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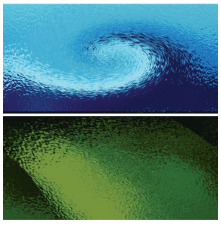

RESEARCH ARTICLE

The recent history of the Tarquinia Salterns offers the opportunity to investigate parallel changes at the habitat and biodiversity levels

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Abstract

1 - Salterns, although artificial habitats, can be considered as coastal wetlands from an ecological, functional and conservational point of view, according to the Ramsar Convention Bureau (1990). Salterns need to be actively managed to survive and, being at the interface between land and sea, experience the impacts of both environments. For these reasons their extension and quality are severely reducing along the Mediterranean coasts.

2 - The Tarquinia Salterns, on the Tyrrhenian coasts of central Italy, suffered a progressive habitat degradation starting with a serious flood in 1987 and getting worse from 1997, when the salt production ceased, to 2003, when a three years long project for their environmental rehabilitation was implemented (2003 – 2006).

3 - To recover the salterns habitat, the water flow, previously slow and laminar, was re-established. Also, the depth of the water column was reinstated through the removal of the excess of organic matter and mud deposited in the pans.

4 - The recent history of the Tarquinia Salterns provides the opportunity to carry on multi-disciplinary studies on the response of biotic and abiotic habitat components under the temporal oscillations of the environmental quality. A first result is that the recovery succeeded in restoring the abiotic conditions characterizing the salterns before their abandon and degradation.

5 - The biodiversity at the genetic level, investigated on the killifish *Aphanius fasciatus*, at the species level, as shown by the abundance of wintering birds; and at the community level, as assessed by the diversity of benthic community, was seriously affected by the environmental degradation. After the ecological recovery, the species and community reverted quickly to the previous diversity levels, while the genetic variation of the target killifish remained at the low levels reached in 2005. This confirms that the different aspects of biodiversity react similarly to the disturbance but display different times of recovery.

Keywords: Tarquinia Salterns, Tyrrhenian coasts, habitat degradation, ecological recovery, salinity, oxygen concentration, temporal changes, biodiversity

Introduction

The wetland coastal areas have always played an important role from both an ecological and economic point of view along the Mediterranean. The intrinsic nature of the transitional water biotopes, undergoing sharp daily and seasonal variations in physical-chemical parameters, confers them peculiarities such as a high productivity and a paramount relevance in coasts protection and in water quality improvement and makes them a unique habitat and food source for many birds species. On the other hand, the same nature of these habitats makes them prone to be threatened by natural and anthropogenic impacts, haltering both their biological components and ecosystem functionality (Dudgeon *et al.*, 2006).

A particular kind of wetlands is represented by salterns (or solar pans, or salinas), in spite their human origin as real industrial plants. Due to the historical salt importance in the political and economic stability of Mediterranean society, the salterns have frequently played a critical role in the economic and cultural development of countries, so that they have always been recognized as a State monopoly.

The Ramsar Convention Bureau (1990) recognized salterns as wetland areas that, although artificial, are not functionally dissimilar from natural wetlands. This means that they share the main ecological features but can be distinguished from other transitional coastal habitats since they are extreme hyperaline environments. Indeed, the design of the salt ponds links a number of interconnected pans of different size and depth so that the water circulation creates a gradient of the physical and chemical parameters, being the salinity the most relevant (Britton and Johnson, 1987; Javor, 1989). This implies that there is a spatial subdivision of the saltern area in micro-habitats characterized by (sometimes dramatically) different environmental conditions (Evangelopoulos *et al.*, 2008). Such heterogeneity entails that the salterns are inhabited by complex biological communities, which include highly specialized as well as marine species, distributed according to the salt concentration gradient (Halse *et al.*, 2002).

The salterns share with the other wetlands the threats due to their landscape position and productivity. Being at the interface between land and sea, they are “receivers” of land-use effluents and subject to the problems due to coastal erosion and water flow modifications (Dudgeon *et al.*, 2006). Unlikely other wetlands, salterns need to be actively managed to survive. However, in the last decades they underwent a progressive loss of economical attractiveness, especially in the Mediterranean area, due to the competition with less expensive salt production systems, as for example salt mining. As a result, many small to medium saltpans were dismissed and about 60% of the salt pond extension existing in the Mediterranean basin went lost (Lopez *et al.*, 2010). This reflects exactly the general trend endured by all wetlands during the last century: about 50% went gone due to agricultural activities, urban expansion and touristic or industrial impacts (European Commission 2007).

A brief story of the Tarquinia salterns

The story of the Tarquinia Salterns is in line with that of many other Mediterranean saltpans progressively closed, abandoned or transformed in acquaculture plants in the last 50 years.

This artificial hypersaline wetland is located on the coasts of northern Latium about 100 Km north of Rome (Fig. 1). The sea salt in the area was exploited since the times of Etruscans, but the salterns in their present form were built in 19th century thanks to Pope Pio VI. The salt production continued along the 20th century, providing wellbeing to the resident population. In 1987 a serious flood brought an enormous quantity of mud in the salt ponds,

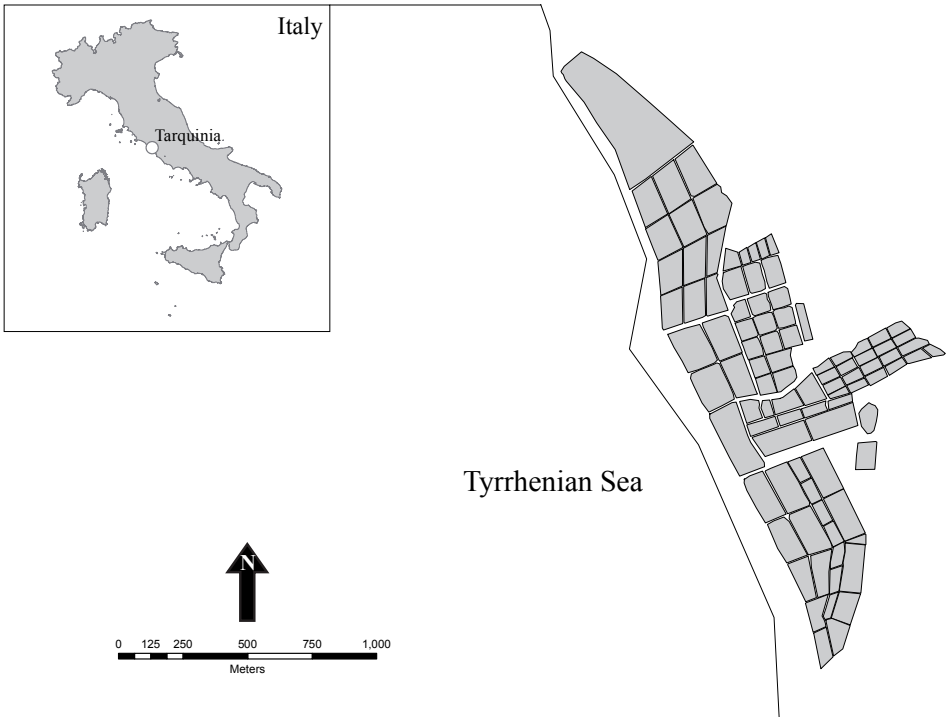

Figure 1. Location and map of the Tarquinia Salterns.

making inactive about 16 ha of the salinas. Since that moment, due also to the lack of competitiveness with respect to the large scale salt production of other Mediterranean regions, the salt production progressively slowed down and failed completely in 1997. The salterns cover an area of 193 ha, with the 70% occupied from nearly 100 shallow salt ponds where salinity ranges from sea values (~35 ‰) to salt deposition values (250 ‰), according to pans depth and surface. This gradient of increasing salinity and the marine water flow, circulating from the northern inflow channel towards the southern crystallization ponds, influences both the abiotic parameters and the biological community. In particular, the communities of plankton and benthos change along the gradient in species richness and composition due to species osmoregulation ability (Nascetti *et al.*, 1998). For example, at the critical salinity value of 60‰, there is a drastic drop in the number of benthic species, with only few mollusca as *Cerastoderma glaucum* and *Abra ovata* surviving together with chyronomid larvae. Since 1980 the Italian Ministry for Agriculture instituted the Natural Reserve "Saline di Tarquinia" (DM 25/01/1980) to protect the flora and fauna of the area, with particular regard to the waterfowl. Moreover, the area was identified as a S.C.I and S.P.A. according to both the "Habitat" Directive 92/43/EEC and the directive 79/409/EEC on the Conservation of Wild Birds.

The reduction in maintenance activities after their abandonment brought the salt pans infrastructures into ruin: the dried embankments of ponds made in wood and stones deteriorated, the water transportation channels became blocked, while the inlet and carry water pumps broken. This resulted into a reduction of water flow and an increasing of organic and inorganic matter sedimentation. This alteration of the hydrological and trophic status of the salterns made the

habitat characterized by stagnant water and high sedimentation rate, resulting in hypoxic sediment layers accumulating nitrogen and phosphorous compounds and in several episodes of eutrophication (Fig. 2).

Figure 2. An algal bloom in the salt pans of the Tarquinia Salterns in 2002, before the ecological recovery of the site.

The ecological recovery of the Tarquinia Salterns

It is widely acknowledged that wetland coastal areas host high levels of biodiversity and therefore deserve strong conservation efforts, especially since they are heavily under the threat of anthropogenic impact (Dudgeon *et al.*, 2006). On these considerations, a Life Project entitled "Environmental rehabilitation of the Natural Reserve of Tarquinia Salt-works" was carried out in the years 2003-2006 thanks to the funding of the European Commission. The aim was to preserve the priority habitat "coastal lagoon" as identified by the "Habitat" Directive 92/43/CEE.

The conservation measures planned within the Life Project included the recovery of overwhelmed ponds and the rehabilitation of salt-work hydraulic reticule. To this aim, the focal action of the project was to take away the sediments from the tanks, hence removing the organic matter and mud deposited. A vegetation clearing of ponds edge also contributed to face the problem of the organic sedimentation. The recovery of water circulation was warranted by the repair of the decaying structures deputed to the water movement such as the water pumps and the inlet channel for the sea water, which was blocked by sediment accumulation. In particular, the water pumps assuring the water inlet to the more confined (southern) part of the salt works were renewed so that the local micro-habitat was recovered to the use of waterfowl. Always in the aim of increasing bird diversity, a freshwater lake was set up in a dry area to allow migrant waterfowl resting or nesting (Fig. 3).

Figure 3. The freshwater lake built within the ecological recovery of the Tarquinia Salterns to allow waterfowl feeding and nesting.

Long term studies on the Tarquinia

The implementation of the Life Project required that a monitoring of the habitat quality was carried out, to verify the efficaciousness of the actions undertaken. To this end, a number of indicators of the habitat conditions were analysed through time, in order to provide a picture of the ecological status of the Tarquinia Salterns before (1997-2003), during (2003-2006) and after (from 2007 ahead) the ecological restoration. Therefore, during the last 14 years (1997-

2010) were scored the physical and chemical water values, the genetic variation of a target organism (the killifish *Aphanius fasciatus*), the structure of the benthic community and, although discontinuously, the presence of migrant wild birds. Also, the knowledge of the ecosystem functioning was deepened (Bellisario *et al.*, 2010a) and the basic studies addressing the possible exploitation of the algae of the genus *Dunaliella* were carried out (Pasqualetti *et al.*, 2010; Tempesta *et al.*, 2010).

The results of these studies all agree in suggesting that the restoration measures undertaken were effective in recovering both the abiotic and biotic habitat components. For example, the oxygen concentration reached its minimum in 2003, just before the start up of the project, with a value of 2.2 ppm. It started to slowly recover during the restoration works, showing minimum values of 3.2 ppm till 2006 and then rising to 6.3 ppm in 2007-2008, a value close to that recorded in 1997 immediately after the plant abandon (5.1 ppm). At the same time, the biodiversity showed the same trend at all levels: genetic, of species and of community. In the years 1998-2003 the gene pool of the local population of the killifish *A. fasciatus* was eroded and a high percentage of alleles went lost (Cimmaruta *et al.*, 2010). The loss of gene diversity slowed down and then stopped in the years following the conservation measures applied (Angeletti *et al.*, 2010). At the species level, the abundance of waterbirds reached its maximum in the years immediately following the restoration (2006) with more than 2.700 wintering birds, including the all time peak of 692 flamingos (Lanzuisi, 2009). At the benthic community level, a reduction of the diversity was observed in 1997-2001 (from 21 to 16 taxa), a change due to the decrease of typical marine species and to the increase of opportunistic and widespread species as the polychaetes *Capitella capitata* and *Spio decoratus* and the chyronomid larvae (Nascetti *et al.*, 1998; Blasi, 2006). Since 2006 a recovery of the diversity in benthic structure was observed (from 16 to 25 taxa), showing more marine and less opportunistic species (Bramucci, 2009; Bellisario *et al.*, 2010b). For example, among the new taxa collected there were the mollusca *Nassarius costulatus* and *Haminoea* sp., the polychaetes *Ophyodromus pallidus* and *Armandia* sp. Also, *Mytilaster* sp. was found again, for the first time after 1997. It is worth noting that the recover of the benthic community occurred despite a serious flood due to heavy rains, that in 2004 caused the outflow of a belt canal of the saltern. The whole area remained submerged under a freshwater bed for some days causing the benthic assemblages undergo a considerably simplification and a shift toward benthic communities typical of nearby freshwater ponds (Blasi, 2006).

Conclusions

The recent history of the Tarquinia Salterns is characterized by the progressive disposal of the salt production, ended in 1997. The progressive alteration of the habitat due to the lack of maintenance was reverted when a restoration project was implemented between 2003 and 2006. The re-establishment of the water flow and pans depth brought the main physical-chemical parameters back to the previous values and prevented further eutrophication.

The temporal oscillation of the environmental quality allowed studying how the biodiversity responded to such changes. The results obtained by complementary approaches investigating the genetic, species and community levels, all indicated that this coastal habitat needs an active management to be maintained. In its absence, the whole system quickly loose biodiversity in terms of genetic variation of resident populations (target: killifish), of species abundance (target: waterbirds) and of community

complexity (target: benthic community). It is worth noting that the biodiversity at the community level has been quickly recovered by the recolonization of the less opportunistic species, while the genetic diversity restoration depends from long period evolutionary forces, such as gene flow from other populations (or mutation on even longer times). Accordingly, a recovery in the abundance of wintering waterbirds and of benthic diversity was recorded already from 2006-2007, while in the same years the genetic variability was no more eroded but did not recuperate.

The data collected on the Tarquinia Salterns between 1997 and 2010 confirmed that, according to Ramsar Convention Bureau (2005), the biodiversity is one of the main criteria to be used in wetland protection.

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