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Teodoro Semeraro, Cosimo Giannuzzi, Leonardo Beccarisi, Roberta Aretano, Antonella De Marco, M. Rita Pasimeni, Giovanni Zurlini Irene PetrosilloA constructed treatment wetland as an opportunity to enhance biodiversity and ecosystem services Ecological Engineering 82 (2015) 517–526

A constructed treatment wetland as an opportunity to enhance biodiversity and ecosystem services

Teodoro Semeraro, Cosimo Giannuzzi, Leonardo Beccarisi, Roberta Aretano, Antonella De Marco, M. Rita Pasimeni, Giovanni Zurlini, Irene Petrosillo

Highlights

- CTW are sustainable technologies for wastewater treatment.
- CTW are engineered ecosystems that mimic natural wetlands.
- We demonstrate that CTW satisfy human needs enhancing biodiversity.
- CTW provide ecosystem services as natural wetlands.

Abstract

Today we have to face new challenges about decreasing water resources, wastewater treatment, limited spaces and ecological preservation. This problem must be solved in a sustainable way using innovative water management strategies that combine technology with landscape design by enhancing ecosystem services provision. An effective way of tackling this problem is to use Constructed Treatment Wetlands (CTW) as low-cost alternative to conventional secondary or tertiary wastewater treatment. The aim of this paper is to evaluate their multifunctional role in terms of biodiversity and ecosystem services' enhancement by taking into account a case study in southern Italy. For this purpose an annual monitoring of fauna and vegetation has been carried out in order to identify species of national and international interest strongly related to the new habitats availability. Results have shown the ability of CTW in providing ancillary benefits, well beyond the primary aim of water purification, such as sustaining wildlife habitats and biodiversity at local and global scales, as well as its potential role in terms of recreational and educational opportunities.

Graphical abstract

Keywords:

Water resource protection

Wastewater treatment

Multifunctional landscapes

Landscape design

Geospatial data

1. Introduction

Linkages between terrestrial and aquatic systems (Meyer et al., 1988, Likens and Bormann, 1995) lead to critical changes in freshwater systems that result from population growth and land use modifications. Today, 54% of the world's population lives in urban areas, a proportion that is expected to increase to 66% by 2050 (United Nations, 2014). All populated areas, ranging from small rural communities to large urban settlements require adequate access to freshwater resources and, when cities grow in population, the total water needed for adequate municipal supply grows (Falkenmark and Widstrand, 1992, Postel et al., 1996, McDonald et al., 2011) as well as the need for a balance between wastewater disposal and water resource protection (Tarr et al., 1984, Burian et al., 2000). In this context, the European Community legislation sees the 91/271/CE Directive that aims at regulating the collection, treatment and discharge of urban wastewaters and those arising from certain industrial sectors, in order to protect water resources.

An adequate water resource protection is crucial since the ecosystem goods and services provided by freshwater systems are multiple, such as supporting numerous species, supplying water for drinking and irrigation, and assimilating wastes through abiotic/biotic cycling (MEA, 2005, Jackson et al., 2001). However, over the past fifty years, public attitude toward the environment has changed and also engineering has added sustainability to its general objectives to adapt itself to the demands of an evolving society (Davidson et al., 2007). This has produced a substantial change in how technology is designed and operates. In this sense, the application of sustainability criteria able to protect the provision of ecosystems goods and services is now the main focus (Wu, 2013), rather than environmental protection based on an end-of-pipe approach (Davidson et al., 2007).

The notion of ecosystem services has been introduced to identify the benefits people derive from the environment (Costanza et al., 1997, De Groot et al., 2002, Farber et al., 2002, CSE et al., 2003, Chee, 2004, MEA, 2005). Undoubtedly, the concept of ecosystem services is not just a semantic decision, but it is integral to any process seeking to clearly illuminate trade-offs between natural resource management and policy (Petrosillo et al., 2010).

Since the concept of ecosystem services has been utilized in environmental planning and management (de Groot, 2006, Fisher et al., 2009), it can be also extended to ecological design and management of human dominated landscapes (Opdam et al., 2006, Nassauer and Opdam, 2008, Jones et al., 2013). The concepts of landscape design refers to all intensively used, managed, conserved, or restored landscapes where people have reshaped the spatial and functional heterogeneity of ecosystems for the benefit of themselves and sometimes nature (Musacchio, 2009).

One example of design and management of landscapes to improve the quality of wastewater before it is discharged to surface or groundwater and re-enters water supplies is the Constructed Treatment Wetlands (CTWs).

To improve water quality, wastewater plants should depend on natural treatment processes and low-carbon systems that rely on vegetative and microbial metabolism with little energy consumption (Cui and Jiang, 2011). The cleansing power of the natural treatments that mimic the humid ecosystems comes from a combination of physical, chemical and biological processes, such as microbial activity, the direct assumption by plants, sedimentation, filtration and adsorption (Brix, 1993). The continued development of this concept has allowed to apply successfully this approach to a wide range of polluted and wastewater sources including domestic sewage, industrial wastewater, landfill leachate, anaerobic digestate, mining waste, animal wastewater, urban storm water and farmyard waste/soiled water (Harrington et al., 2012). In this perspective CTWs treat the wastewater using the same processes that occur in natural wetlands but within a controlled environment (e.g., Knight et al., 2001, Kadlec and Wallace, 2008, Vymazal and Kröpfelová, 2008, Vymazal, 2010).

The need to find a body of water suitable to receive the output streams from the treatment plants has created, and continues to create, highly conflictual situations that are faced, in many regions such as in certain regions of Southern Italy, with almost complete absence of rivers, with problems of salinization of groundwater resources due to its over-exploitation also through the practice of pumping, and finally with the high value of the induced seaside tourism. For this reason, in such rural areas where the urban sprawl is also transforming the landscape altering the natural ecosystems processes and functions, an effective and sustainable water resource management requires planning at landscape scale. In this way the choice to introduce a CTW that emulate natural wetlands can combine the need of the treatment and disposal of wastewater with that of environmental enrichment of the socio-ecological landscape where it is located.

Since natural wetlands deliver a wide range of valuable ecosystem services that contribute to human well-being (e.g., Costanza et al., 1997, MEA, 2005, Byomkesh et al., 2009, Burkhard et al., 2012), the purpose of this paper is to evaluate whether CTWs used for secondary treatment of municipal wastewaters can provide multiple benefits, in addition to the water quality improvement, as well as natural wetlands across the socio-ecological landscapes. In particular, this paper is focused on the assessment of the potential of CTWs in enhancing landscape aesthetic, biodiversity at local and global scales and in supporting recreational and educational opportunities.

2. Materials and methods

2.1. Study area

The study area is represented by a CTW realized in 2008 in the Municipality of Melendugno, province of Lecce, southern Italy (Fig. 1) in the context of the environmental regional restoration policy.

Fig. 1. Location of the CTW under study.

This plant started to operate in August 2009 and it has been designed for the refining of the effluent water from the sewage treatment plant of the three neighboring municipalities (municipality of Calimera, Martignano and Melendugno) and their coastal areas, for a pollution load generated to approximately 41,000 equivalent inhabitants. The technical solution adopted has led to the creation of a system of natural aging with wetlands reconstructed. The plant covers 8.3 ha, and 5.1 ha of them have been occupied by 6 reservoirs working in conditions of the surface flow (FWS systems—free water surface) (Table 1). In particular 5 species of plants have been planted in the CTW: *Phragmites australis*; *Typha latifolia*; *Juncus effuses*; *Lemna* sp. pl.; *Nymphaea alba*. The choice of plants used was made taking into account the purifying effectiveness of the different species, their ecology, the compatibility with the environment and their availability on the territory.

Table 1. Technical specifications of the reservoirs of the CTW.

Reservoirs	Sub-reservoirs	Type	Surface (mq)	Depth (cm)	Volume (m^3)
1	1A	Free water surface	6.055	70–65	4.239
	1B		6.483	65–60	4.538
2	2A		10.441	70–65	7.309
	2B		6.838	65–60	4.787
3	3		5.005	60–20	3.504
4	4		4.282	60–20	2.997
5	5		4.239	60–20	2.967
6	6		7.820	60–20	5.474

According to the report design the hydraulic retention time for the flow rate of 2530 m^3/day is reported to be 14 days, while for the maximum capacity of 4370 m^3/day was approximately 8 days.

2.2. Data collection and methods

The first step of the work has been the identification of the habitats that characterize the CTW. In particular, the habitat map has been realized using the following materials:

- Photos and videos of the constructed wetland taken with a drone in March 2013;
- Color digital orthophotos of the area for the year 2012, set in the reference system WGS84 UTM-Zone 33N.
- CORINE habitat classification (Commission of the European Communities, 1991)

The maps have been elaborated in a vector format for the greater accuracy to represent the geometric properties of the entity mapped than in a raster format (Bernhardsen, 2002) through ArcGIS 10.1 © ESRI. The map of habitats has been validated and updated through inspections and field surveys.

The second step is represented by the characterization of the vegetation carried out to identify the different types of plant communities present in basins and canals, along the banks, on artificial soils and in the garrigue. The sampling method was based on a series of transects 10 m long, chosen randomly, arranged transversely with respect to the border of the basins and able to intercept the habitats of interest. In each transect 1 m^2 plots were placed and all vascular species in each plot were classified, and the coverage of each of them was estimated and recorded according to the values of the ordinal scale of abundance of Braun–Blanquet (Jager and Looman, 1995). Water depth and distance from the bank were recorded for each plot. The determination of the species was carried out directly in the field or, in cases of doubt, in the laboratory with the use of a stereo-microscope. The surveys were conducted in the flowering period from April to July 2013. Subsequently, data were classified through complete linkage agglomerative clustering (Legendre and Legendre, 2012).

As regards to wild fauna species (third step), they are difficult to be sampled and, therefore, any count should be considered as a rough estimate of the real number of species present in the area under study. The methodology used to determine the species of fauna within the system was based on the determination of the morphology and eco-ethology characteristics of different species (mobility, activity, etc.), and the sampling was carried out by:

- listening points and observation points by multiple detectors from fixed locations with the aid of suitable optical instruments;
- observation along the transepts within the study area and walking at constant speed;
- marking on the map the points in which the signs of the presence of individuals were detected (footprint, dens, etc.).

The sampling was conducted over the year 2013 and has included two visits per month for a period of 2 days.

In particular the monitoring of birds has included:

-

spring migration: count in the months of March, April and May.

- autumn migration: count in the months of September, October, and November.

- breeding birds: territory mapping in the months of June, July, and August.

Concerning the amphibians the monitoring included:

- surveys on direct linear paths in the months of March, April, and May.
- search for egg masses and larval forms, in the months of February, March, and April.

Regards mammals the monitoring has been conducted by:

- territory mapping in the months of March, April, May and June.
- night census with light source along transects in the months of March, April, May and June.

While reptiles monitoring has been conducted through the territory mapping in the months of March, April and May.

3. Results

3.1. Map of habitats

Fig. 2 shows the map of habitat present in the CTW under study, based on the CORINE habitat classification system. The basins 1A, 2A, 1B, 2B, 3, 4, 5, 6 have been classified as "Industrial lagoons and ornamental ponds". However, they can be distinguished on the basis of depth and vegetation cover: the basins 1A–2A have a depth from 70 to 65 cm with a little vegetation cover and are, therefore, characterized by large open water areas. The basins 1B–2B have a depth from 65 to 60 cm and are characterized by a greater coverage of rooting aquatic vegetation mainly composed of *Phragmites australis and Typha latifolia*, with the presence of small areas of free water. The basins 3–4–5 have a depth from 60 to 20 cm and are entirely covered by vegetation, while in the basin 6 the water content varies with the seasons and at certain times of the year is completely dry. The channels between the basins ("ditches and small canals") have been also taken into account. They are characterized by floating aquatic vegetation with different species of the genus *Lemna*.

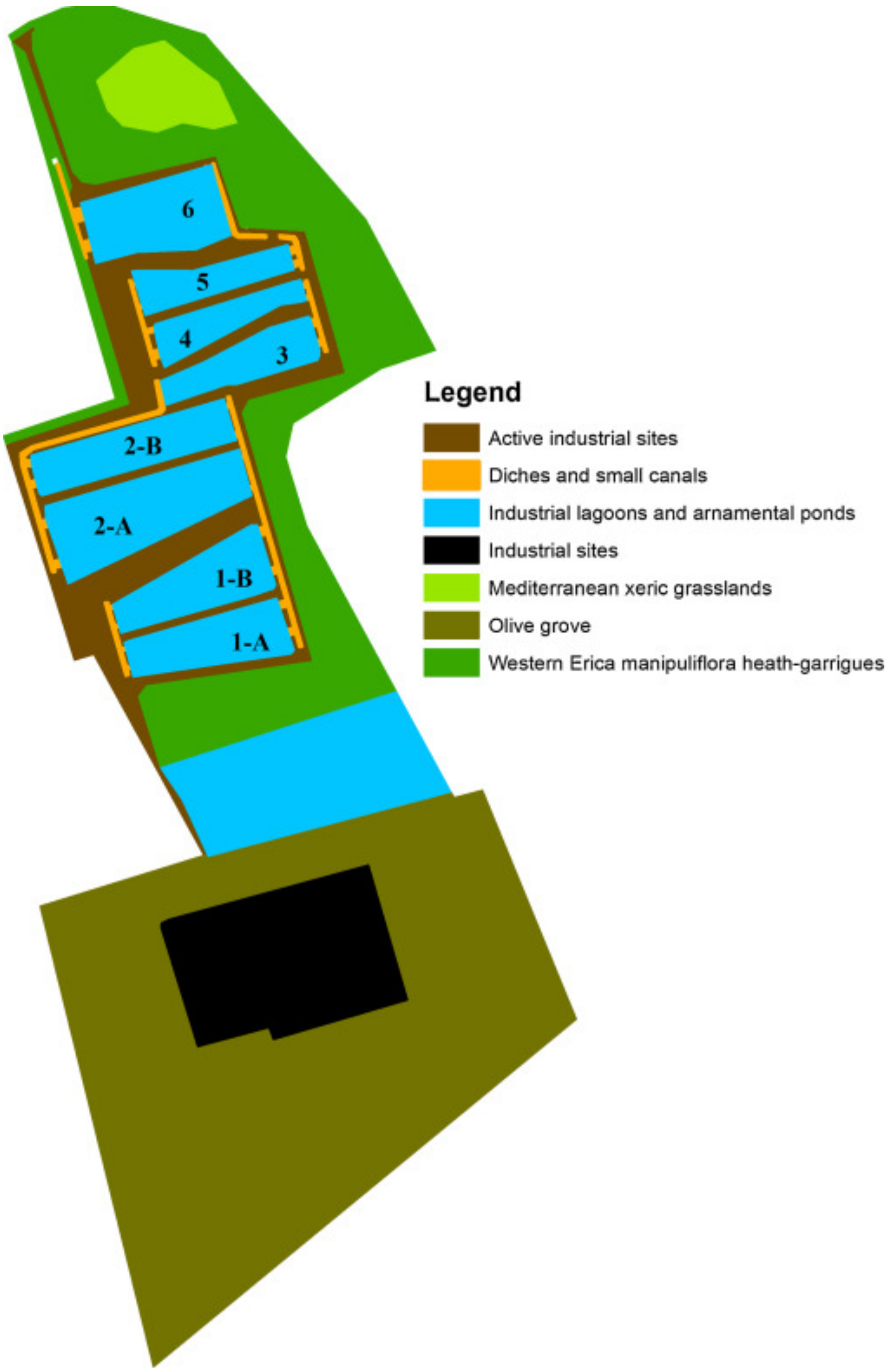

Fig. 2. Map of habitats in the CTW under study.

Along the perimeter of the plant, scrub areas have been also detected: “Western *Erica manipuliflora* heath-garrigues” and a narrow portion of “Mediterranean xeric grasslands”. By looking at the area that has been affected by the implementation of the basins it is possible to see that only a small portion of Western *Erica manipuliflora* heath-garrigues and Mediterranean xeric grasslands have been converted into wetlands (Fig. 3). However, the persistence of this habitat is not compromised because it is guaranteed by the context that depends on the surrounding landscape. Context is important for the biodiversity maintenance because at the patch level a community may depend on the patch quality that may be affected by patch boundary permeability and the neighboring patch types (e.g., Andrén, 1994).

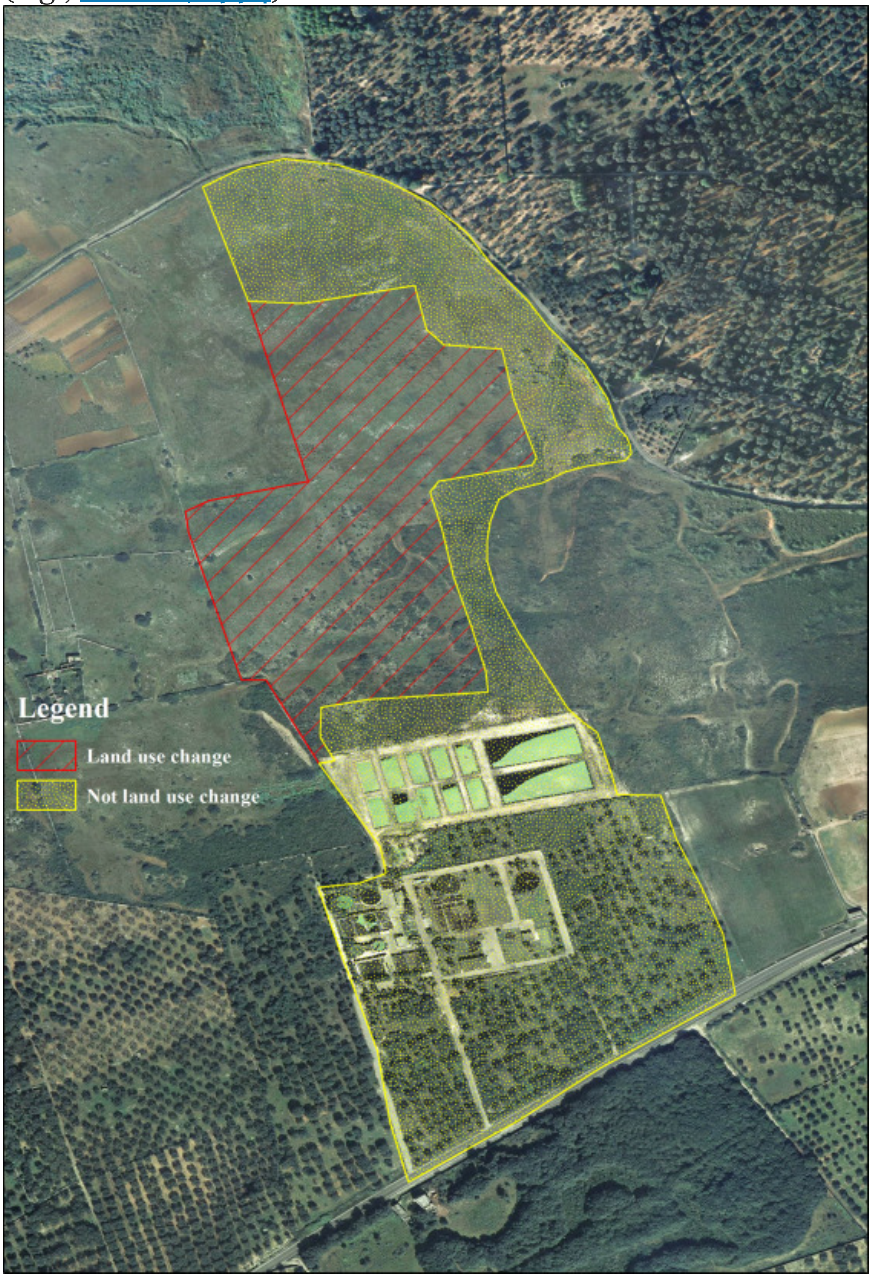

Fig. 3. Orthophoto indicating the area that is changed (conversion of Mediterranean maquis in wetlands) and that is not changed after the construction of the CTW.

3.2. Characterization of the vegetation

During the phase of the construction of the CTW, 5 species of plants were planted: *Phragmites australis; Typha latifolia; Juncus effuses; Lemna* sp. pl.; *Nymphaea* *alba*. In the year 2013 an increase of the number of plants (105 plant species of which 102 volunteers) compared to the phase of start-up of the CTW has been identified. However, the *Nymphaea alba* and *Juncus effuses* are not longer present in the basins. More specifically, 65 plots were needed to conduct the reliefs, which corresponds to a total number of 105 plant species. Consistent with the results of the cluster analysis, plots have been grouped into four major types of vegetation that correspond to one or more types of plant communities as follow:

-Floating aquatic community type

Community with duckweeds, characterized mainly by *Lemna minor, Lemna minuta and Lemna gibba*; it consists of very few species and is found both in deep water (>50 cm) and in shallow waters, where it forms mosaics with the rooted aquatic community.

-Rooted aquatic community type

In this case it is possible to distinguish three types of communities:

- reed thicket, characterized mainly by *Phragmites australis*, whose cover values are always very high; the reed thicket is located in water depths in the range 0–50 cm and is the most common type in the CTW;
- community with cattail, characterized mainly by *Typha latifolia* and *Schoenoplectus lacustris*; it is located in water depths on average higher than those of the reed thicket;
- rooted hydrophytic community, characterized mainly by *Nasturtium officinale*; it is distributed to a water depth between 10 and 50 cm, by the side of the deepest basin;
- -Riparian community type and irregularly flooded meadows

Also in this case it is possible to distinguish three types of communities:

Flooded meadows, characterized mainly by *Cynodon dactylon, Convolvulus arvensis, Portulaca oleracea, Paspalum distichum, Cyperus esculentus* and *Echinochloa crus-galli*; this type is located within the northernmost basin.

Community of low bank, characterized mainly by C*ynodon dactylon, Paspalum distichum* and *Ranunculus sceleratus*; it represents the strip of riparian vegetation closest to the water body of almost all basins and canals;

Community of high bank, characterized mainly by *Cynodon dactylon* and other ruderal species; it is located on the banks of the basins and colonizes widely soils trampled, pads between the basins and the surrounding meadows;

-Xerophile shrub community type

Erica manipuliflora garrigue, characterized mainly by *Erica manipuliflora*, *Cistus* sp. pl., *Rosmarinus officinalis* and *Brachypodium retusum*; this type is not related to the water environment and is the community type originally present in the study area.

3.3. Characterization of fauna

It has been carried out a qualitative and quantitative estimation of species that characterize the CTW, taking into consideration: mammals, reptiles, amphibians and birds.

Fig. 4 represents the number of species detected within the plant. A greater abundance of bird species (73 species) than mammals (6 species), reptiles (3 species) and amphibians (4 species) has been highlighted (Table 2). However, this result is not surprising, since in the Apulia region the vertebrate species consist mainly of bird species.

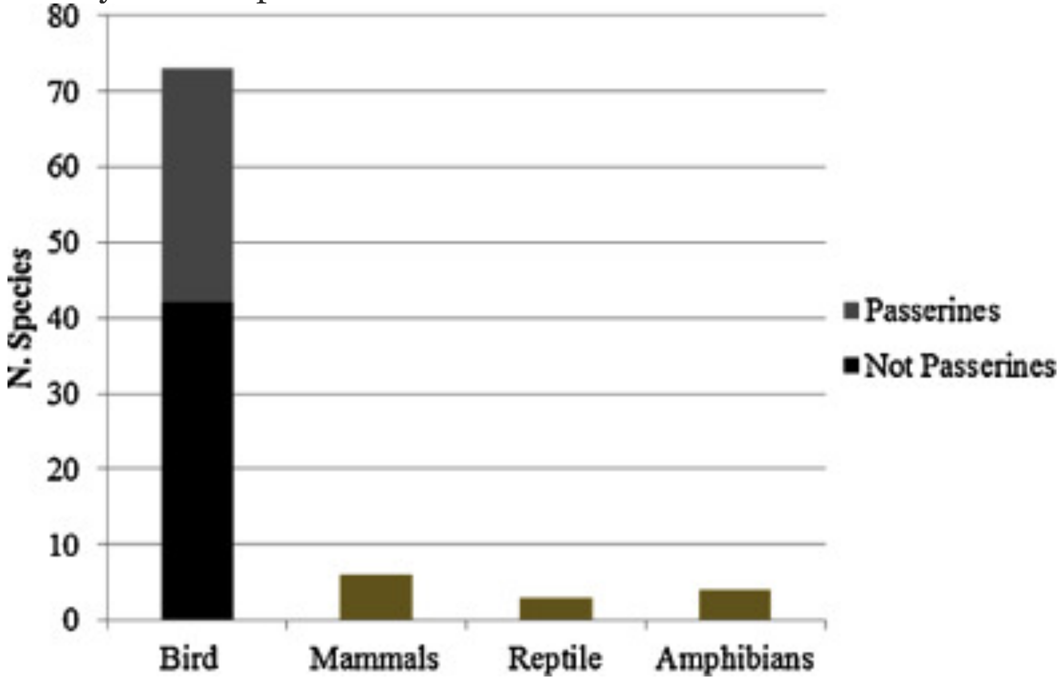

Fig. 4. Number of birds' (passerines and not passerines), mammals', reptiles' and amphibians' species sampled in the CTW.

Table 2. Checklist of wildlife species potentially present in the CTW of Melendugno.

Birds	Amphibians	Reptiles	Mammals
Tachybaptus ruficollis; Ixobrychus minutus; Nycticorax nycticorax; Ardeola ralloides; Egretta garzetta; Ardea alba; Ardea cinerea; Ardea purpurea; Tadorna tadorna; Anas penelope; Anas crecca; Anas platyrhynchos; Anas querquedula; Anas clypeata; Aythya nyroca; Circus aeruginosus; Circus cyaneus; Rallus aquaticus; Gallinula chloropus; Fulica atra; Himantopus himantopus; Charadrius dubius; Calidris minuta; Calidris ferruginea; Calidris alpina; Philomachus pugnax; Lymnocryptes minimus; Gallinago gallinago; Tringa totanus; Tringa nebularia; Tringa ochropus;	*Hyla intermedia*; *Bufo bufo*; *Bufo viridis*; *Pelophylax esculentus*	*Podarcis siculus*; *Hierophis viridiflavus*; *Natrix natrix*	*Erinaceus europaeus*; *Microtus Savii*; *Rattus norvegicus*; *Rattus rattus*; *Apodemus*

Birds	Amphibians	Reptiles	Mammals
Tringa glareola; Actitis hypoleucos; Streptopelia decaocto; Streptopelia turtur; Tyto alba; Athene noctua; Asio otus; Apus apus; Alcedo atthis; Upupa epops; Galerida cristata; Riparia riparia; Hirundo rustica; Delichon urbica; Anthus trivialis; Anthus pratensis; Motacilla flava; Motacilla cinerea; Motacilla alba; Erithacus rubecula; Phoenicurus ochruros; Phoenicurus phoenicurus; Saxicola torquata; Cettia cetti; Cisticola juncidis; Acrocephalus melanopogon; Acrocephalus schoenobaenus; Acrocephalus scirpaceus; Acrocephalus arundinaceus; Philloscopus collybita; Pica pica; Sturnus vulgaris; Passer domesticus; Passer montanus; Fringilla coelebs; Serinus serinus; Carduelis chloris; Carduelis carduelis; Carduelis spinus; Cardueli cannabina; Emberiza schoeniclus; Miliaria calandra.			*sylvaticus*; *Vulpes vulpes*

As regards birds, they have been subdivided in passerines (31 species) and not passerines (42 species). The evaluation of this distinction is of considerable importance because the threatened species listed in Annex I of the Directive 2009/147/EC on the conservation of wild birds are predominantly non-passerines. Their presence is mainly concentrated in the Spring season, when the species cross the continent from the South to the North. Furthermore, it is found that during the Spring season the CTW serves as a stepping stone for over 61 species of birds, while in Autumn, the migration goes from the North to the South and the species that will remain for a short period in the plant are about 58 species. The greatest number of migratory species, especially during the Spring season, consists of 39 not passerines species that represent about the totally amount of not passerines sampled in the CTW (Fig. 5). It is also possible to highlight that some species of birds reside in the area of study for the entire summer, probably because this site offers good trophic opportunities. Moreover it has been detected that 28 species are breeding birds of which 13 are not passerines and 15 are passerines birds. Regard the wintering birds (37 species), the largest number is constituted by not passerines with 22 species, while for passerines there are 15 species.

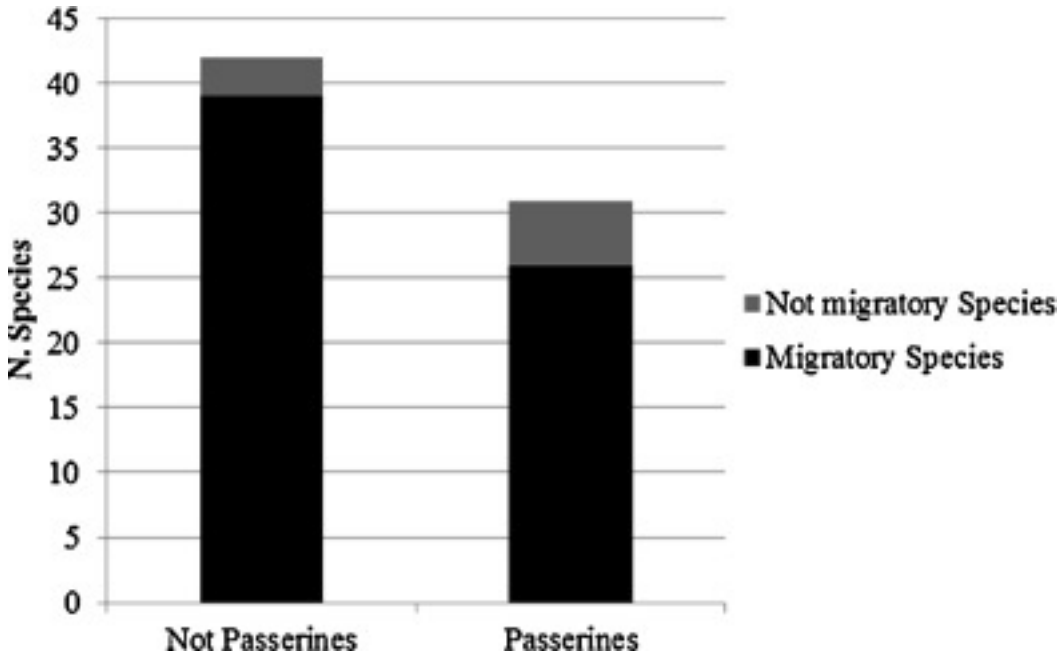

Fig. 5. Number of passerines and not passerines bird species in the CWT, distinguished in not migratory and migratory species.

Since many species of birds sampled are typical of aquatic habitats, it is possible to assert that their presence in this area is linked to the presence of CTW. The species of birds mentioned in Annex I of Directive 2009/147/EC on the conservation of wild birds and their extinction risk category are listed in Table 3. They represent 18% of the total species of birds identified during the monitoring activities. This result highlights the role of the CTW under study in sustaining vulnerable and endangered wild birds.

Table 3. Extinction risk category according to the IUCN red list and Italian red list of species of birds detected in the study area and mentioned in Annex I of Directive 2009/147/EC.

Species IUCN	Red list status	Italian red list status
Ardea alba	Least concern	Least concern
Ardea purpurea	Least concern	Least concern
Circus cyaneus	Least concern	Least concern
Himantopus himantopus	Least concern	Least concern
Philomachus pugnax	Least concern	Least concern
Circus aeruginosus	Least concern	Vulnerable
Egretta garzetta	Least concern	Least concern
Alcedo atthis	Least concern	Least concern
Aythya nyroca	Near threatened	Endangered
Nycticorax nycticorax	Least concern	Vulnerable

Species IUCN	Red list status	Italian red list status
Tringa glareola	Least concern	Least concern
Ardeola ralloides	Least concern	Least concern
Ixobrychus minutus	Least concern	Vulnerable

Source: IUCN, 2014, Rondinini et al., 2013.

4. Discussion and conclusions

At a time when the land use related to human activity is altering the natural environment that is strongly confined in individual protected areas, it becomes essential to develop projects that are able to integrate human needs with the persistence of biodiversity and the provision of ecosystem services. This is also important from the economic viewpoint, because it would allow optimizing the already scarce economic resources in multifunctional projects in the context of socio-ecological systems, where the ecological and socio-economic aspects should not be faced separately.

The environmental sustainability of landscapes is often related to their multifunctionality, but too often anthropogenic landscapes are manipulated to serve a single function, such as croplands for the production of food, or parks for recreation (Lovell and Johnston, 2009). On the other hand, a multifunctional landscape offers opportunities to provide multiple environmental, social, and economic functions and benefits (Wiggering et al., 2003, de Groot, 2006), in addition to considering the interests of landowners and land users (Otte et al., 2007). Frequently, several functions can be found together, but their simultaneity and interactivity, rather than mere collocation, is the hallmark of multifunctionality, and this criterion has found particular application within Europe's multilayered cultural landscapes (Antrop, 2004, Ling et al., 2007).

Although the success of CTWs is frequently assessed based on the performance of pollution reduction, many constructed, restored or created wetlands are dual- or multi-purpose wetlands providing several ecosystem/landscape services (Hickman, 1994, Benyamine et al., 2004, Thiere et al., 2009, Cui and Jiang, 2011, Vymazal, 2011, Everard et al., 2012).

As highlighted in Fig. 6 the socio-ecological landscape where it has been realized the CTW has been deeply transformed over the last sixty years because of urban sprawl in coastal areas due mainly to tourism.

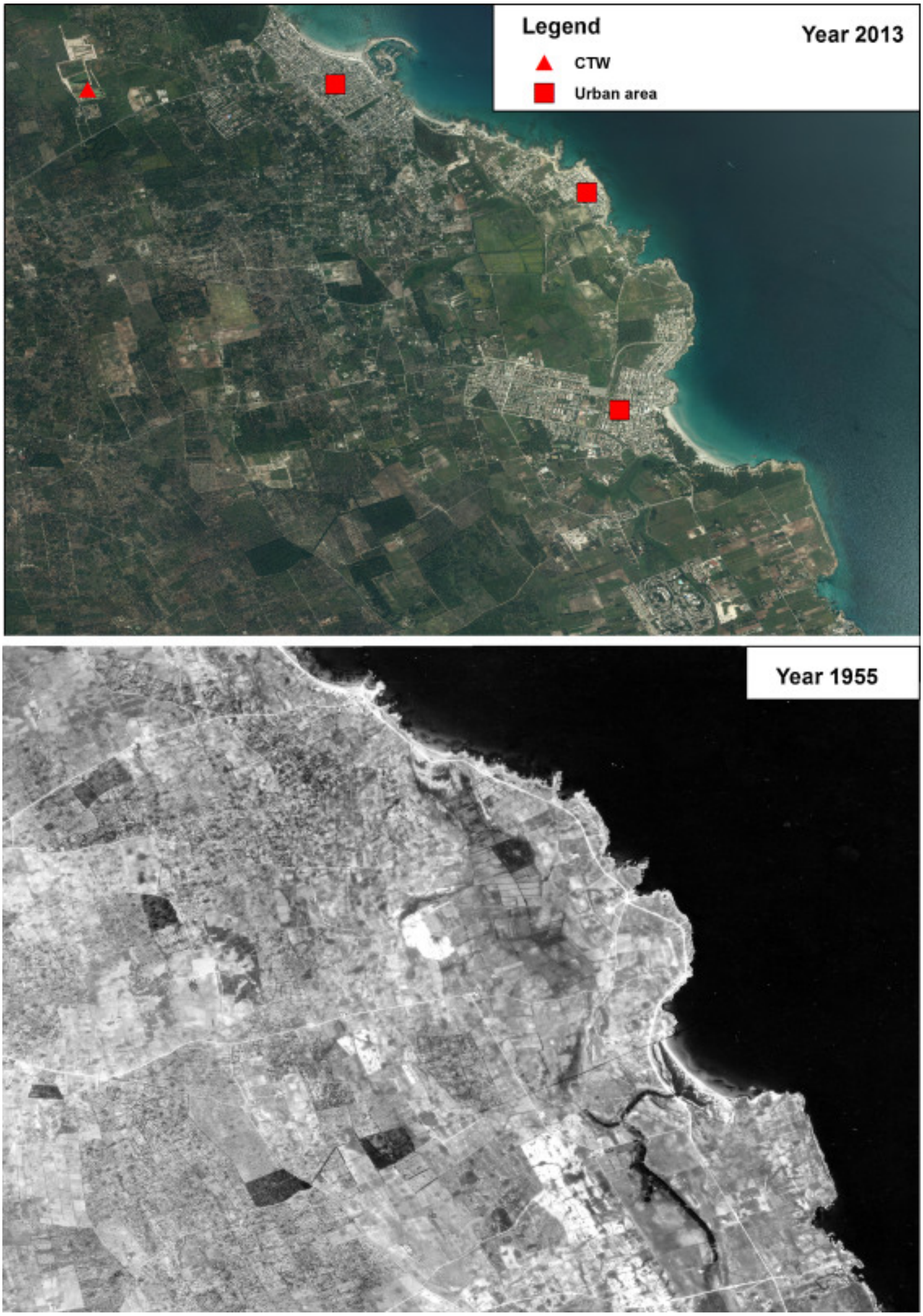

Fig. 6. Aerial photos of 1954 and 2013 of the socio-ecological landscape where the CTW is located.

This driving force has reduced aesthetics and biodiversity and has emphasized the need for a careful water resource protection and management to prevent pollution of sea, avoid compromising bathing and the use of such areas for recreation. In fact, the sewage treatment plant would have to release wastewater in drainage trenches, that are essential for wastewater treatment plants located in areas that have no a significant surface drainage network and where, being highly tourist, it is not recommended the release of wastewater into the sea. This last issue makes it necessary to inhibit bathing an extensive coastline, with obvious negative repercussions on the tourist vocation of the territory. However, the drainage trenches realized, after a short time, demonstrated the inadequacy to support load peaks recorded in the summer period, requiring frequent maintenance interventions to restore the permeability and thus the efficiency of draining. Therefore, the design and realization of the CTW, as an alternative engineered ecosystem for the disposal of wastewater treated with low technological complexity and remarkable simplicity management, has combined the wetland function related to hydrology and water quality with the enhancement of the aesthetics and biodiversity by introducing a pleasant natural element in the landscape.

In this perspective, and according to the socio-ecological landscape context in which the CTW under study is placed, it can be classified as a multi-functional (purpose) intervention, because it may provide a range of services well beyond the primary aim of water purification. As demonstrated by this research, the realization of marsh basins and the new vegetation developed within the plant have provided ancillary ecological benefits such as wildlife habitat provision and biodiversity enhancement. The 18% of the total number of birds species detected in the study area are included in Annex I of Directive 2009/147/EC on the conservation of wild birds, highlighting the ecological value of the site. Furthermore, results have shown that the CTW is strategically located in the dynamic of migration flows of birds and therefore is a site potentially suitable for the permanent presence of different wildlife species. For this reason, CTW carries out an important role in terms of contributing to biodiversity both at the local level, supporting local birdlife, and at the global scale, providing vital nesting and migratory flyway areas.

As such, the results of this research show that these plants, if properly localized, designed and managed over time, may favor the presence of species of high conservation value (Habitat Directive 92/43/CEE and Directive 2009/147/EC) and, thus, strengthen the European Natura 2000 ecological network with benefits at multiple scales. For this reason, these sites should be managed not only as effective infrastructures for the on-site management of wastewaters and for water purification, but also as engineered ecosystems that can mimic "natural areas" in providing wildlife habitats, sink of biodiversity and stepping stones in ecological networks.

In this perspective, these CTWs are also suitable areas for the development of projects for the fruition and environmental communication and education. Many people every year use the CTW for recreation, birdwatching, or scientific study (Fig. 7). In particular, this kind of use has been encouraged designing learning paths and activities to provide educational opportunities and recreation for students, teachers and all citizens interested in learning about the features and the peculiarities of the constructed wetlands and their importance in sustaining wildlife habitats and biodiversity. Moreover, by introducing a valuable natural element, free water surface CTWs integrated with recreational areas can carry a high landscape value.

Fig. 7. Examples of environmental education activities developed in the CTW of Melendugno.

Source: Romagno, 2013.

Therefore, even if CTWs are essentially wastewater treatment systems and are designed and operate as such, they can also directly and indirectly support human well-being by providing several valuable wetland ecosystem services (Mitsch and Gosselink, 2007) such as flood abatement, food, a clean water supply, habitats, aesthetic beauty, educational and recreational benefits (Fig. 8).

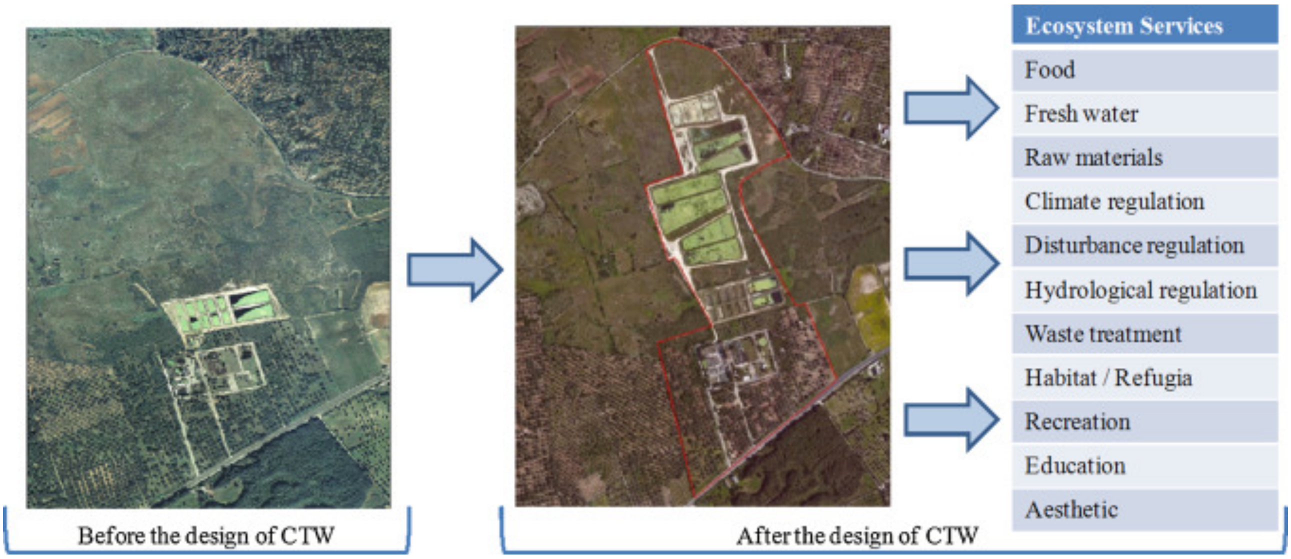

Fig. 8. Potential ecosystem services provided by the designed multifunctional CTW.

A proper design of a CTW should require a multidisciplinary approach: the design skills of engineering must be integrated with sustainable and environmental sciences related to landscape and urban planning. Moreover, the land planner should also think about how these systems may evolve over time even if the water treatment plant was no longer used for this purpose. This should ensure that the CTW could continue to support biodiversity and other services even in the absence of human activity that characterizes it today.

Acknowledgements

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