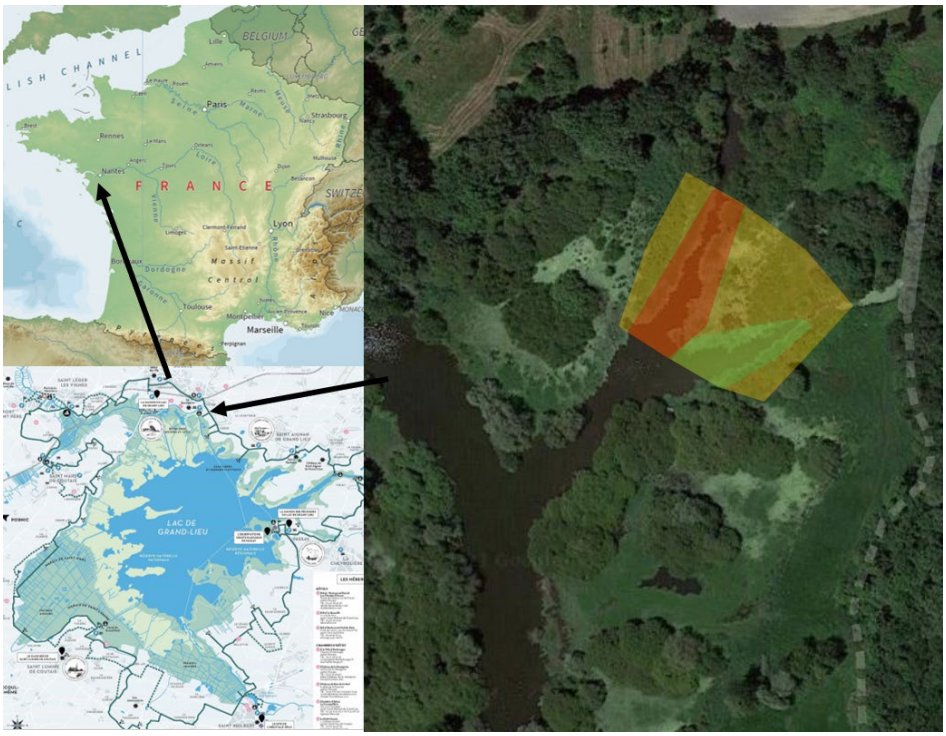
The removal of *Ludwigia* sp. and its consequences for the biodiversity in Lake Grand-Lieu

Lake Grand-Lieu is a large, shallow lake in western France near the City of Nantes. In winter, when the water level is highest, it has a surface area of 2700 ha. It is a bird sanctuary and is considered a natural reserve of national importance because of its diverse flora and fauna. Since the 1990s, invasive plants *Ludwigia grandiflora* var. *hexapetala* and *L. peploides* have colonized the lake and the surrounding land. These amphibious plants (= they can grow in water and meadows) are both native to South America. They were introduced into France as ornamental plants in the 19th century and have since been invading freshwater systems in large parts of the country. Both *Ludwigia* species are therefore subject to regulations in France, and their import has been banned since 2007. In addition, these two species were included in the list of 37 invasive species adopted by the European Commission in July 2016.



The location of our study site in the north of Lake Grand-Lieu, situated close to the city of Nantes in the northwest of France. The yellow area indicates the infestation with Ludwigia (aquatic as well as terrestrial) in this part of Lake Grand-Lieu (during the height of the mass development, the aquatic form of Ludwigia covered almost 80 ha, and the terrestrial form about 115 ha of the entire lake and its surroundings). The red area was used as a control site, whereas plants were removed in the green area (impact site).

At Lake Grand-Lieu, a yearly removal campaign is organized, where plants are removed by hand or mechanically from the lake and its catchment. In shallow water or on land, manual removal is preferred because it enables complete removal of roots and plant fragments, thereby minimizing further dispersion. The local stakeholders report that they have removed more than 1000 t of biomass over 15 years of removal. Since 2014, a decline in *Ludwigia* biomass was observed in the aquatic habitats. In 2016, a total of 64 t biomass was removed at the cost of nearly €30,000.

Four photos from our research site. The top row shows the impact site, to the left a photo before the removal and to the right a photo after the removal. The bottom row shows the control site on the same days as the pictures above.

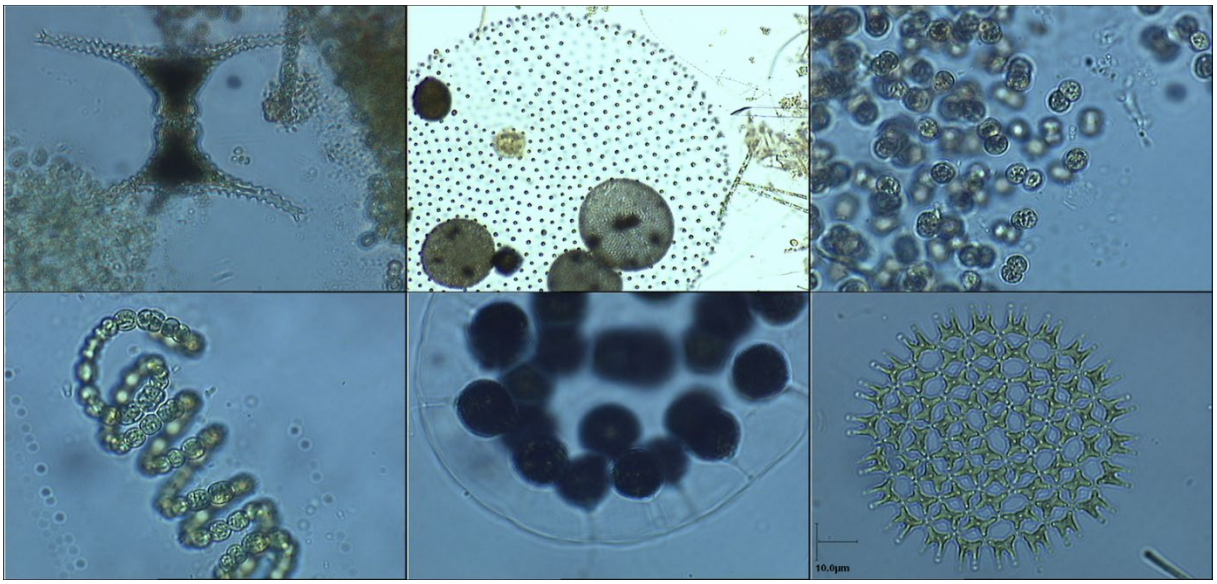
L. grandiflora and *L. peploides* generally develop nearly monospecific, dense stands, thereby limiting human activity (such as fishing, hunting and boating) in many freshwater systems. Moreover, *Ludwigia* species change their environment by reducing the pH, the concentration of dissolved oxygen and the water temperature. In summer, high biological oxygen demand within dense *Ludwigia* stands can lead to oxygen depletion, which could negatively affect aquatic organisms. On the other hand, *Ludwigia* species can also increase the spatial heterogeneity of habitats and even offer valuable habitat for phytoplankton, zooplankton, macroinvertebrates, and fish. Within

the MadMacs project, we are interested to see if *Ludwigia* can indeed provide a useful habitat to support a diverse fauna community, and if so, whether these benefits outweigh the negative impact they have on the lake environment.

The MadMacs experiment was conducted in the north-eastern part of the lake. Here, we sampled phytoplankton and zooplankton (by filtering water), macroinvertebrates (by collecting grab-samples of the upper sediment and sweep-net samples of the water layer between the plants) as well as fish (by electrofishing). This sampling was done before the removal of the *Ludwigia* plants, 1 week after the plant removal as well as 6 weeks after plant removal. To separate the effect of removal from normal changes in the system, samples were taken from the impact site (where plants were manually removed) and the control site where the plants were not removed.

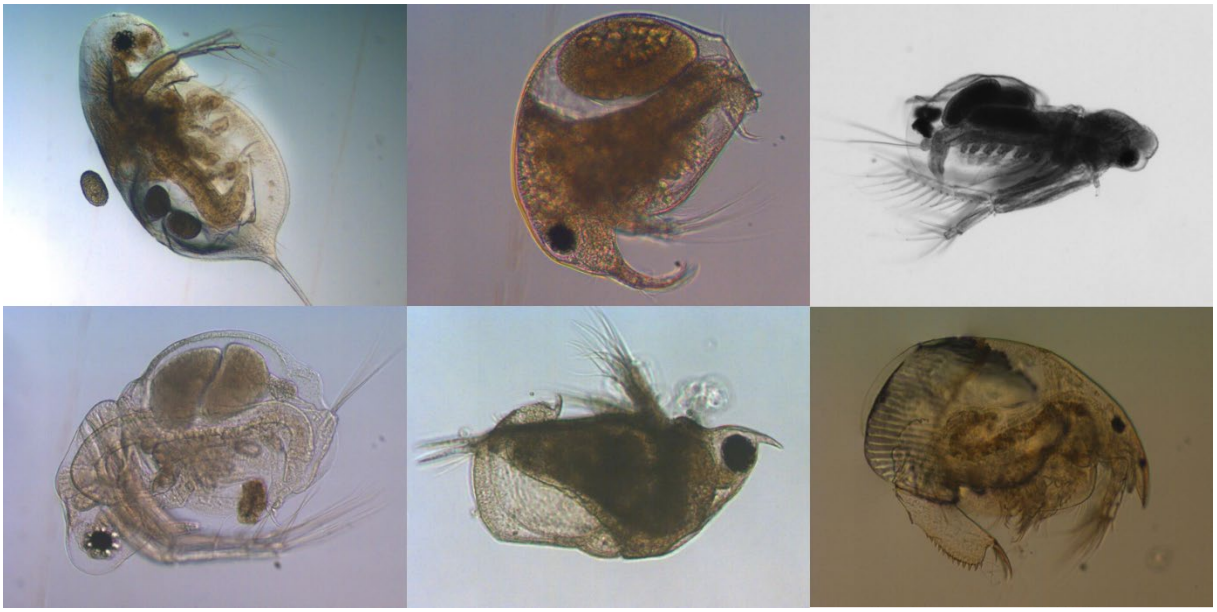
Impressions from the sampling during our three field campaigns.

We found 66 different phytoplankton taxa in our sampling sites. Most of the taxa (28) were green algae. Phytoplankton abundance was dominated by cyanobacteria (54%), followed by green algae (31%), golden algae (7 %), diatoms (6%) and Euglenophytes (2%). One week after the removal, we observed a cyanobacteria bloom at the impact site (i.e. the site where the *Ludwigia* plants were removed), but not at the control site.



A collection of phytoplankton taxa found in Lake Grand-Lieu. From top left to bottom right: Staurastrum, Volvox, Microcystis, Dolichospermum, Eudorina and Pediastrum.

The zooplankton community in Lake Grand-Lieu consisted of around 15% Copepoda and 85% Cladocera. For Cladocera, *Bosmina* was the dominant genus. Before plant removal, the zooplankton community and density in the control and impact site were similar to each other. One week after plant removal, the diversity at the impact site was reduced, even though abundances remained the same. Some genera like *Moina* and *Cyclopoides,* as well as Nauplii, were reduced after the removal of plants, indicating that the plants may provide a habitat and a refuge against fish predation. Other taxa like *Bosmina* showed a higher abundance after the removal of plants. However, six weeks after removal, we observed no differences in the diversity or abundance of zooplankton.



Examples of zooplankton from Lake Grand-Lieu. From top left to bottom right: Daphnia, Bosmina, Diaphanosoma, Moina, Scapholeberis, Alona.

The macroinvertebrate community in Lake Grand-Lieu consisted of a variety of different groups. The most dominant groups were Oligochaeta, Nematodes, and larvae of Diptera (mainly Chironomidae and Ceratopogonidae), but we also found decapods, amphipods, isopods, Ephemeroptera, Heteroptera, Odonata, Coleoptera, Accari, snails, and mussels. During fieldwork, we observed a high abundance of the invasive Louisiana crayfish (*Procambarus clarkia*), which feeds on *Ludwigia* and, unfortunately, also on native vegetation.

A Louisiana crayfish defending himself in the plants (Top left), and binocular images of a Heteropteran (Top right), two specimens of Odonata (Bottom left) and a Mayfly (Bottom right).

Using electrofishing, we found a total of 7 different fish species from 6 different orders. Some of these fish use plants as a direct food source, such as catfish (*Ameiurus melas*), tench (*Tinca tinca*), or roach (*Rutilus rutilus*). Others may use it mainly as a hunting ground to find either zooplankton and macroinvertebrates (for example mosquitofish (*Gambusia affinis*) and eel (*Anguilla anguilla*)) or smaller fish (for example pumpkinseeds (*Lepomis gibbosus*) or pike (*Esox lucius*)). In addition, macrophytes can form breeding and nursery grounds for fish.

Three examples of fish that were caught during electrofishing (left to right): an eel (Anguilla anguilla), a pumpkinseed (Lepomis gibbosus), and a pike (Esox lucius). After recording their presence and measuring their size, all fish were returned to the lake.

All samples are currently being analyzed in the lab to provide a detailed list of presence and abundance data for all groups. Since similar samples were collected in all MadMacs case study sites, we will be able to compile an interesting dataset to assess the biodiversity in different systems containing dense mats of macrophytes. By comparing the effects of macrophyte growth and removal in the different case study sites, we aim to separate global trends from local effects.