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A day on the shore: Ecological impacts of non-motorised recreational activities in and around inland water bodies

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ABSTRACT

With the increasing importance of recreational activities in and around inland water bodies, there is a need for sound knowledge about their ecological impacts. This narrative review summarizes and analyses the ecological effects of the land-based activities walking, biking, nature observing and relaxing on the shoreline as well as the water-based activities swimming, snorkelling, scuba diving, and canyoning. Searching multiple databases with standardized search terms retrieved twenty-six publications for further analyses. While walking was the most studied activity, birds were the most studied organism group, with a focus on individual time budgets and avoidance behaviour. Population-level analyses were exceedingly rare. The most frequently studied activity-effect combinations were walking and birds, walking and terrestrial plants and scuba diving/snorkelling and fishes. Aquatic plants, amphibians, reptiles, water chemical parameters and terrestrial and aquatic algae were underrepresented in the existing literature. No study on mammals was identified. Disturbance often led to temporary behavioural changes of birds and wildlife. Plants were more strongly impacted than animals, suffering from recreation-induced damage and dieback, which led to changes in community composition. The difference in intensity of impact between mobile and sessile organisms calls for different management strategies, depending on local conservation targets. Future studies should focus on underrepresented taxonomic groups and study population or community-level impacts, to collectively provide the sound scientific basis for the sustainable recreational use of inland water bodies, while minimizing or avoiding severe ecological impacts.

1. Introduction

Lakes, reservoirs and rivers cover just 2.3% of the Earth's surface, but are disproportionately rich in biodiversity (Dudgeon et al., 2006) and home to 9.5% of the Earth's known animal species (Reid et al., 2019). One third of all vertebrate species are confined to freshwater (Dudgeon et al., 2006). However, freshwater ecosystems experience substantially greater biodiversity losses than terrestrial ecosystems (Bongaarts, 2019; Dudgeon et al., 2006). Freshwater bodies are naturally in a receiver-position in the landscape, where they accumulate various catchment influences (Reid et al., 2019) and are thus potentially highly sensitive to the net effect of multiple anthropogenic stressors (Birk et al., 2020). Climate change places additional stress on already burdened freshwater bodies (IPCC, 2013; Scheffers et al., 2016).

The numerous impacts on biodiversity resulting from multiple anthropogenic uses of freshwater bodies are well recognized and for some taxa well reported (e.g. Díaz et al., 2019; Grizzetti et al., 2019; Jackson et al., 2016). A plethora of studies have found significant drivers of biodiversity change, such as urbanisation (Chen & Olden, 2020), land use change (Radinger et al., 2016), water abstraction (Boddy et al., 2020), hydropower production (Schwarz, 2019), river regulation (Peipoch et al., 2015), and inland navigation (Zajicek & Wolter, 2019). However, these commercially-centred analyses of anthropogenic impacts on aquatic ecosystems largely ignore an increasing non-commercial recreational use. In the developed world, recreational activities have gained considerable importance due to substantial changes

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in many people's living conditions (Arlinghaus et al., 2021; Venohr et al., 2018). Recreational activities are defined as activities that offer a contrast to work-related activities and the possibility of constructive, restorative and pleasurable benefits (Cole & Hammitt, 1998). The impacts of recreational and tourist activities are best studied in forest and marine systems (Larson et al., 2016). In marine systems, studies have focused, for example, on the impacts of ecotourism on cetacean species (Lusseau, 2004; Trave et al., 2017), or scuba diving on coral reefs (Samia et al., 2019).

Since 1950 there has been a rapid urbanisation process, resulting in as much as 55% of the worlds population now living in cities (United Nations et al., 2019). Hazards to health related to urban lifestyle are on the rise in industrial countries (Béjean & Sultan-Taïeb, 2005; Godfrey & Julien, 2005). At the same time, work strain (Morschhäuser et al., 2010) and dissatisfaction with work schedules has risen (Roberts, 2007). Outdoor recreational activities are seen as a cure for the mental and physical stress of people in ever-growing cities (Frumkin et al., 2017; Morita et al., 2011; Ryan et al., 2010; Wolsko et al., 2019). As water is as much cultural object as material substance (Watson, 2019), even a little waterbody in an urban surrounding can be the core for environmental education and recreational activity (Gunn et al., 1972; Meyerhoff et al., 2019). Inland waters are a popular destination for people in need of a break or a cool-down, because for most people they are easier to reach than marine waters. Small lakes, some of anthropogenic origins, like gravel pits are particularly important locations not only for recreational activities of urban residents (Meyerhoff et al., 2019) but also for environmental education (Gitau et al., 2019), because they are highly abundant and close to many people's home. Spending a day on the (lake-) shore relaxing, walking, biking or swimming are all popular activities (Kochalski et al., 2019). Especially in forests, ponds and water surfaces attract visitors and increase visitor numbers (Janeczko, 2009). Monitoring the impacts of these activities is difficult as they are usually performed by individuals rather than clubs or other organisations and because the widespread nature of a large number of small lakes scattered in the landscape. However, a growing demand for access to surface waters may cause temporary or permanent damage and endanger precisely the scenic beauty which is sought by visitors and consequently also represents a threat to aquatic habitats for flora and fauna (Andrés-Abellán et al., 2005).

The ecological impacts of recreational activities on freshwater bodies have not yet received much academic attention, although the degradation of natural wildland areas by human recreational activities was identified already in the 1990s (Cole & Hammitt, 1998), and first studies about recreation-induced ecological changes were already published in the 1970s in the USA (Liddle, 1973; Liddle, 1975). There are many ways in which recreational behaviour directly impacts the environment, such as disturbing wildlife (Shannon et al., 2017), compacting or degrading soil (Andrés-Abellán et al., 2005) and breaking off parts of plants (Bowles & Maun, 1982). Recreational activities can also cause degradation or loss of habitat and, thus, thereby impact the diversity, composition and abundance of freshwater organisms (Venohr et al., 2018). The term ecological impact suggests an undesirable change as a result of anthropogenic use (Cole & Hammitt, 1998), but is a more precise term than disturbance (Stock et al., 1994) because the term disturbance is value loaded. Ecological impact is therefore the term used in this analysis. The (ecological) impact of visitors on natural areas depends not only on the overall number of visits, but also on the duration and type of activities and the fragility of the respective ecosystem or organism group under consideration (Cole, 1995; Cole & Marion, 1988).

Many inland water bodies are particularly sensitive ecosystems (Dudgeon et al., 2006; Ormerod et al., 2010), with recreational activities found both at the shoreline and in the water. On and in open waters, human presence can damage water plants and disturb aquatic wildlife, for example nesting waterfowl, which may lead to lower reproductive success (Keller, 1989; Yalden & Yalden, 1990). Another threat may be the release of nutrients and chemicals from humans into the water (Poiger et al., 2004), potentially affecting fish (Blüthgen et al., 2012) or invertebrates (Schmitt et al., 2008). Invertebrates are commonly used for monitoring changes in quality of freshwater ecosystems (Hodkinson & Jackson, 2005). Especially benthic invertebrates are used to determine water quality (Carew et al., 2013) and have been studied in recreational contexts to index anthropogenic impacts (Brauns et al., 2011; Hardiman & Burgin, 2011a, 2011b).

Given the increasing importance of recreational activities in and around inland water bodies and the applied need for a sound knowledge base to manage the various demands while conserving and enhancing biodiversity, we conducted a systematic literature review on the ecological effects of recreational activities which take place near or in inland waters. Previous reviews on the effect of recreational activities on nature which bear reference to freshwater systems exists (Table 1). Walking is one of the most common recreational activities on land; accordingly, this activity and the effects of trampling are well studied. Liddle (1975) and Cole & Bayfield (1993) laid the foundations for this research field. Obedzinski et al. (2001) summarised the effects of camping, walking and vehicles on woody vegetation. Anderson et al. (2015) studied the effect of walking on the spreading of non-native species. Other systematic reviews have compared effects of aquatic recreation on wildlife (Larson et al., 2016). Anderson et al. and Larson et al. were the only ones using meta-analytical techniques. Few studies have been published on the ecological effects of non-consumptive land-based activities, such as biking (Nyhof & Trulio, 2015), relaxing on the shore (Bowles & Maun, 1982) and nature observation (Wilkins et al., 2017). Non-comprehensive summaries on recreation-induced effects on freshwater systems exists as well (Venohr et al. 2018).

Yet, the recreational activities swimming, diving, snorkelling and canyoning remain insufficiently studied. In a global systematic review, Larson et al. (2016) analysed, among other publications on different topics, 25 studies dealing with swimming, unfortunately without stating how and which species were impacted. Another review by Brausch & Rand (2011) focused on the influence of chemical components of personal care products on aquatic organisms such as fish, algae or plants without analysing the paths of products into the water, but did not particularly focused on recreational activities as a source. In general, swimming, diving, snorkelling and canyoning are expected to have effects on organisms located in the open water and on the shoreline, but this has not yet been systematically assessed.

Most previous reviews of recreation in freshwater ecosystems did not focus on one specific activity (Table 1) but concentrated on disturbance in general (Blumstein et al., 2005; Cayford, 1993; Price, 2008) or on recreational use in general (Blanc et al., 2006; Carney & Sydeman, 1999; Cole & Landres, 1996). In a more specific approach, Gerba (2000) reviewed the shedding of enteric pathogens during recreational swimming, without, however, linking the amount of material shed by bathers to the effect on aquatic organisms. We are not aware of reviews on the ecological effects of swimming, snorkelling, scuba diving, canyoning, walking, biking or relaxing close to an inland water body.

This study provides the first comprehensive review of recreational activities and their ecological effects, with particular focus on largely unregulated, private activities on the banks and in the littoral zone of freshwaters. In particular, we focus on the land-based activities walking, biking, nature observation and relaxing on the shoreline and on the water-based activities swimming, snorkelling, scuba diving and canyoning. Our literature review focuses on publications that clearly link the impact of a specific activity with a response of organisms or a change in soil or water characteristics. We used material identified with a standardized literature search to determine:

(a) which combinations of activities and impacted organisms were studied,
(b) which aspects of these activities were observed to have an effect and
(c) how severe the observed ecological impacts were.

Table 1
Summary of all reviews found with the search-terms matching the topic of water-related recreation (n = 11).

Activity/ Target Organism	Camping	Disturbance	Recreational use	Personal Care	Vehicles	Walking
Algae				Brausch & Rand, 2011		
Amphibians				Brausch & Rand, 2011		
Animals			Larson et al., 2016			
Aquatic plants				Brausch & Rand, 2011		
Benthic invertebrates				Brausch & Rand, 2011		
Birds		Blumstein et al., 2005 Cayford, 1993 Price, 2008	Carney & Sydeman, 1999			
Fishes				Brausch & Rand, 2011		
Non-native Species						Anderson et al., 2015
Vegetation						Root-Bernstein & Svenning, 2018
Wilderness ecosystems			Cole & Landres, 1996			
Wildlife			Blanc et al., 2006			
Woody vegetation	Obedzinski et al., 2001					Obedzinski et al. 2001

2. Methods

The literature databases and search engines BioOne, AFSA, Web of Science Core Collection, Scopus, Conservation Evidence, Base and Natursport were used with search terms matched to their individual specification and focus (see search terms provided in S1-S8). To detect publications that focus on recreational activities, the search terms "recreation", "leisure", "sport", "tourist" and "outdoor activity" were used. Terms that were used to refer to a water-based location were for example "lake", "river", "freshwater", "marine", "littoral" etc. To ensure a measured impact of some kind, terms like "reaction", "impact*", "disturb*", "effect" or "change" were employed. The ecological aspects were addressed with terms like "animal", "vegetation", "biodiversity", "water" and the main taxonomic classes of the animal kingdom (for details see Tables S1-S8). Google and Google Scholar were used as additional sources with reduced search terms (S5). The German literature base "Natursport" was used to identify grey literature. The search was not limited to studies published in specific years. But as the last query was performed in February 2019, no studies published after this were taken into consideration for analysis.

The search terms yielded over 13,000 records. These were filtered automatically in EndNote by the second author to omit duplicates. Then some of us screened titles and abstracts for the recreational activities of interest. This systematic review represents an in-depth analysis of a

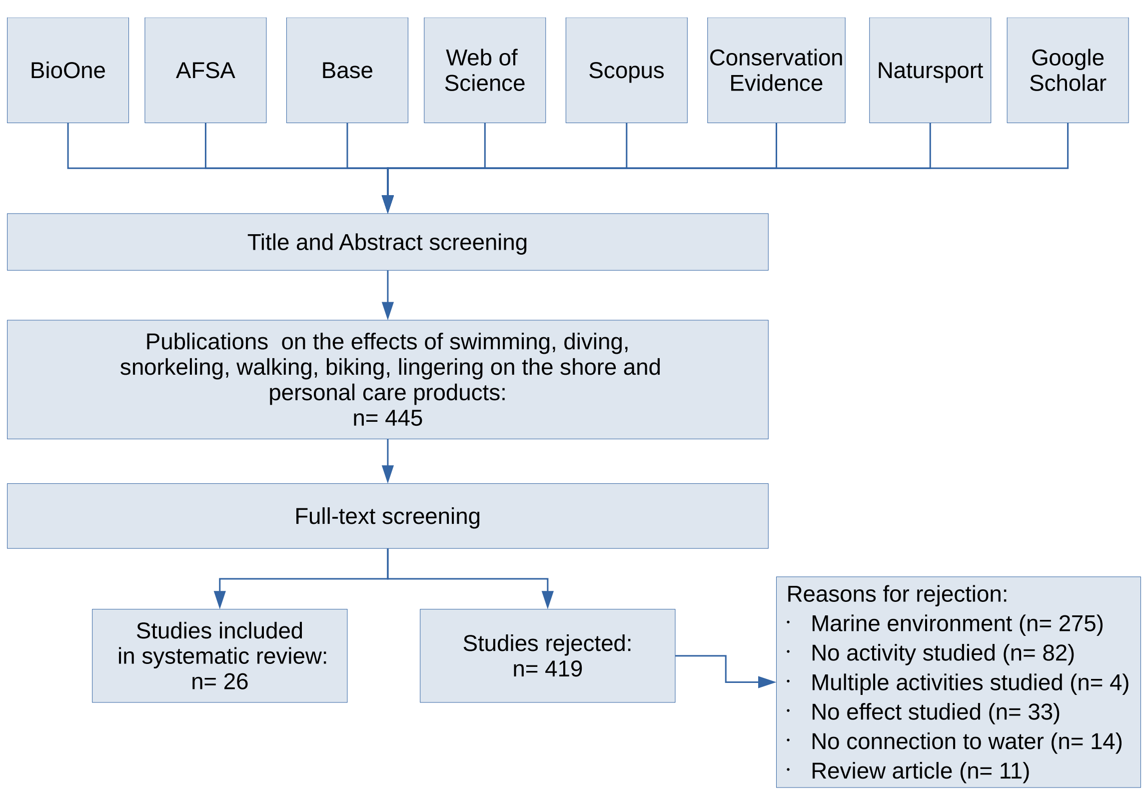

Fig. 1. Flowchart for literature acquisition.

subsample of all recreational activities carried out in freshwater ecosystems. The activities analysed here include biking, relaxing at the shore, nature observation, swimming, snorkelling, scuba diving and walking on land or in a stream (canyoning). Literature about consumptive activities (e.g. angling and hunting) and boating activities were excluded. This selection yielded 445 publications (Fig. 1). After full-text screening performed by the first author we excluded papers for the following reasons: from marine environments (275), no reference to specific activities or laboratory studies (82), reporting cumulative effects from several activities (4), no reference to impacts (33) and reviews. Elven of the excluded reviews were further referred to in introduction and discussion. Additionally, nine of the 419 publications that were discarded from the main-analysis, because they did not meet the quality criteria, were used in the discussion. The main analysis consists of 26 publications.

The information provided by the retrieved papers was manually extracted and saved in a standardized form according to Table 2. Setup information included study duration and location, study design and number of replicates. Organisms studied and species' identity were coded along with the response measured and the response specification. Animals were categorised into the main groups birds, mammals, amphibians, reptiles, invertebrates and fishes. Plants were differentiated into macrophytes and algae. Soil characteristics comprised density and content and water characteristics included water clarity, pH and nutrient load.

For every effect reported, the level of biological organisation at which the study object was affected was determined. As effects on the individual level we defined changes in behaviour, such as statements on time budgets (for example, time spent foraging, vigilant or in comfort), and physical reactions such as damages, injuries or heart rates. An effect at the population level was present when measurements of abundance allowed statements on the relative size of the population or when reproduction was affected. Community composition was impacted when changes in biodiversity or species composition were observed. We defined the ecosystem as the highest level of biological organisation. Changes in habitat structures, such as vegetation cover, in water quality and the compaction of soil fall into this category.

The specific aspect of each activity that had an impact on the environment was noted. In most studies, it was not clearly stated whether the visual, acoustical or olfactory aspect of human presence caused a reaction in the affected animals. Then, presence was noted as the specific aspect of the activity. If mentioned, the visitor number or density was extracted to gain insight on the intensity of human pressure that led to an ecological impact.

Table 2
Parameters and details retrieved from the literature.

Coded Parameter	Variables
Identifier	Authors
	Publication type
	Journal
Study type	A - after impact only
	CI - control vs impact, no before data
	BA - before vs after without control
	G - gradient response model
	BACI - Before /after control impact
Study design	temporal randomised
	spatial randomised
	temporal not randomised
	spatial not randomised
Biotope	Lake
	River
Taxon / Physics	Invertebrates
	Fish
	Amphibia
	Reptiles
	Birds
	Mammals
	Plants
	Algae
	Soil characteristics
	Water characteristics
Activity	Walking
	Dog walking
	Biking
	Swimming/Bathing
	Snorkelling
	Diving
	Camping
	Wildlife observation
Impact	Presence
	Noise
	Trampling
	Paddling
	Pollution/Toxicity
	Damage/Injury
	Extraction/Consumption/Mortality
Response measured	Avoidance
	time budgets
	Physiological
	Abundance
	Reproduction
	Community
	Biodiversity
	Water chemistry
	Pollution
	Soil compaction
Level of biological organisation	Individual
	Population
	community composition
	Ecosystem
Outcome	Positive effect
	Negative effect
	Change
	No effect
Visitors	Density
	Number

3. Results

3.1. *Quantity and quality of publications*

After filtering, 26 articles remained for our analyses. Of the overall limited number of studies, a clear concentration of locations on the northern hemisphere was found. Most studies were carried out in the USA (n = 7) and Germany (n = 6). The remaining 13 studies were performed in nine countries; two studies each in Australia, Brazil, Great Britain and Spain, and one each in Canada, France, Russia, Switzerland and Turkey. The most frequently used study-design was a comparison of control and impacted sites (CI, n = 15). Five studies reported the impact of a recreational activity (A, after impact only), while another five also considered the status before an impact (BA, before vs. after). Only one study used the most comprehensive BACI design comparing before and after observations of both impacted and control plots. Birds were the most frequently studied (9 publications), followed by invertebrates (6), plants (4), soil (4), fishes (3), water (2), amphibians (1), reptiles (1) and algae (1) (Fig. 2). Multiple groups were analysed in four studies. The studies on animals and plants focused on time budgets and abundance rather than biodiversity and reproductive success. Most studies (n = 17) referred responses to recreational activities at the individual level. Effects at population, community and ecosystem level were reported by five, six and four studies, respectively.

Effects of recreational activities on soil and water characteristics were addressed in four and two studies, respectively (Fig. 2). Two studies each focused on soil compaction and the abundance of certain chemical elements in the soil and two focused on water chemistry. Walking was the most frequently studied activity followed by relaxing on the shoreline and scuba diving, while all other activities were examined in one study each. The most investigated impacts were human presence and trampling, while water pollution and noise were only addressed in the swimming and dog walking study, respectively.

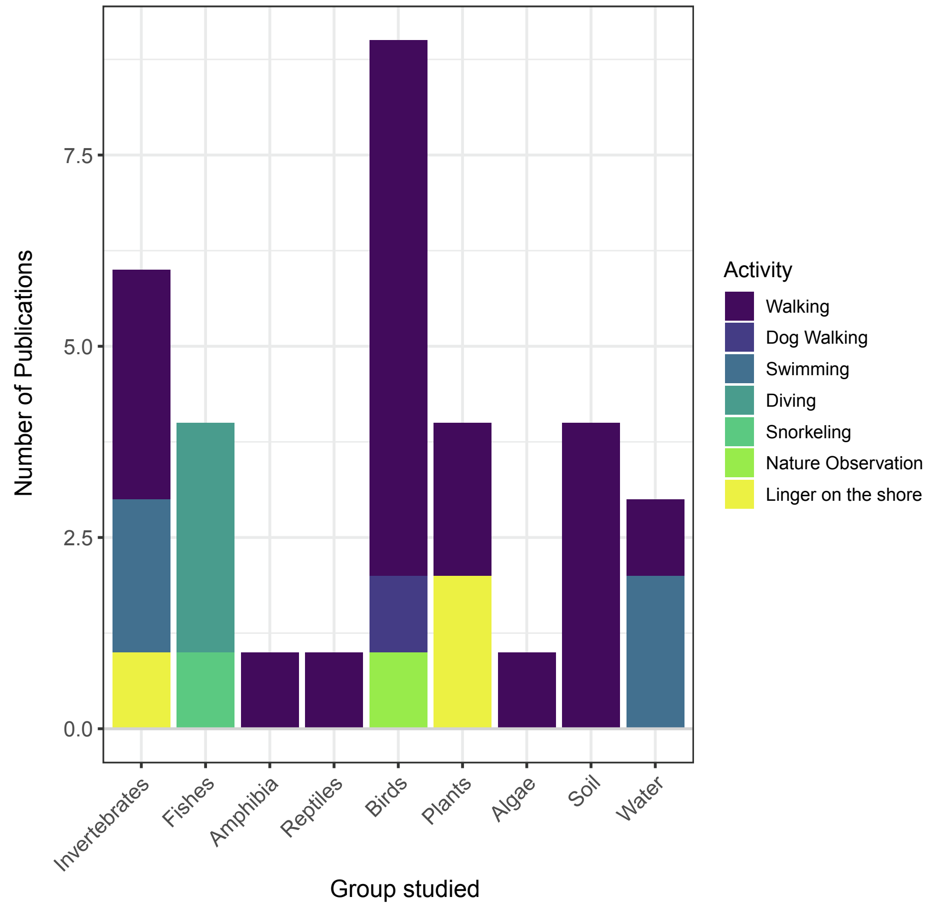

Fig. 2. Bar chart displaying the number of publications studying each combination of study object (Group) and activity. As six publications reported on more than one combination, the total is n = 33.

Most studied habitats were located in or around lakes (n = 17), primarily at the shore (n = 8). The studies relating to rivers (n = 11) concentrated mainly on the river banks (n = 8). One publication studied the benthos of a river.

Human presence was the most studied impact; however only five studies provided information on visitor numbers in their respective study areas. Two of these publications reported results for experimental disturbance. Schmidt & Gassner (2006) tested the influence of two scuba divers on the behaviour of fish, and Hardiman & Burgin (2011a, 2011b) studied the impact of different trampling intensities on invertebrates in a canyon stream. Guillemain et al. (2008) reported one guided tour nearly every day in their study area and the study area of Serengil & Özhan (2006) was visited by 10,000–50,000 people per year. Caires (2007) reported an observed threshold relationship between canyoning and invertebrate drift, where four walkers per 30 min interval led to a significant increase in invertebrate drift. Yalden (1992) reported a peak of 7.8 people per km shoreline. The low number of publications reporting visitor numbers and the differing ways of reporting them impedes a comparison of the recreational usage intensities in terms of impact thresholds.

Another factor for estimating visitor densities is the size of the impacted area. This information was included in eight publications, mainly as the lake surface area or the length of the river section under observation. However, no generalisations can be generated from this information since the output forms were too different across studies.

3.2. *Terrestrial organisms and soil*

3.2.1. *Birds*

Birds were the most commonly studied group, with nine publications. The focus was on responses at the individual level (n = 7). In three cases, effects on the community level were reported. One publication focused on two different levels of biological organisation (individual: individual short term abundance, and community level: species diversity (Fletcher et al., 1999)).

In one study, birdwatching tours did not significantly affect the abundance of waterfowl but induced behavioural changes (Guillemain et al., 2008). The birds spent less time in comfort and increased the time spent foraging and in movement. Guillemain et al. (2008) assumed that waterfowl increased the time spent foraging to compensate for energy loss caused by disturbance. They proposed that the birds became accustomed to disturbances to some extent, so that they did not leave disturbed lakes. However, the waterfowl did not become fully habituated to the disturbance, so that behavioural responses remained visible. This is consistent with findings of a walking experiment showing that waterfowl in a preserved area did not increase tolerance towards pedestrians over the course of one season (Trulio & White, 2017). In another study on waterfowl, the presence of pedestrians increased the time spent vigilant (Fernández-Juricic et al., 2007), while sleeping time was significantly reduced (Bellebaum, 1999; Fernández-Juricic et al., 2007). Birds seemingly not only react to visual stimuli but also recognise danger by acoustic signals. The time spent vigilant significantly increased after the playback of dogs barking, as would occur during dog-walks (Randler, 2006). A similar effect was observed by Randler after a playback of alarm calls of coots. Birdwatching led to a significantly longer vigilance in sandhill cranes, and the time spent foraging was longer than in undisturbed areas (Wilkins et al., 2017). However, human activities explained less than 20% of the variation in crane behaviour at impacted sites compared to undisturbed sites. Wilkins et al. (2017) suggested buffer zones between humans and birds as a management measurement. This was also proposed by Fernández-Juricic et al. (2007) for areas that provide suitable habitats for birds.

Fletcher et al. (1999) did not only focus on the individual-level but also at the level of community and found a higher species richness of raptors, along with a higher number of individuals in control sites along riparian corridors than in sites with a path next to the river. However, the abundance of red-tailed hawk (*Buteo jamaicensis*), known to be insensitive to urbanisation, was not influenced by pedestrians. Overall, there is limited evidence that entire populations of waterfowl or water-related birds are affected by shore use so far.

Yalden & Yalden (1990) detected a sensitivity of golden plovers (*Pluvialis apricaria*) to the presence of people in the pre-incubation period. The parents took more time returning to incubating when people were around, risking the survival of their offspring. Territory fights occurred when the parents tried to lead the flock away from the pedestrians on the shore (Yalden, 1992; Yalden & Yalden, 1990). Yalden (1992) observed a significantly lower number of territories of common sandpipers (*Actitis hypoleucos*) in lake sections with recreational disturbance. Surprisingly, a higher percentage of hatched eggs and fledged chicks was found in the disturbed territories, but the difference was not significant (Yalden 1992). However, the pronounced avoidance of disturbed areas by common sandpipers resulted in an overall smaller population size at the studied lake (Yalden, 1992).

3.3. Amphibians and reptiles

Amphibians and reptiles were considered together in our analysis. Negative impacts of walking, e.g. lower numbers of amphibians in areas with recreational activities (Rodríguez-Prieto & Fernández-Juricic, 2005), avoidance behaviour such as abandoning basking (Nyhof & Trulio, 2015), and longer periods of time taken to return to a disturbed area (Rodríguez-Prieto & Fernández-Juricic, 2005) were reported in three publications. One publication reported the effects of multiple activities (camping, boating, fishing and hiking) on turtles, showing minimal changes in turtle behaviour (Laverty et al., 2016). Rodríguez-Prieto & Fernández-Juricic (2005) found that frog abundance decreased with proximity to recreational areas. Generally, more frogs were found in less visited areas, indicating that recreational activities influenced frogs at a population level. The authors deduced that the responses of frogs to humans may vary with habitat structure because frogs flushed earlier in areas with less vegetation cover.

The basking of turtles was interrupted by walking in 5% and biking in 6% of all events (Nyhof & Trulio, 2015). This value was much higher for cars (45%). Sun basking is crucial for turtles' thermoregulation (Nyhof & Trulio, 2015) and this might ultimately affect the survival of an individual. Laverty et al. (2016) detected minimal effects of recreational activities on the daily movement patterns, annual home range sizes or health of Eastern Musk Turtles (*Sternothernus odoratus*). Yet, a higher number of dead turtles was found on impacted sites compared to non-impacted sites. However, the differences in mortality were not statistically significant.

3.3.1. Algae

Dubovik et al. (2007) studied the impact of walking on algal species diversity in soil. The authors noted a lower abundance and diversity of algal species in impacted areas. In addition, a simplification of taxonomic and biological structure was found. The abundance of one species, *Nostoc commune*, increased with the visitor impact. According to Dubovik et al. (2007), this species is an indicator of pasture loads.

3.3.2. Macrophytes

Four studies focussed on the ecological impacts of recreational activities on terrestrial macrophytes close to water bodies. The trampling associated with walking resulted in a reduced vegetation height (Gremmen et al., 2003), density (Andrés-Abellán et al., 2005; Bonanno et al., 1998) and number of individuals (Bowles & Maun, 1982) as well as in a lower plant species diversity (Andrés-Abellán et al., 2005).

Ninety percent less plant species were found in the most walked-on compared to the least walked-on plots at an waterfall in Spain (Andrés-Abellán et al., 2005). Recreational use, in particular trampling changed the plant species composition towards more resistant and nitrophilous species. The ongoing trampling observed in that study affected the area at an ecosystem level.

Freshwater dunes are sensitive ecosystems, which suffer from the trampling of pedestrians and swimmers. Bowles & Maun (1982) found human activities in dunes to impact plants at the individual level by causing physical damage such as broken leaves and branches, while Bonanno et al. (1998) found lower plant densities and lower species richness both in the ground and tree layer, representing an impact at ecosystem level. Both studies also found that trampling severely affected the ecosystem by reducing the flowering shots and delaying dune stabilization. These effects occurred in both studies at high and low levels of use, indicating that the best way to protect this sensitive ecosystem would be a spatial restriction of access.

3.3.3. Soil characteristics

Four publications analysed the ecological impacts on soil characteristics. Observed effects were the occurrence of bare ground (Andrés-Abellán et al., 2005; Fletcher et al., 1999), soil compaction (Andrés-Abellán et al., 2005; Serengil & Özhan, 2006) and the reduction of the organic matter concentration in the soil (Andrés-Abellán et al., 2005; Serengil & Özhan, 2006). The organic matter and organic carbon contents decreased slightly with increasing intensity of use (Andrés-Abellán et al., 2005). Andrés-Abellán et al. (2005) and Serengil & Özhan (2006) reported an increase in the sand fraction content as well as an increase in the pH value of the soil.

3.4. Aquatic organisms and water characteristics

3.4.1. Invertebrates

Five publications focused on invertebrates; in particular on the abundance of different species in various zones of the shore (Brauns et al., 2011), a higher drift density (Caires, 2007), and changes in the community composition (Hardiman & Burgin, 2011b; Zumkowski & Xylander, 1994). Three publications dealt with, canyoning (walking in the bed of a lotic waterbody). This activity differs from walking on land because it is performed exclusively in the bed of a stream or canyon (Hardiman & Burgin, 2011a, 2011b). A trampling experiment by Hardiman & Burgin (Hardiman & Burgin, 2011b) revealed that the macroinvertebrate abundance immediately after the disturbance was about 70% lower in trampled than in untrampled plots in a canyon stream. However, the macroinvertebrate communities recovered rather quickly, and 15 days after the disturbance no differences were found between trampled and untrampled plots. The community composition recovered to a diversity level similar to that before the disturbance, so that no long-lasting effect on invertebrate populations was visible from on time in-stream trampling. The authors also found that after the disturbance event the abundance in untrampled plots dropped below that in trampled plots. Hardiman & Burgin (2011b) reasoned that the trampling impacted the macroinvertrebrate community but that it rapidly recovered due to recolonisation from neighbouring plots. In an in-situ study on the effect of trampling on stream macroinvertebrates, Hardiman & Burgin (2011a) found no significant relationships between the macroinvertebrate assemblage composition and the visitation level of the canyons. Significant differences were only detected between different canyons. Hardiman & Burgin (2011a) concluded that, the current level of recreation did not lead to a significant negative impact on the macroinvertebrate assemblage. This was perhaps due to the location of the streams in a remote wilderness setting and to a resilience that the macroinvertebrates had developed under conditions with unpredictable natural disturbances. This resilience manifested in high mobility, fast recolonisation or year-round breeding.

Caires (2007) determined a threshold relationship between canyoning and invertebrate drift (four walkers per 30 min interval). This study found an increase in drift density with hiker numbers, but only in four of eight studied taxa. No difference in total benthic invertebrate abundance among sites of different use levels was found. This suggests a rapid recolonisation process.

Brauns et al. (2011) found a more negative impact on macroinvertebrates of artificial beaches for relaxing on the shore than Caires (2007) and Hardiman & Burgin (2011a, 2011b) found for canyoning. Of course, creating a long-lasting beach site is more severe compared to temporary canyoning impact, explaining the difference. The effect of the beach was evident in terms of lower species richness and lower relative abundances of *Coleoptera*, *Crustacea*, *Gastropoda* and *Trichoptera*. Brauns et al. (2011) concluded that the reduction of habitat complexity of the littoral led to unfavourable habitat conditions for the macroinvertebrates and thus to a reduction in abundance. Because artificial beaches had low structural complexity, no characteristic species or a distinct associated community for this shoreline development type exists.

Zumkowski and Xylander (1994) observed drastic changes in the amount and the community assemblage of heteroptera and choleoptera in gravel pit lakes that were used both for swimming and surfing. The differences between impacted and non-impacted areas changed with seasons: at impacted sites individual and species numbers dropped with the beginning of the bathing season in summer and increased again in autumn. At non-impacted sites, constant numbers were observed for all seasons.

The effects of water-based activities on fish were analysed in three publications. The observed effects on fishes of swimming, bathing or snorkelling were mostly negative, particularly concerning their avoidance behaviour (Schmidt & Gassner, 2006), lower abundances (Bessa & Gonçalves-de-Freitas, 2014; Teresa et al., 2011) and lower reproduction (Bessa & Gonçalves-de-Freitas, 2014; Teresa et al., 2011). One publication mentioned positive impacts of recreational activities on the abundance of certain species (Teresa et al., 2011). Abundance of individuals after a disturbance was the factor most often measured. Schmidt & Gassner (2006) measured the direct effect of two scuba divers on fish densities and found a significant difference in densities before and immediately after the dive as well as before and 30 min after the dive. Schmidt & Gassner (2006) noted that the fish stayed in the same horizontal layer when fleeing from the divers. They identified light as the main factor triggering avoidance behaviour. The fishes also returned quickly to their original position after the divers had stirred up sediments. The influence of human presence on the reproduction of fishes was ascertained in a lower number of nests of *Crenicichla lepidota* in highly frequented areas (Bessa & Gonçalves-de-Freitas, 2014) and in a lower number of individuals engaging in reproductive activities (Teresa et al., 2011). Despite some effects of recreational activities on fish observed, spawning habitat destruction remained the most significant reason for the decline of *Crenicichla lepidota* and *Hyphessobrycon eques*.

Teresa et al. (2011) concluded that the species whose abundance was positively affected by disturbance were those that profited from sediment suspension, according with the findings of Schmidt & Gassner (2006). Another study found that, in areas with unregulated snorkelling tourism, the behaviour of territorial fishes was more strongly impacted by the visitors than in areas with controlled tourism (Bessa & Gonçalves-de-Freitas, 2014). These authors concluded that human behaviour in areas with uncontrolled tourism led to reduced aggression of territorial fish, implying a habituation effect.

3.4.2. Water characteristics

Four publications were containing information on some kind of water quality characteristics. No effect of walking on water quality (Hardiman & Burgin, 2011a) or camping on pH-value (Laverty et al., 2016) were found. Two publications found increases of sunscreen compunds in waterbodies used for swimming (Gondikas et al., 2014; Poiger et al., 2004). Hardiman & Burgin (2011a) reported no measurable effect of canyoning on water quality and. They concluded that the levels of recreational pressure in their study area were too low to impact the water quality and therefore thethe river-ecosystem. Poiger et al. (2004) found that the concentrations of UV-filters used from in sunscreen products to increases in the water with increasing visitor numbers. As expected by the authors, the concentration of UV-filters in lakes generally increased in the summer months. Their results indicate a potential of bioaccumulation of UV-filters in recreational waters, due to the lipophilic nature of the compounds. However, the release of sunscreen from the skin while swimming was lower than predicted from input estimates, with an assumed wash-off of less than 50%. Laverty et al. (2016) found no differences in the pH- value of the water of impacted and non-impacted sites in their study area.

A particle analysis showed that titanium dioxide (TiO_2)-contents in the water of a heavily used lake increased during the summer months (Gondikas et al., 2014). This could be addressed by the wash-off of sunscreen, which can contain TiO_2-particles, from the skin of swimmers and people performing water sports. However, this study could not clearly link the increase in TiO_2 in the water to recreational activities, as the particles could be released into the water also through other ways such as facade-paint runoff or natural causes.

3.4.3. Summary

Fig. 3 shows that the studied groups can be devided into two categories. Mobile organisms such as birds, fish, amphibia and reptiles were mainly studied on the individual level. The studies reported abundance, behavioural changes or densities, which does not allow conclusions on the community or the entire ecosystem. Most effects reported for this category seemed not relevant for the survival of the population. Algae, macrophytes and soil were mostly studied on the community- or ecosystem-level and the effects such as simplification of taxonomic structure or reduced biodiversity are of greater ecological importance.

4. Discussion

Despite our systematic search we found only a very little amount of studies investigating potential ecological effects of recreational activities. This holds true for both understudied activities and taxa and it confirms our first assumption that certain combinations of activities and affected organisms are better studied more deeply than others couldan be confirmed for thethe selectedion kinds of activities in our studystudied here. The impacts of swimming on aquatic animals or plants were assessed rarely studied.

Birds were negatively impacted by recreational activities in most analysed studies, but mainly at the individual level. The main studied aspect were behavioural changes. Even though disturbance-induced reduction of rest- and feeding-time might threaten individual fitness, such measures are ecologically less relevant as long as population size or reproduction failures are not measures too (Bateman & Fleming, 2017). Specifically, impacts on the reproduction of birds were comparably rarely studied, precluding generalized insights, although birds are highly relevant in nature conservation frames. The two publications on bird reproduction reported negative effects of recreational activities on reproductive success, but it remained unclear whether these effects affected population abundance. Even though waterfowl and birds next to water are relatively intensively studied, publications on effects of shore based recreation at higher biological levels and with a greater significance to population survival are currently lacking.

Similarly, studies on amphibians and reptiles found avoidance

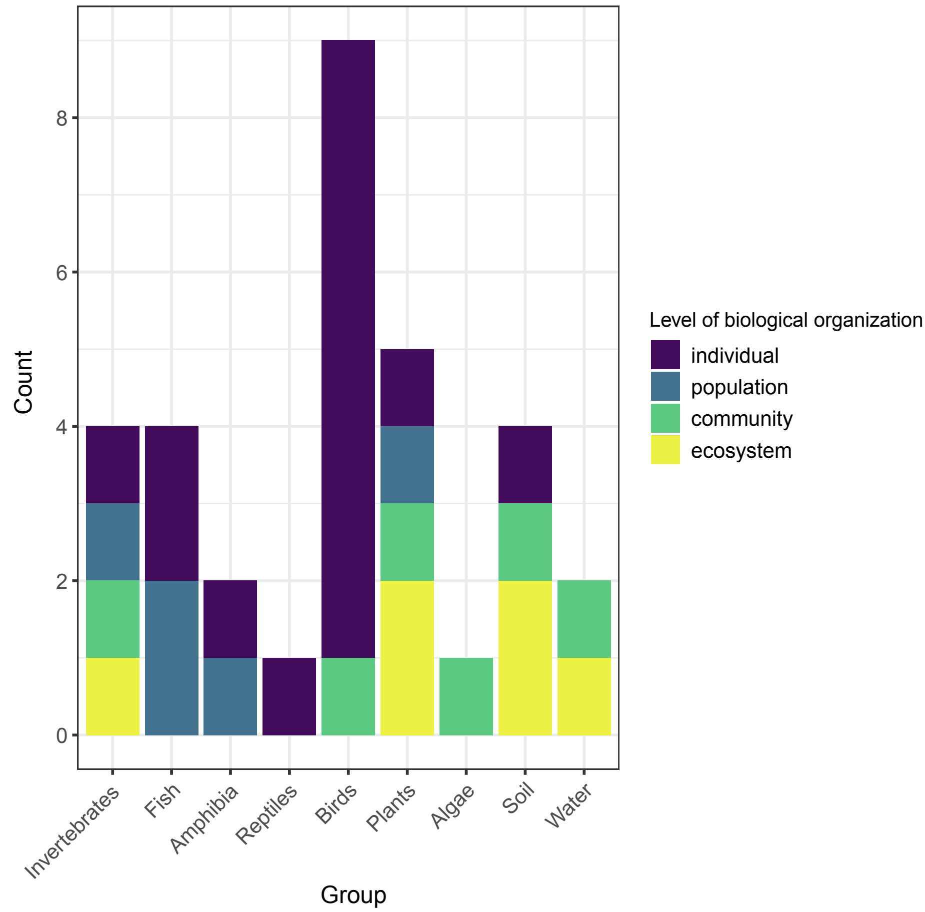

Fig. 3. Level of biological organisation of studied groups.

responses to recreational activities. Whether recreational uses have a long-lasting effect on turtle behaviour was found to depend largely on the density and frequency of the activities (Nyhof & Trulio, 2015). The non-significant difference in home range sizes and mortality in Laverty et al. (2016) might be due to the comparably low user intensity in their study area. Additional studies on the effects of various recreational activities are thus needed to identify thresholds and the behavioural adaptation as well as more severe effects on health and population survival of amphibians and reptiles. Taking into consideration that almost half of the amphibian species and one out of five reptilian species are threatened (Böhm et al., 2013; Stuart et al., 2004), effects of recreation on these two groups should be studied more intensely in general as well as in aquatic, shore-based contexts. If research continues to show effects on populations, as a management method, Rodríguez-Prieto & Fernández-Juricic (2005) proposed the zonation of stream banks. lakes. Low quality areas should then of course be held open to visitors, while high quality areas with an additional buffer zone could be reserved for conservation.

The amount of studies found on aquatic and terrestrial macrophytes was also comparably low, which was surprising given that studying these non-mobile organisms is perhaps easier than for example studying fish under water and effects of shore use seem obvious through trampling effects as revealed in terrestrial studies (Cole & Bayfield, 1993; Liddle, 1975). Especially aquatic vegetation was not studied in the publications found. Results on riparian vegetation however show severe impacts of recreational activities on vegetation growing on the shoreline by reducing abundance and diversity and changing species composition. Thus, we conclude that impacts of shore-based lake use most likely impacts riparian plants, particular herbs.

Other than expected, of the most common aquatic recreation activities swimming, snorkeling and scuba diving, no effects on aquatic algae or aquatic macrophytes were reported. Obviously, nutrient inputs with potential impacts on macrophytes of these recreational activities are of minor importance compared to e.g. land use. In addition, macrophyte-rich waters might be of little attraction for swimmer and snorkeler, which reduces spatial overlap and thus, potential impact. One publication in German found no additional damage caused by diving in lakes that were already used for other activities (Lutz, 1996).

One study found severe impacts of walking on the abundance, diversity and structure of algal communities in soils next to water (Dubovik et al., 2007). This is consistent with findings in algal communities on rocks under water influenced by hikers (Smith, 2009). However, algal growth depends on a combination of factors and the nutrient input by recreationists seems minor compared to the input of agriculture (Chakraborty et al., 2017), wastewater (Chen & Olden, 2020) and the effects of temperature and light (Singh & Singh, 2015).

Soil and its degradation are strongly linked with the status of the vegetation cover. Frequent trampling results in the disappearance of vegetation and this might lead to areas with bare soil prone to erosion and unfavourable for the reestablishment of vegetation. Therefore, management aiming at the protection of vegetation will simultaneously include protection of soil. This can be relatively easily managed by restricting access to existing pathways and areas for access to the water.

The results on the effects of recreational activities on invertebrates can be sorted into two groups. The first contains species located in streams and rivers being impacted by canyoning (Caires, 2007; Hardiman & Burgin, 2011a, 2011b). Drift density was the most common response variable for this group. However, this variable does not imply a lower chance of survival or reproduction of the impacted invertebrates. A rapid recolonisation was reported in all four studies. This shows the non-severity of the reported effects of canyoning on macroinvertebrates. The second group consists of invertebrates in lakes and ponds that are affected by swimming (and surfing) (Brauns et al., 2011; Zumkowski & Xylander, 1994). The landscaping needed for beaches for relaxing on the shore and entering the water as well as swimming which is more locally concentrated seemed to have a stronger and more fundamental impact on invertebrate communities. So far it remains unclear, how many invertebrate species are capable of avoiding threats by migrating and to what extent populations of invertebrates are impacted by recreation alone.

The findings on fish show that they are not only impacted by swimming, snorkelling and diving at an individual level but in some cases also through their reproduction, which in extreme cases could have population level effects (Gwinn & Allen, 2010). Here, similar to the results reported for invertebrates, habitat destruction, especially aquatic macrophytes, through recreational activities is a relevant threat to some fish species if the extend of recreational-induced habitat change is severe and long-lasting. There is no data to support this claim, as the studies reported mainly experimental interventions. However, not only the degradation of banks and fish refuges through activities in the water is a threat to fishes (Schulz, Śmietana, & Schulz, 2006). Also camping on the shore can potentially increase the input of chemicals and nutrients into the water (King & Mace, 1974; Laverty et al., 2016), but there is no hard data how this affects fish in the wild.

The presence of humans in the water can lead to behavioural responses of fishes, but also the sound of underwater breathing apparatuses, which produce sounds in a range that the hearing organs of fishes and decapod crustaceans are most sensitive to, can be problematic (Radford, Kerridge, & Simpson, 2014). Even activities without electric or motor-driven equipment like swimming or muscle driven boats can generate underwater noise as proven in an experiment by Erbe et al. (2016) that could interfere with the acoustic communication of fishes and thereby have an impact on mating success and reproduction (Zelick et al., 1999). Yet, currently it is highly speculative if such effects materialize at the population level as no research has quantified this.

The increasing concentration of UV-filters in the water alone is not a real ecological effect and was not linked to threats to organisms in the studies of Poiger et al. (2004) or Gondikas et al., (2014), experimental studies in the laboratory suggest negative ecological effects of UV-filters. For example, Kaiser et al. (2012) discovered a toxic effect of some UV-filters on the reproduction of snails, and Blüthgen et al. (2012) showed accumulation of the filters in zebrafish and an alteration of their gene expression. However, knowledge of the extent to which UV-filters are released from the skin of bathers into the water, the resulting concentration of UV-filters in a water body, as well as the link to the actual damage to aquatic organisms still lacks. To make matters more difficult, recreational activities are often not the only nor the most dominant source for chemical compunds in the water, for example TiO_2 is used in sunscreen and facade-paint (Gondikas et al., 2014). The direct link from recreational activities to changes in water quality might also be difficult as chemical characteristics of waterbodies will depend on the geology of the surrounding area and the morphology of the lake basin or river bed (King & Mace, 1974). The results of this study agree with Venohr et al. (2018) that the impacts of sunscreens on freshwater organisms are rarely studied, especially in-situ. Likewise, potential pollution of freshwaters through activities like swimming snorkelling or scuba diving is insufficiently studied. The mainly negative effects found in the results of this literature search as well as in additional material underline the importance of further in-situ studies on this topic.

The systematic literature search yielded an insufficient amount of material on the ecological effects of recreation on water quality. This might be due to a real lack of studies on this topic or partly due to the decision on not including publications with divergent keywords or titles. For example, Phillip et al. (2009) reported poor water quality as a result of swimming. But as the main focus of this paper was on hazards to human health and were therefore not mentioned as ecological impacts, it did not show up in the literature search. Although, the strict quality criteria yielded to a reduced number of material for the analysis, we believe that the rigorous sorting process led to a set of literature with a higher quality of the studies that met the criteria and the scope of our review.

A lack of studies on the effects of recreational activities on specific groups does not, however, mean that these are not impacted (Larson et al., 2016). Almost all species are sensitive to recreational activities in their habitat to some degree (Blanc et al., 2006). However, not all effects measured locally or at the individual level in the case of animals will scale up to affect populations or even ecosystem function. Our literature review showed that population or community-level studies of the impact of outdoor recreation at the shores are rather rare and effects are limited to a few studies. This does not mean there are no effects of recreation, but the current body of literature mainly supports the evidence that plants as sessile organisms (e.g., terrestrial plants) seem to be the most impacted by shore based organismsactivities and that mobile organisms such as birds, fishes or invertebrates tend to respond individually, but show compensatory response that limit the long-term impact at the population level or allow rapid recovery after the disturbance. The groups studied in the available literature might reflect the interest of researchers and the ability of researchers to study effects rather than the threats that these groups face (Blanc et al., 2006). Overall, our work revealed a substantial need for more research, especially experimental in-situ work to study cause-and-effect as most study designs employed in the literature employed observational data and basic study designes such as BA and CI.

5. Conclusion

Our systematic review revealed a significant gap of data and research. Although recreational activities on and along freshwaters are of significant, growing importance their potential interference with environmental quality and conservation aim is little studied. Therefore, our results summarise first evidence for negative environmental impacts of selected recreational activities on some taxa, but they are far from being comprehensive. Globally, there is sufficient overlap between species ranges and recreational activities for all taxa in freshwaters, so that the detected lack of studies for most taxa leaves it open, whether there is no conflict or just lack of research and funding.

The analysis of the ecological impacts of recreational activities in and along water bodies collectively revealed that the responses of sessile and mobile organisms to human disturbance differ substantially. Mobile organisms were less affected by recreational activities than sessile ones. For instance, fishes and birds fled and changed their location or altered their behaviour in different ways as a reaction to disturbance through humans, and the literature on population-level impacts is largely absent for these taxa groups. Similarly, mobile invertebrates reacted to temporary disturbance with migration to undisturbed areas and recolonization processes were observed thereafter. The data so far does not suggest strong and lasting population level effects, except when local habitats are altered in a strong fashing, e.g., due to beaches for macroinvertebrates. Sessile organisms, however, such as plants for which damage and dieback were reported, were impacted more severely by shore based recreation. Intact bank vegetation is crucial for the health of an ecosystem; it protects the shoreline and provides food and shelter for other organisms. The studies on water quality showed a variety of results, ranging from no effects to the accumulation of UV-filters in the water. However, the number of studies on water quality and other water characteristics was so low that no generalized statements on this topic could be made.

Whether the use of natural or near-natural inland waters for recreational activities always leads to negative impacts cannot be definitively answered by the findings presented here. The strict quality criteria resulted in an overall small dataset and in a low number of studies on topics that are already known to be under-published like the impacts on water quality. Subsequently, only high quality studies with strong and clear evidence were analysed. Yet, sticking to the systematic process led to a reproducible and up-to-date review on the current literature on the ecological effects of shore- and water-based recreational activities.

Our research suggests that shore based recreation can under some situations have lasting ecological effects, particularly on plants. Under these conditions and depending on local recreational use intensity, management of access or zonation can be a measure to avoid negative ecological impacts caused by people seeking relaxation at the water. However, other measures, such as environmental education should also be considered first to harmonise the interactions between recreational activities and the environment they make use of. Future studies should include underrepresented organism groups to close knowledge gaps and provide a broad and robust knowledge base for informing sustainable management of outdoor recreation. In particular, more studies at the population level and with robust BACI designs are needed because population level or community level impacts of recreation are perhaps more relevant from a conservation perspective than studies that for example studies individual behavioural displacements in birds or fishes that have no consequences for the population as a whole. Thus, rather than local studies, a focus on whole lake studies and whole populations is recommended for the future.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jnc.2021.126073.

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