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REVIEW ARTICLE

Effects of sediment dredging on freshwater system: a comprehensive review

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Abstract
As a common geo-engineering method to control internal load of nutrients and pollutants, sediment dredging has been used in many freshwater basins and has achieved certain effects. However, dredging can disturb water bodies and substrates and cause secondary pollution. It negatively affects the water environment system mainly from the following aspects. Dredging suddenly changes the hydrological conditions and many physical indicators of the water body, which will cause variations in water physicochemical properties. For example, changes in pH, dissolved oxygen, redox potential, transparency, and temperature can lead to a series of aquatic biological responses. On the other hand, sediment resuspension and deep-layer sediment exposure can affect the cycling of nutrients (e.g., nitrogen, phosphorus), the release and valence conversion of heavy metals, and the desorption and degradation of organic pollutants in the overlying water. This can further affect the community structure of aquatic organisms. The aim of this paper is to analyze the relevant literature on freshwater sediment dredging, and to summarize the current knowledge of the potential environmental risks caused by the dredging and utilization of freshwater sediments. Based on this, the paper attempts to propose suggestions to mitigate these adverse environmental impacts. These are significant contributions to the development of environmentally friendly freshwater sediment dredging technologies.

Keywords Freshwater sediments · Dredging · Environmental effects · Physicochemical properties · Aquatic community

Introduction

Freshwater sediments are depositions that accumulate at the bottom of water bodies such as rivers, lakes, and reservoirs for a long time. They are an important part of a multi-phase ecosystem of water bodies. However, sediment deposition in a watershed reduces flood storage capacity. Soil erosion in catchments has long been an important cause of freshwater deposition. In turn, soil erosion is caused by anthropogenic disturbances such as deforestation, excessive agriculture, and mining. The sediment delivery ratio has been confirmed as the relationship function between the soil erosion and the sediment yield (Dutta 2016). About 80% of the world's agricultural land suffers from moderate to severe erosion (Speth 1994), and about 75 billion metric tons of soil per year are removed (Pimentel et al. 1995). For example, it is reported that about 1.6 million metric tons per year of sediment is deposited in Chilika Lake by rivers and streams, which is continuously becoming shallow and sandbanks (Bengtsson et al. 2012). Increased water use, increased evapotranspiration, and decreased rainfall result in decreased freshwater volumes and flow rates. This is also considered to exacerbate the deposition of sediment particles by gravity and their consolidation over time (Dodds 2002).

On the other hand, sediments are the source of various pollutants. Sediment pollution as one of the most serious environmental problems in the aquatic ecological system has attracted international attention, both scientific and political, for its potential toxic threat to aquatic organisms and ecosystem (Yang et al. 2016). For example, about 5.3% of the UK environmental polycyclic aromatic hydrocarbon burden is ultimately associated with freshwater sediment (Wild and Jones 1995). More than 99% of aquatic heavy metals are stored in the sediment in various forms (Salomons and Stigliani 2012). In addition, sediments are polluted by

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eutrophication due to the adsorption of agricultural nutrition like nitrogen and phosphorus (Mateo-Sagasta et al. 2017). Hence, sedimentation management is of critical importance not only for the sustainable development of freshwater resources, but also for the freshwater flora and fauna and the entire water ecosystem.

Sediment dredging is the most commonly used method not only to maintain the sailing depth and flood capacity but also to rapidly reduce the pollution stress (Olsen et al. 2019). For a long-term perspective, proper dredging management has a positive impact on the ecology, water transparency, sediment balance, nutrient budgets, and river morphology downstream of the reservoir (Sumi and Hirose 2009). However, the sediment dredging is still very controversial due to the uncertain negative effects. The agitation and removal of the sediment will dramatically accelerate the secondary release of pollutants in the sediment in a short period of time and seriously change the living environment of benthic microorganism, animal and plant communities (Wang et al. 2014). Environmental window concept has been proposed to protect sensitive biological resources or their habitats from potentially detrimental effects of dredging and disposal operations soon after passage of the National Environmental Policy Act in 1969 (Reine et al. 1998).

The effect of dredging on polluted water bodies is the focus of dredging research and application. Due to the far-reaching effects of dredging on freshwater systems, it is necessary to review and study the relevant literature and make some policy recommendations. This paper systematically reviews the literature on sediment dredging and categorizes its impacts. The impacts of dredging are centered around nutrients, heavy organic matter, and biological communities. The paper also considers short-term and long-term impacts. This paper elucidates the mechanisms underlying changes in the types and levels of various substances in freshwater systems before and after dredging. The paper will contribute to the identification of potential environmental risks associated with bottom dredging.

Research trend of freshwater dredging engineering

Sediment dredging engineering refers to a series of activities such as determining the depth and volume of dredging in an exact area, selecting reasonable dredging equipment, and formulating corresponding secondary pollution prevention programs such as avoiding diffusion and resuspension of fine particles (Yell and Riddell 1995). Therefore, different dredging designs and different dredging equipment have different environmental impacts.

Thematic bibliometrics (a common tool to assess scientific production through mathematical and statistical methods) (Pritchard 1969) was used to identify the growth and hot topic in the field of freshwater sediment dredging. Web of Science (WOS) core collection was chosen as the sources of literature database. The search strategy (TS = "fresh*water" or "river" or "lake" or "reservoir" or "wetland" and "sediment* dredge*") was used to search the related research from their title, abstract, or keywords, in a time span of 1900–2021. In order to pursue valuable literature, the abstracts of references were browsed to identify and discard repetitive research as well as publications in other fields. A total of 1453 publications were identified as being related to freshwater sediment dredging distributed in 61 Web of Science categories. The distribution of research in the top 10 fields can be seen in Fig. 1a. It is obvious that

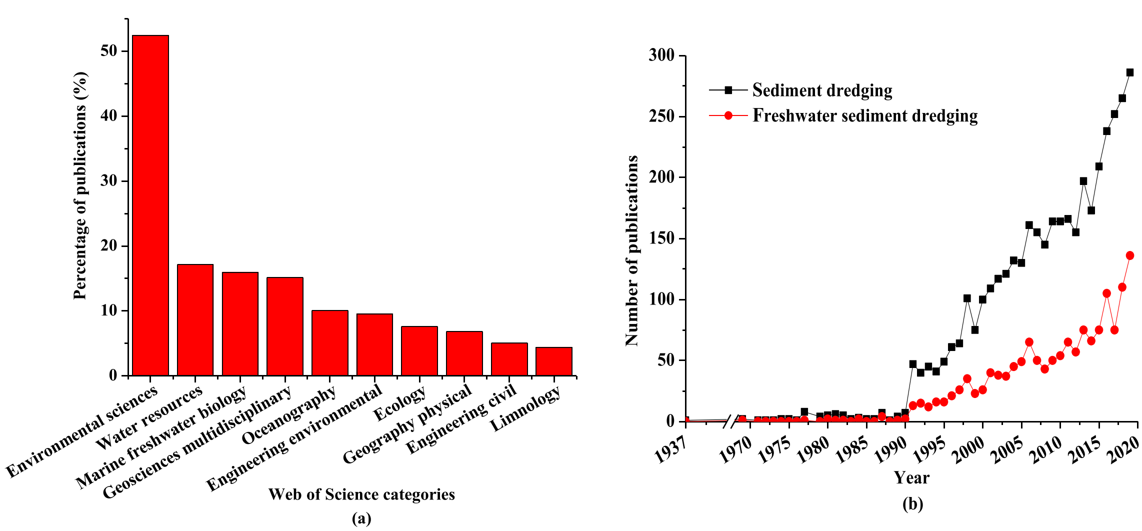

Fig. 1 **a** The publication distribution in Web of Science categories. **b** The growth trend of the publications

environmental science studies were dominant, with the contribution of 52.44% of the total selected publication.

In order to contrast with related research on sediment dredging that not just freshwater, we changed the search strategy to (TS = "sediment* dredge*") with other conditions unchanged. The growth trend of related research can be seen in Fig. 1b. Research on marine sediment dredging dates to 1937, and research on freshwater sediment dredging dates to 1969. From 1990 the aqueous sediment dredging has attracted international attention and entered a rapid development period. Not only from the perspective of research history but also from the perspective of publication volume, the development of freshwater sediment dredging is relatively weak. Therefore, it is necessary to draw on the relevant experience of marine sediment dredging based on a comprehensive summary of the problems related to freshwater sediment dredging.

Effects of dredging on physicochemical properties of freshwater systems

Hydrological characteristics and basic physicochemical indicators

Due to dredging excavation, large holes are formed at the dredge site in the basically flat-water bottom. Water velocities increased at the leading edge of the hole and accompanied by upstream erosion, caused by the increased gradient of water bottom (Fischer et al. 2012). Whereas, water velocities are decreased within the dredge hole, which allows the suspended sediments to fall out of the water column. Afterwards, the sediment-starved water erodes the tail end of the hole when it leaves the hole with rein creased velocities.

The resuspension of riverbed material due to dredging is a non-negligible negative impact. It can lead to turbidity (Pennekamp et al. 1996; Lu et al. 2019), which regulates light transmission in the water and thus affects photosynthesis in submerged vegetation (Erftemeijer and Lewis III 2006). However, due to the complexity of climatic conditions, the width and depth of the watercourse, and upstream and downstream topography, it is difficult to determine the degree, diffusion, reduction of turbidity and its impact on the entire watershed (Grasso and Le Hir 2018; Vagge et al. 2018). Dredging also affects hydrothermal patterns. This is mainly due to the fact that increased water depths and expanded water volumes result in much slower channel flow rates and reduced vertical mixing (Kaur et al. 2007). Ding et al. (2019) found the temperature continues to decline throughout the whole dredging period, which is not immune to impact the input and decomposition of nutrient and furtherly alter the biological activities (Brönmark and Hansson 2002). In addition, dredging can cause noise and stench.

Physicochemical properties of pH, dissolved oxygen (DO), and oxidation reduction potential (Eh) in undredged (UDR), freshly dredged (FDR), and post-dredged (PDR) sediment–water interfaces are commonly used observation indicators. The mean pH values in FDR and PDR water were lower than UDR (Ding et al. 2018; Saeki et al. 1993). The UDR area has a lower pH from 9.13 to 8.51 than the dredged area under the same climatic conditions (Chen et al. 2018). However, the contradictory result has been reported in the literature that the impacts of hydraulic dredging on surface water pH was negligible (Zhang et al. 2010a; Lewis et al. 2001). It can be speculated that the change of pH value is mainly determined by the content of acid-volatile sulfides in the sediment. The enhanced acidity of the FDR and PDR water is caused by the exposure and oxidation of the acid-volatile sulfides in the original bottom sediments, resulting in the release of a large amount of hydrogen ions (Gambrell et al. 1991; Borma et al. 2003). The most reactive fraction of sulfides in natural sediments is primarily FeS, and its oxidation process is as following (Eq. 1) (Tao et al. 2005).

$$\begin{aligned} &FeS_2 + 14Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + 2SO_4^{2-} + 16H^+ \\ &FeS + 8Fe^{3+} + 4H_2O \rightarrow 9Fe^{2+} + SO_4^{2-} + 8H^+ \end{aligned} \quad (1)$$

DO in UDR was reported lower than that in FDR and PDR water under the same aeration frequency. It was reported that DO was increased rapidly to saturation level of 8.6 mg l^{-1} around the fourth day after dredging (Tao et al. 2005). Whereas, different results in other researches have shown that the DO in FDR was the lowest among these three stages (Jing and Li 2016). On one hand, the short-term oxygen consumption of reducing substances in the exposed deep sediments will induce the decrease of DO in the water system (Morgan et al. 2012); on the other hand, the turbidity caused by dredging will also reduce DO through inhibition of photosynthesis by hydrophytes and phytoplankton (Meng et al. 2018). But, from a long-term perspective, dredging has the potential long-term effect of reducing dissolved oxygen depletion capacity (Liu et al. 2006). Therefore, it is recommended that the dredging course should be avoided in the summer to avoid high biological activity that can aggravate the water's hypoxia (Kaur et al. 2007; Chen et al. 2018). Many pieces of research have shown that DO is a crucial factor influencing the Eh value, and a positive correlation between these two factors was found (De Jonge et al. 2012; Eggleton and Thomas 2004). The enhancement of Eh was likely attributed to a rapid and significant increase in DO in the water (Pourabadehei and Mulligan 2016).

Concentration and speciation of nutrients

Dredging can remove surface sediments, which usually contain a high content of organic matter. Hence, it has been wildly used to address the troublesome issue in eutrophic watersheds (Peimin et al. 2000; Zhang et al. 2010a; Liu et al. 2015a; Holmer et al. 2003). The most typical elements of the limiting nutrients in eutrophic freshwaters are nitrogen and phosphorus (Schindler 1971; Zhang et al. 2013; Tyrrell 1999). Transportation and transformation process of nitrogen and phosphorus in freshwater is shown in Fig. 2. The concentration and speciation of nutrients in the watershed are directly and indirectly affected by dredging engineering, due to the disturbance for photosynthesis, bioaccumulation, high-content surface sediment removal, resuspension, etc. Many studies have strived to explore the nutrients accumulation and transformation in pore water and overlying water to evaluate the short-term and long-term effectiveness of dredging (Wang and Feng 2007; Yenilmez and Aksoy 2013; Recknagel et al. 1995). Yu et al. (2016) have suggested that nitrogen cycling rate in sediments was slowed down by the excavation of sediment which contains a lot of organic matter deposition and microbial community. However, the effectiveness of sediment dredging on eutrophication is still debatable. Contradictory results have been suggested among various studies, and these discrepancies may be attributed to the implications of pollution status of the sediments and dredging technics (Fan et al. 2004; Lohrer and Wetz 2003; Peimin et al. 2000). For example, in the overlying water, the phosphorus concentrations decreased from 0.127 to 0.081 mg/L in April, while nitrogen concentrations increased from 1.84 to 2.38 mg/L in October, and the trends of nitrogen/phosphorus rise or fall are completely different in different seasons (Chen et al. 2018). And the removal of surface sediments did not significantly reduce the concentrations in sediment pore water (Chen et al. 2018). Many studies proved that the nitrogen concentration will increase in the short term after dredging because of disturbance and suspension, but it will decrease in the long term (Jing et al. 2019; Morgan et al. 2012; Zhong and Fan 2007). Reddy et al. (2007) confirmed that the net phosphorus release or retention was linearly related to the rate of phosphorus loading/initial sediment concentration. Even though, removal of the top 30 cm of sediment can remove approximately 65% of total phosphorus sediment storage. When the loading rate was as low as 9.4 mg/m^2/year, a linear increase in phosphorus release occurred during the first 156 days after dredging (Reddy et al. 2007). Kleeberg and Kohl (1999) also argued that dredging of surface sediments alone will not reverse eutrophication, unless external loads are also curtailed. Therefore, the reduction of external loads is a key factor for the ultimate effect of dredging on nutrients limitation.

In addition, the distribution of nitrogen in different common forms in the freshwater system (NH_4^+, NO_3^-, NO_2^-, and organic N) is also affected by the dredging projects, and this effect is only short-term (Voutsa et al. 2001; Yu et al.

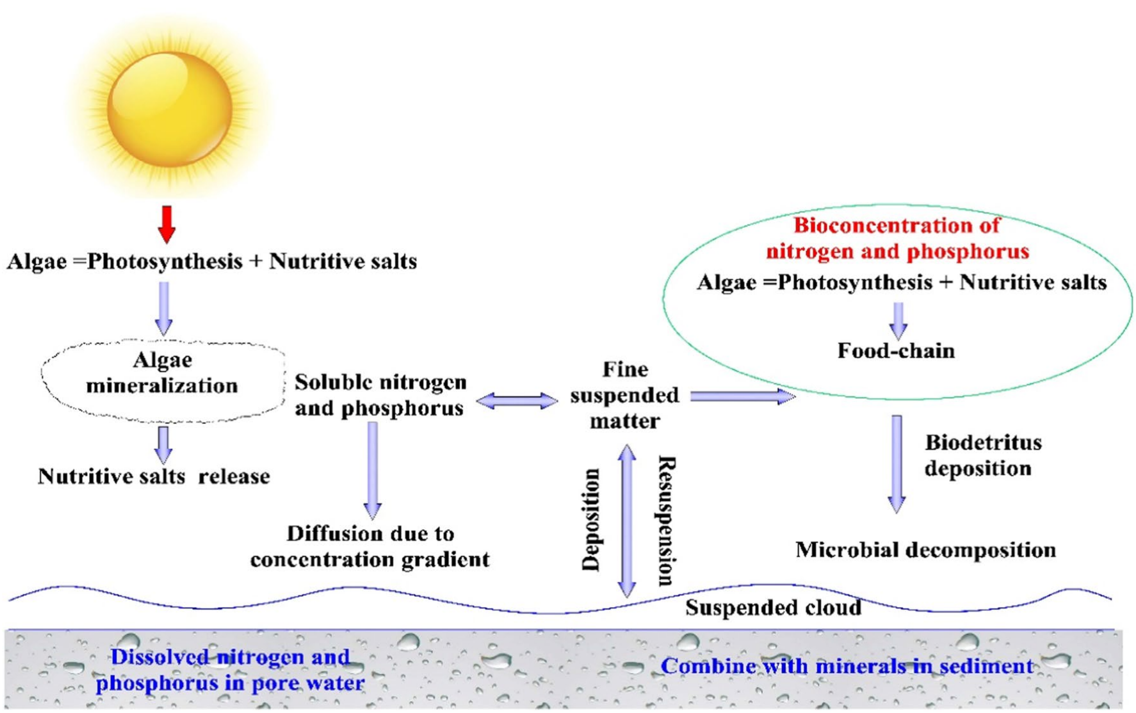

Fig. 2 Transportation and transformation of nitrogen and phosphorus in the freshwater system

2016). And the denitrification was weaked in the dredged sediment–water systems which declined the attenuation of nitrate and further enhanced the nitrate content. Yu et al. (2016) also discovered that the fluxes of $NO_3^- - N$ from PDR sediments to overlying water significantly increased by 58% and the corresponding fluxes of $NH_4^+ - N$ decreased by 78.2% after dredging. However, this result is dramatically related to the external N loadings and the re-sedimentation of suspended particles. Liu et al. (2019) found that the labile $NH_4^+ - N$ concentration increased from 128.24 mg g^{-1} to 296.75 mg kg^{-1} in the surface sediment after dredging and the ammoniacal nitrogen concentrations in pore water of two dredged groups with external loadings were higher than those of UDR groups. Rise of $NH_4{}^+$ concentration may be attributed to the two reasons. Ammonia is predominantly present as $NH_4{}^+$ loosely bound onto the circumneutral sediments as an exchangeable fraction, which is easily resease into waters disturbed by dredging. And organic nitrogen compounds and oxides release $NH_4{}^+$ by dissolving oxygen (Eq. 2) (Choppala et al. 2018).

$$(CH_2O)_a(NH_4^+)_b + aO_2 \rightarrow aCO_2 + bNH_4^+ + aH_2O \qquad (2)$$

The effects on fractions of phosphorus in the water–sediment system were also well studied similar to the researches on the accumulation and transformation of nitrogen during dredging engineering. Wen et al. (2020) reported that after dredging, the content and proportion of mobile phosphorus (the sum of NH_4Cl-P, *Fe–P* and *Org-P*) in the surface sediments were significantly reduced. Attribute to the improvement of DO, the *Org-P* in the surface sediment of FDR release soluble phosphorus rapidly (Eq. 3), while the *Fe*(*II*) monosulfides rapidly oxidized to *Fe*(*III*) oxide minerals possessed stronger retention capacity for PO_4^{3-}, which in turn decreased the phosphorus concentration in the overlying water. Moreover, the mineralization of *Organic-P* is easily adsorbed and combined with calcium ions and converted into Ca-P and Residual-P resulting in the transformation of phosphorus from active to inert fractions. However, the proportion of labile phosphorus (diffusive gradients in thin films and soluble reactive) in pore water of the FRD group was enhanced due to the release of phosphorus from the resuspended matter. But the external loading identically diminished the effectiveness of dredging.

$$(CH_2O)_a(H_3PO_4)_c + aO_2 \rightarrow aCO_2 + cH_3PO_4 + aH_2O \qquad (3)$$

Activation and release of heavy metals and organic pollutants

Sediment dredging is one of the most used means to control endogenous pollution. It removes contaminated river sediments and reduces the possible flux of heavy metals. (Ding et al. 2015a). But some scholars believe that thin layer dredging could temporarily reduce total sediment metal concentrations but not heavy metal bioavailability. Heavy metals do not degrade during dredging but transform between soluble and insoluble forms (Peng et al. 2009; Akcil et al. 2015). Continuous extraction, vitrification, and thermal and biological treatments are often used for the assessment and treatment of heavy metals in sediments (Mulligan et al. 2001; Meers et al. 2005; Kim et al. 2011). Studies have shown that the sediment dredging operation has induced the resuspension of sediment particles. These contain heavy metals deposited by sulfate or adsorbed on organic matter. The root cause of heavy metal pollution that cannot be alleviated after dredging may be the resuspension of the contaminated sediments. Similarly, Liu et al. (2016a, b) have found that heavy metal concentrations (As, Cd, Cr, Cu, Ni, Pb, and Zn) in the FDR surface sediment increased to UDR levels with the influence of metal-adsorbed suspended particulate matter, especially Zn and Cd increased 482.98% and 261.07%. Although the total metal content in the dredged sediment is greatly reduced, the increased heavy metal concentrations were mostly in the relatively bioavailable non-residual fractions (Yu et al. 2019). Wasserman et al. (2013) even straightforwardly points out that the dredging of contaminated sediments is a harmful activity for the environment largely due to the contaminant's resuspension and bio-uptake.

The release mechanism probably depends on the characteristics of metal-adsorbed suspended particulate matter including fine grain size and the pollutant contents (Liu et al. 2016a, b). In the simulation study conducted in Lake Taihu, Yu et al. (2019) figured out that the release of heavy metals after dredging was attributed to the migration of metal sulfides in the deep sediments that are anoxic. Dredging introduces oxidized water, which increases oxidation. This causes sulfide-bound metals to be dissolved by sulfate-reducing bacteria (SRB) into available volatile sulfides (AVS) (Fig. 3). However, the concentrations of trace elements in the water column were not affected by dredging, except for Cu and Zn, which were attributed to the pH neutrality of the sediment and the formation of metal sulfides that were strongly retained in the solid phase (Choppala et al. 2018). In addition, the impact of dredging on the release of heavy metals is also strongly related to time and season. Chen et al. (2019a, b) pointed out that dredging in winter had a positive impact on the release of Co, Zn, and Ni, with the largest increase in soluble Zn and Co in the overlying water in January after dredging, an increase of 166% and 69%, respectively. Sun et al. (2019) also confirmed that dredging effectively remediated metalloid contamination (arsenic, selenium, and antimony) in sediments only in April, July, and/or January, but negligible/negative effects were seen in October. The impact of time and season on the release of heavy metals might be

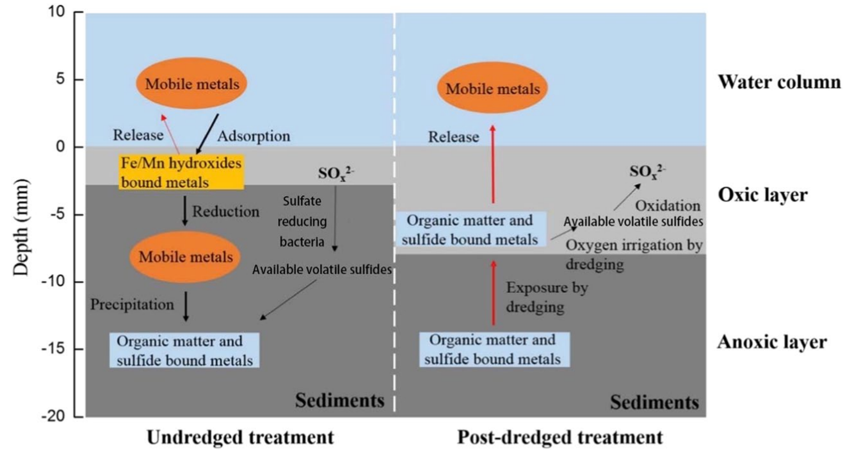

Fig. 3 The effects of dredging on the migration and transformation of heavy metals (Yu et al. 2019)

caused by the degradation of algae in autumn and winter, because the decomposition of algae might reduce oxygen saturation, thereby accelerating the release of metals in sediments (Chen et al. 2019a, b; Yang et al. 2020). Furthermore, after dredging, the influx of high-level metal adsorbed suspended particulate matter from exogenous polluted rivers may also adversely affect the sediment–water interface, thereby increasing the risk of heavy metal pollution in the water environment (Liu et al. 2016a).

In addition, owing to the organic pollutants such as polycyclic aromatic hydrocarbons are hydrophobic, they are more likely to settle and accumulate in sediments (Kafilzadeh 2015), which means that like heavy metals, during the dredging process, the resuspension of sediment, the release of pore water in the bottom sediment, and the adsorption of suspended and resuspended substances will all cause the re-release and diffusion of organic pollutants (Qi et al. 2011). Many studies have confirmed this. Ruocco et al. (2020) believed that dredging might result in the resuspension of sediments and the release of organic pollutants such as polycyclic aromatic hydrocarbons, polychlorinated biphenyls, and organotin compounds, allowing them to diffuse into the water column, which may affect the water environment. Cutroneo et al. (2015) confirmed that dredging was the key factor of rising the mobilization of polycyclic aromatic hydrocarbons concentrations in the water column. This is because dredging removes the surface sediment layer, allowing the organic matter in the deeper sediment layer to be released into the overlying water column (Zhong et al. 2010). Two to three rings polycyclic aromatic hydrocarbons (PAHs) (maximum value 0.105 μg/L) presented the largest concentration in dredging operations and then decreased rapidly because it was more soluble in water, more biodegradable and easier to evaporate, while four rings PAHs predominated at the phase of PDR with the average concentration of 0.057 μg/L (Vagge et al. 2018). The variation of PAHs in the overlaying water can be seen in Fig. 4.

Disturbance to biotic communities

The ecological effects of substrate dredging are also reflected in changes in benthic fauna, phytoplankton species and abundance, and biomass and community structure in the water column. Aquatic biotas govern the cyclic processes of nutrient, energy and organic matter and maintain the dynamic balance of water system. Dredging has the potential to impact aquatic biota through direct entrainment into the dredges and indirectly altering the water and sediment habitats, respectively (Manap and Voulvoulis 2014). For instance, the effects on certain aquatic organisms can be catastrophic due to the increased water turbidity caused by dredging, which interferes with the predation and respiration of some aquatic fauna (Aldridge 2000) and the photosynthesis of submerged vegetation and algae (Freedman et al. 2013). Dredging can also cause macrophyte beds and invertebrates habitats to be destroyed and fish lost, as sediments are removed (Freedman et al. 2013). Additionally, dredging disturbance could significantly change the composition and structure of sediment communities. Given the ecological relevance, changes in overall community trophic and functional structure can eventually affect the entire biological chain (Coates et al. 2015). Such impacts can take decades to recover (Haynes and Makarewicz 1982; Boyd et al. 2005; Waye-Barker et al. 2015), and even when abundance, biomass, and species numbers recover, the original composition, structure, and ecosystem may have been disrupted (Barrio-Froján et al. 2008, Barrio-Froján et al. 2011), and such impacts are long-term (Szymelfenig et al. 2006). For instance, the study of Zhang et al. (2017) indicated that dredging could stimulate aerobic populations but repression of anaerobic groups, resulting from increased sediment dissolved oxygen and oxidation–reduction potential, and one year after the dredging, the microbe and macrobenthos communities had reached alternative state instead of returning to their original state. Therefore, the effect of dredging on biotic communities is a very serious issue that deserves attention.

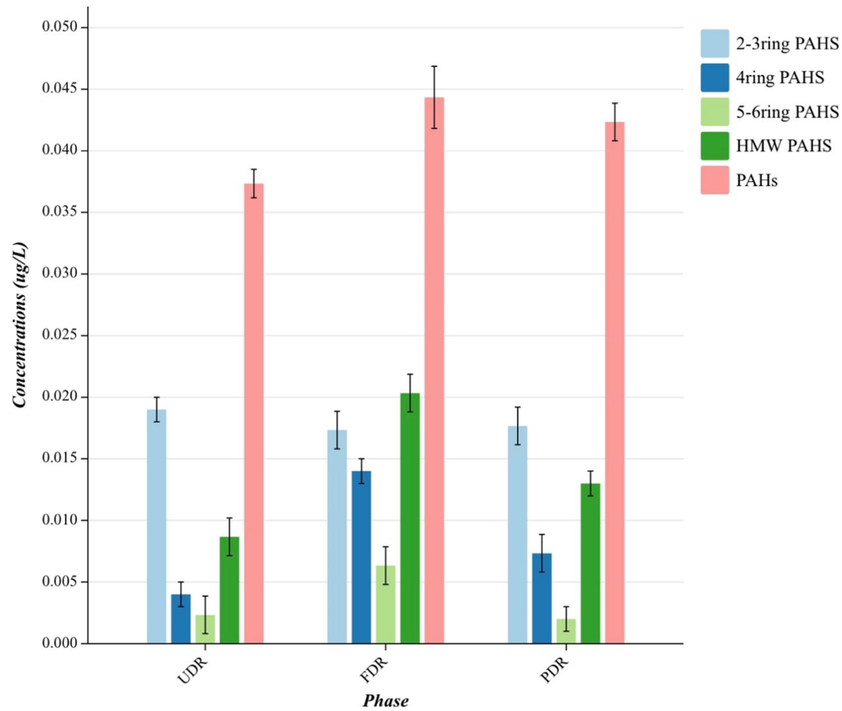

Fig. 4 Concentrations of PAHs according to the number of rings (2–3 rings, 4 rings, 5–6 rings, and HMW (high molecular weight)) during phases UDR (undredged), FDR (fresh dredged), and PDR (post-dredged). Data quoted from (Vagge et al. 2018)

Fishes and invertebrates

Fishes

Freshwater fisheries are globally important ecosystem services with subsistence, commercial and recreational value. Fish are part of a complex ecosystem of interconnected habitats and organisms; hence, perturbation from sediment dredging threats fish populations through pathways (Fig. 5). Dredging can lead to the loss of fish habitat (Erftemeijer and Lewis 2006; Erftemeijer et al. 2012). Habitat degradation and loss can have a significant impact on fish communities (Galzin 1981). Suspended sediments from dredging reduce fish response distances and visual acuity negatively impacting pelagic fish foraging (Sweka and Hartman 2003; Zamor and Grossman 2007). In addition, suspended sediments can damage gill structure and tissue with physiological effects on exposed fish (Hess et al. 2015). Freedman et al. (2013) quantified the differences in fish assemblages sampled by benthic trawls among dredged and undredged sites in the Allegheny River, Pennsylvania, USA by ecological metrics and stable isotope analysis. The results suggested that the habitat loss caused by gravel dredging reduced the benthic fish abundance and diversity due to the lack of suitable spawning habitat or reduced foraging efficiency. Hayer and Irwin (2008) reported that instream gravel dredging contributed to 38% of the species variation in detection probabilities of 87 Piedmont and Coastal Plain fishes collected in four Alabama streams of the Mobile River drainage, and fish species that prefer riffle habitat and coarse substrate were lower in dredged areas, whereas species that preferred fine substrate were more abundant in dredged areas. Conversely, dredging operations may provide multiple habitat types; thus, the response of fishes to dredging is unclear (Rempel and Church 2009). The high-velocity habitat directly upstream of the nickpoint may be beneficial to lotic fish species, while lentic species prefer to be present in dredge holes (Paukert et al. 2008). Additionally, the majority of these studies were conducted in small scale rivers and short-term effects. Kjelland et al. (2015) reviewed those numerous studies have demonstrated the effects of suspended sediments during dredging on exposure and mortality rates of affected fish, deposited eggs, or larvae, and the long-term effects on epigenetic changes should be further conducted.

Benthic fauna

The survival of most benthic communities requires a suitable habitat, such as a certain amount of organic sediment, while excessive dredging could pose a large-scale anthropogenic disturbance to it (Zhang et al. 2014). In particular, the macrobenthos (> 0.5 mm) are used as important indicators of dredging disturbance because they inhabit different substratas exhibit varied behaviors and feeding patterns in response to their different functional needs. And macrobenthos play crucial role in the nutrient recycling, secondary production and pollutant metabolism, dispersion, and burial (Rehitha et al. 2017). Dredging would have some short-term effects on the benthic fauna. For example, benthic animals were removed directly (Jing et al. 2019), resulting in a decrease

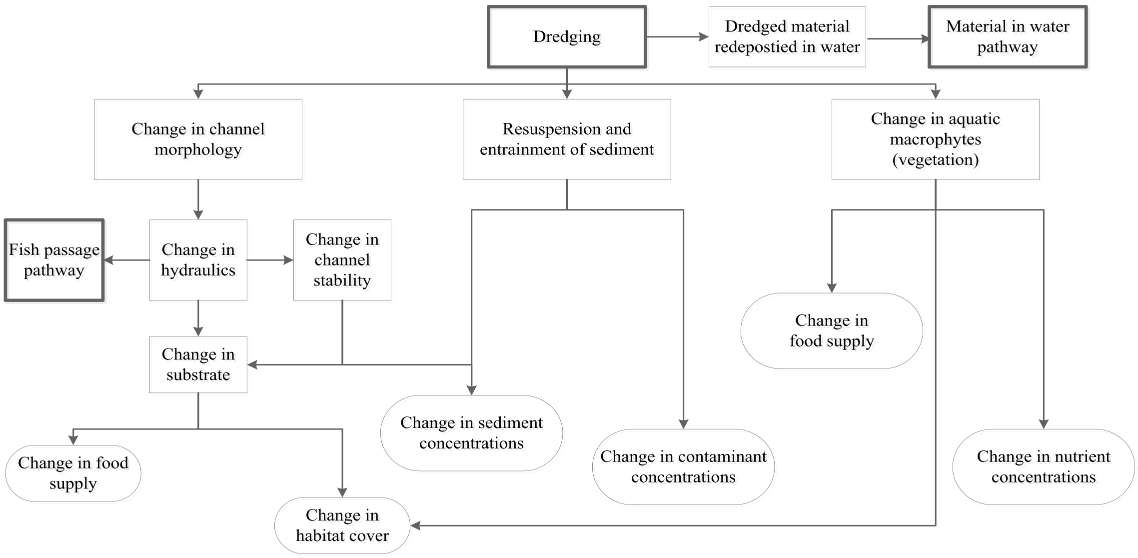

Fig. 5 Potential effects of dredging on fish and fish habitat generalized by Fishers and Oceans Canada (referenced from (Ward-Campbell and Valere 2018))

in abundance, which was directly related to dredging disturbance events (Lewis et al. 2001; Freedman et al. 2013; Rehitha et al. 2017; Bettoso et al. 2020). Meng et al. (2018) proved that there was an alteration in the composition and a reduction in biodiversity of the benthic fauna in the disturbed area, while at the same time, an increase of them in the nearby region, which further shows that benthic communities are more willing to avoid unfavorable living environments. Dredging also completely destroyed the habitat, leading to long-term disruption and alteration in the benthic community, which might need to take several years to recover, with the possibility of never recovering (Ceia et al. 2013), profoundly affecting aquatic ecosystems (Zhang et al. 2014). There are studies having demonstrated that benthic communities were very sensitive to the disturbance of dredging (Zou et al. 2019). For example, many macroinvertebrates live in the sediment for a long time, and the ability to avoid the negative effects of dredging is very weak due to the regular staying still. Moreover, habitat degradation caused by dredging could impede the recolonization of macroinvertebrates, therefore, there would be a considerable decline of the number of macroinvertebrates after dredging (Zou et al. 2019). In addition, for the molluscs, dwelling in the bottom of the water body lead to their preference for a stable substratum, so the unstable substratum caused by dredging would contribute to the decreased density of molluscs (Rehitha et al. 2017).

The adverse effects of dredging on benthic organisms are a major concern for many scholars. Ceia et al. (2013) pointed out that an obvious consequence of dredging activity was the short-term decrease in species density and biomass. Although the number, diversity, and ecological index of the microbenthic communities would gradually return to pre-dredging situation after 2 months of dredging, the macrofauna composition and structure were still dissimilar, and the new assemblage might not have the same ecological functions. This may be attributed to the fact that dredging provides a window of opportunity for new species, enabling them to settle in physically disturbed areas and benefiting from the imbalance of the initial population (Piló et al. 2019). It can be seen that the disturbance caused by dredging contributed to the reduction of sensitive species, with replacing them with tolerant species (Licursi and Gómez 2009; Netto et al. 2012). During the dredging of South Lake Dongting in China, Meng et al. (2020) found that the structure of microbenthic taxonomic and functional assemblages would be strongly affected by the disturbance process, resulting in the simplification of the macroinvertebrate functional structure in the dredging area, which can be proved by the loss of certain feature categories. Therefore, dredging has profound negative effects on benthic communities, and necessary measures should be taken to reduce these effects during the dredging process, such as avoiding breeding period and controlling dredging depth to reduce the destruction of biological habitats.

Zooplankton

In water ecosystem, zooplankton is an important contributor to energy transfer from primary producers to higher nutrient levels (Nandy and Mandal 2020; Abdullah et al. 2017; Degerman et al. 2018), and zooplankton species, abundance, and biomass are often used as important indicators to assess water quality due to its high density, short life span, natural drift and high sensitivity to environmental fluctuations (Gorokhova et al. 2016; Ptacnik et al. 2009). The trophic state of the water column is a key factor affecting the zooplankton community and changes in environmental conditions caused by dredging may lead to changes in the zooplankton community (Karr 1981; Sládecek 1983). Zooplankton abundance and dominant populations can also be a useful indicator of the impact of human activities on the ecology of a water body, and changes in water environment factors can also affect zooplankton community structure (Suikkanen et al. 2007). Zooplankton abundances are higher in the UDR than in PDR areas reduced by large-scale dredging (Lurling et al. 2017). For example, Zhang et al. (2010b) proved that the decrease in the abundance of rotifers was a response to dredging. This appears to be attributable to a reduction in food supply. Because dredging would change the resource utilization and nutritional pathways within the food web (Freedman et al. 2013), which is closely related to the zooplankton community composition. In addition, the polluted suspended sediment caused by dredging contains heavy metals, organic pollutants, etc., which are toxic to plankton including copepods, and it is also one of the reasons for the negative impact of zooplankton (Sew et al. 2018).

Aquatic plants

As a major producer of aquatic ecosystems (Wu et al. 2019), phytoplankton plays an important role in the water environment, and it is considered to be an effective indicator of water ecological changes (Cabrita 2014) due to its quick response ability (Cabrita et al. 2013). Take phytoplankton with simple structure like microalgae as an example, it is considered to be an universal and reliable indicator of the watershed system ecology for their wide distribution, quick generation time, distinct community structure, and specific response to habitats conditions (Thomson and Manoylov 2019). Hence, sediment dredging projects could have an inevitable negative impact on phytoplankton by disturbing water bodies and sediments. For example, the resuspension of contaminated sediments caused by dredging could result in observable toxicity (Nayar et al. 2004), which changed the phytoplankton community structure (Cabrita 2014), particularly influencing the small phytoplankton cells (Lafabrie et al. 2013).

There are studies that have pointed out that, compared to the UDR conditions, the concentration of Cu, Cd, Hg, and Pb in the phytoplankton cells in the PDR environment was significantly higher (Cabrita et al. 2014), which would significantly inhibit the growth rate of the cells, thereby limiting the growth of phytoplankton (Cabrita et al. 2013). This shows that the metal elements released during the dredging process did affect the physiology of phytoplankton. Moreover, Nayar et al. (2004) had also proved that bioavailable heavy metals in the resuspended sediments after dredging might have a large-scale negative impact on the biota, especially on phytoplankton. In addition, there are also reports on the impact of dredging on phytoplankton biomass and abundance. Thomson and Manoylov (2019) believed that dredging could result in the observed diatom species richness to decrease, and the results of the study in Chen et al. (2015) showed that due to frequent anthropogenic activities such as dredging, the species of phytoplankton decreased significantly, especially the diatoms, decreased by 70%, accounting for most of the decreased species of phytoplankton in the Changjiang Estuary. Furthermore, Jing et al. (2019) proved that during the dredging of the South Lake, the phytoplankton biomass decreased with time as the dredging project progressed, and the phytoplankton biomass reached the lowest value when the dredging project was completed.

Another important pathway of the impact is that suspended particles caused by dredging are usually finer than natural coarse sediments. It can seriously decrease the light availability of benthic algae, inhibiting the biomass of these microphytes (Robinson et al. 2005), and these suspended particles might take longer to settle out of the water column (Cunning et al. 2019). The benthic diatoms could be adversely affected as well. In the process of dredging, the increase of turbidity and suspended solids would reduce the penetration of light, causing the density of benthic diatoms to drop immediately after dredging (Licursi and Gómez 2009).

On the contrary, some studies have proved that dredging would not lead to a decrease in phytoplankton biomass, especially in the short term. Lafabrie et al. (2013) believed that brief sediment resuspension events caused by dredging might be beneficial to phytoplankton communities, because although the contaminated sediment would bring about the release of toxic chemicals into the water, it could also strongly stimulate phytoplankton growth within a few hours. However, they also pointed out that the beneficial effects were only short-term, and in the long-term, dredging is still harmful to this important autotrophic component due to toxicity.

Microorganisms

The microbial communities play important roles in the function of lotic ecosystems and become key players in nutrient cycling by the function of decomposing organic matter and degrading various pollutants (Liao et al. 2020). In the water environment, they can affect the circulation of nutrients such as nitrogen, phosphorus and carbon through metabolic activities, further affecting the biogeochemical cycles in sediments, and in turn affect the microbial community themselves (Liu and Yang 2020). Environmental genomics also regards microbial communities as potential biological indicators of environmental conditions (Baniulyte et al. 2008), because the composition and functional characteristics of the microbial community would change following a drastic habitat disturbance (Sui et al. 2020). For instance, in the process of dredging, the ecologically-meaningful planktonic microbial could quickly respond to the resuspension of sediments caused by dredging disturbances, such as a rapid decrease in abundance; therefore, it can be used as a useful tool to evaluate the impact of dredging on the ecosystem (Layglon et al. 2020). Liao et al. (2020) believed that sediment dredging might immediately lead to a significant loss of microbial diversity, because of the greater vulnerability of water microbial communities under intensive watershed disturbances. Studies have also proved that some microorganisms attach onto the surface of suspended sediments for a long time by secreting sticky extracellular polymeric substance, and the number was even 4 to 7 times that of free-floating ones (Lind and Dávalos-Lind 1991). Therefore, the dredging to remove sediments would inevitably cause the loss of microorganisms.

However, for the total microbial biomass, there might be no significant change after dredging (Baniulyte et al. 2008), since the pollutants and nutrients in the surrounding environment were easily absorbed by the suspended sediments in the water body, which contributed to the growth of microbes and improved the survival rate of them (Ramalingam and Chandra 2018). Nevertheless, this could not avoid the negative effects of dredging, owing to the significant changes in the structure and diversity of microbial communities. The study of Wan et al. (2020) indicated that, after dredging, although the plankton bacterial community might display stronger resistance to environmental changes in the short term on account of the insignificant correlation between the physicochemical factor and bacterioplankton community function, in the long run, dredging decreased the diversity and function of the bacterioplankton community, and led to nutrient deficiency, further causing a decline in the regulation of the bacterioplankton community. This phenomenon might imply that microbial community did not have stronger anti-interference ability, and there was a high possibility that it could not return to the initial stable state after dredging. In addition, the dredged cores were extremely susceptible to disturbance, which would cause the microbial community on the sediment surface before dredging to be unable to recover for a long time in the future (Qian et al. 2012). Zhang et al. (2017) also deemed that, after dredging, the micro eukaryotic and as bacterial communities were different from their original state. And one of the reasons that caused community change but the possible exception of biomass might be community succession, where sensitive species were replaced by more tolerant species, which was also one of the responses of microorganisms to the disturbance of dredging (Zhang et al. 2017). In general, the impact of dredging on microorganisms is relatively large, but not many studies have been reported so far. Therefore, the microbial response to dredging interference should be further explored in the future.

Problems and suggestions

As a common engineering method to control internal load of nutrients and pollutants, sediment dredging has been used in many freshwaters. Although positive effects have been achieved, there are still the following problems, including (1) dredging can expose deep sediments to the overlying water, change the physicochemical environment, and release and activate various elements such as nitrogen, phosphorus, heavy metals, and organic pollutants at the sediment–water interface. (2) Based on the above negative impacts, dredging will further irreversibly affect the biomass and community structure of aquatic organisms in freshwater. For this reason, prior to the dredging operation, a preliminary assessment should be made to reasonably predict the dredging parameters including the dredging time, depth, and frequency, so as to find an optimized dredging method to minimize the negative effects of dredging. Below are some suggestions and directions for future research.

1 Determine a reasonable dredging depth

Generally speaking, the concentration of contaminations in sediments gradually decreases as the depth increases. Even though the dredging depth needs to be deep enough to effectively remove contaminations from sediments. However, when it exceeds a certain limit, the deeper the dredging depth is, the more serious the damage to the ecosystem will be. Conversely, if the dredging depth is too shallow, it will not only fail to remove the polluted sediment, but also aggravate the contaminant release. The study of Liu et al. (2015) proved that in Lake Taihu, China, dredging at different depths had significantly different effects on preventing black flowers. And the control effect is the best when the depth was 22.5 cm, the result might attribute to the low levels of acid-volatile sulfide (the most important limiting factor for the occurrence of black flowers in the overlying water) in the sediments after dredging, which reduced the release of hydrogen sulfide to the overlying water. In terms of the control of heavy metal pollution, the dissolved organic matter released from sediments with a depth of 20–30 cm was proved to possess a higher metal binding capacity than those from surface layer sediment. The biological toxicity related to the free ion activity after dredging was reduced (Xu et al. 2016). And Ding et al. (2015) calculated the dredging depth of ten heavy metal-polluted rivers in Pinghu, Zhejiang Province, based on the critical-risk-depth method, and the result suggested that the dredging depth of the ten rivers should be within the range of 35 to 100 cm in order to minimize ecological risks. The depth of dredging can affect different freshwater lakes or areas differently.

Therefore, field investigations and experimental studies are essential before dredging. Specifically, we need to understand the physical characteristics of the sediments at the dredging site, the current and wave conditions, and the vertical distribution and concentration of the contaminants. Then, we need to analyze and estimate the distribution of target contaminants in the sediment profile and their ecological risks. Finally, based on the above information, we determine the appropriate dredging depth for optimal dredging.

2 Choose the right dredging season

In order to reduce pollution, it is significant to choose the season of dredging reasonably. For example, shortly after dredging, the concentration of $NH_4{}^+$-N in pore water will increase, and this release rate will be highly exacerbated in summer (Liu et al. 2016a, b). Based on this reason, the dredging should be carried out in the lower temperature season. And for benthic organisms, winter is the best option because it avoids the breeding period and the growth period of larvae. Dredging work in winter could minimize the impact on aquatic organisms. However, the research of Chen et al. (2019a, b) on the dredging effect of Lake Taihu proved that the capability of dredging to control heavy metal pollution fluctuated over seasons, being positive in spring and summer and negative in winter. Chen et al. (2019a, b) also believed that in April, July, and October, dredging effectively reduced the soluble and unstable heavy metals in the sediments of Lake Taihu and hindered their leaching into overlying water, but the effect was completely opposite in January. Thus, considering the control of heavy metal pollution, the dredging should be carried out in spring and summer instead of winter.

Therefore, the determination of the dredging time cannot be generalized. It is necessary to make a reasonable prediction based on the characteristics of the specific dredging area, comprehensively consider various factors, thereby to achieve a satisfactory dredging effect.

3 Determine the appropriate dredging frequency

In addition to the dredging depth and time, the determination of the appropriate dredging frequency is also an important factor to maintain good dredging results. Increasing dredging frequency can alleviate the pollutant aggravation caused by external input, while too frequent disturbance will not only increase the dredging cost, but also irreversibly disrupt the aquatic biological systems. Chen et al. (2019a, b) concluded that in Lake Taihu, the ability of dredging to control endogenous nutrients diminished over time. They suggested a 5-year cycle to consolidate the positive effects. In Chaohu Lake, more frequent dredging operations are needed to reduce the fluxes of P and N in the sediments due to continuous external inputs of suspended particulate matter and residues (Liu et al. 2019).

Therefore, we recommend that a reasonable dredging frequency schedule be developed based on sediment characteristics and deposition rates. Different sediments behave differently in terms of deposition and resuspension rates. Evaluating these characteristics can help determine appropriate dredging techniques and equipment. For sedimentation rates it helps to gain insight into the dynamics of sediment transport in the water column.

4 Combine the dredging process with protective measures

The negative effects of dredging are unavoidable, but measures could be taken to minimize them while dredging. External measures can reduce the environmental risks associated with sediment dredging. For example, dredging could be combined with other restoration measures. For example, we can restore ecosystems by replanting underwater macrophytes. These plants not only stabilize sediments but also improve water quality. We can employ specialized techniques to retain and dispose of dredged material. It is feasible to utilize constructed wetlands or sedimentation ponds to capture and dispose of nutrient-laden sediments. We can also adjust the method and timing of dredging to minimize disturbance to sensitive habitats and the breeding season. Finally, we can consider recycling clean sediments. Use for beneficial purposes such as land reclamation or construction is also a sustainable option.

Conclusions

By systematically reviewing and analyzing the literature, it is found that since 1990 the aqueous sediment dredging has attracted international attention and entered a rapid development period, but the research on freshwater sediment dredging is relatively weak. Importantly, dredging of freshwater sediments has inevitable impacts on the environment, including secondary releases of nutrients and pollutants to the overlying water system and disturbance and toxicity to aquatic organisms by different pathways during dredging process. However, due to the different hydrogeological conditions of the water body and the different types and concentrations of pollutants in the sediment, the effect and the environmental impact are quite different, and there is no universally applicable law to be found. In general, the effects of dredging on the physicochemical properties, nutrient release, organic matter concentrations and aquatic communities of a water body can be divided into short-term and long-term effects. Overall if dredging is carried out properly it will have a beneficial impact on the freshwater system. The season, location, depth, and equipment of the dredging will also have an impact on the effectiveness of the dredging. In addition, although the utilization of dredged bottom has increased a lot in the world in recent years, the overall utilization is far from adequate. There are no more effective methods to treat contaminants in dredged sediment. These still need to be further explored.

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Data availability All authors sure that all data and materials as well as software application or custom code support the published claims and comply with field standards.

Declarations

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Consent to participate Done.

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References

Abdullah M, Al-Anzi FS, Al-Sharhan S (2017) Efficient fuzzy techniques for medical data clustering. In: 2017 9th IEEE-GCC Conference and Exhibition (GCCCE), pp 1–9
Akcil A, Erust C, Ozdemiroglu S, Fonti V, Beolchini F (2015) A review of approaches and techniques used in aquatic contaminated sedi- ments: metal removal and stabilization by chemical and biotechno- logical processes. J Clean Prod 86:24–36
Aldridge DC (2000) The impacts of dredging and weed cutting on a population of freshwater mussels (Bivalvia: Unionidae). Biol Cons 95:247–257
Baniulyte D, Favila E, Kelly JJ (2008) Shifts in microbial community composition following surface application of dredged river sediments. Microb Ecol 57:160–169
Barrio-Froján CRS, Boyd SE, Cooper KM, Eggleton JD, Ware S (2008) Long-term benthic responses to sustained disturbance by aggregate extraction in an area off the east coast of the United Kingdom. Estuar Coast Shelf Sci 79:204–212
Barrio-Froján CRS, Cooper KM, Bremner J, Defew EC, Hussin WMW, Paterson DM (2011) Assessing the recovery of functional diversity after sustained sediment screening at an aggregate dredging site in the North Sea. Estuar Coast Shelf Sci 92:358–366
Bengtsson L, Herschy RW, Fairbridge RW (2012) Encyclopedia of lakes and reservoirs. Monographiae Biologicae 53:10–26
Bettoso N, Aleffi IF, Faresi L, D'Aietti A, Acquavita A (2020) Macrozoobenthos monitoring in relation to dredged sediment disposal: the case of the Marano and Grado Lagoon (northern Adriatic Sea, Italy). Reg Stud Mar Sci 33:8
Borma LD, Simone ME, Barbosa MC (2003) Acidification and release of heavy metals in dredged sediments. Can Geotech J 40:1154–1163
Boyd SE, Limpenny DS, Rees HL, Cooper KM (2005) The effects of marine sand and gravel extraction on the macrobenthos at a commercial dredging site (results 6 years post-dredging). ICES J Mar Sci 62:145–162
Brönmark C, Hansson L-A (2002) Environmental issues in lakes and ponds: current state and perspectives. Environ Conserv 29:290–307
Cabrita MT (2014) Phytoplankton community indicators of changes associated with dredging in the Tagus estuary (Portugal). Environ Pollut 191:17–24
Cabrita MT, Raimundo J, Pereira P, Vale C (2013) Optimizing alginate beads for the immobilisation of Phaeodactylum tricornutum in estuarine waters. Mar Environ Res 87–88:37–43
Cabrita MT, Raimundo J, Pereira P, Vale C (2014) Immobilised Phaeodactylum tricornutum as biomonitor of trace element availability in the water column during dredging. Environ Sci Pollut Res 21:3572–3581
Ceia FR, Patricio J, Franco J, Pinto R, Fernandez-Boo S, Losi V, Marques JC, Neto JM (2013) Assessment of estuarine macrobenthic assemblages and ecological quality status at a dredging site in a southern Europe estuary. Ocean Coast Manag 72:80–92
Chen D, Dai ZJ, Xu R, Li DJ, Mei XF (2015) Impacts of anthropogenic activities on the Changjiang (Yangtze) estuarine ecosystem (1998–2012). Acta Oceanol Sin 34:86–93
Chen MS, Cui JZ, Lin J, Ding SM, Gong MD, Ren MY, Tsang DCW (2018) Successful control of internal phosphorus loading after sediment dredging for 6 years: a field assessment using high-resolution sampling techniques. Sci Total Environ 616:927–936
Chen MS, Ding SM, Gao SS, Fu Z, Tang WY, Wu YX, Gong MD, Wang D, Wang Y (2019a) Efficacy of dredging engineering as a means to remove heavy metals from lake sediments. Sci Total Environ 665:181–190
Chen MS, Ding SM, Gao SS, Xu SW, Yang CY, Wu YX, Gong MD, Wang D, Wang Y (2019b) Long-term effects of sediment dredging on controlling cobalt, zinc, and nickel contamination determined by chemical fractionation and passive sampling. Chemosphere 220:476–485
Choppala G, Moon E, Bush R, Bolan N, Carroll N (2018) Dissolution and redistribution of trace elements and nutrients during dredging of iron monosulfide enriched sediments. Chemosphere 201:380–387
Coates DA, Van Hoey G, Colson L, Vincx M, Vanaverbeke J (2015) Rapid macro- benthic recovery after dredging activities in an offshore wind farm in the Belgian part of the North Sea. Hydrobiologia 756:3–18
Cunning R, Silverstein RN, Barnes BB, Baker AC (2019) Extensive coral mortality and critical habitat loss following dredging and their association with remotely-sensed sediment plumes. Mar Pollut Bull 145:185–199
Cutroneo L, Castellano M, Carbone C, Consani S, Gaino F, Tucci S, Magri S, Povero P, Bertolotto RM, Canepa G, Capello M (2015) Evaluation of the boundary condition influence on PAH concentrations in the water column during the sediment dredging of a port. Mar Pollut Bull 101:583–593
De Jonge M, Teuchies J, Meire P, Blust R, Bervoets L (2012) The impact of increased oxygen conditions on metal-contaminated sediments part I: effects on redox status, sediment geochemistry and metal bioavailability. Water Res 46:2205–2214

Degerman R, Lefébure R, Byström P, Båmstedt U, Larsson S, Andersson A (2018) Food web interactions determine energy transfer efficiency and top consumer responses to inputs of dissolved organic carbon. Hydrobiologia 805:131–146

Ding T, Tian YJ, Liu JB, Hou J, Guo ZN, Wang JY (2015) Calculation of the environmental dredging depth for removal of river sediments contaminated by heavy metals. Environ Earth Sci 74:4295–4302

Ding YQ, Sun LM, Qin BQ, Wu TF, Shen X, Wang YP (2018) Characteristics of sediment resuspension in Lake Taihu, China: a wave flume study. J Hydrol 561:702–710

Ding R, Guo N, Ma Y (2019) Effects of sediment dredging on crustacean zooplankton community of Shuangqiao Riverin Chaohu Basin. J Lake Sci 31:714–723 (in China)

Dodds W (2002) Freshwater ecology: concepts and environmental applications. Elsevier

Dutta S (2016) Soil erosion, sediment yield and sedimentation of reservoir: a review. Model Earth Syst Environ 2:1–18

Eggleton J, Thomas KV (2004) A review of factors affecting the release and bioavailability of contaminants during sediment disturbance events. Environ Int 30:973–980

Erftemeijer PLA, Lewis RRR III (2006) Environmental impacts of dredging on seagrasses: a review. Mar Pollut Bull 52:1553–72

Erftemeijer PLA, Riegl B, Hoeksema BW, Todd PA (2012) Environmental impacts of dredging and other sediment disturbances on corals: a review. Mar Pollut Bull 64:1737–1765

Fan C, Zhang Lu, Wang J, Zheng C, Gao G, Wang S (2004) Processes and mechanism of effects of sludge dredging on internal source release in lakes. Chin Sci Bull 49:1853–1859

Fischer J, Paukert C, Daniels M (2012) Fish community response to habitat alteration: impacts of sand dredging in the Kansas River. Trans Am Fish Soc 141:1532–1544

Freedman JA, Stauffer JR, Stauffer JR (2013) Gravel dredging alters diversity and structure of riverine fish assemblages. Freshw Biol 58:261–274

Galzin R (1981) Effects of coral sand dredging on fish fauna in the lagoon of the grand cu de sac marin Guadeloupe-French West Indies. Proceedings of the 4th International Coral Reef Symposium, Manila (Philippines)

Gambrell RP, Wiesepape JB, Patrick WH, Duff MC (1991) The effects of pH, redox, and salinity on metal release from a contaminated sediment. Water Air Soil Pollut 57:359–367

Gorokhova E, Lehtiniemi M, Postel L, Rubene G, Amid C, Lesutiene J, Uusitalo L, Strake S, Demereckiene N (2016) Indicator properties of Baltic zooplankton for classification of environmental status within marine strategy framework directive. PLoS ONE 11:e0158326

Grasso F, Le Hir P (2018) Influence of morphological changes on suspended sediment dynamics in a macrotidal estuary: diachronic analysis in the Seine Estuary (France) from 1960 to 2010. Ocean Dyn 69:83–100

Hayer C-A, Irwin ER (2008) 'Influence of gravel mining and other factors on detection probabilities of coastal plain fishes in the Mobile River Basin, Alabama. Trans Am Fish Soc 137:1606–1620

Haynes JM, Makarewicz JC (1982) Comparison of benthic communities in dredged and undredged areas of the St. Lawrence River, Cape Vincent, NY

Hess S, Wenger AS, Ainsworth TD, Rummer JL (2015) Exposure of clownfish larvae to suspended sediment levels found on the Great Barrier Reef: impacts on gill structure and microbiome. Sci Rep 5:1–8

Holmer M, Ahrensberg N, Jørgensen NP (2003) Impacts of mussel dredging on sediment phosphorus dynamics in a eutrophic Danish fjord. Chem Ecol 19:343–361

Jing L, Li H (2016) Environmental effects of lake dredging on dissolved oxygen at sediment-water interface. J Southwest Univ National (Natural Science Edition) 42:632–37

Jing LD, Bai S, Li YH, Peng Y, Wu CX, Liu JT, Liu GX, Xie ZC, Yu GL (2019) Dredging project caused short-term positive effects on lake ecosystem health: a five-year follow-up study at the integrated lake ecosystem level. Sci Total Environ 686:753–763

Kafilzadeh F (2015) Distribution and sources of polycyclic aromatic hydrocarbons in water and sediments of the Soltan Abad Rive, Iran. Egypt J Aquat Res 41:227–231

Karr JR (1981) Assessment of biotic integrity using fish communities. Fisheries 6:21–27

Kaur J, Jaligama G, Atkinson JF, DePinto JV, Nemura AD (2007) Modeling dissolved oxygen in a dredged Lake Erie tributary. J Great Lakes Res 33:62–82

Kim KJ, Kim DH, You JC et al (2011) Electrokinetic extraction of heavy metals from dredged marine sediment. Sep Purif Technol 79(2):164–169

Kjelland ME, Woodley CM, Swannack TM, Smith DL (2015) A review of the potential effects of suspended sediment on fishes: potential dredging-related physiological, behavioral, and transgenerational implications. Environ Syst Decis 35:334–350

Kleeberg A, Kohl J-G (1999) Assessment of the long-term effectiveness of sediment dredging to reduce benthic phosphorus release in shallow Lake Müggelsee (Germany). Hydrobiologia 394:153–161

Lafabrie C, Garrido M, Leboulanger C, Cecchi P, Grégori G, Pasqualini V, Pringault O (2013) Impact of contaminated-sediment resuspension on phytoplankton in the Biguglia lagoon (Corsica, Mediterranean Sea). Estuar Coast Shelf Sci 130:70–80

Layglon N, Misson B, Durieu G, Coclet C, D'Onofrio S, Dang DH, Francois D, Mullot JU, Mounier S, Lenoble V, Omanovic D, Garnier C (2020) Long-term monitoring emphasizes impacts of the dredging on dissolved Cu and Pb contamination along with ultraplankton distribution and structure in Toulon Bay (NW Mediterranean Sea, France). Mar Pollut Bull 156:10

Lewis MA, Weber DE, Stanley RS, Moore JC (2001) Dredging impact on an urbanized Florida bayou: effects on benthos and algal-periphyton. Environ Pollut 115:161–171

Liao HH, Yen JY, Guan YJ, Ke DF, Liu CX (2020) Differential responses of stream water and bed sediment microbial communities to watershed degradation. Environ Int 134:11

Licursi M, Gómez N (2009) Effects of dredging on benthic diatom assemblages in a lowland stream. J Environ Manage 90:973–982

Lind OT, Dávalos-Lind L (1991) Association of turbidity and organic carbon with bacterial abundance and cell size in a large, turbid, tropical lake. Limnol Oceanogr 36:1200–1208

Liu TT, Yang H (2020) Comparative analysis of the total and active bacterial communities in the surface sediment of Lake Taihu. FEMS Microbiol Ecol 96:11

Liu AJ, Kong FX, Wang D, Yu Y, Tao Y (2006) 'Effects of dredging on extracellular microbial enzymes in the sediment of Taihu Lake. China', Journal of Freshwater Ecology 21:399–404

Liu C, Shen QS, Zhou QL, Fan CX, Shao SG (2015) Precontrol of algae-induced black blooms through sediment dredging at appropriate depth in a typical eutrophic shallow lake. Ecol Eng 77:139–145

Liu C, Fan CX, Shen QS, Shao SG, Zhang L, Zhou QL (2016a) Effects of riverine suspended particulate matter on post-dredging metal re-contamination across the sediment-water interface. Chemosphere 144:2329–2335

Liu C, Zhong JC, Wang JJ, Zhang L, Fan CX (2016b) Fifteen-year study of environmental dredging effect on variation of nitrogen and phosphorus exchange across the sediment-water interface of an urban lake. Environ Pollut 219:639–648

Liu C, Yiheng Du, Yin H, Fan C, Chen K, Zhong J, Xiaozhi Gu (2019) Exchanges of nitrogen and phosphorus across the sediment-water interface influenced by the external suspended particulate

matter and the residual matter after dredging. Environ Pollut 246:207–216
Lohrer AM, Wetz JJ (2003) Dredging-induced nutrient release from sediments to the water column in a southeastern saltmarsh tidal creek. Mar Pollut Bull 46:1156–1163
Lu J, Li H, Chen X, Liang D (2019) Numerical study of remote sensed dredging impacts on the suspended sediment transport in China's largest freshwater lake. Water 11:2449
Lurling M, Waajen G, Engels B, van Oosterhout F (2017) Effects of dredging and lanthanum-modified clay on water quality variables in an enclosure study in a hypertrophic pond. Water 9:24
Manap N, Voulvoulis N (2014) Risk-based decision-making framework for the selection of sediment dredging option. Sci Total Environ 496:607–623
Mateo-Sagasta J, Zadeh SM, Turral H, Burke J (2017) Water pollution from agriculture: a global review. Executive summary (Rome, Italy: FAO Colombo, Sri Lanka: International Water Management)
Meers E, Ruttens A, Hopgood M et al (2005) Potential of Brassic rapa, Cannabis sativa, Helianthus annuus and Zea mays for phytoextraction of heavy metals from calcareous dredged sediment derived soils. Chemosphere 61(4):561–572
Meng X, Jiang X, Li Z, Wang J, Cooper KM, Xie Z (2018) Responses of macroinvertebrates and local environment to short-term commercial sand dredging practices in a flood-plain lake. Sci Total Environ 631–632:1350–1359
Meng XL, Chen JJ, Li ZF, Liu ZY, Jiang XK, Ge YH, Cooper KM, Xie ZC (2020) Degraded functional structure of macroinvertebrates caused by commercial sand dredging practices in a flood plain lake. Environ Pollut 263:11
Morgan B, Rate AW, Burton ED (2012) Water chemistry and nutrient release during the resuspension of FeS-rich sediments in a eutrophic estuarine system. Science of the Total Environ 432:47–56
Mulligan CN, Yong RN, Gibbs BF (2001) An evaluation of technologies for the heavy metal remediation of dredged sediments. J Hazard Mater 85(12):145–163
Nandy T, Mandal S (2020) 'Unravelling the spatio-temporal variation of zooplankton community from the river Matla in the Sundarbans Estuarine System. India', Oceanologia 62:326–346
Nayar S, Goh BPL, Chou LM (2004) Environmental impact of heavy metals from dredged and resuspended sediments on phytoplankton and bacteria assessed in in situ mesocosms. Ecotoxicol Environ Saf 59:349–369
Netto SA, Domingos AM, Kurtz MN (2012) Effects of Artificial Breaching of a Temporarily Open/Closed Estuary on Benthic Macroinvertebrates (Camacho Lagoon, Southern Brazil). Estuaries Coasts 35:1069–1081
Olsen Mar, Petersen K, Lehoux AP, Leppänen M, Schaanning M, Snowball I, Øxnevad S, Lund E (2019) Contaminated sediments: review of solutions for protecting aquatic environments (Nordic Council of Ministers)
Paukert C, Schloesser J, Fischer J, Eitzmann J, Pitts K, Thornbrugh D (2008) Effect of instream sand dredging on fish communities in the Kansas River USA: current and historical perspectives. J Freshw Ecol 23:623–633
Peimin P, Guoxiang W, Chunhua H, Weiping H, Chengxin F (2000) Can we control lake eutrophicat ion by dredging? J Lake Sci 12:269–79 (in China)
Peng JF, Song YH, Yuan P, Cui XY, Qiu GL (2009) The remediation of heavy metals contaminated sediment. J Hazard Mater 161(2–3):633–640
Pennekamp JGS, Epskamp RJC, Rosenbrand WF et al (1996) Turbidity caused by dredging: viewed in perspective. Terra et Aqua 1996:10–17
Piló D, Carvalho AN, Pereira F, Coelho HE, Gaspar MB (2019) Evaluation of macrobenthic community responses to dredging through a multimetric approach: Effective or apparent recovery? Ecol Ind 96:656–668
Pimentel D, Harvey C, Resosudarmo P, Sinclair K, Kurz D, McNair M, Crist S, Shpritz L, Fitton L, Saffouri R (1995) Environmental and economic costs of soil erosion and conservation benefits. Science 267:1117–23
Pourabadehei M, Mulligan CN (2016) Resuspension of sediment, a new approach for remediation of contaminated sediment. Environ Pollut 213:63–75
Pritchard A (1969) Statistical bibliography or bibliometrics. J Doc 25:348–349
Ptacnik R, Solimini AG, Brettum P (2009) Performance of a new phytoplankton composition metric along a eutrophication gradient in Nordic lakes. Hydrobiologia 633(1):75–82
Qi WX, Liu HJ, Qu JH, Ren HM, Xu W (2011) PAH desorption from sediments with different contents of organic carbon from wastewater receiving rivers. Environ Sci Pollut Res 18:346–354
Qian B, Liu L, Yan WM, Zhang Y, Xiao X (2012) In situ microsensor studies of long-term environmental effect of sediment dredging in the Shallow Lake. Asian J Chem 24:4408–4414
Ramalingam S, Chandra V (2018) Influence of live microbes on suspended sediment concentration in coastal ecosystem. Mar Geol 405:108–113
Recknagel F, Hosomi M, Fukushima T, Kong D-S (1995) Short-and long-term control of external and internal phosphorus loads in lakes—a scenario analysis. Water Res 29:1767–1779
Reddy KR, Fisher MM, Wang Y, White JR, James RT (2007) Potential effects of sediment dredging on internal phosphorus loading in a shallow, subtropical lake. Lake Reservoir Manage 23:27–38
Rehitha TV, Ullas N, Vineetha G, Benny PY, Madhu NV, Revichandran C (2017) Impact of maintenance dredging on macrobenthic community structure of a tropical estuary. Ocean Coast Manag 144:71–82
Reine KJ, Dickerson DD, Clarke DG (1998) Environmental windows associated with dredging operations. US Army Engineer Research and Development Center [Environmental Laboratory]
Rempel LL, Church M (2009) Physical and ecological response to disturbance by gravel mining in a large alluvial river. Can J Fish Aquat Sci 66:52–71
Robinson JE, Newell RC, Seiderer LJ, Simpson NM (2005) Impacts of aggregate dredging on sediment composition and associated benthic fauna at an offshore dredge site in the southern North Sea. Mar Environ Res 60:51–68
Ruocco N, Bertocci I, Munari M, Musco L, Caramiello D, Danovaro R, Zupo V, Costantini M (2020) Morphological and molecular responses of the sea urchin Paracentrotus lividus to highly contaminated marine sediments: the case study of Bagnoli-Coroglio brownfield (Mediterranean Sea). Mar Environ Res 154:10
Saeki K, Okazaki M, Matsumoto S (1993) The chemical phase changes in heavy metals with drying and oxidation of the lake sediments. Water Res 27:1243–1251
Salomons W, Stigliani WM (2012) Biogeodynamics of pollutants in soils and sediments: risk assessment of delayed and non-linear responses. Springer Science & Business Media
Schindler DW (1971) Carbon, nitrogen, and phosphorus and the eutrophication of freshwater lakes 1. J Phycol 7:321–329
Sew G, Calbet A, Drillet G, Todd PA (2018) Effects of concentration and size of suspended particles on the ingestion, reproduction and mortality rates of the copepod, Acartia Tonsa. Mar Environ Res 140:251–264
Sládecek V (1983) Rotifers as indicators of water quality. Hydrobiologia 1:169–201
Speth JG (1994) Towards an effective and operational international convention on desertification (International Negotiating Committee, International Convention on Desertification, United Nations, New York). In International Convention on Desertification, United Nations

Sui HC, Wang JH, Li Z, Zeng Q, Liu X, Ren L, Liu CY, Zhu YN, Lv LX, Che Q, Liu X (2020) Screening of ecological impact assessment indicators in urban water body restoration process itle. Ecol Ind 113:6

Suikkanen S, Laamanen M, Huttunen M (2007) Long-term changes in summer phytoplankton communities of the open northern Baltic Sea. Estuar Coast Shelf Sci 71(3/4):580–592

Sumi T, Hirose T (2009) Accumulation of sediment in reservoirs. In: Water storage, transport and distribution. UNESCO-IHE and EOLSS Publishers Co. Ltd., Paris, pp 224–252

Sun Q, Ding SM, Chen MS, Gao SS, Lu GH, Wu YX, Gong MD, Wang D, Wang Y (2019) Long-term effectiveness of sediment dredging on controlling the contamination of arsenic, selenium, and antimony. Environ Pollut 245:725–734

Sweka JA, Hartman KJ (2003) Reduction of reactive distance and foraging success in smallmouth bass, Micropterus dolomieu, exposed to elevated turbidity levels. Environ Biol Fishes 67:341–347

Szymelfenig M, Kotwicki L, Graca B (2006) Benthic re-colonization in post-dredging pits in the Puck Bay (Southern Baltic Sea). Estuarine Coastal Shelf Sci 68:489–498

Tao F, Jiantong L, Bangding X, Xiaoguo C, Xiaoqing Xu (2005) Mobilization potential of heavy metals: a comparison between river and lake sediments. Water Air Soil Pollut 161:209–225

Thomson AH, Manoylov KM (2019) Algal community dynamics within the Savannah River Estuary, Georgia under Anthropogenic Stress. Estuaries Coasts 42:1459–1474

Tyrrell T (1999) The relative influences of nitrogen and phosphorus on oceanic primary production. Nature 400:525–531

Vagge G, Cutroneo L, Castellano M, Canepa G, Bertolotto RM, Capello M (2018) The effects of dredging and environmental conditions on concentrations of polycyclic aromatic hydrocarbons in the water column. Mar Pollut Bull 135:704–713

Voutsa D, Manoli E, Samara C, Sofoniou M, Stratis I (2001) A study of surface water quality in Macedonia, Greece: speciation of nitrogen and phosphorus. Water Air Soil Pollut 129:13–32

Wan W, Zhang Y, Cheng G, Li X, Qin Y, He D (2020) Dredging mitigates cyanobacterial bloom in eutrophic Lake Nanhu: shifts in associations between the bacterioplankton community and sediment biogeochemistry. Environ Res 188:109799

Wang XY, Feng J (2007) 'Assessment of the effectiveness of environmental dredging in South Lake, China. Environ Manag 40:314–322

Wang J, Wang J, Zhu L, Xie H, Shao Bo, Hou X (2014) The enzyme toxicity and genotoxicity of chlorpyrifos and its toxic metabolite TCP to zebrafish Danio rerio. Ecotoxicology 23:1858–1869

Ward-Campbell BMS, Valere B (2018) What are the impacts of small-scale dredging activities on inland fisheries productivity? A systematic review protocol. Environ Evidence 7:1–7

Wasserman JC, Barros SR, Lima GB (2013) Planning dredging services in contaminated sediments for balanced environmental and investment costs. J Environ Manage 121:48–56

Waye-Barker GA, McIlwaine P, Lozach S, Cooper KM (2015) The effects of marine sand and gravel extraction on the sediment composition and macrofaunal community of a commercial dredging site (15 years post-dredging). Mar Pollut Bull 99:207–215

Wen S, Zhong J, Li X, Liu C, Yin H, Li D, Ding S, Fan C (2020) Does external phosphorus loading diminish the effect of sediment dredging on internal phosphorus loading? An in-situ simulation study. J Hazard Mater 394:122548

Wild SR, Jones KC (1995) Polynuclear aromatic hydrocarbons in the United Kingdom environment: a preliminary source inventory and budget. Environ Pollut 88:91–108

Wu Z, Kong M, Cai Y, Wang X, Li K (2019) 'Index of biotic integrity based on phytoplankton and water quality index: do they have a similar pattern on water quality assessment? A Study of Rivers in Lake Taihu Basin, China. Sci Total Environ 658:395–404

Xu H, Guo L, Jiang H (2016) Depth-dependent variations of sedimentary dissolved organic matter composition in a eutrophic lake: implications for lake restoration. Chemosphere 145:551–559

Yang C, Yaqiong Wu, Zhang F, Liu L, Pan R (2016) Pollution characteristics and ecological risk assessment of heavy metals in the surface sediments from a source water reservoir. Chem Speciat Bioavailab 28:133–141

Yang JW, Holbach A, Wilhelms A, Krieg J, Qin YW, Zheng BH, Zou H, Qin BQ, Zhu GW, Wu TF, Norra S (2020) Identifying spatio-temporal dynamics of trace metals in shallow eutrophic lakes on the basis of a case study in Lake Taihu, China. Environ Pollut 264:11

Yell D, Riddell J (1995) ICE design and practice guides: Dredging. Thomas Telford Publishing, London

Yenilmez F, Aksoy A (2013) Comparison of phosphorus reduction alternatives in control of nutrient concentrations in Lake Uluabat (Bursa, Turkey): partial versus full sediment dredging. Limnologica 43:1–9

Yu JH, Fan CX, Zhong JC, Zhang L, Zhang L, Wang CH, Yao XL (2016) Effects of sediment dredging on nitrogen cycling in Lake Taihu, China: insight from mass balance based on a 2-year field study. Environ Sci Pollut Res 23:3871–3883

Yu JH, Chen QW, Zhang JY, Zhong JC, Fan CX, Hu LM, Shi WQ, Yu WY, Zhang YL (2019) In situ simulation of thin-layer dredging effects on sediment metal release across the sediment-water interface. Sci Total Environ 658:501–509

Zamor RM, Grossman GD (2007) Turbidity affects foraging success of drift-feeding rosy side dace. Trans Am Fish Soc 136:167–176

Zhang SY, Zhou QH, Xu D, Lin JD, Cheng SP, Wu ZB (2010a) Effects of sediment dredging on water quality and zooplankton community structure in a shallow of eutrophic lake. J Environ Sci 22:218–224

Zhang S, Zhou Q, Dong Xu, Lin J, Cheng S, Zhenbin Wu (2010b) Effects of sediment dredging on water quality and zooplankton community structure in a shallow of eutrophic lake. J Environ Sci 22:218–224

Zhang Z, Song X, Xianguo Lu, Xue Z (2013) Ecological stoichiometry of carbon, nitrogen, and phosphorus in estuarine wetland soils: influences of vegetation coverage, plant communities, geomorphology, and seawalls. J Soils Sediments 13:1043–1051

Zhang R, Zeng FX, Liu WJ, Zeng RJ, Jiang H (2014) Precise and economical dredging model of sediments and its field application: case study of a river heavily polluted by organic matter, nitrogen, and phosphorus. Environ Manage 53:1119–1131

Zhang N, Xiao X, Pei M, Liu X, Liang YT (2017) Discordant temporal turnovers of sediment bacterial and eukaryotic communities in response to dredging: nonresilience and functional changes. Appl Environ Microbiol 83:15

Zhong J, Fan C (2007) Advance in the study on the effectiveness and environmental impact of sediment dredging. J Lake Sci 19:1–10 (in China)

Zhong J, Chengxin Fan Lu, Zhang EH, Ding S, Li B, Liu G (2010) Significance of dredging on sediment denitrification in Meiliang Bay, China: a year long simulation study. J Environ Sci 22:68–75

Zou W, Tolonen KT, Zhu GW, Qin BQ, Zhang YL, Cao ZG, Peng K, Cai YJ, Gong ZJ (2019) Catastrophic effects of sand mining on macroinvertebrates in a large shallow lake with implications for management. Sci Total Environ 695:9

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