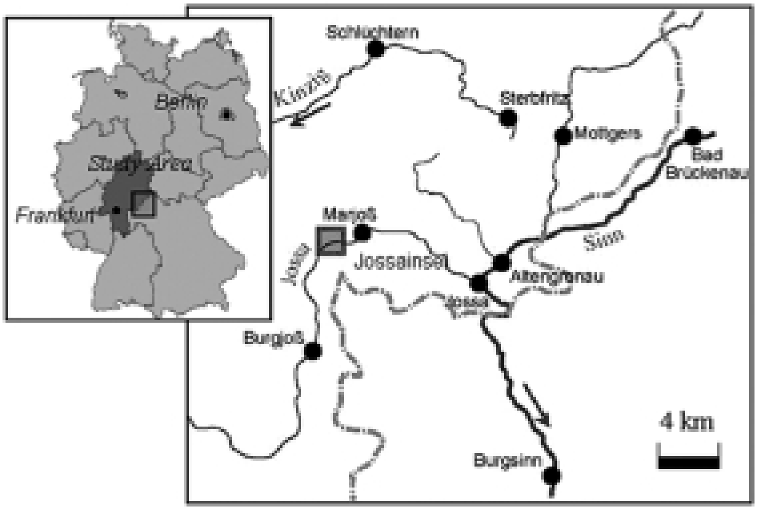


Figure 1. The study area in the Spessart Uplands of Germany. The rectangle shows the study site Jossainsel.

morphic consequences that give beaver great significance as a geomorphic agent.

Methods

To visualise and analyse these beaver-induced alterations, different stages of channel pattern and floodplain morphology (1998-2001) were mapped on the basis of large-scale aerial photographs. Using Geographic Information System (GIS) length of water courses as well as the areal extent of ponds and wetlands were calculated. The additional integration of precise levelling by electronic tacheometry allowed the construction of a digital elevation model (DEM) of the study site. This DEM enabled not only the calculation of pond volumes but also the volume of eroded material by digitising the limits of the area where erosion had occurred, and determination of the former surface elevation level.

The combination of both GIS and DEM allowed the construction of precise large-scale digital maps of the study site. On this basis, sediment depths were mapped in the field by probing with a special measuring rod that was pushed into the sediment as far as it could reach, typically contacting the pond bottom or former soil surface by transition to coarser or more compacted substrates. All field data were added to the GIS and were used to produce a classified map of sediment depth. To calculate the total sediment volume, the sediment depths of each class were averaged and multiplied with the corresponding sedimentation areas. The annual sedimentation rates were calculated by dividing average sediment depth per area by age (in years) of beaver ponds.

Results

The reach of the study site is characterised by a wide, low gradient valley floor. The stream is split up into the main channel Jossa and a lateral channel Jossagraben, which divide and then rejoin after 1 km.

From the year 2000 to 2001 four beaver dams (bp00/1, 00/2, 00/3 and bp01/1) blocked water flow within the Jossagraben impounding four durable beaver ponds in the northeastern part of the study site (figure 2). The amount of impounded water within these ponds fluctuated from 902 m^3 in summer 2000 to 1,708 m^3 in winter 2000/2001 (table 1). Pond drainage led to the development of two back swamps on the floodplain, which stored additional 808 m^3 of water in summer and 1,894 m^3 in winter. The open water surface of all these ponds fluctuated from 5,335 m^2 in summer to 10,059 m^2 in winter. The largest beaver pond was bp00/1 with an area of 2,555 m^2 in winter. However, its value is still surpassed by the area of the beaver induced back swamp (bsw 1 = 4,191 m^2), that could also be called a "secondary beaver pond" in cause of its beaver induced origin.

In autumn 2001 two new dams were built up in the lateral channel Jossagraben (figure 2: map B), leading to large wetlands and the maximum size of the affected area (total submerged area: over 43,700 m^2, corresponding to more than 20% of the study site). The dams increased the total area covered by beaver ponds and back swamps to 11,855 m^2 (table 1). Additionally, these dams enhanced the total water flow length of the affected channel Jossagraben by approximately 140% from 1 km to more than 2.4 km by diverting water onto the floodplain. As a result of this process a multi-channeled (anastomosing) drainage network consisting of numerous interconnected ephemerally, intermittently and perennially occupied channels developed (figure 2).

Most of these channels follow relict drainage ditches or beaver trails. They were deepened by the effects of flowing water and rarely by beaver digging activity. Where pond drainage was concentrated on a few relatively stable channels, linear downcutting and headcut erosion led to the development of one single dominant channel. The total amount of eroded material by these erosion processes was 50 m^3 within three years, corresponding to a total erosion rate of 17 m^3/yr. At least 21 m^3 were due to deep headcut erosion at the mouth of the main diversion channel into the Jossa.

However, the amount of eroded material was surpassed by the effect of beaver dams on sediment storage. An increased fluvial and lacustrine deposition of organic matter, sands and silts led to sediment depths up to 107 cm (average 37 cm) within beaver ponds and up to 38 cm (average 14 cm) on the floodplain (figure 3). This beaver induced sedimentation occurred within an area of 10,740 m^2, leading to a total amount of

Table 1. Selection of the measured values of pond areas, volumes and sediment storage at the Jossainsel study site.

	pond area 2000-2001		max. area	pond volume 2000-2001		pond age	sediment storage 2001		
	min. (summer) (m^2)	max. (winter) (m^2)	(m^2)*	min. (summer) (m^3)	max. (winter) (m^3)	(yrs)	volume (m^3)	average depth (cm)	rate (cm/yr)
beaver ponds									
bp00/1	1775	2555	2555	460	952	2	516	22.7	11.3
bp00/2	386	754	745	67	287	3	243	32.6	10.9
bp00/3	435	682	428	318	380	2.5	147	24.8	9.9
bp01/1	78	78	78	57	89				
bp01/2			552						
bp01/3			1551						
total beaver ponds	2674	4069	5879	902	1708		905	25.1	10.7
drainage network									
back swamps									
bsw 1	2324	4191	4191	800	1284	3	173	11.6	3.9
bsw 2	337	1599	1507	8	610	3	33	12.4	4.1
bsw x		200	278						
wetlands							779		
total drainage network	2661	5990	5976	808	1894	3	985	14.0	4.7
total	5335	10059	11855	1710	3602		1890	17.6	5.9

* autumn 2001

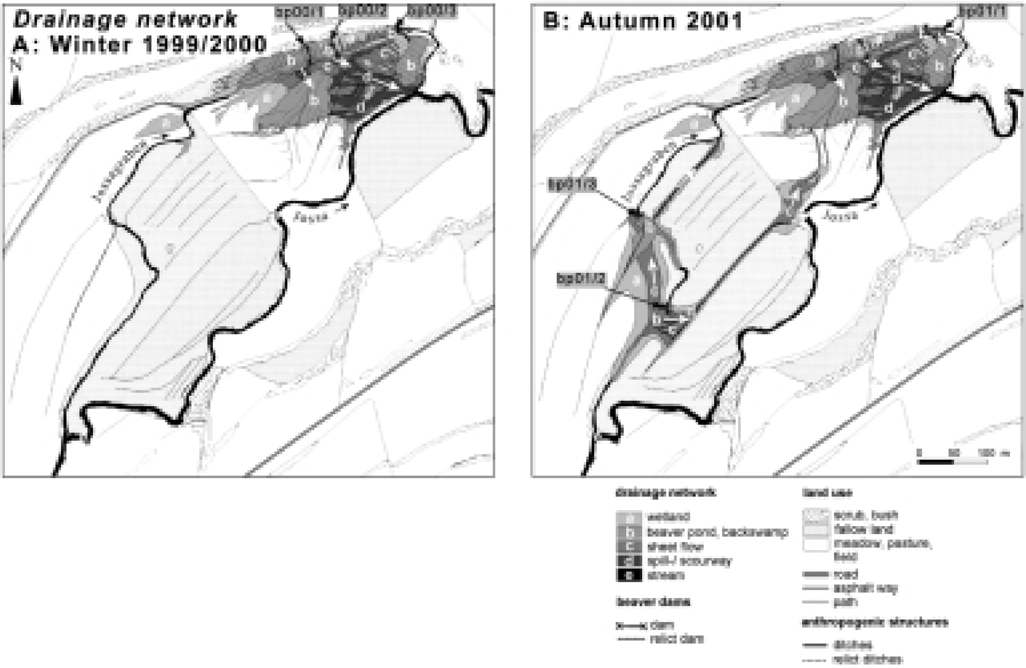


Figure 2. Maps A and B show the formation of a multi-channeled drainage network at the Jossainsel study site from 2000 until 2001. Grey colours distinguish between different stillwater areas, black represent water courses.

1,890 m³ of sediments. Considering a colonisation period of three years this resulted in a sedimentation rate of approximately 6 cm/yr.

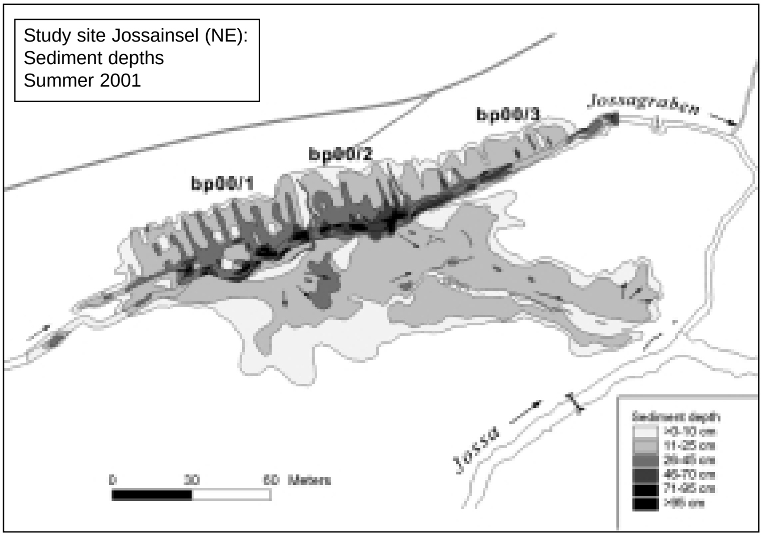
The values of sediment storage within the beaver ponds tend to decrease along the main flow paths. The highest sediment volume occurred in the upper younger pond bp00/1 and the lowest in bp00/3 (table 1), illustrating a downstream reduction of sedimentation in a pond sequence. However, only about 49% of these sediments were deposited within the beaver ponds. The other 51% were caused by permanent overbank flow, leading to accumulation of extended fine, organic rich drainage network deposits on the inundated floodplain (figure 3). This indicates that the multi-channeled drainage network was an important depositional environment.

Discussion

The results illustrate the dynamic character of floodplain sites affected by beavers and show that beavers are important geomorphic agents that alter floodplain morphology in many ways (cf. Naiman et al. 1986, Naiman et al. 1988, Hammerson 1994, Gurnell 1998). However, it is necessary to note that the scale of beaver-induced geomorphic changes depends on the conditions for dam construction, especially river size and hydraulic characteristics e.g. the limitation of dam-building to low order rivers (e.g. Naiman et al. 1988, Gurnell 1998).

As first obvious consequence of beaver dams the areal extent of water surfaces and water-logged areas increased and a complex multi-channeled drainage network developed on wide low gradient valley floors and enhanced the total water flow length. Many other general descriptions or maps of beaver sites in the literature reveal similar conditions (e.g. Townsend 1953, Retzer et al. 1956, Naiman et al. 1988, Zahner 1997, Gurnell 1998, Harthun 1998). The values of the calculated pond areas are comparable to many others e.g. cited by Naiman et al. (1986), Devito & Dillon (1993) and Harthun (1998). But there are no data in literature

Figure 3. Map of the north-eastern part of the Jossainsel study site showing the distribution of sediment depths within the beaver ponds and the adjacent multiple drainage network.



corresponding to the phenomenon of beaver induced back swamps. At Jossainsel such a "secondary beaver pond" exceeded the maximum size of the largest beaver pond in the Spessart Uplands (over 4,000 m^2) cited by Harthun (1998).

Moreover, erosion of soils and deposition of sediments occurred within the impounded stream (beaver pond) as well as on the floodplain (drainage network). Whereas quantitative investigations into beaver induced erosion processes are lacking, apart from some reports about the effects of catastrophic dam failures (e.g. Butler & Malanson 1995), a few studies concentrate on sedimentation processes in beaver ponds.

Some authors provide estimates for sedimentation rates from 0.6 to >2.5 cm per year (Mills 1913, Ives 1942, Devito & Dillon 1993). Others mention the deposition of several cubic meters of sediments behind a dam by a single flood event (Coleman & Dahm 1990) or calculate a deposition of 35-6,500 m^3 of sediments within an area of 100-14,650 m^2 (Naiman et al. 1986).

The values estimated from the Jossainsel (table 1) are comparable to the average sediment depths (21.8-86.0 cm), sediment volumes (9.4-1,290 m^3) and sedimentation rates (3.6-27.9 cm/yr) of the younger ponds in Glacier National Park (USA) mentioned by Butler & Malanson (1995) and Meentemeyer & Butler (1999).

In contrast to Butler & Malanson (1995), our results reveal that downstream reduction of sedimentation in a pond sequence seems to dominate the influence of pond age. The highest sediment volume and sedimentation rate at Jossainsel occurred at the youngest but upper pond bp00/1 and not in the oldest pond bp00/2.

While previous sedimentary research at beaver sites has focused on sediments within beaver ponds, our results also reveal the importance of drainage network deposits at beaver sites on wide spread valley floors.

If we assume a European beaver population of more than 60 million individuals in the early Holocene (Czech & Schwab 2001) and their extinction no earlier than the 17th century in most regions of central Europe, these data provide further rationale for attributing beaver activities a high significance as a factor of holocene floodplain development along low order rivers in central Europe.

Acknowledgements: The study was kindly supported and sponsored by Licher Privatbrauerei, Hessische Gesellschaft für Ornithologie und Naturschutz (HGON) and Geoprax. The use of aerial photographs was enabled by Naturschutzbund Deutschland (NABU) and the Institute of Physical Geography, J.W. Goethe University, Frankfurt / Main.

References

Butler, D.R. 1995. Zoogeomorphology: Animals as geomorphic agents. Cambridge University Press, Cambridge, UK.

Butler, D.R. & G.P. Malanson 1995. Sedimentation rates and patterns in beaver ponds in a mountain environment. Geomorphology 13: 255-269.

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

Czech, A. & G. Schwab 2001. Introduction. In: A. Czech & G. Schwab (eds.). The European beaver in a new millenium. Proceedings of the 2nd European Beaver Symposium: 5-7. Bialowieza, Carpathian Heritage Society, Krakau, Poland.

Devito, K.J. & P.J. Dillon 1993. Importance of runoff and winter anoxia to the P and N dynamics of a beaver pond. Canadian Journal of Fisheries and Aquatic Sciences 50: 2222-2234.

Gurnell, A.M. 1998. The hydrogeomorphological effects of beaver dam-building activity. Progress in Physical Geography 22 (2): 167-189.

Hammerson, G.A. 1994. Beaver (*Castor canadensis*): Ecosystem alterations, management, and monitoring. Natural Areas Journal 14: 44-57.

Harthun, M. 1998. Biber als Landschaftsgestalter. Maecenata, München, Germany.

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

Meentemeyer, R.K. & D.R. Butler 1999. Hydrogeomorphic effects of beaver dams in Glacier National Park, Montana. Physical Geography 20 (5): 436-446.

Mills, E.A. 1913. In beaver world. Reprint with new introduction 1990. Original Boston 1913. University of Nebraska Press, Lincoln, USA.

Naiman, R.J., J.M. Mellilo & J.E. Hobbie 1986. Ecosystem alteration of boreal forest streams by beaver, *Castor canadensis.* Ecology 67 (5): 1254-1269.

Naiman, R.J., C.A. Johnston & J.C. Kelley 1988. Alteration of North American streams by beaver. Bio Science 38 (11): 753-762.

Retzer, J.L., H.M. Swope, J.D. Remington, W.H. Rutherford 1956. Suitability of physical factors for beaver management in the Rocky Mountains of Colorado. Technical Bulletin 2. State Colorado, Department Game & Fisheries, USA.

Townsend, J.E. 1953. Beaver ecology in western Montana with special reference to movements. Journal of Mammalogy 34 (4): 459-479.

Zahner, V. 1997. Einfluß des Bibers auf gewässernahe Wälder. Ausbreitung der Population sowie Ansätze zur Integration des Bibers in die Forstplanung und Waldbewirtschaftung in Bayern. Utz Wissenschaft, München, Germany.

Samenvatting

De ontwikkeling van bevervijvers en het effect van hydro-geomorfologische en sedimentatie-processen op de overstromingsvlakte van de Jossa in Duitsland

Deze bijdrage beschrijft de resultaten van een twee jaar durende studie naar de door bevers (*Castor* spp.) veroorzaakte hydro-geomorfologische veranderingen van in riviertje de Jossa (Spessart, Duitsland). Met behulp van het Geografisch Informatie Systeem en luchtfotografie werden de verschillende stadia van de rivier en de overstromingsvlakte morfologisch gekarteerd. Ook de lengte van de waterlopen, de ruimtelijke uitbreiding van vijvers en wetlands, de sedimentatie-diepte, -volume en sedimentatie-snelheid werden berekend. De erosiesnelheid en de hoeveelheid geërodeerd materiaal werd bepaald met behulp van precieze niveauvergelijkingen. De resultaten laten zien dat beverdammen grote wetlands creëren en in sterke mate de oppervlakte open water vergroten door het verder verhogen van dammen bij bevervijvers. Verder verhogen bevers de lengte van de totale waterstroom door het omleiden van water over de overstromingsvlakte, hetgeen resulteert in een wijdvertakt drainage-netwerk. De nieuwe omleidingskanalen veroorzaken de erosie van 50 m^3 van fijn, lemig fluviaal sediment. Door de reductie van de stroomsnelheid binnen het door dammen ontstane kanaal en door omleiding van water over de overstromingsvlakte, veroorzaakten de beverdammen een depositie van in totaal 1890 m^3 sediment in de bevervijvers en op de overstroomde vlakte.

Received: 17 November 2003
Accepted: 18 February 2004