(Re)shaping human-nature interactions through digital technologies

A literature review of the mediating role of digital technologies in human nature relations

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Reviewed by:
Herman Agricola (Researcher III)

Approved for publication:
Corine van As of team Regional development and Land Use

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The past two decades have shown an incredible development in the domain of (digital) technologies and communication, including in the conservation domain. In this small Knowledge Innovation Project within the KB programme 'nature inclusive transitions', we have explored and identified some of the key-topical questions that consider the role of digital technology in human-nature interactions. Although the amount of research on the link between humans, nature and technology seems to be growing quite fast, our review shows that many topics are still only tentatively explored. Future research could enhance our understanding if and how technology drives social and ecological changes. From such an increased understanding, explicitly try to influence the direction of these forces towards a transformative agenda. In this, a critical investigation into the potential mediating role of technology and how this relates to non-mediated interactions between humans and nature is key to our understanding of emerging socio-ecological-technical systems.

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Contents

Verification

Wageningen Environmental Research (WENR) values the quality of our end products greatly. A review of the reports on scientific quality by a reviewer is a standard part of our quality policy.

Approved reviewer who stated the appraisal,

position: Researcher III

name: Herman Agricola

date: 12-09-2022

Approved team leader responsible for the contents,

name: Corine van As

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1 Introduction

The past two decades have shown an incredible development in the domain of (digital) technologies and communication. The Information Age (Castells, 2010) has now also fully penetrated the field of nature conservation and management. In the last 10 years concepts such as 'Technological Nature' (Kahn et al, 2009), 'Nature 2.0' (Büscher 2014) or 'Digital Conservation' (Arts et al, 2015) have provided a basis for illustrating how technology (potentially) influences people's perception of and interaction with nature.

Although technology is increasingly being recognized as an important driver for how humans interact with their environment, there are still many blind spots in relation to how exactly digital technology is influencing the experience, management and conservation of nature. Some argue that the increasing 'digitalization' of our daily lives will eventually lead to virtual experiences that replace direct, non-mediated nature experiences. In 1990's 'travels in hyperreality', Umberto Eco described how people went to Disneyland in Florida to see mechanical alligators jumping out of the river to catch mechanical deer, when the Florida Everglades were just minutes away and there they could see the real thing – but were not guaranteed such an experience. Such an 'extinction of experience' (Miller, 2005) could structurally change the interaction between people and nature, with consequences for people's physical and mental wellbeing as well as for the future of nature conservation.

Others, on the contrary, argue that the rise of new (social) media and digital technologies might (potentially) attract many more people to nature. Digital technologies allow for new forms of governance on green spaces and offer new possibilities to inform people and engage them with nature through e.g. species identification apps. There are also people who emphasize that an increasing level of digitalization and the use of new technologies will lead to a 'transformation rather than a loss of experience' - which might also offer new possibilities for (re)connecting people with nature and for adjusting nature policies and management (Clayton, 2017).

Recent research has shown how social media can be very influential in shaping public opinions around nature, potentially contributing to actual changes in how it is being managed (Mattijssen et al., 2019). The so-called 'circle of representation', in which people experience, copy and reproduce each other's experience, is strengthened by the use of social media and can possibly lead to an increased influx, and eventually 'over-use' and overcrowding of popular natural areas such as for example the Posbank, the Veluwe or the Wadden Isles in the Netherlands where this phenomenon is already being observed.

Aim of the project
Whether the impact for people or for nature can be negative or positive, the fact is that at the moment there is still limited insight in and knowledge of exactly how digitalization and new technologies are currently shaping the human-nature relationship. This calls for a further exploration of this theme.

The goal of this small Knowledge Innovation Project within the KB programme 'nature inclusive transitions' has been to explore and identify key-topical questions that consider the role of digital technology in human-nature interactions in order to:
1. *identify strategic knowledge questions and gaps in this field*, that can.
2. *help to better position WUR in this field* and eventually.
3. *contribute to systemic solutions that enhance biodiversity and strengthen a nature-inclusive society*.

This goal is addressed based on a semi-systematic review of literature around the central research question:
What are current perspectives on the mediating role of (new) digital technology in human-nature relations?

2 Theoretical Background

Acknowledging the importance of technology for biodiversity conservation and human-nature interactions, Depietri and McPhearson (2017) have argued that the social-ecological systems approach should be broadened to a Social-Ecological ánd Technological systems (SETS) approach. In this SETS framework, technology is recognized as one of the key factors influencing the functioning of ecological systems, both through the biophysical and the social-behavioural domain (Figure 1).
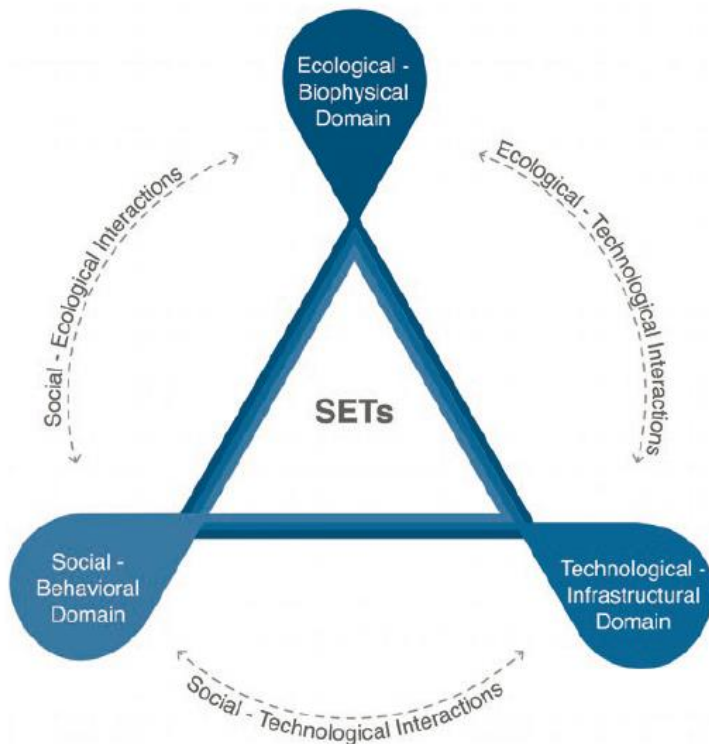
Figure 1   *Conceptualization of the social-ecological-technological (SETs) approach (Depietri and McPhearson, 2017).*

Following this same line of reasoning, Ahlborg et al. (2019) plea for a Socio-Technical-Ecological Systems approach (STES) that starts from *"symmetrical attention to technology, society and environment, specifically targeting interfaces and relationships that are thus far often overlooked"*. Ahlborg et al. (2019) describe society, technology and environment as co-constituted and co-emergent entities (or a nexus).

In spite of repeated calls for connecting the domains, the number of collaborations between scholars of social-ecological systems (SES) and sociotechnical systems (STS) is still limited. As Ahlborg et al. (2019) state, there is *'an unwillingness in the SES community to engage more profoundly with technology as a mediator of human-environment relationships ... due to, first, a lack of knowledge on how to go about integrating technology in conceptual and analytical frameworks, and second, a view of technology that is static and/or determinist. A similar lack of interest and knowledge is present also in the sociotechnical systems (STS) community when it comes to dynamic and complex social-environmental phenomena'.*

With this literature review we have tried to search for articles that, either explicitly or implicitly, pay attention to the **nexus of technology, society and environment**.

3 Methods

Semi-systematic literature review

As there are many different conceptualizations of the technology, society, environment nexus, at this point there is no clear overview of the field and topics of study, which makes it difficult to systematically search for literature through a fixed set of keywords (see also Wong et al. 2013 in relation to this). A semi-systematic study of literature was therefore conducted in order to explore the different bodies of literature, from across scientific disciplines, which focus on the technological mediation of human-nature relationships.

In contrast to a systematic review, a semi-systematic study does not aim to systematically cover all articles published on a certain topic or within a certain field of research (Snyder, 2019). Rather, it aims to identify and understand various relevant research traditions that have implications for the topic being studied, synthesizing these different traditions into meta-narratives in order to provide an understanding of complex and broad fields of study. Compared to systematic literature reviews, semi-systematic reviews are usually more exploratory and conceptually oriented – and usually also more qualitative in scope. For such purposes, a strict and structured approach can even hinder a more creative, cross-cutting, conceptual and integral contribution to the field of study (Snyder, 2019).

Collection of data

For the purpose of this semi-systematic review, literature was collected by exploring many different topics and research domains via Scopus, as well as through contacting various colleagues and peers working on relevant / related topics. Based on this initial collection of literature, a 'snowball' method was applied for collecting additional information via references cited in the articles that were initially collected. At various stages of this analysis, additional search queries were formulated when new topics or insights came up.

Table 1   *Sources for the analysis.*

	Collected	Quick scan	In depth analysis
Total number of relevant sources	179		
Accessible sources		168	
Relevant for the research questions			76

Based on this method, 168 articles were collected and assessed (see Table 1), 11 extra articles or books were considered to be interesting but we did not have access to them. Of the 168 articles 92 were considered to be less relevant after a first assessment (a quick-scan of abstract and conclusions of the articles). We carried out a more in-depth analysis of the remaining 76 articles. Following the semi-systematic literature review method as well as the method for data collection, we do not want to claim that these 76 articles represent a complete or representative overview of the state of the art of literature on the technology, society, environment nexus. However, we do think that this large body of (mostly) topical literature provides us with a big enough sample to distil some of the strategic knowledge questions and gaps that we were aiming for with this exploration.

Besides a general, qualitative analysis of the articles we have tried to give some specific attention to the different kinds of (digital) technologies that are being discussed, the (potential) mediating effects of those technologies and different perspectives on the human-nature relations.

4 Findings

This chapter is divided into two parts. In the first part we will provide a quick overview of some general outcomes from the analysis of the 76 articles from our semi-systematic literature review. This provides an insight into the origins and main focus on the articles, the methods used, the kind of technologies discussed and the effects of digitalization that are discussed in the context of human-nature interactions. This section (4.1) is based on a categorization of all 76 articles and will present some numbers, graphs and clusters that give a first impression of the focus and diversity of articles that we reviewed.

In the second part, to follow our review, we present a more in-depth, qualitative reflection. This reflection concludes with an overview of the most prominent strategic knowledge questions and gaps that we have distilled from this review. This reflection and overview can also be considered as our 'road map' for future research and as our input for a strategic discussion and orientation within WUR to determine how and where WUR can position itself in this field.

4.1 Quantitative findings

Research fields
Almost half of the research methods that are being used in the articles are qualitative, whilst some 30% are quantitative. In some studies, combined research methods were used and for a few studies the methods used were not made explicit or could not be derived.
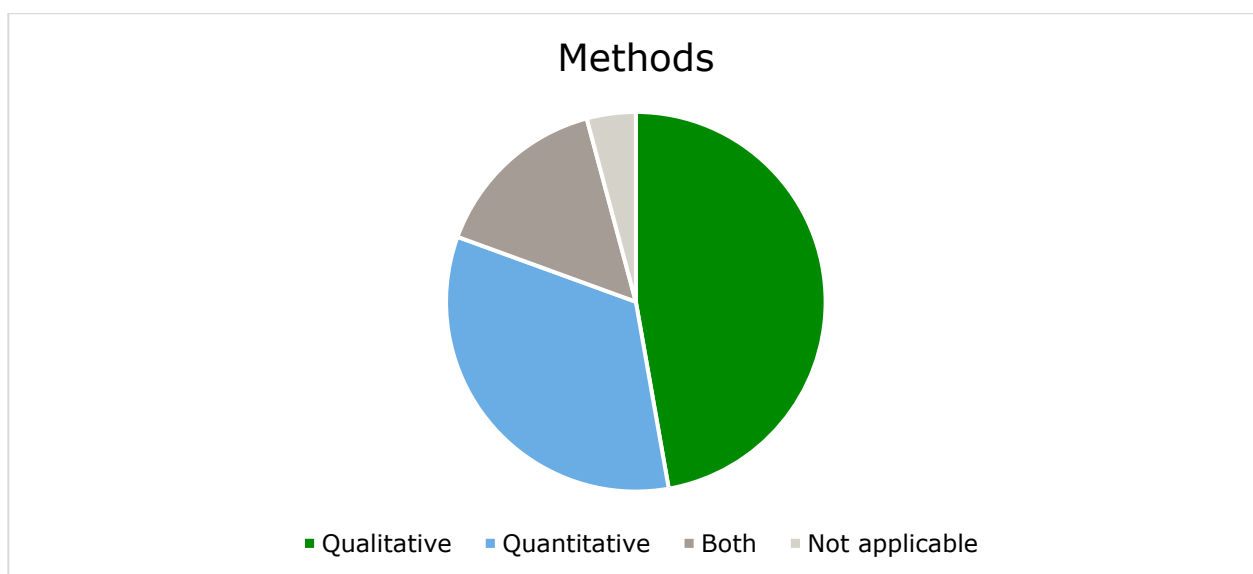
Figure 2   *Qualitative or quantitative methods used.*

Methods used
When examined in more detail it can be seen that there are a few methods that are used more commonly. Content analysis and big data (scraping) can at least partly be related to the use of social media (see technologies as well). There are also quite a few other studies where a review of literature is used to collect data. The number of articles which describe experimental research on the mediating role of digital technology is relatively limited (17).
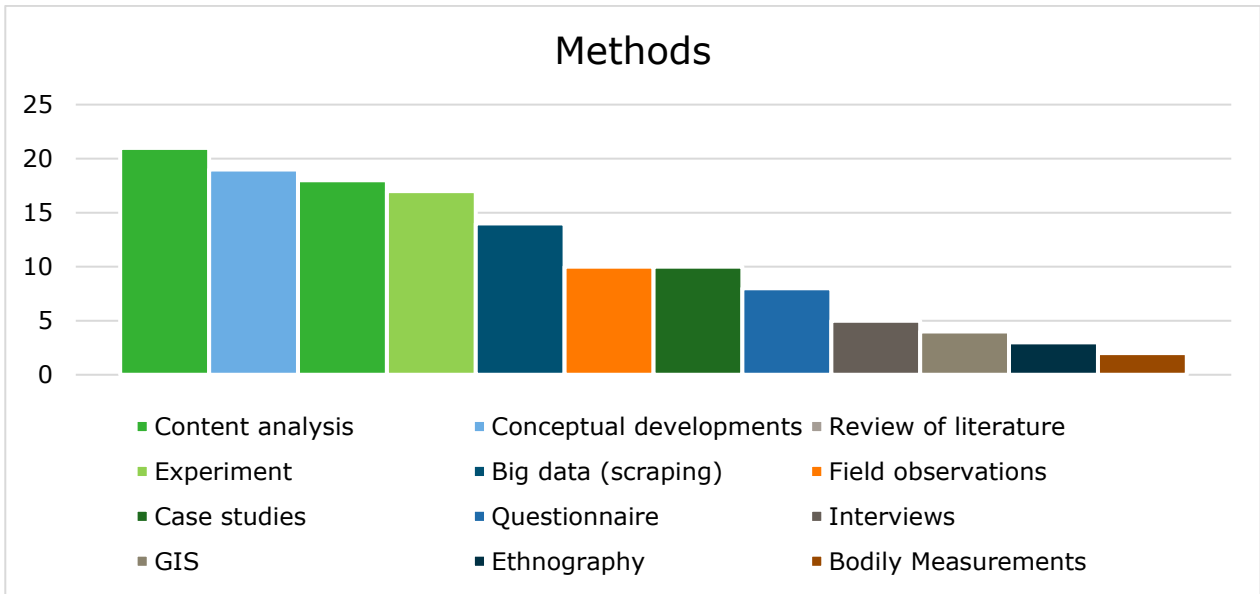
Figure 3   *Type of methods used.*

Kinds of technologies

We were able to identify a wide range of digital technologies that were referred to in relation to the mediating role of technology on human-nature relations. Social media is by far the most often discussed technology. As a much older 'technology', the use of photo & film still plays an important role with its (potential) use having greatly expanded since the introduction of digital photography and the prevalence of photo and film on social media. Overall, we could identify more than ten different forms of technologies that were described to (potentially) have a mediating role on human-nature relations.
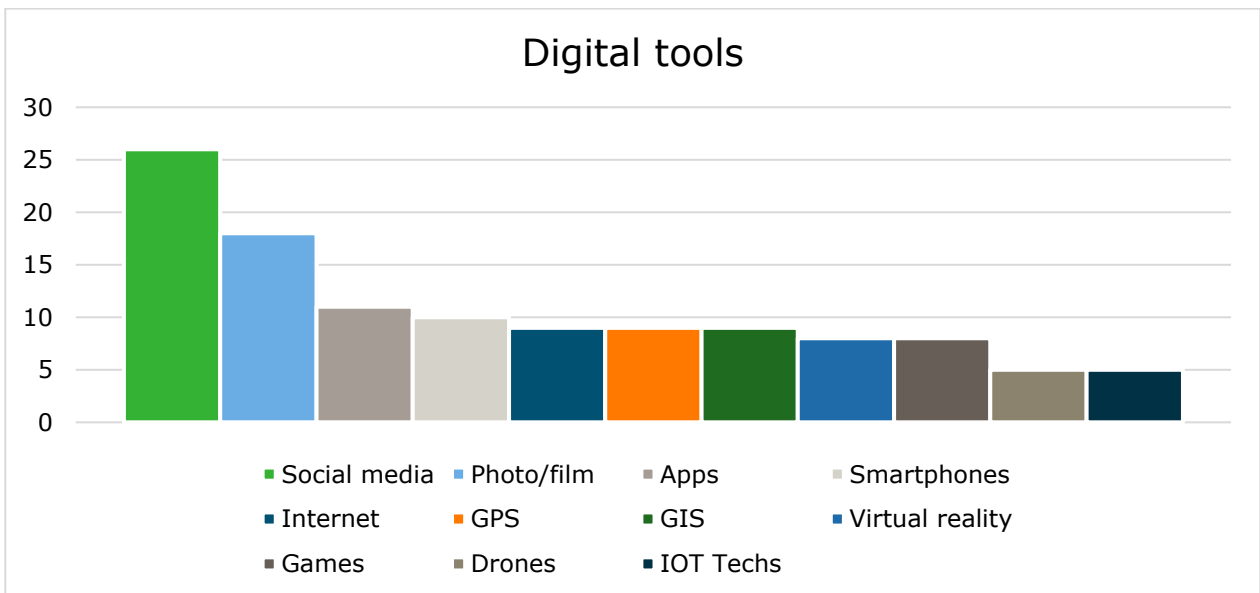
Figure 4   *Type of digital tools to which is referred.*

Kinds of effect

When we examined the kinds of effect that are discussed in relation to these different technologies we could also distinguish a wide range varying from: (increasing) environmental awareness, identifying people's perceptions (e.g. social media) to influencing people's behaviour (e.g. outdoor activities or environmental stewardship). It is important to state that Figure 5 shows the number of studies that focus on *describing* the possible effects of digital technology. Only part of those studies also explicitly contain *empirical research* on these effects and causal relations are not proven in most of these studies. It is also worthwhile to add that, while mostly positive effects are discussed, effects can also be seen as negative.

Categories of effects

- Environmental awareness
- Environmental connectedness
- Data analysis (incl. big data)
- Governance & decision making
- Health & wellbeing
- Group formation

- Perceptions
- Data collection
- Data sharing
- Public debates
- Willingness to act
- Recreation / outdoor activity
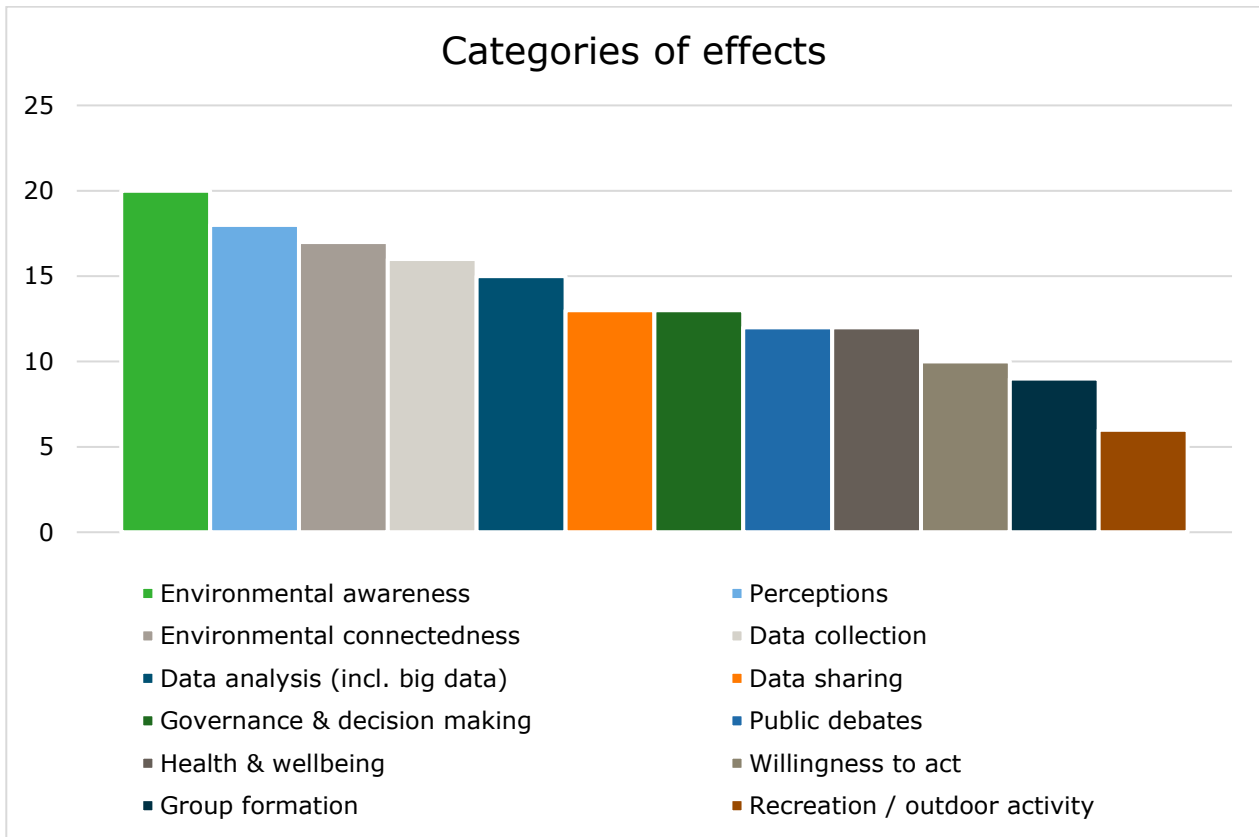
Figure 5   *Type of effects that are discussed.*

4.2   Research clusters

Based on a combination of quantitative and qualitative analysis of the 76 articles we have identified seven research clusters with articles focusing on a certain subject domain. These clusters should be seen as 'working' structure of our findings rather than a rigid division, as some articles could fit in multiple clusters. That being said, the seven clusters below are all distinguishable from the literature, as also shown through the references and anecdotes in the descriptions below:

1. Nature, technology and wellbeing
2. Social media and understanding of nature
3. Participatory governance and social activism
4. Reflective considerations of how digitalization influences the human-nature relationship
5. Digital technologies to (re)connect people with nature
6. Digitalization and new ways to monitor nature
7. Digitalization and new ways to monitor recreational behaviours in nature

4.2.1 Nature, technology and wellbeing

The first cluster consists of studies that specifically focus on human wellbeing and the mediating role of technology in the relationship between nature and human health and well-being (e.g. Annerstedt et al 2013; Hinder, 2016; Plante et al., 2006; Wesselius and van den Berg, 2014). These studies are quite often based on experimental research methods where the effects of (technology-mediated) nature experiences on human wellbeing are investigated.

The level of mediation and the way in which technology is used differs between studies. Several studies specifically focus on the creation of natural experiences through VR-technology (e.g. Plante et al., 2006; Hinder, 2016; Schutte, et al., 2017). The reported impact of virtual nature experience seems to be mixed. For example, a study on carrying out sports activities with VR-glasses shows that engaging in sport via virtual, natural surroundings does contribute to a feeling of relaxation compared to not doing so, but it also shows that engaging in actual outdoor sports has a stronger effect (Plante et al., 2006).

Research by Schutte et al (2017) shows stronger positive effects delivered by virtual reality experiences. VR-Images of the natural environment resulted in higher levels of positive affect and a greater perception of restorativeness. They conclude that "*virtual reality technology may have the potential to enhance well-being*". Another study shows that in indoor relaxation exercises, VR images of natural environments are more effective than VR images of an urban environment (Wesselius, and van den Berg, 2014).

This field of investigation is still in development and so far results seem far from definitive. Most of those studies are still explorative and not always very strong in their methodology. Several of these studies are framed as pilot-studies, are conducted among convenience samples, including friends and relatives, or have very limited numbers of respondents. In addition, few studies compare technology-mediated nature experiences with the effect of non-mediated nature experiences on health and well-being, the latter being a field of research that has been widely investigated. This first exploration suggests that a knowledge gap exists on the potential impact of mediated (virtual) nature experiences on human well-being and more specifically concerning the question of how mediated experiences compare to non-mediated experiences (and what this means for the potential use of technologies in this field)?

4.2.2 Social media and understanding of nature

There are quite a number of studies that specifically focus on social media as a modern means for coming to grips with people's understanding of nature and their construction of values (e.g. Breman et al, 2018; Calcagni et al. 2019; Mörner & Olausson, 2017; Oliver et al, 2018 and Roussel et al, 2019). Through the analysis of the debate on social media, these studies discuss how nature is digitally represented and co-produced and how this influences people's meaning of place and the way in which people relate to nature. Concerning the mediating effects, these studies highlight how social media influences people's perceptions of nature and how they function as a platform for public debates. Several studies (Calcagni et al, 2019; Morner & Olausson, 2019) describe how '*social media can be understood as new arenas for the co-construction of values on nature, where relational values stemming from social-ecological interactions are negotiated and defined*'.

Although social media analysis has quickly become quite popular as a means for gaining access to (part of the) public debate, more recently questions have risen about the use and meaning of these social media data. Partly, these questions relate to the representativeness of the debate on social media as many people are not, or no longer active on these platforms and the 'public voice' that is heard on these media deviates from the wider public opinion. Also the algorithms that 'steer' the debate are not transparent but it is known that the sentiment in online debates is often (far) more negative than real life sentiment. Such an effect was found, for example, in the study of the debate on the wild herbivores in the Oostvaardersplassen (Mattijssen et al. 2019). The online debate and the following offline protests, threats and intimidations strongly influenced policy decisions and management practices but the dominating opinions found on those media deviated from earlier research into nature experiences.

As with the first cluster, there also appears to be a knowledge gap here when it comes to understanding how online constructed values relate to non-mediated values and opinions and what the implications are for social-ecological interactions.

4.2.3 Participatory governance and social activism

Arts et al. had already suggested in 2015 that digital techniques may contribute to participatory governance and social activism in the field of nature management. There are also several studies within this review which discuss and illustrate how digital technologies offer opportunities for nature-related participation and social activism. Möller et al (2019) describe how technical advancement in internet communication technology (ICT) presents novel opportunities for engaging and leveraging civic knowledge and skills into different levels of green governance. Brunner (2017) describes how internet and social media are an effective way of bringing together people and organizing (environmental) protests, even in a country such as China where there is censorship.

Several of these studies refer to the potential of social media to mobilize people and/or start an environmental movement (Brunner, 2017; Mattijssen et al 2019, Zhang et al, 2018) but there are also other examples where for example satellite imagery of data or photography are used to monitor and prevent possible 'eco-criminality' (satellite activism) (Rothe et al, 2018) or citizens become journalists reporting on the effects of natural disasters (Norris et al, 2017). Methodologically, quite a lot of these studies are (partly) based on a review of literature or conceptual reasoning – and thus not so much on a study of concrete governance practices in the field. Even so, about half of these studies do employ a content analysis of documents or use a case study of a specific form of governance (or a specific app/platform).

It is widely recognized that the access to these digital means alters the playing field and has a potentially empowering effect when it comes to environmental governance. At the same time, however, it also raises some new questions about 'environmental justice in the age of big data' (Mah, 2017). In this respect, Mah (2017) mentions three challenges:
- '*voice*' (who has access to media / data and who not, and who is being heard?);
- '*expertise*' (who has the expertise to understand and analyze (big) data and to distinguish between trustful and non-trustable sources? And who decides what kind of expertise is taken into account?);
- '*speed*' (slow processes of change or 'slow environmental violence' is more easily missed or overlooked as opposed to more sudden or shocking environmental changes such as forest fires).

Möller et al (2019) also mention the challenge of the 'digital divide' and the importance of clear participatory frameworks when using digital tools for green governance. Increased understanding of the potential as well as possible pitfalls of digital green governance and social activism can be seen as one of the key questions / challenges in this field. In addition, it is necessary to reflect upon those topics and their implications for environmental justice. It can be expected that the impact of digitalization on social activism for nature conservation may not differ significantly to the impact outside this realm; inspiration may therefore be sought from political theory and research on digital activism.

4.2.4 Reflective considerations of how digitalization influences the human-nature relationship

The studies in this cluster are of a quite different type. They focus on mainly theoretical reflections on how digitalization influences the human-nature relationship, mostly from a sociological or philosophical perspective. This includes studies by Ahlborg et al. (2019); Gulsrud et al, (2018); Nabavi & Daniell, (2017); Fletcher (2017); Büscher (2016); Miller (2005); Levi & Kocher (1999) and Saker & Frith (2019). Many of these studies do not offer original empirical research, although about half of them combine their reflection with a (usually semi-systematic, integrative or loose) review of literature. Many of these papers argue or philosophize how digital technology is changing the human-nature relationship in our current society, providing various perspectives on these changes.

Some studies (Miller, 2005; Kahn et al, 2009) argue that the replacement of real nature experiences by virtual nature experiences will have a negative effect on human well-being and (commitment for) nature

management. Fletcher (2017) argues that there is a likelihood that digital developments will 'increase the widely documented environmental values-behaviour gap between professed commitment to environmental causes and effective action in support of such causes'. Ruginski et al (2019) describe how the use of GPS technology has a negative impact on environmental knowledge and one's ability to navigate which in turn is related to the environmental learning ability. Saker & Frith (2019) conceptualize how mobile virtual reality through the use of smartphones might lead to disengagement of one's surroundings or 'dislocated space' in which the digital supersedes the physical.

Other articles within this cluster are more conceptually focused and discuss how the changes in the human-nature relationship can or should be taken into account in theoretical approaches or conceptual frameworks to study human-nature interactions. Buscher (2016) for example argues that real (material) nature becomes so much intertwined with virtual (online) nature that it is hard to separate the two in practice and the (political) debate. Also some original conceptual frameworks are developed and suggested for scrutinising and understanding this changing relationship. Of these, the Socio-Ecological-Technological Systems approach (SETS, Depietri and McPhearson 2017) or Social Technological Ecological Systems (STES, Ahlborg et al, 2019) may be the most established ones at this moment, but more approaches and conceptualizations are being used and developed on an ongoing basis.

What the studies in this cluster have in common is that they are mostly theoretical or philosophical reflections, raise many questions about how the digital influences the human-nature relationship and make a strong plea for more (integrated) research in this field from a social, technological and ecological perspective.

4.2.5 Digital technologies to (re)connect people with nature

Besides the more reflective considerations of how digitalization could potentially influence the human-nature relationship, there have also been a number of studies that specifically focus on the potential which digital technologies offer for influencing the experience of nature and to (re)connect people with nature. While some of the studies in the above reflective cluster suggest that digitalization has a negative influence on people's connection with and understanding of nature, the studies in this cluster are more positive and highlight the positive, connecting role that digital technologies may play as an interface between people and nature.

Several of these studies focus on photo/film as an important digital tool for making this connection. However, there are also examples from nature-related games, nature-related apps that can transform people's nature-related behaviour and nature documentaries that can improve people's environmental sensitivity. While these studies are quite different in scope, several of them highlight a positive potential or positive effects of digital technology for (re)connecting people to nature. Dillahunt et al. (2017), for example, describe how so-called 'eco-feedback technologies' could lead to stronger engagement and emotional responses among children. Bade (2019), illustrated how a route App helped to create so-called 'hybrid nature experiences' with a positive influence on consciousness, embodiment, amusement and interest. Shrode (2012) describes how species identification apps can help people to identify species which they observe in the field.

Jepson and Ladle (2015) carried out an inventory of over 6000 nature-oriented Apps from Google Play Store. Although they stress the transformative potential of those apps, they also conclude that relatively few of those Apps already use the full technological potential for reconnecting people with nature and also that few of those apps have captured public attention. From a study amongst over 600 students, Barbas et al (2009) argue that watching nature documentaries can enhance environmental sensitivity. Arendt et al (2016) also studied the effect of watching nature documentaries and conclude that these can have a positive effect on donating behaviour, although this effect is stronger if students already felt connected to nature prior to the experiment. Chavez et al (2009) carried out an exploratory study to determine if kids are attracted to the outdoors by technology and concluded that these children displayed a lot of interest in the activities and the technology.

In summary, it can be said that the studies in this cluster see opportunities for digital technologies in bridging the gap between humans and nature and reconnecting the two. While some studies are cautious in the estimated extend of these effects, several articles highlight how digital technologies have contributed to (re)connecting people with nature.

4.2.6 Digitalization and new ways to monitor nature

Digitalization has a huge impact on the monitoring of nature. Examples are numerous, ranging from camera traps to geo-tagging and satellite imagery, often including Geographic Information Systems (GIS), Global Positioning Systems (GPS) or Internet of Things (IoT) technologies (Arts, 2015). Numerous studies describe and discus how such technologies provide novel ways for gaining insight about (the state of) nature. Digital tools can for example aid in showing where wildlife is foraging or where deforestation in taking place.

Most studies in this cluster describe or analyse the impacts of digitalization on collecting data related to nature and environment. Sachdeva et al. (2017) focus on user-generated social media content (on Twitter) as a predictor of pollution. Their research suggests that social media can be a useful tool for the measurement of air quality impacts of wildfire events, particularly in the absence of data from physical monitoring stations. Di Minin et al. (2015) argue that social media data can be used to learn more about spatio-temporal patterns, values, and activities related to biodiversity conservation. This offers opportunities for engaging people in citizen science, which is essential in order to identify both threats to biodiversity and opportunities for conservation.

Some of these articles link digital monitoring to political ecology. Markell et al. (2017) describe how increasingly sophisticated information technology "*has the potential to transform the capacities of government officials, regulated parties, and interested citizens in the environmental compliance sphere. They also have the potential to transform relationships between and among these actors, and the roles each performs*". Rothe et al. (2018) describe how satellite images can be used to 'sense the ground'. As these become more and more available to a wide range of actors they can also be used for 'satellite-activism', although the technological knowledge and financial means to correctly use and interpret these images can still be an obstacle for some stakeholders. Floreano et al. (2015) describe how the advent of a new era of robots – drones – could have a major impact on civilian tasks including transportation, communication, agriculture, disaster mitigation and environment preservation, although there are still some serious technical challenges such as the perceptual intelligence required to negotiate complex environments.

Considering the knowledge questions within this cluster, there seems to be little debate on the fact that a wide range new digital tools offers a huge potential to monitor all kinds of environmental developments. The most important challenge seems to lie in in the awareness of the potential (and pitfalls) and in guiding and steering the use and development of these technologies in such a way that both a wide range of stakeholders and nature itself can benefit from it.

4.2.7 Digitalization and new ways to monitor recreational behaviours in nature

As well as monitoring nature, digital techniques also contribute to the monitoring of people and their behaviour in nature. Although some studies in this field refer to (big) data from e.g. mobile telephone and GPS connections, most monitoring tools focus on social media as a digital tool – sometimes combined with GPS to collect geotagged data, to show for example which green spaces are visited by people, how people represent sense of place (online) or how user-generated data can be used to design attractive green spaces.

Jenkins et al (2016), for example, studied how online user-generated content offers insight in the shared meaning of place. "*By aggregating references to human activities within urban spaces we can observe the emergence of unique themes that characterize different locations, thus identifying places through their discernible sociocultural signatures*". Kullman (2019) also discusses how user generated data offers insight in patterns of interaction between humans and their (urban) environment. Shi et al. (2017) used the mainstream social media in China - Sina microblogging (small weblogs) data combined with night-time light remote sensing and various geographical data to reveal the pattern of human activities and light pollution of the Jiangxi Provincial National Nature Reserves.

Hamstead et al (2018) use geolocated Flickr and Twitter data to explore variation in green space use across New York City's 2143 diverse parks, based on spatially-explicit park characteristics and facilities. Guerrero et al (2016) used Instagram as a source of Volunteered Geographic Information (VGI) that "*can support accessible, transparent, democratic, inclusive, and locally-based governance situations of interest to planners, citizens, politicians, and scientists*". However, they also state that as a tool support scientific and

democratic interaction, VGI data is still challenged by practical, technical and ethical concerns. More research is needed in order to better understand the usefulness and application of this rich data source to governance. Sui et al (2013) also make a plea for further research on the possibilities, pitfalls and challenges surrounding these VGI data and methods.

Also in this cluster, there seems to be little debate on the fact that a wide range new digital tools offers a huge potential to monitor all kinds of environmental behaviours, usually related to recreation/green space visits. This offers opportunities for planning and governance, but also in collecting information on people's perceptions of certain spaces.

5 Conclusions and Roadmap for future research

Although our literature review is conducted in a semi-systematic way and is certainly far from complete, our analysis of 76 articles illustrates and substantiates that technology nowadays is, indeed, deeply penetrating the field of nature conservation. More and more, technology truly seems to be (at) the interface between people and nature and as such, this has a mediating effect on human – environment relationships. Consequently it is of central importance, for both biodiversity conservation and the development of transformative pathways, to investigate what this mediating effect is, and to understand better how technology is influencing the interaction between people and nature and how this impacts conservation practices.

Looking more closely at the body of literature included in our review we could roughly distinguish between three perspectives**, a 'nature-oriented' perspective, a 'self-oriented' perspective and a 'relational' perspective.**

The largest share of articles can be seen as having a *'nature-oriented' perspective* in which the relationship between people, technology and nature is investigated from a biodiversity or conservation-oriented perspective. The focus of these articles was often on the use of technologies in order to strengthen, support or facilitate nature conservation and biodiversity protection. Examples include the technological improvements in gathering or analysing data for biodiversity monitoring and conservation, raising money for conservation or raising environmental awareness and mobilizing people for active contributions to conservation practices.

A smaller share of the literature focus on a *'self-oriented' perspective*. These articles focus on individual benefits to health and well-being related to (technological) nature as well as on individual meanings and understandings of values of nature and on personal development.

A third part of literature is grounded in a more *'relational' perspective,* focusing on relationships between people and nature as well as between people and other people. This included the mediating influence of digital technologies on activities and experiences in nature and on mobilizing active citizens for stewardship and political activism based on their relationships with the natural environment.
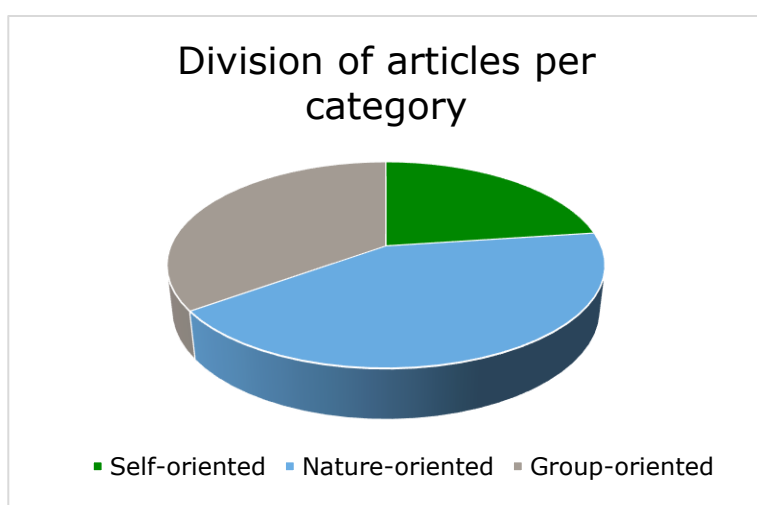

Figure 6 *Division of articles per category.*

Within all three perspectives we have come across illustrations of both promising and more critical perspectives in relation to the mediating effects of digital technologies on nature, people or relations. If we look for example at the *nature-oriented perspective*, it is shown that digital technology has a huge potential to provide better understanding and management of natural systems, (e.g. through citizen science). However, there are also authors that state that the technological potential is still far from being used to its full extent and / or will raise new questions, for example in the field of environmental justice. Others argue that some of the technological innovations might also lead to a commodification of nature.

Regarding a *self-oriented perspective* there are several studies which suggest that digital technology such as virtual reality can have a positive influence on people's health and wellbeing. At the same time, most studies do not compare such mediated experiences to non-mediated experiences (and what this means for the potential use of technologies in this field). There are also indications that virtual experiences cannot replace real life experiences, as they cannot offer the full spectrum of (sensory) experiences that being in actual nature can. It is still unclear whether mediated experiences can be complementary to non-mediated experiences or that they should be regarded as competitive in a world where the average 'screen-time' of most people surpasses time spent outdoors.

From a *relational perspective*, there are several studies that illustrate how digital technology can contribute to an enhanced awareness and feeling of commitment to nature. However, there are also studies arguing that digital technology can contribute to a more shallow human-nature relationship or can even lead to an alienation of people from (everyday) nature. The 'springwatch-effect' refers to a situation where visitors and users demand immediate exciting and stimulating wildlife spectacles instead of more 'real' and mundane experiences of wildlife. The term 'eco-pornography' is used to describe a situation in which idealised versions of nature may result in fleeting, misinformed and superficial connectedness to nature.

In our opinion, what this shows most of all is that, as Ahlborg et al. state (2019): *"technology brings ambivalence into the relation between people and environment"*. This ambivalence is not something to consider as necessarily problematic, however we do emphasize that this is something important to be aware of. Following Arts et al., (2013), we suggest that technology in the socio-ecological domain be conceptualized as a force. Technology is a force that significantly influences the domains of nature and biodiversity conservation, but also a force that is not autonomous, but can be influenced by human agency, *"technology can be both empowering and hindering at the same time. To consider it as a force implies that one tries to gain a better understanding of the mediating effect of technology and consciously explores the manners to guide and steer this force for certain purposes"* (Arts et al., 2015).

5.1 Future Wageningen research

The impact of innovative digital tools and developments on nature conservation and the human-nature relationship is already present and will undoubtedly continue to grow over the coming years and decades. Getting a grip on this development is crucial for Wageningen UR to be able to stay on the edge of current social, ecological and technological developments. In our opinion, future (Wageningen UR) research on nature, biodiversity and a nature-inclusive society should not make the mistake of overlooking technology as an important mediator in social-ecological systems.

Recognizing, understanding and 'steering' the force of technology requires attention for the whole 'chain of technology'; from the identification of its potential to the conscious and responsible design of the technology itself up to the potential uptake by certain stakeholders and the implementation in practice. Different 'links' within this chain will ask for different ways of stakeholder involvement and interaction.

To actively engage with the force of digitalization, we identify **four crucial steps for future WUR research**:

1. *Enhance our understanding of the forces from technology and how it drives social and ecological changes*. This implies, for example, that we try to gain a better understanding of how technology influences the experience(s) of nature of different stakeholders; how it impacts on people's health and wellbeing; or how it is used in various forms of governance.

2. From such an increased understanding, *explicitly try to influence the direction of these forces towards a transformative agenda*. Working on such a transformative agenda asks for an approach of 'responsible research and innovation' that anticipates and assesses potential implications and societal expectations with regard to research and innovation, with the aim of fostering the design of inclusive and sustainable research and innovation;

3. *Critically investigate the (potential) mediating role of technology and how this relates to non-mediated interactions between humans and nature.* Although the amount of research on the link between humans, nature and technology seems to be growing quite fast, our review shows that many topics are still only tentatively explored. In general, review studies of potential impacts are still lacking, and some fields of research may even not produce sufficient studies to allow for a proper review. In addition, research in several of the themes mentioned is still in its infancy, and research methods could sometimes be improved. For example the studies of the impact of virtual reality on health and well-being, or on people's understanding of nature often compare virtual images of natural environments with virtual images of built environment. However, the actual question is of course is whether the benefits of real natural encounters can be substituted by virtual images of nature;

4. *Critically reflect on efforts to influence the impact of digital conservation.* Developing strategies to influence and steer the mediating forces of technologies is an ambitious quest and an uncertain journey. Only if we continuously monitor and evaluate how these efforts influence nature-related technologies can we in time learn how to best develop and use technology. As such, technology management can also be considered as a form of adaptive management. Management that is sensitive to and reflexive of the social, ecological but also technological processes occurring in our technologically mediated environment.
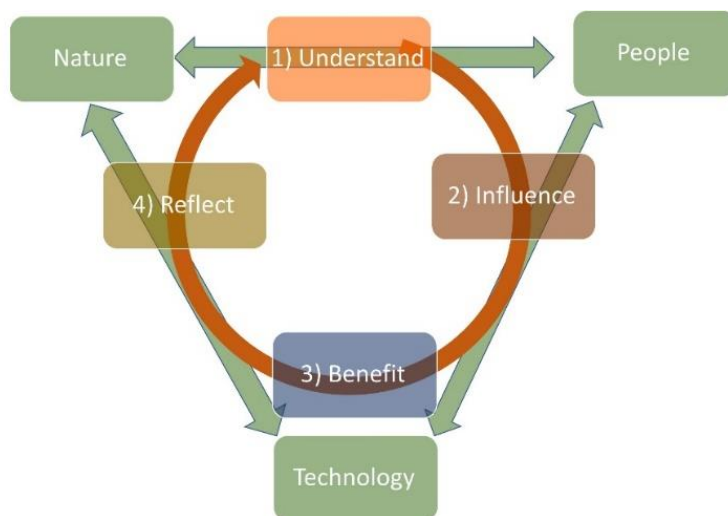
Potentially, WUR has a strong position in this field with its broad range of social, ecological and technological disciplines under one roof. Fortunately, there are already some promising initiatives on the nexus of technology, society and environment. The KB programme Digital Twins, for example, has the ambition to 'explore the transformational impact of digital technologies on society'. The Wageningen UR Digimetis network aims to become 'a leading OneWUR Centre of Excellence that contributes to reflection on the implications of digitalization and digital innovation in the areas of agrifood, nutrition, natural resources, biobased economy and circular economy, by means of social science and humanities research and education'. In addition, the Wageningen UR Transformative Dialogues aim 'for researchers to step outside of their individual boxes and to co-develop more collectively transformative pathways to social-environmental change'. We would like to make a strong plea to explicitly incorporate the mediating role of technological innovation in relation to human-nature relations into these initiatives and dialogues.

5.2   Directions and questions for future research

Our review should be seen as a first step to offer some clues for future (Wageningen UR) research on the interface of social, ecological and technological systems. Based on our tentative analysis, we conclude that a huge array of relevant and scientifically interesting research questions follows from the influence of technology on humans, nature and their relationship. Although almost all of these questions are of relevance to the WUR themes, we suggest a focus on a few core questions that are especially relevant for Wageningen UR and for the KB-programmes 'Nature Inclusive Transitions' (KB-36) and 'Data driven and High Tech' (KB-38) (and potentially a forthcoming investment theme on biodiversity if it includes an area dealing with 'human-wildlife' interactions). Following the 'science for impact' ambitions of Wageningen UR and the specific focus from the KB 36 programme on the 'transition to a sustainable and nature inclusive society', we also suggest focussing on research into the transformative potential of digital conservation.

If we look at the first cluster of '*Nature, technology and wellbeing*', new technologies and mediated nature experiences seem to offer a cautious promise for enhancing human wellbeing, leading to positive emotions. This is especially promising for those groups that have little or no access to non-mediated nature experiences. However, research on the possible health benefits of mediated experiences is still rather anecdotical and should be expanded and improved. Most importantly, mediated and non-mediated nature experiences should be compared in order to understand whether they are complementary or conflicting.

Looking at the cluster of '*Social media and understanding of nature*', the (co-construction of) values for nature through social media should be put in perspective by comparing them with the public voice outside social media and through a better understanding of the algorithms that steer the online debate. Getting a better understanding of the dynamics of debates on social media as well as on how this relates to people's offline actions related to nature can also help to more clearly understand the effect of social media on nature conservation. Only if these aspects are better understood and taken into account, will the transformative potential of these online arenas be given their correct value.

With respect to the cluster of '*Participatory governance and social activism*', one of the principal questions seems to be how technology can contribute to stronger governance structures to protect, enhance and manage natural areas, taking into account questions of environmental justice such as the challenge of the digital divide. Also, it asks for a better understanding of how social movements develop and use technology to self-organize. Such social movements can be green movements, but can also include critical groups who oppose current conservation practices. Big data and social media monitoring techniques can function as early warning systems for emerging critical discourses on nature conservation policies and practices.

The most important message from the cluster of '*reflective considerations of how digitalization influences human-nature relationships*' is to integrate socio-ecological and socio-technical research through a SETS or STES approach. Furthermore, several of the – mostly theoretical – reflections on the loss of real nature experiences and its potentially negative effects on health and wellbeing ask for critical (follow-up) research to be able to assess the true impact of digitalization on human-nature interactions.

The same can be said for the cluster of '*Digital technologies to (re)connect people with nature*'. Although there are several studies suggesting that digital technologies can lead to a transformation rather than a loss of experience, proof of this is still rather anecdotical and this asks for more into-depth research. Efforts to influence the direction of technology and its impacts is especially relevant to this field. Research can focus on digital technologies to (re)connect people with nature and build on emerging studies which show that technology *can* under specific circumstances contribute to (re)connecting people to the natural world.

Looking at the cluster of '*Digitalization and new ways to monitor nature*', new technologies such as camera traps, geo-tagging, species identification apps, satellite imagery, etc., seem to offer a huge potential. Such technologies can strengthen research on pressures and drivers of unsustainable practices and offer techniques to strengthen public and political awareness of unsustainable pressures, drivers and practices. The main (research) challenge here will be to identify the full spectrum of possibilities and to consciously steer the development of (new) technologies in such a way that they indeed contribute to a (nature) inclusive society.

Looking at the final cluster of *'Digitalization and new to monitor recreational behaviours in nature',* user-generated data or Volunteered Geographic Information (VGI) seems to offer many new possibilities for gaining insight into patterns of interaction between humans and their natural environment. However, the use of these data and information is still challenged by practical, technical and ethical concerns that require further research.

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