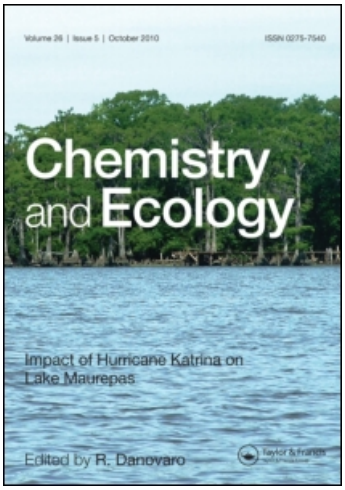

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Sicilian transitional waters: current status and future development

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Sicilian transitional waters: current status and future development

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To appraise the current knowledge of Sicilian transitional waters (TWs), a review was undertaken of the information available on these ecosystems. In detail, a synthesis of the current status is reported, highlighting for each area the ecological features and status, historical data, conservation regime, environmental emergencies and anthropic pressures to which they are subject. The Sicilian TWs reviewed include coastal ponds and lakes, mires and areas with active and nonactive saltworks. Almost all of these ecosystems are affected by several protection regimes because of their high naturalistic value, although current knowledge is limited and fragmented. A few areas have received more attention from the scientific community, whereas others are consistently less studied. The overall picture is one of high heterogeneity in terms of origin, typology, surface, animal and vegetal communities, marine and freshwater exchanges, anthropic pressure and intended use.

Keywords: transitional waters; ecological features; anthropic pressure; ecological status; intended use; Sicily

1. Introduction

Transitional waters, hereafter TWs, are ecotones between terrestrial, freshwater and marine biotopes with a very low inertia to the external and internal forces to which they are exposed [1]. The importance of TWs is widely acknowledged [2–4]. In past decades, their conservation has been recognised as a priority at national and international levels in several acts (e.g. Federal Water Pollution Control Act, USA, 1972), conventions (e.g. Ramsar Convention, 1977), directives (e.g. European Water Framework Directive (WFD), 2000/60/EC) and initiatives (e.g. Mediterranean Wetland Initiative, 1991; Land-Ocean Interactions in the Coastal Zone (LOICZ), 1993).

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TWs represent important, fragile ecosystems in the coastal landscape, providing key ecosystem services such as water quality improvement through the reduction of pollution loads transported by rivers, supply of habitat and food for migratory and resident animals, support to fishery resources and recreational areas for human populations [5]. However, the ability of TWs to provide multiple services and goods relies strongly on the maintenance and conservation of the coastal environment and related functions through sustainable management actions. Nevertheless, knowledge of chemico-physical and ecological features of TWs remains incomplete for many areas. For example, the spatial and temporal scaling of processes, the functional coupling of pelagic and benthic compartments and the dynamics of communities still need to be understood well. In this context, the promotion of an agreed, common approach to studying biogeochemical and ecological processes in TWs is necessary, in order to provide support to management and policy applications.

There are several TW basins along Sicilian coasts (Figure 1), few of them well known. They are concentrated in the north-eastern, south-eastern and western parts of Sicily. In the district of Messina, in the north-eastern part of Sicily, we find the coastal ponds of Lingua on the Island of Salina (Aeolian Islands) and of Oliveri-Tindari, and the coastal lakes of Capo Peloro. Moving southwards, in the district of Catania are brackish mires known as Salatelle di Catania, situated close to the Simeto River mouth. In the Siracusa district, we find the mires of Augusta, Priolo and Siracusa, all of which functioned as saltworks in the past, and the mires of Vendicari. Moving further south there are several basins (the mires of south-eastern Sicily) in the districts of Siracusa and Ragusa. Finally, on the western coast of Sicily, in the district of Trapani, there are the swamps of Capo Feto and Margi, the lagoon-like coastal basin Stagnone di Marsala and the saltworks of Trapani and Paceco. All these areas exhibit high heterogeneity in terms of ecological features, particularly in their origin, depth, size, marine and freshwater exchange, anthropic impact and

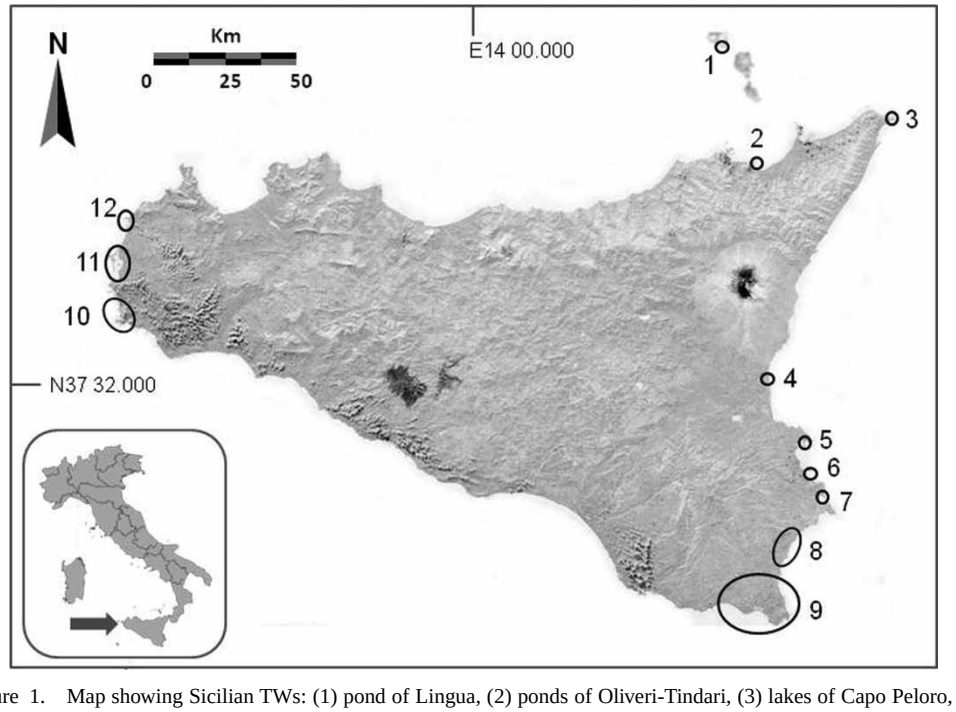

Figure 1. Map showing Sicilian TWs: (1) pond of Lingua, (2) ponds of Oliveri-Tindari, (3) lakes of Capo Peloro, (4) Salatelle di Catania, (5) mires of Augusta, (6) mires of Priolo, (7) mires of Siracusa, (8) mires of Vendicari, (9) mires of south-eastern Sicily, (10) swamps of Capo Feto and Margi (11) Stagnone di Marsala, and (12) saltworks of Trapani and Paceco.

human use. These factors strongly affect the chemico-physical characteristics of the water column and sediments, as well as the associated flora and fauna.

The aim of this article is to summarise knowledge of Sicilian TWs, providing an overview of typology classification, current status (including historical information, ecological features and status), anthropic action and conservation regimes.

2. Typology

As ecotones between freshwater, marine and terrestrial ecosystems, there has always been a need to categorise TWs into operational types from both the scientific and applied points of view. Their origin as ecotones determines an internal heterogeneity, which can be represented by salinity and nutrient boundaries or energy variation thresholds [6], as well as heterogeneity among ecosystems, which can be characterised by very different terrestrial–freshwater, freshwater–marine interfaces.

The first attempts to classify Mediterranean TWs into ecosystem types from an ecological point of view focused on the variation in structural features among ecosystems, using salinity range as the discriminating factor (the Venice System [7]), as well as on structural variability within ecosystems (the confinement concept [8]). More recently, the 2000/60/EC WFD emphasised the need to develop a more effective typological scheme for aquatic ecosystems, including TWs [9], which directly accounts for the significant sources of variability in the biological components of ecosystems, the so-called biological quality elements. In this context, typology is the first milestone in the process of achieving conservation, management and recovery of ecosystem health. Therefore, an accurate definition of typology will maximise the effectiveness of ecosystem monitoring and reinforce conservation strategies.

According to the national directive (Italian law 152/2006) that acknowledges the WFD, TWs are defined as 'surface water bodies in the vicinity of river mouths which are partially saline in character, as a result of their proximity to coastal waters, but which are substantially influenced by freshwater flows'. In particular, five typologies of TWs are reported: delta, estuaries, lagoons, brackish lakes and coastal ponds. However, this classification remains somewhat oversimplified because it does not include a number of widespread coastal basins that share common environmental features with TWs, although they are less, or not at all, affected by freshwater input. For example, only a few Sicilian transitional areas fall within the WFD typologies: Capo Peloro basins can be classified as brackish lakes, while Oliveri-Tindari and Lingua basins can be classified as coastal ponds. Other Sicilian coastal basins that occupy the transitional area between continental and marine domains can be listed under typologies not included in the WFD, such as mires (Salatelle di Catania, Augusta, Priolo, Siracusa, Vendicari and south-eastern Sicilian basins), swamps (Capo Feto and Margi), lagoon-like coastal basins (Stagnone di Marsala) and saltworks (Trapani and Paceco) (Table 1). This classification is based on the following definitions: (1) brackish lakes are well delimited, wide and fairly deep coastal basins that can be affected by different kinds of seawater inflows, through permanent or temporary channels; (2) coastal ponds are shallow coastal basins, seasonally variable in surface and separated from the sea by littoral bars, which can communicate with the sea through mouths and narrow channels; (3) mires are very shallow coastal ponds, characterised mainly by temporal astaticism and instability, often drying up completely during the hot season; (4) swamps are coastal dips featuring temporary or permanent inundation by meteoric, freshwater or marine water; (5) lagoon-like coastal basins are marine shallow areas, partially delimitated by barriers but tightly connected to the sea; and (6) saltworks are mires, swamps or ponds considerably altered by human activities and represent a unique artificial ecosystem made up of external vats, lagoon-like environments communicating with the adjacent open-sea, and a series of smaller and shallower vats subject to increasing confinement.

Table 1. List of Sicilian TWs with indications of typology, geographical references and, when available, geomorphological and chemico–physical variables.

Area	Typology	Basin	Longitude	Latitude	Surface (ha)	outlet	Max. depth (m)	Mean depth (m)	Min. S (PSU)	Max. S (PSU)	Mean S (PSU)	Min. T (°C)	Max. T (°C)	Mean T (°C)	Min. DO (%)	Max. DO (%)	Mean DO (%)
Lingua	Coastal pond	Lingua	14°52′10″ E	38°32′16″ N	3	0	–	3.0	–	–	–	–	–	–	–	–	–
Oliveri-Tindari	Coastal ponds	Verde	15°02′54″ E	38°08′39″ N	2	0	3.0	–	24.2	28.0	26.3	9.2	28.6	19.9	77.5	172.0	113.7
		Mergolo	15°03′09″ E	38°08′23″ N	2	0	3.5	–	26.2	31.6	28.8	9.2	29.1	20.5	80.9	142.8	113.2
		Marinello	15°03′16″ E	38°08′12″ N	2	0	4.0	–	21.7	31.9	27.5	10.5	28.6	20.7	80.2	147.0	110.4
		Porto Vecchio	15°03′10″ E	38°08′32″ N	4	0	3.5	–	31.0	37.3	34.0	9.7	29.3	20.5	90.9	138.7	114.1
		Fondo Porto	15°03′01″ E	38°08′38″ N	1	0	2.0	0.7	22.2	40.2	32.8	8.8	31.5	20.4	44.7	146.1	101.7
Capo Peloro	Coastal lakes	Faro	15°38′13″ E	38°16′07″ N	26	2	28.0	–	34.8	37.7	36.2	12.3	27.8	20.4	93.4	130.9	110.3
		Ganzirri	15°37′02″ E	38°15′39″ N	34	2	7.0	–	30.2	33.3	31.7	11.4	28.5	20.8	75.4	175.4	122.1
Salatelle di Catania	Mires	–	15°02′22″ E	37°24′50″ N	17	0	–	–	–	–	–	–	–	–	–	–	–
Augusta	Mires	Eastern	15°13′50″ E	37°14′39″ N	24	0	–	–	–	–	–	–	–	–	–	–	–
		Western	15°12′47″ E	37°14′39″ N	16	0	–	–	–	–	–	–	–	–	–	–	–
Priolo	Mires	–	15°13′01″ E	37°08′48″ N	29	0	–	–	–	–	–	–	–	–	–	–	–
Siracusa	Mires	–	15°16′12″ E	37°02′54″ N	29	0	–	–	–	–	–	–	–	–	–	–	–
Vendicari	Mires	Piccolo	15°06′14″ E	36°48′43″ N	20	0	0.8	–	20.0	48.5	37.6	10.4	31.7	22.2	76.7	179.2	107.6
		Grande	15°05′53″ E	36°48′22″ N	38	0	0.4	–	26.5	39.4	32.9	10.6	32.2	21.6	92.3	141.0	116.4
		Roveto, Sichilli, Scirbia	15°05′26″ E	36°47′24″ N	130	1	0.4	–	41.6	48.5	45.0	10.7	33.7	22.2	92.3	230.3	130.7
South-eastern Sicily	Mires	Marzamemi	15°06′55″ E	36°44′28″ N	5	1	–	–	–	–	–	–	–	–	–	–	–
		Morghella	15°06′51″ E	36°42′09″ N	57	1	–	–	–	–	–	–	–	–	–	–	–
		Ponterio	15°04′08″ E	36°39′46″ N	5	0	–	–	–	–	–	–	–	–	–	–	–
		Ciaramiraro	15°04′08″ E	36°40′05″ N	11	0	–	–	–	–	–	–	–	–	–	–	–
		Baronello	15°04′08″ E	36°40′29″ N	21	1	–	–	–	–	–	–	–	–	–	–	–
		Auruca	15°03′05″ E	36°41′03″ N	4	0	–	–	–	–	–	–	–	–	–	–	–
		Cuba	15°01′39″ E	36°42′29″ N	51	0	1.0	–	–	–	–	–	–	–	–	–	–
		Longarini	15°00′25″ E	36°42′38″ N	226	1	1.0	–	–	–	–	8.9	27.9	18.7	115.4	153.6	135.7
		Bruno	14°58′57″ E	36°41′57″ N	21	0	–	–	–	–	–	–	–	–	–	–	–
		Gorgo Salato	14°58′26″ E	36°41′41″ N	5	0	–	–	–	–	–	–	–	–	–	–	–
Capo Feto and Margi	swamps	Capo Feto	12°31′44″ E	37°39′47″ N	99	0	–	0.1	–	–	–	14.0	20.0	–	–	–	–
		Margi Spanò	12°30′02″ E	37°40′48″ N	50	0	–	0.1	–	–	–	14.0	20.0	–	–	–	–
		Margi Nespolilla	12°29′43″ E	37°41′24″ N	21	0	–	0.1	–	–	–	14.0	20.0	–	–	–	–
		Margi Milo	12°28′33″ E	37°43′23″ N	53	0	–	0.1	–	–	–	14.0	20.0	–	–	–	–
Stagnone di Marsala	Lagoon-like coastal basin	Stagnone di Marsala	12°27′34″ E	37°51′42″ N	2135	2	4.0	1.0	32.8	47.1	39.9	11.2	29.1	19.5	80.0	115.0	98.0
Trapani and Paceco	Saltworks	–	12°31′01″ E	37°58′53″ N	910	0	–	–	–	–	–	–	–	–	–	–	–

Note: S, salinity; T, water temperature; DO, dissolved oxygen.

3. Current status

3.1. *Historical information*

Most of the Sicilian TWs have been known since ancient times, as shown by archaeological finds and ancient literature. For example, in the Stagnone di Marsala, from the end of the seventh century BC, Mothia Island was one of the most prosperous western Phoenician colonies because of its location, which was particularly favourable to maritime trade. Other areas were celebrated by ancient historians and naturalists for their economic activities, such as the saltworks of Priolo. Augusta and Vendicari basins were cited by Pliny the Elder (first century AD) in the *Naturalis Historia* and the Trapani saltworks by Al-Idrisi (eleventh century AD) in the *Tabula Rogeriana.* The lakes of Capo Peloro were mentioned by the Latin author Caio Giulio Solino (third century AD) with regard to the hunting and fishing activities carried out in the whole area. The millenary activity of the Vendicari Tonnara, an ancient tuna-fishery, is also remarkable: the Tonnara was realised in its modern form during the period of Arab domination, but seems to have existed since prehistory.

The first scientific studies were made and reported in the second half of the nineteenth century, when, for example, zoological and ichthyological features were investigated in the Stagnone di Marsala [10] and in the Capo Peloro area [11]. Ornithology and archaeology were studied in the Salatelle di Catania and Stagnone di Marsala, respectively [12–14]. In the following years, there was an increase in the scientific literature, mainly on the Capo Peloro ponds [15–19], the Oliveri-Tindari area [20,21] and the Stagnone di Marsala [22,23] with regard to geo-morphological, hydrological and biological aspects. The terrestrial botanic aspects of the Salatelle were studied by Pirola [24]. In the last 40 years, our scientific knowledge of Sicilian TWs has increased further, deepening in many fields, although several areas remain poorly studied.

3.2. *Ecological features*

Overall, our scientific knowledge of most Sicilian TWs is incomplete, and for several of them is almost totally lacking. The most plentiful information is available for a small number of areas such as the ponds of Oliveri-Tindari, the lakes of Capo Peloro, the mires of Vendicari, the Stagnone di Marsala and the saltworks of Trapani and Paceco. In most cases, more is known about the terrestrial flora and fauna and avifauna. Indeed all these areas provide ideal feeding and nesting habitats for birds and, because of their geographical location along important Mediterranean bird migratory routes, host a rich avifauna, made up of both resident and migratory species [25]. In this section, we examine what is known of Sicilian TWs, with almost exclusive reference to features of the aquatic environment.

The ponds of Oliveri-Tindari

The Oliveri-Tindari coastal system is located along the Tyrrhenian coast of Sicily in the Gulf of Patti (Messina, Italy), and is characterised by marked geomorphologic dynamism and high structural and hydrobiological complexity [26]. The particular anemological regime of the area determines periodical formations of littoral bars, thus delimiting small coastal ponds, at present five (Verde, Fondo Porto, Porto Vecchio, Mergolo della Tonnara and Marinello). The seaward ponds are mainly influenced by seawater inflows, through infiltration or direct contribution during storms. Conversely, the most important input to the three landward ponds is surface run-off carrying dissolved and particulate matter from the surrounding land (often used for pasture or agricultural exploitation) [27].

The ponds of Oliveri-Tindari have received attention mainly for their hydro-geomorphological features and trophic status [26,28]. The space–time heterogeneity of allochthonous input and inorganic enrichment induces high variability in the trophic status and salinity values [29,30]. Among others, Lake Verde is especially interesting. It is characterised by a very high nutrient load carried by continental and meteoric waters that become enriched in organic and inorganic compounds during their passage over the overhanging, gull-colonised cliff (*Larus michahellis*).

The aquatic flora was first described more than 30 years ago [31]. However, in recent years the macrophyte community has changed considerably owing to the presence of Lessepsian species (the seagrass *Halophila stipulacea* and the macroalga *Caulerpa racemosa*) in addition to native species (e.g. the seagrasses *Cymodocea nodosa* and *Ruppia* sp. and the macroalga *Caulerpa prolifera*). The invertebrate benthic communities were first described in the 1970s [32]. Molluscs have also been the focus of great attention, in particular, the evolution of the trophic–sedimentary environments and mollusc community over the last 20 years [26]. Recently, a marked heterogeneity between and within ponds was detected, the landward ponds being more similar to each other than to the seaward ones [33]. Finally, other recent scientific articles have focused on contamination and the effects of pollution on the water column, sediments and organisms, finding acceptable levels overall [34,35].

The lakes of Capo Peloro

Capo Peloro is a brackish system located in the north-eastern corner of Sicily. It consists of two basins, the Lake of Ganzirri and Lake Faro, communicating with the Ionian Sea and connected to each other by a channel. Owing to the marine input, underground springs and meteorological and climatic conditions, the lakes of Capo Peloro are characterised by large fluctuations in chemico-physical variables, especially salinity, temperature and, mainly in Lake Faro, dissolved oxygen [36].

The lakes have been widely investigated for their hydrological and sediment features [37,38], trophic status [33,36] and zooplanktonic [39–41] and benthic communities [33].

The Lake of Ganzirri features mainly sandy bottoms and large *mattes* of the green alga *Chaetomorpha linum*, which are covered with dense tufts of epiphytes. Decomposition processes lead to significant oxygen uptake and hence to periodic dystrophic crises in summer [36]. Recent application of the LOICZ biogeochemical model showed the lake to be a net exporter of dissolved inorganic phosphorous (DIP) and dissolved inorganic nitrogen (DIN) towards the sea [36].

Lake Faro is a deep, meromictic and strongly stratified coastal lake, characterised by H_2S in the hypolimnion and by a red water layer at the chemocline ($\sim$10 m) due to the presence of phototrophic sulphur bacteria [37,38]. Sporadic input of Levantine Intermediate Waters (LIW) from the upwelling system of the Strait of Messina clearly affects the physical and chemical environment [38].

In both lakes, particular attention has been focused on zooplankton. While Lake Faro is characterised by an abundant and diverse assemblage of both marine and brackish copepod species [39], in the Lake of Ganzirri only a few species of calanoid copepods are present [39]. Furthermore, in Lake Faro a new species (*Pseudocyclops costanzoi*) was recently described for the first time [41] and another species (*Pseudocyclops xiphophorus*), previously recorded only in coastal waters of Mozambique [40], was also found. As regards macrozoobenthos, a recent study of species composition and distribution highlighted very high spatial variability [33]. For example, in shallow zones of Lake Faro there is a richer community than in the deepest, anoxic part of the basin. Even in the Lake of Ganzirri there is a clear segregation of the invertebrate fauna between the shallow area, more influenced by the sea, and the deeper, confined one.

A few articles have dealt with ichthyofauna, the main species of the lakes of Capo Peloro being *Aphanius fasciatus*, *Liza aurata*, *Mugil cephalus* and *Sparus aurata* [42–44].

Mires of Vendicari

Vendicari is a large brackish coastal system partly modified and reduced because of human intervention. At present, it comprises three very shallow mires: Piccolo, the northernmost and deepest and the only one that does not dry up in summer, probably because of underground wellsprings [45]; Grande, which communicates with the adjacent sea through a recently built, small, artificial channel [46]; and Roveto, Sichilli and Scirbia, considered three sub-basins of a whole, which are the southernmost and shallowest basins and communicate with the open sea through a mouth.

The high ecological and naturalistic value makes the mires of Vendicari an area of great interest. Most studies have focused on their hydrological and geological aspects [47–49]. As regards faunal assemblages, a clear tendency towards monospecificity was observed in the mires [45]. This trend is especially evident for harpacticoid copepods (*Enhydrosoma bucholtzi*), amphipods (*Gammarus aequicauda*), gastropod molluscs (*Hydrobia ventrosa*) and fish (*Aphanius fasciatus*). The same is true for the zooplankton, made up of only two typical brackish species belonging to cladocers (*Moina salina*) and calanoid copepods (*Arcodiaptomus salinus*), although a recent study revealed that many zooplankton species in the mires of Vendicari persist in a dormant stage in the sediments, suggesting that biodiversity levels may change over time [50].

Avifauna, including both permanent and migrant species, is the most extensively studied biological component, showing a large diversity in species due to the well conserved habitat. In particular, in addition to numerous important and attractive species (e.g. *Phoenicopterus ruber roseus*, *Bubulcus ibis*, *Platalea leucorodia*, *Plegadis falcinellus*, *Ciconia ciconia* and *Ciconia nigra*) [51–53], the presence of a few threatened species (e.g. *Burchinus oedicnemus*, *Calandrella brachydactyla*) was also recorded.

The Stagnone di Marsala

The Stagnone di Marsala is an extensive coastal basin on the north-western coast of Sicily. With freshwater input absent, the water records higher salinity values than those of the adjoining open sea [54]. Water exchange depends on two openings: a narrow, shallow mouth in the northern part and a wider, deeper mouth in the southern. On the basis of the geomorphological features, two sub-basins can be identified within the Stagnone: the northern one shows more marked lagoon-like characteristics, whereas the southern shows more marine features [55]. Tightly connected to the basin is a system of saltworks.

This area is widely described for its hydrological features [56], trophic status [54], aquatic communities [57–60] and ecological importance [61,62], being a biotope of great naturalistic value in the Mediterranean area. The LOICZ biogeochemical model found the basin to be a sink for DIN and a source for DIP [55].

The main ecological value of the Stagnone is the presence of the seagrass *Posidonia oceanica* [57], which forms a plateau, a barrier reef and atoll-like structures, while *Cymodocea nodosa* is the dominant seagrass. The Stagnone hosts a number of endemic species and species which have evolved particular morphological differentiations. For example, a new Copepoda Calanoida species, *Stephos marsalensis*, has been indentified [58]. Both the resident (e.g. *Atherina boyeri*, *Aphanius fasciatus*, *Pomatoschistus tortonesei*, *Syngnathus typhle*, *Syngnathus abaster*) and transient (e.g. Mugilidae, *Sparus aurata*, *Diplodus* spp.) ichtyofauna have been described [59,60], the Stagnone being an important area for fish, with its rich and complex phytobenthic community. The food webs have also been investigated, resolving the relationships among consumers and

the main primary producers, showing an important role for epiphytes and detrital organic matter, above all in the central part of the basin [63].

The saltworks have also been intensively studied, mainly with regard to their ecological and trophic features [64,65] and faunal composition [66–68]. A new Lessepsian species, *Brachidontes pharaonis* (Bivalvia), was recorded [69].

The saltworks of Trapani and Paceco

The saltworks of Trapani and Paceco, together with those of Marsala, are the only ones still active in Sicily. From an ecological point of view, the saltworks represent a good model of enclosed and confined areas showing features typical of hyperaline lagoons, extreme environments and sharp gradients, where specific experimental hypotheses can be tested [70–72]. Because of the marked batimetrical and chemico-physical differences among the vats inside the saltworks and the consequent environmental gradients, large differences are also observed in their biological communities. Animal and vegetal communities typical of lagoon-like environments are present in the external vats, whereas only halo-tolerant bacteria and microalgae tolerate the extreme conditions of the confined ones. The seagrasses *Ruppia* sp. and *Cymodocea nodosa*, several species of macroalgae, a fairly rich invertebrate community and several transient (e.g. Mugilidae, *Sparus aurata*) and resident (e.g. *Syngnathus abaster*, *Atherina boyeri*, *Aphanius fasciatus*) fish are generally present in the vats proximal to the sea. Moving towards the landward vats, a progressive reduction in species number occurs and a few dominant species (e.g. *Artemia salina*, Branchiopoda) [73], as well as the microbial mat formed by diatoms, micro-algae (e.g. the red colonies of *Dunaliella salina*) and cyano- and halobacteria (e.g. the endemic species *Halobacterium drepanensis*) are present [72,74].

More than 200 species of both wintering and nesting birds were identified in the area; among them attractive species such as *Phoenicopterus ruber roseus*, *Ardea alba*, *Egretta garzetta*, *Alcedo atthis*, *Platalea leucorodia* and *Recurvirostra avosetta* [70].

The remaining Sicilian TWs (i.e. the pond of Lingua, the Salatelle di Catania, the mires of Augusta, Priolo, Siracusa and south-eastern Sicily, and the swamps of Capo Feto and Margi) are poorly studied at present. There are large gaps in our knowledge of most biological and ecological aspects related to the aquatic environment. By contrast, their terrestrial flora and fauna, mainly avifauna, have been studied [75–77].

The pond of Lingua

The pond of Lingua is a small, shallow basin on the Island of Salina (Aeolian Islands). Formed when littoral bars were created by the strong marine currents in the channel between the islands of Salina and Lipari, its location means the pond is affected by both marine and meteoric water input. It is colonised by the seagrass *Ruppia* sp. [25].

The Salatelle di Catania

The Salatelle di Catania are brackish retrodunal mires, forming a wide wet area close to the Simeto River mouth. These basins, which include both perpetual and temporary mires, are mainly fed by infiltrated groundwater, which is a mixture of continental freshwater and marine water [25]. Little information is available on this system. In the perpetual mires, the seagrasses *Ruppia* sp. and *Althenia* sp. are found, together with the macroalga *Lamprothamnium papulosum*. As regards the macrofauna, insect larvae and the fish *Aphanius fasciatus* are the only components recorded [78]. In the temporary mires, which dry up in summer, life is reduced to Cyanophyceae and Chlorophyceae mainly in autumn and spring respectively, because of the extreme conditions [78].

The Salatelle are an area of high avifaunistic value ([79]). The lasting presence of the purple gallinule *Porphyrio porphyrio* is also worthy of attention. After a drastic reduction in numbers and the subsequent risk of extinction due to hunting and habitat degradation, international action for the reintroduction of wild birds has resulted in recolonisation of native areas [80].

The mires of Augusta, Priolo and Siracusa

The mires of Augusta and Priolo are both marshy areas, used in the past as saltworks. They are fed by meteoric water and through bottom infiltration as well as by sea water from sea storms [25].

The wetlands of Siracusa share their main characteristics with the above mires and represent the sole residual of an old coastal swamp, later transformed into saltworks that were active until recent times [25]. The area is characterised by depositions from the nearby River Ciane and erosive phenomena that periodically transform the morphology of the whole area.

Most of these mires are colonised, at least temporarily, by the seagrasses *Ruppia* sp. and *Althenia* sp. and the macroalga *Lamprothamnium papulosum*. Euryhaline fish (mainly *Aphanius fasciatus* and Mugilidae) were also recorded [25].

The mires of south-eastern Sicily

The wetlands in south-eastern Sicily, which are in continuity with those of Vendicari, are made up of the following brackish mires: Marzamemi, Morghella, Ponterio, Ciaramiraro, Baronello, Auruca, Cuba, Longarini, Bruno, Salato, as well as a number of small swampy dips, such as Punta Pilieri, Chiusa dell'Alga and Parrino, which are now almost completely dried up. These are separated from the sea by dunal sand bars. Their depth increases in the winter months from meteoric and sea water input, the latter through infiltration or direct contribution from waves. A few of the mires (e.g. Longarini) have a direct connection with the sea through channels. Most are colonised by the seagrass *Ruppia* sp. and the macroalga *Lamprothamnium papulosum* [25]. Records of the ichthyofauna are also available and the most abundant species are *Atherina boyeri*, *Aphanius fasciatus*, *Liza ramado*, *Liza saliens* and *Mugil cephalus* [25].

The swamps of Capo Feto and Margi

The Capo Feto and Margi areas are characterised by the typical features of a swamp. Capo Feto is the more southerly, and constitutes a large dip separated from the sea by a narrow littoral bar. Moving north-westwards along the Sicilian coast, the Margi swamps are located in the following sequence: Margi Spanò, Margi Nespolilla and Margi Milo. Freshwater and marine water floods occur in winter when the area appears as a typical wetland, while drying events occur in summer when only the network of reclamation channels and a few ponds persist. These processes determine periodic and drastic transformations in the surrounding landscape. At Capo Feto all drainage of the wetland is currently achieved through a network of artificial channels: the main channel is oriented east–west with perpendicular secondary channels, assuring drainage of groundwater and rainwater [81,82]. A number of drainage channels are also present in the Margi.

The swamp of Capo Feto was investigated for nutrient load and balance and was found to be a heterotrophic system, acting as a net sink for both DIN and DIP [82].

3.3. *Ecological status*

The concept of ecological status (or ecological quality status, EcoQS) was elaborated during the early 1990s to be used in a new framework of European water policy and is defined as follows:

'ecological water quality is an overall expression of the structure and function of the biological community taking into account natural physiographic, geographical and climatic factors, as well as physical and chemical conditions, including those resulting from human activities' [83].

Transitional and coastal waters are some of the most productive ecological systems on Earth and are recognised as having an extremely high value for human society. However, they are being severely threatened by anthropic pressure and sea level rise induced by climate change [84]. Management of these ecosystems is very important, but the key biological signals indicating the intensity of anthropic stress and ecological status must be identified. In particular, the lack of coupling between primary and secondary production, which characterises shallow waters [85], together with the high variability and heterogeneity of TWs, do not allow simple parametric characterisation of their ecological status, which might be better achieved through the definition of appropriate biological indicators [86].

The WFD establishes a framework for the protection of estuarine (= transitional) waters, among others. The most important objective of this legislation is to achieve a good ecological status for all waters by 2015, basing the ecological quality concept upon the status of the biological, hydro-morphological and physico-chemical quality elements [87]. Despite this, it is necessary to determine reference conditions for each typology taken into account by the WFD and, likewise, to assess the EcoQS for each of the water bodies [88].

In this context, the case of Sicilian TWs is critical because of both the lack of knowledge and the peculiarity of most of the areas, which do not fall into any of the typologies in recent regulations. Furthermore, the sole monitoring plan activated by the Sicilian Regional Agency for Environmental Protection (ARPA Sicilia), according to the national regulations in place at that time (Italian law 152/1999), was carried out in recent years (2005–2006) and included only some of the TWs [33]. In order to establish ecological quality, ARPA Sicilia selected the following parameters and variables: trophic status index (TRIX, based on DIN and DIP, chlorophyll-*a* and dissolved oxygen), suspended matter quality (total suspended matter, C/N ratio, particulate organic carbon and water transparency), sediment quality (grain size and chemical contamination: polycyclic aromatic hydrocarbons, heavy metals, polychlorinated biphenyls, pesticides and tributyltin compounds). A biological approach was also used to investigate more thoroughly the ecological quality of the areas and this focused on the hygienic/sanitary conditions (based on Enterococci, faecal coliforms, aerobic heterotrophic and alophilic vibrio bacteria), the microbial metabolic processes involved in the mineralisation of organic matter (based on bacterial enzymatic activity) and the soft-bottom macrobenthic communities (based on diversity indices). Based on expert analysis of these data, four classes were established: high, good, mediocre, or scarce

Table 2. Ecological status of Sicilian TWs as reported by ARPA Sicilia based on trophic status index (TRIX), suspended matter (SM) and sediment quality, hygienic and sanitary conditions and macrobenthic diversity [33].

Area	Basin	TRIX	SM quality	Sediment quality	Hygienic/ sanitary conditions	Microbial activity	Macrobenthic diversity	Ecological status
Oliveri-Tindari	Marinello	Good	Good	Scarce	Good	Good	Mediocre	Good
	Verde	Mediocre	Mediocre	Mediocre	Mediocre	Mediocre	Scarce	Mediocre
	Mergolo	Good	Good	Good	Good	Good	Scarce	Good
	Porto Vecchio	High	High	Good	Good	High	Good	Good
Capo Peloro	Ganzirri	Mediocre	Good	Scarce	Mediocre	Good	Scarce	Mediocre
	Faro	Good	Good	Scarce	Good	Mediocre	Mediocre	Mediocre
Vendicari	Piccolo	Mediocre	Mediocre	Mediocre	High	Mediocre	Scarce	Mediocre
	Grande	Mediocre	Mediocre	Mediocre	Good	Scarce	Scarce	Mediocre
	Roveto	Scarce	Scarce	Mediocre	Good	Scarce	Scarce	Scarce
Stagnone di Marsala	Stagnone	High	High	Good	High	High	Good	High

(Table 2), and an ecological status class was assigned to each basin. The overall status of the basins was found to be very heterogeneous and variable both among and within sites, ranging from high (e.g. the Stagnone di Marsala) to poor ecological quality status (e.g. Vendicari) (Table 2) [33]. However, caution should be taken when considering these results as this study was a general preliminary monitoring survey: further, more detailed scientific investigation is needed, using the elements and metrics provided by the recent normative and validated indices. In addition, it is important to take into account the intrinsic features of each basin when considering these results. The case of Vendicari is emblematic. It is considered to be of poor ecological value because of its very low depth, extreme fluctuations in environmental variables, and a drying up in summer that prevents the formation of a rich benthic community. However, this site is home to a very rich avifauna and is considered one of the most important wet areas in Sicily.

4. Anthropic action

Sicilian TWs are unique ecosystems because of their high ecological and naturalistic value. However, they are also recreational areas for human populations. In spite of their value, all TWs in Sicily are exposed to a great deal of anthropic pressure. In order to identify the pressures affecting these areas and their subsequent weaknesses, as well as to describe their potential in terms of service supply, full and accurate recognition of anthropic activity is crucial.

The Land Cover project is part of the CORINE programme [89] and provides consistent localised geographical information. The nomenclature and accompanying definitions have been the subject of extensive discussion, both with the end-users of the CORINE database and with various experts in European member states. With regard to TWs, the marked distinction between WFD and CORINE definitions is debated in particular and remains unresolved [90]. However, what the CORINE database is able to provide, is detailed information on the cover of the Sicilian TWs and adjacent areas (Table 3). Sicilian TWs as a whole are surrounded by highly anthropised areas, and as such are threatened by a number of human activities: urbanisation, building without planning permission, land reclamation activities and hydrological regime alteration, intensive agriculture, greenhouse production and consequent pollutant discharge, contaminant and waste product dumping from industry, tourism, arson, fishing and hunting activities.

Taking a closer look, several areas are greatly affected by urban impacts (e.g. Augusta mires, Capo Peloro lakes, Trapani and Paceco saltworks). Other areas are less affected by urban presence, such as Capo Feto and Margi swamps and Vendicari mires, although they are effectively influenced by agriculture and its connected drainage. Augusta, Priolo and Siracusa mires are severely damaged areas, being totally enclosed by a highly urbanised and industrialised area, characterised by the presence of an oil refinery (Polo Petrolchimico Siracusano). Indeed, they are subject to size reduction, urban solid waste build-up and unauthorised contaminant discharge, which have greatly modified the natural ecosystem equilibrium. In the 1980s, construction of the underground Italian–Algerian methane pipeline, which crosses Capo Feto, markedly changed the original features of the area.

A general plan which assesses the productive potential and intended uses of Sicilian TWs is lacking. These areas, in fact, do not fall within any management plan, although they are subject to diverse protection regimes (see next paragraph). Management plans would enable regulation of the activities carried out in the TWs and surrounding areas: both recreational and productive activities could improve the quality of the areas, if managed sustainably. If not, such activities could have potentially negative impacts.

For example, recreational and tourist activities (e.g. bathing, nature trails) take place in most Sicilian TWs, such as the ponds of Lingua and Oliveri-Tindari, the Salatelle and the mires of Vendicari and the Stagnone di Marsala, due to their location, great naturalistic value and historical

Table 3. Cover of the Sicilian TWs and surrounding areas, derived from the Land Cover project CORINE database.

Area	Continuous urban fabric	Discontinuous urban fabric	Industrial or commercial units	Road and rail and associated land	Port areas	Non-irrigated arable land	Vineyards	Fruit trees and berry plantations	Olive groves	Complex cultivation patterns	Land principally occupied by agriculture, with significant areas of natural vegetation	Natural grassland	Sclerophyllous vegetation	Beaches, dunes, and sand plains	Bare rock	Salt marshes	Salines	Water courses	Coastal lagoons
Lingua	–	x	–	–	–	–	–	–	–	x		–	x	–	–	–	–	–	–
Oliveri-Tindari	x	–	–	x	–	–	–	–	–	–	–	–	–	x	x	–	–	–	–
Capo Peloro	x	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x
Salatelle di Catania	–	x	–	–	–	x	–	x	–	–	–	x	–	–	–	–	–	–	–
Augusta	x	x	–	–	–	–	–	–	–	x	–	–	–	–	–	–	x	–	–
Priolo	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–
Siracusa	–	x	x	–	–	–	–	–	–	x	–	–	–	–	–	x	x	–	–
Vendicari	–	x	–	–	–	x	–	–	–	x	–	x	x	x	–	x	–	–	–
South-estern Sicily	–	x	–	–	x	x	x	–	x	x	–	–	–	–	–	x	–	–	–
Capo Feto and Margi	–	–	–	–	–	–	–	x	–	x	–	–	–	–	–	x	–	–	–
Stagnone di Marsala	–	–	–	–	–	–	x	–	–	–	x	–	x	–	–	–	x	–	–
Trapani and Paceco	x	x	x	–	x	x	x	–	–	x	–	–	–	–	–	–	x	x	–

and archeological importance. Meanwhile, the Vendicari area represents a model of well-managed eco-compatible tourism; elsewhere, tourism is mainly a source of impact and pollution.

Following historical traditions, a number of Sicilian TWs are or could be potentially exploited for aquaculture activities. In the Capo Peloro area, with its high primary production, both lakes were exploited historically for shellfish farming (*Mytilus galloprovincialis*, *Ostrea edulis*, *Venerupis aurea* and *Cerastoderma edule*). However, in recent years, this activity has been regulated and thus greatly reduced because of contamination and related health risks. Several microbiological studies have shown the risks involved in the human consumption of these aquaculture products owing to the presence of bacterial and viral pathogenic species [37,91] from the surrounding urban settlements. In the past, aquaculture activities have been proposed for other areas, such as the mires of Siracusa, Vendicari and south-eastern Sicily, as a way of enhancing their value [92,93].

The saltworks of the Stagnone and Trapani-Paceco are the only salt production centres still active today. These became disused in the last century and suffered decline. At present, with the institution of nature reserves and the reactivation of salt production, the area has been requalified. Aquaculture activities have also been proposed as a requalification action in the saltworks of Trapani and Paceco [94,95].

5. Conservation regimes

Owing to their widely recognised natural value, Sicilian TWs fall into several categories of protected area: Natural Oriented Reserves (NOR), Sites of Community Importance (SCI), Special Protection Zones (SPZ), Important Bird Areas (IBA) and International Important Wet Zones. The above-mentioned protection regimes are characterised by different use limitations and purposes.

NORs are created to protect biotic communities and ecosystems, preserving natural processes and genetic resources in order to provide natural environments that are ecologically important

Table 4. Conservation regimes of Sicilian TWs.

TW	NOR	SCI (code)	SPZ (code)	IBA	Ramsar
Pond of Lingua	Le Montagne delle Felci e dei Porri	ITA030029	ITA030044	Isole Eolie – 152	–
Ponds of Oliveri-Tindari	Laghetti di Marinello	ITA030012		–	–
Lakes of Capo Peloro	Laguna di Capo Peloro	ITA030008	ITA030042	Monti Peloritani – 153	–
Salatelle di Catania	Oasi del Simeto	ITA070001	ITA070029	–	–
Mires of Augusta	–	ITA090014	ITA090014	–	–
Mires of Priolo	Saline di Priolo	ITA090013	ITA090013	–	–
Mires of Siracusa	Fiume Ciane e Saline di Siracusa	ITA090006	ITA090006	–	–
Mires of Vendicari	Oasi faunistica di Vendicari	ITA090002	ITA090029	Pantani di Vendicari e di Capo Passero – 167	x
Mires of south-eastern Sicily	Pantani della Sicilia Sud-Orientale	ITA090003	ITA090029	Pantani di Vendicari e di Capo Passero – 167	–
		ITA090004			–
		ITA090005			–
Swamps of Capo Feto and Margi	–	ITA010006	ITA010006	Capo Feto – 162	–
Stagnone di Marsala	Isole dello Stagnone di Marsala	ITA010021 ITA010026 ITA010001	ITA010028	Stagnone di Marsala e Saline di Trapani – 158	–
Saltworks of Trapani and Paceco	Saline di Trapani e Paceco	ITA010007	ITA010028	Stagnone di Marsala e Saline di Trapani – 158	–

Note: NOR, Natural Oriented Reserve; SCI, Site of Community Importance; SPZ, Special Protection Zone; IBA, Important Bird Area.

as models for scientific studies and educational activities (Italian law 394/91). SCIs and SPZs, which make up Nature Web 2000 (Birds Protection Directive 79/409/CEE, Habitats Directive 92/43/CEE), are designed to preserve biodiversity, species and habitats of EU interest. The IBA plan is undertaken by BirdLife International, which is made up of several environmentalist associations, and is aimed at protecting areas with high concentrations of birds. International Important Wet Zones are included in the list drawn up during the Ramsar Convention (1971) (Italian laws D.P.R. 448/76, D.P.R. 184/87), in order to protect wet environments and their ecological functions.

Every Sicilian TW is subject to a number of protection regimes (Table 4): the convergence of several protection plans in the same area can be problematic because of the consequent management overlap, triggering frequent management conflicts. Some protected areas are an evident contradiction between their conservation purpose and their location: Priolo mires are a case in point because of their complete enclosure in an industrial unit, a very natural 'navel' in totally human-impacted surroundings.

6. Conclusion

Sicilian TWs are ecologically important areas which, in many cases, function as highly naturalistic buffer zones, even when embedded within human-impacted surroundings. From this overview, the role of TWs as suppliers of diverse services is further reinforced, even when they are located in highly disturbed coastal sites. At the same time, Sicilian TWs are poorly studied. The fragmentary knowledge of most of these basins is notable. More scientific data on these systems is fundamental for many purposes, including management actions that should take into account the results of thorough and continuous environmental monitoring. Monitoring TWs is vital in order to prevent further deterioration, to protect and enhance the status of aquatic ecosystems and connected terrestrial ecosystems, and to promote sustainable exploitation. In the immediate future, monitoring actions will be carried out according to Italian law 152/2006 using a markedly biological approach. This is considered to provide a more precise evaluation of the current ecological quality of TWs, without the ambiguities that arose from a previous approach based almost exclusively on abiotic features.

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