Guidelines for restoring and managing Mediterranean ponds and canals

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Glossary

Amphibious Vegetation: Specialized wetland plants adapted to extreme seasonal water fluctuations. They survive submerged during the wet/flooded phase and switch to a terrestrial growth form when the water recedes during the dry season (typical for Natura 2000 Habitat Type 3170).

Aquatic vegetation (Hydrophytes): Plants adapted to growing directly in or under water. Submerged - plants growing entirely under the water surface (e.g., stoneworts, pondweeds); Floating / Floating-leaved - plants with leaves resting on the water surface, anchored or free-floating (e.g., water-lilies, duckweeds).; Emergent - plants rooted in waterlogged sediment with stems and leaves extending above the water surface (e.g., reeds, bulrushes, sedges).

Canals: Artificial waterways created for irrigation or drainage purposes that can provide habitat for aquatic organisms.

Canal Network: Man-made or modified channels used for drainage, flood control, and irrigation. In Croatia, primary and secondary canals are managed by Hrvatske Vode, while tertiary and local detail channels often fall under the jurisdiction of local municipalities, drainage/irrigation authorities, or private landowners.

Clearing (scrub clearing): The removal of small woody growth (stem diameter $\emptyset < 5$ cm) and shrubs to maintain water flow and access.

Debris: Debris in the water refers to any type of human-made or natural object that is floating, suspended, or settled in a water body. Debris in water can come from a variety of sources, including litter, industrial waste, construction materials, and natural sources such as fallen trees and branches.

Ecosystem services: The benefits that humans derive from ecosystems, including provisioning services (e.g., food, water), regulating services (e.g., climate regulation, flood control), and cultural services (e.g., recreation, aesthetic value).

Endemic species: Species that are naturally found only in a particular geographic area and are not found anywhere else in the world.

Habitat: A specific type of environment where a particular species naturally occurs or thrives.

Invasive species: non-native plants, animals and pathogens usually spread by human activities, and may be the greatest threat to the long-term health and sustainability of wetlands. They are known to rapidly spread outside their natural range, altering the ecosystem and causing environmental or economic damage, or harm to human health.

Maintenance: Regular, small-scale management activities (such as selective mowing or removing trash) that prevent habitat degradation without altering the original shape, depth, or hydrology of the waterbody.

Mowing: The cutting of herbaceous vegetation along canal banks and beds, including grasses, sedges, and reeds

Natura 2000: The European Union's ecological network of protected areas designed to ensure the long-term survival and conservation of Europe's most valuable and threatened species and habitats.

Natura 2000 species: Species that are listed under the Natura 2000 network as being of special conservation concern.

Ponds: Small, shallow bodies of still water (natural or man-made), typically up to 2 meters deep, that hold water permanently or dry out seasonally. According to European ecological standards, ponds range in size from 1 m^2 up to 2 hectares. In Mediterranean karst landscapes, they represent vital biodiversity hotspots and crucial water sources for wildlife and livestock

Protected areas: Designated areas of land or water that are managed for the conservation of natural or cultural resources and provide important ecosystem services.

Protected species: Species that are legally protected from hunting, harvesting, or other forms of exploitation, typically because they are rare, threatened, or endangered.

Renovation: The process of improving or updating an existing ecosystem or creating an environment to better meet current needs or standards.

Restoration: Active technical intervention on a degraded, silted-up, or dried-out pond or canal to restore its original water holding capacity, hydrological function, and ecological value.

Riparian zone: A transitional area between land and a water body with elements of both, where soil and vegetation are under the constant influence of stagnant or flowing water. This zone serves as an important habitat for diverse species and plays significant roles in nutrient cycling, water quality, flood control, and ecosystem services.

Riparian Vegetation: Plant communities growing along the immediate banks and shorelines of ponds, streams, and canals, forming a natural transition zone (buffer) between aquatic and dry upland habitats.

Sediment/Silt: Fine organic and inorganic particulate matter that accumulates at the bottom of ponds and canals

Wetlands: Areas of land where the water level is close to or at the surface most of the year, and which provide important ecosystem services such as water purification and flood control.

Wells: Deep, narrow water structures with vertical drystone-lined walls built to tap into underground water sources. Unlike ponds, animals cannot step directly into a well. Therefore, wells are typically accompanied by adjacent stone or concrete drinking troughs (kamenice), into which water is poured for livestock.

1 Introduction

1.1 Intention and Scope of the Guidelines

These guidelines provide practical, technically sound, and legally compliant standards for the restoration and routine maintenance of Mediterranean ponds and canal networks. They are designed for land managers, public institutions, conservation practitioners, municipalities, and field contractors operating within Mediterranean karst and coastal landscapes.

The scope of this document addresses:

- Routine Maintenance: Interventions required to preserve existing, functional ponds and canals (e.g., partial vegetation management, selective desilting, and erosion control).
- Habitat Restoration: Physical interventions required to recover existing ponds that have dried out, silted up, or breached their impermeable layers due to severe eutrophication, succession, or physical damage.

This document does not cover the excavation of entirely new, artificial ponds in locations where no historical water body or natural depression previously existed.

1.2 Mediterranean Ponds and Canals - Characteristics and Biodiversity Value

Wetlands are areas in which water covers the soil periodically or during the whole year or is near its surface. Along with coral reefs and tropical rainforests, they are the most productive ecosystems in the world (Russi et al., 2013). They can be found on all continents except Antarctica (Moorhead et al., 2003). Types of wetlands differ from one another based on soil type, topography, hydrology, climate, chemical composition of water, vegetation, and anthropogenic influence. They support unique and high levels of biodiversity, from microscopic animals and bacteria to vertebrates and from algae to

angiosperms, but also many terrestrial organisms indirectly (e.g. nursery habitats) (Kingsford et al., 2016). There are various types of wetlands, some of which are marine/coastal wetlands (offshore wetlands, cliffs, and shallow coral reefs), inland wetlands (river mouths, lakes and marshy areas near the lakes, streams, and rivers, flooded woods and meadows, real swamps) and artificially made wetlands like saltworks, irrigation canals, former gravel pits and ponds (Ramsar National Report, 2019).

Mediterranean wetlands possess unique characteristics that distinguish them from freshwater habitats in other climate regions. Situated in zones with hot, dry summers and mild, rainy winters, these ecosystems often experience severe seasonal fluctuations in water availability, ranging from reduced surface area to complete summer desiccation (Naselli-Flores et al., 2011). Consequently, Mediterranean wetlands, whether permanent or temporary, are often isolated from other water bodies. These unique habitats support high diversity of plant and animal life, including endemic, and rare species adapted to these specific conditions. (Mediterranean Wetlands: Outlook, 2012).

CULTURAL LANDSCAPE AND HUMAN ADAPTATION

Because much of the Mediterranean region is built out of permeable limestone, natural surface water is inherently scarce. For centuries, local communities adapted to this harsh karst terrain by constructing artificial freshwater reservoirs, primarily wells, ponds, and irrigation canals. These traditional water systems served vital socio-economic functions, providing drinking water for households and livestock (cattle, sheep, goats, donkeys), as well as spaces for washing clothes and crop irrigation. Mediterranean wetlands have thus been shaped and managed by humans for thousands of years, becoming an integral part of the region's cultural landscape. Over time, these ponds and canals have become irreplaceable oases of biodiversity and primary freshwater reservoirs for local wildlife in the dry Mediterranean region (Oertli et al., 2005; Cuenca-Cambronero et al., 2023). Beyond supporting biodiversity, they provide essential ecosystem services, including nutrient cycling, carbon sequestration, and seasonal water retention (Ramsar Convention on wetlands, 2018).

CURRENT TRENDS, THREATS, AND CONSERVATION IMPORTANCE

In recent decades, the decline of traditional agricultural practices, particularly livestock grazing, has reduced the need for many ponds that once provided water for livestock and other everyday activities. As a result, these ponds have increasingly been neglected, left to natural succession, or intentionally drained or filled in, sometimes due to urban development or unfounded concerns about mosquitoes (Ruiz, 2008; Biggs & Williams, 2024). In contrast, irrigation canals that continue to serve remaining agricultural production have retained their practical function and are therefore more likely to remain in use.

Across the Mediterranean basin, freshwater wetlands face unprecedented pressures: more than 48% of natural Mediterranean wetlands have been degraded or lost since 1970, leading to a critical situation where 36% of Mediterranean freshwater species are currently threatened with extinction, including 41% of endemic species (Wetland-Based Solutions, 2020; Galewski et al., 2021). The primary drivers of this decline include hydrological alterations, water abstraction, agricultural intensification, scrub encroachment following pastoral abandonment, and direct backfilling (Ruiz, 2008; Wetland-Based Solutions, 2020).

Recognizing their high biodiversity value and cultural heritage, many Mediterranean wetlands are now protected under international and European conservation frameworks, such as the Ramsar Convention, the EU Water Framework Directive (2000/60/EC), and the Natura 2000 network (Mediterranean Wetlands Outlook, 2012). However, while legislative frameworks like the EU Water Framework Directive primarily set thresholds for larger water bodies exceeding 50 hectares, small freshwater habitats, such as traditional ponds, wells, and ditches, have historically fallen into a protection gap across Europe (Cuenca-Cambronero et al., 2023). Notably, among small standing waters, only one specific pond type is designated as a Priority Habitat under the EU Habitats Directive: Mediterranean temporary ponds (Habitat Type 3170*) (Ruiz, 2008).

Despite their small surface area, small ponds collectively support a higher proportion of rare, specialized, and threatened species than larger lakes or river systems, serving as

irreplaceable biodiversity refuges across the landscape (Oertli et al., 2005; Cuenca-Cambronero et al., 2023; Biggs & Williams, 2024).

IMPORTANCE OF POND AND CANAL MAINTENANCE AND RESTORATION

To preserve these hotspots of biodiversity in the Mediterranean region, it is crucial to regularly maintain existing habitats and restore those that have disappeared, as their small size makes them exceptionally vulnerable to rapid succession, siltation, and the loss of rare species without active management (Sayer et al., 2023; Biggs & Williams, 2024).

Proper maintenance is essential to ensure the long-term ecological balance, health, and functionality of Mediterranean ponds and canals. Without targeted, routine interventions, these habitats rapidly degrade through natural succession or siltation and may eventually disappear altogether, leading to the local loss of native flora and fauna and loss of the traditional cultural landscape.

Sustainable maintenance practices, such as selective vegetation management, sediment control, and erosion prevention, help mitigate the accumulation of nutrients and pollutants that impair water quality. By controlling invasive non-native species and managing plant succession, managers can maintain ecosystem balance and prevent any single competitive species from dominating the habitat.

Beyond their ecological value, the sustainable management of ponds and canals contributes to broader environmental sustainability. As these habitats are often embedded within agricultural or semi-urban landscapes, they are vulnerable to nutrient runoff and diffuse pollution. Regular maintenance can help reduce these pressures and support more sustainable land use across the surrounding watershed. It also helps safeguard habitats for threatened and endangered Mediterranean species, while allowing people to access and enjoy these areas responsibly for educational and recreational purposes.

2 Principles of Restoration, Maintenance, and Site Prioritization

2.1 Distinguishing Routine Maintenance from Habitat Restoration

Understanding the distinctions among routine maintenance, active restoration, and passive restoration is essential for effective resource allocation and sustainable wetland management (Wetland-Based Solutions, 2020; Cuenca-Cambronero et al., 2023).

Routine maintenance

Involves ongoing, regular, and non-structural interventions on functional ponds or active canals (MINGOR, 2022; Freshwater Habitat Trust, 2011). The primary goal is to prevent excessive natural succession, scrub encroachment, or nutrient accumulation without altering the basin profile, overall depth or underlying hydrogeology (Freshwater Habitat Trust, 2011; Biggs & Williams, 2024.) Routine maintenance is significantly more cost-effective and ecologically less disruptive than allowing a site to degrade.

Active habitat restoration (direct interventions)

Refers to major, structural, or physical interventions required when a pond or canal has lost its primary functionality and reached a point where routine maintenance is no longer sufficient (e.g., complete summer desiccation due to clay liner damage, severe eutrophication, or total terrestrialization) (Saldi-Caromile et al., 2004; Wetland-Based Solutions, 2020). Restoration aims to restore the habitat's ability to retain water, improve its ecological condition, and allow natural succession to resume. (Wetland-Based Solutions, 2020; Nelson et al., 2024). Physical restoration interventions must focus on reinstating self-sustaining natural ecological processes and recovering historic basin dimensions without breaching the underlying impermeable clay layer or altering its original profile and boundaries (Saldi-Caromile et al., 2004; Freshwater Habitat Trust, 2011; Nelson et al., 2024).

Passive habitat restoration (indirect interventions)

Before initiating active physical interventions (whether maintenance or restoration), project managers must determine whether passive restoration is sufficient for natural regeneration (Wetland-Based Solutions, 2020).

Passive restoration focuses on eliminating or mitigating external drivers of degradation within the surrounding catchment (such as halting agricultural fertilizer runoff, preventing waste dumping, or regulating livestock access) without physically excavating or reshaping the basin itself (USEPA, 2000). Small freshwater ecosystems are inherently dynamic and resilient; once chronic external pressures are halted, native seed banks and biological communities often recover naturally without requiring costly or disruptive mechanical works (Wetland-Based Solutions, 2020).

Limit intervention

Active physical intervention is not always appropriate or necessary, and in the following specific cases, non-intervention or gentle protection is recommended (Freshwater Habitat Trust, 2011):

Woodland Ponds

Ponds located in woodland areas, surrounded by valuable old trees, and those associated with significant bog and fen microhabitats should be conserved for their intrinsic value and left undisturbed rather than artificially opened up (Norfolks Wildlife Trust, 2023).

Fluctuating ponds

Deepening naturally fluctuating, shallow Mediterranean ponds is generally not an optimal management strategy. Seasonal water-level fluctuations, including periods of shallowing (e.g., a reduction in water depth from 1 m to 0.5 m), create and maintain suitable conditions for specialized species adapted to periodically exposed shorelines (drawdown zone / beach margin species). When algal blooms occur during dry periods, the underlying issue is typically excessive nutrient accumulation rather than shallow water depth. As water evaporates, the reduced water volume concentrates dissolved nitrates and phosphates, potentially worsening water quality. Management should therefore prioritize reducing nutrient inputs and selectively removing accumulated sediment from areas where it

negatively affects water quality, rather than artificially deepening the pond basin (Suffolk Wildlife Trust, 2023).

Mediterranean temporary ponds (Habitat Type 3170*)

If a pond is identified as Natura 2000 Priority Habitat Mediterranean temporary ponds, interventions in priority habitat type 3170* must strictly respect its natural summer desiccation phase and must never convert temporary ponds into permanent water bodies. Therefore, artificial deepening and hydrological connection to permanent waters are not recommended.

Permanent inundation destroys the natural summer desiccation phase required by specialized flora (e.g. *Isoëtes* spp.) and fauna (e.g. *Triops* sp., breeding amphibians) (Ruiz, 2008; Biggs & Williams, 2024). Also, direct connections allow fish and generalist predators to colonize the site, leading to the rapid loss of characteristic temporary pond species through competition and predation (Ruiz, 2008).

Ponds in an abandoned landscape

Restoring a pond has little long-term value if the surrounding landscape is completely abandoned, with no local community, livestock, or water demand to maintain site accessibility, as the habitat will rapidly re-terrestrialize.

However, even in the absence of traditional agriculture or livestock, long-term site maintenance can be successfully sustained by engaging alternative local stakeholders. For example, if a pond is situated along a hiking or biking trail, local mountaineering clubs, hunting associations, or tourist boards can incorporate the site into their activities. These groups can adopt the pond and organize routine, low-impact maintenance (such as volunteer litter clean-ups, hand-clearing of encroaching vegetation, or basic drystone wall repairs) ensuring the habitat remains open, functional, and accessible over time (Wetland-Based Solutions, 2020).

2.2 Site Assessment and Prioritization Protocol

BASELINE ECOLOGICAL CONDITION ASSESSMENT

Before starting any physical work, field teams should assess the wetland's baseline ecological health and structural integrity using the standardized *SFEU (Still Freshwater Ecosystem Units) Ecological Condition Assessment Methodology* (BIOM, 2025a). This rapid field protocol evaluates 21 parameters across four key domains:

- **Hydrology:** Water presence/seasonality, water source type (precipitation vs. spring/groundwater), transparency/visual quality, and average depth.
- **Biodiversity**: Presence and diversity of aquatic and shoreline vegetation, number of vegetation layers, and presence of key biological indicator groups (native herpetofauna and Odonata), presence of invasive vertebrates and invasive plants.
- **Physical and morphological features**: Bank profile/slope, partial shade coverage, water accessibility for wildlife and livestock.
- **Pressures:** Surrounding landscape context (within 100 m buffer), traces of ecosystem usage**.**
- **Negative condition indicators:** Presence of solid waste, dead animals, entrapment hazard and other negative condition indicators.

The resulting score (ranging from -6 to 32 points) places the site into one of five classes: from Class I (severely degraded, poor integrity) to Class V (highly functional, good integrity). This score provides an essential scientific baseline for intervention planning and longterm post-restoration monitoring.

SITE PRIORITIZATION PROTOCOL

Because time, equipment, and financial budgets are limited, project managers need a clear, objective way to select which wetlands to restore first. To get the best return on investment for nature and local communities, restoration practitioners and planners are encouraged to use the SFEU Restoration Prioritization Protocol (BIOM, 2025b).

This decision-making tool takes the initial baseline score (BIOM, 2025a) and combines it with practical and social criteria using three categories:

- **Ecological (50% weight / factor 0.5)**: Directly uses the initial score from baseline ecological condition assessment. It also evaluates the risk of total site loss within 10 years, potential negative impact of restoration on flora and fauna, presence of Natura 2000 species and probability of restoration success.
- **Socio-Economic (30% weight / factor 0.3)**: Evaluates stakeholder water demand, long-term cost-efficiency of restoration, number of potential wetland use, site isolation and logistical complexity of the site.
- **Structural (20% weight / factor 0.2)**: Assesses wetland dimension, traffic hazard risks to animals near busy roads, water retention risks, restoration complexity and terrain accessibility

Each category is scored separately, and composite scores are calculated using the following formula: Final Priority Score = (Ecological Score × 0.5) + (Socio-Economic Score × 0.3) + (Structural Score × 0.2). Sites with the highest final scores represent top priorities for restoration funding and field works.

For complete field forms and scoring guidebooks, please see the technical manuals published by Association BIOM: SFEU (Still Freshwater Ecosystem Units) Ecological Condition Assessment Methodology (BIOM,2025a) and Criteria and Protocol for Small Freshwater Ecosystem (SFE) Restoration Prioritization (BIOM, 2025b).

3 Governance, Planning, and Pre-Restoration Phase

3.1 Institutional Framework and Stakeholder Roles

Across European and Mediterranean countries, small freshwater habitats (such as traditional ponds, wells, and drainage canals) exhibit diverse legal statuses, tenure systems, and governance structures (Cuenca-Cambronero et al., 2023). Land ownership directly influences how restoration and maintenance activities are planned, funded, and permitted (Cuenca-Cambronero et al., 2023). Generally, ownership and legal status fall into four primary categories across the EU:

- **Public Domain and State Ownership**

This category includes waterbodies situated on public state land, within state forests, or classified as public water resources. In these cases, waterbodies are managed directly by national water agencies, state forest enterprises, or protected area public authorities (e.g., in Croatia, public waters and canal networks are managed under state jurisdiction by Hrvatske vode and Hrvatske šume).

- **Municipal and Communal Ownership**

Ponds located on public municipal land or historic common pastures (communal land). Management responsibilities typically rest with local city or municipal councils, local drainage boards, or traditional grazing associations.

- **Private Ownership**

A significant proportion of European ponds and agricultural ditches are located on private agricultural land, commercial farms, or private estates (Cuenca-Cambronero et al., 2023). While private landowners retain property rights, physical interventions altering water regimes, excavation, or vegetation clearing usually require formal regulatory compliance and environmental permits from competent regional authorities (Wetland-Based Solutions, 2020).

- **NGO and Community Stewardship**

Land owned, leased, or managed by environmental non-governmental organizations (NGOs), land trusts, or local civil society groups (such as mountaineering clubs, hunting associations, or local tourist boards) dedicated to long-term habitat conservation (Still Water Revival, 2023; Cuenca-Cambronero et al., 2023).

3.2 Goal Setting and Management Planning

The first steps which precede the restoration or maintenance activities are defining the restoration goals and objectives. Restoration goals should describe the desired future condition of a site by taking into consideration the way that ecosystem appeared to function historically (Gayton, 2001). Once goals have been established, it is important to create measurable short-term objectives and corresponding activities to achieve them. A typical long-term objective for restoration is to have the ecosystem resemble and perform like it did before it was damaged or degraded, even though it is not always feasible to exactly replicate past conditions. Furthermore, a reference ecosystem that is similar and in good or excellent condition can also be used to define a goal (Douglas). Restoring a pond is very complex, and proper preparation is essential for completing the entire process.

3.3 Obtaining permissions

Small freshwater habitat restoration and maintenance projects must comply with local, regional, national, and EU legal frameworks before any field work begins (Freshwater Habitats Trust, 2011; Wetland-Based Solutions, 2020). Depending on the site's protection status, land ownership, and target species, project teams should check cadastral boundaries, identify all relevant rights-holders, and secure the necessary environmental permits, species derogations, and landowner consents to ensure full legal compliance across EU Member States (Wetland-Based Solutions, 2020; Still Water Revival, 2023; Nelson et al., 2024).

In addition to the European Natura 2000 network (designated under the EU Habitats (92/43/EEC) and Birds (2009/147/EC) Directives), sites may also fall under national, regional, or local protection categories (such as National Parks, Nature Reserves, or Protected Landscapes, depending on individual Member State legislation). When planning restoration or maintenance in any protected wetland, interventions must align with these nature conservation laws as well as broader frameworks such as the EU Water Framework Directive (2000/60/EC) and the Ramsar Convention.

Landowners and project managers should follow this four-step process before starting any work on site:

STEP 1: VERIFY THE SITE'S PROTECTION STATUS

Field managers should check the geographic location of the target pond or canal against official Natura 2000 GIS layers, using either the European Environment Agency's Network Viewer or national/regional environmental portals (Ruiz, 2008; Wetland-Based Solutions, 2020). This quick check determines whether the site lies within a Special Area of Conservation (SAC) or Special Protection Area (SPA).

STEP 2: CONTACT COMPETENT NATURE AUTHORITY

If OUTSIDE Natura 2000 Sites or Protected Areas

Formal nature protection permits and Natura 2000 assessments (under Article 6(3) of the EU Habitats Directive) are generally not required for routine maintenance.
Note: If strictly protected species inhabit the site, a mandatory species derogation permit must still be secured under STEP 3, regardless of the site's overall protection status.

If INSIDE Natura 2000 Sites or Protected Areas

If the target site is located within a Natura 2000 site or a nationally protected area, the project proponent must contact the competent nature authority and obtain the relevant approvals or formal consents in accordance with national nature conservation legislation prior to initiating any field work (Wetland-Based Solutions, 2020).

STEP 3: PROTECTED SPECIES REQUIREMENTS

Prior to initiating physical work, field managers should compile a list of resident species at the site using existing biological databases, management records, species atlases, or field surveys. This species list is then checked against relevant conservation legislation, such as Annexes II and IV of the EU Habitats Directive or equivalent national regulations, to determine their protection status. If strictly protected species are present on site, formal authorization and species derogation permits must be obtained from the competent environmental ministry or designated nature protection authority before any restoration activities or species interventions begin.

STEP 4: SECURE LANDOWNER CONSENTS AND CULTURAL HERITAGE APPROVALS

Ponds are frequently located on communal land, public forestry plots, or private parcels. Before starting field work, project teams must complete property checks and secure necessary authorizations (Still Water Revival, 2023; Nelson et al., 2024):

- **Landowner consent:** Written consent must be obtained from the legal land owner, whether private individuals, municipalities, public forestry agencies, or water management authorities (Wetland-Based Solutions, 2020; Still Water Revival, 2023).
- **Cultural heritage approval:** If the site includes historical landscape features (such as traditional drystone masonry or historic well headworks), project teams must consult the competent cultural heritage authority before making structural changes (Still Water Revival, 2023). The authority will issue specific conservation guidelines (such as using local stone, traditional drystone techniques without cement, or machinery buffer zones) which must be integrated into the project execution plan.

3.4 Seasonal Timing of Works

The best time for physical restoration and maintenance interventions on Mediterranean ponds and canals depends on various factors such as the type of vegetation, species composition, the size of the habitat, and the local climate.

In general, the best time to do maintenance activities is during late summer and early autumn (typically September to November) (Still Water Revival, 2023; Sayer et al., 2023; Norfolks Wildlife Trust, 2023). During this dry period, water levels reach their annual minimum or ponds desiccate completely, ensuring that the surrounding ground is dry and firm enough to support machinery without causing severe soil compaction or rutting, while making sediment removal and desilting of the basin floor significantly easier (Still Water Revival, 2023; Sayer et al., 2023). Furthermore, executing physical works in late summer and early autumn avoids sensitive biological phases, ensuring that animal breeding, egg-laying, aquatic insect emergence, and bird nesting are completed without interruption (Ruiz, 2008; MINGOR, 2022).

While routine maintenance on native vegetation is restricted to late summer and autumn, the management of Invasive Alien Species (IAS) (e.g., *Ambrosia artemisiifolia, Reynoutria spp., Amorpha fruticosa*) represents a strict exception to standard seasonal timing (MINGOR, 2022). Removal of invasive plants must not be delayed until autumn; instead, it must strictly follow species-specific eradication plans and phenological management protocols (MINGOR, 2022; Sayer et al., 2023). This often requires multiple, targeted mechanical or manual interventions throughout the growing season (specifically prior to flowering and seed set) to prevent seed dispersal and rapid re-sprouting (Ruiz, 2008; MINGOR, 2022).

Mediterranean climates exhibit pronounced interannual rainfall variability and summer droughts. Maintenance schedules must adapt to local weather patterns, avoiding heavy machinery operations during periods of heavy rainfall, saturated soils, or extreme heatwaves (Saldi-Caromile et al., 2004; Still Water Revival, 2023).

When planning restoration or maintenance across a wetland complex or network of multiple adjacent ponds, physical interventions must never be executed on all ponds simultaneously in a single season (Freshwater Habitats Trust, 2015; MINGOR, 2022). Instead, management activities must be staggered across multiple seasons using a rotational approach—such as restoring or maintaining only 1 to 2 ponds per year within a landscape cluster (Freshwater Habitats Trust, 2015). Maintaining adjacent, undisturbed functional ponds ensures that temporary biological refugia remain continuously available

for mobile aquatic fauna (such as freshwater turtles, amphibians, and dragonflies) and provides an immediate, local source of organisms for natural recolonization once physical works at a target site are completed (Saldi-Caromile et al., 2004; Freshwater Habitats Trust, 2015; MINGOR, 2022).

3.5 Machinery Selection

Equipment Selection:

- Tracked excavators (preferably with rubber tracks) must be prioritized over wheeled machinery ("rubber ducks" or wheeled loaders) when operating on wet or soft soils. Tracks distribute machine weight over a larger surface area, greatly reducing ground pressure, deep soil compaction, and severe rutting (Freshwater Habitats Trust, 2011; Saldi-Caromile et al., 2004).
- Medium to large tracked excavators with long-reach arms are preferred because they can operate from stable, dry ground outside the pond basin, excavating sediment across the entire floor without needing to drive directly into the wet basin (Freshwater Habitats Trust, 2011; Sayer et al., 2023).
- In steep, narrow, or highly sensitive karst landscapes where standard excavators cannot maneuver without destroying mature trees or stonework, specialized lightweight machinery (such as articulated spider excavators -"spider hoes") or manual hand labor should be utilized (Saldi-Caromile et al., 2004).

3.6 Site Protection

Prior to bringing heavy equipment onto a site, field managers must conduct a preliminary site inspection to identify and mark all sensitive natural features and cultural infrastructure (Freshwater Habitats Trust, 2011; Still Water Revival, 2023).

High-value ecological features (such as rare plant patches, amphibian hibernation sites, turtle nesting sites, critical tree root zones) must be explicitly mapped on project plans and physically delineated on the ground using high-visibility tape or safety fencing to prevent accidental vehicle encroachment (Freshwater Habitats Trust, 2011; Bradbury, 2021).

In traditional Mediterranean landscapes, protective buffer zones must be established around historic drystone structures and well headworks (Still Water Revival, 2023). Machinery operations and spoil dumping are strictly prohibited on or immediately adjacent to traditional drystone walls to prevent structural collapse caused by weight and vibrations (Still Water Revival, 2023).

Access Corridor Management:

- Machinery access must be strictly restricted to a single, designated entry and exit route to concentrate physical disturbance within a narrow corridor (Saldi-Caromile et al., 2004; Freshwater Habitats Trust, 2011).
- Where soft or sensitive soils must be crossed, temporary protection measures (such as timber mats or aggregate layers over geotextile fabrics) should be deployed (Saldi-Caromile et al., 2004; Freshwater Habitats Trust, 2011).
- Upon completion of physical works, all temporary mats must be removed, and compacted soils along the access corridor should be lightly scarified (de-compacted) and re-vegetated (Saldi-Caromile et al., 2004; Bradbury, 2021).

3.7 Prevention of Pathogen and Invasive Species Transfer

Wetland maintenance and restoration activities can unintentionally introduce or spread aquatic and terrestrial invasive species, as well as pathogens, if proper precautions are not taken. Furthermore, physical disturbance of the site can create ideal conditions for invasive species to establish. To minimize these risks, all participants, including field staff, contractors, and volunteers, must be educated on species identification and biosecurity protocols prior to field activities.

Before initiating any restoration or maintenance work, management plans should account for the following (Cal-IPC, 2012):

- Identify existing invasive species within the target area and consult with the competent Ministry regarding approved control and removal methods.
- Assess the risk of new invasive species invading the disturbed site post-intervention.

- Strictly enforce the prohibition of any intentional or unauthorized introduction of non-native species.

Before entering or moving between wetland sites, adhere to the following check-clean-dry protocol (National Biodiversity Data Centre, 2023; Torsney et al., 2025):

- Ensure that all machinery, equipment, footwear, and clothing are thoroughly checked and free from mud, soil, seeds, plant fragments, or invertebrates.
- Clean and fully dry all items for at least 48 hours before reuse. If complete drying is not feasible, thorough disinfection is mandatory.
- When working in known infested areas, use dedicated footwear and equipment, or clean tools immediately before moving to uninfested sites.

4 Technical Restoration and Maintenance Activities on Ponds

No single design in Mediterranean ponds restoration can fit all wetland habitat requirements, so where appropriate, mosaic of habitats should be enabled in the context of different vegetation composition, shape, and depth of water body to create habitat diversity (Thompson & Luthin, 2010).

4.1 Tree and Shrub Removal

Over time, unmanaged Mediterranean ponds and canals naturally succeed toward dense shrubland or closed forest canopy, causing open, sunny aquatic microhabitats to gradually disappear under heavy shade (Norfolks Wildlife Trust, 2023; Biggs & Williams, 2024). Accumulation of dense overhanging branches leads to excessive organic leaf litter deposition, water acidification, oxygen depletion, and the suppression of submerged aquatic vegetation (Sayer et al., 2023; Still Water Revival, 2023). Because the vast majority of aquatic plants, dragonflies, and breeding amphibians require sunlit waters, active management is necessary to maintain a balanced mosaic of open water and dappled woody cover (Norfolks Wildlife Trust, 2023; Biggs & Williams, 2024).

SPATIAL GUIDELINES, ORIENTATIONS, AND CANOPY CONTROL

To maximize solar radiation and warmth reaching the water basin while stimulating the germination of buried aquatic seed banks (such as stoneworts, *Charophyta*), it is recommended to maintain at least 50% to 70% of the pond margin open and sunny (Norfolks Wildlife Trust, 2023; Sayer et al., 2023; Biggs & Williams, 2024). Trees and scrub should primarily be cleared from the south and west sides, while leaving some tree cover to the north and east, to act as a windbreak and maintain habitat heterogeneity (Norfolks Wildlife Trust, 2023; Sayer et al., 2023). This positioning allows the pond to receive essential sunlight throughout the day, encouraging the growth of aquatic plants (Norfolks Wildlife Trust, 2023; Sayer et al., 2023).

Old, mature trees with high landscape, historical, or ecological value (e.g., ancient oaks or veteran trees providing bat roosting cavities) should not be felled merely to open up the

canopy (MINGOR, 2022; Norfolks Wildlife Trust, 2023). Management around valuable landmark trees should focus on selective crown thinning, pruning lower overhanging branches (creating a "tunnel effect"), paired with regular removal of accumulated leaf litter if the tree remains (Suffolk Wildlife Trust, 2023).

ROOT EXTRACTION AND MECHANICAL PRECAUTIONS

Woody species that spread aggressively via root suckers (e.g., *Prunus spinosa*) must be removed by extracting as much root mass as possible, as root penetration through clay liners or traditional drystone walls is a primary cause of structural leakage and collapse (Still Water Revival, 2023).

On dry, historic pond banks, mature trees should be coppiced down to low stumps using chainsaws rather than pulled out with heavy excavators (Sayer et al., 2023). Ripping out large root systems from dry original banks causes severe structural tearing, bank erosion, and damage to clay seals (Sayer et al., 2023; Still Water Revival, 2023). In contrast, self-seeded invasive trees (e.g., willows or alders) growing directly inside the wet basin floor may be uprooted using a long-reach excavator bucket once top-coppiced (Sayer et al., 2023).

4.2 Aquatic Vegetation Management

Aquatic and emergent vegetation in and around a Mediterranean pond plays a crucial role in maintaining good water quality, absorbing excess nutrients, stabilizing shoreline soils against wave erosion, and creating essential microhabitats (BIOM, 2025a; Florida Fish and Wildlife Conservation Commission, 2023). Shoreline and aquatic plant stands provide vital egg-laying substrates, feeding grounds, and hiding places for amphibians (e.g., newts and frogs), aquatic reptiles (freshwater turtles), and aquatic invertebrates (such as dragonfly larvae and aquatic beetles) (Florida Fish and Wildlife Conservation Commission, 2023; Still Water Revival, 2023).

CONTROL METHODS

To control overabundant or encroaching vegetation, management in Mediterranean wildlife ponds must rely on manual (hand-pulling, rake twirling) or mechanical methods

(MINGOR, 2022; Florida Fish and Wildlife Conservation Commission, 2023). Physical harvesting extracts plant biomass along with its accumulated nutrients out of the pond before vegetation decays (Florida Fish and Wildlife Conservation Commission, 2023; Suffolk Wildlife Trust, 2023). Removing this organic material prevents dead plants from settling on the pond bed, thereby halting the future accumulation of anaerobic organic muck (Florida Fish and Wildlife Conservation Commission, 2023; Suffolk Wildlife Trust, 2023).

Seasonal thinning of excess aquatic vegetation every autumn can help reduce the progressive build-up of nutrients like nitrates and phosphates and prevents progressive basin siltation (Suffolk Wildlife Trust, 2023). During all management operations, field workers must retain at least 20% to 25% of the pond basin densely vegetated to serve as an immediate biological refugium for aquatic fauna (Suffolk Wildlife Trust, 2023).

Consequently, chemical controls (herbicides) and the introduction of non-native fish (such as grass carp or goldfish) are prohibited in natural Mediterranean ponds and protected areas (MINGOR, 2022; Still Water Revival, 2023). Synthetic herbicides pose severe toxic risks to non-target aquatic fauna while leaving dead plants to rot on the pond bed (MINGOR, 2022), whereas introduced fish disrupt fragile food webs by preying on amphibian larvae and continuously churning bottom sediment, which erodes and punctures the underlying impermeable clay liner (Still Water Revival, 2023).

MANAGING EXCESS ALGAE AND DUCKWEED

The presence of algae and duckweed is a natural feature of many ponds and does not necessarily indicate poor ecological condition. However, excessive or persistent growth of filamentous algae (e.g. *Cladophora* spp. and *Spirogyra* spp.) or free-floating duckweeds (*Lemna* spp.) can reduce light penetration and, when large amounts of biomass decompose, deplete dissolved oxygen in the water. These changes can negatively affect other aquatic organisms (Bradbury, 2021; Suffolk Wildlife Trust, 2023).

Excessive growth is often associated with an increased supply of nutrients, particularly phosphates. Preventing nutrient inputs, for example by limiting nutrient-rich runoff from surrounding land, is therefore an important long-term measure to reduce the risk of

recurring growth. In newly created or restored ponds, algal growth may also change naturally as aquatic vegetation becomes established. Intervention should therefore be based on the extent and persistence of the growth and its effects on the pond ecosystem, rather than on the mere presence of algae or duckweed.

- To remove free-floating duckweed (*Lemna* spp.), use a sampling net with fine mesh.
- When filamentous algae is in its active growth stages, grab or twist a stick amongst the algal mats and drag it to remove large sheaths in a single motion (Suffolk Wildlife Trust, 2023).

Fauna Rescue

To minimize accidental mortality of aquatic fauna during vegetation and algal removal, field workers should follow a two-step rescue protocol:

1. Before removing harvested plants or blanketweed from the basin, material should be vigorously swirled and shaken in the water (or in a bucket of pond water) to immediately release trapped macroinvertebrates, aquatic snails, and amphibian larvae (Freshwater Habitats Trust, 2015; Bradbury, 2021).
2. Harvested biomass should then be deposited gently on the damp pond edge, immediately above the waterline, for 24 to 48 hours (overnight), allowing any remaining animals to safely crawl back into the water (Bradbury, 2021; Suffolk Wildlife Trust, 2023). However, in ponds where protected newts are actively breeding or developing, intensive algal removal must be suspended during the larval period to avoid accidental mortality (MINGOR, 2022; Suffolk Wildlife Trust, 2023).

GRAZING AS A MAINTENANCE TOOL

Grazing can be an effective and sustainable management tool to control riparian and emergent vegetation around Mediterranean ponds and canals. Controlled livestock grazing (e.g., by cattle, sheep, or horses) suppresses the encroachment of woody shrubs and invasive plants, maintains open water margins, and promotes structural vegetation

diversity. Additionally, livestock hoof prints create beneficial microhabitats that provide micro-shelter and temporary moisture retention for freshwater turtles and other wetland fauna (Somers et al., 2000).

Seasonal grazing, particularly during late autumn and winter, is most effective for managing riparian vegetation while minimizing soil compaction, bank erosion, and plant degradation. Year-round grazing may be implemented only if stocking density is kept strictly low (Somers et al., 2000). However, grazing must be tightly regulated (using properly positioned temporary fencing and routine monitoring) to prevent bank collapse, overgrazing, nesting site destruction, and water quality deterioration from excessive nutrient inputs via fecal droppings (Somers et al., 2000).

4.3 Pond Sealing and Substrate Integrity

Determining the hydrological mechanics and permeability of a Mediterranean pond is a critical pre-requisite before conducting any deep excavation or restoration work (Department of Primary Industries and Fisheries, 2007; Still Water Revival, 2023). In karst environments, traditional ponds rely on an impermeable bottom layer. This layer was historically constructed from local puddled clay, bentonite, or compacted fine sediments to retain rainwater and surface runoff (Department of Primary Industries and Fisheries, 2007; Still Water Revival, 2023).

SUBSTRATE DIAGNOSTICS AND ASSESSMENT

Before altering the pond basin, managers must determine whether the water body is naturally semi-permeable or fully sealed (Department of Primary Industries and Fisheries, 2007; Freshwater Habitat Trust, 2011):

- Consult local livestock owners and long-term residents regarding the pond's historical water retention behavior, drying frequency, and structural history during summer months (Still Water Revival, 2023).
- Where baseline data is lacking, conduct a preliminary soil test or hydrogeological site assessment to determine soil texture, hydraulic conductivity, underlying karst topology, and existing clay layer thickness (Department of Primary Industries and Fisheries, 2007).

GUIDELINES FOR CLAY LINING

If a pond has lost its water-holding capacity due to mechanical damage, desiccation cracking, or root penetration, re-sealing the basin may be required (Department of Primary Industries and Fisheries, 2007; Still Water Revival, 2023):

- When applying or replacing a natural clay liner, a uniform layer of at least 20–30 cm of high-quality, compacted clay or bentonite should be laid across the entire bottom and lower margins (Department of Primary Industries and Fisheries, 2007). Clay should be evenly spread on gentle basin slopes, thoroughly puddled, and compacted (historically via boot-treading and livestock trampling) to form a continuous impermeable seal (Still Water Revival, 2023).

ASSESSMENT AND DISADVANTAGES OF SYNTHETIC MATERIALS AND CONCRETE

The use of artificial liners (e.g., concrete geotextiles, EPDM rubber membranes, PVC liners, or concrete sealing) in natural and semi-natural Mediterranean karst ponds is generally discouraged (Freshwater Habitat Trust, 2011; Still Water Revival, 2023):

- Synthetic membranes prevent natural root penetration, hinder the establishment of native aquatic vegetation, and eliminate the natural mud substrate required by macroinvertebrates, amphibians, and terrapins for overwintering, egg-laying, and burrowing (Department of Primary Industries and Fisheries, 2007; Freshwater Habitat Trust, 2011). Furthermore, certain synthetic geotextiles can leach chemical additives that are toxic to aquatic organisms (Department of Primary Industries and Fisheries, 2007).
- In dynamic karst landscapes, sharp underlying rocks can easily puncture thin synthetic liners, while unanchored membranes may shift or tear under heavy livestock trampling (Department of Primary Industries and Fisheries, 2007). Synthetic liners also present a slippery surface hazard for entering wildlife and livestock, increase drowning risk, and can inflate under sub-membrane groundwater pressure (Department of Primary Industries and Fisheries, 2007).

EXCEPTIONAL CONDITIONS FOR ARTIFICIAL LINING

Synthetic or concrete geotextiles should only be considered as an exceptional last resort in severely degraded, highly permeable artificial sites where natural clay is entirely

unavailable and human water demand strictly necessitates permanent water retention (Department of Primary Industries and Fisheries, 2007; Freshwater Habitat Trust, 2011).

4.4 Silt and Mud Removal

Not all pond restorations need to include mud removal and sometimes light works to reduce encroachment of trees and bushes around the pond edge are sufficient.

However, if a pond has become heavily silted, it may be necessary to remove the excess sediment, restore the original depth of the pond, and address any issues in the catchment area that caused the siltation (Ruiz, 2008). If the pond mud is black, foul-smelling and full of poorly decomposed leaves, it is necessary to remove it to create a hospitable environment for plants. The silt at the bottom of the pond may contain accumulated pollutants or naturally occurring substances that can lower water quality, deplete dissolved oxygen and prevent aquatic vegetation from being established (Suffolk Wildlife Trust, 2023). To achieve a significant improvement, aim to remove mud from one-third to one-half of the pond area, rather than cleaning the entire pond in one go. It's important to avoid removing underlying clay and altering the natural dimensions of the pond.

Removing materials from a silted wetland must be done with caution. Start by removing a portion of the sediments and assessing the wetland's functionality. After determining the appropriate depth for removing materials, the remaining sediments can be taken out. Excavation machinery, preferably tracked excavators equipped with long-reach arms operating from dry land margins (as detailed in Section 3.5 Machinery Selection), must never breach or penetrate the underlying impermeable clay liner (Freshwater Habitats Trust, 2011; Still Water Revival, 2023). As soon as the excavator bucket reaches the light-colored clay layer, digging must immediately cease (Sayer et al., 2023). If clay is accidentally displaced during desilting, it should be separated from dark organic mud and re-compacted over the basin floor (Still Water Revival, 2023).

Gentle slopes should be left to enable various vegetation types to establish themselves during the flooded period and prevent erosion.

All excavated mud and organic silt must be handled and disposed of in accordance with the protocols outlined in Section 6 (Disposal of Managed and Excavated Material) to prevent nutrient leaching and protect surrounding terrestrial habitats.

DEALING WITH SHORELINES AND DEPTH

Ponds that naturally dry out or fluctuate seasonally contain a biologically diverse zone known as the "drawdown zone". During summer months, water levels typically recede by at least half a meter, exposing this fluctuating margin, an area of mud and specialized vegetation that is submerged during winter and spring, but gradually dries out as water levels recede (Freshwater Habitats Trust, 2011). This dynamic drawdown zone provides exceptional microhabitats for specialized flora, invertebrates, amphibians, birds, and small mammals (Freshwater Habitats Trust, 2011).

Therefore, during pond restoration/maintenance or desilting operations, field workers must leave shoreline margins in their natural state without steepening their profile or altering original depth gradients. It is recommended to preserve shallow areas, as they are the most beneficial for wildlife. Preserving shallow marginal areas (often less than 30 cm deep) is crucial, as the majority of aquatic species reside in extremely shallow water between 1 cm and 10 cm deep right against the bank edge (Freshwater Habitats Trust, 2011). If you want to improve a pond for wildlife, focus on these marginal areas. To maintain these areas, the pond's edge should slope gently at a 3-12° angle. Margins that are 20-30° steep are usually too steep, as a 20° slope would only allow for a narrow 35cm-wide band of critical wildlife-rich area (where water will be less than 10 cm deep) (Freshwater Habitat trust, 2011).

4.5 Invasive Alien Species (IAS) Removal

Invasive Alien Species (IAS) can threaten the ecological integrity of small freshwater ecosystems by altering habitats, disrupting ecological balance and outcompeting native species. Their presence should therefore be considered when planning and implementing restoration measures. (Ruiz, 2008). Common invasive species include aggressive aquatic and riparian plants (e.g., *Arundo donax*, *Paspalum* spp.), invasive crustaceans (e.g.,

Procambarus clarkii), alien fish introduced near urban or agricultural areas, and non-native freshwater turtles (e.g., *Trachemys* spp.) (Ruiz, 2008).

Active control measures must align with national legislation, EU Regulation No 1143/2014, and established management frameworks for Natura 2000 Habitats (Ruiz, 2008). Prior to initiating eradication programs, the competent ministry must be consulted to ensure regulatory compliance and species-specific approval.

When managing IAS in Mediterranean wetland habitats, implementation should follow these strategic guidelines:

- Non-native turtles (*Trachemys* spp.) and introduced fish should be target-captured (e.g., using specialized traps or nets) to prevent severe predation on native amphibians and macroinvertebrates (Ruiz, 2008). Public awareness campaigns should accompany these efforts to address unauthorized pet releases (Ruiz, 2008).
- In temporary ponds, natural summer desiccation acts as an effective biological control that eliminates introduced fish (Ruiz, 2008). However, burrowing species like the red swamp crayfish (*Procambarus clarkii*) can survive droughts in deep sediment burrows; thus, intervention must focus on identifying and controlling invasion pathways (such as adjacent irrigation channels) (Ruiz, 2008).
- Invasive plant species should be evaluated via a preliminary risk assessment and eradicated manually or mechanically as soon as possible (Ruiz, 2008). Because wind, water, and animals can re-introduce seeds or root fragments, multi-year monitoring and follow-up removal are essential to prevent re-establishment (Ruiz, 2008).
- In cases where IAS establishment is driven by altered flooding patterns (e.g., due to dredging or damming), restoring natural hydro-regimes may allow native biotic communities to naturally recover and outcompete invasive flora (Ruiz, 2008).
- Consult existing specific protocols on IAS removal or management for your targeted species in your targeted type of weatland, and availabiliy of recommended specific tools.

To prevent the accidental transfer of invasive seeds, fragments, or pathogens between sites during field operations, field staff and contractors must strictly enforce the

standardized biosecurity protocols (Check-Clean-Dry) (Torsney et al., 2025), as described in Chapter 3.7 (Prevention of pathogen and invasive species transfer).

4.6 Microhabitat Features

Enhancing structural heterogeneity within and around a pond provides essential microhabitats for wildlife, particularly herpetofauna (reptiles and amphibians), macroinvertebrates, and small mammals (Somers et al., 2000).

RESTORATION OF DRYSTONE WALLS

Drystone walls surrounding or adjacent to traditional Mediterranean ponds are of exceptional ecological value (Still Water Revival, 2023):

- drystone walls increase the vertical complexity of the habitat, offering shaded, humid micro-crevices that shield amphibians and reptiles from extreme summer heat and desiccation.
- the un-mortared gaps between stones serve as primary overwintering sites (hibernacula) and predator-free refuges.

Existing drystone walls should be carefully preserved and restored using traditional dry-stacking techniques with local stone. Mortar or cement should never be used during restoration, as it seals vital micro-crevices and destroys habitat functionality (Still Water Revival, 2023);

INSTALLATION OF ESCAPE RAMPS

Ponds with steep, artificial, or eroded banks present a severe drowning hazard for terrestrial animals, livestock, and juvenile freshwater turtles (Still Water Revival, 2023):

- install gentle egress ramps or rock ladders along steep edges to allow trapped animals to climb out safely.
- ramps should be constructed using natural materials such as unpolished local stones, logs, or low-sloped earth mounds covered with native vegetation, oriented at an angle of less than 15°.

DEADWOOD AND WOODY DEBRIS (*BRUSH PILES*)

Felled timber and pruned branches generated during tree and shrub removal should be repurposed on-site rather than burned or discarded:

- stack cut branches and logs into low-density brush piles (deadwood habitats) in sunny terrestrial spots within 5–20 meters of the pond edge, outside the high-water line (Somers et al., 2000; Freshwater Habitats Trust, 2011; Bradbury, 2021; Sayer et al., 2023). Brush piles must be located where they do not shade the open water surface or block incoming overland runoff (Freshwater Habitats Trust, 2011; Sayer et al., 2023).
- these structures provide thermal refuge, foraging sites, and nesting cover for small mammals, lizards, snakes, and beneficial insects.

AQUATIC AND SHORELINE BASKING STRUCTURES

Place large natural rocks and stable wooden logs directly along the shoreline and/or anchored into deeper water zones. These exposed, sunlit structures serve as essential basking platforms (thermoregulation sites) for native freshwater turtles. (Florida Fish and Wildlife Conservation Commission, 2023).

5 Technical Guidelines for Canal Network Maintenance

Canals in the Mediterranean region play a dual role: they help manage water for farming and flood control, while also providing important shelter for local wildlife.

When carrying out maintenance work in canal networks, field teams should always follow their own country's environmental guidelines and regulations. In Croatia, for example, work is based on the official handbook published by the Ministry (*Handbook for the Application of Freshwater Ecosystem Conservation Measures*; MINGOR, 2022).

The practical steps described below highlight only a selection of these measures. We present them here as a helpful guide, especially for regions or practitioners that do not yet have their own detailed standards. However, if your country already has specific rules for canal maintenance, you should always follow those first.

For more detailed instructions and the complete set of measures, please consult the mentioned Croatian handbook.

5.1 Removal of Riparian and Amphibian Vegetation in the Canals

Amphibious vegetation must not be mowed (MINGOR, 2022). If mowing amphibious vegetation on a specific section of a watercourse is unavoidable, it should be limited to one bank per growing season (year), leaving the vegetation on the opposite bank completely untouched.

Mowing of aquatic vegetation is allowed only when water flow is significantly impaired, posing a direct threat to property or human health (MINGOR, 2022). If it's necessary to mow/clear aquatic vegetation in a canal bed, it should be done in a maximum of 2/3 of the watercourse's width, leaving undisturbed bed substrate, aquatic and marsh vegetation on both sides (except in cases where it hinders the operation of pumping stations). For

canalized watercourses, mowing within the canal bed should follow a sinusoidal (meandering) pattern (MINGOR, 2022).

Riparian vegetation should not be mowed or cleared within a minimum width of 2 meters on both sides of the watercourse. Along agricultural land, this 2-meter buffer should be maintained wherever possible to prevent nutrients and pollutants from washing into the water. Where leaving a full 2-meter buffer is not possible and mowing is necessary, leave the maximum possible width and limit mowing to one bank only within a single vegetation season (year), leaving the opposite bank completely untouched. Also on the bank where clearing takes place, keep well-developed shrubs intact as much as possible to help stabilize the bank and provide shade for the watercourse. In exceptional cases where mowing riparian vegetation on both banks of a watercourse is unavoidable, work should be staggered over time. At any given moment, at least 30% of the riparian vegetation along every 100-meter stretch must be left unmowed, maintaining a minimum width of 2 meters from the water's edge (MINGOR, 2022).

When performing mowing or clearing works in settlements, tourist, or sports-recreational areas where multiple cuts per year are required, at least 10% of the vegetation surface must be left undisturbed during each intervention as short strips or patches every 100 meters to serve as wildlife refugia (MINGOR, 2022).

All mowed plant material must be immediately extracted from the channel bed and banks to prevent nutrient enrichment, oxygen depletion, and downstream blockage (MINGOR, 2022).

5.2 Removal of Trees and Shrubs in the Canals

This section outlines conservation measures for selective felling operations targeting shrubs over 5 cm in diameter and trees over 10 cm in trunk diameter (MINGOR, 2022).

Woody vegetation along watercourses should be kept in its natural state whenever possible. Tree and shrub removal is permitted only when water flow is severely restricted,

posing a direct risk to property or human health (MINGOR, 2022). When interventions are necessary, maintenance work must follow a gradual, step-by-step approach to minimize environmental impact.

As a first step, operators should restore flow simply by trimming overhanging branches up to the highest water level mark (creating a "tunnel" effect), and removing only individual trees that directly obstruct the water. If pruning alone is insufficient, clearing must be limited to a single bank, choosing the side with less developed vegetation while leaving the opposite bank completely untouched (MINGOR, 2022).

If the previous measures are insufficient to restore required water flow, work should focus on minimal selective thinning. This means prioritizing the removal of smaller trees and shrubs with a trunk diameter under 20 cm, while preserving larger trees and tree groups wherever they do not block water flow (MINGOR, 2022).

Special care must be taken to protect mature trees with cracks or hollows that serve as roosts or nesting sites for bats and birds. If strictly protected species are discovered, the relevant public nature management authorities must be contacted immediately for further guidance. Additionally, once mature trees are cut, the trunks should be left on site for 24 hours prior to removal, giving roosting bats and other tree-dwelling wildlife enough time to safely escape (MINGOR, 2022).

5.3 Removal of Debris in the Canals

An important consideration for canals is the management of water flow. Canals must be maintained to ensure that water flow is strictly controlled and does not cause bank erosion or damage to the surrounding vegetation (MINGOR, 2022). Where needed, bio-engineering bank protection measures (such as vegetative cover or stone barriers) should be implemented to prevent bank failure (MINGOR, 2022).

Another important consideration is the removal of sediment and debris from the canals. While this is important for maintaining water flow, it should be done carefully to avoid

damaging aquatic habitats or disrupting the natural balance of the ecosystem. Where feasible, debris should be removed manually or using specialized equipment (e.g., long-reach excavators operating from dry ground outside the channel) rather than deploying heavy machinery directly within the canal (MINGOR, 2022).

Naturally fallen logs, branches, and deadwood should be left in the canal wherever they do not pose an immediate flood risk. If a fallen log blocks the water flow, it should be reoriented parallel or at a 45° angle to the bank instead of removing it completelly. Complete removal should be limited only to high-risk locations where blockages could occur, such as swallow holes, culverts, bridges, and water control structures (MINGOR, 2022).

6 Disposal and Management of Excavated Material

Physical interventions during pond restoration or maintenance generate substantial quantities of excavated material. To ensure environmental compliance, preserve surrounding sensitive habitats, and optimize project costs, field managers must distinguish between few categories of material: organic woody debris (branches and brush), mineral spoil (clean mineral subsoil, clay, or overburden excavated during basin profiling), and organic mud/silt (wet, nutrient-rich anaerobic sludge extracted during desilting).

6.1 Aquatic Vegetation and Algae Disposal

Removal of submerged aquatic plants, emergent vegetation, or filamentous algae generates nutrient-dense green biomass (Florida Fish and Wildlife Conservation Commission, 2023). Following the required 24 to 48-hour dewatering and fauna rescue period on the damp pond margin (see chapter 4.2 - Fauna Rescue) (Bradbury, 2021; Suffolk Wildlife Trust, 2023), all harvested plant material must be completely removed from the basin and its immediate margins (Suffolk Wildlife Trust, 2023).

Leaving rotting vegetation near the waterbody leads to nutrient leaching during rain events, causing re-eutrophication and oxygen depletion (Florida Fish and Wildlife Conservation Commission, 2023). Harvested biomass should be transported off-site to a green-waste processing facility (Sayer et al., 2023). If invasive alien plants are present in the harvested material, follow the IAS control protocol or contact the competent authority for disposal instructions.

6.2 Organic Debris and Brush Piles

Pruning trees and removing shrubs generates woody debris that requires proper management. Where suitable, this material can be left in dry areas around the pond and arranged in small piles to provide shelter for wildlife, including places where amphibians can spend the winter (see Section 4.6: Microhabitat Features) (Somers et al., 2000; Bradbury, 2021).

However, if woody biomass cannot be accommodated on-site without shading the water body, blocking surface water flow, or creating a fire hazard, all excess material must be removed from the wetland basin and buffer zone and transported off-site to a licensed green-waste depot or landfill (Somers et al., 2000; Freshwater Habitats Trust, 2011). Burning brash directly next to the pond must be strictly avoided, as wind-blown ash acts as an unwanted fertilizer in the water column (Sayer et al., 2023).

6.3 Spoil Disposal

The disposal of excavated mineral spoil is typically the most time-consuming and costly aspect of a pond construction or restoration project (Freshwater Habitats Trust, 2011; Sayer et al., 2023). To minimize transport costs and machinery traffic, spoil should be repurposed on-site wherever posible to create beneficial landscape features, retain water, or divert polluted runoff away from the pond basin (Freshwater Habitats Trust, 2011).

High-nutrient topsoil must be strictly separated from underlying mineral subsoil during excavation (Saldi-Caromile et al., 2004; Freshwater Habitats Trust, 2011). Topsoil must never be dumped inside the pond basin, along immediate shoreline edges, or uphill of the pond where rainfall could wash nutrients back into the water column (Freshwater Habitats Trust, 2011; Sayer et al., 2023).

Moderate amounts of mineral spoil can be spread thinly around the site at a distance of at least 3 to 4 meters away from the pond margin, taking care not to pile material higher than 30 cm (Freshwater Habitats Trust, 2011). Spoil must never form a continuous raised rim or embankment around the pond perimeter, as this blocks clean surface runoff from entering the water body (Freshwater Habitats Trust, 2011).

6.4 Mud Disposal

Unlike clean mineral subsoil, dredged pond mud is a wet, highly organic sludge packed with accumulated nitrates and phosphates (Norfolk Wildlife Trust, 2023; Suffolk Wildlife Trust, 2023).

Before final transport, dredged mud must undergo a 24 to 48-hour temporary dewatering phase on the damp pond margin immediately above the waterline, allowing trapped aquatic macroinvertebrates, snails, and amphibian larvae to safely return to the water column (Bradbury, 2021; Suffolk Wildlife Trust, 2023).

Before removing the bulk of dredged mud, a small portion of the uppermost sediment layer should be retained and re-spread along the shallow margins. This preserves the native propagule bank (including charophyte oospores and invertebrate resting eggs) which supports the natural recovery of native pond communities (Biggs & Williams, 2024; Sayer et al., 2023).

Once dewatered, the sediment may be considered for agricultural reuse, provided that all mandatory environmental analyses and statutory approvals are completed first (see Section 6.5). Where legally and agronomically suitable, the material is spread thinly across neighboring arable fields (ideally stubble fields), left to dry, and subsequently plowed in as a natural soil conditioner and fertilizer (Norfolk Wildlife Trust, 2023; Sayer et al., 2023).

Dredged mud must never be dumped onto species-rich grasslands, wildflower meadows, or within the vegetated buffer zone (at least 10 meters wide) surrounding the pond. Keeping this buffer zone free of excavated sediment prevents nutrients and pollutants from leaching back into the water body during rainstorms (Norfolk Wildlife Trust, 2023; Sayer et al., 2023).

6.5 Mandatory Regulatory Compliance and Analytical Requirements for Sediment Reuse

To safety utilize excavated sediment on agricultural soils or adjacent land, the material must comply with national environmental frameworks governing waste management, soil protection, and water resources.

While specific threshold values and administrative procedures vary across Mediterranean countries, standard regulatory compliance typically requires prior physical, chemical, and biological testing to guarantee soil safety and prevent contamination.

Prior to land application, laboratory testing must be conducted to assess sediment quality and safety. Depending on national jurisdiction, the required analytical parameters generally include:

- Physicochemical and agronomic parameters: pH, electrical conductivity (E.C.), moisture content (H_2O), dry matter (S.T.), loss on ignition at 550 °C (G.Ž./Ž.O.), organic carbon (C_{org}), total organic matter (O.T.), total nitrogen (N), phosphorus (P_2O_5), potassium (K_2O), calcium (Ca), magnesium (Mg), iron (Fe), and manganese (Mn).
- Contaminant and ecotoxicological screening: Heavy metals (Zn, Cu, Cd, Pb, Ni, Cr, Hg, As, Mo, Co), polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs).
- Microbiological safety: Pathogen screening for *Escherichia coli* and *Salmonella* spp.
- IAS screening: Inspection for viable fragments or propagules of invasive alien plant species to prevent spreading invasive weeds across agricultural landscapes (Freshwater Habitats Trust, 2011; Sayer et al., 2023).

An official analytical report verifying that all parameters meet statutory limits and confirming the complete absence of invasive alien species (IAS) must be submitted to competent national or local authorities before applying sediment to agricultural land.

7 Post-Restoration Recovery and Monitoring

Physical excavation and structural restoration mark only the beginning of a pond's ecological recovery. Long-term functionality requires appropriate post-restoration management, strict adherence to natural regeneration principles, and routine adaptive monitoring (Freshwater Habitats Trust, 2011; MINGOR, 2022).

7.1 Post-Excavation Water Filling and Sources

Water quality and source selection are decisive factors for the long-term ecological stability of Mediterranean ponds. There are three primary water sources for ponds: (i) unpolluted surface runoff/rainwater; (ii) groundwater; and (iii) inflow streams, ditches, or springs (Freshwater Habitat Trust, 2011).

Rainwater running off clean, uncultivated semi-natural catchments is the ideal water source. Catchment areas must be free from intensive agricultural runoff, road drainage, livestock yards, or urban surfaces to prevent the influx of agrochemicals and nutrients (Freshwater Habitat Trust, 2011). Direct feeding from agricultural ditches or urban drains should be strictly avoided as it introduces chronic nutrient pollution, triggering severe eutrophication (Freshwater Habitat Trust, 2011).

Following excavation or maintenance, ponds should be allowed to fill naturally through seasonal precipitation and natural surface runoff. Transporting external water via water tankers should remain a last resort, as tap or municipal water often contains chemical additives (such as chlorine), while unverified external water sources risk introducing unwanted nutrients, pathogens, or invasive species.

7.2 Natural Vegetation Recovery

Following mechanical restoration or mud removal, a common misconception is that ponds must be immediately re-planted or inoculated with sediment from other water bodies to accelerate recovery (Freshwater Habitats Trust, 2011; Biggs & Williams, 2024)

The Principle of "Don't Plant Up"

Active planting or seeding following pond creation or restoration is generally unnecessary (Freshwater Habitat Trust, 2011). The early pioneer stage of a newly created or restored pond is a short but ecologically critical phase that supports specialized species (Freshwater Habitat Trust, 2011). Artificially introducing aquatic plants or transferring sludge/sediment from other sites forcibly shortens this early successional stage and risks introducing invasive species (Freshwater Habitat Trust, 2011; Cal-IPC, 2012). Mediterranean pond sediments naturally harbor resilient seed, egg, and cyst banks capable of rapid regeneration upon re-wetting (Ruiz, 2008). Provided that suitable water conditions are established, native aquatic vegetation will rapidly recolonize the site naturally (Freshwater Habitat Trust, 2011).

7.3 Post-Restoration and Maintenance Monitoring

To verify whether restoration goals are being met and to catch new pressures early, a structured monitoring protocol should be established:

- **Hydrological and water quality monitoring**

Regularly check seasonal water depth fluctuations, hydroperiod duration, and potential indicators of severe eutrophication (e.g., persistent algal blooms or thick duckweed cover) (Suffolk Wildlife Trust, 2023).

- **Biological surveys**

Conduct periodic field surveys using standardized indicator groups (such as dragonflies/Odonata, amphibians, and native freshwater turtles) to assess species recolonization and population health.

- **Early detection of invasive species**

Inspect the pond and surrounding buffer zone annually for early incursions of invasive alien plants (e.g., *Arundo donax, Paspalum paspalodes*) or invasive fauna (e.g., *Trachemys* turtles or red swamp crayfish) to ensure prompt eradication before populations become established (Cal-IPC, 2012).

- **Adaptive maintenance**

Schedule small-scale, preventative maintenance tasks (e.g., minor hand-clearing of encroaching scrub on the southern bank or repairing drystone walls) as needed based on monitoring observations.

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