ICWATER RDI FUNDED PROJECTS

Project: Mass development of aquatic macrophytes - causes and consequences of macrophyte removal for ecosystem structure, function, and services

Acronym: MadMacs

Outcomes and expected impact:

Scientific impact. At international scientific conferences aquatic macrophytes are often treated as either a **problem** (and methods are discussed how to remove them), or as a **solution** for improving the status of turbid freshwater ecosystems (and methods are discussed how to support the growth of macrophytes). Ironically, these two fields of science to date have worked quite separately from each other. We aim for the first time to **combine and balance** these two aspects with each other. The collaborative efforts of the consortium will create new and exciting knowledge, which will facilitate differentiation between site-specific and general consequences of macrophyte removal, and balance the benefits and dis-benefits of dense aquatic vegetation.

Societal impact. We will contribute to the sustainable management of water bodies, by quantifying which combination of factors lead to massive macrophyte growth. This will enable handling the underlying causes of macrophyte mass development, instead of unsustainably trying to "cure the symptoms", which generally is current practice. We will quantify and compare all different aspects of benefits and dis-benefits of macrophyte removal to society. This will support informed and balanced management decisions, instead of "listening to those who happen to have the strongest lobby", which often is current practice. We will thereby contribute to the well-being of society, as sustainably-managed ecosystems in the long run are most beneficial to society.

Economic impact. We hope to introduce a new way of thinking in macrophyte management, by quantifying the benefits and dis-benefits of macrophyte removal. We will develop a cook-book tool on how to balance the benefits and dis-benefits of macrophyte removal. This can potentially save a substantial amount of money by preventing management measures which cost more than they gain. We will develop a tool to forecast the likelihood that a given water body will develop massive aquatic vegetation, and to forecast the consequences of macrophyte removal for a water body. We anticipate that management authorities and SMEs will apply this tool to plan ecosystem restoration measures (to anticipate which effect a specific restoration measure, e.g. nutrient reduction, or flow increase, will have for macrophyte development, and to see if macrophyte removal is likely to have the desired effect in their ecosystem of interest). This will improve the quality and cost-effectiveness of restoration measures, thereby strengthening the growth of SMEs who apply these methods. Overall, MadMacs will substantially contribute to an improved and more cost-effective management of aquatic ecosystems.

New tools for water management: MadMacs will provide information to which degree macrophytes contribute to the provision of clean

water (UN SDG 6). We will develop guidelines ("cookbook") how to balance the benefits and dis-benefits of dense aquatic vegetation in water courses. We will develop a tool to forecast the likelihood that a water body will develop massive aquatic vegetation, and to forecast the consequences of macrophyte removal.

Improved eco-technological solutions for the remediation and mitigation of degraded aquatic ecosystems: Macrophytes are a cost-effective, "green", and relatively easy to use tool to improve water quality in degraded (multi-stressed) aquatic ecosystems. MadMacs will measure the capacity of macrophytes to purify water across a range of different ecosystems, and provide guidelines to determine when the benefits of dense aquatic vegetation to society are greater than the dis-benefits.

Knowledge on assessing the vulnerability and resilience of ecosystems to multiple pressure factors: MadMacs will develop a model to assess the multiple and interacting causes of macrophyte mass development, thereby developing a risk assessment tool which can be used to assess when aquatic ecosystems are likely to develop massive aquatic vegetation.

Participation of stakeholders: Six key institutional stakeholders are actively involved in WP2 and 3, and have expressed their willingness to co-ordinate the removal of aquatic vegetation at the case study sites with the MadMacs scientific needs. Other stakeholders will be informed about project outcomes by an active dissemination strategy.

Raised social awareness for water related issues: Water courses with dense aquatic vegetation are often perceived negatively by the public. We will inform managers and the public of the benefits and dis-benefits of dense aquatic vegetation, and of the underlying causes leading to macrophyte mass development. This will lead to an improved understanding, and introduce a more balanced (informed) relation of society towards aquatic ecosystems. We will directly involve MSc students from all five participating countries in MadMacs. The involvement of students will contribute to a long-term raise of awareness for the management of water courses with dense aquatic vegetation.

Improved trans-disciplinary research: MadMacs combines basic science (ecosystem metabolism) with applied science (macrophyte management) and cross disciplinary science (ecosystem services framing).

Improved international cooperation: Our case studies are from five countries on three continents, and have quite different management histories. The key stakeholders will benefit from the exchange of experiences, and actively have expressed their interest in learning from each other. All partners, but particularly the Postdoc, PhD and MSc students, will benefit from the trans-national exchange of experiences in order to reach a common goal.

Address questions relating to water challenges faced by society: Mass development of macrophytes is an international problem, and considerable resources are spent on macrophyte removal without sufficient knowledge of the benefits and dis-benefits of these actions. MadMacs will address this issue, and develop guidelines how to balance the benefits and dis-benefits of dense aquatic vegetation for improved management.

Stimulate mobility of researchers within the consortium: Post-doctoral researchers and PhD students will travel to several of the case study sites, and contribute to sampling, measuring and the completion of the questionnaires within WP3. Within budget limitations, senior scientists will also participate. The timing and location for the kick-off meeting is strategically chosen to enable method testing at one of the case study sites for all project participants. All partners will benefit from the trans-national exchange of experiences.

List of deliverables expected:

D1.1 mid-term progress report;
D1.2 final progress report.
D2.1 draft model;
D2.2 BN tool to assess the risk of mass development and the consequences of macrophyte removal;
D2.3 manuscript on global probabilistic modelling;
D3.1-3.3 method descriptions and several manuscripts on the effects of macrophyte removal;
D3.4.1 questionnaire for ecosystem service evaluation (in English);
D3.4.2 manuscript on ecosystem service evaluation;
D4.1 "cookbook"-tool on how to balance the benefits and dis-benefits of dense aquatic vegetation

Expected research results to communicate and disseminate	**Target groups for communication and dissemination activities:**
1. Field work activities and project background	water managers, general public, scientific community (freshwater ecology)
2. Main results: do macrophyte "mass developments" have some positive aspects, or are they only a nuisance?	water managers, general public, scientific community (freshwater ecology)
3. Tool to assess the consequences of macrophyte removal, and "cookbook" tool how to balance the benefits and dis-benefits of aquatic vegetation	water managers, scientific community (freshwater ecology)
We will execute a set of "real-world experiments" in a harmonized BACI design at six case study sites in water bodies in five countries (Norway, Germany (2),	

France, South Africa, Brazil).

***Juncus bulbosus* in the River Otra (Norway):** mass development of the native macrophyte *J. bulbosus* is the most serious environmental problem in rivers in southern Norway. Annually, on average 250 000 € are spent on abatement measures, but regrowth is generally observed after few years. The Otra River is subject to hydromorphological alterations, climate change and anthropogenic pollution, and the river is used for recreation and hydropower generation. The stakeholder involved in this case study is "Krypsivprosjektet på Sørlandet" (KPS), a consortium of hydroelectric power companies, Energy Norway, the Norwegian Water Resources and Energy Directorate (NVE), and representatives from Norwegian environmental authorities.

***Elodea nuttallii* in Lake Müggelsee (Germany):** mass development of the non-native species *E. nuttallii* is a challenge in many water bodies in Germany. In Lake Müggelsee, this species has dramatically increased in abundance. The lake is used intensively for drinking water production, navigation, and recreation, and is subject to climate change, anthropogenic pollution, hydromorphological alterations and an invasion of non-native dreissenid mussels. Risks of mowing *Elodea* have so far not been quantified, but could potentially be serious because a switch to a turbid state could affect drinking water production, especially if cyanobacteria should develop blooms. The stakeholder involved in this case study is the Senatsverwaltung Berlin (regional environmental authority).

***Native macrophytes* in the lower River Spree (Germany):** From the mid-1990s, macrophyte vegetation gradually has increased. In recent years, submerged and floating-leafed macrophytes (mostly *Sagittaria sagittifolia*, *Sparganium emersum* and *Nuphar lutea*) attained a wet weight of 700-800 tons in a 30-km river section, of which about 250-300 t are mechanically removed each year. In parallel with the development of macrophyte biomass, the water level rose by 20-50 cm, causing problems for farmers and residents. Mowing the aquatic vegetation impaired water quality in the downstream river sections and of lakes in the Berlin region. This river section is intensely used for recreation,

and the Spree is a main source of drinking water for Berlin. The stakeholder involved is the agency responsible for landscape management (Wasser- und Landschaftspflegeverband Untere Spree).

***Ludwigia* sp. in Lake Grand-Lieu (France):** Lake Grand-Lieu is a large lake with extensive beds of floating-leaved macrophytes. Two non-native aquatic plants (*Ludwigia peploides* and *L. grandiflora*) colonized the lake in the 1990s, developing dense mats in the lake and canals and causing problems for biodiversity conservation and for human activities such as fishing and boating. The lake is affected by eutrophication, climate change, hydromorphological alterations and the invasion of the non-native *Ludwigia* sp. Since 2002, 5-10 tons of *Ludwigia* were removed annually. The management of these invasive species is costly and inefficient, because regrowth is regularly observed, and macrophyte removal reportedly enhanced the development of cyanobacteria in the lake, with negative consequences for fishing and on biodiversity. The stakeholder involved in this case study is the Natural Reserve of Lake Grand-Lieu.

***Eichhornia crassipes* in Hartebeespoort Dam (South Africa):** Despite efforts to control, *E. crassipes* remains South Africa's most problematic aquatic macrophyte. Hartebeespoort Dam currently is a hotspot of *E. crassipes* invasion. The plant has been present since the 1970s and was successfully controlled in the 1980s using herbicides. In 2016, however, herbicidal control was halted, resulting in massive plant growth. A steering committee has been put in place to draw up a control plan, but this excludes the use of herbicides, which to many seems to be the only viable option. The dam is subject to serious anthropogenic pollution, climate change, and hydromorphological alterations. The primary use of the dam is for irrigation, as well as for domestic and industrial use. The stakeholder in this case study is the Department of Environmental Affairs: Natural Resource Management Programmes.

***Urochloa arrecta* in the River Guaraguaçu (Brazil):** *U. arrecta* is an invasive aquatic grass which in the last years produced mass developments in several water bodies in South Brazil. One of these is the River Guaraguaçu, a tidal river.

The plant biomass affects the use of the river for navigation, jeopardizes environmental quality for tourism and fisheries, and probably affects the diversity of native species. The River Guaraguaçu is in LAGAMAR, a key region for biodiversity conservation in South Brazil harbouring several endangered species. The river is subject to anthropogenic pollution, climate change, and other invasive species such as catfish which may benefit from the dense *U. arrecta* beds. Management of *U. arrecta* has not yet started, but is under discussion. The stakeholder involved in this case study is the Instituto Ambiental do Paraná, the environmental agency responsible for managing the area.	
Water Policy context / project contribution to policies (National, European, International – UN SDGs): Problems with macrophyte mass development occur across the world, but managers do not generally exchange experiences between countries, and particularly not across continents. Many water managers feel left alone with their particular problem of nuisance growth in their particular system, and their experiences often cannot be compared with each other due to the lack of a harmonized study design. MadMacs will apply a homogenized BACI study design. This will generate new knowledge useful to predict the general consequences of macrophyte removal, and will be broadly applicable for management. Poor water quality affects the well-being of societies across the world. Macrophytes have the potential to purify water, but this potential is often unknown to water managers, nor have the benefits and dis-benefits of macrophyte removal been assessed against each other. We will be the first to provide such data, on a trans-national basis, and use them to provide internationally applicable guidelines for a new, knowledge-based management of water courses with dense aquatic vegetation. We will provide innovative solutions in the sense that the "informed-do-nothing-option", i.e. not removing macrophyte mass developments, in some (but not all) cases may turn out to be the best option, in addition to being the cheapest. We will contribute to the sustainable management of water bodies, by quantifying	

which combination of factors lead to massive macrophyte growth. This will enable handling the underlying causes of macrophyte mass development, instead of unsustainably trying to “cure the symptoms”, which generally is current practice. We will quantify and compare all different aspects of benefits and dis-benefits of macrophyte removal to society. This will support informed and balanced management decisions, instead of “listening to those who happen to have the strongest lobby”, which often is current practice. We hope to introduce a new way of thinking in macrophyte management, by consistently quantifying the benefits and dis-benefits of macrophyte removal. This can potentially save a substantial amount of money by preventing management measures which cost more than they gain.	