# MACROPHYTE CONTROL PLAN IN JADRO AND VRLJIKA RIVERS



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# 1. REFERENCE MACROPHYTE COMMUNITIES IN THE JADRO AND VRLJIKA RIVERS

(from the *Methodology of Sampling, Laboratory Analyses, and Determination of the Ecological Quality Ratio of Biological Quality Elements*, Croatian Waters, 2025)

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## 1. JADRO RIVER

In the Jadro River, the reference macrophyte community is a bryophyte-dominated community (*Rhynchostegium - Fontinalis* type – RF = *Platyhypnidium - Fontinalis* – PF). The community is characterized by:

- A type of community typical for spring areas, small to medium-sized mountain and submountain fast-flowing streams on karst substrates.

### 1.1. Species-rich bryophyte community

- Characteristic of spring areas and mountain/submountain watercourses with relatively stable water levels (i.e., non-drying watercourses); represents the reference community of fast-flowing streams.
- May be very species-rich or composed of only a few species (e.g., in cases of strong water flow or significant shading).
- Along with *Rhynchostegium riparioides* and *Fontinalis antipyretica*, the community includes other moss species such as *Cinclidotus aquaticus*, *C. fontinaloides*, *C. riparius*, *C. danubicus*, *Cratoneuron filicinum*, *Palustriella commutata*, *Hygrohypnum luridum*, *Fissidens crassipes*, *Leptodictyum riparium*, and others.
- In mountainous, fast-flowing streams, a very good ecological status is indicated by the absence of disturbance indicators or their very rare, isolated appearance.
- In good status, disturbance indicators appear moderately, while their co-dominance indicates moderate status. In such cases, bryophyte diversity decreases, often leaving only 1–2 species; red algae disappear, and species from other communities and disturbance indicators emerge.
- In conditions of good or better potential, the community consists of more bryophyte species, and the composition and number of species depend on water flow velocity and potential drying of the riverbed. Red macroalgae and charophytes may also be present in very oligotrophic, cool, and well-oxygenated waters.



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- Occurrence of this community in lowland rivers indicates altered hydromorphology, i.e., artificially increased flow velocity. If pure stands of this community develop without representatives of other morphological types, they indicate poor ecological status — in such cases, the community does not indicate increased nutrient levels but rather increased flow velocity.

### 1.2. Species-poor bryophyte community

- Characteristic of smaller watercourses with significant fluctuations in water level, i.e., those that dry up in summer; generally small streams in the Dinaric region, primarily in the sub-Mediterranean zone.
- Under conditions of extreme fluctuations in water volume, the moss community usually consists only of *Fontinalis antipyretica* and *Rhynchostegium riparioides*, with other species appearing sporadically and individually.
- Such species-poor communities are not a result of anthropogenic disturbance, but a reflection of natural hydrology.
- Water quality degradation is indicated by the same changes as in species-rich communities. The appearance of marsh species (helophytes), which are not necessarily associated with nutrient-rich waters, suggests altered hydrology — i.e., artificial slowing of the flow and resulting marsh formation.

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## Disturbance Indicators:

- **Indicators of eutrophication**: filamentous macroalgae from the genera *Cladophora*, *Vaucheria*, *Rhizoclonium*, *Spirogyra*, *Mougeotia*, *Zygnema*, *Oedogonium*, and others, developed in larger quantities; narrow-leaved pondweeds (*Potamogeton pectinatus*, *P. crispus*, *P. pusillus*, *P. berchtoldii*, *P. trichoides*), *Zanichellia palustris*, *Elodea canadensis*, *E. nuttallii*, *Egeria densa*, *Ceratophyllum demersum*, *C. submersum*, *Leptodictyum riparium*.
- **Indicators of potamalization**: *Sparganium emersum*, *S. erectum*, *Sagittaria sagittifolia*, *Glyceria maxima*, *Phalaris arundinacea*, *Phragmites australis*, *Typha latifolia*, *T. angustifolia*, *Glyceria fluitans* agg., *Nuphar lutea*, *Potamogeton natans*, *Lemna* spp., and all other species of slow and still waters, including herbaceous species.
- **Indicators of ritralization**: as bryophyte communities develop in the fastest-flowing waters, any further acceleration of flow will completely prevent the development of any macrophyte vegetation.





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# 2. VRLJIKA RIVER

In the Vrljika River, the reference macrophyte community is a herbid community (*Berula - Nasturtium* type – BN). Characteristics of the community include:

- Dominance of herbids and other morphological forms of vascular plants (myriophyllids and magnopotamids) (Table 1).
- This community type is typical for small to medium-sized karst watercourses in the Mediterranean and continental parts of the Dinaric ecoregion, as well as for small to medium-sized streams in the Pannonian ecoregion.
- Herbaceous emergent-leaved species (herbids) dominate.
- The most frequent and consistent species in this community is *Berula erecta*.
- Other common herbid species include *Agrostis stolonifera*, *Mentha aquatica*, *Veronica anagallis-aquatica*, *V. beccabunga*, *Myosotis scorpioides*, *Nasturtium officinale*, *Juncus articulatus*, *Apium repens*, as well as the submerged rooted species *Myriophyllum spicatum* and the moss *Fontinalis antipyretica*.
- In conditions of very good ecological status or good and higher ecological potential, the above characteristic herbid species dominate, along with aquatic and semi-aquatic mosses, submerged algae from the Characeae family, and other submerged species if deeper water is present (e.g., species from the genera *Ranunculus*, *Potamogeton*, and *Myriophyllum spicatum*).
- Under very good ecological conditions, disturbance-indicating species are absent or appear only individually.
- Good ecological status and good to high potential are indicated by a low share of disturbance indicator species, while their co-dominance suggests moderate ecological status/potential.
- In moderate ecological status/potential, community diversity decreases:
    - It may be composed of a monodominant stand of one characteristic herbid species, with only sporadic presence of others.
    - Some more nitrophilous species such as cattails or tall sedges may appear, but with low cover.
    - A small share of ruderal or invasive species may also be present, while submerged disturbance indicators (e.g., *Ceratophyllum demersum*, *Potamogeton pectinatus*) should be absent or appear as isolated individuals.



## 2.1. *Berula - Agrostis* Community



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- Characteristic of shallow, relatively slow-flowing karst waters, and particularly important in tufa-forming waterfalls of karst rivers.
- Basophilic mosses are significantly represented (e.g., *Palustriella commutata*, *Cinclidotus aquaticus*, *Pellia endiviifolia*, *Fissidens crassipes*, *Eucladium verticillatum*, etc.), as well as charophytes (Characeae).
- In summer months, when water levels are lower, a larger number of helophytes develop (e.g., *Mentha aquatica*, *Lythrum salicaria*, *Myosotis scorpioides*, *Phragmites australis*, and others).

### 2.2. *Berula - Nasturtium* Community

- Characteristic of fresh, relatively fast-flowing and spring-origin sections of karst watercourses.
- Due to the flow velocity, other helophytes are typically absent, and *Nasturtium officinale* grows in large cushion-like forms.
- *Hippuris vulgaris*, submerged forms of *Juncus articulatus* (also cushion-like), *Jungermannia atrovirens*, and *Fontinalis antipyretica* may also appear.

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## Disturbance Indicators:

- **Indicators of eutrophication**: filamentous macroalgae from the genera *Cladophora*, *Vaucheria*, *Rhizoclonium*, *Spirogyra*, *Mougeotia*, *Zygnema*, *Oedogonium*, and others, developed in larger quantities; narrow-leaved pondweeds (*Potamogeton pectinatus*, *P. crispus*, *P. pusillus*, *P. berchtoldii*, *P. trichoides*), *Zanichellia palustris*, *Elodea canadensis*, *E. nuttallii*, *Egeria densa*, *Ceratophyllum demersum*, *C. submersum*, *Leptodictyum riparium*.
- **Indicators of potamalization**: *Lemna minor*, *L. gibba*, *L. minuta*, *Spirodela polyrhiza*, *Glyceria maxima*, *G. fluitans* agg., *Phalaris arundinacea*, *Phragmites australis*, *Sparganium erectum*, *Typha latifolia*, *T. angustifolia*, *Potamogeton natans*, *P. nodosus*, *Nuphar lutea*, and other species typical of slow and still waters.
- **Indicators of ritralization**: species with finely divided leaves – *Myriophyllum spicatum*, *Ranunculus fluitans*, *R. peltatus*, *R. penicillatus*.

*Table 1. Description of morphological type*

| | |
|---|---|
| **Isoetids** | Low-growing plants with a rosette of narrow leaves (*Juncus*, *Pilularia*, *Eleocharis acicularis*) |
| **Nymphaeids** | Plants with floating leaves (*Alisma*, *Baldellia*, *Hydrocotyle*, *Nymphaea*, *Nuphar*, *Potamogeton*, *Ranunculus*, *Sagittaria*) |
| **Elodeids** | Small-leaved submerged plants with whorled, undivided leaves (*Elodea*, *Hippuris*) |
| **Parvopotamids** | Submerged plants with undivided leaves and entire margins (*Potamogeton*, *Zanichellia*) |
| **Magnopotamids** | Submerged plants with broad, undivided leaves with entire margins (*Nuphar*, *Potamogeton*) |
| **Myriophyllids** | Submerged plants with leafy shoots and divided leaves (*Apium*, *Hottonia*, *Myriophyllum*, *Oenanthe*, *Ranunculus*, *Sium*) |
| **Charids** | Submerged plants with whorled branches, anchored to sediment by rhizoids (*Chara*, *Nitella*, *Nitellopsis*, *Tolypella*) |
| **Batrachids** | Plants with both floating and submerged leaves – submerged leaves may be divided or undivided (*Ranunculus* subgen. *Batrachium*, *Potamogeton*) |
| **Peplids** | Plants with elongated or spatulate leaves forming a rosette at the shoot tip (in submerged forms the rosette may be underdeveloped) (*Callitriche*, *Ludwigia*, *Montia*, *Peplis*) |
| **Vallisnerids** | Plants with long, ribbon-like floating or submerged leaves gathered in a rosette (*Sparganium emersum*, *Vallisneria spiralis*) |
| **Stratiotids** | Freely floating plants with emergent leaves or clearly emergent plant parts (*Hydrocotyle*, *Pistia*, *Stratiotes*) |
| **Graminoids** | Grasses, i.e., members of the Poaceae family (*Agrostis*, *Glyceria*, *Phalaris*) |
| **Herbids** | Herbaceous, so-called "green" plants (*Apium*, *Berula*, *Myosotis*, *Nasturtium*, *Oenanthe*, *Sium*, *Veronica*) |
| **Equisetids** | Horsetails (*Equisetum* spp.) |
| **Juncids** | Submerged plants with undivided, narrow, entire leaves with septa (*Juncus* spp.) |
| **Lemnids** | Floating plants with small floating leaves or shoots (*Azolla*, *Lemna*, *Ricciocarpos*, *Spirodella*, *Wolffia*) |
| **Hydrocharids** | Floating pleustophytic plants with large leaves (*Hydrocharis*) |
| **Ceratophyllids** | Pleustophytes with large, divided underwater leaves (*Ceratophyllum*, *Utricularia*) |
| **Ricciellids** | Small submerged pleustophytes (*Riccia fluitans*, *R. rhenana*, *Lemna trisulca*) |

# 2. CONTROL OF MACROPHYTE VEGETATION

## 1. REMOVAL OF MACROPHYTE VEGETATION

### 1. Area of Implementation

The removal of macrophyte vegetation, along with the removal of barriers, creates preconditions for the formation of natural karst river habitats in areas where they have been altered due to hydromorphological changes in the Vrljika and Jadro rivers. The planned removal area covers approximately **9,000 m²** of riverbed, including:

- **6,500 m²** in the Vrljika River, and
- **2,500 m²** in the Jadro River.

**Barrier 1 – Opačica**, near the Vrljika spring, slows the river flow, which allows for a significant presence of macrophytes and filamentous green algae of the genus *Cladophora*, though within a relatively small area.

Around **Barrier 2 – Old waterworks** in the Vrljika River, the water flow is slowed or marsh-like, and the accumulation of organic material covering the river bottom is increased, creating favorable conditions for the growth of macrophyte species that indicate potamalization and eutrophication. Additional changes caused by anthropogenic impacts include very dense accumulations of filamentous green algae (*Cladophora*), which are present throughout the spring area and, in some places, are so dominant that they completely cover the riverbed.

**Barrier 1 – Voljak Bridge – Vrilo I** in the Jadro River created a bottleneck that facilitates the proliferation of macrophytes, further narrowing the flow. Therefore, their removal is planned in a total area of **2,500 m²**. During low water levels, macrophyte vegetation in the entire water column is extremely dense and lush, leaving little open water surface.



### 2. Macrophyte Removal Method

To avoid degradation of reference macrophyte communities and deterioration of the ecological status of the water bodies in the Vrljika and Jadro rivers, it is crucial to conduct macrophyte vegetation removal in a way that primarily targets disturbance indicator species mentioned in Chapter 1, while minimizing the destruction of individuals belonging to reference macrophyte communities.

The selected macrophyte removal method should be effective and as non-invasive as possible to river ecosystems. If mechanical removal is used, it should preferably be a

selective method such as **manual removal**, **suction dredging**, etc. Based on past experience of macrophyte removal by the staff of the Public Institution More i Krš, **manual removal** is considered an ineffective measure due to its extremely short-term effect and very difficult or impossible implementation. Therefore, the use of **mechanization** is recommended as a more effective measure.

For smaller areas, especially those densely overgrown, **manual pulling or removal of entire plants with roots** (e.g., by diving) can be applied. Mechanical removal and collection of plants may serve as a temporary control method only on **small areas (less than 0.4 ha)**. Removal from larger areas in this way is not feasible. Removal should be carried out carefully, avoiding leaving any plant parts (e.g., roots, stems) in or near the water. The method of pulling, as implemented by the staff of the Public Institution More i Krš, proved extremely challenging and ultimately ineffective, confirming the need for implementing **mechanization as a long-term solution**.

If a less selective mechanical method is used, the one that causes the least degradation to the river ecosystem should be chosen, such as:

- **cutting of submerged vegetation** in heavily overgrown areas, or
- **removal using boats and raking**. Raking is done with specially equipped boats and removes the entire plant with roots. According to the experience of the Public Institution More i Krš, this method has also proven to be **ineffective, very challenging, and time-consuming**.



### 3. Personnel Qualifications

Macrophyte vegetation removal is performed under the **supervision of experts in aquatic ecosystems and macrophytes**, with experience in:

- inventorying,
- mapping, or
- monitoring the condition of macrophytes.

### 4. Timeframe for Implementation

Removal activities should be conducted **during the vegetation season**, ideally from **May to October**.

Removal is **not recommended between December and March** due to:

- spawning of **softmouth trout** (*Salmo obtusirostris*), and

- higher water levels, which affect the effectiveness of macrophyte removal.

If macrophyte monitoring determines a **renewed excessive occurrence** of disturbance indicator species, a second round of removal is to be carried out **within the first year** after the initial removal.

### 5. Disposal of Macrophytes

Following the removal work, the site should be monitored for several days to **identify and remove any remaining plant parts** in the water or along the shore. Floating residues near the shore should be collected using nets.

Plant material should be transported to the designated **disposal site**. To prevent plant fragments from returning to the water, the disposal site must be located **outside the flood zone**. At the disposal site, plant residues should be **spread out in a layer no thicker than 10–15 cm** to ensure **rapid drying and die-off**.

In addition to on-site disposal, the removed plant material may also be delivered to a **composting facility** or **biogas plant**.

If invasive alien species (IAS) are being removed, care must also be taken to clean all clothing and equipment used during the removal, as they could serve as vectors for the spread of plant fragments.



## 2. MONITORING AND LIMITATION OF MACROPHYTE VEGETATION SPREAD

### 1. Monitoring Implementation

Monitoring must be conducted both before and after the removal activities. Pre-removal monitoring includes surveying the removal area and sampling macrophytes to identify disturbance indicator species and assess the ecological status of the water at the site.
Post-removal monitoring is carried out at least 6–9 weeks after the removal during the vegetation season and includes visual inspection of water surfaces to detect any reoccurrence of excessive macrophyte growth indicative of disturbance. If no excessive growth is observed, macrophyte sampling and ecological status assessment of the site are conducted.

## 2. Limitation of Macrophyte Spread

If excessive regrowth of macrophyte vegetation occurs despite prior removal, macrophytes are removed again according to the instructions outlined in Section 2.1. Monitoring, consisting of visual inspection and sampling, must be carried out regularly after each removal.

## 3. Qualifications for Monitoring Implementation

Monitoring of macrophyte vegetation must be conducted by an expert in aquatic ecosystems and macrophytes, with experience in inventory, mapping, or monitoring of macrophyte conditions.

## 4. Timing of Monitoring

Monitoring should be performed once or twice during the vegetation season following the initial removal, depending on the density of the population that was removed and the effectiveness of the removal. Sampling is conducted as follows (according to the *Methodology for Sampling, Laboratory Analyses and Determination of the Ecological Quality Ratio of Biological Quality Elements*, Croatian Waters, 2025):

- Sampling is performed from June to September (July and August are optimal);
- Given seasonal fluctuations in weather and water levels, researchers may choose a different sampling time if necessary;
- Avoid early sampling when plants are not fully developed, as this hinders or prevents identification, and underdeveloped communities may lead to underestimation of species abundance;
- Avoid late sampling as many species lose their vegetative parts before winter, surviving only through persistent organs;
- Medium or low water levels are preferable for optimal visibility and species density determination;
- Avoid sampling during high water; at least two weeks should pass after high water levels before sampling in Dinaric ecoregion watercourses.



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## 3. PILOT/PRELIMINARY REMOVAL OF MACROPHYTES

As part of the project, pilot/preliminary macrophyte removal activity in the special ichthyological reserve Vrljika – "Spring and Riparian Zone of the Vrljika River" – was carried out on September 3 and 4, 2024, by the Public Institution *More i krš*, in cooperation with *Croatian Waters* and the responsible Imotski Office (Figure 1). Below are the results of the activity and suggestions for future macrophyte removal efforts.

Aquatic vegetation was removed exclusively by hand, without the use of mechanical or chemical means to destroy the plant cover. Although this method is the most environmentally friendly, it proved to be extremely demanding and time-consuming due to the density and resilience of the vegetation in the area. All removed vegetation was carefully extracted from the river and properly disposed of outside the boundaries of the special reserve, in accordance with ecological guidelines and current regulations.

Despite intensive efforts and the involvement of a significant number of personnel from both institutions, the goals were not fully achieved. Due to specific field conditions, inaccessibility of certain parts of the watercourse, and the dense, deeply rooted vegetation, manual removal proved ineffective. This hindered the achievement of the desired level of watercourse clearing, which may negatively impact water flow and the river's ecological balance in the future. In light of this, consideration should be given to alternative vegetation removal methods that align with ecological guidelines and regulations, while also enabling more effective removal of undesirable vegetation. The possibility of using adapted tools or methods that do not disrupt the natural balance, but would allow for better results in future cleaning efforts, should be explored.



picture 1. Removal of macrophytes in the special ichthyological reserve Vrljika – "Spring and Riparian Zone of the Vrljika River", on September 3 and 4, 2024..