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Complete List of Authors:	Venohr, Markus; Leibniz-Institute of Freshwater Ecology and Inland Fisheries, Ecohydrology Langhans, Simone; Leibniz-Institute of Freshwater Ecology and Inland Fisheries, Ecosystem Research Peters, Oliver; Leibniz-Institute of Freshwater Ecology and Inland Fisheries, Ecohydrology Holker, Franz; Leibniz-Institute of Freshwater Ecology and Inland Fisheries, Ecohydrology Arlinghaus, Robert; Leibniz-Institute of Freshwater Ecology and Inland Fisheries, Biology and Ecology of Fishes; Humboldt-Universität zu Berlin, Division of Integrative Fisheries Management, Faculty of Life Sciences Mitchell, Lewis; University of Adelaide, School of Mathematical Sciences Wolter, Christian; Leibniz-Institute of Freshwater Ecology and Inland Fisheries, Biology and Ecology of Fishes

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The underestimated dynamics and impacts of water-based recreational activities on freshwater ecosystems

Authors: Markus Venohr[1a], Simone D. Langhans[1b,2], Oliver Peters[1a], Franz Hölker[1a], Robert Arlinghaus[1c,3], Lewis Mitchell[4], Christian Wolter[1c]

Affiliations

[1a)] Department Ecohydrology, [b)] Department Ecosystem Research, [c)] Department Biology and Ecology of Fishes, Leibniz-Institute of Freshwater Ecology and Inland Fisheries, Müggelseedamm 310, 12587 Berlin, Germany

[2] Department of Zoology, University of Otago, 340 Great King Street, Dunedin 9016, New Zealand

[3] Division of Integrative Fisheries Management, Faculty of Life Sciences, Humboldt-University Berlin, Germany

[4] School of Mathematical Sciences, University of Adelaide, Adelaide 5005, SA Australia

Address correspondence to Markus Venohr, Department Ecohydrology, Leibniz-Institute of Freshwater Ecology and Inland Fisheries, Justus-von-Liebig-Str. 7, 12489 Berlin, Germany, Telephone: +49-30-6392-4074, m.venohr@igb-berlin.de

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Abstract

Recreational activities on, in and along freshwaters (e.g., boating, bathing, angling) positively contribute to human well-being, but can concurrently stress aquatic ecosystems. While outdoor recreation, aquatic ecosystems and human well-being form coupled social-ecological systems, inherent fluxes and interactions between these have rarely been properly quantified. This paper synthesizes information on links between water-based recreational activities, effects on freshwater ecosystems integrity and recreational quality and proposes a novel framework for assessment and integrated management. This framework is based on understanding relationships between recreational quality, demand and use and recreational use-induced impacts on ecosystem state and function as well as ecological and social carrying capacities. Current management approaches of freshwater ecosystems addressing economic, environmental or recreational aspects are poorly linked and harmonized, and are further constrained by inadequate information on the dynamics and densities of recreational uses. Novel assessment and monitoring methods are needed to capture the short-term peak dynamics of water-based recreational uses, and we argue social media could play an increasingly important role here. An integrative recreation ecology management concept combined with peak usage information, has great potential to form the basis for next generation management approaches of freshwater and other ecosystems.

Keywords: recreation ecology, freshwater, social-environmental carrying capacity, social media, usage peaks, integrative management.

Résumé (needs to be updated)

Les activités récréatives sur, dans et à proximité des eaux douces (navigation, baignade, pêche…) contribuent au bien-être humain, mais impactent ces écosystèmes. Activités récréatives, écosystèmes aquatiques et bien-être humain forment un système d'interactions socio-écologiques, bien que les flux inhérents et les interactions n'aient que rarement été quantifiés. Dynamique et densité des usages guident la satisfaction perçue et les impacts environnementaux. Leur gestion durable est limitée par manque d'informations sur leurs dynamiques spatio-temporelles (d'usage et d'impacts écologiques). Cet article propose une synthèse exhaustive de la littérature sur les liens entre activités récréatives, effets environnementaux, qualité des écosystèmes et satisfaction de l'usager; et conceptualise les interactions socio-écologiques au sein d'un nouveau cadre de gestion et d'évaluation de ces activités. Les données géoréférencées extraites des réseaux sociaux (ici Twitter) y sont proposées pour approcher plus en détail dynamiques, timing et intensités des usages aquatiques récréatifs. Ces données, calibrées sur les enregistrements d'activités, pourraient constituer les outils de suivi 'next-gen' nécessaires pour l'évaluation des dynamiques et impacts des usages récréatifs.

Mots-clés : écologie récréative, eaux douces, capacité d'accueil socio-environnementale, réseaux sociaux, pics d'utilisation, gestion intégrée.

Introduction

People heavily depend on surface waters. Surface waters provide a multitude of ecosystem services (ESS) that contribute directly and indirectly, knowingly and unconsciously, to human well-being through recreation, scenic value, biodiversity provision, and the provision of nutritional products (e.g., Arlinghaus 2004; Bruce *et al.* 2005; Pretty *et al.* 2007).

Most people prefer to settle in the vicinity of freshwaters. Globally, approximately 50 % of the population lives within less than 3 km from freshwater ecosystems (Kummu et al. 2011). In urban environments, promenades are commonly favorite places to spend time, and the mere existence of surface waters potentially enhances human health and well-being (Völker and Kistemann 2011, 2013). Water is of such importance to people that visibility of surface water, compared to other landscape features, accelerates property prices (Luttik 2000).

Water-based recreation is important to people but their spatio-temporal distributions are not well known. However, official tourism data mostly neglect day-trips and only few scientific studies explicitly consider them (Wynen 2013) . Nonetheless, day-trips predominantly contribute to all recreational activities, e.g. approximately 87 % in Finland (Vesterinen et al. 2010) and 60-70 % in the Netherlands, Germany, and Latvia (Eurostat 2013). Estimates on participation rates in given recreational activities are mainly available from broad national or regional surveys, without necessarily being scaled down to local demands and use intensities on specific freshwater ecosystems (e.g., Arlinghaus et al. 2015). In contrast, locally monitored visitor numbers at individual locations are typically rare and often have such specific aims and boundary conditions, so that they cannot be easily scaled up to representative assessments of spatio-temporal use intensities and analyses of the cultural value of ecosystems at regional or national scales (e.g., Cord et al. 2015). This pervasive knowledge gap on the spatio-temporal dynamics of recreational uses of aquatic ecosystems is a major limitation for economic, social, cultural and ecological assessments of freshwaters (Sonter et al. 2016).

Environmental quality and recreational activities are closely linked. The attractiveness of a location and its biodiversity can be strong factors attracting visitors (Habibullah et al. 2016), but often cause conflicts between recreational interests and objectives of environmental protection, for example when tourism hot spots overlap with threatened species (Siikamäki et al. 2015). A range of negative impacts of recreational activities on species and ecosystem functioning have been reported for terrestrial, marine, and coastal systems (Ballantyne et al. 2014, Roche et al. 2015, Barnett et al. 2016), as well as for lakes and rivers (Lewin et al. 2006, Marion et al. 2016), but these strongly vary in space and time depending on both social and ecological contexts. Cumulatively across freshwater-based recreation activities, it is unclear if and how much recreational activities contribute to the global phenomenon that freshwater ecosystems are subjected to far greater biodiversity loss than terrestrial and marine ecosystems (Bruce et al. 2005, Loh et al. 2005, Collen et al. 2014, Vidal-Abarca 2014).

In Europe, impacts from water based recreational activities, such as recreational angling, boating or swimming, are perceived as pronounced; they rank fourth of all reported threats on freshwater ecosystems (EEA 2015). Consequently, European countries evaluated the implementation of protected areas as one of the five most beneficial measures to mitigate pressures from recreation (EEA 2015). At the same time and surprisingly, according to the ecological status assessment only 642 out of more than 127,000 European water bodies were classified as heavily modified due to recreation as primary use (Fehér et al. 2012). In contrast, 58,400 (56%) river water bodies were found to significantly suffer from habitat loss and habitat alterations (Fehér et al. 2012). This indicates a potentially systematic underestimation of impacts from water based recreational activities, and leads to the question whether classical conservationist approaches like protected areas will succeed in achieving ecological improvements. Indeed, recreational impacts can be managed using many other tools that do not prohibit access to a site entirely, such as spatial and temporal zoning (Abell et al. 2007, Manning 2010). However, such management strategies demand explicit local and regional knowledge about ecosystem status and recreational use, latter acting as both, ecosystem service and stressor to the respective ecosystems. Such knowledge is mostly missing, and overarching environmental policies, such as the European Union's Water Framework Directive (2000/60/EC, WFD), are explicitly and solely ecosystem-status oriented, neglecting the feedback of ecosystems to human well-being through recreation. The transfer from ecological status to human well-being is conceptulised via ecosystem services, which yet rarely consider trade offs between impacted water quality and water based recreational activities. Accordingly, in Europe river basin management approaches currently focus primarily on measures improving hydromorphology of and reducing nutrient inputs into surface waters rather than on recreational uses (Fehér et al. 2012). Yet, it is completely unknown whether these management approaches are sufficient to achieve the environmental targets, and whether recreational uses interfere or compromise rehabilitation efforts.

Despite the current global deterioration of most ecosystems, including freshwaters (Dudgeon et al. 2006), human well-being associated with the supply of cultural services from nature is increasing (Raudsepp-Hearne et al. 2010, Shepherd et al. 2016). Limiting or prohibiting recreational uses in protected areas is often heavily conflict-prone, because peoples' freedom of choice is affected (Stoll-Kleemann 2010). Conflicting interests will possibly gain importance if, as predicted by Gossling and Peeters (2015), the global impact and resources consumed by tourism will increase by 92% for water during the period 2010-2050. Though, it is widely unkown whether the measures implemented to improve ecosystem status will also improve benefits to people. Future management of freshwaters should jointly protect ecosystem needs, while considering people's recreational demands to secure the supply of the full range of ESS, as well as those that are recreation-based (EEA 2015).

Human well-being and recreational quality has been found to increase with improving environmental quality, e.g., bathing quality with increased water clarity (Graefe et al. 1984, Bruce et al. 2005, Doi et al. 2013, Weyland and Laterra 2014). However, subjective, non-monetary requirements to surface waters' quality could be uncoupled from environmental conditions representing good ecological status (e.g., Collier 2014, Allan et al. 2015). For example, increased water clarity in lakes and rivers is preferred by most swimmers, but could at the same time reduce catch rates and therewith satisfaction of anglers (Arlinghaus et al. 2014). This indicates that the link between ecological status and recreation quality is often not linear and positive, and strongly varies subjectively and with recreation type.

This non-linearity between recreational preferences, ecological status and ecosystems' degradation due to recreational uses potentially causes fundamental management trade-offs, but is rarely assessed and considered when managing freshwater ecosystems. Assessing the multiple and partly interacting pressures from recreational activities on aquatic ecosystems requires profound knowledge on the ratio between ESS supply (Maes et al. 2013) and demand (Wolff et al. 2015), as well as on their spatio-temporal dynamics. Only a small number of studies have jointly evaluated supply and demand in aquatic environments (Burkhard et al. 2012, Villamagna et al. 2014, Geijzendorffer and Roche 2014, Roche et al. 2015), while focusing on individual recreation types (see e.g. Melstrom et al. 2015, Hunt et al. 2016 in recreational fishing). In selected regions, first steps towards a change from single-objective, single-species management to an ecosystem-based management approach, explicitly integrating socio-economic dimensions and human well-being, could be observed (FAO 2012). There exist first landscape models developed for recreational fisheries that explicitly incorporate the multi-dimensional utility offered by selected lakes or river sections and consider dynamic demand responding to local changes in fishing quality (e.g., Hunt et al. 2011).

Most importantly, the few management approaches that do comprise interactions of multiple recreational uses and their impacts on water quality, ecosystem status and ESS are rarely and insufficiently considered by managers (Keeler et al. 2012, Russi et al. 2012, Hering et al. 2015). Besides lacking proper monitoring data, one contributor to this negligence is the common separation of responsibilities of public agencies in different sectors (e.g., water quality in environmental ministries, fisheries in agricultural ministries, and tourism in development and economics ministries).

This raises concerns as to whether different water-based recreational activities can be managed jointly and sustainably while also targeting ecological status and ecosystem improvement (Monz et al. 2013). Integration towards joint management frameworks in the field of recreation ecology demands intensive attention to the bi-directional links between environmental and recreation quality paired with socio-economic aspects of recreational preferences and perceived quality, which is not the case at present. In short, an integrative management approach and assessments with feedbacks among ecosystems, users, and management are needed.

Objectives

We synthesize existing information on water-based recreational activities to conceptualize their importance, dynamics, and potential impacts on ecosystem quality and management. First, we evaluate current knowledge on the links between various recreational uses, quality of freshwaters, and human perceptions and preferences in three areas: (1) the impacts of recreational activities on aquatic ecosystems and water quality, (2) the link between perceived ecological site qualities and participation in recreation, and (3) the needs for an improved consideration of the spatial distribution and temporal dynamics of recreational activities. Our final goal is developing an integral management and assessment framework to overcome current limitations in understanding the importance of recreational activities for sustainable management of freshwater ecosystems. To derive the required high spatio-temporal resolution of dynamics, timing, and densities of water-based recreational uses, we include an outlook on how geotagged data from social media platforms can be analyzed to help assess recreational activities.

Pressures and impacts of water-based recreational activities on aquatic ecosystems

Outdoor recreation activities and tourism, even if well managed, can affect multiple ecosystem functions and threaten biodiversity. We distinguished and elaborate on pressures and resulting impacts on aquatic ecosystems in Table 1. These are each linked to recreation type specific impacts. It is becoming obvious that recreational activities can impact freshwater systems across multiple levels of organization - from individuals to ecosystems. However, although the knowledge of the ecological impacts of water-based recreational activities is still developing, especially the ecosystem-scale ramifications have yet to be examined in detail.

Physical-chemical pressures resulting from recreational activities can impact aquatic ecosystems in various ways, e.g. directly by noise or waves produced by boats or damage resulting from trampling, or indirectly by increased concentrations of chemicals and organic substances (e.g. nutrients, oil, toxic matrials, bacteria) or other materials (e.g. sediments, plastic, cigarette butts).

Damage of riparian vegetation along sea and lake shores by recreational visitors and its various resulting consequences have been widely reported (Pickering and Hill 2007, Karwan et al. 2011, Vlasov 2012, Monz et al. 2013, Ikomi and Arimoro 2014, Sweeney and Newbold 2014, Vidal-Abarca 2014, Weirich and Miller 2014, Wyles et al. 2014, Rankin et al. 2015). An impairment of riparian buffer strips can reduce their capacity to retain nutrients and fine sediment loads to surface waters (Weissteiner et al. 2013) or to control shading / light availability and water temperature (Sweeney and Newbold 2014). This can finally result in a habitat degradation or loss.

Physical or chemical pressures caused by recreational activities include direct emissions of nutrients from detergents, urea, ground baiting or feeding wild water birds, protozoans and enteric viral pathogens, remains of sun-screens and cosmetics with UV-filters from water users, and direct emissions of engine oil spillage and anti-fouling paint residuals from recreational boating, as well as effluents and run-off from accommodation roads and service facilities, boat waves, light pollution along illuminated boat piers, biking and running paths, and noise generated from visitors or engines (see Table 1).

Whereas some pressures are well analyzed and also quantified, others are rather under-studied in the context of freshwater-based recreation activities. For example, at six Mediterranean beaches, Munari et al. (2015) allocated 52% of all remaining litter to shoreline and recreational activities and about 40% to smoking. Nicotine loads from littered cigarette butts in waste water was further identified as potential threat to urban waters (Roder Green et al. 2014). Nicotine and its metabolites were found to alter heart rates and induce distortions in growth developments (e.g., eye distance or length) and anxiety-like behavioral responses in zebrafish and medaka embryos (Lee and Lee 2015b, Stewart et al. 2015). Currently, no study is available on recreation-related cigarette butt disposal, and the resulting nicotine concentrations and potential impacts on freshwater ecosystems.

Similarly, scientific evidence is largely missing on residence time, aging, partitioning, and by-products of UV-filters in freshwater systems, originating from sun-screens and cosmetics entering surface water through swimmers or incomplete elimination in waste water treatment plants. Studies explicitly addressing the impacts of sun-screens on freshwater organisms are extremely rare (but see Díaz-Gil et al. 2017). In addition, evidence for microbiological contamination of surface waters due to recreation is based on relatively few studies (Gerba 2000). Hence, additional studies to assess the importance of microbial impacts on the bio-chemical composition of water and habitat quality are required.

Pressures from recreation activities can cause degradation or loss of habitats and, thus, potentially impact diversity, composition, and abundance of freshwater organisms. Recreational activities might also influence the physiology of animals and affect their behavior resulting in altered species assemblages. For example, motorboat noise was found to directly modify fish assemblage structure, as prey fishes were caught more easily by predators when exposed to noise (Simpson et al. 2016). Recreational activity is further shaping aquatic biodiversity as an important vector for invasive species, e.g. introduced by boats and gears used in different waters, through fish stocking or illegally releasing of pets (Freyhof and Brooks 2011).

Link between perceived ecological site qualities and participation in recreation

The engagement in recreational activities in, on or along freshwater ecosystems is a consequence of users' preferences and the expected outcomes derived from recreational activities (Driver 1985, Hunt 2005, Manning 2010). Individual decisions on whether, where, when, and how to spend recreation time is governed by a complex mixture of drivers. These include quality of known sites, socialization into the activity, potential substitutes for preferred recreation activities, tradition, weather forecasts, recent news articles, availability of time age, gender, education, having children, or availability of a car (e.g., Hunt 2005, Brandenburg et al. 2007, Manning 2010, Wynen 2013) .

After a person has decided to participate in a recreational activity, the frequency of her participation and her site choice is affected by multiple utility-determining criteria (Hunt 2005, Hunt et al. 2007, Beardmore 2013, Dolnicar et al. 2015). Key criteria can be broken down into a range of attributes (Freudenberg and Arlinghaus 2009) including: travelling and other costs, environmental quality (determined for example by presence of iconic species, scenic appeal or water clarity), social quality (e.g., crowding), infrastructure availability (e.g., boat ramps, beaches, camp sites) and regulations (e.g., restrictions in the accessibility of recreation sites) (Hunt 2005, Keeler et al. 2015a).

Research has shown that crowding, i.e. user densities, number of threatened and rare animals at a site, water visibility, expected rewards such as spotting wild animals or catching fish in recreational angling, run-off conditions, accessibility, available (or non-available) parking lots, on-site staff etc. affect the exerted activities (Hunt 2005, Howat and Assaker 2013, Wood et al. 2013, Loomis and McTernan 2014, Keeler et al. 2015a). Some of these activities are directly or indirectly affected by ecological attributes, e.g., scenic beauty, water clarity, quality of beaches and campsites in remote areas, and the availability of fish or wildlife. Thus, the experienced recreational quality will be affected by the ecological status of a site or ecosystem, at least to some degree. However, the importance of ecological attributes for how quality of a given locality is perceived will strongly differ from person to person and from activity to activity. One example is water clarity: whereas activities on and in freshwaters (e.g., swimming, boating, diving) are usually fostered by clear water and little algae or macrophytes (Keeler et al. 2015a), some fishing might be negatively affected, because clearer water usually means fewer fish (Baer *et al.,* 2016). Near-natural or wilderness areas are likely to positively affect wildlife-dependent recreational uses (e.g., bird watching) that are often associated with preferences for near-natural shore vegetation, macrophytes, and a diverse terrestrial and aquatic flora and fauna (Naidoo and Adamowicz 2005, Johnstone and Markandya 2006, Arnegger et al. 2010, Conradie et al. 2013, Kolstoe and Cameron 2017, Sorice et al. 2017). However, dense vegetation can also limit accessibility of surface waters and will not universally be preferred by all user types (Eiswerth et al. 2005). In fact, different recreational uses are not only associated with different demands on the environmental settings but also with variation in demand for infrastructures (e.g., boat slips, toilets, lights) (Hunt 2005).

In general, one can conclude that environmental quality is important to the utility derived by users and there is ample variation in what exactly affects the demand of individuals. Moreover, there might be ecological thresholds for the quality of some activities. However, recreational requirements for water and quality traits of ecosystems as well as for site characteristics may, depending on the respective use, deviate from environmental quality goals defined purely from the perspective of environmental management or conservation.

Given the above, a first step to link recreation ecology with conservation, using an explicit feedback framework, needs properly defined preference functions of different user groups. First studies that assessed stated or revealed user preferences reported alignments of surrogates of ecosystem quality and user preferences. For example, users' perception of the quality of surface waters was found to be in line with the observed water quality at a selected site (Smith et al. 2015). Also, users correlated the degradation of the recreational value of water-based activities in urban waters in Vienna with the degrading status of the respective aquatic biodiversity (Steinwender et al. 2008). However, functional links among user preferences and ecosystem quality remain often vague and describe broad classes of quality indicators, e.g., water clarity (Silva 2014). Moreover, visitors and recreational users such as swimmers or boaters often assess water quality by visual and olfactory senses (Lee and Lee 2015a, Smith et al. 2015) and not necessarily by considering overall ecological quality including a holistic assessment of multiple ecological criteria.

Satisfied water quality expectations can result in maintaining visiting rates and lead to loyalty to a specific location, i.e. the intention to revisit (Taplin 2013, Melstrom et al. 2015). Keeler *et al.* (2015) found that improved water quality was associated with an increased number of visits to lakes in northern USA, and visitors were willing to travel approximately one hour farther for every meter of increased water clarity. Also, in Finland, increased water clarity of 1 m was predicted to result in an 6 % and 15% increase in swimmers and fishers, respectively, however no effects were predicted for boating (Vesterinen et al. 2010). Whether increased water clarity correlates with an improvement in other ecosystem traits (e.g., biodiversity), and how this is perceived by visitors, is less clear. It is likely that trade-offs are involved that vary with the respective recreational activity. For example, high water clarity will benefit scenic beauty and swimming, but decrease fish productivity and may render boating more difficult when intensive macrophyte beds develop in shallow water (which in turn can impact swimmers).

Generally, when asked in abstract terms, people prefer "good" water quality in surveys, but quality aspects may not always be relevant or not primarily relevant when choosing a destination. This is particularly true in cases when holidays are planned several months in advance, as revealed by a survey at the German Baltic coast (Dolch and Schernewski 2002, Preißler 2008). Consequently, a distinction must be made between holidays and regional, day- or weekend-trips. Regardless of their quality, water body types seem to be relevant for the selection process, as they provide a different spectrum of opportunities for recreation activities. For example, lakes in northern Germany were visited by more people but less frequently than rivers (BTU-Cottbus 2014). Further, even within a user group, for example recreational anglers, different water body types will be preferred (Arlinghaus 2004, Hunt et al. 2011 Ward *et al.* 2013b). Water bodies in vicinity to urban areas, with preeminent recreation qualities or infrastructures (e.g., boat ramps) will attract disproportionally high levels of visitors, potentially predisposing these systems to excessive impacts such as overfishing (Ward et al. 2013a, Mee et al. 2016). This in turn will affect the future quality and demand of these systems (e.g., Hunt et al. 2011). Although water quality or ecological traits in general (e.g., biodiversity) appear to be important criteria for recreational visits to surface waters, as far as we are aware, no study describes lower water quality thresholds as decisive for recreational participation, except when explicitly hazardous to health (e.g., due to excess of *E. coli* thresholds).

Some water-based recreational activities do not depend on high environmental quality and can utilize entirely artificial environments, for example biking or dog walking. Consequently, further work is needed to link objective measures of ecological quality with demand for recreation, and understand how this varies with culture, region, and type of recreational activity. This work then needs to be coupled within an explicit feedback loop to recreation-induced ecosystem impacts to be able to study relationships among quality and demand and learn what the systematic effects of management interventions are.

Conceptual framework to link recreational satisfaction, recreational use and ecosystem impact in freshwater ecosystems

Currently, academic and managerial silos prevent developing integrative assessments of and management approaches for outdoor recreation in and around aquatic ecosystems. Within the recreation-oriented social sciences, there is also little integration among social-psychological approaches and recreation economics (Fenichel et al. 2013). Moreover, there is very little integration of applied social/economic and ecological sciences and management components dealing with conservation and ecosystem quality in freshwater systems, which motivated us to develop a framework to link the disjointed concepts.

Of key importance in the proposed framework is to conceptualize the decision-making process of users and how it is linked to ecosystem quality. According to economic theory, preferences by users are expressed in choices they make to maximize the utility associated with recreation at a given site (Hunt 2005). Thus, changes to attributes that determine utility affect participation decisions (Hunt 2005). Social-psychologists in the field of outdoor recreation pursue a comparable framing, but use different concepts and terminologies (Manning 2010). In that particular research tradition, people are seen to participate in outdoor recreation to satisfy their needs (Manfredo et al. 1996). There are many factors that determine both utility and satisfaction (Hendee 1974, Driver 1985, Arlinghaus 2006, Arlinghaus et al. 2014) and the importance of each factor varies among people, even when they engage in the same activity. This is reflected in heterogeneous user preferences, expectations, and behavior (Johnston et al. 2010). Logically, different recreation activities will tap into different attributes of the social-ecological environment to a different degree. Expectations of utility to be enjoyed at a given site as well as structural conditions within society (e.g., amount of free time, income, knowledge of how to participate in a given activity) and supply (availability and quality of sites), will in turn determine peoples' participation decisions. These participation decisions will leave impacts in the ecosystem and affect the social environment (e.g., crowding), thereby changing the local recreational qualities (as a function of the ecological, social and structural environment), which in turn leads to new individual-based participation decisions in space and time.

A simple conceptual model (Figure 1) describes the resulting links between ecosystem and recreational quality (represented as recreation demand) and ultimately realized ecological services (represented as recreation use). The term recreation demand here considers, beyond the attractiveness of a site, factors like the size of the population living within travel distance, accessibility and awareness of a site or concurring recreational sites as substitutes.

Recreational demand for each site is also expected to be a function of environmental quality (Bockstael et al. 1987), as shown for boating, fishing, and swimming. This acknowledges that environmental quality is just one of several dimensions that affect recreation demand. We disentangle ecosystem status from perceived ecosystem quality to unveil an environmental quality that ultimately drives choice behavior of users. For example, several studies explored how changes in water quality affect recreational demand, and estimated the demand as a function of different characteristics such as fish catch rates (Englin et al. 1997, Massey et al. 2006), Secchi depth, dissolved oxygen level, temperature, chemical oxygen demand (COD), turbidity, pH, and color (Bockstael et al. 1987, Egan et al. 2004). Several functional forms such as linear (Bockstael et al. 1989, Parsons and Jo Kealy 1994, Pendleton 1994, Whitehead et al. 2008, Keeler et al. 2015b), quadratic, and semi-log (Eom and Larson 2006) were used widely in the application of the empirical demand models, suggesting that ecosystem quality plays a role, although is not necessarily the prime driver of demand and does not necessarily link quality and demand linearly.

For social-ecological systems sigmoidal relationships are commonly used to describe regime shifts and to derive thresholds, when systems shift to a new stable state after a perturbation (Schlüter et al. 2012), e.g. when peaks in recreational activities disrupt ecological processes (e.g., Biggs et al. 2009). There is some evidence from recreation choice models and satisfaction studies suggesting that the probability of user participation as well as their satisfaction can scale non-linearly with changes in utility-determining attributes, particularly in relation to ecosystem quality (e.g. fish abundance and catch rates in recreational angling; Hunt et al. 2011, Arlinghaus et al. 2014, Johnston et al. 2015). Because recreational demand is limited by the regional population size and available leisure time, and as further ecosystem traits are only some of many factors affecting utility, we thus propose a sigmoidal relationship to describe recreational demand as a function of ecosystem quality (Figure 1a). The asymptote maybe caused by negative effects on user satisfaction correlating with increased demand and user density, e.g., effects of crowding. We exemplify this possibility by the grey horizontal area in Figure 1a. However, this function is scale dependent and visitor growth can, at a single site in a landscape, also appear to be unlimited. At the lower part of the curve in Figure 1a, the effect of poor ecosystem quality may vary for different recreational use types. For example, while for bathing a minimum standard of the water quality exists below which participation drops to zero (e.g., very turbid, algae rich water or when water quality poses a health risk), recreational angling or boating might still be performed, resulting in a positive intercept with the demand axis (Figure 1a).

We follow Monz et al. (2013), who also suggested a sigmoidal-shaped curve for the relationship between recreational uses (the actual number of visitors) and ecosystem impact (Figure 1b). Few visitors, below a primary ecological threshold, cause only little and reversible damage, whereas at high use levels, when the ecological carrying capacity is exceeded (secondary threshold), any further increases cause little additional ecological damage. The cause-response functions may again differ between different recreational activities and aquatic ecosystems, which is a matter of thorough empirical study in the emerging field of recreation ecology (Monz et al. 2013).

Assuming that both ecological and social status (e.g., with respect to crowding) affect the quality of a local recreational experience at a given site, leads to at least two potential conditions that will limit recreational quality and, hence, recreational demand. Demand should be constrained if 1) the environmental quality of freshwaters and/or riparian areas becomes unacceptably low, and/or 2) the local user density becomes too high causing social impacts, thereby reducing the experienced recreational quality (e.g., Graefe *et al.* 1984; Navarro Jurado *et al.* 2012; Salerno *et al.* 2013). Both conditions depend on the ecological and social resilience of the ecosystem, on culture, the type of social community (e.g., urban or rural community), the kind of recreational use (e.g., whether it is social or not), and the subjective perception of local conditions by individual users. Different adaptation strategies to unacceptable environmental or social quality will apply for individual users, e.g. visiting different water bodies at different times of day or changing recreational activity). This may result in substitution of users with higher tolerances (e.g., for crowding) or with different preference structures (Manning 2010). These substitution patterns might initially create stability in local recreational use (and also in average user satisfaction when measured on site, Manning 2010) unless the conditions deteriorate further and effectively reduce recreational use.

In general, peoples' local and regional preferences at available sites and substitution relationships among sites will determine complex patterns that define whether a change in either ecological or social quality affects average recreational quality (and recreational satisfaction).

We propose to simplify a complex situation that varies strongly across regions and activities by assuming that recreational demand is unlikely to grow infinitely with increasing recreational quality. Rather, recreational demand might reach some ceiling determined by the size of the regional population of users in light of the supply of recreational opportunities (Figure 1c). In fact, unless we deal with a tourism destination where travelers can be drawn almost without limit, there will be leisure time limits in any given regional population from which a site or ecosystem can “draw” only a limited number of people independent of the recreational quality of the site. For example, factors such as urbanization or weekly working hours exert negative effects on participation rates in recreational activities (Post et al. 2008, Arlinghaus et al. 2015). However, increasing recreational quality exerts linearly and fosters participation (Fix and Loomis 1998, Hunt et al. 2017). Thus, in Figure 1c we assume a region where increases in recreation quality affect recreation demand linearly and positively, until reaching a ceiling caused by constrains on leisure time by a finite population of recreationists.

In Figure 1a we conceptualize that saturation of demand with increasing ecosystem quality occurs where social carrying capacity is exceeded. However, we acknowledge that this concept is volatile and strongly affected by local and regional contexts and may vary substantially from person to person (as shown by the grey area). We nevertheless use social carrying capacity because of its conceptual similarity to ecological carrying capacity, which is popular in conservation sciences. We believe that these descriptions can help us navigate the interaction of recreation, quality, and impact (Figure 1). We note that both social and ecological carrying capacity could be operationalized by context depending multiple measures. Social carrying capacity involves crowding or other issues that correlate with number of people, e.g., littering, constrained ability to enjoy freedom of choice (e.g., with taking services or fishing sites), or regulatory constraints (e.g., temporal zoning) that reduce satisfaction. Shelby and Heberlein (1986) used perceived crowding as an evaluative standard in defining social carrying capacity, and this conceptualization is common in leisure sciences related to outdoor recreation (Manning

2010). The concept of social carrying capacity is then described as unacceptably high visitor densities, which has been applied for diving (Zhang and Chung 2015), boating (Lorenz and Pusch 2012, Lorenz et al. 2013), fishing (Hunt 2005, Arlinghaus et al. 2014) or island visitors (Viñals et al. 2016). When quantifying the impacts of carrying capacities on satisfaction and demand, social carrying capacity appeared as potentially, but not always, more limiting than environmental carrying capacity (Santiago et al. 2008, Lorenz and Pusch 2012, Lorenz et al. 2013). However, social carrying capacity extends the mere interaction of “too many people” to also affecting more fundamental components of an outdoor experience, such as altering the feeling of self-determination and losing control over personal choice (e.g., of sites) during recreation (Manning 2010).

Conceptualizing thresholds with the help of social and ecological carrying capacities is useful for outlining key dynamic interactions among quality, demand, use, and impacts that can either have an amplifying or a dampening effect (Figure 2). High ecosystem quality increases demand, which positively affects recreational use. As long as the ecosystem impact of such level of recreation remains low enough (e.g., water quality is still acceptable), and/or the visitor density is below a certain threshold (e.g., social carrying capacity for crowding is not exceeded for most visitors, Figure 1a), recreation satisfaction by those that choose to visit a site remains high. Management interventions can then further improve environmental (or social quality, e.g., through infrastructure, Fig. 3), further fostering demand and use. At higher recreation use, however, ecological and/or social carrying capacities might be exceeded (Figure 2). This can lead to either declining ecosystem status, reducing demand, or reducing the social quality of the experience, again reducing demand and in turn use. Both amplifying and de-amplifying recreational loops can occur depending on the social-ecological context and dynamics. An alternative scenario is simply self-regulation, when reduced demand helps ecosystem and social qualities to recover.

Local and regional specificities (e.g., supply and demand and alternative uses of ecosystems for non-recreation activities) will determine the interplay of the factors shown in Figure 2 and its trajectories.

Finally, we add the management perspective and link the recreational and ecological quality loops with management and policy decision making (Figure 3). Importantly, from a recreation ecology perspective we propose the management loop should not only evaluate the ecosystem status, but also recreational quality and base decisions on an integrated assessment of ecology and social dimensions. Such management is currently rarely done as most aquatic ecosystem management is predominantly focused on ecological targets. The management loop we suggest balances recreational use and carrying capacities (ecological and social), while considering often competing freshwater and catchment uses (e.g., agriculture, energy production). The ecological quality loop addresses the links between extent and combination of stressors, ecosystem resilience, and impacts on aquatic ecosystems and habitats (Figure 3Figure). However, depending on institutions and countries, management commonly focuses either on the recreational site or on the ecological site (like the WFD) or Nature Conservation Legislation). These isolated views are expected to produce only suboptimal outcomes (Johnston et al. 2010, Levin et al. 2013). Therefore, we propose a framework that facilitates the integrated assessment of recreational and ecological health of aquatic ecosystems. In this sense, the management loop can be understood as a connecting element to achieve balanced functioning and provisioning of ecological quality and recreational quality, respectively, in light of stakeholder objectives. Recreational uses and their management have to be assessed and implemented in addition to ecological rehabilitation measures for example to improve water and habitat quality (Hall et al. 2014), minimize health risks (e.g., from harmful algal blooms and pollution), and sustain and if possible improve recreational qualities for a variety of user groups. Although the present model is meant to show the interactions and feedbacks and is focused on aquatic ecosystems, it conceptually considers stressors originating from “external” social-ecological systems like waste water discharges or agriculture.

Improved assessment of the spatial distribution and temporal dynamics of recreational activities

In order to put the frameworks elaborated in Figures 2 to 4 into operationalization, there is an urgent need to improve visitor monitoring and assessment methods accounting for the spatio-temporal dynamics of recreational activities in a landscape of lakes and rivers. Such assessments help understand demand and monitor use and analyze and predict recreational impacts as well as responses of users to changes in the environment. Ecologically, different recreational activities predispose disproportional pressure levels and combinations on aquatic ecosystems. However, current practices to determine cultural, recreation-based ESS are usually not sufficient to link recreational uses, impacts, and ecosystem functioning. A clear identification of links between recreational activities and ecosystem conditions and, vice versa, between ecological site quality and recreational quality and user satisfaction has to enumerate and consider distinct recreational users in combination with spatio-temporal patterns of water body uses.

Annual averages of highly skewed distributions, e.g., average numbers of boats passing a river section or swimmers in a lake are not suitable to quantify their potential impacts on aquatic habitats, flora, and fauna and on water quality during usage peaks (Arlinghaus and Mehner 2003, Wolter et al. 2003, Arlinghaus 2004). These aggregated data are also inadequate to develop predictive models of user dynamics and to infer user preferences from observed behaviors.

Because day and weekend trips constitute the biggest share of all recreational activities (e.g., Vesterinen et al. 2010), they are expected to peak at few weekends during the high season. Thus, ecological impacts of recreational activities should be better assessed as short-term, extreme events like peak uses rather than according to annual averages. For example, daily visitor counts from 2013 to 2015 provided by the Berliner Bäder-Betriebe (BBB, the company that maintains the public swimming pools and beaches in Berlin) show a strong increase of daily visitors with increasing maximum daily air temperatures. Natural bathing waters received 30% of all visitors during the 5 % hottest days. Visitor numbers were significantly higher during weekends and holidays compared to working days (Figure 4**Error! Reference source not found.**). In contrast, days with maximum air temperatures below 30 °C or less than six hours of sunshine resulted in significantly lower visitor numbers. This is just one example of highly skewed distributions of recreational users that demand sophisticated, high intensity sampling programs and alternative real-time assessments methods additionally to on-site visits. We advocate for a greater use of social media data as one of the toolboxes that could be used for monitoring recreational activities in the future.

It could also be important to consider visitor monitoring and assessment methods accounting for daily dynamics of recreational activities (Cooke et al. 2017). For example, recreational fishing at night is quite popular due to its environmental (presence of nocturnal species, scenic appeal) and social quality (less crowded). In addition, several recreational uses (e.g. boating, biking, running) require the installation of artificial lights along boat piers, and biking and running paths that are potentially impacting aquatic systems at night (Perkin et al. 2011). Because the night is an ecologically relevant time period for many aquatic organisms - 30% of all vertebrates and over 60% of invertebrates are nocturnal (Hölker et al. 2010) - aggregated daily data are inadequate for developing management concepts to mitigate potential ecological impacts of nocturnal recreational activities.

Currently, recreational uses of freshwaters are locally determined by visitor counts or more often inferred from surveys asking for visiting frequency "after the fact" (i.e., offsite surveys by mail or phone). Visitor counts provide true numbers, but they can hardly be generalized for other locations and are often costly and difficult to generate for large spatial scales, as for example hundreds of lakes in a water-rich landscape. Recreational activities determined from surveys are in turn often spatially inexplicit and cannot be used to assess waterbody-specific uses. Also, as noted before, recreational activities derived from statistics mostly provide averages or only consider rough frequencies or distributions of visits, but not the temporal dynamics or timing of visits (Vesterinen et al. 2010, BTU-Cottbus 2014).

There are some models that describe daily visitors and recreational uses as a function of external variables, but these are either not directly related to rivers and lakes (Cole et al. 2005, Resource Systems Group 2013), or they only address site-specific activities (e.g., Santiago et al. 2008). Individuality and spatio-temporal heterogeneity in users and spatial ecological conditions considerably complicate the modelling of social-ecological systems, but their consideration is of utmost importance for sustaining ESS (Levin et al. 2013). Activity-specific counts, densities, spatio-temporal distributions, and frequencies of recreational uses as well as the spatio-temporal configuration of different user types may be much stronger predictors to assess ecological impacts of recreational uses. This is in agreement with Bujosa *et al.* (2015) who found user densities, rather than absolute counts, are a much better descriptor to assess user preferences when analyzing onsite recreational activities. Quantifying user density, however, requires detailed knowledge on the number of users, the size of a specific location, and on the timing of recreational uses. At larger scales, heterogeneity in recreational uses cannot be determined with any available approach or data set yet. Especially challenging is the quantification of the various individual, license-free recreational activities such as swimming, bathing, kayaking, and boating. Analysis of social media could provide one alternative to traditional on-site user count and off-site survey methods.

In conclusion, a sufficient temporal resolution of recreational activity peaks and dynamics on and along freshwaters is missing for most ecosystems. Instead, what is usually available is simply national level interest or participation data in certain recreational uses or local-level assessment data for selected recreational activities. What is needed, though, is regional-level assessment of all recreational activities at temporal and spatial scales that are conducive to water-body specific management.

Using social media data for identifying spatial and temporal use patterns of water-based recreation

Social media, such as Facebook, Flickr, Twitter, and Instagram among others, are increasingly used in private and professional contexts worldwide. With enabled GPS devices, activities on social media platforms, i.e. posting messages on Twitter or uploading pictures on Flickr, are tagged with the coordinates of the user's location, which generates geotagged data. Geotagged data can be accessed in real-time, and the visiting times and locations can be further linked to on-site characteristics including weather conditions, sunshine duration, and accessibility of the site. This enables spatio-temporal explicit analyses of peoples' recreational activities (Sonter et al. 2016) including environmental triggers and potential effects on ecosystems. Such data offer an unprecedented opportunity of monitoring and assessing recreational activities at site-specific and larger spatial scales. Geotagged data are increasingly used to explore business-related, political, or social topics (e.g., Piryani et al. 2017). However, they have rarely been used in ecological contexts.

In a freshwater recreation context, one of the first attempts to obtain travelling distance information used geotagged Flickr data and combined these with water quality parameters and cost estimates in a classical travel cost model (Wood et al. 2013, Keeler et al. 2015a). Howarth (2014) used photos from Flickr and Google Panoramio to model the spatial distribution of recreational activities at the Great Barrier Reef, which were found to concentrate around tourist infrastructures and particular islands rather than along the reef itself. Daume (2016) analyzed the content of 2842 tweets as reference for invasive alien species and concluded that tweets are a rich source of biodiversity information. Mitchell *et al.* (2013) analyzed the sentiment and expression of 80 million words derived from geotagged twitter messages and linked them to environmental conditions to create a map of happiness across the USA. Orsi and Geneletti (2013) used geotagged Flickr and Panoramio photographs to feed a gravity model estimating the volume of visitor flows from access points at an Italian UNESCO World Heritage Site. This method allowed estimating visitor flows over a large trail network and assessing the intensity of trampling damages. Sonter et al. (2016) used geotagged data from social media to study temporal dynamics and values of nature based recreation activities within conserved lands in Vermont, USA. They found that using social media can help to correct misleading results from static models on the impact and importance of landscape attributes. Similar approaches describing spatio-temporal visitor dynamics on and along lakes and rivers are still missing, and are suggested as future impact assessment and management tool in the context of recreation ecology. Clearly, calibration studies are needed to see if social media-derived patterns agree with validated on-site measures either assessed by visual counts through interviewers or by use of cameras, flights, drones, or vehicle counting devices. Once social media data are calibrated, however, they can serve as a powerful tool to assess the spatio-temporal patterns of recreational uses. When combined with further information on site and ecosystem characteristics, e.g., those assessed with real-time sensors, remote sensing or through citizen science, such data could be used to analyze, describe and predict use intensities. Personalized data from selected social media could then also be used to study preferences using variants of choice modelling or with machine learning applications.

Conclusions

Outdoor recreation and aquatic ecosystems can be considered as bi-directionally coupled social-ecological systems, whose fluxes (services and benefits) and interactions have rarely been properly quantified (Jobstvogt et al. 2014, Villamagna et al. 2014). Direct effects of recreational uses on ecosystems and biodiversity have been described in several individual studies, but feedbacks to a range of different recreational demand types (activities) and human well-being have usually been neglected or not quantified at large scales (Arlinghaus et al. 2017). A joint and harmonized management framework that considers recreational demands, environmental impacts resulting from recreation, and ecological targets, is missing, and we envisage that the framework we propose inspires further work.

Currently, water quality, navigation, recreation, and other water uses are commonly managed by different agencies at different administrative levels with some recreation activities such as individual bathing hardly managed at all. Different users are often in conflict where one activity inflicts on the quality of another. Management is needed to develop solutions that maximize the well-being of as many people as possible while minimizing ecological impacts and therefore reaching ecological quality standards. Today, regulations and management of a range of recreational activities around waters are poorly linked and harmonized. However, all these outdoor activities and aquatic ecosystems form complex and interlinked social-ecological systems, which have to be jointly considered to minimize ecosystem impacts and increase human well-being and ecosystem service flows. Because recreational uses and their impacts on lakes and rivers are not treated in an integrative manner across administrative sectors, current conservation strategies are also insufficient to stop biodiversity loss and may at the same time even harm the quality of the cultural services that ecosystems provide (Santos-Martín et al. 2013). This commonly results in support of only one single, politically most preferred water-based ESS, without feedback from other intended and unintended developments. For example in Germany, large rivers are utilized as waterways and hence are managed to improve the economic service of navigation, which leads to substantial habitat and ecological impairments (Liedermann et al. 2014) while negatively affecting recreation. As another example, in Europe, objectives of the EU-WFD entail reaching a good ecological status, which is not necessarily associated with the interests of recreational activities and other ESS, e.g. nutritional limitations for fish production or impeded accessibility of surface waters for bathers by dense riparian buffer strips or macrophytes (Terrado et al. 2016). By contrast, the number of waters primarily managed for recreation is – with the exception of angling - currently limited, although it is recreation by which the majority of society personally interacts with natural aquatic ecosystems. The environmental triggers for recreational quality and user satisfaction as well as potential feedback to the other management cycles that are associated with water and ecosystems certainly need further investigation.

It is not intended to question the environmental goals of regulations like the EU-WFD, but given the socio-economic importance of recreational activities a harmonization of the various management goals seems inevitably needed. Balancing demands for recreational uses on, in, and along waters with conservation and management of biodiversity and other ESS would significantly improve existing management approaches. Possibly, an integrative view that considers human well-being as a whole would come up with strikingly different management scenarios than the ones that are currently focused on selected ecosystem status targets or human uses of ecosystems (e.g., navigation).

In many areas of the world, recreational uses on and along freshwaters have not yet been spatio-temporally explicitly estimated. However, this is vital to understand the links between various recreational uses and freshwater quality conditions as well as human preferences and to tailor management approaches. The joint evaluation of ESS supply and demand is also a major prerequisite and profound element of the emerging science of recreation ecology. A detailed quantification of recreational uses not only links these to pressures on freshwater systems, but allows estimating timing, frequency, and utilization peaks of recreational activities. These spatio-temporal dynamics of recreational uses enable the analyses of processes, i.e. how extreme events, peak pressures, frequency, and duration of recreational uses interfere with or impact on ecosystem processes and functions, such as juvenile fish recruitment (e.g., Wolter and Arlinghaus 2003) or filter activity of unionid mussels (e.g., Lorenz et al. 2013) . Correlations between water quality, weather conditions, and recreational uses could also allow estimating limiting factors and main drivers for changing uses and defining appropriate indicators. We present the potential of geotagged data, e.g. from Twitter, for analyzing recreational activities with high temporal resolution at large spatial scales. This opens up novel opportunities to derive use dynamics, frequencies, and dynamics of recreational activities as inputs for the integrated frameworks presented in this paper.

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References

Abell, R., Allan, J.D., and Lehner, B. 2007. Unlocking the potential of protected areas for freshwaters. Biol. Conserv. **134**(1): 48–63. doi:10.1016/j.biocon.2006.08.017.

Allan, J.D., Smith, S.D.P., Mcintyre, P.B., Joseph, C.A., Dickinson, C.E., Marino, A.L., Biel, R.G., Olson, J.C., Doran, P.J., Rutherford, E.S., Adkins, J.E., and Adeyemo, A.O. 2015. Using cultural ecosystem services to inform restoration priorities in the Laurentian Great Lakes. Front. Ecol. Environ. **13**(8): 418–424. doi:10.1890/140328.

Arlinghaus, R. 2004. Angelfischerei in Deutschland - eine soziale und ökonomische Analyse. *In* Heft 18. *Edited by*Leibniz-Institut für Gewässerökologie und Binnenfischerei (IGB) im Forschungsverbund Berlin e.V. Berlin.

Arlinghaus, R. 2006. On the Apparently Striking Disconnect between Motivation and Satisfaction in Recreational Fishing: The Case of Catch Orientation of German Anglers. North Am. J. Fish. Manag. **26**(3): 592–605. doi:10.1577/M04-220.1.

Arlinghaus, R., Alós, J., Beardmore, B., Daedlow, K., Dorow, M., Fujitani, M., Hühn, D., Haider, W., Hunt, L.M., Johnson, B.M., Johnston, F., Klefoth, T., Matsumura, S., Monk, C., Pagel, T., Post, J.R., Rapp, T., Riepe, C., Ward, H., and Wolter, C. 2017. Understanding and Managing Freshwater Recreational Fisheries as Complex Adaptive Social-Ecological Systems. Rev. Fish. Sci. Aquac. **25**(1): 1–41.

Arlinghaus, R., Beardmore, B., Riepe, C., Meyerhoff, J., and Pagel, T. 2014. Species-specific preferences of German recreational anglers for freshwater fishing experiences, with emphasis on the intrinsic utilities of fish stocking and wild fishes. J. Fish Biol. **85**(6): 1843–1867. doi:10.1111/jfb.12546.

Arlinghaus, R., and Mehner, T. 2003. Socio-economic characterisation of specialised common carp (Cyprinus carpio L.) anglers in Germany, and implications for inland fisheries management and eutrophication control. Fish. Res. **61**(1–3): 19–33. doi:10.1016/S0165-7836(02)00243-6.

Arlinghaus, R., Tillner, R., and Bork, M. 2015. Explaining participation rates in recreational fishing across industrialised countries. Fish. Manag. Ecol. **22**(1): 45–55. doi:10.1111/fme.12075.

Arnegger, J., Woltering, M., and Job, H. 2010. Toward a product-based typology for nature-based tourism: a conceptual framework. J. Sustain. Tour. **18**(7): 915–928. Routledge. doi:10.1080/09669582.2010.485680.

Bacela-Spychalska, K., Grabowski, M., Rewicz, T., Konopacka, A., and Wattier, R. 2013. The “killer Shrimp” dikerogammarus villosus (crustacea, amphipoda) invading alpine lakes: Overland transport by recreational boats and scuba-diving gear as potential entry vectors? Aquat. Conserv. Mar. Freshw. Ecosyst. **23**(4): 606–618. doi:10.1002/aqc.2329.

Baer, J., Eckmann, R., Rösch, R., and Arlinghaus, R. 2016. Managing Upper Lake Constance Fishery in a Multi- Sector Policy Landscape: Beneficiary and Victim of a Century of Anthropogenic Trophic Change. Inter-Sectoral Gov. Inl. Fish. (Photo 1): 1–15.

Ballantyne, M., Gudes, O., and Marina, C. 2014. Landscape and Urban Planning Recreational trails are an important cause of fragmentation in endangered urban forests: A case-study from Australia. Landsc. Urban Plan. **130**: 112–124. Elsevier B.V. doi:10.1016/j.landurbplan.2014.07.004.

Barnett, A., Payne, N.L., Semmens, J.M., and Fitzpatrick, R. 2016. Ecotourism increases the field metabolic rate of whitetip reef sharks. BIOC **199**: 132–136. Elsevier Ltd. doi:10.1016/j.biocon.2016.05.009.

Barros, A., and Marina Pickering, C. 2017. How Networks of Informal Trails Cause Landscape Level Damage to Vegetation. Environ. Manage. **60**(1): 57–68. Springer US. doi:10.1007/s00267-017-0865-9.

Beachler, M.M., and Hill, D.F. 2003. Stirring up Trouble? Resuspension of Bottom Sediments by Recreational Watercraft. Lake Reserv. Manag. **19**(1): 15–25. doi:10.1080/07438140309353985.

Beardmore, B. 2013. The Importance of Understanding Angler Heterogeneity for Managing Recreational Fisheries. Simon Fraser University.

Biggs, R., Carpenter, S.R., and Brock, W.A. 2009. Turning back from the brink: detecting an impending regime shift in time to avert it. Proc. Natl. Acad. Sci. U. S. A. **106**(3): 826–31. doi:10.1073/pnas.0811729106.

Bockstael, N.E., McConnell, K.E., and Strand, I.E. 1989. Measuring the Benefits of Improvement in Water Quality: The Chesapeake Bay. Mar. Resour. Econ. **6**(1): 1–18.

Bockstael, N.E., Strand, I.E., and Hanemann, W.M. 1987. Time and the Recreational Demand Model. Am. J. Agric. Econ. **69**(2): 293. doi:10.2307/1242279.

Bonanno, S.E., Leopold, D.J., and Hilaire, L.R. St. 1998. Vegetation of a Freshwater Dune Barrier Under High and Low Recreational Uses. J. Torrey Bot. Soc. **125**(1): 40–50. Available from http://www.jstor.org/stable/2997230.

Boyle, A., and Samson, F.B. 1985. Effects of Nonconsumptive Recreation on Wildlife : A

Review. Wildl. Soc. Bull. **13**(2): 110–116. Available from http://www.jstor.org/stable/3781422.

Brandenburg, C., Matzarakis, A., and Arnberger, A. 2007. Weather and cycling – a first approach to the effects of weather conditions on cycling. Meteorol. Appl. **14**: 61–67. doi:10.1002/met.6.

Brauns, M., Wagner, C., Garcia, X., Walz, N., and Pusch, M.T. 2011. Human lakeshore development alters the structure and trophic basis of littoral food webs. : 916–925. doi:10.1111/j.1365-2664.2011.02007.x.

Bruce, A., Bandyopadhyay, J., Belausteguigotia, J., Bo, P., Cassar, A., Meadors, L., Saade, L., Siebentritt, M., Stein, R., Tortajada, C., Allan, T., Bauer, C., Bruch, C., Guimaraes-pereira, A., Kendall, M., Landry, C., Rodriguez, E.M., Meinzen-Dick, R., Moellendorf, S., Porras, I., Ratner, B., Shea, A., Swallow, B., Thomich, T., Voutchkov, N., Editors, R., Constanza, R., Jacobi, P., and Rijsberman, F. 2005. Freshwater Ecosystem Services. *In* Millennium Ecosystem Assessment. Island Press. Available from http://www.millenniumassessment.org/documents/document.312.aspx.pdf.

BTU-Cottbus. 2014. Stickstofflimitation in Binnengewässern: Ist Stickstoffreduktion ökologisch sinnvoll und wirtschaftlich vertretbar? Abschlussbericht des BMBF-Verbundprojekts NITROLIMIT I. BTU Cottbus-Senftenberg, Lehrstuhl Gewässerschutz (Hrsg.).

Bujosa, A., Riera, A., Hicks, R.L., and McConnell, K.E. 2015. Densities Rather than Shares: Improving the Measurement of Congestion in Recreation Demand Models. Environ. Resour. Econ. **61**(2): 127–140. Springer Netherlands. doi:10.1007/s10640-014-9785-9.

Burger, J. 1998. Effects of Motorboats and Personal Watercraft on Flight Behavior over a Colony of Common Terns. Condor **100**(3): 528–534.

Burgin, S. 2017. Indirect Consequences of Recreational Fishing in Freshwater Ecosystems : An Exploration from an Australian Perspective. doi:10.3390/su9020280.

Burkhard, B., Kroll, F., Nedkov, S., and Müller, F. 2012. Mapping ecosystem service supply, demand and budgets. Ecol. Indic. **21**: 17–29. Elsevier Ltd. doi:10.1016/j.ecolind.2011.06.019.

Cambray, J.A. 2003. Impact on indigenous species biodiversity caused by the globalisation of alien recreational freshwater fisheries. Hydrobiologia **500**: 217–230.

Carney, K.M., and Sydeman, W.J. 1999. A review of human disturbance effects on nesting colonial waterbirds. Waterbirds **22**(1): 68–79. doi:10.2307/1521995.

Chapman, R., and Jones, D.N. 2009. Just feeding the ducks : quantifying a common wildlife-human interaction Author. The Sunbird **39**(2): 19–28.

Cole, D.N., Cable, S., Gimblett, R., Hallo, J.C., Newman, P., and Vallerie, W.A. 2005. Computer Simulation Modeling of Recreation Use: Current Status, Case Studies, and Future Directions. Fort Collins.

Collen, B., Whitton, F., Dyer, E.E., Baillie, J.E.M., Cumberlidge, N., Darwall, W.R.T., Pollock, C., Richman, N.I., Soulsby, A.M., and Böhm, M. 2014. Global patterns of freshwater species diversity, threat and endemism. Glob. Ecol. Biogeogr. **23**(1): 40–51. doi:10.1111/geb.12096.

Collier, M. 2014. Novel ecosystems and the emergence of cultural ecosystem services. Ecosyst. Serv. **9**: 166–169. doi:https://doi.org/10.1016/j.ecoser.2014.06.002.

Conradie, N., Zyl, C. Van, and Strasheim, A. 2013. What inspires birders to migrate South towards Africa ? A quantitative measure of international avitourist motivation. South. African Bus. Rev. **17**(1): 128–167.

Cooke, S.J., and Cowx, I.G. 2006. Contrasting recreational and commercial fishing: Searching for common issues to promote unified conservation of fisheries resources and aquatic environments. Biol. Conserv. **128**(1): 93–108. doi:10.1016/j.biocon.2005.09.019.

Cooke, S.J., Lennox, R.J., Bower, S.D., Treml, M.K., Stoddard, E., Donaldson, L.A., and Danylchuk, A.J. 2017. Fishing in the dark : the science and management of recreational fisheries at night. Bull. Mar. Sci. **93**(2): 519–538.

Cord, A.F., Roeßiger, F., and Schwarz, N. 2015. Geocaching data as an indicator for recreational ecosystem services in urban areas: Exploring spatial gradients, preferences and motivations. Landsc. Urban Plan. **144**: 151–162. Elsevier B.V. doi:10.1016/j.landurbplan.2015.08.015.

Darrigran, G. 2002. Potential impact of filter-feeding invaders on temperate inland freshwater environments. Biol. Invasions (Simberloff 2001): 145–156.

Daume, S. 2016. Ecological Informatics Mining Twitter to monitor invasive alien species — An analytical framework and sample information topologies. Ecol. Inform. **31**: 70–82. Elsevier B.V. doi:10.1016/j.ecoinf.2015.11.014.

Díaz-Gil, C., Cotgrove, L., Smee, S.L., Simón-Otegui, D., Hinz, H., Grau, A., Palmer, M., and Catalán, I.A. 2017. Anthropogenic chemical cues can alter the swimming behaviour of juvenile stages of a temperate fish. Mar. Environ. Res. **125**: 34–41. doi:10.1016/j.marenvres.2016.11.009.

Doi, H., Katano, I., Negishi, J.N., Sanada, S., and Kayaba, Y. 2013. Effects of biodiversity, habitat structure, and water quality on recreational use of rivers. Ecosphere **4**(8): 1–11.

Dolch, T., and Schernewski, G. 2002. Hat Wasserqualität eine Bedeutung für Touristen? Eine Studie am Beispiel des Oderästuars. *In* Aktuelle Ergebnisse der Küstenforschung. 20. AMK-Tagung Kiel, 30.5- 1.6.2002. Berichte aus dem Forschung- undTechnologiezentrum Westküste der Universität Kiel. *Edited by* A. Dascheit and H. Sterr. Büsum. pp. 197–205.

Dolnicar, S., Coltman, T., and Sharma, R. 2015. Do Satisfied Tourists Really Intend to Come Back? Three Concerns with Empirical Studies of the Link between Satisfaction and Behavioral Intention. J. Travel Res. **54**(2): 152–178. doi:10.1177/0047287513513167.

Driedger, A.G.J., Dürr, H.H., Mitchell, K., and Cappellen, P. Van. 2015. Plastic debris in the Laurentian Great Lakes : A review. J. Great Lakes Res. **41**(1): 9–19. International Association for Great Lakes Research. doi:10.1016/j.jglr.2014.12.020.

Driver, B.L. 1985. Specifying what is produced by management of wildlife by public agencies. Leis. Sci. **7**(3): 281–295. doi:http://dx.doi.org/10.1080/01490408509512126.

Dudgeon, D., Arthington, A.H., Gessner, M.O., Kawabata, Z.-I., Knowler, D.J., Lévêque, C., Naiman, R.J., Prieur-Richard, A.-H., Soto, D., Stiassny, M.L.J., and Sullivan, C.A. 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. Biol. Rev. Camb. Philos. Soc. **81**(2): 163–82. doi:10.1017/S1464793105006950.

Eagleston, H., and Marion, J.L. 2017. Sustainable campsite management in protected areasA study of long-term ecological changes on campsites in the boundary waters canoe area wilderness, Minnesota, USA. J. Nat. Conserv. **37**: 73–82. Elsevier GmbH. doi:10.1016/j.jnc.2017.03.004.

EEA. 2015. State of nature in the EU - Results from reporting under the nature directves 2007-

2012. European Environment Agency, Copenhagen. doi:10.2800/603862.

Egan, K.J., Herriges, J.A., Kling, C.L., Downing, J.A., Egan, K.J., Herriges, J.A., Kling, C.L., and Downing, J.A. 2004. Recreation Demand Using Physical Measures of Water Quality of Water Quality. CARD Work. Pap. **Paper 394.** Available from http://lib.dr.iastate.edu/card_workingpapers/394%0AThis.

Eiswerth, M., Darden, T., Johnson, W., Agapoff, J., and Harris, T. 2005. Input–output modeling, outdoor recreation, and the economic impacts of weeds. Weed Sci. **53**(1): 130–137. doi:doi:10.1614/WS-04-022R.

Englin, J., Lambert, D., and Shaw, W.D. 1997. A Structural Equations Approach to Modeling Consumptive Recreation Demand. J. Environ. Econ. Manage. **33**(1): 33–43. doi:10.1006/jeem.1996.0976.

Eom, Y.S., and Larson, D.M. 2006. Improving environmental valuation estimates through consistent use of revealed and stated preference information. J. Environ. Econ. Manage. **52**(1): 501–516. doi:10.1016/j.jeem.2005.11.001.

Eurostat. 2013. Tourism satellite accounts (TSA) in Europe. Luxembourg: Publications Office of the European Union. doi:http://bookshop.europa.eu.

FAO. 2012. Technical guidelines for responsible fisheries - Recreational Fisheries. *In* Fisheries Management. Rome.

Fehér, J., Gáspár, J., Veres, K.S., Kiss, A., Globevnik, L., Peterlin, M., Kirn, T., Stein, U., Prins, T., Spiteri, C., Laukkonen, E., Heiskanen, A.-S., Austner, K., Semeradova, S., and Künitzer, A. 2012. Hydromorpholgical alterations and pressures in European rivers, lakes, transitional and coastal waters. European topic centre for assessment by EEA water report, Prague.

Fenichel, E.P., Abbott, J.K., and Huang, B. 2013. Modelling angler behaviour as a part of the management system: Synthesizing a multi-disciplinary literature. Fish Fish. **14**(2): 137–157. doi:10.1111/j.1467-2979.2012.00456.x.

Fix, O., and Loomis, J. 1998. Comparing the economic value of mountain bikingusing revealed and stated preferences. J. Environ. Plan. Manag. **41**(2): 227–236.

Freudenberg, P., and Arlinghaus, R. 2009. Benefits and Constraints of Outdoor Recreation for People with Physical Disabilities: Inferences from Recreational Fishing. Leis. Sci. **32**(1): 55–71. doi:10.1080/01490400903430889.

Freyhof, J., and Brooks, E. 2011. European red list of freshwater fishes. Luxembourg: Publications Office of the European Union. doi:doi:10.2779/85903.

Gabel, F., Garcia, X.F., Schnauder, I., and Pusch, M.T. 2012. Effects of ship-induced waves on littoral benthic invertebrates. Freshw. Biol. **57**(12): 2425–2435. doi:10.1111/fwb.12011.

Gabel, F., Lorenz, S., and Stoll, S. 2017. Effects of ship-induced waves on aquatic ecosystems. Sci. Total Environ. **601–602**: 926–939. Elsevier B.V. doi:10.1016/j.scitotenv.2017.05.206.

Gabel, F., Pusch, M.T., Breyer, P., Burmester, V., Walz, N., and Garcia, X.F. 2011. Differential effect of wave stress on the physiology and behaviour of native versus non-native benthic invertebrates. Biol. Invasions **13**(8): 1843–1853. doi:10.1007/s10530-011-0003-1.

Geijzendorffer, I.R., and Roche, P.K. 2014. The relevant scales of ecosystem services demand. Ecosyst. Serv. **10**: 49–51. Elsevier. doi:10.1016/j.ecoser.2014.09.002.

Gerba, C.P. 2000. Assessment of enteric pathogen shedding by bathers during recreational activity and its impact on water quality. Quant. Microbiol. **2**(1): 55–68.

doi:10.1023/A:1010000230103.

Gossling, S., and Peeters, P. 2015. Assessing tourism's global environmental impact 1900-2050. J. Sustain. Tour. **23**(5): 639–659. Taylor & Francis. doi:10.1080/09669582.2015.1008500.

Gozlan, R.E., Peeler, E.J., Longshaw, M., St-hilaire, S., and Feist, S.W. 2006. Effect of microbial pathogens on the diversity of aquatic populations , notably in Europe. Microbes Infect. 8 **8**: 1358–1364. doi:10.1016/j.micinf.2005.12.010.

Graefe, A.R., Vaske, J.J., and Kuss, F.R. 1984. Social carrying capacity: An integration and synthesis of twenty years of research. Leis. Sci. **6**(4): 395–431. doi:10.1080/01490408409513046.

Graham, A.L., and Cooke, S. 2008. The effects of noise disturbance from various recreational boating activities common to inland waters on the cardiac physiology of a freshwater fish, the largemouth bass (Micropterus salmoides). Aquat. Conserv. Mar. Freshw. Ecosyst. **18**: 1315–1324. doi:DOI: 10.1002/aqc.941.

Grubisic, M., Singer, G., Bruno, M.C., van Grunsven, R.H.A., Manfrin, A., Monaghan, M.T., and Hölker, F. 2017. Artificial light at night decreases biomass and alters community composition of benthic primary producers in a sub-alpine stream. Limnol. Oceanogr. **62**(6): 2799–2810. doi:10.1002/lno.10607.

Habibullah, M.S., Din, B.H., Chong, C.W., and Radam, A. 2016. Tourism and Biodiversity Loss: Implications for Business Sustainability. Procedia Econ. Financ. **35**(October 2015): 166–172. Elsevier B.V. doi:10.1016/S2212-5671(16)00021-6.

Hall, H.R., McCarty, C., and Clark, M.W. 2014. Regulatory protection and definition for recreational uses of Florida lakes. Lake Reserv. Manag. **30**(2): 115–118.

doi:10.1080/10402381.2014.898349.

He, X., Hörmann, G., Strehmel, A., Guo, H., and Fohrer, N. 2015. Natural and Anthropogenic Causes of Vegetation Changes in Riparian Wetlands Along the Lower Reaches of the Yellow River, China. Wetlands **35**(2): 391–399. doi:10.1007/s13157-015-0628-4.

Helmers, A., Platek, A., Ponte, M., Secen, N., and Cottenie, K. 2016. The impacts of anthropogenic disturbance on plant species richness in the freshwater lakes of Algonquin Provincial Park. Stud. by Undergrad. Res. Guelph Vol. **9**(1): 5–13.

Hendee, J.C. 1974. A Multiple-Satisfaction Approach to Game Management. Wildl. Soc. Bull. **2**(3): 104–113.

Hering, D., Carvalho, L., Argillier, C., Beklioglu, M., Borja, A., Cristina, A., Duel, H., Ferreira, T., Globevnik, L., Hanganu, J., Hellsten, S., Jeppesen, E., Kode, V., Lyche, A., Nõges, T., Ormerod, S., Panagopoulos, Y., Schmutz, S., Venohr, M., and Birk, S. 2015. Managing aquatic ecosystems and water resources under multiple stress — An introduction to the MARS project. Sci. Total Environ. **503–504**: 10–21. doi:10.1016/j.scitotenv.2014.06.106.

Hickey, V. 2010. The Quagga Mussel Crisis at Lake Mead National Recreation Area , Nevada (U . S . A .). Conserv. Biol. **24**(4): 931–937. doi:DOI:10.1111/j.1523-1739.2010.01490.x.

Hölker, F., Wolter, C., Perkin, E.K., and Tockner, K. 2010. Light pollution as a biodiversity threat. Trends Ecol. Evol. **25**(12): 681–682. doi:10.1016/j.tree.2010.09.007.

Howarth, C. 2014. Where to go ? Using Social Media to Assess the Spatial Distribution of Recreation on the Great Barrier Reef. Imperial College London.

Howat, G., and Assaker, G. 2013. The hierarchical effects of perceived quality on perceived value, satisfaction, and loyalty: Empirical results from public, outdoor aquatic centres in Australia. Sport Manag. Rev. **16**(3): 268–284. Sport Management Association of Australia and New Zealand. doi:10.1016/j.smr.2012.10.001.

Hunt, L.M. 2005. Recreational Fishing Site Choice Models: Insights and Future Opportunities. Hum. Dimens. Wildl. **10**(3): 153–172.

Hunt, L.M., Arlinghaus, R., Lester, N., and Kushneriuk, R. 2011. The effects of regional angling effort, angler behavior, and harvesting efficiency on landscape patterns of overfishing. Ecol. Appl. **21**(7): 2555–2575. doi:10.1890/10-1237.1.

Hunt, L.M., Bannister, A.E., Drake, D.A.R., Fera, S.A., and Johnson, T.B. 2017. Do Fish Drive Recreational Fishing License Sales? North Am. J. Fish. Manag. **37**(1): 122–132. Taylor & Francis. doi:10.1080/02755947.2016.1245224.

Hunt, L.M., Boots, B.N., and Boxall, P.C. 2007. Predicting Fishing Participation and Site Choice While Accounting for Spatial Substitution, Trip Timing, and Trip Context. North Am. J. Fish. Manag. **27**(3): 832–847. doi:10.1577/M06-079.1.

Hunt, L.M., Fenichel, E.P., Fulton, D.C., Mendelsohn, R., Smith, J.W., Tunney, T.D., Lynch, A.J., Paukert, C.P., and Whitney, J.E. 2016. Identifying Alternate Pathways for Climate Change to Impact Inland Recreational Fishers. Fisheries **41**(7): 362–372. doi:10.1080/03632415.2016.1187015.

Ikomi, R.B., and Arimoro, F.O. 2014. Effects of recreational activities on the littoral macroinvertebrates of Ethiope River, Nider Delta, Nigeria. Assoc. Aquat. Sci. Niger. **29**(1B): 155–170.

Jacobsen, L., Baktoft, H., Jepsen, N., Aarestrup, K., Berg, S., and Skov, C. 2014. Effect of boat noise and angling on lake fish behaviour. J. Fish Biol. **84**(6): 1768–1780. doi:10.1111/jfb.12395.

Jain-Schlaepfer, S.M.R., Blouin-demers, G., Cooke, S.J., and Bulté, G. 2017. Do boating and basking mix ? The effect of basking disturbances by motorboats on the body temperature and energy budget of the northern map turtle. Aquat. Conserv. Mar. Freshw. Ecosyst. **27**: 547–558. doi:10.1002/aqc.2693.

Jobstvogt, N., Watson, V., and Kenter, J.O. 2014. Looking below the surface: The cultural ecosystem service values of UK marine protected areas (MPAs). Ecosyst. Serv. **10**: 97–110. Elsevier. doi:10.1016/j.ecoser.2014.09.006.

Johnson, L.E., Ricciardi, A., and Carlton, J.T. 2001. Overland dispersal of aquatic invasive species: A risk assessment of transient recreational boating. Ecol. Appl. **11**(6): 1789–1799. doi:10.1890/1051-0761(2001)011[1789:ODOAIS]2.0.CO;2.

Johnston, F.D., Arlinghaus, R., and Dieckmann, U. 2010. Erratum: Diversity and complexity of angler behaviour drive socially optimal input and output regulations in a bioeconomic recreational-fisheries model. Can. J. Fish. Aquat. Sci. **67**(11): 1897–1898. doi:10.1139/F10-113.

Johnston, F.D., Beardmore, B., and Arlinghaus, R. 2015. Optimal management of recreational fisheries in the presence of hooking mortality and noncompliance – predictions from a bioeconomic model incorporating a mechanistic model of angler behavior. Can. J. Fish. Aquat. Sci. **72**: 37–53.

Johnstone, C., and Markandya, A. 2006. Valuing river characteristics using combined site choice and participation travel cost models. J. Environ. Manage. **80**: 237–247.

doi:10.1016/j.jenvman.2005.08.027.

Jones, D.N., and Reynolds, S.J. 2008. Feeding birds in our towns and cities : a global research opportunity. J. Avian Biol. **39**: 265–271. doi:10.1111/j.2008.0908-8857.04271.x.

Jovanovic, B. 2015. Review of titanium dioxide nanoparticle phototoxicity: Developing a phototoxicity ratio to correct the endpoint values of toxicity tests. Environ. Toxicol. Chem. **34**(5): 1070–1077. doi:10.1002/etc.2891.

Karwan, D.L., Aalto, R., Aufdenkampe, A.K., Denis Newbold, J., and Pizzuto, J.E. 2011. Characterization and source determination of stream suspended particulate material in White Clay Creek, USA. Appl. Geochemistry **26**(SUPPL.): S354–S356. Elsevier Ltd. doi:10.1016/j.apgeochem.2011.03.058.

Keeler, B., Wood, S., Polasky, S., and Kling, C. 2015a. Recreational demand for clean water: evidence from geotagged photographs by visitors to lakes. Front. Ecol. Environ. **2**(13): 76–81. Available from http://www.esajournals.org/doi/10.1890/140124 [accessed 7 May 2015].

Keeler, B.L., Polasky, S., Brauman, K.A., Johnson, K.A., Finlay, J.C., O'Neill, A., Kovacs, K., and Dalzell, B. 2012. Linking water quality and well-being for improved assessment and valuation of ecosystem services. Proc. Natl. Acad. Sci. U. S. A. **109**(45): 18619–24. doi:10.1073/pnas.1215991109.

Keeler, B.L., Wood, S.A., Polasky, S., Kling, C., Filstrup, C.T., and Downing, J.A. 2015b. Recreational demand for clean water: Evidence from geotagged photographs by visitors to lakes. Front. Ecol. Environ. **13**(2): 76–81. doi:10.1890/140124.

Kidd, K.R., Aust, W.M., and Copenheaver, C.A. 2014. Recreational stream crossing effects on sediment delivery and macroinvertebrates in southwestern Virginia, USA. Environ. Manage.

54(3): 505–516. doi:10.1007/s00267-014-0328-5.

Kolstoe, S., and Cameron, T.A. 2017. The Non-market Value of Birding Sites and the Marginal Value of Additional Species : Biodiversity in a Random Utility Model of Site Choice by eBird Members. Ecol. Econ. **137**: 1–12. Elsevier B.V. doi:10.1016/j.ecolecon.2017.02.013.

Konstantinou, I.K., and Albanis, T.A. 2004. Worldwide occurrence and effects of antifouling paint booster biocides in the aquatic environment: A review. Environ. Int. **30**(2): 235–248. doi:10.1016/S0160-4120(03)00176-4.

Kummu, M., de Moel, H., Ward, P.J., and Varis, O. 2011. How close do we live to water? A global analysis of population distance to freshwater bodies. PLoS One **6**(6): e20578. doi:10.1371/journal.pone.0020578.

Lee, L.-H., and Lee, Y.-D. 2015a. The impact of water quality on the visual and olfactory satisfaction of tourists. Ocean Coast. Manag. **105**: 92–99. Elsevier Ltd. doi:10.1016/j.ocecoaman.2014.12.020.

Lee, W., and Lee, C.C. 2015b. Developmental toxicity of cigarette butts - An underdeveloped issue. Ecotoxicol. Environ. Saf. **113**(2014): 362–368. Elsevier. doi:10.1016/j.ecoenv.2014.12.018.

Lester, L.A., Avery, H.W., Harrison, A.S., and Standora, E.A. 2013. Recreational boats and turtles: Behavioral mismatches result in high rates of injury. PLoS One **8**(12): 1–8. doi:10.1371/journal.pone.0082370.

Lethlean, H., Dongen, W.F.D. Van, Kostoglou, K., Guay, P., and Weston, M.A. 2017. Landscape and Urban Planning Joggers cause greater avian disturbance than walkers. Landsc. Urban Plan. **159**: 42–47. Elsevier B.V. doi:10.1016/j.landurbplan.2016.08.020.

Leung, Y.-F., and Marion, J.L. 2000. Recreation impacts and management in wilderness: A state-of-knowledge review. Wilderness Sci. a Time Chang. Wilderness Ecosyst. Threat. Manag.: 23–48. doi:10.1098/rspb.2005.3251.

Levin, S., Xepapadeas, T., Crépin, A.-S., Norberg, J., de Zeeuw, A., Folke, C., Hughes, T., Arrow, K., Barrett, S., Daily, G., Ehrlich, P., Kautsky, N., Mäler, K.-G., Polasky, S., Troell, M., Vincent, J.R., and Walker, B. 2013. Social-ecological systems as complex adaptive systems: modeling and policy implications. Environ. Dev. Econ. **18**(2): 111–132. doi:https://doi.org/10.1017/S1355770X12000460.

Lewin, W.-C., Arlinghaus, R., and Mehner, T. 2006. Documented and Potential Biological Impacts of Recreational Fishing: Insights for Management and Conservation. Rev. Fish. Sci. **14**(4): 305–367. doi:dx.doi.org/10.1080/10641260600886455.

Liddle, M.J. 1991. Recreation ecology: Effects of trampling on plants and corals. Trends Ecol. Evol. **6**(1): 13–17. doi:10.1016/0169-5347(91)90141-J.

Liddle, M.J., and Scorgie, H.R.A. 1980. The effects of recreation on freshwater plants and animals: A review. Biol. Conserv. **17**(3): 183–206. doi:10.1016/0006-3207(80)90055-5.

Liedermann, M., Tritthart, M., Gmeiner, P., Hinterleitner, M., Schludermann, E., Keckeis, H., and Habersack, H. 2014. Typification of vessel-induced waves and their interaction with different bank types, including management implications for river restoration projects. Hydrobiologia: 1–15. doi:10.1007/s10750-014-1829-1.

Loh, J., Green, R.E., Ricketts, T., Lamoreux, J., Jenkins, M., Kapos, V., and Randers, J. 2005. The Living Planet Index: using species population time series to track trends in biodiversity. Philos. Trans. R. Soc. Lond. B. Biol. Sci. **360**(1454): 289–295. doi:10.1098/rstb.2004.1584.

Loomis, J., and McTernan, J. 2014. Economic Value of Instream Flow for Non-Commercial Whitewater Boating Using Recreation Demand and Contingent Valuation Methods. Environ. Manage. **53**: 1–10. doi:10.1007/s00267-014-0232-z.

Lorenz, S., Gabel, F., Dobra, N., and Pusch, M.T. 2013. Modelling the effects of recreational boating on self-purification activity provided by bivalve mollusks in a lowland river. Freshw. Sci. **32**(1): 82–93. doi:10.1899/12-054.1.

Lorenz, S., and Pusch, M.T. 2012. Estimating the recreational carrying capacity of a lowland river section. Water Sci. Technol. **66**(9): 2033–2039. doi:10.2166/wst.2012.418.

Luttik, J. 2000. The value of trees, water and open space as reflected by house prices in the Netherlands. Landsc. Urban Plan. **48**(3–4): 161–167. doi:10.1016/S0169-2046(00)00039-6.

Maes, J., Teller, A., Erhard, M., Liquete, C., Braat, L., Berry, P., Egoh, B., Puydarrieux, P., Fiorina, C., Santos-Martín, F., and Maria Luisa Paracchini1, Hans Keune8, 19, Heidi Wittmer9, Jennifer Hauck9, Ingeborg Fiala10, Peter H. Verburg11, Sophie Condé12, Jan Philipp Schägner1, Jesús San Miguel1, Christine Estreguil1, Ole Ostermann1, José I. Barredo1, Henrique Miguel Pereira13, A, G.B. 2013. Mapping and Assessment of Ecosystems and their Services. Luxembourg: Publications Office of the European Union. doi:10.2779/12398.

Manfredo, M.J., Driver, B.L., and Tarrant, M. a. 1996. Measuring leisure motivation : A meta-analysis of the recreation experience preference scales. J. Leis. Res. **28**(3): 188–213.

Manfrin, A., Singer, G., Larsen, S., Weiß, N., van Grunsven, R.H.A., Weiß, N.-S., Wohlfahrt, S., Monaghan, M.T., and Hölker, F. 2017. Artificial Light at Night Affects Organism Flux across Ecosystem Boundaries and Drives Community Structure in the Recipient Ecosystem.

Front. Environ. Sci. **5**(61). doi:10.3389/fenvs.2017.00061.

Manning, R.E. 2010. Studies in Outdoor Recreation: Search and Research for Satisfaction, Third Edition. Oregon State University Press, Corvallis. Available from http://osupress.oregonstate.edu/book/studies-in-outdoor-recreation-0.

Marion, J.L., Leung, Y.-F., Eagleston, H., and Burroughs, K. 2016. A Review and Synthesis of Recreation Ecology Research Findings on visitors Impacts to Wilderness and Protected Natural Areas. J. For. **3**(114): 352–362. doi:http://dx.doi.org/10.5849/jof.15-498.

Martinez-Abrain, A., Oro, D., Jimenez, J., Stewart, G., and Pullin, A. 2010. A systematic review of the effects of recreational activities on nesting birds of prey. Basic Appl. Ecol. **11**(4): 312–319. doi:10.1016/j.baae.2009.12.011.

Massey, D.M., Newbold, S.C., and Gentner, B. 2006. Valuing water quality changes using a bioeconomic model of a coastal recreational fishery. J. Environ. Econ. Manage. **52**(1): 482–500. doi:10.1016/j.jeem.2006.02.001.

Mccarthy, K.P., and Destefano, S. 2011. Effects of Spatial Disturbance on Common Loon Nest Site Selection and Territory Success. **75**(2): 289–296. doi:10.1002/jwmg.50.

Mee, J.A., Post, J.R., Ward, H., Wilson, K.L., Newton, E., and Cantin, A. 2016. Interaction of ecological and angler processes: Experimental stocking in an open access, spatially structured fishery. Ecol. Appl. **26**(6): 1693–1707. doi:10.1890/15-0879.1.

Melstrom, R.T., Lupi, F., Esselman, P.C., and Stevenson, R.J. 2015. Valuing recreational fishing quality at rivers and streams. Water Resour. Res. **51**(1): 140–150. doi:10.1002/2014WR016152.

Mitchell, L., Frank, M.R., Harris, K.D., Dodds, P.S., and Danforth, C.M. 2013. The Geography of Happiness: Connecting Twitter Sentiment and Expression, Demographics, and Objective Characteristics of Place. PLoS One **8**(5): e64417. doi:10.1371/journal.pone.0064417.

Monz, C., Pickering, C.M., and Hadwen, W.L. 2013. Recent advances in recreation ecology and the implications of different relationships between recreation use and ecological impacts. Front. Ecol. Environ. **11**(8): 441–446. doi:10.1890/120358.

Mosisch, T.D., and Arthington, A.H. 2001. Polycyclic aromatic hydrocarbon residues in the sediments of a dune lake as a result of power boating. Lakes Reserv. Res. Manag. **6**: 21–32.

Munari, C., Corbau, C., Simeoni, U., and Mistri, M. 2015. Marine litter on Mediterranean shores: Analysis of composition, spatial distribution and sources in north-western Adriatic beaches. Waste Manag. **49**: 483–490. Elsevier Ltd. doi:10.1016/j.wasman.2015.12.010.

Murphy, K.J., and Eaton, J.W. 1983. Effects of Pleasure-Boat Traffic on Macrophyte Growth in Canals. J. Appl. Ecol. **20**(3): 713–729. Available from http://www.jstor.org/stable/2403122.

Naidoo, R., and Adamowicz, W. 2005. Biodiversity and nature-based tourism at forest reserves in Uganda. Environ. Dev. Econ. **10**(2): 159–178. doi:doi:10.1017/S1355770X0400186X.

Navarro Jurado, E., Tejada Tejada, M., Almeida García, F., Cabello González, J., Cortés Macías, R., Delgado Pena, J., Fernández Gutiárrez, F., Gutiárrez Fernández, G., Luque Gallego, M., Malvarez Garcia, G., Marcenaro Gutierrez, O., Navas Concha, F., Ruiz de la Rua, F., Ruiz Sinoga, J., and Solis Becerra, F. 2012. Carrying capacity assessment for tourist destinations. Methodology for the creation of synthetic indicators applied in a coastal area. Tour. Manag. **33**(6): 1337–1346. Elsevier Ltd. doi:10.1016/j.tourman.2011.12.017.

Niesar, M., Arlinghaus, R., Rennert, B., and Mehner, T. 2004. Coupling insights from a carp, Cyprinus carpio, angler survey with feeding experiments to evaluate composition, quality and phosphorus input of groundbait in coarse fishing. Fish. Manag. Ecol. **11**(3–4): 225–235. doi:10.1111/j.1365-2400.2004.00400.x.

Nyström, B., Becker-Van Slooten, K., Bérard, A., Grandjean, D., Druart, J.C., and Leboulanger, C. 2002. Toxic effects of Irgarol 1051 on phytoplankton and macrophytes in Lake Geneva. Water Res. **36**(8): 2020–2028. doi:10.1016/S0043-1354(01)00404-3.

O'Toole, A.C., Hanson, K.C., and Cooke, S.J. 2009. The Effect of Shoreline Recreational Angling Activities on Aquatic and Riparian Habitat Within an Urban Environment : Implications for Conservation and Management. Environ. Manage. **44**: 324–334. doi:DOI 10.1007/s00267-009-9299-3.

Orams, M.B. 2002. Feeding wildlife as a tourism attraction : a review of issues and impacts. Tour. Manag. **23**: 281–293.

Orsi, F., and Geneletti, D. 2013. Using geotagged photographs and GIS analysis to estimate visitor flows in natural areas. J. Nat. Conserv. **21**(5): 359–368. Elsevier GmbH. doi:10.1016/j.jnc.2013.03.001.

Ostendorp, W., Schmieder, K., and Jöhnk, K. 2004. Assessment of human pressures and their hydromorphological impacts on lakeshores in Europe. Int. J. Ecohydrol. **4**(4): 379–395.

Parsons, G.R., and Jo Kealy, M. 1994. Benefits transfer in a random utility model of recreation. Water Resour. Res. **30**(8): 2477–2484. doi:10.1029/94WR01047.

Pease, M.L., Rose, R.K., and Butler, M.J. 2005. Effects of human disturbance on the behavior wintering ducks. Wildl. Soc. Bull. **33**(1): 103–112. doi:https://doi.org/10.2193/0091-7648(2005)33[103:EOHDOT]2.0.CO;2.

Pendleton, L.H. 1994. Environmental quality and recreation demand in a caribbean coral reef. Coast. Manag. **22**(4): 399–404. doi:10.1080/08920759409362246.

Perkin, E.K., Hölker, F., Richardson, J.S., Sadler, J.P., Wolter, C., and Tockner, K. 2011. The influence of artificial light on stream and riparian ecosystems: questions, challenges, and perspectives. Ecosphere **2**(11): art122. doi:10.1890/ES11-00241.1.

Pickering, C.M., and Hill, W. 2007. Impacts of recreation and tourism on plant biodiversity and vegetation in protected areas in Australia. J. Environ. Manage. **85**(4): 791–800. doi:10.1016/j.jenvman.2006.11.021.

Piryani, R., Madhavi, D., and Singh, V.K. 2017. Analytical mapping of opinion mining and sentiment analysis research during 2000-2015. Inf. Process. Manag. **53**(1): 122–150. Elsevier Ltd. doi:10.1016/j.ipm.2016.07.001.

Post, J.R., Persson, L., Parkinson, E.A., and Kooten, T. van. 2008. Angler numerical response across landscapes and the collapse of freshwater fisheries. Ecol. Appl. **18**: 1038–1049. doi:http://dx.doi.org/10.1890/07-0465.1.

Preißler, S. 2008. Wasserqualität an europäischen Küsten und ihre Bewertung durch Touristen. *Edited by*G. Schernewski and N. Stybel. EUCC – Die Küsten Union Deutschland e.V., Hamburg. Available from http://databases.eucc-d.de/files/documents/00000738_IKZM-Oder_Berichte54.pdf.

Pretty, J., Peacock, J., Hine, R., Sellens, M., South, N., and Griffin, M. 2007. Green exercise in the UK countryside: Effects on health and psychological well-being, and implications for policy and planning. J. Environ. Plan. Manag. **50**(2): 211–231. doi:10.1080/09640560601156466.

Rankin, B.L., Ballantyne, M., and Pickering, C.M. 2015. Tourism and recreation listed as a threat for a wide diversity of vascular plants: A continental scale review. J. Environ. Manage. **154**: 293–298. Elsevier Ltd. doi:10.1016/j.jenvman.2014.10.035.

Raudsepp-Hearne, C., Peterson, G.D., Tengö, M., Bennett, E.M., Holland, T., Benessaiah, K., MacDonald, G.K., and Pfeifer, L. 2010. Untangling the Environmentalist's Paradox: Why Is Human Well-being Increasing as Ecosystem Services Degrade? Bioscience **60**(8): 576–589. doi:10.1525/bio.2010.60.8.4.

Resource Systems Group. 2013. User Capacity and Recreation Site Modeling for Yosemite Valley.

Roche, R.C., Monnington, J.M., Newstead, R.G., Sambrook, K., Griffith, K., Holt, R.H.F., and Jenkins, S.R. 2015. Recreational vessels as a vector for marine non-natives: developing biosecurity measures and managing risk through an in-water encapsulation system. Hydrobiologia **750**(1): 187–199. doi:10.1007/s10750-014-2131-y.

Roder Green, A.L., Putschew, A., and Nehls, T. 2014. Littered cigarette butts as a source of nicotine in urban waters. J. Hydrol. **519**(PD): 3466–3474. Elsevier B.V. doi:10.1016/j.jhydrol.2014.05.046.

Russi, D., ten Brink, P., Farmer, A., Badura, T., Coates, D., Förster, J., Kumar, R., Davidson, N., and Russi, Daniela; ten Brink, Patrick; Farmer, Andrew; Badura, Tomas; Coates, David; Förster, Johannes; Kumar, Ritesh; Davidson, N. 2012. The Economics of Ecosystems and Biodiversity for Water and Wetlands (TEEB),. doi:10.1007/s13398-014-0173-7.2.

Salerno, F., Viviano, G., Manfredi, E.C., Caroli, P., Thakuri, S., and Tartari, G. 2013. Multiple Carrying Capacities from a management-oriented perspective to operationalize sustainable tourism in protected areas. J. Environ. Manage. **128**: 116–125. Elsevier Ltd. doi:10.1016/j.jenvman.2013.04.043.

Santiago, L.E., Gonzalez-Caban, A., and Loomis, J. 2008. A model for predicting daily peak visitation and implications for recreation management and water quality: Evidence from two rivers in Puerto Rico. Environ. Manage. **41**(6): 904–914. doi:10.1007/s00267-008-9079-5.

Santos-Martín, F., Martín-López, B., García-Llorente, M., Aguado, M., Benayas, J., and Montes, C. 2013. Unraveling the relationships between ecosystems and human wellbeing in Spain. PLoS One **8**(9): e73249. doi:10.1371/journal.pone.0073249.

Schludermann, E., Liedermann, M., Hoyer, H., Tritthart, M., Habersack, H., and Keckeis, H. 2014. Effects of vessel-induced waves on the YOY-fish assemblage at two different habitat types in the main stem of a large river (Danube, Austria). Hydrobiologia **729**(1): 3–15. doi:10.1007/s10750-013-1680-9.

Schlüter, M., McAllister, R.R.J., Arlinghaus, R., Bunnefeld, N., Eisenack, K., Hölker, F., Milner-Gulland, E.J., Müller, B., Nicholson, E., Quaas, M., and Stöven, M. 2012. New horizons for managing the environment: A review of coupled social-ecological systems modeling. Nat. Recource Model. **25**(1): 219–272.

Schmitt, C., Oetken, M., Dittberner, O., and Wagner, M. 2008. Endocrine modulation and toxic effects of two commonly used UV screens on the aquatic invertebrates Potamopyrgus antipodarum and Lumbriculus variegatus. Environ. Pollut. **152**: 322–329. doi:10.1016/j.envpol.2007.06.031.

Schummer, M.L.., and Eddleman, W.R.. 2003. Effects of Disturbance on Activity and Energy Budgets of Migrating Waterbirds in South-Central Oklahoma. J. Wildl. Manage. **67**(4): 789–

795.

Selman, W., Sciences, B., and Drive, C. 2013. Effects of Human Disturbance on the Behavior and Physiology of an Imperiled Freshwater Turtle. J. Wildl. Manag. **77**(5): 877–885. doi:10.1002/jwmg.538.

Shelby, B., and Heberlein, T.A. 1986. Carrying capacity in recreation settings. Oregon State University Press, Corvallis. Available from http://osupress.oregonstate.edu/book/carrying-capacity-in-recreation-settings.

Shepherd, E., Milner-Gulland, E.J., Knight, A.T., Ling, M.A., Darrah, S., van Soesbergen, A., and Burgess, N.D. 2016. Status and Trends in Global Ecosystem Services and Natural Capital: Assessing Progress Toward Aichi Biodiversity Target 14. Conserv. Lett. **9**(6): 429–437. doi:10.1111/conl.12320.

Siikamäki, P., Kangas, K., Paasivaara, A., and Schroderus, S. 2015. Biodiversity attracts visitors to national parks. Biodivers. Conserv. **24**(10): 2521–2534. doi:10.1007/s10531-015-0941-5.

Silva, C.G. 2014. Calculating Willingness-To-Pay As a Function of Biophysical Water Quality and Water Quality Perceptions by. Utah State University. Available from http://digitalcommons.usu.edu/etd/3325.

Simpson, S.D., Radford, A.N., Nedelec, S.L., Ferrari, M.C.O., Chivers, D.P., McCormick, M.I., and Meekan, M.G. 2016. Anthropogenic noise increases fish mortality by predation. Nat. Commun. **7**: 10544. Nature Publishing Group. doi:10.1038/ncomms10544.

Smith, A.J., Duffy, B.T., and Novak, M.A. 2015. Observer rating of recreational use in wadeable streams of New York State, USA: Implications for nutrient criteria development. Water Res. **69**: 195–209. Elsevier Ltd. doi:10.1016/j.watres.2014.11.022.

Sonter, L.J., Watson, K.B., Wood, S.A., and Ricketts, T.H. 2016. Spatial and temporal dynamics and value of nature-based recreation, estimated via social media. PLoS One **11**(9): 1–16. doi:10.1371/journal.pone.0162372.

Sorice, M.G., Oh, C., and Ditton, R.B. 2017. Royal Swedish Academy of Sciences Managing Scuba Divers to Meet Ecological Goals for Coral Reef Conservation Linked references are available on JSTOR for this article : Managing Scuba Divers to Meet Ecological Goals for Coral Reef Conservation. **36**(4): 316–322.

Steenhof, K., Brown, J.L., and Kochert, M.N. 2014. Temporal and spatial changes in golden eagle reproduction in relation to increased off highway vehicle activity. Wildl. Soc. Bull. **38**(4): 682–688. doi:10.1002/wsb.451.

Steinwender, A., Gundacker, C., and Wittmann, K.J. 2008. Objective versus subjective assessments of environmental quality of standing and running waters in a large city. Landsc. Urban Plan. **84**(2): 116–126. doi:10.1016/j.landurbplan.2007.07.001.

Steven, R., Pickering, C., and Guy Castley, J. 2011. A review of the impacts of nature based recreation on birds. J. Environ. Manage. **92**(10): 2287–2294. Elsevier Ltd. doi:10.1016/j.jenvman.2011.05.005.

Stewart, A.M., Grossman, L., Collier, A.D., Echevarria, D.J., and Kalueff, A. V. 2015. Anxiogenic-like effects of chronic nicotine exposure in zebrafish. Pharmacol. Biochem. Behav. **139**: 112–120. Elsevier Inc. doi:10.1016/j.pbb.2015.01.016.

Stoll-Kleemann, S. 2010. Reconciling Opposition to Protected Areas Management in Europe: The German Experience. Sci. Policy Sustain. Dev. **43**(5): 32–44. doi:dx.doi.org/10.1080/00139150109605145.

Sweeney, B.W., and Newbold, J.D. 2014. Streamside forest buffer width needed to protect stream water quality, habitat, and organisms: A literature review. J. Am. Water Resour. Assoc. **50**(3): 560–584. doi:10.1111/jawr.12203.

Taplin, R.H. 2013. The influence of competition on visitor satisfaction and loyalty. Tour. Manag. **36**: 238–246. doi:10.1016/j.tourman.2012.12.012.

Terrado, M., Momblanch, A., Bardina, M., Boithias, L., Munné, A., Sabate, S., Solera, A., and Acuna, V. 2016. Integrating ecosystem services in river basin management plans. J. Appl. Ecol. **53**: 865–875. doi:10.1111/1365-2664.12613.

Tjärnlund, U., Ericson, G., Lindesjöö, E., Petterson, I., Akerman, G., and Balk, L. 1996. Further Studies of the Effects of Exhaust from Two-Stroke Outboard Motors on Fish. Mar. Environ. Res. **42**(1–4): 267–271.

Turner, A.M., and Ruhl, N. 2007. Phosphorus Loadings Associated with a Park Tourist Attraction : Limnological Consequences of Feeding the Fish. Environ. Manage. **39**: 526–533. doi:10.1007/s00267-005-0155-9.

Vesterinen, J., Pouta, E., Huhtala, A., and Neuvonen, M. 2010. Impacts of changes in water quality on recreation behavior and benefits in Finland. J. Environ. Manage. **91**(4): 984–994. Elsevier Ltd. doi:10.1016/j.jenvman.2009.12.005.

Vidal-Abarca, M. 2014. Understanding complex links between fluvial ecosystems and social indicators in Spain: An ecosystem services approach. Ecol. Complex. **20**: 1–10. doi:10.1016/j.ecocom.2014.07.002.

Villamagna, A.M., Mogollón, B., and Angermeier, P.L. 2014. A multi-indicator framework for mapping cultural ecosystem services : The case of freshwater recreational fishing. Ecol.

Indic. **45**: 255–265. Elsevier Ltd. doi:10.1016/j.ecolind.2014.04.001.

Viñals, M.J., Planelles, M., Alonso-Monasterio, P., and Morant, M. 2016. Recreational carrying capacity on small mediterranean islands. Cuad. Tur. **37**(September 2015): 437–463. doi:http://dx.doi.org/10.6018/turismo.37.256341.

Vlasov, B.P. 2012. Recreational use and environmental problems of lakes of protected areas in Belarus. Acta Geogr. Silesiana (11): 1–74.

Völker, S., and Kistemann, T. 2011. The impact of blue space on human health and well-being - Salutogenetic health effects of inland surface waters: A review. Int. J. Hyg. Environ. Health **214**(6): 449–460. doi:10.1016/j.ijheh.2011.05.001.

Völker, S., and Kistemann, T. 2013. Reprint of: “I'm always entirely happy when I'm here!” Urban blue enhancing human health and well-being in Cologne and Düsseldorf, Germany. Soc. Sci. Med. **91**: 141–152. Elsevier Ltd. doi:10.1016/j.socscimed.2013.04.016.

Ward, H.G., Askey, P.J., and Post, J.R. 2013a. A mechanistic understanding of hyperstability in catch per unit effort and density-dependent catchability in a multistock recreational fishery. Can. J. Fish. Aquat. Sci. **70**(10): 1542–1550.

Ward, H.G., Quinn, M.S., and Post, J.R. 2013b. Angler Characteristics and Management Implications in a Large, Multistock, Spatially Structured Recreational Fishery. North Am. J. Fish. Manag. **33**(3): 576–584.

Waterkeyn, A., Vanschoenwinkel, B., Elsen, S., and Anton-pardo, M. 2010. Unintentional dispersal of aquatic invertebrates via footwear and motor vehicles in a Mediterranean wetland area. Aquat. Conserv. Mar. Freshw. Ecosyst. **587**: 580–587. doi:10.1002/aqc.1122.

Weirich, C.A., and Miller, T.R. 2014. Freshwater harmful algal blooms: Toxins and children's health. Curr. Probl. Pediatr. Adolesc. Health Care **44**(1): 2–24. Elsevier. doi:10.1016/j.cppeds.2013.10.007.

Weisbrod, C.J., Kunz, P.Y., Zenker, A.K., and Fent, K. 2007. Effects of the UV filter benzophenone-2 on reproduction in fish. Toxicol. Appl. Pharmacol. **225**(3): 255–266. doi:10.1016/j.taap.2007.08.004.

Weissteiner, C.J., Bouraoui, F., and Aloe, A. 2013. Reduction of nitrogen and phosphorus loads to European rivers by riparian buffer zones. Knowl. Manag. Aquat. Ecosyst. (408): 8. doi:10.1051/kmae/2013044.

Weyland, F., and Laterra, P. 2014. Recreation potential assessment at large spatial scales: A method based in the ecosystem services approach and landscape metrics. Ecol. Indic. **39**: 34–43. Elsevier Ltd. doi:10.1016/j.ecolind.2013.11.023.

Whitehead, J.C., Pattanayak, S.K., Van Houtven, G.L., and Gelso, B.R. 2008. Combining Revealed and Stated Preference Data to Estimate the Nonmarket Value of Ecological Services: An Assessment of the State of the Science. J. Econ. Surv. **22**(5): 872–908. doi:DOI 10.1111/j.1467-6419.2008.00552.x.

Whitfield, A.K., and Becker, A. 2014. Impacts of recreational motorboats on fishes: A review. Mar. Pollut. Bull. **83**(1): 24–31. Elsevier Ltd. doi:10.1016/j.marpolbul.2014.03.055.

Wolff, S., Schulp, C.J.E., and Verburg, P.H. 2015. Mapping ecosystem services demand: A review of current research and future perspectives. Ecol. Indic. **55**: 159–171. Elsevier Ltd. doi:10.1016/j.ecolind.2015.03.016.

Wolter, C., and Arlinghaus, R. 2003. Navigation impacts on freshwater fish assemblages: The ecological relevance of swimming performance. Rev. Fish Biol. Fish. **13**(1): 63–89. doi:10.1023/A:1026350223459.

Wolter, C., Arlinghaus, R., Grosch, U., and Vilcinskas, A. 2003. Fische & Fischerei in Berlin. Zeitschrift für Fischkd. **Supplement**: 163.

Wood, S., Guerry, A., Silver, J., and Lacayo, M. 2013. Using social media to quantify nature-based tourism and recreation. Sci. Rep. **3**: 2976. doi:10.1038/srep02976.

Wyles, K.J., Pahl, S., and Thompson, R.C. 2014. Perceived risks and benefits of recreational visits to the marine environment: Integrating impacts on the environment and impacts on the visitor. Ocean Coast. Manag. **88**: 53–63. The Authors. doi:10.1016/j.ocecoaman.2013.10.005.

Wynen, J. 2013. Explaining travel distance during same-day visits. Tour. Manag. **36**: 133–140. Elsevier. doi:10.1016/j.tourman.2012.11.007.

Wysocki, T., and Gavin, L. 2006. Paternal involvement in the management of pediatric chronic diseases: Associations with adherence, quality of life, and health status. J. Pediatr. Psychol. **31**(5): 501–511. doi:10.1016/j.biocon.2005.10.020.

Zhang, L., and Chung, S.S. 2015. Assessing the Social Carrying Capacity of Diving Sites in Mabul Island, Malaysia. Environ. Manage. **56**(6): 1467–1477. Springer US. doi:10.1007/s00267-015-0586-x.

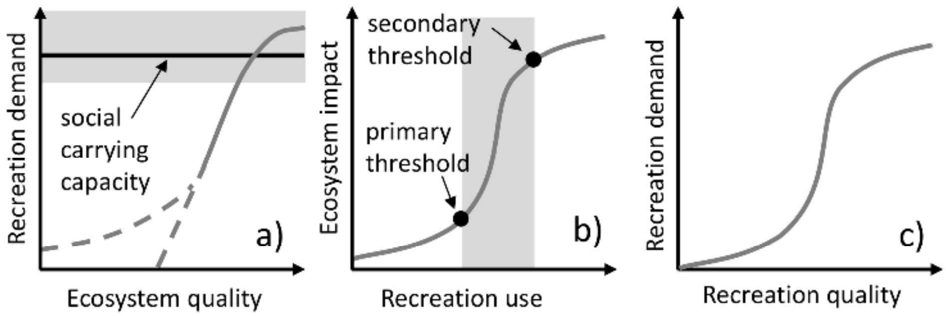
Table 1. Examples of potential freshwater impacts on different organizational levels related to recreational activities and respective pressures. Pressures are [1] presence / disturbance (e.g. sudden or rapid movement) / feeding, [2] noise, [3] physical damage / damage of streambed sediment structure (from trampling, vegetation clearance, litter, propellers, paddles), [4] turbidity / creation of waves, [5] light pollution / reduced light penetration, [6] nutrient input (from urea, skin, bait, feeding animals, sewage discharge), [7] chemical input (from spillage of engine oil, exhausts, litter, sunscreens, cosmetics, insect repellents and biocides), [8] exploitation (e.g. overfishing), [9] introduction of invasive species (from fish stocking/illegal release of fishes, several vectors as ships, vehicles, soles), [10] pathogen input.

Figure 1. Conceptual relationships among recreation quality, recreation demand and use, and ecosystem impacts. Dashed lines in panel a) indicate varying effects of poor ecosystem quality on different recreation types. Grey boxes indicate areas where social carrying capacity (a) and ecological carrying capacity (b) are likely to exert effects or be exceeded.

Figure 2. Scenarios for relationships among improved ecosystem quality and recreational demand and use leading to either amplifying or dampening feedbacks depending on whether ecological or social carrying capacities are exceeded or not, with resulting effects on future demand and use.

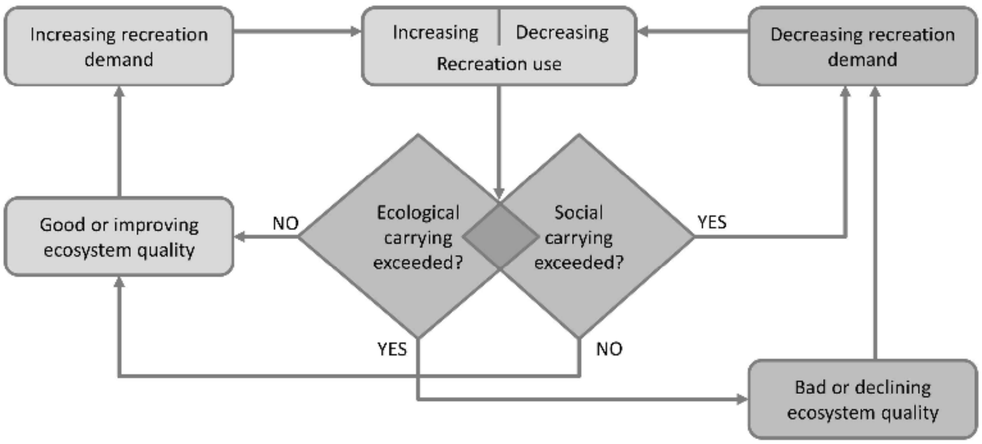
Figure 3. The multi-loop concept linking ecological quality, recreational quality, and ecosystem management that is responsive to recreational quality.

Figure 4. Sum of daily visitors in dependence of the maximum daily air temperature in natural bathing waters of Berlin during 2013 and 2015 (gray areas describe the 95 % confidence interval; data provided by BBB).



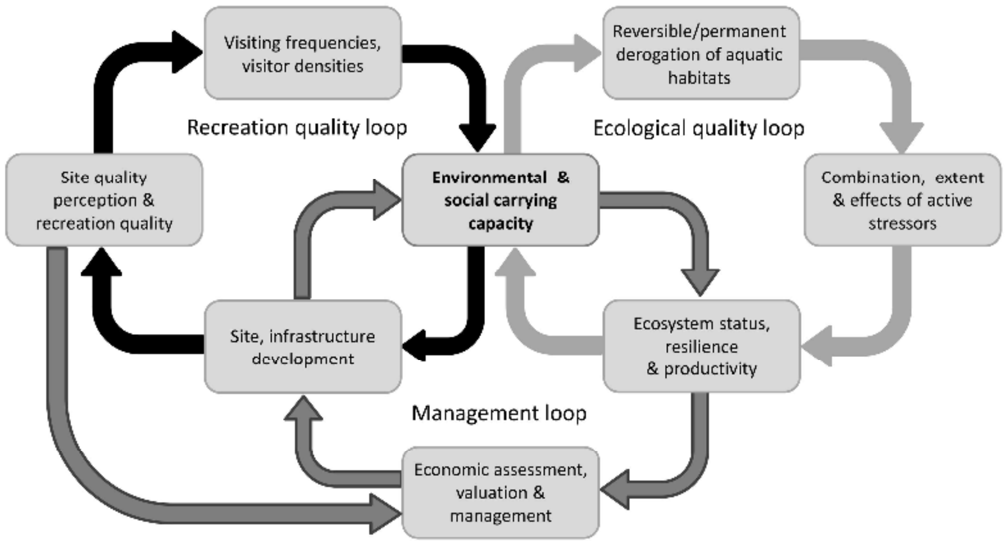
Conceptual relationships among recreation quality, recreation demand and use, and ecosystem impacts. Dashed lines in panel a) indicate varying effects of poor ecosystem quality on different recreation types. Grey boxes indicate areas where social carrying capacity (a) and ecological carrying capacity (b) are likely to exert effects or be exceeded.

170x60mm (300 x 300 DPI)



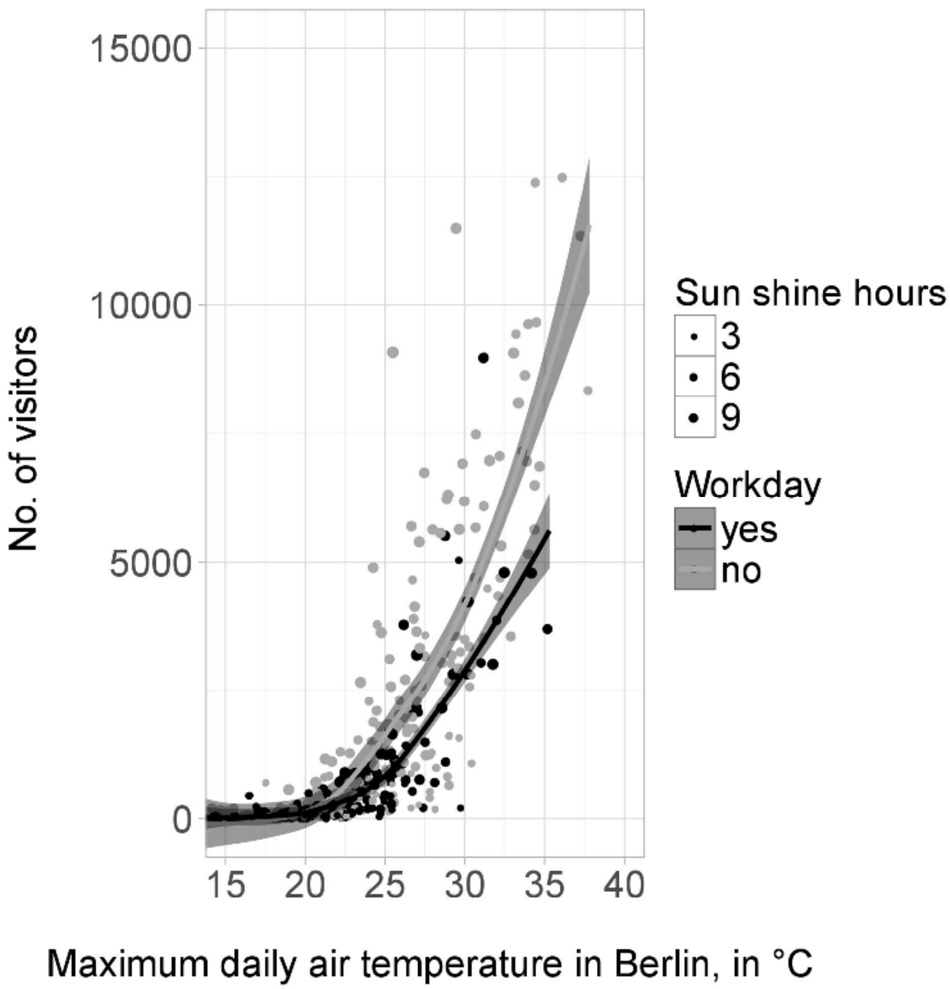
Scenarios for relationships among improved ecosystem quality and recreational demand and use leading to either amplifying or dampening feedbacks depending on whether ecological or social carrying capacities are exceeded or not, with resulting effects on future demand and use.

220x100mm (300 x 300 DPI)



The multi-loop concept linking ecological quality, recreational quality, and ecosystem management that is responsive to recreational quality.

240x130mm (300 x 300 DPI)



Sum of daily visitors in dependence of the maximum daily air temperature in natural bathing waters of Berlin during 2013 and 2015 (gray areas describe the 95 % confidence interval; data provided by BBB).

149x149mm (300 x 300 DPI)

Table 1. Examples of potential freshwater impacts on different organizational levels related to recreational activities and respective pressures. Pressures are [1] presence / disturbance (e.g. sudden or rapid movement) / feeding, [2] noise, [3] physical damage / damage of streambed sediment structure (from trampling, vegetation clearance, litter, propellers, paddles), [4] turbidity / creation of waves, [5] light pollution / reduced light penetration, [6] nutrient input (from urea, skin, bait, feeding animals, sewage discharge), [7] chemical input (from spillage of engine oil, exhausts, litter, sunscreens, cosmetics, insect repellents and biocides), [8] exploitation (e.g. overfishing), [9] introduction of invasive species (from fish stocking/illegal release of fishes, several vectors as ships, vehicles, soles), [10] pathogen input.

Recreation activity	**Freshwater examples of impacts at different organizational level**			
	Individual	**Population**	**Community**	**Ecosystem**
Swimming	- behavior and physiology changes in turtles (Selman et al. 2013)[1]		- decreased trophic complexity of littoral food webs (Brauns et al. 2011)[1]	
	- endocrine modulation and toxic effects on aquatic invertebrates (Schmitt et al. 2008)[7] - toxic effects on cladocerans (Jovanovic 2015)[7] - estrogenic effects on physiology and reproduction in fish (Weisbrod et al. 2007)[7]			
Motor-boating	- multiple effects on biology and ecology of fishes; change of behavior, communication, habitat structure of fishes (Whitfield and Becker 2014)[1,2,3,4,5,6,7,9]			
	- injuries and mortality of turtles due to behavioral mismatches (Lester et al. 2013)[3]		- decline of native species diversity, trophic interactions and ecosystem functioning (Darrigran 2002, Hickey 2010, Bacela-Spychalska et al. 2013)[9]	

Recreation activity	Freshwater examples of impacts at different organizational level			
	Individual	Population	Community	Ecosystem
	- alteration of swimming speed and habitat use of fish species (Jacobsen et al. 2014)[2]		- negative impacts on plants (decrease of submerged and floating plants) and animals (Liddle and Scorgie 1980)[1,2,3,4,6,7]	- reduced self-purification activity through behavior changes of bivalve mollusks (Lorenz et al. 2013)[4]
	- increased cortisol secretion in fish (Wysocki and Gavin 2006) [2]	- increased fish mortality by predation (Simpson et al. 2016)[2]	- effect on invertebrates-fish interaction and dislodges benthic invertebrates (Gabel et al. 2011, 2012)[4]	- effects on sediment and nutrient budget, planktonic, benthic and fish communities (Gabel et al. 2017)[4]
	- sublethal physiological disturbances of fish (Graham and Cooke 2008)[2]	- changed nesting behavior of birds (Boyle and Samson 1985, Burger 1998)[2]	- decline of freshwater plant species richness (Helmers et al. 2016)[3]	- remobilizing sediments, thus indirect effects on biogeochemical cycles in aquatic ecosystems (Beachler and Hill 2003, Ikomi and Arimoro 2014)[4]
	- toxic effects on aquatic organisms (Mosisch and Arthington 2001, Konstantinou and Albanis 2004)[7]	- increased alertness and energy expenditure of birds by boat fishing (Schummer and Eddleman 2003)[2]	- change in community composition and abundance of aquatic macrophyte (Murphy and Eaton 1983)[3,4,5,7]	- dispersal of aquatic invasive species by transient recreational boating (Johnson et al. 2001)[9]
	- disruption of biological functions in rainbow trout (Tjärnlund et al. 1996)[7]	- decreased rate of energy assimilation of basking animals	- increased drift densities of young-of-the-year fish (Schludermann et al. 2014)[4]	

Recreation activity	Freshwater examples of impacts at different organizational level			
	Individual	**Population**	**Community**	**Ecosystem**
		(Jain-Schlaepfer et al. 2017)[1,2,4]	- disturbance of fish habitat (Wolter and Arlinghaus 2003)[4] - liberation of antifouling paints causes toxic effects on phytoplancton and macrophytes (Nyström et al. 2002)[7]	
Canoeing	- sublethal physiological disturbances of fish (Graham and Cooke 2008)[2]		- decline of freshwater plant species richness (Helmers et al. 2016)[3]	
Camping	- temporal and spatial changes in Golden Eagle reproduction (Steenhof et al. 2014)[1]			- changes in vegetation and forest cover causes reduced water infiltration, increasing runoff and erosion rates (Eagleston and Marion 2017)[3]
Walking/ hiking/ biking along rivers/ lakes	- changes in overall plant communities, plant morphology and plant anatomy (Liddle and Scorgie 1980, Liddle 1991)[3,4] - changes in behavior of wintering ducks (Pease et al. 2005)[1,2]		- decrease in vegetation cover (He et al. 2015)[3]	

Recreation activity	Freshwater examples of impacts at different organizational level			
	Individual	Population	Community	Ecosystem
			- landscape level damage to vegetation (Pickering and Hill 2007, Barros and Marina Pickering 2017)[3] - change in macroinvertebrate species behavior and composition (Kidd et al. 2014)[3] - changes in community structure of aquatic invertebrates (Waterkeyn et al. 2010)[9] - disruptions and displacement of birds (Lethlean et al. 2017)[1]	
Angling	- effects on demography, abundance, evolutionary trajectories of fish; changes in trophic cascades, trait-mediated effects on aquatic ecosystems (Lewin et al. 2006)[1,2,3,4,6,7,8,9,10]			
	- fish diseases and mortality (Gozlan et al. 2006)[10]		- habitat loss, vegetation clearance for gaining access to angling site and for greater ease of casting (O'Toole et al. 2009, Burgin 2017)[3] - shapes aquatic fish biodiversity(Cooke and Cowx 2006, Freyhof and	- nutrient input of groundbait (Niesar et al. 2004)

Recreation activity	Freshwater examples of impacts at different organizational level			
	Individual	**Population**	**Community**	**Ecosystem**
			Brooks 2011)[9] - multiple effects on biodiversity and trophic cascades (Cambray 2003)[9]	
Multiple recreational use	- changes in physiology, behavior, reproductive success, and population trends of water birds (Carney and Sydeman 1999, Steven et al. 2011)[1.2]		- change of species and community composition, change of wildlife behavior (Leung and Marion 2000)[1,3,6,9,10]	- eutrophication through breadthrowers (Turner and Ruhl 2007)[6]
	- changed behavior of birds, dependence and malnutrition from feeding (Orams 2002, Jones and Reynolds 2008, Chapman and Jones 2009)[1]	- distributional effects, decreased nest attendance and breeding success of birds (Martinez-Abrain et al. 2010)[1]	- injuries, contaminants and alien species from plastic debris (Driedger et al. 2015)[3,7,9]	
	- littering causes toxic effects, changed behavior and development of fish (Lewin et al. 2006, Lee and Lee 2015b, Stewart et al. 2015)[7]	- changes of vegetation, bird habitat and structures of macroinvertebrate communities from infrastructure development (Ostendorp et al. 2004, He et al. 2015)[1,3]		
		- effects on common loon nest site selection and limitation of overall production (Mccarthy and Destefano 2011)[1,2]	- lower plant species richness, ground cover of vegetation and density of colonizing species (Bonanno et al. 1998)[3]	

Recreation activity	Freshwater examples of impacts at different organizational level			
	Individual	Population	Community	Ecosystem
			- alteration of organism flux and community structure of invertebrates (Manfrin et al. 2017)[5] - decrease of periphyton biomass (Grubisic et al. 2017)[5]	

1