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OPINION PAPER

Raw water transfers: why a global freshwater invasion pathway has been overlooked

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Abstract Zhu et al. (Science 380:1230, 2023, https://doi.org/10.1126/science.adi6022) recently reported in *Science* that 'water diversions' carry a range of freshwater invasive non-native species (INNS) in China, and make calls for the Chinese government to take actions to monitor this invasion pathway and prevent future spread. This issue is not confined to China however. Water diversions, more commonly known internationally as 'water transfers' or 'raw water transfers', exist globally in large numbers. Despite worldwide occurrence, this major invasion pathway has received little attention within the field of freshwater ecology or invasion ecology, beyond a limited number of regional studies which offer little context regarding the global nature of the pathway. We discuss the factors contributing to the widespread lack of awareness of this uniquely complex invasion pathway, and emphasise the importance of future collaboration and knowledge sharing in this emerging field. Transdisciplinary research is needed to develop effective management techniques for this invasion pathway and ensure that the threat to global freshwater biodiversity posed by INNS is dealt with comprehensively.

Keywords Freshwater · Invasion pathways · Environmental engineering · Water resources · Climate change

Background

Zhu et al. (2023) recently reported in *Science* that 'water diversions' carry a range of freshwater invasive non-native species (INNS) (also known as 'invasive alien species') in China, and make calls for the Chinese government to take actions to monitor this invasion pathway and prevent future spread.

The authors make an important and timely point, however this issue is not confined to China. Water diversions, more commonly known internationally as 'water transfer' or 'raw water transfer', exist globally in large numbers. The number of water transfer schemes is rapidly increasing worldwide, driven by the need to secure water resources for a growing human population in an era of climate change and urbanisation (Garrote, 2017; Shumilova et al., 2018).

The term water transfer describes the movement of large volumes of freshwater from one waterbody to another via complex networks of infrastructure, to support human water requirements. Water transfer schemes can operate at a range of scales, from local

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intra-basin transfers to typically larger inter-basin schemes spanning hundreds of kilometres (Davies et al., 1992). This translocation of water has major impacts on the freshwater environment and forms a pathway for INNS spread.

Despite worldwide occurrence, the vast majority of ecological investigations of water transfer schemes as an invasion pathway have occurred on a small number of schemes, notably a single transfer in China (Zhan et al., 2015) and the Orange-Great Fish River water transfer in South Africa, which has facilitated the spread of several invasive fish species including the catfish *Clarias gariepinus* Burchell, 1822 *(*Cambray & Jubb, 1977); Kadye & Booth, 2012).

As such, the scale of this pathway is currently underestimated globally, and it remains largely unheard of within the wider fields of freshwater ecology and environmental policy. Indeed, water transfers are not explicitly referenced within international invasion pathway classification frameworks (see Convention on Biological Diversity 2014, UNEP/CBD/SBSTTA/18/9/Add.1) (CBD, 2014) despite posing a high invasion risk.

Importantly, whilst Zhu et al. (2023) rightly encourage government action, it should be noted that owing to the paucity of previous research in this field, effective management methods are currently lacking, with typical barriers and screening unable to prevent species spread (Snaddon et al., 1998). The authors also suggest that the government adapt the timing of water transfer events to avoid overlap with invasive species breeding periods. Given the extremely large size and importance of China's South-to-North water transfer in providing water to millions of people, this is unlikely to be a practical solution. Furthermore, it is unlikely to be effective against the wide range of taxa which are reportedly transported, which includes several species of fish and aquatic plants.

Barriers to knowledge

Why is this major freshwater invasion pathway largely ignored in a global context? There are several barriers to knowledge which may explain the current state of limited awareness:

Firstly, water security is a key concern for nations across the globe. Consequently, the networks of natural waterbodies and artificial infrastructure which make up water transfer schemes—rivers, reservoirs, pipelines, aqueducts, canals (Davies et al., 1992) are often considered 'critical national infrastructure'. This means that regulators and stakeholders may be reluctant to share information about these systems and the associated impacts in the public sphere. Knowledge of these systems is therefore largely confined within water resource management and engineering sectors.

Secondly, water resource management, and therefore the ownership of water transfer schemes, varies between countries (Speight, 2015; Bosch et al., 2021). Schemes may be operated by either central government, local authorities, or a privatised water industry. Each stakeholder has different concerns and approaches, and the degree of public information sharing depends on individual stakeholder cultural and procedural practices.

Thirdly, the water transfer invasion pathway is simply not as obvious or intuitive as other anthropogenic pathways of spread such as vector-transport or intentional release, which historically have been subject to greater levels of research and management activity. Water transfer schemes are diffuse and complex, with large networks consisting of many subterranean pipes and tunnels, and open canals and aqueducts; that connect chains of individual reservoirs and rivers across large distances. The scale and nature of the pathway means it is not self-evident, and a background understanding of water resource management or policy is often a prerequisite for knowledge of these systems. To illustrate, a visitor to a reservoir may see water entering via a small aqueduct. From this observation it would be impossible to know that this water has been sourced, via a system of a mechanical pumps and underground pipes, from a river 30 km away. That same onlooker would also be unable to observe that water is also exiting the reservoir via a submerged opening, and being pumped through a system of tunnels and aqueducts to another distant reservoir.

Lastly, the wider complexity and profundity of impacts associated with water transfer schemes may have historically reduced the focus on their role as an invasion pathway. Though commonly used across the globe, the re-distribution of large water volumes through water transfer schemes remains a contentious form of environmental management, and is associated with a range of political and socioeconomic consequences (Gupta & van der Zaag, 2008). Issues of social equity relating to water access, flooding and

draught have therefore understandably formed a key focus of water transfer scheme assessments to date (Flörke et al., 2018).

Where environmental impacts of schemes are considered, the focus is often on impacts to water quality, river flow, and erosion, rather than the ecological impact of INNS introduction (Snaddon et al., 1998). Given that many water transfer schemes were developed in the early to mid-1900s, before the issue of INNS was understood as it is today, this is perhaps unsurprising.

In amongst this complex landscape of environmental, political and socioeconomic consequences of water resource manipulation, combined with the esoteric nature of the pathway, the issue of water transfers spreading INNS at global scales has been under-estimated.

Steps forward

In an era defined by climate change and population growth, the issue of water security is of paramount importance. However, as the number of water transfer schemes continues to grow, so does the ever-increasing threat to global freshwater biodiversity, which is disproportionately impacted by INNS (Moorhouse & MacDonald, 2014).

Some individual countries are beginning to take practical steps to manage this invasion pathway at a national scale; such as England and Scotland, where agencies of the central governments have recently introduced requirements for water resource managers to work collectively and with external stakeholders to develop innovative management techniques (Environment Agency, 2021; SEPA, 2022). However, given the global nature of this pathway, widespread action is urgently needed. We therefore reiterate the calls for action made by Davies et al. (1992) and Snaddon et al. (1998), and more recently by Zhu et al. (2023), and urge scientists to contend with the barriers to knowledge outlined previously, and (i) immediately take steps to identify which RWTs governance structures are in place within their countries, (ii) try to ascertain what information on RWT schemes is available, and (iii) engage with stakeholders on the issue of INNS spread through RWTs. Until the global scale of this issue is fully recognised and afforded greater collaborative and transdisciplinary research attention, much-needed management progress will be hindered.

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Declarations

Conflict of interest The authors have no conflicts of interest to declare that are relevant to the content of this article.

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