Sensing River and Floodplain Biodiversity – Developing a Prototype

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Abstract: Freshwaters, such as rivers and floodplains, are among the world's most diverse ecosystems, but they are losing biodiversity faster than any other ecosystem, mainly due to human activities. A major problem is the low awareness of biodiversity loss. Triggering emotions and amazement may increase people's biodiversity perception in a more holistic way. Therefore, with an immersive audio-visual VR-simulation prototype based on 3D point clouds and sound recordings above and below water developed in the Unity game engine, we want to allow for sensing river biodiversity. Feedback from a user study demonstrates that the prototype can promote laypersons' awareness of biodiversity loss and provides insights for its further enhancement.

Keywords: Virtual reality (VR), 3D point clouds, immersive audio-visual simulation, river and floodplain restoration, river and floodplain biodiversity, awareness raising

1 Introduction

The functioning of the biosphere is recognized as an important prerequisite for nature's contributions to people and in turn human well-being, making it a core aspect of the 2030 Agenda for Sustainable Development's 17 goals (UNITED NATIONS 2015, IPBES 2019, PHAM-TRUFFERT et al. 2020). Particularly the biodiversity-focused Sustainable Development Goals (SDGs) 14 "Life Below Water" and 15 "Life on Land" have been identified as valuable systemic multipliers of positive influences across all goals (PHAM-TRUFFERT et al. 2020, OBRECHT et al. 2021). However, biodiversity, defined as the diversity within and between species, habitats, and of ecosystems, is declining globally at an unprecedented rate (IPBES 2019). Primary causes are human population growth, accompanied by increasing demand for energy and material goods, and human activities such as dam construction, water abstraction, agriculture, and urbanization (IPBES 2019). Lack of awareness among the public and other stakeholders is considered to be a critical aspect of poor implementation of measures to address biodiversity loss (DARWALL et al. 2018). Hence, the Convention on Biological Diversity (CBD 2021) and IPBES (2022) call on science and educational organizations to promote awareness raising. In this paper, we explore the quality of an audio-visual simulation of a river floodplain in a user study for raising people's awareness of biodiversity loss.

2 Awareness Raising of Biodiversity Loss in Rivers / Floodplains

Freshwaters such as rivers and floodplains are among the most diverse ecosystems worldwide but are facing a decrease in biodiversity faster than any other ecosystem, mainly due to human activities such as drainage, agricultural or industrial water pollution, or construction of dams

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(TOCKNER & STANFORD 2002, DESJONQUÈRES et al. 2019). The recent Living Planet Index (WWF 2022) reports an average global decline of freshwater species populations of 83 % in the last 50 years, compared to a global average decline in all monitored species populations of 69 %. Therefore, there are not only increasing efforts to measure the losses (LINKE et al. 2018, DESJONQUÈRES et al. 2019), but also to raise awareness of this problem among non-specialists and the larger public (DARWALL et al. 2018, MONACCHI & KRAUSE 2017).

A major challenge of awareness building of biodiversity loss in general and of freshwater habitats in particular, is that many people do not directly perceive it (DARWALL et al. 2018). In turn, they are less emotionally involved and less motivated to take actions against the loss (GEHLBACH et al. 2022), an effect that is well recognized in landscape perception research (KING et al. 2017). In this context, rather than acquiring knowledge and understanding of biodiversity, it seems that the triggering of emotional, intuitive links between people and species has a greater impact on the value people place on biodiversity (KING et al. 2017). For example, sensory stimuli such as photos and people's amazement may increase engagement with the environment and a perception of biodiversity in a more holistic way as an interconnected part of nature rather than as a separate aspect (KING et al. 2017).

GEHLBACH et al. (2022) show how photos depicting the costs of biodiversity loss can enhance the recognition of the problem by fostering the viewers' valuing of biodiversity and evoke positive motivational behaviour to make greater donations to biodiversity-supporting charities. In that study, the implemented photos were chosen to trigger negative emotions. As such photos might also cause a sense of helplessness of the viewer preventing further actions, the researchers recommend investigating effects of stimuli that foster positive emotions on the motivational behaviour to help enhance biodiversity. Furthermore, LINDQUIST et al. (2020) demonstrate that multisensory simulations providing not only depictions of a landscape with a lot of varied vegetation, but also realistic auralizations of the environmental sound enhanced the perceived biodiversity experience leading to higher biodiversity ratings. Congruent audio-visual stimuli increased the perceived realism of as well as the preference for the depicted landscapes and even more, when these were shown in a head mounted display (LINDQUIST et al. 2020). As such immersive audio-visual stimuli have high potential to evoke feelings of connection with nature, to foster people's biodiversity perception in a depicted landscape, and might help raising support for actions against biodiversity loss (KING et al. 2017, DERINGER & HANLEY 2021), their targeted use needs further investigation.

Concerning sound, audio recordings are a valuable source for gathering ecological information and for ecoacoustic monitoring because environmental sounds not only reflect the behaviour of animals but also the structure and functioning of their habitats (LINKE et al. 2018, DESJONQUÈRES et al. 2019, STOWELL & SUEUR 2020, PARSONS et al. 2022). Recent efforts aim to increase the use of ecoacoustics as a tool for river and floodplain restoration and management (STOWELL & SUEUR 2020, PARSONS et al. 2022). This includes also communicating to researchers from other disciplines and to the broader public what happens to the natural soundscape, and what this means regarding biodiversity (MONACCHI & KRAUSE 2017). Audio-visual combinations of the spectrogram and the audio records are frequently used to provide expert users with good understanding of a sound (PARSONS et al. 2022). However, an immersive audio-visual simulation of the soundscape in combination with associated visual elements is regarded more supportive for laypeople due to a direct and intuitive experience (MONACCHI & KRAUSE 2017).

3 Method

Our objective was to provide people a sensual experience of a section of the Sarine river floodplain (Canton of Fribourg, Western Switzerland) through an immersive audio-visual VR simulation that users can freely explore (Fig. 1).

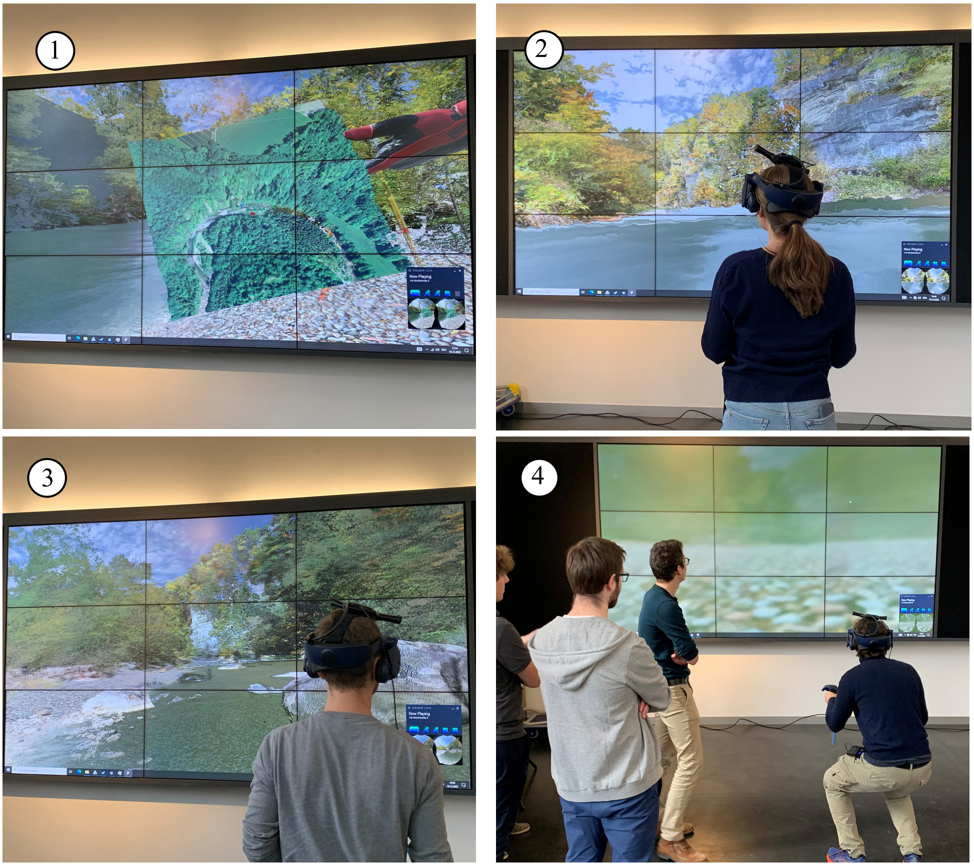

Fig. 1: Different perspectives in the virtual environment: (1) Minimap, (2) location downstream, (3) location upstream, (4) underwater

Despite the impacts of hydropower production with residual flow management, the assessed stretch of the Sarine floodplain represents a complex, dynamic mosaic of contrasting aquatic-terrestrial habitats (i. e., floodplain forest, islands, gravel, large wood accumulations and various channels and ponds). Occasional artificial flooding from the upstream dam maintains habitat connectivity and dynamics. This coupling of aquatic-terrestrial habitats still promotes and maintains high biodiversity (see TONOLLA et al. 2020 and DOERING et al. 2021 for a detailed description of the Sarine). For this reason, the Sarine floodplain is listed as a floodplain of national importance that is even slightly affected (FOEN 2020). In the following, the development of the audio-visual simulation focussed on the representation of the aquatic-terrestrial habitat diversity in general and how its quality was tested in a user study.

3.1 Audio-Visual Simulation

An audio-visual simulation prototype was created in the Unity game engine version 2022.1.0.f1 (www.unity.com) for presentation with the HTC Vive Pro Eye equipped with a wireless adapter (www.vive.com). LiDAR data from terrestrial laser scanning in the floodplain with a RIEGL VZ-1000 was used for realistic above ground visualization. This point cloud data was combined with a digital surface model (DSM) mesh acquired with a WingtraOne drone (www.wingtra.com). The water area was animated using the Unity plugin River Auto Material 2019 package (NATUREMANUFACTURE 2022) and the MS UnderWater Effect asset (SCHULTZ 2020) made the underwater effects more realistic. A big challenge was the visualization of the massive point clouds (> 330 mio points, 50 GB) with high density for realistic representation of the environment. With the PotreeConverter the point cloud was transformed into an octree data structure (https://github.com/potree/potree). Further, a shader was applied that dynamically loads the point clouds in a hierarchical level of detail structure with frustum culling (FRAISS 2017). When loading the point cloud at game start, the algorithm first analyses the point cloud hierarchy and then continuously checks, which points need to be loaded. Thus, only the points that are actually visible as pixels on the screen are rendered. Sounds were recorded simultaneously above and below the water surface at different positions in the river using a Zoom F4 field recorder with a Sennheiser Ambeo VR microphone and two DolphinEar Pro hydrophones (https://dolphinear-global.com). The VR mic was mounted on top of a monopod. The hydrophones were attached to each end of a 20 cm long rod and hung over the top of the monopod about 60 cm below the VR mic (Fig. 2).

Fig. 2:
Setup of the sound recording above and below the water surface

The recordings were processed in the digital audio workstation REAPER (www.reaper.fm) and integrated into the Unity scene using the plug-in Steam Audio (https://valvesoftware.github.io/steam-audio/doc/unity). In addition, user interaction with the virtual environment was enabled through features such as walking on the ground, ducking to see underwater, or teleporting to another position, including the use of a minimap (see Fig. 1 (1)).

3.2 User Study

The aim of the user study was to get feedback on the quality of the prototype in terms of engaging people with the environment and increasing their awareness of biodiversity through experiencing environmental sounds above and below water. The main question was whether the VR simulation experience had an effect on how much participants were aware of and would support action against biodiversity loss. We also wanted to identify ways in which the prototype could be improved.

Procedure: After being informed about the overall procedure and giving their written consent, participants stated their current feelings of pleasure, arousal and control of the situation using the 9-point Self-Assessment Manikin scale (SAM, BRADLEY & LANG 1994) and answered questions on their personal characteristics. They were then given controllers and instructed on how to navigate the environment. Then, they put on the VR goggles. Participants saw the virtual floodplain environment and heard environmental sounds. They were asked to go to two locations marked on the minimap and perceive the environment above and below the water surface. They were asked to look for differences and think about which location might provide richer structures for insects, fish and plants on land and in the water. After 5 minutes of exploration, they proceeded with filling out a second questionnaire. They were again asked to rate their current emotions using the SAM as well as questions related to their perceptions during the VR experience. The entire process took about 20 minutes.

Questionnaire: Before perceiving the VR simulation, participants were asked to answer *(i) Personal questions* on a 5 item Likert-type scale (1: not at all, 2: a little, 3: moderately, 4: quite a bit, 5: very much) on how frequently they experience real rivers or other water landscapes, indicating the participants' familiarity with the presented environmental system (WILLIAMS et al. 2007). Further, using the same Likert-type scale, they stated how concerned they are about biodiversity loss in rivers, providing feedback on their level of awareness (DARWALL et al. 2018), and answered how much they would support actions against biodiversity loss (DERINGER & HANLEY 2021, GEHLBACH et al. 2022). To reveal if participants, e. g., due to their job or leisure activities have high familiarity with the perceived environment type, they were also asked whether they have a special relation to rivers or other water landscapes and if yes, why. Finally, participants were asked to provide *(ii) Sociodemographic information* (gender, age, education, occupation) and indicate with yes or no whether they work with VR technology professionally, often play computer games or frequently work with virtual landscapes, or if their daily occupation handles biodiversity.

After perceiving the VR simulation, participants were first asked again to state how concerned they are about the biodiversity loss in rivers and how much they would support actions against biodiversity loss in order to see whether a change occurred. Then, they were asked to indicate on the 5 item Likert-type scale (see above) their ratings for: *(iii) Landscape perception* ("How amazed did you feel exploring the perceived landscape?" (KING et al. 2017), "How much did you like this perceived landscape" (GEHLBACH et al. 2022), "How realistic was your experience of the perceived landscape?", "How vivid did you find the perceived landscape?", "How realistic did you find the perceived environmental sound?", "How congruent did you find the visual and aural landscape experience?" (LINDQUIST et al. 2020), "How much did you feel emotionally connected with the perceived landscape?" (DERINGER & HANLEY 2021), "How much did you like location 1 [resp. 2]" (GEHLBACH et al. 2022)).

This was followed by questions on *(iv) Experienced biodiversity* ("How rich in species / wild / natural in character / varied do you rate the experienced landscape?" (LINDQUIST et al. 2020, GYLLIN & GRAHN 2005), "How much did you experience differences between the two locations concerning perceived species richness, wilderness, naturalness and variedness?"). The rating was performed again with the same 5 item Likert-type scale. For analysis, an index of the perceived biodiversity was calculated by averaging the participants' ratings for the first four questions (cv. LINDQUIST et al. 2020).

Then, participants answered questions related to their *(v) Immersion* ("I had troubles with VR (cyber sickness) before." (yes/no), "Perceiving the VR environment,… I felt nauseated / dizzy / had a dry mouth / had problems coordinating / was fully involved with the environment / felt distracted from daily problems / felt sad / happy / stimulated / was bored / felt stressed / was surprised / felt in control of the situation / was captivated by the simulation" (1: strongly disagree, 2: disagree, 3: neither agree nor disagree, 4: agree, 5: strongly agree). Based on these questions, two indices were calculated. For the "immersion" index the participants' average ratings of the questions asking if they felt involved / distracted from daily problems / happy / stimulated / in control of the situation; were surprised / captivated by the simulation (the higher the value, the higher the immersion). The "no-immersion" index takes the average ratings for the questions if they felt nauseated / dizzy / sad / stressed; had a dry mouth / problems coordinating; were bored (the higher the value, the less the immersion).

Concerning *(vi) Navigation*, participants who used the teleportation, the minimap, and / or the ducking feature, were asked to rate using a Likert-type scale (1: not at all, 2: a little, 3: moderately, 4: quite a bit, 5: very much) how comfortable they perceived the respective feature for navigating through the environment, and how much it broke their immersion in the VR environment.

(vii) Perception of landscape elements and of environmental sound was retrieved using bipolar adjective ratings on a 5-point scale from "very" to "neutral" to "very" of the opposite adjective, as they can help adjusting specific characteristics of the VR environment (MANYOKY et al. 2016): Scenery lighting (dark/bright); atmosphere (un-/pleasant); entire scenery's as well as tree/water animation (static/dynamic); entire scenery's as well as tree/water/ground colouring (in-/coherent); tree/water/ground realism (un-/realistic); environmental sound (in-/accurate; from one direction/spatially surrounding; change in sound when dipping head below water surface (in-/accurate; dull/clear). In an open question format, participants could also respond to what disturbed them, and what they expected and missed to hear in this floodplain. Finally, they could comment on the study.

Statistical analysis: The data was statistically analysed using the software IBM SPSS Statistics, version 28.0.1.1 (14). First, two groups were generated based on the statement whether the users were professionally involved in biodiversity. Descriptive analyses, and due to non-normal data distribution, non-parametric tests were then used to assess the change in concern about biodiversity loss as well as the change of the level of support of actions against biodiversity loss. Further, the users' emotions, experienced biodiversity, landscape perception, and immersion were analysed.

4 Results of the User Study

In total 33 people (11 women, 22 men, aged between 18 – 64 years, 53% 25 – 34 years; 26 % 35 – 44 years) participated in the study. All but two participants had an academic background (12% BSc, 53 % MSc, 3% MAS, 26% PhD). Most of the participants stated that they experience real rivers or other water landscapes with a moderate frequency (*Mean* = *M* = 3.39, *SD* = 1.09, *n* = 33). 21 % of the participants indicated that they work with VR technology professionally, 39 % had experience with virtual landscapes. Half of the participants were professionally involved in biodiversity and will be referred to as "experts", while the remaining participants will be referred to as "laypersons" (i. e., other academics or students).

Concernment about biodiversity loss: Overall, participants' concernment about biodiversity loss in rivers and floodplains before the VR experience was quite high (*Median* = *Md* = 4, *SD* = 1.21), as was their rating of how much they would support actions to address biodiversity loss (*Md* = 4, *SD* = .87). A Mann-Whitney U test indicated that experts almost do not change their level of concern (*M* = -0.06, *SD* = .243, *n* = 17), while 44% of the laypersons indicated that their concern has increased (*M* = .38, *SD* = .155, *n* = 16), *U (n1=17, n2=16)* = 191.5, *z* = 2.568, *p* = .045. The effect size after COHEN (1992) is *r* = .45 and corresponds to a large effect according to GIGNAC & SZODORAI (2016). An asymptotic Wilcoxon test revealed that laypersons' concern ratings were significantly higher after the VR experience, *z* = -2.13, *p* < .033, *n* = 16 with *r* = .53 (large effect). A Mann-Whitney U test showed that the mean differences in the rated level of support for actions against biodiversity loss of experts and laypersons are not significantly different, *U (n1=17, n2=16)* = 168, *z* =.085, *p* = .26.

Emotions: The participants' happiness was generally quite high before the VR experience (*M* = 6.91, *SD* = 1.04, *n* = 33). After the VR experience it was significantly higher (*M* = 7.48, *SD* = 1.46, asymptotic Wilcoxon test: *z* = -2.64, *p* = .008, with *r* = .46 (large effect). The participants were quite amazed (*M* = 4.12, *SD* = .82) and they quite liked the perceived landscape (*M* = 4.06, *SD* = .90). They felt moderately connected with the perceived landscape (*M* = 3.64, *SD* = 1.03). The liking of the two locations, which should be compared, differs slightly (location 1: *M* = 3.55, *SD* = .94; location 2: *M* = 4.12, *SD* = .70). Experts and laypersons do not differ significantly in the scores of the emotional landscape perception ratings.

Biodiversity perception: Overall, the perceived biodiversity was rated to be little to moderate (*M* = 2.48, *Md* = 2.5, *SD* = .69). The participants perceived only little differences between the two locations (*M* = 1.48, *Md* = 2.0, *SD* = .83). 41 % of the participants perceived no differences at all.

Landscape perception: Overall, the participants rated the visual realism as moderate (*M* = 3.42, *Md* = 3, *SD* = .97), as was their rating regarding the perceived vividness of the landscape (*M* = 3.70, *Md* = 4, *SD* = .88). In contrast, they rated the environmental sound as quite a bit to very realistic (*M* = 4.36, *Md* = 5, *SD* = .74), and the perceived audio-visual congruency as quite high (*M* = 4.09, *Md* = 4, *SD* = .72). According to the mean bi-polar adjective ratings, the participants perceived the scene and the landscape elements overall not to be extreme concerning lightning, animation, and colouring. However, the scene was found a little and the trees very static. The latter were also found a little unrealistic. The bi-polar adjectives of the sound characteristics show mostly neutral ratings.

Immersion: Nearly all participants stated that they did not have troubles with VR (cyber sickness) before. The immersion index shows that the participants were moderately to quite a bit immersed (*M* = 3.62, *Md* = 3.57, *SD* = .46). According to the no-immersion index, the participants had only low general signs of distraction from immersion (*M* = 1.66, *Md* = 1.57, *SD* = .58). The participants rated the three different features similarly as moderately to quite a bit comfortable for navigation: teleportation (*M* = 3.91, *SD* = 1.01), minimap (*M* = 3.73, *SD* =.88), and ducking (*M* = 3.76, *SD* =.90). According to the mean responses, teleportation (*M* = 2.24, *SD* = .79) broke the immersion a bit more than the other two features. However, the breaking of immersion for all features was rated to be only a little, whereby the ducking broke it the least of all three (ducking: *M* = 1.88, *SD* = 1.05; minimap: *M* = 2.00, *SD* = 1.12).

Aspects for enhancement: The nature of the point clouds, which become less dense the closer one gets, disturbed several participants and according to their comments reduced their sense of immersion. In single feedbacks, the lack of detail in the trees and the underwater area was criticized. Further, artefacts such as the overlapping river and river bank as well as offsets between the mesh of the DSM and the point cloud layer were reported as distracting. Regarding environmental sound, the majority of the participants expected to hear water and birds. Some mentioned also wind or rustling leaves and fish as well as the floating debris. Further, they expected maybe frogs, nearby urban sounds and the own footsteps. Other aspects address sound characteristics that should be improved, e. g., that the sound of water could be more intense, and that the underwater sound was one-dimensional and did not change over time. Moreover, there was not much change in volume and sounds between above and below water or between the two locations being compared for differences.

5 Discussion and Conclusion

The results show that the prototype raised laypersons' awareness of biodiversity loss in floodplains, supporting the hypothesis that high fidelity audio-visual simulations that evoke positive emotions may enhance recognition of biodiversity loss (KING et al. 2017, LINDQUIST et al. 2020, GEHLBACH et al. 2022). This finding needs to be interpreted with caution, as the sample size of 33 is rather small and the "laypersons" in our study do not represent the general public. Further, the simulation quality could be improved, especially with regard to the point cloud rendering. It works very well for medium to long range details, but at close range the limited point resolution was perceived as disturbing. Point rendering techniques such as EWA splatting (ZWICKER et al. 2002) might be useful to overcome this problem.

The representation of the environmental sound above and below water in the prototype is a first attempt to integrate this aspect into the VR simulation. At least the audio-visual simulation was perceived as congruent. Further development is necessary to provide a scientifically based relationship between the sounds and the actual habitat quality. This may foster the much-needed better understanding of river and floodplain biodiversity among both the general public and experts (MONACCHI & KRAUSE 2017, DARWALL et al. 2018).

We see the application of further advanced immersive audio-visual VR simulations in particular in the extensive river restoration measures. In Switzerland, e. g., about a quarter of the 16000 km of degraded rivers and floodplains are planned to be restored by 2090, which requires intensive and diverse participatory processes. Audio-visual VR simulations will be an excellent participatory tool to visualize and assess the changes due to restoration measures.

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