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Original article

# Effects of recreational use on restored urban floodplain vegetation in urban areas

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A R T I C L E I N F O

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A B S T R A C T

Urban river restorations focus on restoring aquatic and riparian habitats, increasing flood protection, and enhancing recreational potential. The increased recreational value such newly created urban green spaces is a key benefit of these measures as urban riparian areas are highly valued for recreation. However, high recreational pressure may contribute to the loss of natural vegetation and of biodiversity in restored riparian sites. This study investigates the impact of different recreational intensities and use types on the vegetation structure and vegetation quality by documenting direct (foot-traffic, breaking of branches, stems and roots) and indirect damages (litter and excrements). The major results are fourfold. First, while the proportion of some vegetation types can be correlated to the recreational intensity, neither recreation intensity nor recreation types enhanced the colonization success of invasive species. However, monitoring data showed that human-induced disturbances such as hydro-morphological changes favor alien plant establishment. Second, the study suggests a tipping point for pioneer vegetation at around a density of one user per 10 m river stretch. Already at lower user densities, pressure from trampling can slow down vegetation development. Third, the results indicate that users prefer urban greening and gravel bar elements rather than natural vegetation. Finally, while intensity of direct damages on the vegetation are weakly correlated with the user density, indirect damages increase with the user density. This study concluded that the identification of user hotspots would be helpful in developing a resilient restoration design, which in addition to information about the sensitive vegetation types in relation to recreational users and nature friendly recreational behavior could decrease vegetation damages. In particular, younger recreational users should be targeted by environmental protection campaigns.

## 1. Introduction

Floodplains are hotspots for biodiversity and threatened by many human activities. Hydro-morphological modifications of the river system enabled land use changes of riparian vegetation to agricultural land or residential areas, leading to long-term destruction of natural habitats and a decrease in biodiversity (Kollmann et al., 2019). Riparian restoration has been identified worldwide as an expedient strategy to reestablish biodiversity. The recent IPBES assessment report urgently stresses the restoration of terrestrial and freshwater ecosystems that have undergone significant degradations to protect and safeguard biodiversity (IPBES, 2019).

While riparian restoration is urgently need, restoration efforts are hindered at many levels. First, one of the major bottleneck for river restoration and particularly for floodplain restoration in an urbanizing world is the lack of space (Zingraff-Hamed et al., 2020). Second, because of their inherent nature, riparian vegetation require water-related perturbations. Flood frequency, intensity and duration influence the vegetation type and enable succession cycles typical for this ecosystem (Junk et al., 1989; Scholz et al., 2005; Egger et al., 2019; Muhar et al., 2019). However, man-made river constructions, e.g., dams and dykes, and water management practices, e.g., water diversion, highly affect the hydrological system (Blöschl et al., 2019; Walsh et al., 2005), related freshwater (Zingraff-Hamed et al., 2018a), riparian species' physical habitats (Ochs et al., 2019), species composition (Catford et al., 2011), and even socio-economic riverine value (Auerswald et al., 2019). In Germany, for example, 33 % of the riparian vegetation are flooded during extreme flood events and 46 % are natural floodplain vegetation that are disconnected from the river system (Brunotte et al., 2009). Third, while the number of river restoration projects greatly increased in

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the last decade, little has been done for riparian area. For example, in Europe, the Water Framework Directive mandates the restoration of all European water bodies that are not up to a certain ecological quality standard but did not consider the floodplain in its assessment of the river status. In France for example, only 30 % of the river restorations implemented or planned prior 2015 targeted an improvement of the riparian habitats (Zingraff-Hamed et al., 2017b), and 83 % of these were urban river restorations.

Especially in urban areas, riparian areas are reduced to minimalist green lines within the urban landscape. However, they play a crucial role in delivering numerous ecosystem services (Haase, 2017; Riis et al., 2020; Groffman et al., 2003) as combatting the transfer of nutrients and sediments in freshwater system (Uggeldahl and Olsen, 2019) and serving as migration corridors (Aziz and Rasidi, 2014). Furthermore, they provide large societal co-benefits such as recreational areas (Uggeldahl and Olsen, 2019). Reviewing river restoration goals, rural projects mainly intend to improve aquatic habitats and longitudinal river continuum, while urban projects target ecological quality of aquatic and terrestrial habitats, flood protection and increase of the recreational potential of the riverine area (Zingraff-Hamed et al., 2017b). The monitoring of recreational users showed that the restoration of urban rivers led to an important increase of recreational density (Jähnig et al., 2011).

However, since high recreational density can negatively affect habitats, urban river restoration often seeks to combine conflicting goals. Studies indicate that recreational use can affect insects (e.g., Bennett et al., 2013), birds (e.g., Huhta and Sulkava, 2014), mammals (e.g., Pineiro et al., 2012), soil and vegetation (e.g., Sarah and Zhevelev, 2007). Findings in Spain showed that native vegetation is most impacted by recreational users (Andrés-Abellán et al., 2005). This result shows the dilemma of restoration projects as increased recreation opportunities and increased leisure uses can counteract measures to safeguard species and habitats that are key targets of the restoration effort. For example, while the Isar river restoration in Munich succeed in improving the aquatic habitat quality for a sensitive fish species, suitable restored habitats lost up to 76 % to their surface because of recreational pressure (Zingraff-Hamed et al., 2018b). With of their inherent properties, and especially because of their high tolerance to physical perturbation, riparian vegetation maybe less impacted by recreational use. A variety of studies investigate or review impacts of trampling on natural (Monz et al., 2013, 2010; Cole and Monz, 2002; Pescott and Stewart, 2014) or protected areas such as National Parks (Mason et al., 2015) and urban forests (Littlemore and Barker, 2001; Malmivaara-Lämsä et al., 2008; Hamberg et al., 2008). The effect of recreational use on aquatic habitat quality (e.g., Cooke and Xia, 2020) such as the management of recreational fisheries and biodiversity (e.g., Nikolaus et al., 2020) have been assessed. However, most studies focus on trails, remote areas and only a minority is related to urban areas (Ballantyne and Pickering, 2015). Little is known about the impacts of recreational uses on restored riverine vegetation and even less in an urban context.

This study investigated the effect of recreational uses on an urban restored river's riparian vegetation and especially focused on i) variations of the vegetation structure along a recreational intensity gradient, and ii) linkage between riparian vegetation degradation and recreational use. The aims of the study are twofold: provide understanding about urban restored riverine habitat sensitivity in the context of recreational uses, and elaborate on user-specific measures to manage recreational pressure on urban restored habitats.

## 2. Material and methods

### 2.1. Case study site

The Isar river is an alpine river that sources in Austria, flows north crossing the German state of Bavaria and joins the Danube river in Deggendorf. It crosses Munich, the capital of Bavaria (Fig. 1). This urban section of the river was restored between 1999 and 2011 to fulfill three major goals: ecological quality, flood protection, and high recreational potential. The eight-kilometer long restoration of the southern section of the urban river from the Großhesseloher Bridge (48 ° 4′ 28″ N, 11 ° 32′ 24″ E) to the Museum Island (48 ° 7′ 48″ N, 11 ° 35′ 0″ E) is a renown good practice example. It won the first German award "Gewässerentwicklungspreis" for river development in 2007 and inspired many EU funded research projects, e.g. PHUSICOS and NATURVATION as a forerunner of socio-ecological river restoration (including societal co-benefits in the planning and using an innovative collaborative planning process) (Lupp et al., 2021; Zingraff-Hamed et al., 2019). The studied area is located within the Natura 2000″Upper Isar Valley" area (8034−371) and within the "Isar Riparian Vegetation" (LSG-00120.09) landscape protection area.

A review of botanical literature identified the natural riparian vegetation that should be found in our study area (Fig. 2). However, major modifications of the hydro-morphological status of the Isar led to a decline in riparian vegetation structure and biodiversity. Degradation began in the 1820′s with the Isar regulation and continued in the beginning of the 20th century with major hydrological perturbation,

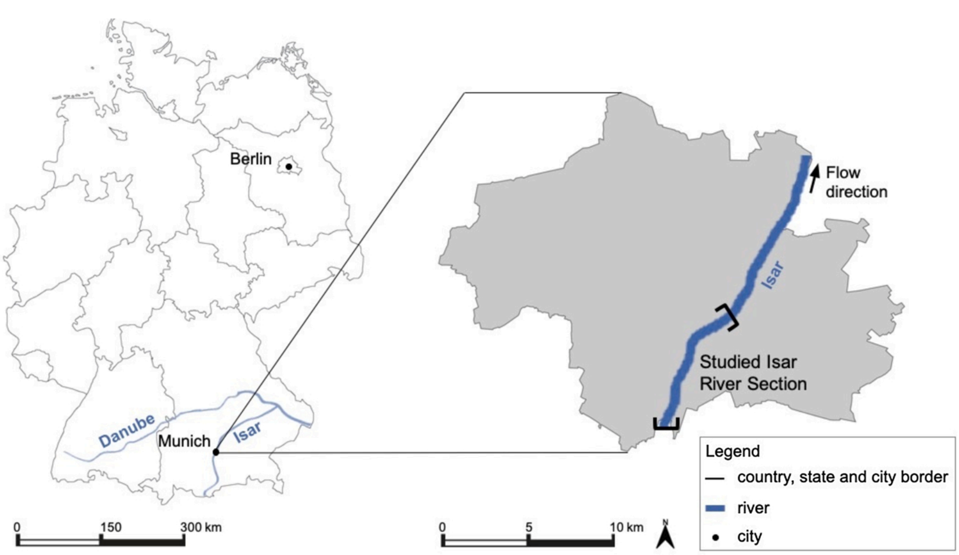


**Fig. 1.** Localization of the Isar River Restoration in Munich.

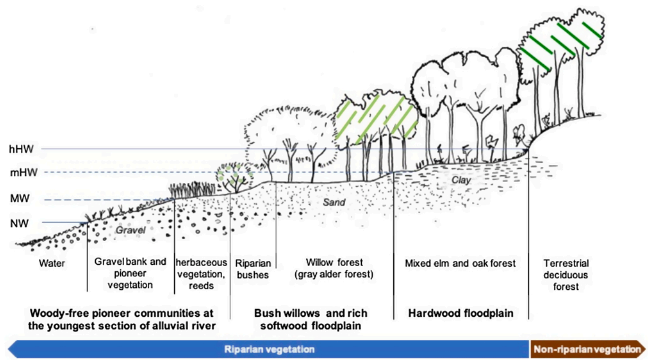


**Fig. 2.** Schematic cross-section of a naturally created intact vegetation structure of a floodplain at the middle course of the Isar (modified from Ellenberg and Leuschner, 2010). NW: minimal water level, MW: mean water level, mHW: mean annual high water level, hHW: extreme high water level.

namely the construction of 28 hydroelectric power plants and of the Sylvenstein Reservoir (1954–1959). Botanical monitoring performed between 1890 and 1961 showed a structural decline and decrease in vegetation-free gravel banks, in pioneer vegetation and in the softwood forest in favor of the hardwood floodplain, and an increase in agricultural areas (Seibert, 1962). The natural maximum riparian expansion was reduced to two kilometers at the middle Isar, and in the urban area of Munich riparian areas were reduced down to 50 m within the now restored section (Karl et al., 1998; Neumann et al., 2011).

One of the measures implemented by the Isar river restoration was the removal and relocation of dams to enable more room for the river. Because of the limited space available and river regulation upstream, the pristine river and original floodplain conditions could not be restored. Moreover, public consideration led to maintaining large recreational lawns in order to maximize the recreation potential. However, restoration measures enabled the successful restoration of habitats for sensitive plant species as *Myricaria germanica* L. (Zingraff-Hamed et al., 2017a). Moreover, the ecological improvement (Kollmann et al., 2019) and the near-natural waterscape resulted in an increase of recreational potential of the riverine area that became one of the most popular recreation areas in Munich for nature-based activities (Zingraff-Hamed et al., 2017a; Düchs, 2014) such as jogging, walking, swimming, picnics, barbeques, and socializing. A survey performed in 2013 counted within the eight-kilometer restored river in mean 600 users per day over six months (Zingraff-Hamed et al., 2018b) and estimated that the annual number of users was between 110,000 and 150,000. The recreational use at the Isar saw a great increase during the Covid-19 pandemic, offering a large and well-ventilated green open-space. Counting monitoring performed in 2020 found a maximal of 10.000 users in a day, and regularly counted 5.000 visitor during hot summer days.

## 2.2. Transects

The monitoring procedure is based on the transect analysis performed during periods of low water levels. In order to investigate the linkage between recreational use density and riparian vegetation damage within the eight-kilometer section we distributed 100 transects within the study area. We took much care to have equal number of transects (N = 20) within each recreational user density category (N = 5). We used the user density categories defined in a preliminary study on user density at the eight kilometer long restored Isar which was published in 2018 (Zingraff-Hamed et al., 2018b). According to Garniel (2002) guidelines for transect analyses, transects were four meters wide, started in the middle of the river, extended perpendicularly within the floodplain, and stopped at the end of the flooding area, namely the dam upper line, excluding the relict of riparian vegetation that is disconnected from the river system. Where no dams exist, we used the flood map published in 2018 as source for data by the city government of Munich for kilometer 140.95–155.10 of the river. Because of the floodplain's variation in width, transects ranged between 23 m and 149.5 m. Since restoration measures were implemented only on east embankments and since recreational use is clustered there, transects were distribute only on this riverside.

The cumulative length of the area of each user density category differs, and consequently the distance between transects vary between 25 m and 115 m. However, within a category, the distance between transects is constant (Fig. 3). To exclude effects on the vegetation structure due to bridges, e.g. shading, 10 m of each side of the bridges were removed from the investigated areas. Transects crossing trash containers were relocated five meters away.

## 2.3. Variables

Variables used and monitored in this analysis are gathered under four themes: vegetation type, damages, user density, and type of recreational use. The mapping exercise was performed using QGIS (Version: 3.10.5- A Coruna) and data was entered in Microsoft Excel.

### 2.3.1. Vegetation types

A floodplain vegetation type mapping was performed on the transects for 10 days: 18.06.2020, 20−22.06.2020, 27−30.06.2020, 03.07.2020 and 06.07.2020. The vegetation types used were those defined by Ellenberg and Leuschner (2010) (Fig. 2). However, due to the riverine area being used as an urban recreation area, some vegetation types are from urban greening rather than natural riparian vegetation. We consequently added a number of "human-made" vegetation types within the list, e.g. recreational lawns, as well as vegetation-free areas, e.g. gravel bars (Table 1). Afterwards, in order to exclude variation due to different transect lengths, the surfaces of each vegetation type for each transect were calculated as a proportion.

### 2.3.2. Damages

Damage monitoring was performed on the transects during the same 10 days: 18.06.2020, 20−22.06.2020, 27−30.06.2020, 03.07.2020 and 06.07.2020. According to Olschowy (1990), four types of damages can be assessed and described by the two criteria of duration and effect on the vegetation (Table 2). Because of the limited timeline of the study, long-term effects and changes could not be measured. Diffuse and global effects were limited to what could be observed within the study area and the timeline. Based on Seibert (1962), only visually clearly identifiable damages to vegetation and signs of recreational uses associated with those damages were monitored for this study (Table 3).

### 2.3.3. User density

The intensity of recreational users was taken from a preliminary study that was published in 2017 (Zingraff-Hamed et al., 2018b). They established a map of hot-spots and cold-spots and identified five recreational user density categories: very low, low, medium, high and very high (Table 4). According to the methodological approach used to lay the transects, 20 transects are located in each recreational user density category. This variable was used to group the transects for the statistical analysis.

### 2.3.4. Type of recreational uses

To identify the type of recreational uses at all transects simultaneously, a mapping exercise was performed using aerial photography published by Google Earth Pro (Version 7.3.3.7786). Two pictures were used, those taken on 08.04.2018 and 03.06.2019. The first picture has the advantage that users were not hidden below vegetation cover which starts to grow in south Bavaria at the end of April (Kollmann et al., 2019). The second picture corresponds to the higher number of users according to the results of Zingraff-Hamed et al. (Zingraff-Hamed et al., 2018b). Recreational user types were manually counted within each

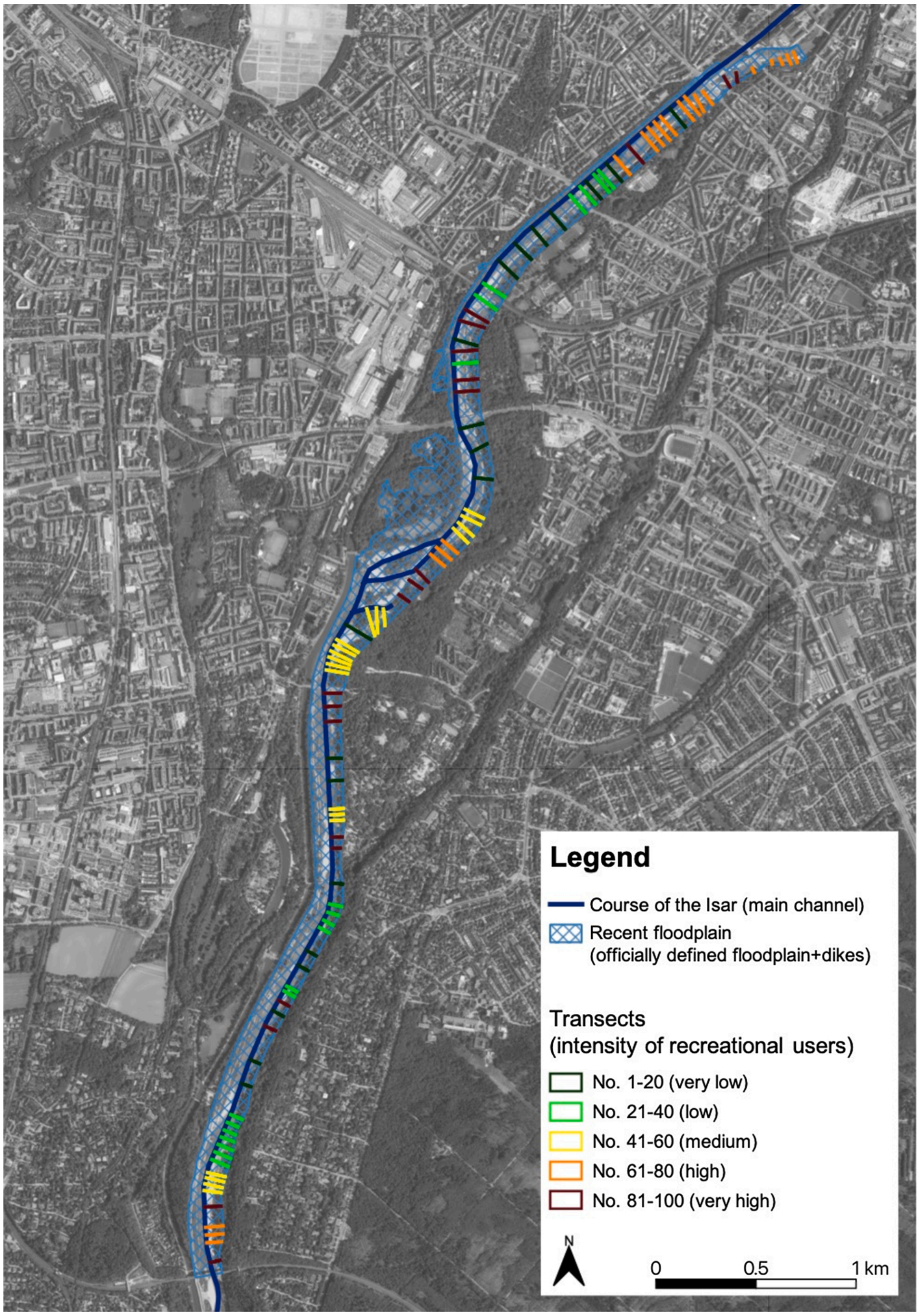


**Fig. 3.** Spatial location of the individual sample areas along the investigated section of the Isar. The numbering of the transects for each intensity level starts with the most northerly located sample area (map source: Bayerische Vermessungsverwaltung 2020). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

transect using the recreational use type key in Table 5.

### 2.4. Data analysis

Statistical analysis was performed using the IBM SPSS Statistics software (IBM Corp. 2017). For all significant statistical tests *p*value $<$ 0.05 was selected. In order to investigate the effects of recreational use at urban restored river on riparian vegetation in the case of the Isar in Munich, the statistical analyses approach followed three steps. First, the data were described in order to give an overall overview of the vegetation structure and damages observed. Second, variations of the vegetation structure along a recreational intensity gradient were studied comparing the proportion of each vegetation type to the different recreational use densities. Normal distribution (Shapiro-Wilk test) and homogeneity of variance (Levene test) were unsuccessfully tested which led us to use the Kruskal-Wallis and Mann-Whitney test (Gower, 1971; Greenacre, 2006). Due to the multiple comparisons with the Mann-Whitney, test we performed a Bonferroni correction to correct the alpha error. Third, to investigate the linkage between riparian vegetation degradation and recreational use, correlation tests between the number and type of recreational users and with the vegetation degradation type were performed using Buhl's method for metric scaled

**Table 1**
Overview of the section, descriptions, and typical plants for all mapped sections of the floodplain zones.

| Sections | Descriptions | Vegetation Types (examples) |
|---|---|---|
| Main stream | Constant flow through the main channel | *Schwimmrasen mit Ranunculus aquatillis* |
| Backwater and oxbow lake | Side channel through which the main stream does not completely flow | *Hippuris vulgaris, Schoenoplectus lacustris* |
| Vegetation-free gravel bank | Natural mostly vegetation-free gravel or sand banks | – |
| Pioneer vegetation | Gravel or sand banks with new vegetation from non-woody pioneer plants | *Silene vulgaris, Tusilago farfara* |
| Grasslands | Natural or man-made species-rich and dry, warm stocks (e.g. dyke embankments) | *Lotus corniculatus, Salvia pratensis* |
| Herbaceous vegetation/ reeds | Final section of woody-free pioneer vegetation under regular flood influence | *Barbarea vulgaris, Phalaris arundinacea* |
| Recreational lawns | Woody-free, partially species-rich, areas intensively used by humans with high foot-traffic | *Plantago major, Poa annua* |
| Invasive neophytes | Dominant stands of fast-growing, neophytic vascular plants gem. BfN (2020a: 1 ff.) | *Fallopia japonica, Impatiens glandulifera* |
| Riparian bushes | The youngest part of the alluvial forest succession with gaps in stock consisting mainly of pioneer trees (≤ 3 m vegetation height) | *Salix alba, Salix purpurea* |
| Softwood floodplain | Mostly closed stands of woody vegetation with little disturbance from flooding (> 3 m vegetation height) | *Populus nigra, Salix alba* |
| Hardwood floodplain | Floodplain forest far from the river, inundated exclusively by peak floods and thus poorly stocked with flood-tolerant species | *Fraxinus excelsior, Ulmus minor* |
| Other vegetation types | Artificially created and regularly maintained vegetation types or other vegetation formations not typical for the floodplain (e.g., hedges or sports areas, parks and green areas) | *Aesculus hippocastanum, Thuja occidentalis* |
| Vegetation-free areas | Structures such as weirs and bridge sections or officially designated footpaths and cycle paths | – |

**Table 2**
Overview of four basic types of floodplain stresses associated with recreational use.

| Type of Effect/Disturbance | Example Cases | Potential Impact |
|---|---|---|
| Immediate (direct) disturbances or damage | Bark injury | Decrease of health |
| Secondary (indirect) disturbances or damages | Damage due to foot traffic | Degradation |
| Long-term effects | Camping sites | Structural change |
| Widespread or global effects | Waste | Ecosystem degradation |

parameters (Bühl, 2010). The Spearman test (rho-Test) was applied. Because of the limited number of transects we used the methods described by Steiner and Benesch (2008) to identify correlation.

## 3. Results

### 3.1. Overall data description

Despite the low water table, the higher proportion of the transect cover is main stream and backwater (31.86 %) followed by non-natural and non-vegetal cover (11.47 %) and man-made urban greening (23.50

**Table 3**
Overview of mapped damages and adverse effects as well as causes of damage, the affected ecological level and potential impacts.

| Causes of Damage | Ecological Levels | Designation of the Mapped Element (description/ demarcation) | Potential Impacts (examples) |
|---|---|---|---|
| Physical | Biotope | Footpaths (paths with > 2 m distance to the Isar and without official designation or distortion in the OpenstreetMap map file (OSM 2020)) | -Absence of vegetation development (Ostendrop 2009: 33 ff.) -Difficulty for plants to germinate due to soil compaction (BfN 1997: 49 ff.) |
| | | Entrance paths (access areas) to gravel banks or to the water body (≤ 2 m distance to Isar) | -Extensive destruction/ degradation of riparian vegetation due to increased bank erosion (ibid.) |
| | | Removal/relocation of material (e.g., for the construction of "cairns" or sandcastles) | -Absence of vegetation development (Ostendrop 2009: 33 ff.) -Inhibition of photosynthesis due to water turbidity (Schenk 2005: 51) |
| | Organism | Single or multiple trampled plants (e.g., at open spaces and storage areas and along pathways) | -Damage to the vegetation cover (damage due to foot-traffic) (Ostendrop et al. 2010: 91) -Shift in species composition due to selection of impact-resistant species e.g., *Polzgonum aviculare, Plantago major und Poa annua* (Schaefer 2012: 298) |
| | Basic plant organs or structure | Broken/bent trunks or branches | -Direct plant damage and increased susceptibility to rot damage (Reinartz & Schlag 1997: 23 ff.) |
| | | Exposed, damaged and severed roots on woody plants | -Rot damage and growth deficits due to disturbed water and mineral supply (ibid.) |
| | | Bark injuries on the trunks of woody plants | -Rot damage and growth deficits as immediate consequences, crown damage develops later due to supply disturbances (ibid.) |
| Chemical | Biotope | Organic and inorganic waste (e.g., glass, plastics, food scraps, paper, residual waste, polystyrene and metals) | -Soil and water eutrophication change site conditions, which lead to a shift in the species composition of the existing vegetation (Schenk 2005: 141; Kasperek 1993: 122) -direct plant damage caused by toxic pollutants (Kasperek 1993: 122) |
| | | Feces from humans and dogs | -Soil and water eutrophication lead to the shift of the existing species composition to nitrophyic vegetation (Schenk 2005: 141; Kasperek 1993: 122) |
| | | Bonfires or used charcoal | -Soil and water eutrophication alter site conditions, which can lead to shifts in the |

(continued on next page)

**Table 3** (*continued*)

| Causes of Damage | Ecological Levels | Designation of the Mapped Element (description/ demarcation) | Potential Impacts (examples) |
|---|---|---|---|
| | | | species composition of existing vegetation (Schenk 2005: 141; Kasperek 1993: 122) -Risk of forest fire (Schenk 2005: 141) |

**Table 4**
Overview of the five intensity levels and their quantitative descriptions.

| Intensity Level of Recreational Users | Quantitative Description |
|---|---|
| Very low | No recreational users |
| Low | One recreational user on the gravel bank and not in the water |
| Middle | Two or more recreational users on the gravel bank or in the water |
| High | One recreational user in the water and one or more recreational users on the gravel bank |
| Very High | More than two recreational users in the water and more than two recreational users on the gravel bank |

**Table 5**
Table of the four types of recreational users mapped and examples of associated activities/forms of activities.

| Designation of Mapped Element | Quantitative Description |
|---|---|
| Standing activities | Walking (with or without a dog), jogging, etc. |
| Riding activities | Riding non-motorized (e.g., bicycle) and motorized vehicles (e.g., E-scooter or Segway) |
| Passive activities | Resting, nature watching, sunbathing, camping, sitting, etc. |
| Water-based activities | being in or on the water (e.g., swimming or water sports) |

%) (Fig. 4). As a result, only a third of the floodplain remains for natural vegetation cover. Riparian forest and woody-free vegetation cover share an equal proportion of the remaining area.

Impacts of recreational users were highly visible for all transects. Within the transects organic and inorganic waste (N = 77) and vegetation breakage (N = 10) were observed. Few root damages (N = 6), trampling trails (N = 5), trodden down vegetation (N = 3) and other vegetation damages were recorded (Fig. 4). Very little users were counted within the transects (mean = 0.7).

### *3.2. Variations of the vegetation structure along a recreational intensity gradient*

Fig. 5 presents the proportion of cover type within the transects. The data have been summarized to display the mean proportion within areas with similar user intensity, in order to ease visual comparison. Each cumulative bar plot summarized the vegetation cover for a user intensity, namely very low, low, medium, high or very high. Floodplain zones, namely vegetation types, are displayed in the same order. Differences between the area with different user intensity were significant for the proportion of a) Vegetation-free gravel bars - This had the largest proportion in sites with medium recreation intensity. However, no significant differences were observed between the different user types. The second highest proportions were observed for very high recreational intensity; b) Pioneer vegetation - This had the largest proportion in sites with medium, followed by low and very low recreation intensity. No significant differences were observed between the different user types; c) calcareous grassland - This existed only for very low to low recreational user intensity; d) Man-made urban greening – This had a higher proportion in sites with very high recreational user intensity, and decreased with the intensity gradient. Interestingly, while 18.86 % of the floodplain studied was dedicated to recreational lawns, the proportion of cover within the transects is not correlated to the user intensity. This kind of vegetation is preferred for walking, sunbathing or cycling. It is also worth mentioning that neophyte proportion is not correlated to recreation intensity or user type. Finally, riparian forest is mostly used for cycling.

### *3.3. Linkage between vegetation damages and recreational use*

The quantity of organic and inorganic trash such as human and animal feces is correlated to the recreational use intensity and decreased with the recreational gradient. Furthermore, it is correlated to the use type lying, picknicking, and barbecuing.

No correlation between the recreational use intensity or the use type and the existence of trampled trails were found. They were almost everywhere (97 % of the transects) (Fig. 6). There was also no correlation between the recreational use intensity or the use type and the existence of entrance paths, removal and relocation of materials, single or multiple trampled plants, bonfires, bark injuries, breakage of plants, branches, steams, and roots. Interestingly, damage to root systems were correlated to the recreational use intensity, with a higher proportion of damage correlated to medium recreational use intensity (Fig. 6). An overview of the correlations is synthetized in Table 6.

## 4. Discussion

### *4.1. Preferences and impacts*

The study investigated the variations of the vegetation structure along a recreational intensity gradient and showed that the proportion of some vegetation types can be correlated with the recreational intensity. Particularly important results are that high proportions of vegetation free gravel bar and pioneer vegetation are found in medium recreational user density. Proportions decrease with the increase of recreational user intensity while favoring man-made vegetation such as in recreational lawns.

Gravel bars are produced by dynamic flood pulses and related sedimentation and erosion processes in this alpine river (Egger et al., 2019). Gravel bars are not caused by recreational uses or created by landscape designers. We can partly explain the correlation between the proportion of gravel bars and the user intensity by their attractiveness for recreational users. Gravel bars offer proper soil to sit on, higher temperatures, and direct access to water. This assumption should be verified using methods in social sciences, e.g. a survey of preferences for recreation. However, some of our results suggest that gravel bar localization only partially explain user distribution. For instance, in areas with very high recreational user density, gravel bar proportions are lower than in area with medium recreational user density. This indicates that other cover types attract more recreational users than gravel bars. Further geographical aspects, e.g., existence of bridges and public transportation, may also influence user distribution. However, while recreational uses did not induce gravel existence, they increase their lifetime in an anthropogenic system by decreasing vegetation development on it. Human-induced river hydro-morphological changes reduced hydrologic dynamics and consequently decreased the frequency, the intensity and duration of natural perturbations. This induces rapid vegetation growth within the floodplain and causes loss of near-natural alpine river landscape elements such as large gravel bars (Guzelj et al., 2020; Ochs et al., 2019). Consistent foot-traffic limits vegetation growth keeping the gravel bar free of vegetation.

This statement is confirmed by the observations on the proportions of pioneer vegetation along the recreational user gradient. Pioneer

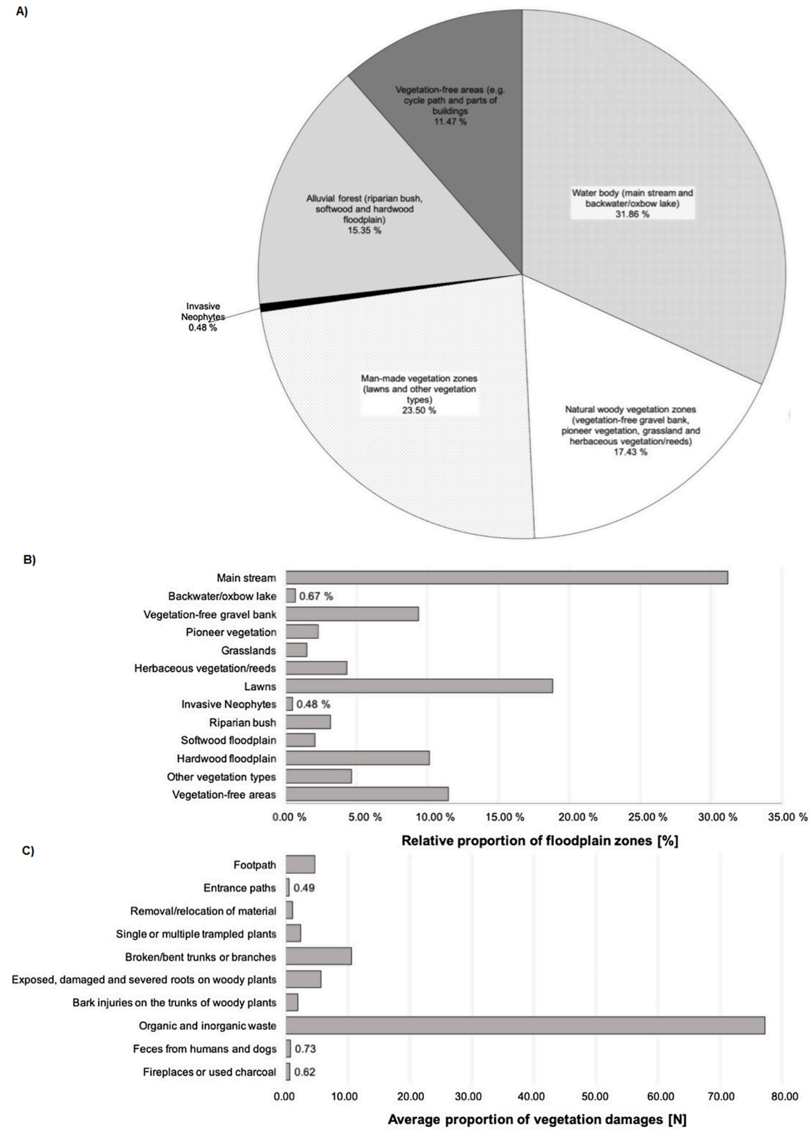


**Fig. 4.** Overall results namely A) Relative proportion of summarized floodplain zones for all sections, B) Relative proportion of all types of floodplain zones, and C) Relative proportion of damages.

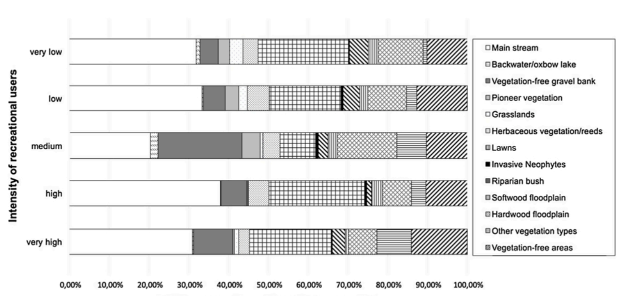


**Fig. 5.** Relative proportion of summarized floodplain zones for all five categories of intensity of recreational users.

vegetation exist usually between gravel bars and herbaceous vegetation (Ellenberg and Leuschner, 2010) indicating that it is expected that the correlation between gravel bars and pioneer vegetation with recreational user intensity follows the same trend. However, while this is true for medium user intensity, this is not the case for other user intensities. Studies have shown that disturbances due to recreation caused a decline of geophytes and an increase of species with high reproduction capacities (Vakhlamova et al., 2016). Because of its high reproduction rate and high tolerance to physical perturbation, pioneer vegetation has been characterized as being highly tolerant to recreational pressures (Seibert, 1962; Zingraff-Hamed et al., 2017a). In our study, pioneer vegetation proportion did not increase with recreation intensity. Rather, pioneer vegetation benefited from lower user density and disappeared with high to very high user intensity. This observation is consistent with botanical studies in the same case study site on specific pioneer species (e.g, Zingraff-Hamed et al., 2017a). The result of our study suggests that between the high end of the medium recreational user intensity category and the low end of the high recreational user intensity category, namely around one user per 10 river-meters, there exists a tipping point for pioneer vegetation. This result is crucial in order to elaborate on a user management plan. However, this result may be strongly depend of the species composition. However, it is a good insight guiding site-specific investigations.

It is worth noting that the vegetation cover type characterized by "urban greening" elements is positively correlated to recreational user density. Higher proportions of this vegetation type are correlated with a very high recreational user density. This is described by publications

**Fig. 6.** Picture of the vegetation damages observed. Left: trampling trails. Right: root breakage. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

which show that urbanities prefer landscapes that are designed with urban greening for urban recreational proposes rather than natural landscapes (Vakhlamova et al., 2016; Qiu et al., 2013). In the case of urban rivers, urbanities preferred a balance between natural vegetation and urban greening (Hu et al., 2019). However, the existence of recreational lawns are not significantly correlated to recreational user density and do not attract particularly high recreational user densities in comparison with other vegetation types. Moreover, recreational lawns are greatly impacted by users evidenced by the fact that these lawns experience much foot-traffic. This can be explained by the type of activities found in this vegetation type. This is correlated with activities with foot-traffic (e.g. walking) and not with passive activities. This result indicates that the existence of recreational lawns will not significantly influence user distribution but rather increase trails and vegetation maintenance cost.

Finally, the proportion of transect covered by neophytes is very low and is not correlated with recreational user density. This is in contradiction with other studies focusing on non-riparian vegetation. For example, Vakhlamova et al. (2016) found that the proportion of alien plant species is larger in urban forests than in suburban forests. They identified recreational disturbances as a driver of alien species colonization. In our study, few transects present abnormally higher proportions of neophytes (6.4 %). They are all located downstream of dams. These results suggest that neophyte development in riparian areas is driven by hydro-morphological degradation rather than by pressure due to recreation.

### 4.2. Direct and indirect damages

Our study also investigated the vandalism and vegetation damages along the recreational intensity gradient and showed that damages such as damages from foot-traffic or branches, stems and roots breakages are not correlated with recreational intensity but with some type of activities. Furthermore, it was expected but also worrying that trash and excrement are the major damages caused by recreational users.

Trails caused by foot-traffic exist throughout the whole area without significant variation between the user density and the type of use. It is worth noting that these trails are parallel to the river course and located mostly within the recreational lawns. Studies showed that muddy trail sections and informal trails were perceived as reducing the quality of users' walking experience (Verlič et al., 2015). In some extreme cases, 5–15 of such trails are parallel and only separated by 20 cm–100 cm of grass. Muddy trail sections and parallel informal trails are overly perceived as negatively impacting the recreational quality of urban green spaces (Verlič et al., 2015). This has been described in parks as being caused by major rain events turning the related trails into a muddy trail with puddles (Opaschowski, 1991). These trails showed increased erosion during flood events cause by a lack of vegetation cover. Improved maintenance of the these trails could reduce the expansion of vegetation degradation (Ammer and Pröbstl, 1991).

Entry paths also exist throughout the whole area without significant variation with the user density. However, high to very high density areas are characterized by mineral-based river embankments. These can be natural, e.g., gravel bars, so as structural, e.g., stone blocks used as stairs. In our study area, we observed a similar user intensity (very high density) on both natural and structural mineral-based embankments. We supposed that this phenomenon applies particularly in Central European and North American rivers, namely where thermal comfort remain good even in sunlight exposition. However, the soil type did not inform about the shadow degree. Moreover, it should be mentioned, that the water body provides a significant cooling effect and that user preferences may be influenced by other parameters as for example the dirtying and soiling potential of the embankment. In areas with medium user density, the high proportion of gravel bars also displayed this characteristic. Interestingly, for the medium user density category, areas with riparian natural herbaceous vegetation and reeds showed high amounts of vegetation damage caused by foot-traffic. This indicates that the higher the recreational use density is, the higher the amounts of damages to natural vegetation are. Reeds as riparian forests have been identified as being very sensitive to trampling (Seibert, 1974). Identification of user hotspots along with information about the sensitive vegetation types should help with designing resilient entry paths to decrease damages.

Despite damage to the vegetation being a common phenomenon, there is limited knowledge regarding the extent of intentional causes of damage and the reasons for it. In the case of the Isar in Munich, few vegetation damages can be linked to use type. However, this observation provides crucial insights to discuss management measures and especially prevention. Breakage of branches and roots is correlated to the existence of bonfires. This has already been documented by Nohl (1998). Tree bark damages we observed are correlated to observed biking activities and can be explained by the use of trees to support bikes during a break from riding. This is confirmed by the fact that tree bark damages appear almost exclusively along concrete paths. Protective structures have a limited effect on vandalism and damages to trees (Richardson and Shackleton, 2014). In order to decide on the relevance of implementing management tools such as prohibition of access, physical vegetation protection (e.g., cages) or signs with information, the effect of both branch and root damage and bark injuries on the health of the plant should be further investigated. Previous studies already suggest that riparian forests are particularly resistant to physical damages (Seibert, 1971) but systematic documentation is still missing.

While intensity of direct damages on the vegetation (trampling, breakage, injuries) are weakly correlated with the user density, intensity of indirect damages such as litter and excrement increases with the user density. They are especially correlated to the number of passive users (barbecue, sunbathing, picknicks, etc.). Niebuhr (2017) identified fishermen as the major source of trash in Germany at recreational water bodies and other studies have identified biking and walking activities as major contributors (Olschowy, 1990; Wu et al., 2020; Andrés-Abellán et al., 2005; Huhta and Sulkava, 2014; Sarah and Zhevelev, 2007).

**Table 6**
Overview of test results from all statistical analyses. (For interpretation of the references to colour in this Table legend, the reader is referred to the web version of this article).

| Floodplain Zoning of Mapped Areas | Intensity of Recreational Users | Forms of Recreational Use | | |
|---|---|---|---|---|
| | | Standing Activities | Passive Activities | Riding Activities |
| Vegetation-free gravel bank | | | | |
| Pioneer vegetation | | | | |
| Grasslands | | | | |
| Herbaceous vegetation/reeds | | | | |
| Recreational lawns | | | | |
| Invasive Neophytes | | | | |
| Riparian bush | | | | |
| Softwood floodplain | | | | |
| Hardwood floodplain | | | | |
| Other vegetation types | | | | |

| Damages/Degradations of Mapped Areas | Intensity of Recreational Users | Forms of Recreational Use | | |
|---|---|---|---|---|
| | | Standing Activities | Passive Activities | Riding Activities |
| Damage due to foot-traffic | | | | |
| Entrance paths | | | | |
| Removal/relocation of material | | | | |
| Trampled plants | | | | |
| Broken branches | | | | |
| Root damage | | | | |
| Bark damage | | | | |
| Organic or inorganic waste | | | | |
| Feces | | | | |
| Bonfires/used charcoal | | | | |

Statistically significant ($p \leq 0.05$).

Statistically insignificant ($p > 0.05$).

However, these studies were based on rural sites and mostly Nature Parks and cannot be extrapolated to an urban context, because recreational use significantly differs between these sites (Vakhlamova et al., 2016). While litter and dog excrements are mostly distributed in gravel bars and grass, human excrements are located in bushes and forests. This distribution can be explained by the fact that human look for hidden locations to defecate, while dogs stay close to their owners during daily walkies. Both excrements led to an increase of nitrophile vegetation such as *Urtica dioica* and could be avoided by providing sanitary facilities. However, they should be located above the flood line. Litter reduction could be facilitated by frequent collection and emptying of garbage cans. However, these measures are very expensive, and the city of Munich has already invested 40 million Euro each year to clean the city, which includes 120,000 Euro to clean-up the 15 km of urban riparian areas per weekend during peak times. According to local press, a private company in charge of litter collection at the Flaucher (a one-kilometer-long river stretch with extremely high recreational user density) declared a collection of 15 $m^3$ of litter in one day. Information and rising environmental education could increase the awareness for these issues.

In Munich, visitors to the riparian areas of the Isar frequently light bonfires at gravel bars for barbecuing. Streams have already been found to be preferred sites for this activity (Hegetschweiler et al., 2007). However, the whole Isar embankment in Munich has been a landscape protection area since 1964, and fires in non-authorized areas result in a lump-sum fine of 35 Euro. Interestingly, damages caused by fires are located outside of the authorized areas. Studies on bonfire preferences indicate that visitors frequently build fires for barbecuing outside of dedicated picnic sites and suggest two possible reasons for this behavior (Hegetschweiler et al., 2007). First, the existing picnic sites may not be attractive enough for visitors. Second, the number of sites for barbecuing may not be sufficient for the high visitor demand during peak days. Studies showed that recreational users in urban green spaces are younger than in suburban areas or forests (Vakhlamova et al., 2016) and there are also differences in the type of use (Lupp et al., 2016). In urban areas users prefer walking, sports, sitting and talking, and playing with children (Vakhlamova et al., 2016). Unfortunately, younger recreational users or groups leading certain lifestyles have a lower affinity towards the environment (Markevych et al., 2017; Lupp and Konold, 2008). These groups are more likely to litter and to violate environmental legislation (Wu et al., 2020). Accordingly, prohibitions and fines for damaging behavior was not worth regulating until now. In this context, the authorities should strengthen environmental protection campaigns and environmental education targeted at the different groups, e.g. younger recreational users.

### 4.3. Methodological limitations

The method we used did not allow studying the causality of the correlation between vegetation type and user intensity and use type. Further studies should combine methodological approaches and especially integrate methods of the social sciences to explain user preferences and recreational behavior. For example, the combination of botanical monitoring, user mapping and user surveys could deliver in-depth knowledge on the linkage between user distribution, density, and vegetation existence and damage (Clivaz et al., 2013). This would be crucial to establish recreational management plans rather than prohibition measures and education programs which have limited results and cause a lack of awareness in civil society for restoration efforts (Sterl et al., 2008). Moreover, support and acceptance from the citizens is crucial to leverage funding (Zingraff-Hamed et al., 2019; Lupp et al., 2021).

It was out of the scope of this study to identify the species that were more sensitive or resistant to recreational pressures. However, for applied research focusing on a single case, it would be very interesting for the planning of restoration measures to identify target species ahead of time that have high recovery potential and high resilience to user pressure to increase the chances of restoration success. Few local research already suggest that user distribution models, habitat suitability models including knowledge on species sensitivity would be crucial to strategically plan restoration measures (Zingraff-Hamed et al., 2017a).

## 5. Conclusion

The potential conflict between nature conservation or restoration and recreational use is of major concern in urban areas, and especially when huge investments and efforts are taken to restore habitats. Balancing between a high standard of ecological quality and offering recreation opportunities is crucial for urban river restoration on the one hands side to achieve environmental policy targets and on the other hands side to leverage willingness to pay for ecological recovery. In this context, this study investigated the impacts of different recreational intensities and use types on the vegetation structure and vegetation quality by documenting direct (trampling, breaking of branches, stems and roots) and indirect damages (litter and excrements). The results provided insight for the development of strategies to reduce conflicts. First, prior to planned restoration projects, identification or estimation of user hotspots would better support the development of a more resilient restoration design. This can be done by managing user distribution, e.g. creating attractive places for intense use where habitats are less sensitive, and adapting the design itself, e.g. enable access to water without the need of trampling sensitive vegetation. Second, in the short to medium term, user management plans could prevent reaching tipping points for sensitive vegetation structures. Finally, environmental education can lead to more nature-friendly recreational uses in the long-term. In particular, younger recreational users should be targeted by environmental protection campaigns. Inclusion of citizens in the planning should also increase awareness and leverage environment-friendly behavior. Further research should integrate methods including analyses of visitor flows and behavior analyses of recreational users.

## Author statement

The work did not involves the use of animal or human subjects. The authors ensure that the work described has been carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans; EU Directive 2010/63/EU for animal experiments; Uniform Requirements for manuscripts submitted to Biomedical journals. Authors inform that user intensity was obtained observing anonymous users during their freely performed activities in public spaces – no photos or human identity have been recorded. The privacy rights of human subjects have been observed.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interest.


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