Science of the Total Environment 782 (2021) 146671

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Mechanical removal of macrophytes in freshwater ecosystems: Implications for ecosystem structure and function

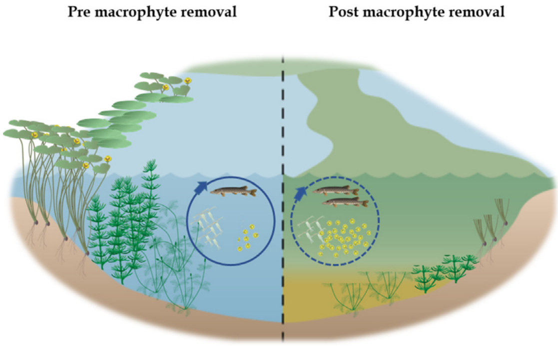
Kirstine Thiemer [a,b,*], Susanne C. Schneider [a,b], Benoît O.L. Demars [a]

[a] *Norwegian Institute for Water Research, Gaustadalleen 21, 0349 Oslo, Norway*
[b] *Faculty of Environmental Sciences and Nature Conservation, Norwegian University of Life Sciences, P.O. Box 5003, 1430 Ås, Norway*

HIGHLIGHTS

- Macrophyte removal affects ecosystem structure and functions.
- Most removal studies were done in rivers and evaluated single ecosystem properties.
- Modelling of removal on interrelated ecosystem properties with a Bayesian network.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 14 January 2021
Received in revised form 2 March 2021
Accepted 17 March 2021

Available online 27 March 2021

Editor: Jan Vymazal

Keywords:
Freshwater ecosystems
Weed cutting
Management
Nuisance growth
Aquatic plants
Bayesian networks

ABSTRACT

Macrophytes are generally considered a nuisance when they interfere with human activities. To combat perceived nuisance, macrophytes are removed, and considerable resources are spent every year worldwide on this practice. Macrophyte removal can, however, have severe negative impacts on ecosystem structure and functioning and interfere with management goals of healthy freshwater ecosystems. Here, we reviewed the existing literature on mechanical macrophyte removal and summarised current information from 98 studies on short- and long-term consequences for ecosystem structure and functioning. In general, the majority of studies were conducted in rivers and streams and evaluated short-term effects of removal on single ecosystem properties. Moreover, most studies did not address the interrelationships between ecosystem properties and the underlying mechanisms. Contrasting effects of removal on ecosystem structure and function were found and these discrepancies were highly dependent on the context of each study, making meaningful quantitative comparisons across studies very difficult. We illustrated how a Bayesian network (BN) approach can be used to assess the implications of macrophyte removal on interrelated ecosystem properties across a wide range of environmental conditions. The BN approach could also help engage a conversation with stakeholders on the management of freshwater ecosystems.

Contents

---

[*] Corresponding author at: Norwegian Institute for Water Research, Gaustadallen 21, 0349 Oslo, Norway.
E-mail address: Kirstine.thiemer@niva.no (K. Thiemer).

https://doi.org/10.1016/j.scitotenv.2021.146671
0048-9697/

1. Introduction

Mass development of aquatic macrophytes is a worldwide problem (Barrett, 1989; Hussner et al., 2017; Verhofstad et al., 2017) and considerable resources are spent every year on macrophyte removal (Hilt et al., 2006; Vereecken et al., 2006; Verhofstad and Bakker, 2019). Macrophytes are often negatively perceived as water weeds, notably during periods of mass development (nuisance growth) when very high densities of aquatic plants interfere with human activities. The removal of macrophytes is desired for the prevention of flooding of adjacent land (Boerema et al., 2014; Vereecken et al., 2006), prevention of clogging of hydropower plants (Dugdale et al., 2013), facilitation of irrigation (Armellina et al., 1996), disease control (Bicudo et al., 2007), trade and commerce (Güereña et al., 2015) together with recreational activities such as angling, swimming, boating and water skiing (Bickel and Closs, 2009; Verhofstad and Bakker, 2019).

Mass development generally results from a combination of multiple drivers promoting plant growth (light, temperature, nutrients) and minimising plant loss (lack of disturbance and biological control), when a species is present that is able to benefit from these conditions (Riis and Biggs, 2001). The controlling role of light and nutrient supply from diffusive or point sources is well established in shallow lakes with the theory of alternative stable states (Hilt et al., 2006; Verhofstad et al., 2017), and ecosystems recovering from nutrient enrichment have likewise been shown to exhibit excessive plant growth (Hilt et al., 2011). Increases in nutrient supply may also be indirect. Liming in oligotrophic systems, for example, can promote the degradation of sediment organic matter and boost CO_2, NH_4 and PO_4 supply causing excessive plant growth (Roelofs et al., 1994). In river systems, water regulation (discharge and depth), nutrient supply (sewage effluents, fine sediment accumulation upstream of weirs, land use) and management of river bank (clearance of river banks leading to improved light availability) may boost the development of plant biomass across the channel (Chambers and Prepas, 1994), even in oligotrophic systems with perennial aquatic plants (Moe et al., 2013; Rørslett, 1988). Degraded ecosystems may be sensitive to the introduction of new species able to invade for lack of biological control or because they have biological traits more suited to the modified environment (Hussner et al., 2017).

Solutions to combat perceived nuisance growth of macrophytes include mechanical removal (cutting, dredging), chemical treatment (herbicide, salt) or biological control (biocontrol agents such as herbivorous fish and insects or shading) (Hussner et al., 2017). However, these management practices are costly and generally only have short-term effects due to plant regrowth. They can therefore not be considered a sustainable solution. A more progressive management is using nature-based solutions to promote sustainable economic, societal, and environmental benefits (Boerema et al., 2014; Güereña et al., 2015).

The disadvantages macrophytes have for humans' conflict, at the same time, with the societal benefits that macrophytes provide (i.e. ecosystem services). The benefits of aquatic macrophytes are often overlooked by the public and might be underestimated in decision making by water managers. The ecosystem services provided by aquatic macrophytes include supporting (e.g., habitats for fish and macroinvertebrate), provisioning (e.g. food, fodder, fertiliser, biomass fuel), regulating (e.g. nutrient cycling, water purification, pest and disease control), and cultural services (e.g. aesthetic pleasure, inspiration for culture, art and design, recreation and tourism) (Boerema et al., 2014; García-Llorente et al., 2011).

These ecosystem services rely on the role that aquatic macrophytes play in ecosystem structure and function (Caraco et al., 2006; Engelhardt and Ritchie, 2001; Gurnell, 2014; Jeppesen et al., 1998). Many individual studies have quantified the effects of macrophyte removal on individual ecosystem properties, and time has come to synthesise this research and explore the implications at the level of the whole ecosystem level. Today, many countries prohibit chemical treatment and while biological control with non-native species has been successful in different parts of the world (Hill and Coetzee, 2017), it introduces additional ecological uncertainties for native species (Hussner et al., 2017). Here, we focus our review on the effects of mechanical removal of aquatic plants (both submerged and free-floating), hereafter referred to as macrophyte removal, as is used worldwide in rivers and lakes. We distinguish short-term from long-term consequences on aquatic ecosystems. Short-term effects were defined as the necessary period for plant regrowth and ecosystem recovery, which may take weeks (Bal et al., 2017; Garner et al., 1996; Spencer et al., 2006) to years (Caffrey and Monahan, 2006; Painter, 1986; Rørslett and Johansen, 1996). Long-term consequences may emerge from repeated macrophyte removal (Baattrup-Pedersen et al., 2002). We also briefly discuss the complexity of assessing the consequences of aquatic plant removal on aquatic ecosystems, depending on the local context and removal methods used. For this, we used a Bayesian network (BN) approach as a first attempt to synthesise how macrophyte removal affects ecosystem structure in different freshwater ecosystems and how the current lack of a holistic approach may influence the conclusions derived from single organism studies. Finally, we identified research needs.

Table 1
Criteria for inclusion of peer-review publications.

Criteria	Include	Exclude
Language	English	Other languages
Ecosystem	River, Streams, lakes	Estuaries, lagoons, coastal waters, sea, wetlands, dryland
Location	Global	
Organisms	Macrophytes, macroinvertebrates, fish, benthos, periphyton, birds, mammals	
Ecosystem functioning	Carbon and nutrient cycling	
Ecosystem services	No	
Maintenance type	Macrophyte cutting, dredging including removal of plants	Channelization of river, removal of debris jams
Vegetation	Submerged, emergent, free-floating	Riparian vegetation

2. Publication search criteria

A systematic search was conducted to find relevant literature concerning mechanical removal of macrophytes (last search, 10.07.2020). Web of Science, PubMed and Google Scholar academic search engines were used to find the relevant scientific peer-reviewed papers using combinations of the following search terms in title and author keywords : ((fish* OR macrophyte* OR*macroinvertebrate*OR periphyton OR "aquatic weed*" OR "water weed" OR "aquatic plant*") AND (dredg*OR cut*OR mow* OR remov*)). Studies retrieved from the automatic search that clearly did not concern macrophyte removal were discarded. In addition, relevant articles from reference lists of papers and our own general knowledge were used to identify additional important literature. The initial search yielded 532 studies in total. From these studies, we selected all papers which met the criteria in Table 1 which gave a total of 98 papers of which 86 had an experimental setup. The other 13 papers were mainly review papers or papers on ecosystem services. Grey literature, in the form of reports and management plans were not included. However, conclusions from these were indirectly used in this review as several peer-reviewed papers used the local knowledge. Information on the effect of removal was extracted from each study which met the inclusion criteria: species removed, removal area, size of study and each ecosystem property measured.

3. General trends in publications

The 86 experimental papers covered studies on mechanical macrophyte removal in 25 countries, with the largest proportion of studies from America and Europe (Fig. 1). The majority of studies have been conducted in streams and rivers (Fig. 2A) and evaluated the effects of single-event removal of submerged macrophytes (Fig. 2B). The effects of removal on macrophytes, fish, macroinvertebrates and hydraulic properties have been the most frequently studied ecosystem properties, whereas the consequences of removal on benthic algae, mussels and zooplankton have only been evaluated in very few studies (Fig. 2C). Only nine studies have examined more than one ecosystem property (Fig. 2D). The consequences of macrophyte removal on separate ecosystem properties have mostly been documented through short-term studies with a mean range of 14 months including before and after sampling (Fig. 2E) and the effects of partial removal have been the most studied (Fig. 2F). An overview of the consequences of macrophyte removal for several ecosystem properties is summarised below from the data compiled in Appendix A.

4. Consequences of mechanical macrophyte removal for ecosystem structure

4.1. Macrophytes

The influence of aquatic plant removal on the growth and survival of macrophytes causes long-term effects on community structure. Following removal, increased relative growth rates have been reported for several species such as *Sparganium erectum* (L.) (Bal et al., 2017), *Myriophyllum spicatum* (L.) (Crowell et al., 1994) and *Lagarosiphon major* (Ridl. Moss ex Wager) (Bickel and Closs, 2009) which may be a compensatory mechanism and a response to plant damage similar to herbivory (van Zuidam and Peeters, 2012). Increased growth rates may further be stimulated by improved light conditions and low self-shading post removal (Binzer et al., 2006). Despite increased growth rates, ten studies found reduced standing biomass by the end of the growth season (Armellina et al., 1996; Bal et al., 2017; Bal et al., 2006; Caffrey and Monahan, 2006; Crowell et al., 1994; Garbey et al., 2003; He et al., 2019; Schooler et al., 2007; Thiébaut et al., 2008). Removal was found to have more severe effects on survival of species with an apical meristem growth point, such as *Potamogeton compressus* (L.) and *Potamogeton lucens* (L.), with both being less tolerant to cutting (van Zuidam and Peeters, 2012) than species with basal meristem growth points, e.g. *Sparganium emersum* (Rehmann) (Baattrup-Pedersen et al., 2003) and free-floating macrophyte species such as *Eichhornia crassipes* (Mart.) (Spencer et al., 2006).

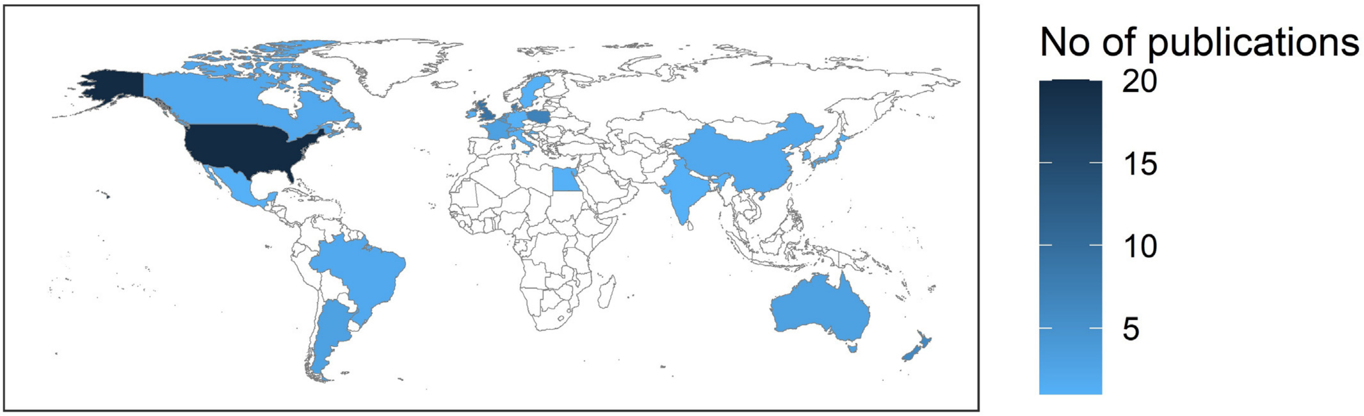


Fig. 1. Map showing the distribution of studies evaluating the consequences of macrophyte removal with colours based on the number of studies.

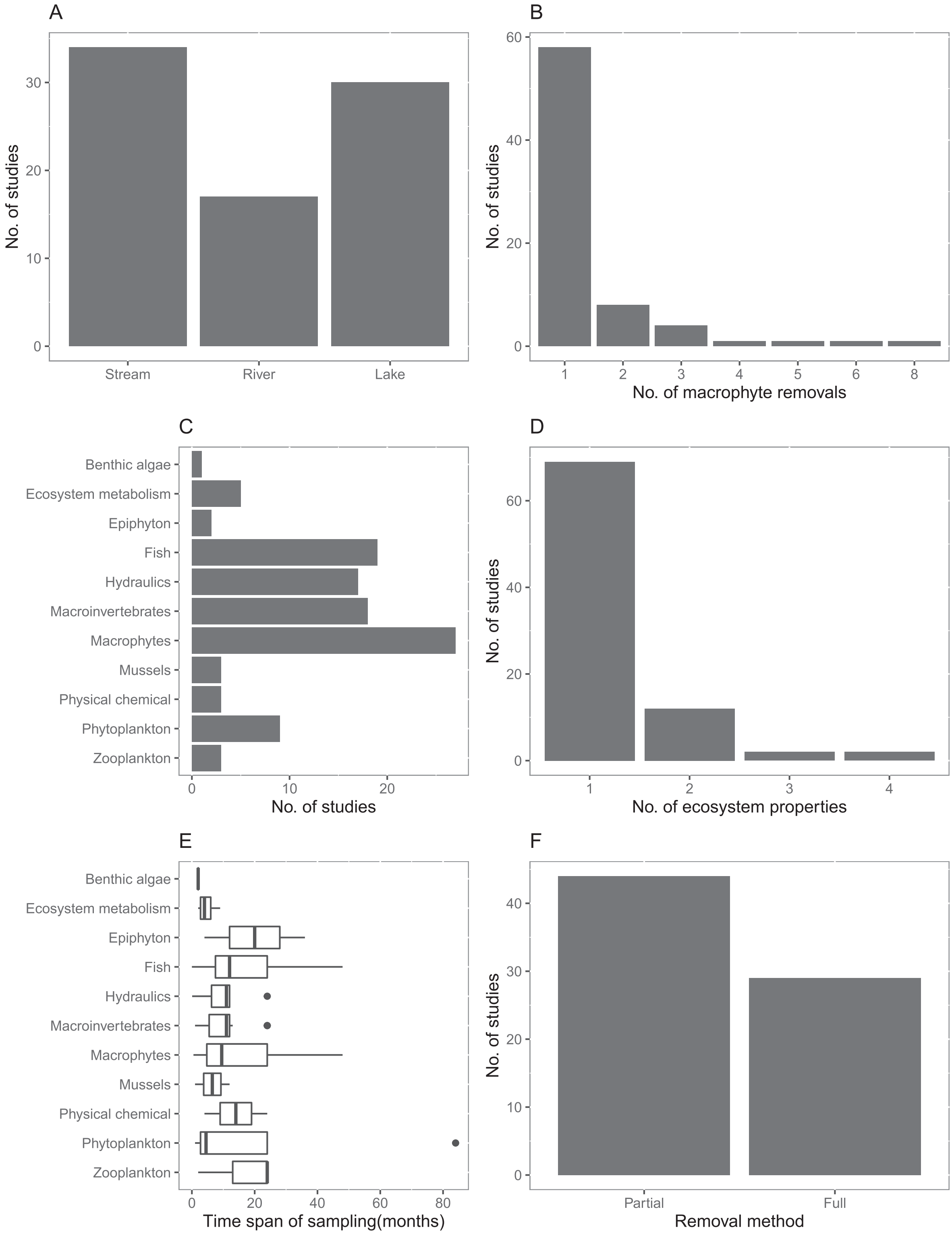


Fig. 2. Descriptive statistics for the 86 studies on mechanical macrophyte removal that met the inclusion criteria. A) Distribution of studies from lakes, river or streams B) Number of studies with different numbers of macrophyte removal events, C) Number of studies of separate ecosystem properties, D) Distribution of studies evaluating more than ecosystem property, E) Boxplot showing the duration of studies (months) for separate ecosystem properties, F) Number of studies with full and partial removal.

The effects of differences in tolerance to removal may be more pronounced for the composition of macrophyte communities in ecosystems where macrophyte removal is repeated annually. In lowland streams, annual macrophyte removals, over a period of 20 years, made the species composition of macrophyte more homogeneous and dominated by fast-growing species with basal meristem growth points, rhizomes and high dispersal capacities (e.g. *Sparganium* sp. and *Elodea canadensis* (Michx.)) (Baattrup-Pedersen et al., 2002). Shannon-diversity and speciess richness have also been reported to decrease 19–66% and 16–40%, respectively (Baattrup-Pedersen et al., 2003;

Baattrup-Pedersen et al., 2002; Baattrup-Pedersen and Riis, 1999; Best, 1994; Strien and Strucker, 1991). The altered species composition towards a community with a less complex structure, are likely to have knock-on effects on ecosystem structure and functioning, however these inter-relationships have not yet been revealed.

4.2. Macroinvertebrates

The consequences of macrophyte removal for macroinvertebrate abundance and diversity have been frequently studied in rivers (Appendix A, Table 1). In small rivers with submerged macrophytes, removal has been shown to instantly reduce abundance by 20–70% (Armitage et al., 1994; Dabkowski et al., 2016; Kaenel et al., 1998; Lusardi et al., 2018). The highest declines in abundance were found in taxa using macrophytes directly as substrate (i.e. *Simuliidae* and *Chironomidae*), whereas taxa living in or on the bottom sediments proved to be more resistant (Kaenel et al., 1998). Four studies did not find a significant effect on abundance, likely due to the late sampling of invertebrates post removal enabling a possible recovery (Armitage et al., 1994; Buczyński et al., 2016; Laughton et al., 2008; Ward-Campbell et al., 2017). Similar findings were reported from lakes with submerged macrophytes (Habib and Yousuf, 2014; Miliša et al., 2006). We did not find studies on invertebrate abundance in systems dominated by free-floating plants, although it is likely that the absolute number of invertebrates will be less affected as changes in surface for colonization are smaller and the sediment is usually not disturbed during removal of free-floating plants. Changes in overall macroinvertebrate diversity were less clear. Shannon-diversity was found either to decline significantly (23–44%) (Gray et al., 1999; Habib and Yousuf, 2014; Miliša et al., 2006), to stay unchanged (Bickel and Closs, 2009; Buczyński et al., 2016; Dabkowski et al., 2016) or to increase (14% increase) (Lusardi et al., 2018). These contrasting findings likely reflect the different contexts of the studies, such as differences in methods and time of sampling following the removal.

Reduced abundance and potential changes in diversity post removal may only be temporary. Invertebrate abundance has been reported to recover within 1-10 months depending on the time for plants to regrow and colonization from upstream or nearby areas (Habib and Yousuf, 2014; Kaenel et al., 1998; Monahan and Caffrey, 1996). Long-term studies on invertebrate community response are currently lacking.

4.3. Phyto- and zooplankton

Phyto- and zooplankton require a sufficient water residence time to develop (Reynolds, 2000) and thus the effects of macrophyte removal for phyto- and zooplankton abundance and diversity have mostly been studied in lakes rather than rivers (Appendix A). Removal of macrophytes in eutrophic waters may cause regime shifts: a study modelling combined effects of removal and high external nutrient loads found that removal of >30% of the submerged macrophytes in a lake with high nutrient input was sufficient to trigger a regime shift to an alternative stable state with higher phytoplankton biomass (Kuiper et al., 2017). Accordingly, an increase in phytoplankton biomass up to 83% and a shift towards communities dominated by fast growing cyanobacteria has been reported after removal of free-floating macrophytes (Bicudo et al., 2007; James et al., 2002; Zhu et al., 2019). The increase in phytoplankton biomass was explained by increased light availability due to the lack of macrophytes, and more resuspended sediment leading to increased availability of nutrients for phytoplankton growth. However, removal of submerged macrophytes has also been reported to lead to an initial decrease in phytoplankton biomass, followed by recovery after several weeks and possible exceedance of phytoplankton biomass in control sites (Alam et al., 1996; Morris et al., 2006; Wile, 1978). This was likely due to sediment disturbance during the removal leading to considerably increased turbidity, hence reducing light availability and impairing initial phytoplankton growth, while the lack of competition by macrophytes later boosted phytoplankton growth.

The effects of macrophyte removal on zooplankton have scarcely been studied (Appendix A). A decline in zooplankton abundance and a shift in community composition towards small zooplankton species has been reported post removal. These were suggested to be a result of increased fish predation on the larger Cladocera, and downstream displacement in rivers as macrophytes provide velocity refuge and are a food source for zooplankton (Garner et al., 1996; Mangas-Ramírez and Elías-Gutiérrez, 2004). Partial removal of macrophytes has been suggested to promote higher zooplankton abundance and diversity. In a study with removal of only free-floating macrophytes, zooplankton diversity increased from 11 to 40 species and was explained by higher habitat heterogeneity in partially cut areas where macrophytes with different life forms coexisted (Choi et al., 2014).

4.4. Fish

Macrophyte removal can be detrimental to fish populations, either directly when plants are harvested (Engel, 1990; Mikol, 1985) or indirectly through enhanced predation risk from larger fish (Unmuth et al., 1999), reduced food availability due to increased flow velocity (Garner et al., 1996) or deterioration of important spawning habitats (Lusardi et al., 2018; Swales, 1982). Reduced survival and abundance following macrophyte removal have been reported for fish fry and smaller fish in both rivers and lakes (Engel, 1990; Mikol, 1985; Mortensen, 1977). Mechanical harvesting of submerged macrophytes was also found to remove 2-25% of the standing juvenile population (Engel, 1990; Mikol, 1985). In eight studies, fish abundances were reduced by up to 60% after macrophyte removal (Greer et al., 2012) (Appendix A). In one study, a more severe outcome was found in a highly eutrophic lake, as no fish were recorded post-removal of macrophytes (Mangas-Ramírez and Elías-Gutiérrez, 2004). This was explained by oxygen depletion and increased ammonia concentrations following removal which were deemed lethal for fish. Conversely, in some cases, macrophyte removal has had no significant effect on fish abundance (Bickel and Closs, 2009; Laughton et al., 2008; Unmuth et al., 1999; Wile, 1978) and actually increased survival and growth of some fish age classes (Holmes et al., 2019; Olson et al., 1998; Unmuth et al., 1999; Unmuth et al., 1998). Increases in larger fish classes were suggested to be most profound when partially removing the dense vegetation of submerged macrophytes, thus allowing fish to spread out into formerly unoccupied areas, likely causing less cannibalism and competition (Unmuth et al., 1999). Hence, making general conclusions on the consequences of macrophyte removal on fish population structure are complex, as fish community structure will depend greatly on the local context, such as the species present in the system, their interaction, the trophic state, together with removal practice (partial or full removal).

5. Consequences of mechanical macrophyte removal on ecosystem functioning

5.1. Hydraulic properties

Macrophytes provide important protection to riverbanks and the lake littoral zone and stabilise the sediment by reducing flow velocities (Kaenel et al., 1998; Verschoren et al., 2017; Wilcock et al., 1999). In rivers, macrophyte removal generally enhanced discharge capacity, where flow velocities increased by 30–40% (Old et al., 2014; Wilcock et al., 1999), water level was lowered by up to 50% (Kaenel et al., 2000) and the Manning roughness coefficient was reduced by 25–73% (Bal and Meire, 2009; Old et al., 2014; Vereecken et al., 2006; Verschoren et al., 2017). The most profound effects on hydraulics were found when macrophytes were removed from larger areas (Verschoren et al., 2017). We found no studies describing the consequences of macrophyte removal on hydraulic functioning in lakes. Removal of submerged and free-floating macrophytes will likely increase shore wave exposure and resuspension of sediment to the water column, as suggested in comparative studies (Horppila and Nurminen, 2005; James et al., 2004).

5.2. Sediment transport

Hydraulic transport and retention capacity of dissolved and particulate material is tightly coupled to physical properties and will be affected by macrophyte removal (Verschoren et al., 2017). An increase in suspended sediment concentration has been reported downstream of removal sites with highest maximum peaks during or shortly after (hours to days) removal (Greer et al., 2017; Rasmussen et al., 2021). Elevated suspended sediment concentrations which are detrimental to fish have been measured at stations several km downstream of a removal, lasting up to 77 days (Greer et al., 2017). Similarly, in lakes, turbidity increased during or shortly after removal with the use of mechanical shredding (Alam et al., 1996; James et al., 2002).

5.3. Nutrient cycling

Aquatic macrophyte removal is likely to impact on nutrient cycling and metabolism in freshwater ecosystems (Bernot et al., 2006; Levi et al., 2015; O'Brien et al., 2014). Aquatic plants can play a significant role in nutrient cycling in oligotrophic ecosystems, but despite several attempts (Ensign and Doyle, 2005; O'Brien et al., 2014) we found no studies that successfully quantified the impact of macrophyte removal on nitrate, ammonium and phosphate cycling rates. O'Brien et al. (2014) recorded a marginal increase in water phosphate concentration, but not ammonium or nitrate concentrations after plant removal. The retention of nutrients by quatic plants (net uptake) is generally very small in nutrient rich rivers relative to fluxes (House et al., 2001).

5.4. Ecosystem metabolism

Submerged and emergent macrophytes can be major contributors to primary production in freshwater ecosystems, thus influencing ecosystem metabolism and diel variation in oxygen concentration (O'Brien et al., 2014). Gross primary production (GPP) was found to decrease by up to 70% after removal in streams with high biomass of submerged macrophytes (Kaenel et al., 2000; O'Brien et al., 2014). However, the reduction in GPP may only last a short time, as partial recovery of GPP can be caused by enhanced growth of filamentous algae, stimulated by higher nutrient concentrations and increased light availability post removal (Kaenel et al., 2000). We found no studies in ecosystems dominated by free-floating macrophytes, however GPP increases following removal is likely as better light conditions may stimulate growth of submerged macrophytes or phytoplankton depending on nutrient availability in the system. Ecosystem respiration (ER) was found either to decrease (Kaenel et al., 2000; Madsen et al., 1988) or to stay unchanged (Carpenter and Gasith, 1978; O'Brien et al., 2014). The discrepancy in ER responses may be caused by differences in removal practices. Studies finding lower ER also report elimination of organic sediment retained in plant beds and epiphytic heterotrophs following plant removal (Kaenel et al., 2000). The effects on ecosystem metabolism and oxygen balance following macrophyte removal may be different in different ecosystems and more research is needed to understand how these relationships may differ.

We did not find any studies on how removal may impact other metabolic pathways, notably those involving green-house gases (N_2O, CH_4 and CO_2), such as denitrification, methanogenesis or methanotrophy. This said, rooted aquatic plants with large radial oxygen loss in the root system can increase the coupling of nitrification-denitrification sediment fluxes (Kreiling et al., 2011) and oxidation of methane into carbon dioxide (Ribaudo et al., 2017). Floating plants may considerably lower dissolved oxygen in the water column (where respiration largely exceeds aquatic photosynthesis) and increase denitrification (Tall et al., 2011). Denitrification may not otherwise be significantly altered (Pinardi et al., 2009; Tall et al., 2011), unless denitrification is limited by the availability of organic carbon in the sediment (generally higher in aquatic plant patches). The decomposition of aquatic plant dead tissue in the sediment is known to produce methane ebullition in anoxia, predictable from plant water content and stoichiometry (Grasset et al., 2019).

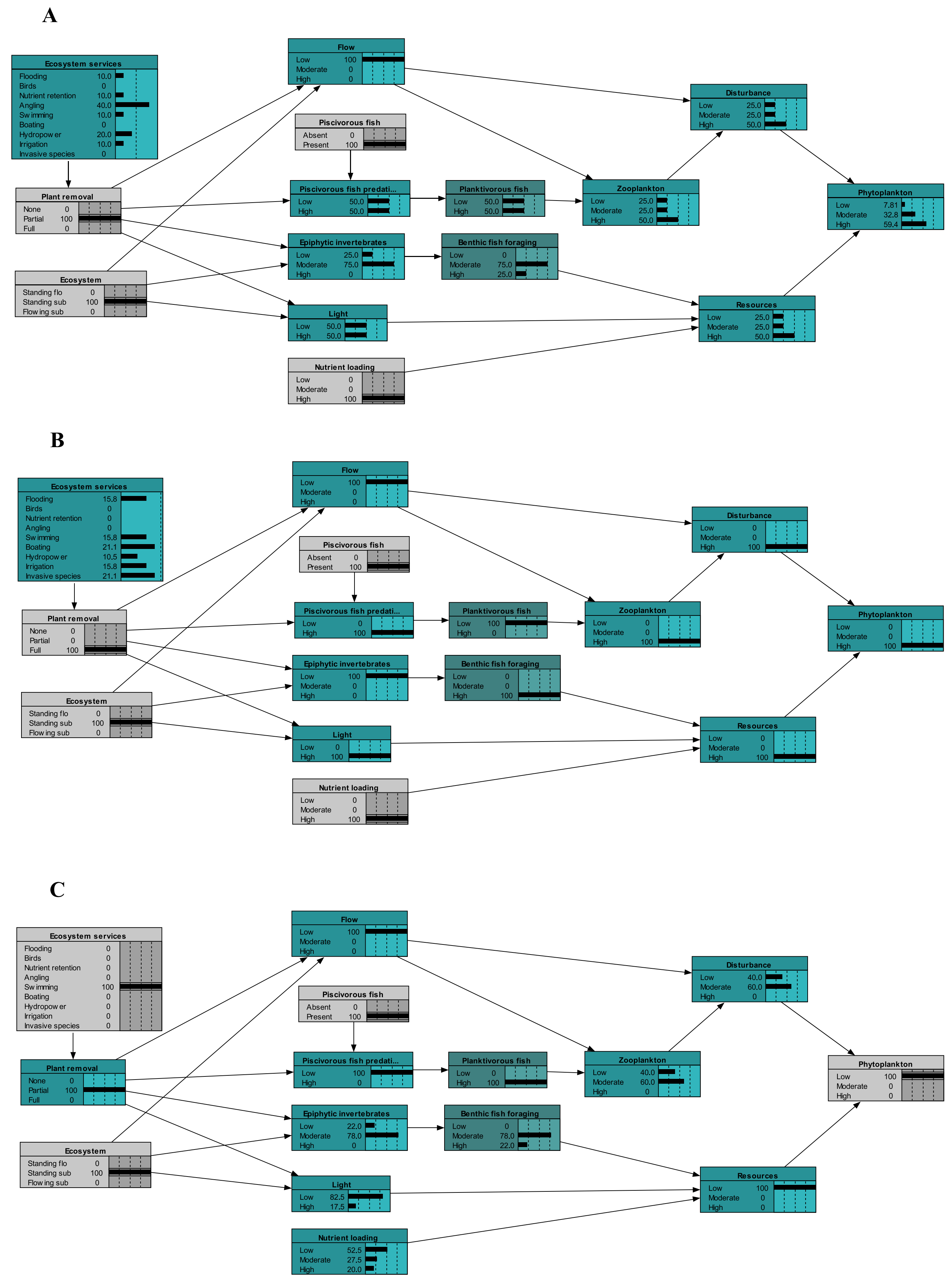
6. The complexity of evaluating consequences of macrophyte removal

The overall effects of macrophyte removal for ecosystem structure and function are complex and making generalisations isnot straightforward. The shifts in species abundances and composition, as well as trophic interactions following removal are poorly understood. The derived effects of macrophyte removal, including alterations in biochemical cycles and hydraulic conditions, may likely stimulate further changes in food-web structure. Moreover, current studies have very distinct contexts e.g. macrophyte species removed, removal method, ecosystem types, trophic states, time of removal, size of study and study design. Replication within each combination is infrequent or completely lacking (Appendix A). Due to the scarcity of studies on the consequences of macrophyte removal with regard to different ecosystem properties, performing an unbiased formal meta-analysis of previous work is unfeasible. Furthermore, the effect reported in the studies on single ecosystem properties does not necessarily reflect the direct influence of removal, as indirect effects, such as inter-relationships with other ecosystem properties are not considered and the underlying drivers for the potential change remain unaddressed. This suggests that a new approach to evaluating the consequences of macrophyte removal at the ecosystem level is needed.

7. Synthesising effects of macrophyte removal on ecosystem level – an example using a Bayesian network approach

Our review of the existing literature showed that consequences of macrophyte removal have mainly been documented through short-term studies evaluating single ecosystem properties without considering the underlying mechanisms and interrelationships between ecosystem properties (Fig. 2D). Moreover, the results were highly dependent on the context of each study, making meaningful quantitative comparisons across studies very difficult. We therefore chose a Bayesian network (BN) approach to identify important consequences of macrophyte removal. These networks can be used to explore and understand the interrelationships between environmental factors and their influence on the response variable (end-point) of interest (Stewart-Koster et al., 2010), thus BNs can be helpful in management decisions of freshwater ecosystems with mass development of aquatic macrophytes. A Bayesian network (BN) is a model based on probabilities and consists

Fig. 3. A) BN showing probabilities of each category in each node following partial removal in a lake dominated by submerged macrophytes and with high nutrient loading and presence of piscivorous fish B) BN showing probabilities of each category in each node following full removal in a lake dominated by submerged macrophytes and with high nutrient loading and presence of piscivorous fish C) BN showing probabilities of removal practice given the goal of low phytoplankton abundance and swimming possibilities in a lake dominated by submerged macrophyte with high nutrient loading and presence of piscivorous fish. BN models are based on expert knowledge and developed for illustrative purposes. Grey boxes indicate nodes that have been specified.


A
Ecosystem services
Flooding 10.0
Birds 0
Nutrient retention 10.0
Angling 40.0
Swimming 10.0
Boating 0
Hydropower 20.0
Irrigation 10.0
Invasive species 0
Plant removal
None 0
Partial 100
Full 0
Ecosystem
Standing flo 0
Standing sub 100
Flowing sub 0
Flow
Low 100
Moderate 0
High 0
Piscivorous fish
Absent 0
Present 100
Piscivorous fish predati...
Low 50.0
High 50.0
Planktivorous fish
Low 50.0
High 50.0
Epiphytic invertebrates
Low 25.0
Moderate 75.0
High 0
Benthic fish foraging
Low 0
Moderate 75.0
High 25.0
Light
Low 50.0
High 50.0
Nutrient loading
Low 0
Moderate 0
High 100
Disturbance
Low 25.0
Moderate 25.0
High 50.0
Zooplankton
Low 25.0
Moderate 25.0
High 50.0
Resources
Low 25.0
Moderate 25.0
High 50.0
Phytoplankton
Low 7.81
Moderate 32.8
High 59.4
B
Ecosystem services
Flooding 15.8
Birds 0
Nutrient retention 0
Angling 0
Swimming 15.8
Boating 21.1
Hydropower 10.5
Irrigation 15.8
Invasive species 21.1
Plant removal
None 0
Partial 0
Full 100
Ecosystem
Standing flo 0
Standing sub 100
Flowing sub 0
Flow
Low 100
Moderate 0
High 0
Piscivorous fish
Absent 0
Present 100
Piscivorous fish predati...
Low 0
High 100
Planktivorous fish
Low 100
High 0
Epiphytic invertebrates
Low 100
Moderate 0
High 0
Benthic fish foraging
Low 0
Moderate 0
High 100
Light
Low 0
High 100
Nutrient loading
Low 0
Moderate 0
High 100
Disturbance
Low 0
Moderate 0
High 100
Zooplankton
Low 0
Moderate 0
High 100
Resources
Low 0
Moderate 0
High 100
Phytoplankton
Low 0
Moderate 0
High 100
C
Ecosystem services
Flooding 0
Birds 0
Nutrient retention 0
Angling 0
Swimming 100
Boating 0
Hydropower 0
Irrigation 0
Invasive species 0
Plant removal
None 0
Partial 100
Full 0
Ecosystem
Standing flo 0
Standing sub 100
Flowing sub 0
Flow
Low 100
Moderate 0
High 0
Piscivorous fish
Absent 0
Present 100
Piscivorous fish predati...
Low 100
High 0
Planktivorous fish
Low 0
High 100
Epiphytic invertebrates
Low 22.0
Moderate 78.0
High 0
Benthic fish foraging
Low 0
Moderate 78.0
High 22.0
Light
Low 82.5
High 17.5
Nutrient loading
Low 52.5
Moderate 27.5
High 20.0
Disturbance
Low 40.0
Moderate 60.0
High 0
Zooplankton
Low 40.0
Moderate 60.0
High 0
Resources
Low 100
Moderate 0
High 0
Phytoplankton
Low 100
Moderate 0
High 0

of the main factors of a system (nodes) and their conditional dependencies illustrated by arrows connecting the nodes (Stewart-Koster et al., 2010) (Fig. 3). The network is quantified by conditional probability tables (CPTs) for each node and can consist of observed data or expert knowledge (Korb and Nicholson, 2004; Pollino et al., 2007). Here we use the BN approach as a first attempt to synthesise potential short-term effects of macrophyte removal from different freshwater ecosystems for a specified end-point. The structure of the network is important to guide the collection of measurements in specific case studies, so that node states and CPTs could be derived from measurements prior to and following removal events. We used the NETICA software v. 6.07 (Norsys, 2005) to construct the BN. The CPTs used in the network were based on general (qualitative) knowledge for illustrative purposes. Detailed information on the construction of the BN and the conditional probability tables can be retrieved in Supplementary Information 1.

7.1. Description of mechanical macrophyte removal network

One major short-term consequence of cutting aquatic plants is to increase the risk of phytoplankton bloom (Kuiper et al., 2017). We illustrate how BN can help us quantify this risk through an understanding of causal mechanisms. Phytoplankton growth is controlled by changes in resource supply (light and nutrient availability) and disturbance frequency (flow and trophic cascades) (Fig. 3A) (Bernes et al., 2015; Reynolds, 2000).

In the BN, the availability of *resources* is a function of three predictor variables: *light*, *nutrient* and bioturbation (*benthic fish foraging*). *Light* is a function of *plant removal* and *ecosystem*. *Plant removal* indicates the proportion of macrophyte removal (i.e. none, partial or full) and *ecosystem* represents either lake dominated by submerged or floating macrophytes or rivers dominated by submerged macrophytes. *Nutrient loading* represents the nutrient supply in the system and has three rates (low, moderate and high). *Benthic fish foraging* is an inverse function of the availability of *epiphytic invertebrates* and indicates the proportion of fish feeding on benthic invertebrates and thus a higher risk of bioturbation and associated nutrient release to the water column (Carpenter et al., 1998; Fausch et al., 1997). The availability of *epiphytic invertebrates* is a function of *plant removal* and *ecosystem*.

The variable *disturbance* is a function of *flow* and *zooplankton*, which describes the hydrological disturbance (including water residence time) and the potential grazing pressure. *Flow* is a function of two predictor variables, *plant removal* and *ecosystem* and has three categories (low, moderate and high) representing hydrological disturbance conditions for zooplankton development. *Zooplankton* abundance is a function of *flow* and *planktivorous fish*. High *zooplankton* abundance results from hydrological stability and low predation pressure (i.e. low *flow* and low *planktivorous fish*). *Planktivorous fish* abundance preying on *zooplankton* is a function of *piscivorous fish predation* itself dependent on *piscivorous fish* presence and *plant removal*. Finally, *plant removal* indicates the proportion of macrophyte removal (none, partial or full) dependent on desired *ecosystem services*, e.g. full removal benefits recreational users, reduce the risk of flooding or eradiate specific target species that may be invasive to the area (Baattrup-Pedersen et al., 2003; Verhofstad and Bakker, 2019), partial removal can benefit fisheries (Bickel and Closs, 2009) and no removal can be beneficial for nutrient retention and birds (Klaassen and Nolet, 2007). In this BN each node in the model contains two to three states.

7.2. Evaluating short-term consequences of mechanical removal using a Bayesian network approach

In this hypothetical example, we used the BN model described above to synthesise and illustrate potential short-term effects of macrophyte removal on different ecosystem properties. The *a priori* assumption for the BN model is that the ecosystem of interest has a mass development of aquatic macrophytes conflicting with human interest, such as prevention of flooding and/or recreational activities. It is possible to specify conditions by setting the probability of a given state in the nodes and the nodes are then updated *via* the CPTs (Stewart-Koster et al., 2010). A given BN can therefore be adjusted to local conditions.

Let's assume a lake is filled with submerged macrophytes, has high nutrient loading and hosts piscivorous fish, by setting the probabilities to 100% of the states in the respective nodes (*ecosystem*, *nutrient loading* and *piscivorous fish*) (Fig. 3A). What is the risk of phytoplankton bloom if macrophytes were partially removed? The probability of high phytoplankton abundance following partial removal of submerged plants is 59.4%, due to high resources (50%) and despite high disturbances (50%, zooplankton grazing and removal of plant protection). By only changing the management practice to full removal (*plant removal*; Full 100%) in the BN, the probability of high phytoplankton abundance now increases to 100% (Fig. 3B). More interesting are the effects on the trophic cascade in the two BNs. For BNs with partial and full plant removal, the probabilities for moderate *Epiphytic invertebrates* are 75% and 0%, high *Planktivorous fish* 50% and 0% and high *zooplankton* 0% and 100% respectively (Fig. 3A-B). Thus, the choice of management practice can have very different implications for ecosystem structure. Again, we emphasise that the probabilities were obtained by expert knowledge and are used for illustrative purpose only. The states of the nodes and conditional probability tables in the BN should be based on values derived from the system under study for more realistic probabilities.

In addition, the BN can also be used to identify possible options for managing mass development of aquatic macrophytes. Assuming the same conditions as the previous example but allowing the variable *nutrient loading*, a goal for managers could be to reduce the risk of high phytoplankton abundance when removing the macrophytes in order to ensure recreational activities such as swimming. Further specifying the conditions by setting phytoplankton abundance to low and swimming to 100%, the BN suggests that the only option for this is to choose partial plant removal (Fig. 3C, *plant removal*; Partial 100%) and to reduce the nutrient loading to either low or medium (Fig. 3C, *nutrient loading*, Low 52.5%, Medium 27.5%).

These examples illustrate how BNs can be used to assess effects of mechanical macrophyte removal in a holistic way as the interrelationships between ecosystem properties are also considered and not only the direct effects on single ecosystem properties. The BN approach could help engage the stakeholders in conversation.

8. Research needs

In the future, mass development of aquatic macrophytes will likely increase in many freshwater ecosystems interfering with human activities and potentially resulting in more frequent removal (Hussner et al., 2017; Verhofstad et al., 2017). Currently, no studies have evaluated the effects of macrophyte removal on interrelated ecosystem properties for the whole ecosystem, thus a holistic evaluation of the consequences of macrophyte removal is lacking Appendix A. Considering the social and economic importance of freshwater ecosystems and knowing the important role of macrophytes, there is an urgent need for more research on macrophyte removal in order to understand the implications for whole ecosystem structure, functions and services. This will require large scale experiments covering different macrophyte species, ecosystem types and geographical gradients, where both parameters on ecosystem structure and functions are estimated. Consistent and comparable data can then be used to make general conclusions on consequences of macrophyte removal. This would enable management decisions to be based on balanced knowledge rather than just the prevailing negative perception of macrophytes. However, the long-term consequences of macrophyte removal on other ecosystem properties have received little attention and few studies exists, meaning that more research is needed to understand these long-term effects.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2021.146671.

CRediT authorship contribution statement

KTH, BDE and SSC conceived the idea for the paper. KTH did the literature search and extracted data from relevant publications. KTH led the writing of the paper and made the figures. All authors participated in writing and critically read the final MS. The authors have no conflicts of interest to declare.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

This study was funded by the Research Council of Norway (297202/E10), the German Federal Ministry of Education and Research (033WU005), the French Agence National de Recherche (N° ANR-18-IC4W-0004-06), the South African Water Research Commision (K5/2951), and the Fundação Araucária in Brazil (N° 186/2019) for funding of MadMacs (Mass development of aquatic macrophytes - causes and consequences of macrophyte removal for ecosystem structure, function, and services) in the frame of the collaborative international consortium of the 2017 call of the Water Challenges for a Changing World Joint Programme Initiative (Water JPI). Additional funding was provided by Krypsivprosjektet på Sørlandet, NIVA and NMBU to support PhD-student KTH in Norway. Finally, we would like to thank Joanna Kemp for linguistic corrections and two anonymous reviewers for improving the manuscript.

Appendix A

Table 1
Overview of studies evaluating the consequences of mechanical macrophyte removal in freshwater ecosystems.

Ecosystem property	Plant species removed	Effect of removal	Removal practice	Ecosystem[a]	Trophic state	Study size	Design[b]	Country	Reference
Macrophytes									
Shannon-diversity	Not specified	19% reduction	Not specified	Stream	Not specified	79 streams	CI	DNK	Baattrup-Pedersen et al. (2003)[c]
	Not specified	48–66% reduction	Partial annual removal in a 20y period	Stream	Not specified	2 streams, 4 sites	CI	DNK	Baattrup-Pedersen et al. (2002)[c]
	Not specified	43% reduction	Not specified	Stream	Not specified	14 streams	CI	DNK	Baattrup-Pedersen & Riis (1999)[c]
	Not specified	Increased (only on the floodplain) and certain species disappeared)	Partial	River	Not specified	1 river, 5 sites	BACI	POL	Stępień et al. (2019)[c]
Richness	Not specified	28% reduction	Not specified	Stream	Not specified	79 streams	CI	DNK	Baattrup-Pedersen et al. (2003)[c]
	Not specified	25–40% reduction	Partial annual removal in a 20y period	Stream	Not specified	2 streams, 4 sites	CI	DNK	Baattrup-Pedersen et al. (2002)[c]
	Not specified	16.3% reduction	Not specified	Stream	Not specified	14 streams	CI	DNK	Baattrup-Pedersen & Riis (1999)[c]
	Not specified	No significant effect	Different practices	Ditch	Not specified	320 ditches	BA	NLD	Strien & Strucker (1991)[c]
	Not specified	16% of species negative affected	Different practices	Ditch	Not specified	5 ditches	BA	NLD	Best (1994)[c]
Standing macrophyte biomass	*Myriophyllum verticillatum*	92.5% reduction (g DM/m^2)	Full	River	Not specified	1 river	CI	IRE	Caffrey & Monahan (2006)
	Not specified	≈90% reduction (g DM/m^2)	Full	River	Not specified	1 river, 2 sites	BACI	ARG	Armellina et al. (1996)
	Elodea nuttallii and *Elodea canadensis*	63% reduction (g DM/m^2)	Full	River	Eutrophic	1 river	CI	FRA	Thiébaut et al. (2008)
	Myriophyllum spicatum	Reduction (g DM/m^2)	Full	River	Not specified	1 lake, 5 sites	CI	USA	Crowell et al. (1994)
	Potamogeton lucens and *Potamogeton compressus*	80% reduction (g DM)	Partial	Not specified	Not specified	Experiment	BACI	NLD	van Zuidam and Peeters (2012)
	Ranunculus peltatus	Reduced standing biomass production (g/m^2)	Full	River	Oligotrophic	1 stream	BACI	FRA	Garbey et al. (2003)
	Egeria densa	13–43% reduction (g WM/m^2)	Partial	Lake_S	Eutrophic	1 lake	BACI	USA	Johnson & Bagwell (1979)
	Elodea nuttallii	Reduced shoot biomass (mg DW)	Partial	Not specified	Not specified	Experiment	CI	DEU	He et al. (2019)
	Stuckenia pectinata	No significant effect on standing biomass (g DM/m2) when cutting is done early in the season. Reduced standing biomass if cutting is performed later in the season	Full	River	Not specified	1 river, 4 sites	CI	BEL	Bal et al. (2006)
	Sparganium erectum	No significant effect on standing	Full	River	Eutrophic	1 river	BACI	BEL	Bal et al. (2017)

(continued on next page)

Table 1 (*continued*)

Ecosystem property	Plant species removed	Effect of removal	Removal practice	Ecosystem[a]	Trophic state	Study size	Design[b]	Country	Reference
	and *Potamogeton natans*	biomass (g DM/m2) when cutting is done early in the season. Reduced standing biomass if cutting is performed later in the season							
	Alternanthera philoxeroides	Reduction (g)	Full	Not specified	Not specified	Experiment	BACI	AUS	Schooler et al. (2007)
Relative growth rate	*Eichhornia crassipes*	4-Fold increase	Partial	Lake_F	Not specified	1 lake, 3 sites	CI	USA	Spencer et al. (2006)
	Myriophyllum spicatum	Increase	Full	Lake_S	Not specified	1 lake, 5 sites	CI	USA	Crowell et al. (1994)
	Lagarosiphon major	Increase	Partial	Lake_S	Oligotrophic	1 lake, 10 sites	BACI	NZL	Bickel & Closs (2009)
	Elodea nuttallii	Decrease in growth rate (mg DW/d)	Partial	Not specified	Not specified	Experiment	CI	DEU	He et al. (2019)
Morphological traits associated with growth and reproduction	*Elodea nuttallii*	No significant effect on regrowth strategy	Full	River	Eutrophic	1 river, 1 site	CI	FRA	Nino et al. (2005)
	Potamogeton lucens and *Potagometon compressus*	Number of reproducing organs reduced	Partial	Not specified	Not specified	Experiment	BACI	NLD	van Zuidam and Peeters (2012)
	Luronium natans	Flowering and reproduction reduced	Full	River	Eutrophic	3 streams	BACI	DNK	Nielsen et al. (2006)
	Ranunculus peltatus	Flowering inhibited and no significant effect on degree of branching	Full	River	Oligotrophic	1 stream,	BACI	FRA	Garbey et al. (2003)
	Myriophyllum spicatum	Shoot and root weight reduced	Full	Lake_S	Not specified	1 lake, 2 sites	CI	USA	Painter (1986)[c]
Macro-invertebrates									
Community assembly	*Ceratophyllum demersum* and *Myriophyllum spicatum*	Decrease in *Lymnaeidae*, *Planorbidae* and *Chironomidae*. *Psychodidae*, *Glossiphoniidae*, *Pyralidae*, and *Pisauridae*, which were present in smaller numbers before the removal, got completely removed from the system. Increase in *Gammaridae* and *Coenagrionidae*	Partial	Lake_S	Eutrophic	1 lake, 4 sites	BACI	IND	Habib & Yousuf (2014)
	Not specified	Not specified	Partial	Not specified	Not specified	4 lakes	CI	USA	Gray et al. (1999)
	Saw grass and willows	No changes in Coleoptera, Trichoptera, decrease in Oligochaeta, Plecoptera, Chironomidae and Diptera	Partial	Lake_S	Oligotrophic	1 lake,2 sites	BACI	HRV	Miliša et al. (2006)
	Ceratopteris thalictroides	Dominance of *P. hypodelum* and *T. ciuskus seductus*, mites (*Frontipoda* sp., *Coaustraliobates* sp. *Unionicolidae*) and Chironomidae (*Tanypodinae*,*Orthocladiinae*, *Chironominae* sp.). Decrease in mayflies Tasmanocoenis arcuata and *Thraulus* sp. and *lepidopteran* larvae Nymphulinae	Partial	River	Not specified	1 river	CI	AUS	Carey et al. (2017)
	Not specified	No significant changes	Full	River	Not specified	4 streams, 8 sites	BACI	CAN	Ward-Campbell et al. (2017)
	Lagarosiphon major	Decrease in Chironomidae and Trichoptera taxa (*Paroxyethira hendersoni*). Increase in mollusc taxa (*Gyraulus*, *Lymnaea and Potamopyrgus*) and Chydoridae	Partial	Lake_S	Oligotrophic	1 lake, 10 sites	BACI	NZL	Bickel & Closs (2009)
	Phragmites australis and *Elodea canadensis*	No significant changes	Partial	River	Not specified	1 river, 10 sites	BACI	POL	Buczyński et al. (2016)
	Sparganium emersum and *Elodea canadensis*	Not specified	Full	River	Not specified	1 river, 8 sites	BACI	IRE	Monahan & Caffrey (1996)
	Ranunculus penicillatus	No significant changes	Full	River	Not specified	1 river, 4 sites	BACI	GBR	Armitage et al. (1994)
	Ranunculus aquatilis	Decrease in *Hyallela*, *Simulium*, *Baetis*, *Diphetor*, *Brachycentrus*, *Juga* and *Oligochaetes*. Increase in *Opioservus* (larvae), *Rhithrogena*, *Protoptila* and *Physa*	Partial	River	Not specified	1 river, 4 sites	CI	USA	Lusardi et al. (2018)
Shannon-diversity	*Ceratophyllum demersum* and	23% reduction	Partial	Lake_S	Eutrophic	1 lake, 4 sites	BACI	IND	Habib & Yousuf (2014)

Table 1 (*continued*)

Ecosystem property	Plant species removed	Effect of removal	Removal practice	Ecosystem[a]	Trophic state	Study size	Design[b]	Country	Reference
	Myriophyllum spicatum								
	Not specified	44% reduction	Partial	Not specified	Not specified	4 lakes	CI	USA	Gray et al. (1999)
	Saw grass and willows	32% reduction	Partial	Lake_S	Oligotrophic	1 lake,2 sites	BACI	HRV	Miliša et al. (2006)
	Lagarosiphon major	No significant effect	Partial	Lake_S	Oligotrophic	1 lake, 10 sites	BACI	NZL	Bickel & Closs (2009)
	Phragmites australis and *Elodea canadensis*	No significant effect (only dragonflies)	Partial	River	Not specified	1 river, 10 sites	BACI	POL	Buczyński et al. (2016)
	Phragmites australis	No significant effect	Partial	River	Not specified	1 river, 10 sites	BACI	POL	Dabkowski et al. (2016)
	Ranunculus aquatilis	14% increase	Partial	River	Not specified	1 river, 4 sites	CI	USA	Lusardi et al. (2018)
ASPT score	*Ranunculus penicillatus*	No significant effect in ASPT score	Full	River	Not specified	1 river, 4 sites	BACI	GBR	Armitage et al. (1994)
Richness	*Ceratopteris thalictroides*	Reduced taxa richness	Partial	River	Not specified	1 river	CI	AUS	Carey et al. (2017)
	Not specified	No significant effect	Full	River	Not specified	4 streams, 8 sites	BACI	CAN	Ward-Campbell et al. (2017)
	Lagarosiphon major	No significant effect	Partial	Lake_S	Oligotrophic	1 lake, 10 sites	BACI	NZL	Bickel & Closs (2009)
	Sparganium emersum and *Elodea canadensis*	No significant effect	Full	River	Not specified	1 river, 8 sites	BACI	IRE	Monahan & Caffrey (1996)
Abundance									
	Ranunculus fluitans and *Myriophyllum spicatum*	65% reduction (no. ind./m^2)	Partial	River	Eutrophic	2 streams, 4 sites	BACI	CHE	Kaenel et al. (1998)
	Phragmites australis	Reduction (no. of ind.)	Partial	River	Not specified	1 river, 10 sites	BACI	POL	Dabkowski et al. (2016)
	Ranunculus aquatilis	9-Fold reduction (no. ind./m^2)	Partial	River	Not specified	1 river, 4 sites	CI	USA	Lusardi et al. (2018)
	Not specified	3–23% reduction in no. ind. of larger mussels (*Anodonta anatina*, *A. cygnea*, *Uniopictorum* and *U. tumidus*)	Partial	River	Not specified	1 river	BA	GBR	Aldridge (2000)
	Not specified	70% reduction (no. of ind.)	Full	River	Not specified	4 rivers	CI	POL	Grygoruk et al. (2015)
	Ranunculus spp.	20% reduction (no. ind./m^2)	Full	River	Not specified	1 river, 5 sites	Not specified	GBR	Dawson et al. (1991)
	Sparganium emersum & *Elodea canadensis*	48–89% reduction (no. ind/m^2)	Full	River	Not specified	1 river, 8 sites	BACI	IRE	Monahan & Caffrey (1996)
	Saw grass and willows	51–58% reduction (no. ind./dm^3)	Partial	Lake_S	Oligotrophic	1 lake,2 sites	BACI	HRV	Miliša et al. (2006)
	Ceratophyllum demersum & *Myriophyllum spicatum*	75% reduction (no. ind./m^2)	Partial	Lake_S	Eutrophic	1 lake, 4 sites	BACI	IND	Habib & Yousuf (2014)
	Myriophyllum spicatum	Reduction (no. of ind., only *Euhrychiopsis lecontei*)	Full	Lake_S	Mesotrophic	1 lake, 3 sites	CI	USA	Sheldon and O'Bryan (1996)
	Not specified	No significant effect in occurrence	Full	River	Not specified	4 streams, 8 sites	BACI	CAN	Ward-Campbell et al. (2017)
	Not specified	No significant effect (no. of ind.)	Full	River	Not specified	1 river, 4 sites	BACI	GBR	Armitage et al. (1994)
	Ranunculus spp.	No significant effect on no. ind. of larger mussel (*Margaritifera margaritifera*)	Partial	River	Not specified	1 river, 3 sites	BACI	GBR	Laughton et al. (2008)
	Potamogetan crispus, *Callitriche obtusangula*, *Glyceria pedicillata*, *Ceratophyllum demersum*, *Nasturtium officinale*	No significant effect on the number of *Bithynia tentaculata*, *Lymnaea peregra*, *Physa fontinalis* and *Planorbis planorbis*	Partial	Stream	Eutrophic	1 stream	CI	GBR	Daldorph and Thomas, 1991
	Phragmites australis and *Elodea canadensis*	No significant effect (no. of ind.)	Partial	River	Not specified	1 river, 10 sites	BACI	POL	Buczyński et al. (2016)
	Phragmites australis and *Elodea canadensis*	62% increase in occurrence of heteroptera	Partial	River	Not specified	1 river, 10 sites	BACI	POL	Płaska et al. (2016)
Biomass	Not specified	No significant effect (g/m^2)	Partial	Not	Not specified	4 lakes	CI	USA	Gray et al. (1999)

(*continued on next page*)

Table 1 (*continued*)

Ecosystem property	Plant species removed	Effect of removal	Removal practice	Ecosystem[a]	Trophic state	Study size	Design[b]	Country	Reference
				specified					
	Lagarosiphon major	104% increase (mg invertebrate AFDM/g plant DM)	Partial	Lake_S	Oligotrophic	1 lake, 10 sites	BACI	NZL	Bickel & Closs (2009)
	Ranunculus spp.	12% reduction (g invertebrates/m^2 plant DM)	Full	River	Not specified	1 river, 5 sites	Not specified	GBR	Dawson et al. (1991)
Drift rates	*Ranunculus aquatilis*	2-Fold increase	Partial	River	Not specified	1 river, 8 sites	CI	USA	Lusardi et al. (2018)
Filamentous algae									
Biomass	*Myriophyllum spicatum*	No significant effect on biomass (g/m^2)	Full	Lake_S	Not specified	1 lake, 2 sites	CI	USA	Nichols (1973)
Phytoplankton									
Community assemblage	*Cyperus luzulae* and *Salvina auriculata*	Increase in cyanobacteria (*Cylindrospermopsis raciborskii*, *Pseudanabaena* sp. and *Geitlerinema* sp.) and decrease in diatoms and flagellates	Partial	Lake_F	Not specified	1 lake	BA	BRA	Wojciechowski et al. (2018)
	Eichhornia crassipes	Increase in Cyanophyta (*Microcystis aeruginosa* and *Oscillatoria lutea*) and Euglenophyta (*Euglena acus* and *Phacus* sp.) and decrease in diatoms	Full	Lake_F	Eutrophic	1 lake, 4 sites	BA	MEX	Mangas-Ramírez & Elías-Gutiérrez (2004)
	Vallisneria americana and *Potamogeton tricarinatus*	No changes in cyanobacteria and decrease in Euglenophyta	Full	Lake_S	Eutrophic	1 lake	CI	AUS	Morris et al. (2006)
Abundance	*Myriophyllum spicatum*	63% reduction in chl.a. concentration	Partial	Lake_S	Not specified	1 lake, 2 sites	BACI	CAN	Wile (1978)
	Vallisneria americana and *Potamogeton tricarinatus*	67% reduction in chl.a. concentration	Full	Lake_S	Eutrophic	1 lake	CI	AUS	Morris et al. (2006)
	Alternanthera philoxeroides and *Azolla caroliniana*	Reduction in chl.a. concentration	Partial	Lake_F	Not specified	1 lake	BA	USA	Alam et al. (1996)
	Ceratophyllum demersum and *Potamogeton* spp.	No significant effect in chl.a. concentration	Partial	Lake_S	Not specified	1 lake	BA	USA	Engel (1990)
	Eichhornia crassipes	7–83% increase in chl.a. concentration	Full	Lake_F	Eutrophic	1 lake, 1 site	BACI	BRA	Bicudo et al. (2007)
	Nymphoides peltata	24–30% increase in chl.a. concentration	Partial	Lake_F	Eutrophic	1 lake, 6 sites	BA	CHN	Zhu et al. (2019)
	Cyperus luzulae and *Salvina auriculata*	Increase in cell densities	Partial	Lake_F	Not specified	1 lake	BA	BRA	Wojciechowski et al. (2018)
	Trapa natans	35% increase in chl.a. concentration	Partial	Lake_F	Eutrophic	1 lake, 2 sites	BACI	USA	James et al. (2002)
	Salvinia natans and *Spirodela polyrhiza*	Increased chl.a. concentration	Partial and full	Lake_F	Not specified	1 lake	CI	KOR	Choi et al. (2014)
Zooplankton									
Community assemblage	*Salvinia natans* and *Spirodela polyrhiza*	Increase in large cladocerans and decrease rotifers and small cladocerans	Partial and full	Lake_F	Not specified	1 lake	CI	KOR	Choi et al. (2014)
Shannon-diversity	*Salvinia natans* and *Spirodela polyrhiza*	Increase	Partial and full	Lake_F	Not specified	1 lake	CI	KOR	Choi et al. (2014)
Richness	*Salvinia natans* and *Spirodela polyrhiza*	Increase	Partial and full	Lake_F	Not specified	1 lake	CI	KOR	Choi et al. (2014)
Abundance	*Eichhornia crassipes*	75% reduction in calanoid (ind./L), 80% reduction in cyclopoid (ind./L) and 89% reduction in Cladocerans (ind./L)	Full	Lake_F	Eutrophic	1 lake, 4 sites	BA	MEX	Mangas-Ramírez & Elías-Gutiérrez (2004)
	Salvinia natans and *Spirodela polyrhiza*	Increase (ind./L)	Partial and full	Lake_F	Not specified	1 lake	CI	GBR	Choi et al. (2014)
	Nuphar lutea	Increase in rotifers and *Ceriodaphnia quadrangulu* (ind./L) and decrease in *Polyphemus pediculus* and *chydorids* (ind./L)	Partial	River	Not specified	1 river	BA	GBR	Garner et al. (1996)
Fish									
Diversity	Not specified	Reduction in both richness and Brillouin's diversity	Partial	River	Not specified	1 river, 7 sites	CI	USA	Freedman et al. (2013)
Abundance	*Ceratophyllum demersum* and *Potamogeton* spp.	25% reduction (total no. of individuals, of these 90% *Micropterus salmoides* and	Partial	Lake_S	Not specified	1 lake	BA	USA	Engel (1990)

Table 1 (*continued*)

Ecosystem property	Plant species removed	Effect of removal	Removal practice	Ecosystem[a]	Trophic state	Study size	Design[b]	Country	Reference
		Lepomis macrochirus fry)							
	Myriophyllum spicatum and *Potamogeton crispus*	2–8% reduction (no. of individuals juvenile *Micropterus salmoides* and *Lepomis macrochirus*)	Partial	Lake_S	Not specified	1 lake	CI	USA	Mikol (1984)
	Myriophyllum spicatum and *Potamogeton crispus*	38.7 no. ind./m3 removed	Partial	Lake_S	Oligotrohic	1 lake, 10 sites	BA	USA	Booms (1999)
	Not specified	Reduction in *Anguilla dieffenbachi* biomass (g/m^2) and increase of *Gobiomorphus* spp. (no. individuals/m2)	Full	River	Not specified	1 stream, 3 sites	BACI	NZL	Holmes et al. (2019)
	Egeria spp.	60% reduction (CPUE)	Partial	River	Not specified	3 streams, 23 sites	BA	NZL	Greer et al. (2012)
	Ranunculus fluitans, *Callitriche* spp. and *Sparganium emersum*	26% reduction (no. of individuals)	Partial	River	Not specified	1 river, 4 sites	BACI	GBR	Swales (1982)
	Eichhornia crassipes	All three fish species disappeared after removal (*Cyprinus carpio*, *Poecilia sphenops* and *Heterandria jonessi*)	Full	Lake_F	Eutrophic	1 lake, 4 sites	BA	MEX	Mangas-Ramírez & Elías-Gutiérrez (2004)
	Ranunculus spp.	No significant effect (no. individuals/100 m^2 of 0y and 1y *Salmo salar* and *Salmo trutta)*	Partial	River	Not specified	1 river, 3 sites	BACI	GBR	Laughton et al. (2008)
	Myriophyllum spicatum	No significant effect (no. of individuals of *Micropterus salmoides* and *Lepomis macrochirus)*	Partial	Lake_S	Meso-eutrophic	1 lake	BA	USA	Unmuth et al. (1998)
	Myriophyllum spicatum	No significant effect (no. individuals/100 net days of *Lepomis gibbosus* and *Stizostedion vitreum* and 93% reduction in in no. Individuals/100 net day of *Perca flavescens)*	Partial	Lake_S	Not specified	1 lake, 2 sites	BACI	CAN	Wile (1978)
	Lagarosiphon major	No significant effect on *Gobiomorphus cotidianus* (CPUE)	Partial	Lake_S	Oligotrohic	1 lake, 10 sites	BACI	NZL	Bickel & Closs (2009)
	Myriophyllum spicatum	0.06 fish/kg plant DW removed	Partial	Lake_S	Not specified	1 lake	BA	USA	Unmuth et al. (1998)
Growth rates	*Nuphar lutea*, *Glyceria fluitans* and *Phragmites communis*	Reduced growth rate of 0+ *Rutilus rutilus*	Partial	River	Not specified	1 river	BA	GBR	Garner et al. (1996)
	Myriophyllum spicatum	Increased growth rate (mm/d) of 2y and 4y *Micropterus salmoides* and reduced 5y *Micropterus salmoides* and 4-5y *Lepomis macrochirus*	Partial	Lake_S	Meso-eutrophic	1 lake	BA	USA	Unmuth et al. (1999)
	Myriophyllum spicatum	35% increase in growth rate (mm/y) for 3y and 4y *Lepomis macrochirus*	Partial	Lake_S	Not specified	13 lakes, 4 impact and 9 control	CI	USA	Olson et al. (1998)
Survival	*Myriophyllum spicatum*	Increase 2,3 and 5y *Micropterus salmoides* and 4-6y *Lepomis macrochirus*	Partial	Lake_S	Meso-eutrophic	1 lake	BA	USA	Unmuth et al. (1999)
	Not specified	Reduced survival of *Salmo trutta* fry	Full	River	Not specified	3 streams, 8 sites	CI	DNK	Mortensen (1977)
Habitat use	*Ranunculus aquatilis*	3.2-Fold reduction in utilization by 0y and 1y steelhead	Partial	River	Not specified	1 river, 25 sites, 132 snorkel surveys	CI	USA	Lusardi et al. (2018)
Hydraulic Rivers									
Flow velocity (m/s)	Native species	>40% increase	Partial	River	Not specified	1 stream, 3 sites	BA	GBR	Old et al. (2014)
	Nupar lutea, *Potamogeton crispus*, *Potamogeton natans* and *Sparganium emersum*	18–19% increase	Partial and full	River	Eutrophic	2, same site, 2 years	CI	POL	Verschoren et al. (2017)
	Egeria densa and *Potamogeton crispus*	30% increase	Full	River	Not specified	1 river, 6 sites	BA	NZL	Wilcock et al. (1999)
	Ranunculus fluitans and *Myriophyllum spicatum*	50–60% increase	Full	River	Eutrophic	2 streams	BACI	CHE	Kaenel et al. (2000)

(continued on next page)

Table 1 (*continued*)

Ecosystem property	Plant species removed	Effect of removal	Removal practice	Ecosystem[a]	Trophic state	Study size	Design[b]	Country	Reference
	Ranunculus aquatilis	42-Fold increase	Partial	River	Not specified	1 river, 4 sites	CI	USA	Lusardi et al. (2018)
	Native species	No significant effect	Full	River	Not specified	3 streams, 6 sites	BACI	DNK	
Water level	Native species	11–16 cm reduction	Partial	River	Not specified	126 streams	BA	DNK	Baattrup-Pedersen et al. (2018)
	Nupar lutea, *Potamogeton crispus*, *Potamogeton natans* and *Sparganium emersum*	5–15 times reduction	Partial and full		Eutrophic	2, same site, 2 years	CI	POL	Verschoren et al. (2017)
	Native species	17–28% reduction	Partial	River	Not specified	1 stream, 3 sites	BA	GBR	Old et al. (2014)
	Ranunculus fluitans and *Myriophyllum spicatum*	48–49% reduction	Full	River	Eutrophic	2 streams	BACI	CHE	Kaenel et al. (2000)
	Egeria densa and *Potamogeton crispus*	40% reduction	Full	River	Not specified	1 river, 6 sites	BA	NZL	Wilcock et al. (1999)
	Native species	No significant effect	Full	River	Not specified	3 streams, 6 sites	BACI	DNK	Pedersen et al. (2011)
Manning's coefficient	*Egeria densa* and *Potamogeton crispus*	Reduced	Full	River	Not specified	1 river, 6 sites	BA	NZL	Wilcock et al. (1999)
	Nupar lutea, *Potamogeton crispus*, *Potamogeton natans* and *Sparganium emersum*	20–74% reduction	Partial and full	River	Eutrophic	2, same site, 2 years	CI	POL	Verschoren et al. (2017)
	Native species	>40% reduction	Partial	River	Not specified	1 stream, 3 sites	BA	GBR	Old et al. (2014)
	Sparganium emersum, *Potamogeton natans*, *Potamogeton pectinatus* and *Potamogeton trichoides*	27–87% reduction	Partial and full	River	Not specified	Experimental flumes	BA	BEL	Vereecken et al. (2006)
	Potamogeton natans, *Sagittaria sagittifolia* and *Callitriche platycarpa*	Reduced	Full	River	Not specified	2 streams	BA	BEL	Bal & Meire (2009)
	Phragmites australis	No significant effect	Full	River	Not specified	1 stream, 2 sites	CI	ITA	Errico et al. (2019)
	Potamogeton spp.	No cut: 0.033, Cut banks: 0.069, but highly influence by discharge	Partial	River	Not specified	1 river, 4 sites	CI	EGY	Bakry (1996)
Water transient storage (As:A)	*Potamogeton pusillus*	55% reduction	Full	Chanellised stream	Not specified	1 stream	BACI	USA	Ensign & Doyle (2005)
	Not specified	Reduced	Full	Stream	Not specified	1 stream	CI	SWE	Salehin et al. (2003)
Reaeration coefficient	*Egeria densa* and *Potamogeton crispus*	30% increase (Ks(20))	Full	River	Not specified	1 river, 6 sites	BA	NZL	Wilcock et al. (1999)
	Ranunculus fluitans and *Myriophyllum spicatum*	91–260% increase (Ks(20))	Full	River	Eutrophic	2 streams	BACI	CHE	Kaenel et al. (2000)
Biogeo-chemistry									
Diel oxygen curves	*Ranunculus fluitans* and *Myriophyllum spicatum*	121–144% reduction (O_2 mg/L)	Full	River	Eutrophic	2 streams	BACI	CHE	Kaenel et al. (2000)
Ecosystem gross primary production	Not specified	56% reduction (g $O_2/m^2/d$)	Full	Not specified	Not specified	1 lake	BACI	USA	Carpenter & Gasith (1978)
	Elodea canadensis, *Juncus articulatus* and *Mimulus guttatus*	8% reduction (mg $O_2/m^2/d$)	Full	River	Eutrophic	3 streams, 5 sites	BACI	NZL	O'Brien et al. (2014)
	Ranunculus fluitans and *Myriophyllum spicatum*	67–70% reduction in one stream (mg $O_2/m^2/d$) and no significant effect in one stream (mg $O_2/m^2/d$)	Full	River	Eutrophic	2 streams	BACI	CHE	Kaenel et al. (2000)
	Not specified	96% reduction (mg O_2/L/h)	Full	River	Eutrophic	1 stream	BACI	USA	Madsen et al. (1988)
Ecosystem respiration	Not specified	39% reduction (mg O_2/L/h)	Full	River	Eutrophic	1 stream	BACI	USA	Madsen et al. (1988)
	Ranunculus fluitans and *Myriophyllum spicatum*	67–70% reduction (mg $O_2/m^2/d$) in one stream and no significant effect in one stream (mg $O_2/m^2/d$)	Full	River	Eutrophic	2 streams	BACI	CHE	Kaenel et al. (2000)

Table 1 (*continued*)

Ecosystem property	Plant species removed	Effect of removal	Removal practice	Ecosystem[a]	Trophic state	Study size	Design[b]	Country	Reference
	Not specified	No significant effect (g $O_2/m^2/d$)	Full	Not specified	Not specified	1 lake	BACI	USA	Carpenter & Gasith (1978)
	Elodea canadensis, *Juncus articulatus* and *Mimulus guttatus*	No significant effect (mg $O_2/m^2/d$)	Full	River	Eutrophic	3 streams, 5 sites	BACI	NZL	O'Brien et al. (2014)
Turbidity	*Hydrilla verticillata*	155% increase during removal but no significant effect 1.5 month after	Partial	Lake_S	Not specified	1 Lake	BA	USA	Alam et al. (1996)
	Trapa natans	Increase immediately after harvest (>50 NTU peak)	Partial	Lake_F	Eutrophic	1 lake, 2 sites	BACI	USA	James et al. (2002)
Nutrient uptake	*Elodea canadensis*, *Juncus articulatus* and *Mimulus guttatus*	No significant effect	Full	River	Eutrophic	3 streams, 5 sites	BACI	NZL	O'Brien et al. (2014)
Suspended sediment	*Glyceria fluitans* and *Potamogeton* spp.	Increase	Full	River	Not specified	3 streams, 5 sites	BACI	NZL	Greer et al. (2017)
	Not specified	Increase	Full	Stream	Not specified	2 streams	BA	DNK	Rasmussen et al. (2021)
	Species not specified but removal of submerged macrophytes	No significant effect of release of dissolved phosphorus	Full	Lake_S	Meso-eutrophic	1 lake, 2 sites	CI	JPN	Kohzu et al. (2019)

[a] Lake_F= Lake dominated by floating macrophytes, Lakes_S= Lake dominated by submerged macrophytes, River also includes streams.

[b] BA= Before-after, CI= Control impact and BACI= Before-after-control-impact design.

[c] Long-term consequences.

References

Alam, S.K., Ager, L.A., Rosegger, T.M., Lange, T.R., 1996. The effects of mechanical harvesting of floating plant Tussock Communities on water quality in Lake Istokpoga, Florida. Lake Reserv. Manag. 12, 455–461. https://doi.org/10.1080/07438149609354285.

Aldridge, D.C., 2000. The impacts of dredging and weed cutting on a population of freshwater mussels (Bivalvia: Unionidae). Biol. Conserv. 95, 247–257. https://doi.org/10.1016/S0006-3207(00)00045-8.

Armellina, A.D., Bezic, C.R., Gajardo, O.A., Dall'Armellina, A., 1996. Propagation and mechanical control of Potamogeton illinoensis Morong in irrigation canals in Argentina. J. Aquat. Plant Manag. 34, 12–14.

Armitage, P.D., Blackburn, J.H., Winder, J.M., Wright, J.F., 1994. Impact of vegetation management on macroinvertebrates in chalk streams. Aquat. Conserv. Mar. Freshw. Ecosyst. 4, 95–104. https://doi.org/10.1002/aqc.3270040202.

Baattrup-Pedersen, A., Riis, T., 1999. Macrophyte diversity and composition in relation to substratum characteristics in regulated and unregulated Danish streams. Freshw. Biol. 42, 375–385. https://doi.org/10.1046/j.1365-2427.1999.444487.x.

Baattrup-Pedersen, A., Larsen, S.E., Riis, T., 2002. Long-term effects of stream management on plant communities in two Danish lowland streams. Hydrobiologia 481, 33–45. https://doi.org/10.1023/A:1021296519187.

Baattrup-Pedersen, A., Larsen, S.E., Riis, T., 2003. Composition and richness of macrophyte communities in small Danish streams - influence of environmental factors and weed cutting. Hydrobiologia 495, 171–179. https://doi.org/10.1023/A:1025442017837.

Baattrup-Pedersen, A., Ovesen, N.B., Larsen, S.E., Andersen, D.K., Riis, T., Kronvang, B., Rasmussen, J.J., 2018. Evaluating effects of weed cutting on water level and ecological status in Danish lowland streams. Freshw. Biol. 63, 652–661. https://doi.org/10.1111/fwb.13101.

Bakry, M.F., 1996. Impact of mechanical cutting on the channel roughness. Water Resour. Manag. 10, 479–486. https://doi.org/10.1007/BF00422551.

Bal, K.D., Meire, P., 2009. The influence of macrophyte cutting on the hydraulic resistance of lowland rivers. J. Aquat. Plant Manag. 4.

Bal, K.D., Belleghem, S.V., Deckere, E.D., Meire, P., 2006. The re-growth capacity of sago pondweed following mechanical cutting. J. Aquat. Plant Manag. 44, 139–141.

Bal, K.D., Verschoren, V., Sara, J.R., Meire, P., Schoelynck, J., 2017. Consequences of different cutting regimes on regrowth and nutrient stoichiometry of *Sparganium erectum* L. and *Potamogeton natans* L. River Res. Appl. 33, 1420–1427. https://doi.org/10.1002/rra.3190.

Barrett, S.C.H., 1989. Waterweed invasions. Sci. Am. 261, 90–97.

Bernes, C., Carpenter, S.R., Gårdmark, A., Larsson, P., Persson, L., Skov, C., Speed, J.D.M., Donk, E.V., 2015. What is the influence of a reduction of planktivorous and benthivorous fish on water quality in temperate eutrophic lakes? A systematic review. Environ. Evid. 4, 1–28. https://doi.org/10.1186/s13750-015-0032-9.

Bernot, M.J., Tank, J.L., Royer, T.V., David, M.B., 2006. Nutrient uptake in streams draining agricultural catchments of the midwestern United States. Freshw. Biol. 51, 499–509. https://doi.org/10.1111/j.1365-2427.2006.01508.x.

Best, E.P.H., 1994. The impact of mechanical harvesting regimes on the aquatic and shore vegetation in water courses of agricultural areas of the Netherlands. Vegetation 112, 57–71. https://doi.org/10.1007/BF00045100.

Bickel, T., Closs, G., 2009. Impact of partial removal of the invasive macrophyte Lagarosiphon major (hydrocharitaceae) on invertebrates and fish. River Res. Appl. 25, 734–744. https://doi.org/10.1002/rra.1187.

Bicudo, D.D.C., Fonseca, B.M., Bini, L.M., Crossetti, L.O., Bicudo, C.E.D.M., Araújo-Jesus, T., 2007. Undesirable side-effects of water hyacinth control in a shallow tropical reservoir. Freshw. Biol. 52, 1120–1133. https://doi.org/10.1111/j.1365-2427.2007.01738.x.

Binzer, T., Sand-Jensen, K., Middelboe, A.-L., 2006. Community photosynthesis of aquatic macrophytes. Limnol. Oceanogr. 51, 2722–2733. https://doi.org/10.4319/lo.2006.51.6.2722.

Boerema, A., Schoelynck, J., Bal, K., Vrebos, D., Jacobs, S., Staes, J., Meire, P., 2014. Economic valuation of ecosystem services, a case study for aquatic vegetation removal in the Nete catchment (Belgium). Ecosyst. Serv. 7, 46–56. https://doi.org/10.1016/j.ecoser.2013.08.001.

Booms, T.L., 1999. Vertebrates removed by mechanical weed harvesting in Lake Keesus, Wisconsin. J. Aquat. Plant Manag. 37, 34–36.

Buczyński, P., Zawal, A., Buczyńska, E., Stępień, E., Dąbkowski, P., Michoński, G., Szlauer-Lukaszewska, A., Pakulnicka, J., Robert, S., Czachorowski, S., 2016. Early recolonization of a dredged lowland river by dragonflies (Insecta: Odonata). Knowl. Manag. Aquat. Ecosyst. 43. https://doi.org/10.1051/kmae/2016030 2016.

Caffrey, J.M., Monahan, C., 2006. Control of Myriophyllum verticillatum L. in Irish canals by turion removal. Hydrobiologia 570, 211–215. https://doi.org/10.1007/s10750-006-0183-3.

Caraco, N., Cole, J., Findlay, S., Wigand, C., 2006. Vascular plants as engineers of oxygen in aquatic systems. BioScience 56, 219–225. https://doi.org/10.1641/0006-3568(2006)056[0219:VPAEOO]2.0.CO;2.

Carey, N., Strachan, S.R., Robson, B.J., 2017. Impacts of Indian waterfern (Ceratopteris thalictroides (L.) Brongn.) infestation and removal on macroinvertebrate biodiversity and conservation in spring-fed streams in the Australian arid zone. Aquat. Conserv. Mar. Freshw. Ecosyst. 28, 466–475. https://doi.org/10.1002/aqc.2828.

Carpenter, S.R., Gasith, A., 1978. Mechanical cutting of submersed macrophytes: Immediate effects on littoral water chemistry and metabolism. Water Res. 12, 55–57. https://doi.org/10.1016/0043-1354(78)90196-3.

Carpenter, S.R., van Donk, E., Wetzel, R.G., 1998. Nutrient-loading gradient in shallow lakes: report of the group discussion. In: Jeppesen, E., Søndergaard, Martin, Søndergaard, Morten, Christoffersen, K. (Eds.), The Structuring Role of Submerged Macrophytes in Lakes, Ecological Studies. Springer, New York, NY, pp. 393–396 https://doi.org/10.1007/978-1-4612-0695-8_30.

Chambers, P.A., Prepas, E.E., 1994. Nutrient dynamics in riverbeds: the impact of sewage effluent and aquatic macrophytes. Water Res. 28, 453–464. https://doi.org/10.1016/0043-1354(94)90283-6.

Choi, J.-Y., Jeong, K.-S., La, G.-H., Joo, G.-J., 2014. Effect of removal of free-floating macrophytes on zooplankton habitat in shallow wetland. Knowl. Manag. Aquat. Ecosyst. 11. https://doi.org/10.1051/kmae/2014023.

Crowell, W., Troelstrup, N., Queen, L., Perry, J., 1994. Effects of harvesting on plant communities dominated by Eurasian watermilfoil in Lake Minnetonka, MN. J. Aquat. Plant Manag. 32, 56–60.

Dabkowski, P., Buczynski, P., Zawal, A., Stepien, E., Buczynska, E., Stryjecki, R., Czachorowski, S., Smietana, P., Szenejko, M., 2016. The impact of dredging of a small lowland river on water beetle fauna (Coleoptera). J. Limnol. 75. https://doi.org/10.4081/jlimnol.2016.1270.

Daldorph, P.W.G., Thomas, J.D., 1991. The effect of nutrient enrichment on a freshwater community dominated by macrophytes and molluscs and its relevance to snail control. J. Appl. Ecol. 28, 685–702 https://doi.org/10.2307/2404576.

Dawson, F.H., Clinton, E.M.F., Ladle, M., 1991. Invertebrates on cut weed removed during weed-cutting operations along an English river, the River Frome, Dorset [WWW Document]. Aquac. Res. https://doi.org/10.1111/j.1365-2109.1991.tb00500.x.

Dugdale, T.M., Hunt, T.D., Clements, D., 2013. Aquatic weeds in Victoria: Where and why are they a problem, and how are they being controlled? Plant Prot. Q. 28, 35–41.

Engel, S., 1990. Ecological impacts of harvesting macrophytes in Halverson Lake, Wisconsin. J. Aquat. Plant Manag. 28, 41–45.

Engelhardt, K.A.M., Ritchie, M.E., 2001. Effects of macrophyte species richness on wetland ecosystem functioning and services. Nature 411, 687–689. https://doi.org/10.1038/35079573.

Ensign, S.H., Doyle, M.W., 2005. In-channel transient storage and associated nutrient retention: evidence from experimental manipuljations. Limnol. Oceanogr. 50, 1740–1751. https://doi.org/10.4319/lo.2005.50.6.1740.

Errico, A., Lama, G.F.C., Francalanci, S., Chirico, G.B., Solari, L., Preti, F., 2019. Flow dynamics and turbulence patterns in a drainage channel colonized by common reed (Phragmites australis) under different scenarios of vegetation management. Ecol. Eng. 133, 39–52. https://doi.org/10.1016/j.ecoleng.2019.04.016.

Fausch, K.D., Nakano, S., Kitano, S., 1997. Experimentally induced foraging mode shift by sympatric charrs in a Japanese mountain stream. Behav. Ecol. 8, 414–420. https://doi.org/10.1093/beheco/8.4.414.

Freedman, J.A., Carline, R.F., Stauffer, J.R., 2013. Gravel dredging alters diversity and structure of riverine fish assemblages. Freshw. Biol. 58, 261–274. https://doi.org/10.1111/fwb.12056.

Garbey, C., Thiébaut, G., Muller, S., 2003. Impact of manual spring harvesting on the regrowth of a spreading aquatic plant: Ranunculus peltatus SCHRANK. Arch. Für Hydrobiol. 156, 271–286.

García-Llorente, M., Martín-López, B., Díaz, S., Montes, C., 2011. Can ecosystem properties be fully translated into service values? An economic valuation of aquatic plant services. Ecol. Appl. 21, 3083–3103. https://doi.org/10.1890/10-1744.1.

Garner, P., Bass, J.a.B., Collett, G.D., 1996. The effects of weed cutting upon the biota of a large regulated river. Aquat. Conserv. Mar. Freshw. Ecosyst. 6, 21–29. https://doi.org/10.1002/(SICI)1099-0755(199603)6:1<21::AID-AQC171>3.0.CO;2-Z.

Grasset, C., Abril, G., Mendonça, R., Roland, F., Sobek, S., 2019. The transformation of macrophyte-derived organic matter to methane relates to plant water and nutrient contents. Limnol. Oceanogr. 64, 1737–1749. https://doi.org/10.1002/lno.11148.

Gray, M.J., Kaminski, R.M., Weerakkody, G., Leopold, B.D., Jensen, K.C., 1999. Aquatic invertebrate and plant responses following mechanical manipulations of moist-soil habitat. Wildl. Soc. Bull. 29, 770–779.

Greer, M.J.C., Closs, G.P., Crow, S.K., Hicks, A.S., 2012. Complete versus partial macrophyte removal: the impacts of two drain management strategies on freshwater fish in lowland New Zealand streams. Ecol. Freshw. Fish 21, 510–520. https://doi.org/10.1111/j.1600-0633.2012.00569.x.

Greer, M.J.C., Hicks, A.S., Crow, S.K., Closs, G.P., 2017. Effects of mechanical macrophyte control on suspended sediment concentrations in streams. N. Z. J. Mar. Freshw. Res. 51, 254–278. https://doi.org/10.1080/00288330.2016.1210174.

Grygoruk, M., Frąk, M., Chmielewski, A., 2015. Agricultural rivers at risk: dredging results in a loss of macroinvertebrates. Preliminary observations from the Narew Catchment, Poland. Water 7, 4511–4522. https://doi.org/10.3390/w7084511.

Güereña, D., Neufeldt, H., Berazneva, J., Duby, S., 2015. Water hyacinth control in Lake Victoria: transforming an ecological catastrophe into economic, social, and environmental benefits. Sustain. Prod. Consum. 3, 59–69. https://doi.org/10.1016/j.spc.2015.06.003.

Gurnell, A., 2014. Plants as river system engineers. Earth Surf. Process. Landf. 39, 4–25. https://doi.org/10.1002/esp.3397.

Habib, S., Yousuf, A.R., 2014. Impact of mechanical deweeding on the phytophilous macroinvertebrate community of an eutrophic lake. Environ. Sci. Pollut. Res. 21, 5653–5659. https://doi.org/10.1007/s11356-013-2470-7.

He, L., Bakker, E.S., Alirangues Nunez, M.M., Hilt, S., 2019. Combined effects of shading and clipping on the invasive alien macrophyte Elodea nuttallii. Aquat. Bot. 154, 24–27. https://doi.org/10.1016/j.aquabot.2018.11.014.

Hill, M.P., Coetzee, J., 2017. The biological control of aquatic weeds in South Africa: current status and future challenges. Bothalia 47. https://doi.org/10.4102/abc.v47i2.2152 12 pages.

Hilt, S., Gross, E.M., Hupfer, M., Morscheid, H., Mählmann, J., Melzer, A., Poltz, J., Sandrock, S., Scharf, E.-M., Schneider, S., van de Weyer, K., 2006. Restoration of submerged vegetation in shallow eutrophic lakes – a guideline and state of the art in Germany. Limnologica 36, 155–171. https://doi.org/10.1016/j.limno.2006.06.001.

Hilt, S., Köhler, J., Kozerski, H.-P., van Nes, E.H., Scheffer, M., 2011. Abrupt regime shifts in space and time along rivers and connected lake systems. Oikos 120, 766–775. https://doi.org/10.1111/j.1600-0706.2010.18553.x.

Holmes, R.J., Hayes, J.W., Closs, G.P., Beech, M., Jary, M., Matthaei, C.D., 2019. Mechanically reshaping stream banks alters fish community composition. River Res. Appl. 35, 247–258. https://doi.org/10.1002/rra.3407.

Horppila, J., Nurminen, L., 2005. Effects of different macrophyte growth forms on sediment and P resuspension in a shallow lake. Hydrobiologia 545, 167–175. https://doi.org/10.1007/s10750-005-2677-9.

House, W.A., Duplat, D., Denison, F.H., Henville, P., Dawson, F.H., Cooper, D.M., May, L., 2001. The Role of macrophytes in the retention of phosphorus in the River Thame. England. Chem. Ecol. 17, 271–291. https://doi.org/10.1080/02757540108035559.

Hussner, A., Stiers, I., Verhofstad, M.J.J.M., Bakker, E.S., Grutters, B.M.C., Haury, J., van Valkenburg, J.L.C.H., Brundu, G., Newman, J., Clayton, J.S., Anderson, L.W.J., Hofstra, D., 2017. Management and control methods of invasive alien freshwater aquatic plants: a review. Aquat. Bot. 136, 112–137. https://doi.org/10.1016/j.aquabot.2016.08.002.

James, W.F., Barko, J.W., Eakin, H.L., 2002. Water quality impacts of mechanical shredding of aquatic macrophytes. J. Aquat. Plant Manag. 40, 36–42.

James, W.F., Barko, J.W., Butler, M.G., 2004. Shear stress and sediment resuspension in relation to submersed macrophyte biomass. Hydrobiologia 515, 181–191. https://doi.org/10.1023/B:HYDR.0000027329.67391.c6.

Jeppesen, E., Søndergaard, Martin, Søndergaard, Morten, Christoffersen, K., 1998. The structuring Role of Macrophytes in Lakes. Springer, Ecological Studies.

Johnson, R.E., Bagwell, M.R., 1979. Effects of mechanical cutting on submersed vegetation in a Louisiana lake. J. Aquat. Plant Manag 17, 54–57.

Kaenel, B.R., Matthaei, C.D., Uehlinger, U., 1998. Disturbance by aquatic plant management in streams: effects on benthic invertebrates. Regul. Rivers Res. Manag. 14, 341–356. https://doi.org/10.1002/(SICI)1099-1646(199807/08)14:4<341::AID-RRR504>3.0.CO;2-2.

Kaenel, B.R., Buehrer, H., Uehlinger, U., 2000. Effects of aquatic plant management on stream metabolism and oxygen balance in streams. Freshw. Biol. 45, 85–95. https://doi.org/10.1046/j.1365-2427.2000.00618.x.

Klaassen, M., Nolet, B.A., 2007. The role of herbivorous water birds in aquatic systems through interactions with aquatic macrophytes, with special reference to the Bewick's Swan — Fennel Pondweed system. In: Gulati, R.D., Lammens, E., De Pauw, N., Van Donk, E. (Eds.), Shallow Lakes in a Changing World, Developments in Hydrobiology. Springer Netherlands, Dordrecht, pp. 205–213 https://doi.org/10.1007/978-1-4020-6399-2_19.

Kohzu, A., Shimotori, K., Imai, A., 2019. Effects of macrophyte harvesting on the water quality and bottom environment of Lake Biwa, Japan. Limnology 20, 83–92. https://doi.org/10.1007/s10201-018-0556-0.

Korb, K.B., Nicholson, A.E., 2004. Bayesian Artificial Intelligence. Chapman and Hall, Coca Raton, FL.

Kreiling, R.M., Richardson, W.B., Cavanaugh, J.C., Bartsch, L.A., 2011. Summer nitrate uptake and denitrification in an upper Mississippi River backwater lake: the role of rooted aquatic vegetation. Biogeochemistry 104, 309–324. https://doi.org/10.1007/s10533-010-9503-9.

Kuiper, J.J., Verhofstad, M.J.J.M., Louwers, E.L.M., Bakker, E.S., Brederveld, R.J., van Gerven, L.P.A., Janssen, A.B.G., de Klein, J.J.M., Mooij, W.M., 2017. Mowing submerged macrophytes in shallow lakes with alternative stable states: battling the good guys? Environ. Manage. 59, 619–634. https://doi.org/10.1007/s00267-016-0811-2.

Laughton, R., Cosgrove, P., Hastie, L., Sime, I., 2008. Effects of aquatic weed removal on freshwater pearl mussels and juvenile salmonids in the River Spey, Scotland. Aquat. Conserv. Mar. Freshw. Ecosyst. 18, 44–54. https://doi.org/10.1002/aqc.821.

Levi, P.S., Riis, T., Alnøe, A.B., Peipoch, M., Maetzke, K., Bruus, C., Baattrup-Pedersen, A., 2015. Macrophyte complexity controls nutrient uptake in lowland streams. Ecosystems 18, 914–931. https://doi.org/10.1007/s10021-015-9872-y.

Lusardi, R.A., Jeffres, C.A., Moyle, P.B., 2018. Stream macrophytes increase invertebrate production and fish habitat utilization in a California stream. River Res. Appl. 34, 1003–1012. https://doi.org/10.1002/rra.3331.

Madsen, J.D., Adams, M.S., Ruffier, P., 1988. Harvest as a control for sago pondweed (Potamogeton pectinatus L.) in Badfish Creek, Wisconsin: frequency, efficiency and its impact on stream community oxygen metabolism. J. Aquat. Plant Manag. 29, 94–99.

Mangas-Ramírez, E., Elías-Gutiérrez, M., 2004. Effect of mechanical removal of water hyacinth (Eichhornia crassipes) on the water quality and biological communities in a Mexican reservoir. Aquat. Ecosyst. Health Manag. 7, 161–168. https://doi.org/10.1080/14634980490281597.

Mikol, G., 1984. Effects of mechanical control of aquatic vegetation on biomass, regrowth rates, and juvenile fish populations at Saratoga Lake, New York. Lake Reserv. Manag. 1, 456–462. https://doi.org/10.1080/07438148409354556.

Mikol, G.F., 1985. Effects of harvesting on aquatic vegetation and juvenile fish populations at Saratoga Lake, New York. J. Aquat. Plant Manag. 23, 59–63.

Miliša, M., Kepčija, R.M., Radanović, I., Ostojić, A., Habdija, I., 2006. The impact of aquatic macrophyte (Salix sp. and Cladium mariscus (L.) Pohl.) removal on habitat conditions and macroinvertebrates of tufa barriers (Plitvice Lakes, Croatia). Hydrobiologia 573, 183–197. https://doi.org/10.1007/s10750-006-0271-4.

Moe, T.F., Brysting, A.K., Andersen, T., Schneider, S.C., Kaste, Ø., Hessen, D.O., 2013. Nuisance growth of *Juncus bulbosus*: the roles of genetics and environmental drivers tested in a large-scale survey: *the roles of genetics and environmental drivers tested in a large-scale survey*. Freshw. Biol. 58, 114–127. https://doi.org/10.1111/fwb.12043.

Monahan, C., Caffrey, J.M., 1996. The effect of weed control practices on macroinvertebrate communities in Irish Canals. Hydrobiologia 340, 205–211. https://doi.org/10.1007/BF00012756.

Morris, K., Bailey, P.C.E., Boon, P.I., Hughes, L., 2006. Effects of plant harvesting and nutrient enrichment on phytoplankton community structure in a shallow urban lake. Hydrobiologia 571, 77–91. https://doi.org/10.1007/s10750-006-0230-0.

Mortensen, E., 1977. Density-dependent mortality of trout fry (Salmo trutta L.) and its relationship to the management of small streams. J. Fish Biol. 11, 613–617. https://doi.org/10.1111/j.1095-8649.1977.tb05719.x.

Nichols, S.A., 1973. The effects of harvesting aquatic macrophytes on algae. Trans Wis Acad Sci Arts Lett 61, 165–172.

Nielsen, U.N., Riis, T., Brix, H., 2006. The effect of weed cutting on Luronium natans. Aquat. Conserv. Mar. Freshw. Ecosyst. 16, 409–417. https://doi.org/10.1002/aqc.755.

Nino, F.D., Thiébaut, G., Muller, S., 2005. Response of Elodea Nuttallii (Planch.) H. St. John to manual harvesting in the north-east of France. Hydrobiologia 551, 147–157. https://doi.org/10.1007/s10750-005-4457-y.

Norsys, 2005. NETICA. Available at. http://www.norsys.com.

O'Brien, J.M., Lessard, J.L., Plew, D., Graham, S.E., McIntosh, A.R., 2014. Aquatic macrophytes alter metabolism and nutrient cycling in lowland streams. Ecosystems 17, 405–417. https://doi.org/10.1007/s10021-013-9730-8.

Old, G.H., Naden, P.S., Rameshwaran, P., Acreman, M.C., Baker, S., Edwards, F.K., Sorensen, J.P.R., Mountford, O., Gooddy, D.C., Stratford, C.J., Scarlett, P.M., Newman, J.R., Neal, M., 2014. Instream and riparian implications of weed cutting in a chalk river. Ecol. Eng. 71, 290–300. https://doi.org/10.1016/j.ecoleng.2014.07.006.

Olson, M.H., Carpenter, S.R., Cunningham, P., Gafny, S., Herwig, B.R., Nibbelink, N.P., Pellett, T., Storlie, C., Trebitz, A.S., Wilson, K.A., 1998. Managing macrophytes to improve fish growth: a multi-lake experiment. Fish. Manag. 23, 6–12. https://doi.org/10.1577/1548-8446(1998)023<0006:MMTIFG>2.0.CO;2.

Painter, D.S., 1986. Long-term effects of mechanical harvesting on Eurasian watermilfoil. J Env. Manage 15, 263–271.

Pedersen, M.L., Baattrup-Pedersen, A., Rørth, F.R., Madsen, T.V., Larsen, S.E., 2011. Short-term impacts of weed cutting on the physical habitats in lowland rivers: the importance of the initial environmental conditions. Pol. J. Environ. Stud. 20, 1271–1280.

Pinardi, M., Bartoli, M., Longhi, D., Marzocchi, U., Laini, A., Ribaudo, C., Viaroli, P., 2009. Benthic metabolism and denitrification in a river reach: a comparison between vegetated and bare sediments. J. Limnol. 68, 133–145. https://doi.org/10.4081/jlimnol.2009.133.

Płaska, W., Kurzątkowska, A., Stępień, E., Buczyńska, E., Pakulnicka, J., Szlauer-Łukaszewska, A., Zawal, A., 2016. The effect of dredging of a small lowland river on aquatic Heteroptera. Ann. Zool. Fenn. 53, 139–153. https://doi.org/10.5735/086.053.0403.

Pollino, C.A., Woodberry, O., Nicholson, A., Korb, K., Hart, B.T., 2007. Parameterisation and evaluation of a Bayesian network for use in an ecological risk assessment. Environ. Model. Softw. 22, 1140–1152. https://doi.org/10.1016/j.envsoft.2006.03.006 Bayesian networks in water resource modelling and management.

Rasmussen, J.J., Kallestrup, Helena, Thiemer, Kirstine, Alnøe, A.B., Henriksen, Lisbeth, D., Larsen, S.E., Baattrup-Pedersen, Annette, 2021. Effects of different weed cutting methods on physical and hydromorphological conditions in lowland streams. Knowl. Manag. Aquat. Ecosyst. https://doi.org/10.1051/kmae/2021009.

Reynolds, C.S., 2000. Hydroecology of river plankton: the role of variability in channel flow. Hydrol. Process. 14, 3119–3132. https://doi.org/10.1002/1099-1085(200011/12)14:16/17<3119::AID-HYP137>3.0.CO;2-6.

Ribaudo, C., Bertrin, V., Jan, G., Anschutz, P., Abril, G., 2017. Benthic production, respiration and methane oxidation in Lobelia dortmanna lawns. Hydrobiologia 784, 21–34. https://doi.org/10.1007/s10750-016-2848-x.

Riis, T., Biggs, B.J.F., 2001. Distribution of macrophytes in New Zealand streams and lakes in relation to disturbance frequency and resource supply—a synthesis and conceptual model. N. Z. J. Mar. Freshw. Res. 35, 255–267. https://doi.org/10.1080/00288330.2001.9516996.

Roelofs, J.G.M., Brandrud, T.E., Smolders, A.J.P., 1994. Massive expansion of Juncus bulbosus L. after liming of acidified SW Norwegian lakes. Aquat. Bot. 48, 187–202. https://doi.org/10.1016/0304-3770(94)90015-9.

Rørslett, B., 1988. Aquatic weed problems in a hydroelectric river: the R. Otra, Norway. Regul. Rivers Res. Manag. 2, 25–37. https://doi.org/10.1002/rrr.3450020104.

Rørslett, B., Johansen, S.W., 1996. Remedial Measures Connected with Aquatic Macrophytes in Norwegian Regulated Rivers and Reservoirs. Regul. Rivers Res. Manag. 12, 509–522. https://doi.org/10.1002/(SICI)1099-1646(199607)12:4/5<509::AID-RRR410>3.0.CO;2-3.

Salehin, M., Packman, A.I., Wörman, A., 2003. Comparison of transient storage in vegetated and unvegetated reaches of a small agricultural stream in Sweden: seasonal variation and anthropogenic manipulation. Adv. Water Resour., Modeling Hyporheic Zone Processes 26, 951–964. https://doi.org/10.1016/S0309-1708(03)00084-8.

Schooler, S.S., Yeates, A.G., Wilson, J.R.U., Julien, M.H., 2007. Herbivory, mowing, and herbicides differently affect production and nutrient allocation of Alternanthera philoxeroides. Aquat. Bot. 86, 62–68. https://doi.org/10.1016/j.aquabot.2006.09.004.

Sheldon, S.P., O'Bryan, L.M., 1996. The effects of harvesting Eurasian watermilfoil on the aquatic weevil Euhrychiopsis lecontei. J. Aquat. Plant Manag. 34, 76–77.

Spencer, D.F., Ksander, G.G., Donovan, M.J., Liow, P.S., Chan, W.K., Greenfield, B.K., Shonkoff, S.B., Andrews, S.P., 2006. Evaluation of waterhyacinth survival and growth in the Sacramento Delta, California, following cutting. J. Aquat. Plant Manag. 44, 50–60.

Stępień, E., Zawal, A., Buczyński, P., Buczyńska, E., Szenejko, M., 2019. Effects of dredging on the vegetation in a small lowland river. PeerJ 7. https://doi.org/10.7717/peerj.6282.

Stewart-Koster, B., Bunn, S.E., Mackay, S.J., Poff, N.L., Naiman, R.J., Lake, P.S., 2010. The use of Bayesian networks to guide investments in flow and catchment restoration for impaired river ecosystems. Freshw. Biol. 55, 243–260. https://doi.org/10.1111/j.1365-2427.2009.02219.x.

Strien, A.J.V., Strucker, R.C.W., 1991. Effects of mechanical ditch management on the vegetation of ditch banks in Dutch peat areas. J. Appl. Ecol. 28, 501–513.

Swales, S., 1982. Impacts of weed-cutting on fisheries: an experimental study in a small lowland river. Aquac. Res. 13, 125–137. https://doi.org/10.1111/j.1365-2109.1982.tb00043.x.

Tall, L., Caraco, N., Maranger, R., 2011. Denitrification hot spots: dominant role of invasive macrophyte Trapa natans in removing nitrogen from a tidal river. Ecol. Appl. 21, 3104–3114. https://doi.org/10.1890/11-0061.1.

Thiébaut, G., Di Nino, F., Peltre, M.C., Wagner, P., 2008. Management of aquatic exotic plants: the case of Elodea species. Proceedings of Taal 2007: The 12th World Lake Conference, p. 1066.

Unmuth, J.M.L., Hansen, M.J., Rasmussen, P.W., Pellett, T.D., 1999. Effects of mechanical harvesting of Eurasian watermilfoil on angling for Bluegills in fish lake, Wisconsin. North Am. J. Fish. Manag. 21, 448–454. https://doi.org/10.1577/1548-8675(2001)021<0448:EOMHOE>2.0.CO;2.

Unmuth, Sloey, D., J., Lillie, R.A., 1998. An evaluation of close-cut mechanical harvesting of Eurasian watermilfoil. J. Aquat. Plant Manag. 36, 93–100.

Vereecken, H., Baetens, J., Viaene, P., Mostaert, F., Meire, P., 2006. Ecological management of aquatic plants: effects in lowland streams. Hydrobiologia 570, 205–210. https://doi.org/10.1007/s10750-006-0181-5.

Verhofstad, M.J.J.M., Bakker, E.S., 2019. Classifying nuisance submerged vegetation depending on ecosystem services. Limnology 20, 55–68. https://doi.org/10.1007/s10201-017-0525-z.

Verhofstad, M.J.J.M., Alirangues Núñez, M.M., Reichman, E.P., van Donk, E., Lamers, L.P.M., Bakker, E.S., 2017. Mass development of monospecific submerged macrophyte vegetation after the restoration of shallow lakes: Roles of light, sediment nutrient levels, and propagule density. Aquat. Bot. 141, 29–38. https://doi.org/10.1016/j.aquabot.2017.04.004.

Verschoren, V., Schoelynck, J., Cox, T., Schoutens, K., Temmerman, S., Meire, P., 2017. Opposing effects of aquatic vegetation on hydraulic functioning and transport of dissolved and organic particulate matter in a lowland river: a field experiment. Ecol. Eng. 105, 221–230. https://doi.org/10.1016/j.ecoleng.2017.04.064.

Ward-Campbell, B., Cottenie, K., Mandrak, N., McLaughlin, R., 2017. Maintenance of agricultural drains alters physical habitat, but not macroinvertebrate assemblages exploited by fishes. J. Environ. Manage. 203, 29–39. https://doi.org/10.1016/j.jenvman.2017.07.032.

Wilcock, R.J., Champion, P.D., Nagels, J.W., Croker, G.F., 1999. The influence of aquatic macrophytes on the hydraulic and physico-chemical properties of a New Zealand lowland stream. Hydrobiologia 416, 203–214. https://doi.org/10.1023/A:1003837231848.

Wile, I., 1978. Environmental effects of mechanical harvesting. J. Aquat. Plant Manag. 16, 14–20.

Wojciechowski, J., Burda, T.M., Scheer, M.B., da Costa, E.A.D., Fernandes, L.F., Wojciechowski, J., Burda, T.M., Scheer, M.B., da Costa, E.A.D., Fernandes, L.F., 2018. Potential effects of mechanically removing macrophytes on the phytoplankton community of a subtropical reservoir. Acta Bot. Bras. 32, 588–594. https://doi.org/10.1590/0102-33062018abb0015.

Zhu, J., Peng, Z., Liu, X., Deng, J., Zhang, Y., Hu, W., 2019. Response of aquatic plants and water quality to large-scale nymphoides peltata harvest in a shallow lake. Water 11, 77. https://doi.org/10.3390/w11010077.

van Zuidam, J.P., Peeters, E.T.H.M., 2012. Cutting affects growth of Potamogeton lucens L. and Potamogeton compressus L. Aquat. Bot. 100, 51–55. https://doi.org/10.1016/j.aquabot.2012.02.005.