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Making waves: Lessons learned from the COVID-19 anthropause in the Netherlands on urban aquatic ecosystem services provisioning and management

Margaret Armstrong [a,b,*], Hazal Aksu Bahçeci [a], Ellen van Donk [a,c], Asmita Dubey [a], Thijs Frenken [a], Berte M. Gebreyohanes Belay [a], Alena S. Gsell [a], Tom S. Heuts [a,d], Lilith Kramer [a,b,e], Miquel Lürling [a,b], Maarten Ouboter [f], Laura M.S. Seelen [a,g], Sven Teurlincx [a], Nandini Vasantha Raman [a], Qing Zhan [a], Lisette N. de Senerpont Domis [a,b,h,i]

[a] Department of Aquatic Ecology, Netherlands Institute of Ecology (NIOO-KNAW), Droevendaalsesteeg 10, Wageningen 6708 PB, the Netherlands
[b] Aquatic Ecology and Water Quality Management Group, Wageningen University & Research, Wageningen, the Netherlands
[c] Ecology and Biodiversity research group, University of Utrecht, Utrecht, the Netherlands
[d] Department of Aquatic Ecology & Environmental Biology, Radboud University, Nijmegen, the Netherlands
[e] Department of Freshwater Ecology and Water Quality, Deltares, Delft, the Netherlands
[f] Waternet, Regional Water Authority Amstel, Gooi and Vecht, Amsterdam, the Netherlands
[g] Programming and Monitoring, Regional Water Authority Brabantse Delta, Breda, the Netherlands
[h] Faculty of Geo-Information Science and Earth Observation, University of Twente, Enschede, the Netherlands
[i] Faculty of Electrical Engineering, Mathematics and Computer Science, University of Twente, Enschede, the Netherlands

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ABSTRACT

The anomalous past two years of the COVID-19 pandemic have been a test of human response to global crisis management as typical human activities were significantly altered. The COVID-instigated anthropause has illustrated the influence that humans and the biosphere have on each other, especially given the variety of national mobility interventions that have been implemented globally. These local COVID-19-era restrictions influenced human-ecosystem interactions through changes in accessibility of water systems and changes in ecosystem service demand. Four urban aquatic case studies in the Netherlands demonstrated shifts in human demand during the anthropause. For instance, reduced boat traffic in Amsterdam canals led to improved water clarity. In comparison, ongoing service exploitation from increased recreational fishing, use of bathing waters and national parks visitation are heightening concerns about potential ecosystem degradation. We distilled management lessons from both the case studies as well as from recent literature pertaining to ecological intactness and social relevance. Equally important to the lessons themselves, however, is the pace at which informed management practices are established after the pandemic ends, particularly as many communities currently recognize the importance of aquatic ecosystems and are amenable to their protection.

1. Welcome to the anthropause

The anomalous past two years of the coronavirus (COVID-19) pandemic have been a test of human response to global crisis management as typical human activities were significantly altered (Searle et al., 2021). This phenomenon, coined an "anthropause" (Rutz et al., 2020), can be viewed as an intentional and abrupt cessation of human behaviour patterns in response to disruption from a pandemic (COVID-19), pollution disaster (Chernobyl), environmental catastrophe (Hurricane Katrina) or military intervention (Korean demilitarized zone; Searle et al., 2021). Few times in recorded human history has such a pause occurred at this all-encompassing global and sectoral scale while also being well-documented.

Efforts to contain COVID-19 have resulted in varying degrees of national interventions to limit human contact that ranged from social-distancing measures to selective travel restrictions to full lockdowns

* Corresponding author at: Department of Aquatic Ecology, Netherlands Institute of Ecology (NIOO-KNAW), Droevendaalsesteeg 10, Wageningen 6708 PB, the Netherlands.
E-mail address: M.Armstrong@nioo.knaw.nl (M. Armstrong).

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(Primc and Slabe-Erker, 2020). In Europe, most countries imposed various mobility restrictions from spring 2020-winter 2021, with the severity of the restrictions following the wax and wane of the recorded infections. In contrast to other notorious but localized anthropauses (Fukushima), the COVID-19 anthropause has resulted in drastic, widespread reduction of some human activities (travelling; March et al., 2021) and increases in others (recreation in urban nature spaces; Venter et al., 2020).

Our water systems have demonstrated a ripple effect of the COVID-19 anthropause on the biosphere. Some of the shifts and reductions in human activities have been attributed to positive system changes, such as moratoriums of industrial heavy metal pollution or reduced commercial fishing pressures (Mandal, 2020). However, not all anthropause trends provided a respite for aquatic systems. Human activities have also negatively affected water systems such as with beach overcrowding instigating littering (Miller-Rushing et al., 2021; Zielinski and Botero, 2020) and publicly-applied disinfectants entering surface waters (Chu et al., 2021).

All water systems are uniquely defined by their location, hydromorphology, human use and management approach (Wetzel, 2001). Ergo, the types of systems being studied (e.g. inland or coastal, lentic or lotic, temperate or tropical, etc.) will influence which of the COVID-19 effects have been observed and what water management take-away message this anthropause has had. Water systems in heavily urbanized areas, for instance, are inundated with continuous pressures stemming from constant exposure to human activities, infrastructure and now pandemic management. Attaining an overview of COVID-19 impacts on urban waters is therefore relevant for human management of, and engagement with, these systems while also presenting outlooks on a future in a more urbanized world.

While undesirable, COVID-19 provided a unique opportunity for studying effects of changing human pressures and uses within human-ecosystem interactions. Under present pandemic conditions, these interactions are susceptible to change due to altered opportunities, capability and motivation for humans to engage with nature (Soga et al., 2021). Restrictions from COVID-19 mandates could, for instance, either alleviate some pressures to these systems by reducing human interactions or could contribute to the pressures with increased human demand due to continued access to the ecosystem. Knowledge gathered during this time can be monumental for informing and improving management and policy regarding adaptation to a more urbanized world with higher likelihoods of pandemics (de Senerpont Domis and Teurlincx, 2020), time delays of pandemic repercussions (Soga et al., 2021) and to adoption of more sustainable practices for ecosystems (Folke et al., 2021). The implications of informed management on human-ecosystem interactions can support mutually beneficial feedback for both society and nature (e.g. Pereira et al., 2020), as has been suggested in the context of social-ecological models (Mooij et al., 2019). In reviewing literature from the COVID-19 anthropause, we saw a lag in the number of papers aimed at discerning the effects of the pandemic on surface waters in highly urbanized areas. Below, we address this gap by reflecting on the implications that the pandemic anthropause has had on the human-ecosystem-management interactions by defining this relationship and presenting case studies of recreational service demands for water bodies in the Netherlands. Finally, from the case study observations and with evidence from recent literature, we derive management lessons regarding best practices for future implementation.

2. Conceptual framing of human-ecosystem-management interactions

The sheer magnitude of human influence on the biosphere in this epoch is evident in its delineation as the "Anthropocene" (Trischler, 2016) and the COVID-19 lockdown period as an "anthropause." August 2021 saw the IPCC unequivocally attribute climate change to human actions and register this pressure as "code red" (IPCC, 2021). Cumulative human activities across the planet have also manifested as habitat degradation by way of land use change (de Senerpont Domis and Teurlincx, 2020), biodiversity loss and overall incapability of ecosystems to handle variability in pressures (Folke et al., 2021).

These human-ecosystem interactions are a two-way feedback wherein the biosphere also affects human wellbeing and behaviors (Folke et al., 2021). Societies are dependant upon stability in ecosystem functioning (Comberti et al., 2015) and provisioning of services (e.g. benefits such as food, recreation, nutrient cycling; de Senerpont Domis and Teurlincx, 2020) as outlined in frameworks on the interdependence of human, animal and environmental health (One Health triad, Eco-health transdisciplinary approach; Rabinowitz et al., 2018; Zinsstag, 2012). For example, environmentally healthy urban aquatic systems pose less risk for cyanotoxin poisoning of wildlife, pets and humans (e.g. Merel et al., 2013). Perpetuating the fallacy of perceiving humans as separate from the biosphere will lead to societal destabilization through the collapse of ecosystem functions (Rockström et al., 2009), as is already illustrated with the negative feedback of deteriorating water system functions on present day societies (Folke et al., 2021).

Management of aquatic ecosystems requires accounting for the interlinked connections between human-built and natural systems. Separately, these two types of systems span numerous sectors and are based on complex connections amongst various drivers, demands and feedbacks (DPSIR framework; Tscherning et al., 2012). However, considering the implications of one system in isolation from the other is a disservice to both humans and the biosphere as there can be connections and repercussions between the interlinked systems that are unaccounted for. Understanding and working with both types of systems, particularly with elaborating on the feedback from human-nature interactions (ecosystem services and services-to-ecosystems connections; Comberti et al., 2015), can facilitate beneficial outcomes to ecosystem functioning and human uses. Frameworks such as the IPBES Conceptual Framework (Díaz et al., 2015) integrate knowledge from multiple sources by making explicit linkages between the elements of human well-being, biodiversity and ecosystems, ecosystems goods and services, natural and anthropogenic drivers, and anthropogenic assets. Further, the framework draws the connection of this knowledge to governance and decision-making.

3. Changes to ecosystem service demand

Human settlements have a long history of placement in proximity to water systems, including today with over 50% of the global population living within 3 km of freshwater bodies (Kummu et al., 2011) and with many urban centers still situated in relation to rivers (Di Baldassarre et al., 2013), lakes (Trudeau and Richardson, 2016) and other water bodies. The biosphere's water systems are capable of providing abundant ecosystem services, though limitations can arise depending upon the degree of ecosystem functioning, the rate of service exploitation and if there is demand for competing finite water services or resources. During the COVID-19 anthropause there have been abrupt shifts in typical service demands in response to local pandemic measures, such as with use of blue spaces for recreation. We will illustrate examples of changes in ecosystem demand under the COVID-19 anthropause with four case studies from Dutch water systems. In the Netherlands, strict pandemic restrictions starting 15 March 2020 resulted in episodic closing of schools and non-essential businesses, restricted international travelling, limited house visits and social-distancing (COVID-19 pandemic in the Netherlands, 2021). These restrictions bore consequences for outdoor activities due to changing demand for aquatic cultural services of recreational boating and swimming (CICES 6.1.1.1), recreational fishing (CICES 1.1.6.1), and shoreline walking (CICES 3.1.1.2; classification codes from CICES version 5.1; see Seelen et al., 2022).

3.1. Decreased human activities: recreational boating

The reduction of recreational boating in Amsterdam canals during the pandemic had an impact on the underwater ecosystem. A large portion of this reduced pressure has been attributed to the suspension of international tourism (International Tourism and Covid-19 | Tourism Dashboard, 2022). Boating traffic data was obtained from the tracking of receiver-outfitted boats through the municipality of Amsterdam's "The Digital Canal" programme (De DigitaleGracht, 2022) to discern general trends of boat movement. Water transparency data was collected biweekly through Secchi depth readings by the Amstel, Gooi and Vecht water authority's monitoring programme. Fig. 1 shows the coinciding trends in water quality and boat traffic. With less boat activity in the canals since the first lockdown in March 2020, there was an observed decrease in resuspension of solid matter resulting in an increase in water clarity relative to previous years (Fig. 1A-C). The increased light penetration permitted the establishment of submerged macrophytes (Fig. 1D; Amsterdamse grachten helderder dan ooit dankzij coronamaatregelen, 2020), demonstrating that the diminished demand for one service (boating) reduced pressure exerted upon the ecosystem and created the conditions for improving another service (habitat).

3.2. Increased human activities: fishing, bathing and national park visits

During the pandemic, some human activities intensified as people were seeking solace in the outdoors (Venter et al., 2020). In the Netherlands, outdoor physical activities were not restricted and therefore public outdoor spaces were possibly utilized more. In contrast to boating, other recreational activities (fishing, bathing and national park visits) saw a perceived increase in demand during the anthropause as compared to previous years. Alterations of service demand for fishing, bathing and national park visits were not directly or uniformly measured as boating had been. We therefore validated this perceived change in services demand with different sources of proxy data to derive shifts in human interests. Case study data is available at https://doi.org/10.5281/zenodo.6551591.

Annual numbers of fishing licenses sold, as reported by Sportvisserij Nederland (Royal Dutch Angling Association), was utilized as proxy data for the number of people interested in or utilizing fishing services. We compared reported regional numbers from 2016 to 2020 to trace shifts in trends (visualized with ggplot2). Fig. 2A illustrates an increase in licenses sold during 2020 as compared to previous years. As there were no alterations to fishing legislation, license accessibility and license prices during the COVID-19 pandemic, we infer that the increase in licenses sold is due to an increased demand during the anthropause. While humans can benefit mentally and physically from such recreational activities (Venter et al., 2020), environmental repercussions can arise if the activities are not managed. For instance, having an increased number of anglers using a limited number of fishing locations can negatively affect fish through the more frequent exertion of stress, even with catch-and-release practices (Brownscombe et al., 2017). Additionally, having a finite number of sanctioned fishing locations could instigate angling in undesignated, unmanaged water systems. Further, unsanctioned practices could occur with self-stocking of angling or bait fish in the water system, effectively altering the local food web dynamic (Matern et al., 2018).

Bathing water areas similarly garnered more public interest during the anthropause, as derived from proxy data comparing public interest through the measure of Google search trends before and during the pandemic (search term "zwemmen buiten" (English translation:

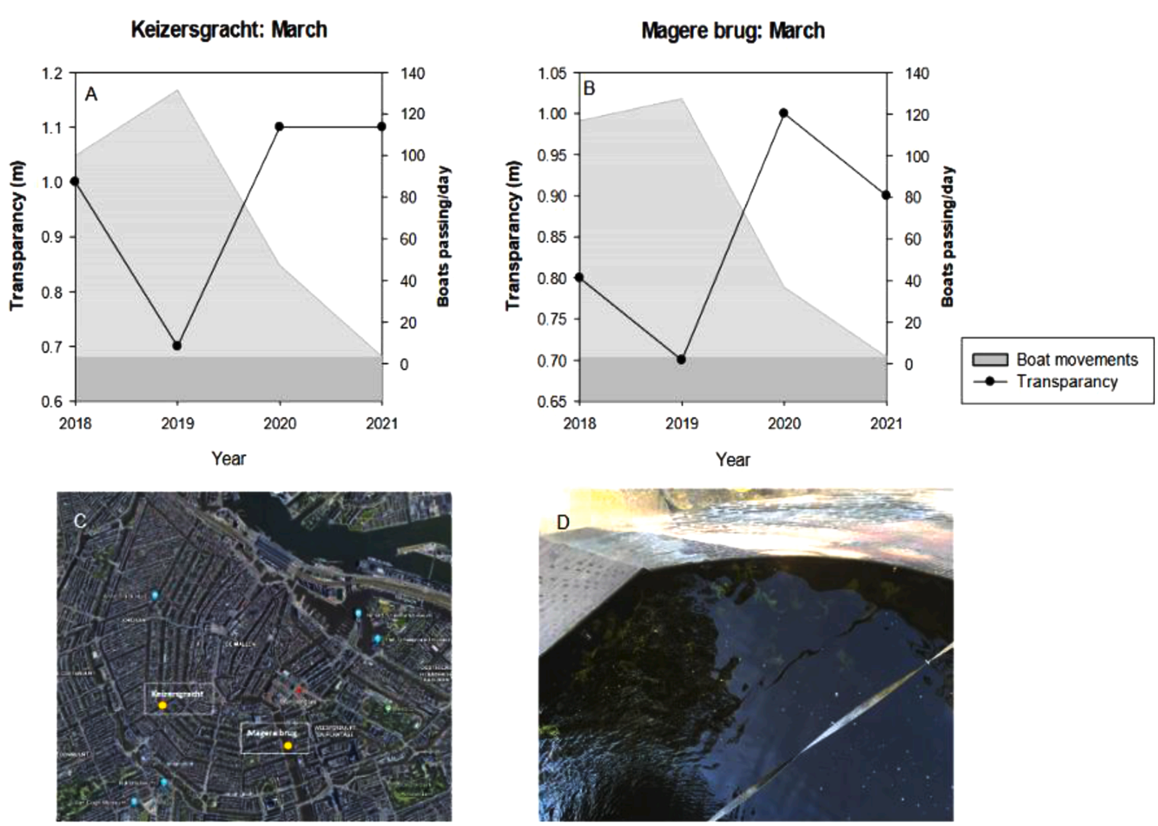

Fig. 1. Shifts in Amsterdam canal water transparency versus boating traffic. 2018–2021 average March water transparency versus boating activity at Magere brug (**A**) and Keizersgracht (**B**). Map of the locations **(C)**. *Nuphar lutea* growth in Keizersgracht (7–5–2020) **(D)**. Water transparency data were averaged from biweekly Secchi disc readings collected by the Regional Public Water Authority Amstel, Gooi and Vecht as part of their water quality monitoring programme. Boating traffic data was collected from receiver-outfitted boats passing through remotely monitored sections of the canals, as managed by the municipality of Amsterdam's project "The Digital Canal.".

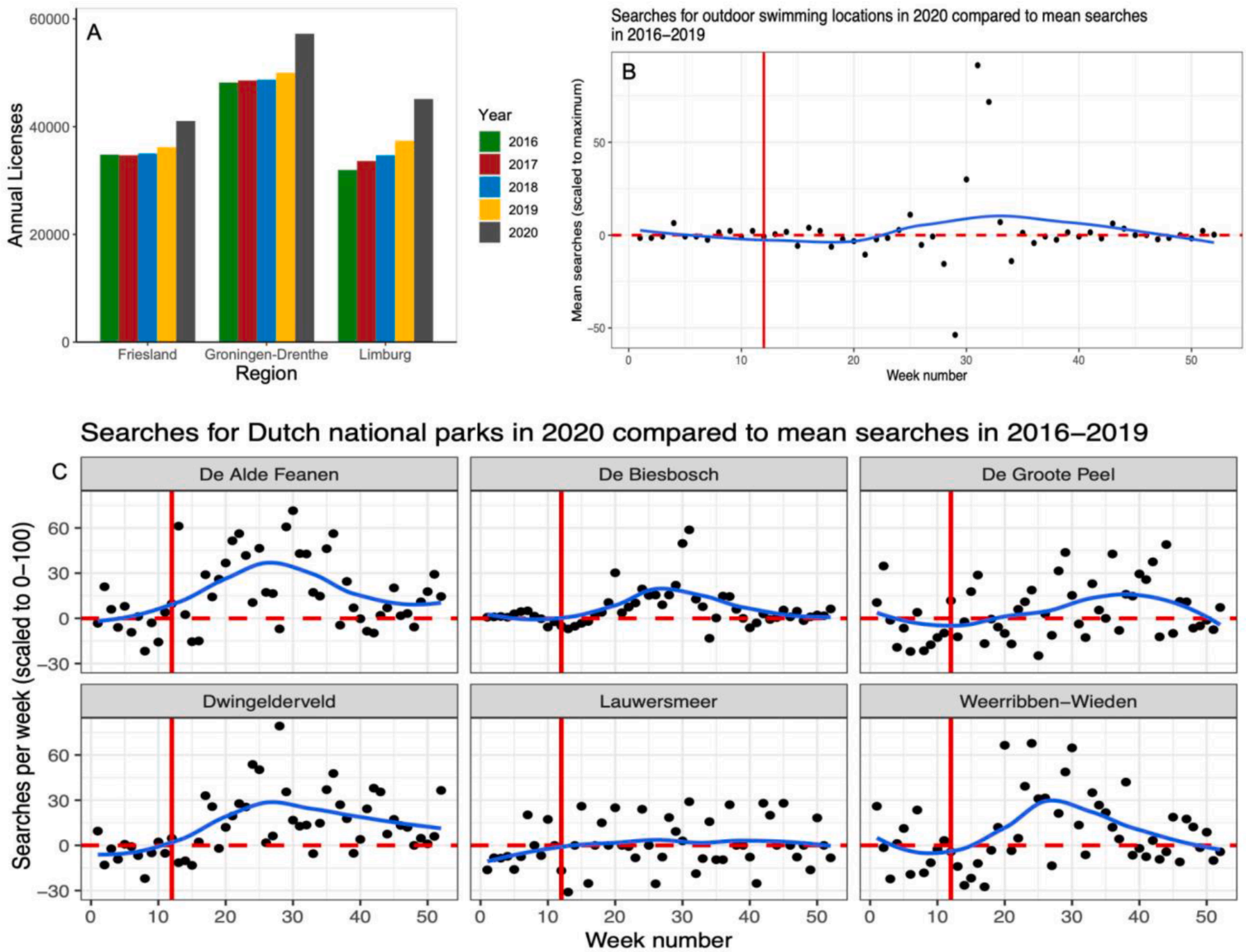

Fig. 2. Changes in Dutch aquatic recreation before and during the COVID-19 anthropause. Shifts are shown with **A.** annual fishing licenses for ages 6+ from 2016 to 2020 by Netherlands regions (Sportvisserij Nederland; R package *ggplot2*, Wickham et al., 2021), **B.** recreational swimming and **C.** national parks containing water systems. Weekly Google trend search frequencies during 2020 (black dots) were scaled and compared to the average weekly search frequencies for 2016–2019 (dashed red horizontal line) to illustrate deviations from previous years. A LOESS smoothing function (Jacoby, 2000) for the 2020 data is applied (blue line). The start of the 2020 anthropause is delineated (red vertical line). In the Netherlands, the pandemic started with the first recorded infection in February 2020 and the anthropause with the enactment of stringent mobility restrictions and social distancing in March 2020 (COVID-19 pandemic in the Netherlands, 2021).

"swimming outside") from 2016 to 2020 searched on 4 October 2021; Fig. 2B). We visualized the trends in searches for bathing waters and compared the pre-pandemic data to the pandemic period using a LOESS smoothing function (Jacoby, 2000) and Wilcoxon signed rank test (wilcox.test: Wilcoxon Rank Sum and Signed Rank Tests, 2022). Assuming that increased search behaviour translates in increased human traffic (e.g. Clark et al., 2019) at the swimming sites, the increased demand raises concern over the risk of spreading COVID-19 with numerous individuals from different households being in close proximity at these sites (Publieksvoorlichting, 2021). Other health risks are also concerning as the demand for bathing opportunities can lead to people swimming in non-designated sites. As these unsanctioned locations are not subject to monitoring under the European Union's Bathing Directive, swimmers can be exposed to pathogens and contract illnesses. From an environmental perspective, there is the omnipresent concern that increases in crowds heighten the likelihood of pollutants such as microbial exposure and increased turbidity (e.g. Graczyk et al., 2010). From the pandemic, additional concerns arise with macro- or microplastics from littered personal protective gear (Ammendolia et al., 2021) being introduced into the system and affecting the biota (Parashar and Hait, 2021).

Alterations in accessibility of urban water services during the pandemic, such as through the closure or limited capacity of recreation areas, could lead to increased use of blue-green spaces outside of city limits. Google search trends for national park locations was used as a proxy dataset for human demand in shoreline walking (trend data for the park names from 2016 to 2020 searched on 3 June 2021; Fig. 2C). 2020 pandemic data was visualized and compared against pre-pandemic data using the LOESS smoothing function (Jacoby, 2000) and Wilcoxon signed rank test (wilcox.test: Wilcoxon Rank Sum and Signed Rank Tests, 2022). Interest in Dutch national parks containing wetlands or open water systems was perceived to increase during the anthropause as compared to previous years. Given the connection between blue-green spaces and mental health (Pouso et al., 2021), it can be hypothesized that prolonged immobility in urban centers (the anthropause) can bolster an interest in spending time in blue-green spaces, including systems in non-urban areas. With the observed shift in water systems use, there are concerns about pressures that could be introduced with the increased demand. Similar to bathing waters, increased water system use can lead to increased littering (Parashar and Hait, 2021). Further concerns include the additional anthropogenic noise pollution (Templeton et al., 2021) from more visitors disturbing inhabitants (fish, birds, mammals) and the increased foot traffic causing physical wear of shorelines and pathways (Salesa and Cerdà, 2020).

4. Lessons learned from the anthropause for water quality management

The COVID-19 anthropause permitted an unplanned experiment with shifted human pressures on water systems, the first of its kind in the Anthropocene (Chowdhury et al., 2021). In some systems, the anthropause has shown us visions of desirable futures (Pereira et al., 2020). As society hits "play" from this anthropause, distilling the management lessons learned from the pandemic-induced shift in human-ecosystem interactions in order to maintain the positive social and ecological COVID-19 outcomes in water systems will be important, both for immediate and future management applications. Anthropause-derived insights should therefore be disseminated for adoption in management decisions and policies (Chowdhury et al., 2021), particularly given the hyper-connectivity of our current societal and economic activities which can easily instigate future pandemics and associated anthropauses (de Senerpont Domis and Teurlincx, 2020).

While plenty of recent studies have hinted towards the pertinence of implementing the anthropause takeaways into management and policies, few elaborate on what specific lessons can be applied to urban water system management. In this section, we highlight six lessons for enhancing management of water systems with the sustainability principles of “ecological intactness” and “social relevance” (Smith et al., 2021) based on evidence from both COVID-19-era papers and our Dutch case study observations.

Working within a water system’s constraints is the first step in maintaining optimal human-ecosystem interactions. Therefore, defining ecosystem service operating and accessibility guidelines according to ecological needs (i.e. ecological intactness) as through a “services to ecosystems” approach (Comberti et al., 2015) can support management of human-ecosystem interactions. Three ecological-based takeaway lessons include the following:

4.1. *Define recreational ecosystem service use thresholds*

Boundaries for utilizing water systems can be set to avoid compromising vital functions or overtaxing uses. As our analysis of boating data showed, temporary cessation of boating can lead to fast changes in habitat. To foster these positive developments in water quality in the post-COVID-19 era, zoning canals to designate specific boating pathways can delineate areas for habitat and other water usage. In addition, limits can be placed on the number of people utilizing the system, such as with bathing areas having a maximum number of swimmers that can be present simultaneously and over the course of a time period.

4.2. *Establish short-term anthropauses*

As observed from the most restrictive periods of the anthropause, cessation of human interference permitted water system improvements (e.g. Loh et al., 2021). Enacting intermittent periods of restricted access after the pandemic could similarly promote periods for recovery, especially for vulnerable systems. For instance, no-boating periods in Amsterdam canals during spring vegetation growth periods can permit habitat establishment. Rotating access to bathing, fishing and scenic water systems can also decentralize recreational pressures for individual sites and mitigate synergistic pressures stemming from chronic system use (Sanjari et al., 2009). Further research will be needed to ascertain the duration of the improved ecosystem conditions and methods for maintaining the recovery after anthropauses end.

4.3. *Continue scientific monitoring and (intersectoral) research*

Despite the abrupt onset of COVID-19, existing ecological and social research programs, such as the Amsterdam canal water quality monitoring network and various citizen science projects, have supported knowledge-gathering even during society’s tumultuous adjustment period. Continuing to support scientific research and engaging with science-management intersectoral collaborations can safeguard knowledge production from future disruptions.

Fulfillment of water system uses for society’s needs (i.e. social relevance) is an additional aspect that has been affected by the anthropause. Here we reflect on three lessons for optimizing social investment in urbanized water systems:

4.4. *Identify the (new) recreators*

The anthropause may have bolstered recreator numbers as lockdown conditions permitted some individuals to have more time and opportunities to explore local natural spaces (Venter et al., 2020). Identifying which community demographics increased their use of nature during this time period and reviewing what systems were utilized (urban versus rural, green or blue spaces) could help develop management practices that foster the continued engagement of people with water ecosystems post-anthropause (de Senerpont Domis and Teurlincx, 2020).

4.5. *Identify societal barriers to blue-green spaces*

Blue-green spaces tend to be unequally distributed throughout urban communities, as was highlighted with COVID-19 lockdown restrictions (Pouso et al., 2021). Managing and creating these systems to be more accessible to all people can help bolster individual and community health (Venter et al., 2020). Conferring with marginalized groups about their experiences before and during the pandemic can help identify these accessibility issues and develop solutions (Dushkova et al., 2021).

4.6. *Improve existing infrastructure*

Existing and future water system infrastructure can be improved to sustainably accommodate more visitors. For instance, durable pathways can be installed to prevent erosion of paths (Bates et al., 2020). Mapping locations of frequent litter accumulations and installing refuse or recycling bins can help maintain the integrity of the water system and aesthetics of the surrounding area (Ammendolia et al., 2021). Building sanitation stations (hand sanitizer dispensers) to support hygiene during the pandemic and in e.g. influenza season can protect visitor health (Miller et al., 2021).

Of importance for all anthropause-derived management suggestions is the pace that knowledge is implemented. Under pandemic circumstances, numerous communities are aware of and invested in the value that the biosphere provides (Soga et al., 2021) and likely to be more receptive to management actions that support continued water functioning and service provisioning (Klenert et al., 2020). However, it is uncertain what proportion of nature enthusiasts will retain the same high regard and valuation of natural systems once other sources of recreation, wellness and businesses re-open (McGinlay et al., 2020). There are too many present-day drivers of ecosystem degradation to not leverage every opportunity for stimulating positive, informed and pre-emptive action (Strokal and Kroeze, 2020). Acting in the current pandemic window to maintain the remembrance of human and nature interconnectedness might have a good return on investment in establishing pertinent policies in the post-pandemic. Numerous institutions (IPCC, IPBES) and initiatives (UN Decade of Ecosystem Restoration) are similarly striving for a paradigm shift with water as a source of life, not just a resource to use (Seelen et al., 2019). Fostering a more eco-centric mindset in society going forward can subsequently promote prolonged and sustainable human-nature interactions, which will be paramount for handling climate change, extreme climatic events, societal evolution and future pandemics.

5. Conclusions

- Recent literature has demonstrated that human responses to the COVID-19 anthropause have had tremendous reach with implications extending to numerous sectors and systems, including aquatic ecosystems which are susceptible to anthropogenic pressures.
- Previously published studies illustrate that the effects of the anthropause (positive or negative) on water systems depended on a combination of the local health mandates (lockdowns, social distancing requirements), societal values (ecosystem service use and demand) and the water system itself (type, ecological health).
- Dutch urban water systems have experienced mixed effects on water uses during the anthropause that were linked to changes in ecosystem service accessibility and demand.
- Distilling the lessons from urban systems and implementing best practices during or soon after the pandemic can help retain society's positive perceptions and valuation of ecosystems, foster more environmentally conscious communities and establish environmentally-focused management practices.

CRediT authorship contribution statement

Margaret Armstrong: Conceptualization, Methodology, Investigation, Writing – original draft, Writing – review & editing, Visualization, Project administration. **Hazal Aksu Bahçeci:** Conceptualization, Writing – review & editing. **Ellen van Donk:** Conceptualization, Writing – review & editing. **Asmita Dubey:** Conceptualization, Writing – review & editing. **Thijs Frenken:** Conceptualization, Investigation, Writing – review & editing. **Berte M. Gebreyohanes Belay:** Conceptualization, Writing – review & editing. **Alena S. Gsell:** Conceptualization, Investigation, Writing – review & editing. **Tom S. Heuts:** Investigation, Writing – original draft, Writing – review & editing. **Lilith Kramer:** Conceptualization, Writing – review & editing, Visualization. **Miquel Lürling:** Conceptualization, Investigation. **Maarten Ouboter:** Conceptualization, Methodology, Investigation, Visualization. **Laura M.S. Seelen:** Conceptualization, Investigation, Writing – review & editing. **Sven Teurlincx:** Conceptualization, Writing – review & editing, Visualization. **Nandini Vasantha Raman:** Conceptualization, Writing – review & editing. **Qing Zhan:** Conceptualization, Writing – review & editing. **Lisette N. de Senerpont Domis:** Conceptualization, Methodology, Investigation, Writing – original draft, Writing – review & editing, Visualization, Project administration.

Declaration of Competing Interest

The authors declare that there is no conflict of personal, professional or financial interest.

Data availability

Datasets and R scripts from the case studies are available at the following website address: https://doi.org/10.5281/zenodo.6551591.

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