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The Influence of Macrophyte Cutting on the Hydraulic Resistance of Lowland Rivers

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INTRODUCTION

Macrophyte growth has an important effect on river flow velocity patterns during summer when high vegetation biomass (up to 1100 g.m^{-2}) is present (Champion and Tanner 2000). Within vegetation patches, velocity measurements have shown a decline in stream velocity (Watson and Rose 1982, Sand-Jensen and Mebus 1996). Due to this decreased velocity, flow is deflected around the vegetation patches (Sand-Jensen and Pedersen 1999) resulting in highly variable stream velocities within natural cross sections (Marshall and Westlake 1990, Sukhodolova et al. 2004). In general, the average flow is obstructed and channel resistance increases, leading to greater water depths (Pitlo and Dawson 1990). The increase in channel resistance can be an order of magnitude greater than the minimal channel resistance (Bakry et al. 1992), but under exceptional conditions this parameter can increase even further (Green 2003).

The natural variation of macrophytes in space and time is highly variable (Barrat-Segretain 1996, Feijoó et al. 1996). When a patch is formed, flow conditions change and colonization by other species is possible. This gradual appearance and decline of species alters the dynamic characteristics of the resistance associated with vegetation; therefore, a better understanding of seasonal vegetation development is needed.

To reduce flow resistance and ensure drainage of surrounding arable land and prevent flooding at high precipitation events, macrophytes are mechanically cut and removed from the system. River management objectives are to ensure hydraulic efficiency, minimize the impact on river ecosystems, and monitor the effect of vegetation regrowth on flow resistance. For example, high vegetation cutting regimes reduce hydraulic resistance but are detrimental to the ecosystem and increase maintenance costs (Dawson 1989). Also, the effectiveness of this technique is dependent on the vegetation regrowth capacity. The regrowth capacity from cut stems is high, and within three to five weeks (Rawls 1975, Cooke et al. 1990, Crowell et al. 1994, Bal et al. 2006) biomass can reach pre-harvested values, resulting in a second and even third cutting regime. With this frequent vegetation removal the travel time of water is reduced (Hamill 1983), re-

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sulting in increased flooding risks downstream of the maintained river stretch (Trepel et al. 2003). Therefore, a better understanding of the seasonal vegetation variation and the impact of vegetation cutting on channel flow resistance is necessary to increase the efficiency of vegetation removal.

We investigated the impact of vegetation removal on the hydraulic flow resistance of three lowland rivers to (1) increase the knowledge on the seasonal variation of macrophyte abundance in combination with their effect on river flow resistance, and (2) quantify the temporal impact of river management on the hydraulic efficiency of lowland rivers.

MATERIALS AND METHODS

We calculated resistance on three lowland river stretches (Desselse Nete, Wamp, and Grote Caliebeek) in the Nete catchment (Belgium) during the growing season of 2005. These rivers were chosen because they have well-developed aquatic vegetation populations that were cut once a year, with the exception of the Wamp where the vegetation was not removed. The macrophyte community in these river stretches was dominated by a single species, *Potamogeton natans* L. (>75% of the macrophyte coverage). Other species, such as *Sagittaria sagittifolia* L., *Callitriche platycarpa* Kütz, *Stuckenia pectinatus* L., and *Ranunculus penicillatus* were present but in densities reaching a maximum of 5%. Because *P. natans* concentrates its leaves on/or nearby the water surface, and due to its relatively high stem diameter (up to 0.6 cm), a high impact on the resistance is expected.

Vegetation cutting times differed between the beginning of May for Grote Caliebeek and end of June for Desselse Nete. Biomass was collected with a lightweight sampler according to the design of Marshall and Lee (1994). This 360º rotating device cut the stems just above the sediment surface on an area of approximately 0.22 m². For each sampling site, 10 biomass samples were collected randomly along a length of approximately 100 m. Dry mass of the samples was determined by drying them for 48 hr at a temperature of 75 °C.

The most widely used equation to calculate the hydraulic resistance, especially in vegetated streams in which flow resistance is mainly generated due to skin drag (Lee and Ferguson 2002), is the Manning equation:

$$Q A^{-1} = k R^{2/3} S^{1/2} n^{-1}$$

where R = hydraulic radius (m); S = energy gradient (dimensionless); k = factor to keep the equation dimensionally correct ($m^{1/3} s^{-1}$); n = Manning coefficient (dimensionless); Q = discharge ($m^3 s^{-1}$); and A = cross-sectional area (m^2).

The downside of using this equation is that the resistance factor (n) in the equation assumes that the objects, in this case macrophytes, are rigid. However, due to their flexibility and their marginal positive buoyancy, macrophytes tend to lay over with increasing velocity, reducing the Manning coefficient in this manner.

The energy grade line (S) of the different lowland rivers was measured by determining elevation differences between up- and downstream points. The hydraulic radius of a river channel is defined as the ratio of its cross sectional area (A) versus the wetted perimeter (part of the river bank in contact

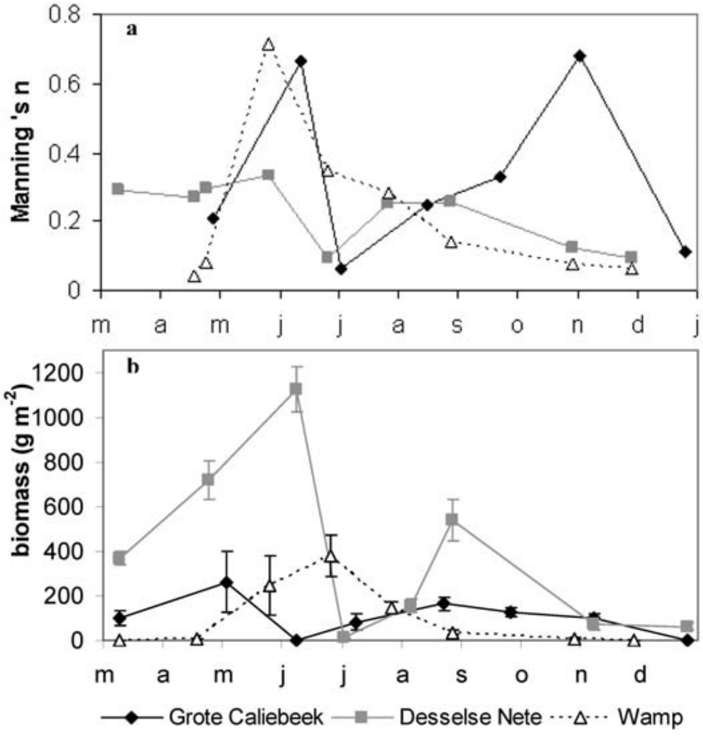

Figure 1. Seasonal variation of the Manning's n (a) and macrophyte biomass (b) on three slow flowing lowland rivers during 2005. Error bars (n = 10) are shown.

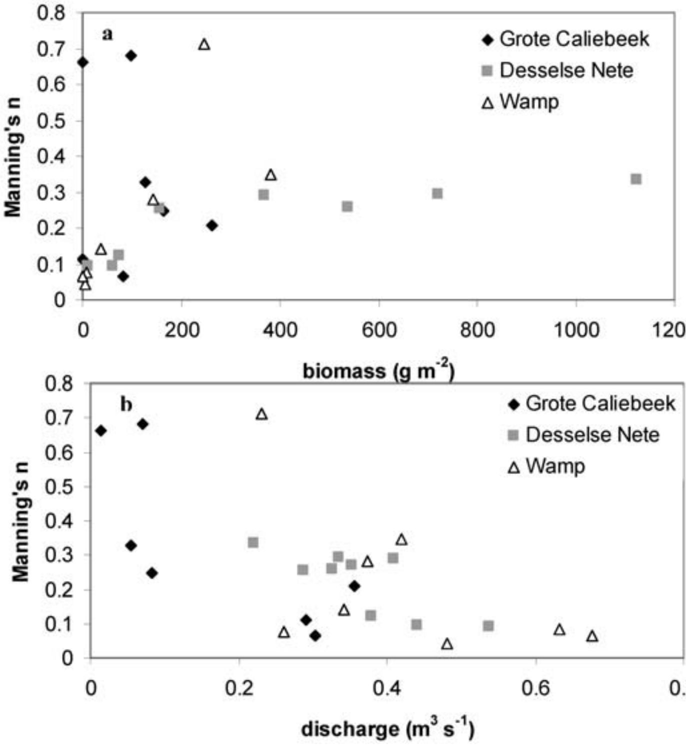

Figure 2. The effect of biomass (a) and discharge (b) on the Manning's n coefficient.

with the water). By measuring the bottom profile and the water level on a fixed location, the wetted perimeter and cross sectional area of the three river stretches could be determined and thus the hydraulic radius calculated.

No river bends were present in the study stretches. Velocity measurements were taken at fixed cross sections on a bridge on stretches not disrupted by aquatic vegetation, resulting in more accurate discharge calculations. Five or six velocity measurement points were performed with an electromagnetic flow meter (Valeport, type 801) for 30 sec each along the width of each cross section (Table 1). At each point, a vertical velocity profile was measured with intervals of 20 cm. When water depth was below 40 cm, water velocities were measured each 10 cm. By integrating the velocities, cross section discharges were calculated. Velocity and water depth measurements started March 2005, when new vegetation appeared, and continued until December 2005.

RESULTS AND DISCUSSION

The hydraulic resistance on all three lowland rivers, as indicated by the computed Manning's n, increased in spring until June, when maximum values were reached of 0.34, 0.66, and 0.71 for the Desselse Nete, Grote Caliebeek, and Wamp, respectively (Figure 1a). On other river systems, resistance values ranged between 0.25 and 2.25 (Dawson 1978, Watson 1987, Hearne and Armitage 1993, Green et al. 2006), which is within the range of our experiments. Resistance increased for Wamp and Grote Caliebeek by a factor of 7.6 and 2.2, respectively, in 1 mo, comparable with the three- to five-fold increase found in other river systems (Bakry et al. 1992, Champion and Tanner 2000, Sellin and van Beesten 2004). This sharp increase in resistance until June was not seen on Desselse Nete because biomass, consisting entirely of leafless *Potamogeton natans* L. stems, was still high in winter (260 g m^{-2}; data not shown), resulting in increased resistance. These stems were not divided evenly along the river, but followed the cutting pattern used in 2004. Points with lower stem density were those where vegetation was mechanically cut. Next winter, after a total removal of the vegetation during summer, much lower and more evenly spread *P. natans* infestations were observed. Further research is needed to explain this variation.

The increase in resistance followed almost the same pattern as the biomass growth (Figure 1b). When resistance was plotted against biomass, significant linear relations were found for Desselse Nete ($R^2 = 0.70$, $p < 0.01$, $F = 13.9$) and Wamp ($R^2 = 0.56$, $p = 0.05$, $F = 6.45$; Figure 2a). This relation was not significant for Grote Caliebeek ($R^2 = 0.06$, $p = 0.61$, $F = 0.3$) due to high resistance values in June and November,

TABLE 1. SUMMARY OF CALCULATED DISCHARGES, MEASURED WATER DEPTHS, ENERGY GRADIENTS (S) AND HYDRAULIC RADII (R) OF THREE LOWLAND RIVERS DURING 2005.

		Grote Caliebeek	Desselse Nete	Wamp
May	Discharge (m^3 s^{-1})	0.36	0.34	0.63
	Depth (m)	0.84	1.24	0.52
	S (m m^{-1})	0.0014	0.0012	0.0005
	R (m)	5.18	5.48	8.84
June	Discharge (m^3 s^{-1})	0.02	0.22	0.23
	Depth (m)	0.28	1.08	0.83
	S (m m^{-1})	0.0007	0.0010	0.0011
	R (m)	4.06	5.16	9.46
July	Discharge (m^3 s^{-1})	0.30	0.54	0.42
	Depth (m)	0.50	0.81	1.06
	S (m m^{-1})	0.0005	0.0010	0.0003
	R (m)	4.50	4.62	10.02
August	Discharge (m^3 s^{-1})	0.08	0.29	0.37
	Depth (m)	0.51	1.04	1.06
	S (m m^{-1})	0.0005	0.0010	0.0002
	R (m)	4.52	5.08	9.92
September	Discharge (m^3 s^{-1})	0.05	0.33	0.34
	Depth (m)	0.41	1.11	0.77
	S (m m^{-1})	0.0007	0.0012	0.0001
	R (m)	4.32	5.22	9.34
November	Discharge (m^3 s^{-1})	0.07	0.38	0.26
	Depth (m)	0.49	0.79	0.40
	S (m m^{-1})	0.0028	0.0009	0.0002
	R (m)	4.48	4.58	8.60
December	Discharge (m^3 s^{-1})	0.29	0.44	0.68
	Depth (m)	0.38	0.77	0.36
	S (m m^{-1})	0.0028	0.0008	0.0010
	R (m)	4.26	4.54	8.52

despite the low biomass, probably a result of cutting activities and natural senescence. In June, these high resistance values were the result of very low discharges, around 0.015 $m^3 s^{-1}$ (Figure 2b). The high resistance values in November were the result of the high-energy gradient (0.0028 m m^{-1}) and low discharges (0.07 $m^3 s^{-1}$; Table 1).

Together with the growth of aquatic vegetation, the water depth increased on all three lowland rivers, as shown by Dawson and Robinson (1984). This linear relation between water depth and biomass was significant (all p values <0.03) for all three rivers.

On both managed river stretches (Desselse Nete and Grote Caliebeek) the resistance was strongly reduced after vegetation removal to values around 0.09 and 0.07 but increased again due to fast regrowth (Rawls 1975, Cooke et al. 1990, Crowell et al. 1994, Bal et al. 2006), resulting in a second resistance peak later in the season. This regrowth indicates that vegetation cutting did not happen when biomass reached a peak, or belowground reserves would be depleted (Linde et al. 1976) resulting in low regrowth. In the unmanaged stretch of Wamp, only one resistance peak was seen early in the vegetation season (June). This peak did not occur when biomass was highest (July), but one month earlier due to low discharges and a high energy gradient (Table 1). From this moment on, a decrease in resistance occurred together with a decline in biomass.

Vegetation cutting in combination with harvesting is a useful tool to increase drainage when flooding threatens human activities, but only for a short period. Within one month, biomass will increase again resulting in increased water levels. Over time an integrated approach is necessary, including the reduction of nutrients to prevent unnaturally high macrophyte biomass. With strategic timing and frequency of cutting practices, river management can result in less but more efficient cutting activities causing fewer hydraulic problems.

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