Estimating the recreational carrying capacity of a lowland river section

Stefan Lorenz and Martin T. Pusch

ABSTRACT

Recreational boating represents a major human use of inland waters in many regions. However, boating tourism may affect the ecological integrity of surface waters in multiple ways. In particular, surface waves produced by boating may disturb freshwater invertebrates, such as interrupting the filtration activity of benthic mussels. As mussels may significantly contribute to self-purification, disturbance may have crucial impacts on water quality, and thus on water tourism. In this paper we calculate the carrying capacity of a river section for sustainable boating tourism based on the preservation of water quality. This approach is complemented by spatial and social approaches for carrying capacity estimates. The ecological carrying capacity significantly decreases with lower water levels during summer. Hence, the analysis of variables that influence the river's carrying capacity allows the formation of recommendations for management measures that integrate social, touristic and ecological aspects.

Key words | boating tourism, mussels, self-purification, Spree river, sustainability, water management

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INTRODUCTION

Rivers and lakes constitute some of the most valuable natural resources for tourism, as they provide opportunities for multiple touristic activities, like swimming, fishing, sailing or boating (Postel & Carpenter 1997). The multiple ways to use the natural resources of lakes and rivers allow the establishment of a broad array of secondary business segments, such as boat rentals, camping grounds, restaurants and hotels (e.g. CBSPOR 2011).

Growing urban development of the shores of inland waters is expected to produce increasing detrimental effects on surface water systems, such as pollution, physical alteration of shoreline areas, and disturbance of aquatic flora and fauna (Gabel *et al.* 2008). To avoid devaluing major lake resources, the detrimental effects of water-based tourism must be mitigated and regulated. Hence, the carrying capacity of the surface water body under use must be estimated to ensure the sustainable operation of water-related tourism businesses.

The carrying capacity concept was first developed in the field of population ecology and wildlife management, where it was defined as the number of individuals of one species that can be maintained within a given habitat area (Wagar 1964). This concept was also applied to the management of visitor numbers to national parks and wild lands. By applying the concept of carrying capacity to humans, two additional aspects emerged. First, visitors affect the environmental resources of the area they use in a more variable way (as previously hypothesised in wildlife management), and second, visitors affect their own perception of the environment at the same time. Furthermore, crowding or social conflicts also influence a visitor's personal experience and recreational effect (Wagar 1964).

Previous efforts to estimate the carrying capacity of lakes for water-based tourism accounted for these aspects by, for example, estimating the minimum required lake surface area needed for the safe operation of a single boat type (e.g. Jaakson *et al.* 1990; ERM Inc 2004; Rajan *et al.* 2011). The size of this area has mostly been determined based on the social perception of boaters, recorded through interviews and surveys. This specification varies greatly between low and high horsepower boats, as well as for muscle-driven vessels (i.e. kayaks, canoes). An approach to determine the touristic carrying capacity of rivers has been developed, which is based on boat counts and user

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surveys (Rebellato 2007). However, existing estimates of the touristic carrying capacity of lakes have primarily focused on the human component, thus neglecting the potential ecological impacts of tourism. For a more comprehensive approach, four different components have been recommended to estimate the recreational carrying capacity (O'Reilly 1986; Shelby & Heberlein 1986). These comprise ecological, spatial, economic as well as social aspects. Among these, environmental aspects deserve special attention, as these variables are often regularly monitored but may exhibit considerable variation depending on, for example, season and river discharge.

While the impacts of human use of inland waters are generally well known (Goudie 2006), less is understood about the specific effects arising from recreational activities. Motorised boating activities were found to constitute a major source of noise and unburned fuel emissions into surface waters, although the amount of these inputs varies greatly among the engine types (see e.g. Jüttner *et al.* 1995, Mosisch & Arthington 1998). Thus, it has been suggested to analyse impacts on water quality in order to assess the pollution impacts of recreational watercrafts, which might affect total suspended solids, turbidity, dissolved oxygen, pH and temperature (Rebellato 2007). However, natural processes may also influence these parameters of water quality. In contrast to pollution, the formation of surface waves by all kinds of watercrafts has largely been neglected so far, even though the ecological impacts are strong enough to determine the ecological carrying capacity for boating tourism.

The main pathways of environmental effects that originate from water tourism link boating activities with: (1) key variables of ecosystem health, (2) related political goals, and (3) respective actions of water management (Figure 1). Consequently, the major effects originating from water touristic activities, such as sediment resuspension, the disturbance of wildlife and impact of waves, may affect water quality and water ecology. Water quality variables like turbidity and dissolved oxygen and ecosystem processes like the water filtration activity of mussels are negatively influenced by these impacts. This leads to a decline in the visitor's perception of nature experience and quality. Furthermore, impacts on wildlife (such as waterfowl, invertebrates or mussel filtration activity) might also cause conflicts with regulatory requirements, e.g. the European Water Framework Directive (EC 2000). Hence, a sustainability analysis may be developed to establish integrated water tourism management by using the thresholds identified for various types of use and the related carrying capacity for water tourism.

As the success of water tourism is significantly influenced by the available water quality (Bockstael *et al.* 1989), touristic development should seek to minimise detrimental effects on the self-purification capacity of surface waters, as this would reduce system resilience (Zeng *et al.* 2011). In an earlier study (Lorenz *et al.* submitted) we described the

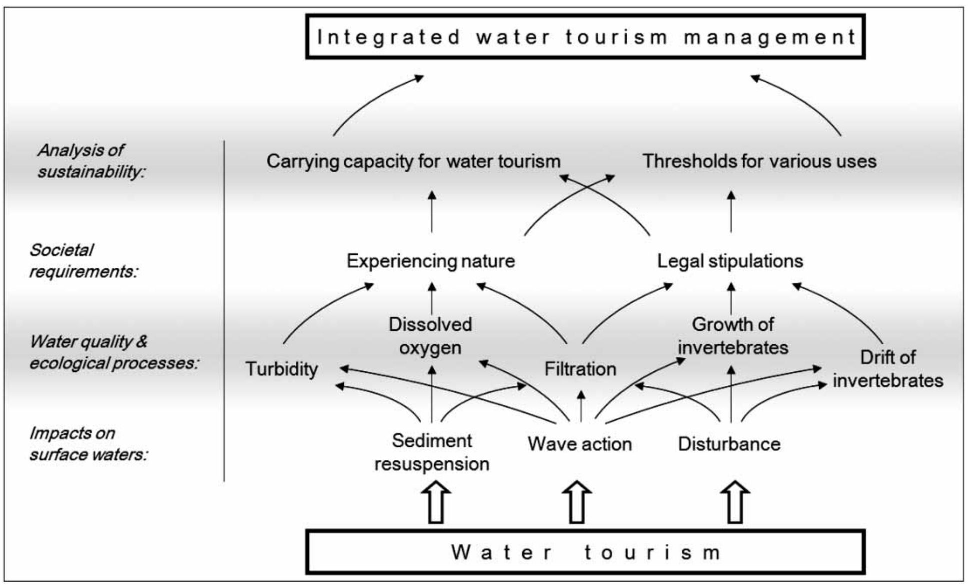

Figure 1 | Conceptual model of the major effects of water tourism on river ecosystems. The effects have impacts on different levels of perception that require consideration in an overall water tourism management strategy. All effects might be additionally impacted if framework conditions, such as water availability, are altered by unswayable events like climate change.

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impacts of wave formation from boating on freshwater mussels, which transfer organic matter from the water column to the benthic zone by their filter-feeding activity. Therefore, freshwater mussels directly contribute to the self-purification of surface waters, as most of the organic matter is processed by microbial degradation activity associated with the sediments (Fischer & Pusch 2001). Consequently, any impairment of this self-purification potential will produce negative effects on water quality. Decreasing water quality will in turn affect water tourism; for instance, the attractiveness of boat launching sites is strongly determined by water quality (Bockstael *et al.* 1989).

Hence, we aim to estimate the carrying capacity of a river section used for boating tourism based on an ecological approach that considers self-purification as the key ecosystem process for the preservation of acceptable water quality. By comparing this ecological approach with the spatial and social components that are estimated in parallel the development of integrative concepts to estimate the carrying capacity of surface waters for boating tourism is feasible.

METHODS

Study site

The 21.1 km long river section of the Krumme Spree (Welker & Walz 1998) serves as a connection between two lakes with intensive touristic use, and thus constitutes an ideal area to conduct studies on the impact of boating on water ecosystems. The mean width of this river section is about 25 m, with mean depth ranging from 1.4 to 2.5 m. As calculations of *Usable Lake Areas* suggest the importance of restricted areas (e.g. no-wake areas or shallow water depths) to protect shorelines (Rajan *et al.* 2011), this concept is not as directly applicable to our study river. Therefore, for our calculations we adopted the notion that the shallower portions of lakes (i.e. of less than 1.5 m deep) are the most susceptible to environmental impacts (Wagner 1991). As the Krumme Spree was straightened due to intense building activities between 1906 and 1911, it now has an almost homogeneous trapezoidal cross-section (Pusch & Hoffmann 2000). Hence in this river section, portions of river of less than 1.5 m depth would extend 3 m from the shoreline, reducing the *Total River Area* from 0.528 km^2 to 0.400 km^2 of *Usable River Area*.

Application of the carrying capacity concept to a river section

To apply the current concept of estimating touristic carrying capacity from lakes to rivers, the respective terms and equations required adjustment. The *Optimal Boating Density* describes the recommended space for various boat categories, measured in square metres per boat. We reviewed several carrying capacity studies (Jaakson *et al.* 1990; ERM Inc. 2004; CBSPOR 2011) to obtain values of *Optimal Boating Densities* that were applicable to the watercraft types that are used for boating tourism on the Spree River. Through collating the various published values, we adopted a density of 5,261 m^2/boat for muscle-driven boats, 36,422 m^2/boat for open motorboats (<15 HP), 28,328 m^2/boat for motorised rowing and rafting boats (<10 HP), and 60,703 m^2/boat for yachts (>15 HP). The *Optimal Boating Density* for the observed boating mix of the Krumme Spree was defined by the following equation (after Dearlove 2010):

$$\begin{aligned}&\text{Optimal boating density}\\&\text{of observed boating mix}\\&\quad=\left(\begin{matrix}\text{range of optimal}\\\text{boating densities}\end{matrix}\times\begin{matrix}\text{proportion of}\\\text{motorised boats}\end{matrix}\right)\\&\quad+\begin{matrix}\text{optimal boating density}\\\text{of muscle driven boats}\end{matrix}\end{aligned}\tag{1}$$

The *Range of Optimal Boating Densities* was derived by subtracting the minimum of the *Optimal Boating Densities* for the boat categories from the maximum (60,703–5,261 = 55,442), where the proportions of boating at the Krumme Spree correspond to muscle-driven boating = 0.39, open motorboats = 0.29, motorised rowing and rafting boats = 0.11 and yachts = 0.21. Therefore, the *Optimal Boating Density* for the observed boating mix on the Krumme Spree amounts to an estimated 39,081 m^2/boat. As the areas that are required per boat describe only the water surface area that is needed for the safe operation of this type of boat, we had to recalculate these values for the straight course of rivers instead of lake areas. Assuming that these areas would enclose a boat like a circle, we can take the radius of these circles as the area in running river metres that is required per boat type between consecutive boats. The results of this calculation for the different boat types are: 41 running river metres for muscle-driven boats, 108 m for open motorboats (<15 HP), 95 m for motorised rowing and rafting boats

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(<10 HP), 139 m for yachts (>15 HP), and 112 m for the observed boating mix. By using the following equation, this leads to an *Estimated Carrying Capacity* of 188 boats of the observed mix that could be present on the river at any one time:

$$\text{Estimated carrying capacity} = \frac{\text{river length}}{\text{requested area for observed boating mix}} \tag{2}$$

At mean peak use on weekends during July, an average of six boats per hour passes the Krumme Spree (Lorenz *et al.* submitted). To transfer the carrying capacity of 188 boats at the same time on the river into the number of boats per hour, we assume that all boats were moving with a constant velocity of 8 km/h. This leads to a carrying capacity of 257 boats per hour on the whole river section of the Krumme Spree. By using Equation (3), the *Observed Carrying Capacity* of the Krumme Spree is estimated to be 2.3%:

$$\text{Observed carrying capacity}\,[\%] = \frac{\text{total number of boats per hour}}{\text{estimated capacity per hour}} \times 100 \tag{3}$$

RESULTS AND DISCUSSION

Hydrology

Although the water level exceeds the proposed 1.8 m water depth during most of the boating season at the Krumme Spree (Lorenz *et al.* submitted), in the summer months this level may drop by about 0.9 m with receding discharge (Figure 2). An exponential regression model between discharge and water level at the sampling site in the Krumme Spree (Lorenz *et al.* submitted) revealed that with each 1 m^3/s reduction in discharge, the water level falls by about 4.5 cm ($y = 2.061 + 2.027 \times (1–0.971^x)$, $R^2 = 0.92$, $P < 0.0001$).

Estimation of the ecological carrying capacity

As estimated by Lorenz *et al.* (submitted) by use of coupled hydraulic–ecological modeling, motorboats cause the most adverse effects on the filtration activity of freshwater mussels in the shallow marginal zone by their intense wave production, while effects of motorised rafting and rowing

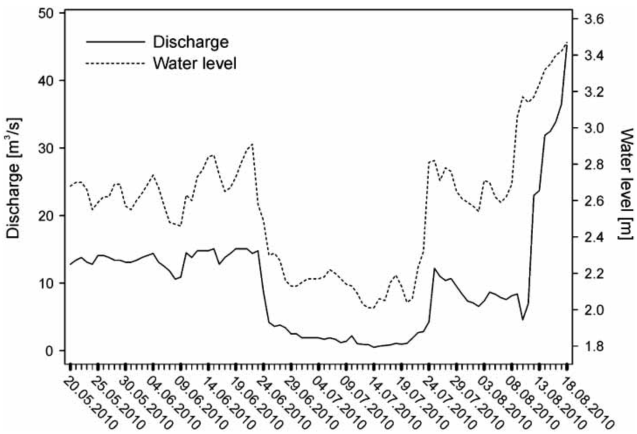

Figure 2 | Dynamics of discharge (records from the nearest gauging station of Leibsch) and related water level fluctuations on the Krumme Spree (Lorenz *et al.* submitted) during the summer months of 2010.

boats or yachts were partially significantly smaller. Therefore, we can state that the number of motorboats on the river constitutes the limiting factor for the estimation of the ecological carrying capacity. This coupled hydraulic–ecological model estimated a number of 93 motorboats passing by within one hour that would be sufficient to prevent filtration activity of all mussel specimens (with boats navigating at assumed 10 km/h). Using Equation (4), this would correspond to 321 boats per hour for a scenario with the observed boating mix:

$$\text{Ecological carrying capacity} = \sum \frac{\text{proportion of boat type} \times \text{maximum no. of motorboats}}{\text{proportion of motorboats}} + \text{maximum no. of motorboats} \tag{4}$$

Under the hydrological conditions of a summer drought as described in Pusch & Hoffmann (2000) with the water depth reduced to 1.5 m, the estimated maximum number of boats would be 62 motorboats per hour until complete mussel filtration would be inhibited, leading to the calculation of 214 boats per hour of the observed boating mix by using Equation (4). By assuming the observed minimal discharge during the summer of 2010 of 0.49 m^3/s, taking into account the above described accompanying drop in water level, the above number would further be reduced to 203 boats. As the number of boats that are able to pass the river within one hour until mussel filtration completely ceases declines with the lowering of the water level (Lorenz *et al.* submitted), we consequently calculated the maximum number of boats

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from the observed boating mix at each water depth by using Equation (4) (Figure 3). This calculated boating density is further referred to as the *Ecological Carrying Capacity* of the river Krumme Spree.

Estimation of the social carrying capacity

The *Estimated Carrying Capacity* per hour (from now on referred to as the *Social Carrying Capacity*) that is able to pass the river under social and spatial aspects varies by a small number of boats if the water level drops. The almost homogeneous, trapezoidal cross-section of the Krumme Spree results in a reduction of the *Usable River Area* with lowered water levels. With a given 26.6° slope of the riprap, the mean river width would be lowered by about 0.44 m each time the water level drops about 10 cm. Therefore, there is an equal reduction in the *Social Carrying Capacity* at each water level drop. Based on this lowered *Usable River Width*, the *Social Carrying Capacity* was calculated by replacing the *Requested Area for the Observed Boating Mix* from Equation (2) with the *Adjusted Area for the Observed Boating Mix* derived from Equation (5). Within this equation, the loss of river area (in square metres) over one section of the *Requested Area for the Observed Boating Mix* was calculated from the *lowered river width*. Assuming that this area must also be considered for the safe operation of boats when the water level declines, the radius of a circle containing this area must be added to the original *Requested Area for the Observed Boating Mix* for each water level reduction. The dependence of the *Social Carrying Capacity* on varying water levels is also plotted in Figure 3:

$$\text{adjusted area for observed boating mix} = \text{requested area for observed boating mix} + \sqrt{\frac{\text{lowered river width} * \text{requested area for observed} \times \text{boating mix}}{\pi}} \quad (5)$$

Dependence of the carrying capacity on framework conditions

The *Ecological Carrying Capacity* shows a clearly stronger dependency on river water level than the *Social Carrying Capacity*. At water depths greater than 170 cm, the *Ecological Carrying Capacity* exceeds the *Social Carrying Capacity* several times. As the effects of open motorboats and motorised rowing and rafting boats vanish at water depths exceeding 190 cm (Lorenz *et al*. submitted), and effects of muscle-driven boats only extend down to water depths of about 100 cm, the *Ecological Carrying Capacity* for water depths between 190 and 275 cm only depends on the number of yachts passing the river. Above this water level, the *Ecological Carrying Capacity* of the Krumme Spree is nearly unlimited with respect to the boating tourism of the mentioned boat types concerning the self-purification activity based on mussel filtration. However, at water levels below 170 cm, the *Ecological Carrying Capacity* drops below the line of the *Social Carrying Capacity*. Thus, the *Ecological Carrying Capacity* becomes the more important component during times of low river discharge, and should then be considered instead of social and spatial aspects.

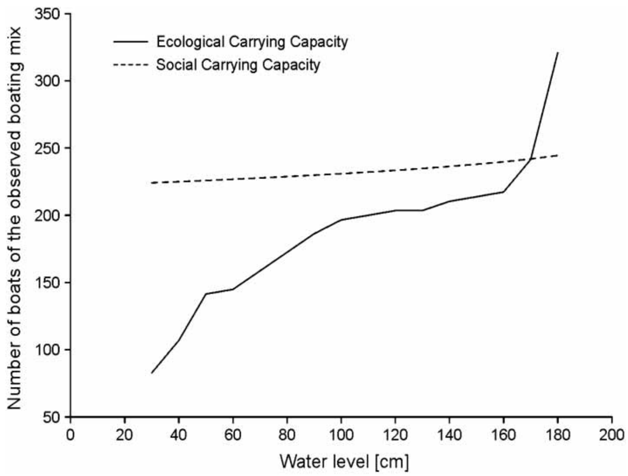

Figure 3 | Dependence of the ecological carrying capacity (black line) and the social carrying capacity (dashed line) of the Krumme Spree on the water level of the river. If the water level drops below 170 cm, the ecological carrying capacity constitutes the limiting component determining the maximum number of boats that is tolerable on the river.

The ecological status of surface waters is influenced by the natural dynamics of framework conditions, such as climatic variation, and by pressures exerted by humans. Consequently, the carrying capacity for a given human use is influenced by this variability and other uses as well. Restoration efforts in the Krumme Spree section could increase flow velocity during drought periods by decreasing channel depth by 0.5–1 m (Pusch & Hoffmann 2000; Pusch *et al*. 2001), aiming to compensate for the considerable decline in the water levels predicted by the climate change scenarios (Federal Environmental Agency 2005). However, the implementation of these restoration measures would

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clearly reduce the ecological carrying capacity of this river section for boating activities, which in turn might be compensated for by a potential change in the actual boat mix (ERM Inc. 2004).

CONCLUSIONS

We developed an ecological approach that aims to assure sustainable water tourism in the river section of the Krumme Spree. The approach considers all kinds of watercrafts present in this river section exerting a wave impact on the self-purification activity from freshwater mussels. The ecological carrying capacity showed a marked dependence on the actual water depth of the river, as the self-purification activity of benthic mussels is significantly reduced when shallow river reaches are used for boating. Thus, our approach also allows implications for an integrated water resource management to be derived that might preserve this river section as an area for water tourism. Increased water retention within the catchment area might contribute to maintaining water levels above critical thresholds. Alternatively, a shift in the boating mix on the river during times of low flow, involving a smaller proportion of motorboats, would contribute to the preservation of the river's ecological integrity. Consideration of such results could lead to changes in regulatory policies or to an adaptation of business strategies of the local boating and tourism industry. Our results suggest that specific concepts for water tourism should be developed for each water body, based on detailed information of respective social and ecological requirements. We could demonstrate that the relative importance of social and environmental aspects towards estimating the overall carrying capacity depends on key framework conditions. Therefore, we recommend the consideration of ecological approaches estimating the carrying capacity for boating tourism in sensitive river or lake ecosystems.

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