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Ecological water management in the Alhambra y Generalife

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Abstract

The Alhambra and Generalife use the water from the River Darro to irrigate the cultivated and forest areas and for most of their water features since it was built, in the SXIII. Here, we present a water management system based on recovering the dynamics of aquatic ecosystems in a Monument of high historical and landscaping value, declared world heritage by UNESCO since 1984. This system has achieved notable improvements in the quality of the waters and in their appearance and has encouraged the return of fauna that are beneficial for the surrounding area. This has contributed to a significant increase in the biodiversity of the ecosystems that we manage and in their environmental health. The naturalization process within different hydraulics structures has enabled to reduce the amount of algaecides and chlorine we use in the maintenance of the main water features. It has also achieved a visible improvement in the quality of the water, an increase in the biodiversity in the area, support for pest control in cultivated areas and a clear improvement in various sensory aspects of the ponds. In this way, this management system is contributing to the following Sustainable Development Goals (SDG): G3. Good health and wellbeing, G6. Clean water and sanitation aG11 Sustainable cities and communities and G15. Life on land.

Keywords: Renaturalization, water quality, biodiversity, sustainable development goals, hydraulic historical heritage

1. INTRODUCTION

Permanent water bodies (such as lakes or ponds) and small watercourses are common features of green areas, parks and gardens. In Mediterranean climates, where over the course of the year there are long periods with many hours of sunlight and high temperatures, the maintenance and management of these spaces often poses a complex challenge for the managers, who want to ensure that they are pleasant, aesthetically pleasing spaces and that they do not become breeding-grounds for mosquitoes. They must also try to prevent the water from looking murky or smelling bad, while at the same time enabling it to act as a reservoir of biodiversity, so multiplying the environmental services that water bodies provide.

Figure 1. The capturing and transporting system from the Darro river to the Alhambra y Generalife.

Figure 2. The hydraulic surface network.

Since 1970, we have lost 83% of the biodiversity of the fauna that inhabit freshwater ecosystems at a global level (WWF Living Planet Report 2020), while according to the IUCN, amphibians are the most endangered group of vertebrates worldwide (Stuart et al., 2004; Houlahan et al., 2000; Pechmann et al, 1991). 40% of their species are at risk (UICN 2008, 2021) and 59% of European species (Temple & Cox, 2009). In the Mediterranean Basin, the accelerated depletion of their numbers is an important consequence of the general process of desertification in which we are currently immersed, together with changes in land use and in the share-out and distribution of the waters in the Mediterranean Basin (Cox et al., 2006).

Improving the access of endangered species to water bodies provides an opportunity for the conservation of species in decline (Valdez et al., 2021; Magnus and Rannap, 2019), even in gardens (van Heezik et al., 2012; Muller and Kelcey, 2010) that are widely used by the public.

In 1984, the Alhambra and Generalife Group of Monuments were declared part of World Heritage. Their exceptional universal value was said to be the fruit of the perfect balance between architecture, landscape and nature, in which water plays a leading role, both as a fundamental component of the plant and animal life that make up the different ecosystems within the Monument and as part of the ingenious engineering systems constructed and developed for its management, storage and enjoyment.
Traditionally, the maintenance of ornamental water infrastructures has required:

- Periodic cleaning of the different water features, with the application of products such as bleach, chlorine, detergent, algaecide, etc, to remove the organic remains stuck to the surfaces.
- Introduction of ornamental fishes (cyprinid species) to control the algae growth.

However, this system has the following results:

- Pools with poor aesthetic appeal, with murky water and limited plant and animal diversity.
- High maintenance costs, as it is often necessary to empty them completely, clean them, remove mud and sludge, etc.
- High dependence on chemical products.

Here we present a water management model based on the dynamics inherent in the functioning of natural aquatic ecosystems. The aim was to bring about the naturalization of water mass and recovery of habitats. The following results were obtained:

- High aesthetic quality: transparent water and aesthetically pleasing environments.
- An increase in ecosystem services: Vertebrate and invertebrate fauna associated with the water bodies provide environmental services to the surrounding areas (gardens and green areas) and to the people who enjoy them (Hill et al., 2021; Muller et al., 2010).

2. METHODOLOGY

The methodology used could be summarized in the next steps:

Phase 0

Pitfall traps are adapted by installing ramps integrated into restoration projects, finding the best way to integrate them into the water feature or camouflage them within it.

Initial restoration of the water bodies thorough cleaning ('system reset'), removing sludge, fish excrement and a complete cull of all the fish.

Once the water feature is clean, algae and plants are planted, and "useful" invertebrates and zooplankton components are added. Finally, the amphibian larvae are added.

Phase 1

During the first 6 months - 1 year, everything must be carefully monitored and maintained to enable the algae at the bottom to establish themselves. These oxygenate the water ('stonewort's' Charophyceae), the rest of the planted vegetation and the proliferation of micro and macro fauna. At the beginning, the continuous removal of filamentous algae is required, together with various small corrective actions, so as to achieve the desired ecosystem equilibrium.

Phase 2

The water surfaces are now wonderfully transparent, the vegetation at the bottom (Charophyceae) and on the surface (water lilies and 'knotweed' - *Polygonum*) looks shiny and attractive, hosting a large number of amphibians, reptiles (water snakes) and invertebrates (backswimmers, dragonflies, mayflies, mud snails, etc). The ultimate objective here is to maintain the water in a healthy ecological condition via oxygenation and the elimination of excess organic material.

In order to accomplish and maintain Phase 2, the following maintenance operations must be carried out continuously throughout the water management system:

Stop using chlorine (granulated or in tablets) and algaecides, in both the water vessels that are being naturalized, and in the channels that lead into them. The vessels will be cleaned (much less frequently) outside the amphibian reproduction season (when eggs are being laid or there are larvae present). Before beginning the cleaning work, the amphibians and invertebrates (water snails) are removed by hand, and placed in the shade in containers designed for this purpose. Once the water vessels have been cleaned, the fauna are released, the meadow of Charophyceae algae is replanted on the bottom and the ornamental phanerogams (lilies and knotweeds) are pruned, removing any dead leaves or cutting back the centres in the event of excessive growth.

The maintenance schedule for the network of channels by which the water enters the system takes into account the biological cycles of their resident amphibians and their annual development, so enabling them to reproduce. Cleaning work is performed at the end of the summer and in the autumn, once the amphibians are fully developed. Before cleaning begins, the fauna are rescued *in situ* and removed. Once the cleaning work is complete, they are released in the same place they were found.

Fish culls will be performed according to a strict protocol to avoid animal suffering. The ponds at the end of the water circuit (next to the palaces) are stocked with fish for ornamental reasons. These populations are controlled each year by selective culls of the least attractive individuals and of the young fish from that year.

In order to contribute to the overall improvement in the quality of the water, which comes straight from the River Darro and contains large amounts of organic material and particles in suspension, an organic filtering system has been installed in the water tanks at the entrance to the circuit. This consists of 40 square trays (1.5 m long -90 m^2 of filtering area-) mounted on a system of floats, with helophytes planted on top (rushes *Juncus effusus*, *Scirpus maritiums*, irises *Iris pseudoacorus*, and reeds *Typha* sp.).

Amphibian censuses–are carried out continuously to find out which species reproduce in pools. Nocturnal censuses are carried out at the right time of year (early spring and autumn) with appropriate weather conditions. The number of adults in each pond is noted down together with the first spawning.

3. RESULTS

From an initial situation of murky waters with almost no visibility, no sense of depth and unpleasant smells as the temperatures rose, we moved to an intermediate situation with phytoplankton ("green water phase") and the presence of mosquitoes. After predators were added, there was a radical improvement in the aesthetic appearance in just a few weeks, increasing the visual quality of the historic ponds. These improvements can be summarized as follows

- The plants had much more foliage than at the beginning of the programme.
- The consumption of phytotoxins in the natural environment has been reduced.
- The water features do not have to be cleaned so often.
- Many points in the water circuit have been naturalized or corrected: actions of this kind have been taken in 29 ponds/troughs, on 3 stretches of water channel and a water course (stream).
- Presence of amphibians: the space within the Alhambra and Generalife that could be considered an ideal habitat for amphibians has increased in both volume and area
- Amphibians: the biodiversity of amphibians in and around the monument is currently 5 species (4 tailless and 1 tailed, Table 1), with 3 species categorized as endemic. Two taxa belong to endangered categories worldwide (Vulnerable - VU and Near Threatened - NT).

Table 1. Amphibian species, endemic condition, categories of threat, and location in Monument zones.

English name	Spanish name	Scientific name	Iberian Endemic	IUCN categories	Previous presence
Sharp ribbed newt	Gallipato	*Pleurodeles waltl*	No	NT	No
Betic midwife toad	Sapo partero bético	*Alytes dickhilleni*	Yes	VU	No
Iberian painted frog	Sapillo pintojo ibérico	*Discoglossus galganoi*	Yes	LC	No
Spiny toad	Sapo común	*Bufo spinosus*	No	LC	Yes
Iberian waterfrog	Rana común	*Pelophylax perezi*	Yes	LC	Yes

- Naturalization of water mass: the naturalized water mass volume has increased in 3.156m^3, their visual quality, especially in terms of its transparency, has been improved. The vigour and the flowering of the water plants has been enhanced.
- Amphibians: one endangered species (Sharp ribbed new *Pleurodeles waltl*) has been fully introduced in 3 spaces. A further 2 species (Iberian painted frog *Pelophylax perezi* and Betic midwife toad *Alytes dickhilleni*) are currently undergoing naturalization in water channels and pools:
- Aquatic reptiles: the presence of amphibian larvae attracts water snakes (Viperine snake *Natrix maura*).
- Birds: the presence of aquatic macroinvertebrates has attracted insect-eating birds, which come to the pools to hunt.

- An important increases in Whittaker biodiversity indexes (Whittaker, 1972): At the beginning of the works, 2008, the aquatic vertebrate local diversity in the area of Alhambra (α) was just 3 species the 50% of surrounded species, the Darro valley, in 2021 this parameter, β biodiversity, up until 71% (Figure 3).

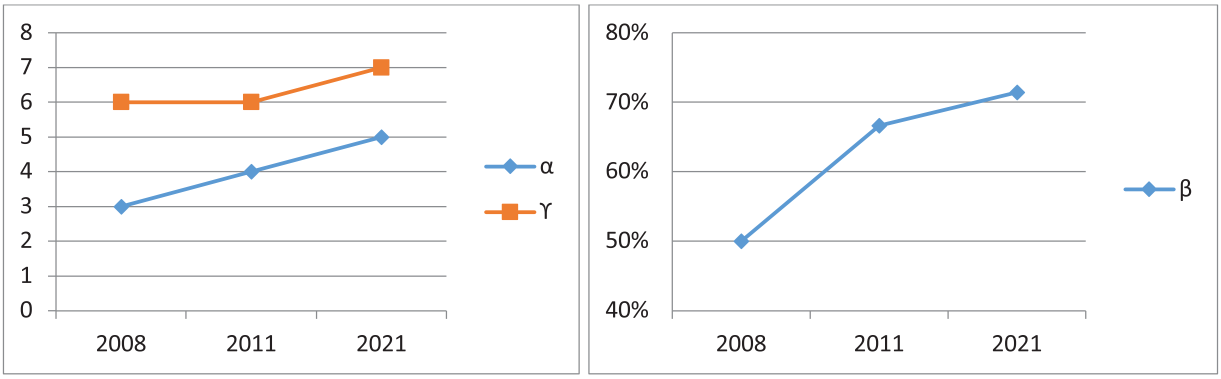

Figure 3. Parameters α and ϒ represents Alhambra area and Darro Valley area, respectively. Nº aquatic vertebrates (Left panel). The evolution of β parameter (rigth panel)

4. CONCLUSIONS

The appearance and the quality in of the water in the naturalized pools and water tanks has improved markedly. In the water systems managed in this way, there has been an explosion of fauna that is beneficial for the surrounding area, so contributing to a significant increase in the biodiversity of the ecosystems being managed and their environmental health (Caneva *et al.*, 2020).

Naturalization has led to a reduction in the use of algaecides and chlorines for the maintenance of the main water features.

The naturalization of the water bodies produces a general improvement in all the ecosystems in the area, by supporting pest control in these spaces (Hill et al., 2021; Beebee, 1979).

The management of water and water features according to environmental criteria is possible even in places like the Alhambra y Generalife that have very strict policies regarding aesthetic quality and heritage conservation by managing water in this way, the Monument helps enhance/promote the following UN Sustainable Development Objectives: 3. Health and wellbeing, 6. Clean water and sanitation and 15. Life of terrestrial ecosystems.

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