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MAPPING OF *RUPPIA SPIRALIS* MEADOWS WITHIN THE SALTMARSHES OF HYÈRES (PROVENCE, FRANCE): A KEY SPECIES FOR AN ECOSYSTEM-BASED APPROACH

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RUPPIA SPIRALIS
SALTMARSHES
MAPPING
ECOSYSTEM-BASED APPROACH

ABSTRACT. – The saltmarshes of Hyères (Provence; France) are Mediterranean lagoons and wetlands deeply altered since Antiquity; they are an example of a socio-ecosystem characterized by industrial activities since 1848 for salt production and artisanal fishing. After the end of the industrial exploitation in 1995, saltmarshes of Hyères became property of the *Conservatoire du Littoral* (Coastal Protection Agency) in 2001 and managed by the *Toulon Provence Méditerranée* metropolitan area. Since then, access to the sites is still restricted in order to preserve the historical heritage of the site and biodiversity of birds. The present work aims to localize and map Magnoliophyta aquatic meadow habitats in order to: (i) better understand the water management of the saltmarshes, inducing the presence or absence of Magnoliophyta and (ii) assess the health status of macrophytes community. The main observed Magnoliophyta was *Ruppia spiralis*, Linnaeus ex Dumortier, its presence in such brackish waters can be considered as an indicator of good conservation status. Our results show a relatively high abundance of *R. spiralis*, strongly related with environmental conditions and water management. This study is the first step of an ecosystem-based approach; *R. spiralis*, as a primary producer, belongs to a major functional compartment of the ecosystem, which constitutes the saltmarshes.

INTRODUCTION

The saltmarshes of Hyères (Salin des Pesquiers and Vieux Salins, Provence, France; 550 ha and 330 ha, respectively) (Fig. 1) are two coastal lagoons that have been profoundly altered since the 16th century by human activities, *i.e.,* mainly artisanal fisheries and, since 1848, salt production. After the end of salt exploitation in 1995, the saltmarshes of Hyères became the property of the *Conservatoire du Littoral*, a French public agency that is government funded, in 2001. They are managed by *Toulon Provence Métropole* metropolitan area. Since then, access to the sites has been restricted in order to preserve the historical heritage and the waterfowl diversity. The Magnoliophyta *Ruppia spiralis*, Linnaeus ex Dumortier plays an important functional role as a primary producer and a habitat for juvenile fishes (Menéndez 2002, Casagranda & Boudouresque 2007, Lenfant *et al*. 2015). It can be defined as an ecosystem engineer (Verhoeven 1980). Within the two saltmarshes, a heterogeneous connectivity and a wide range of environmental conditions are induced by (i) a complex water circulation, (ii) a various depth of ponds and channels (from few centimeters to more than 1 m depth), (iii) the water level of numerous ponds which is sometimes more than 30 cm below the zero level (NGF: *Nivellement Général de la France* – General leveling of France).

The mapping and the assessment of *Ruppia spiralis* meadows and other macrophytes vitality have been held within the aquatic compartments of the two saltmarshes (*i.e*., Salin des Pesquiers and Vieux Salins). Such survey can provide indices of the ecological status and the quality of the ecosystem functioning. The results presented in this study are intended to support the management team for improving the water management plan, while emphasizing the focus on the connectivity between the lagoon habitats and the open sea.

MATERIALS AND METHODS

The case study of the saltmarshes of Hyères: Coastal wetlands and lagoon along the Bay of Hyères (Hyères, Provence, Northwestern Mediterranean Sea, France) were deeply transformed by human activities since the Antiquity. The spread of the city of Hyères (named *Olbia* during the Antiquity) filled hundreds of hectares of wetlands, causing the fragmentation of the ecological continuity between the peninsula of Giens to the eastern part of the Bay. Since the Middle Age, two distinct areas were identified, Salin des Pesquiers and Vieux Salins. The first one was a coastal lagoon surrounded by wetland where an important local fishery was established providing considerable incomes (Réveillon 2018). The second, smaller, was exploited for salt production since Antiquity, but at an artisanal scale. From 1848 to 1995 these two areas were converted into an intensive salt

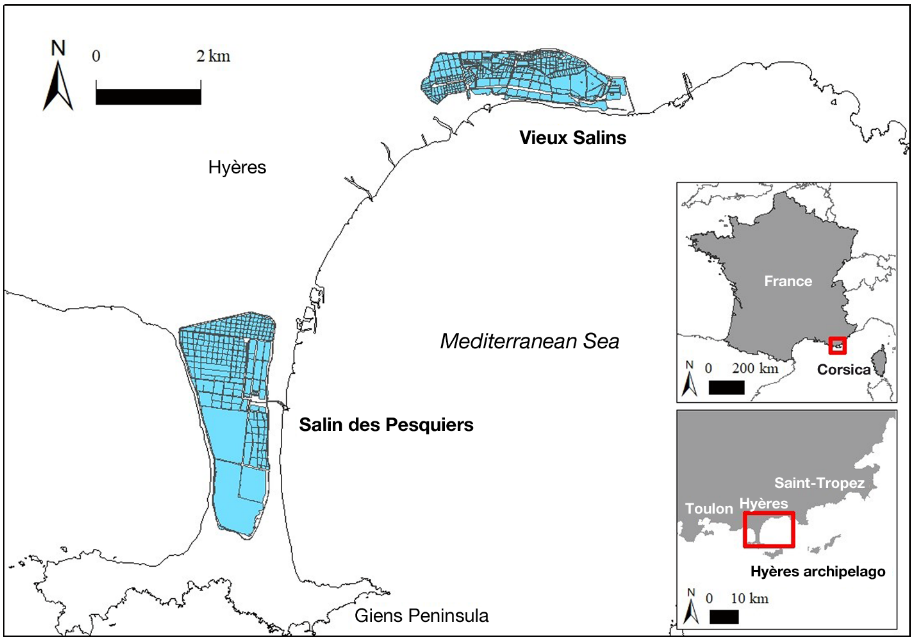


Fig. 1. – Saltmarshes of Hyères (Salin des Pesquiers and Vieux Salins) location.

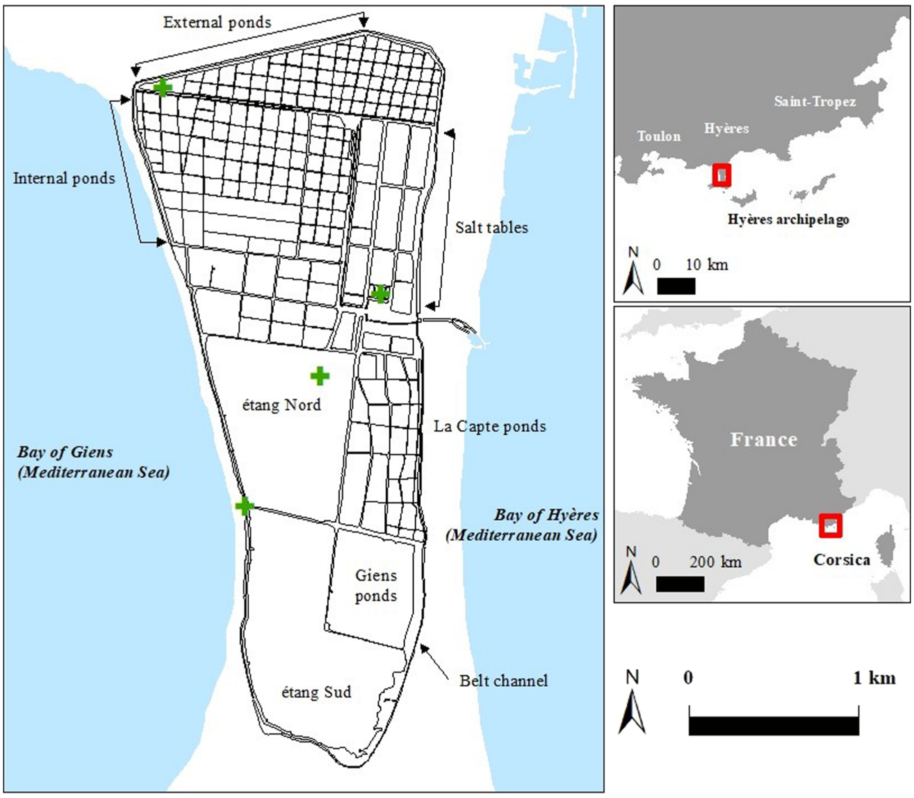


Fig. 2. – Toponymy within Salin des Pesquiers site. Green crosses correspond to sampling sites for biometry analyses.

production zone. In 2001, the whole site became the property of the *Conservatoire du Littoral* and managed by the *Toulon Provence Méditerranée* local authority. Since 2012, the sites are part of the Adhesion Area of Port-Cros National Park (Astruch *et al*. 2018). The first management goals and the water management plan were mainly focused on the historical heritage (*i.e.*, salt production, 'la *mémoire du sel*') and the conservation of waterfowl and wintering birds (Audevard 2017). A species-centered approach rather favored the so-called 'heritage taxa' (rare, threatened, charismatic). However, managers already identified the low connectivity with the open sea and related issues with fish assemblages (Conservatoire du Littoral, Toulon Provence Méditerranée & Parc national de Port-Cros 2011; CREOCEAN 2011). The water management is inherited from the previous salt exploitation (belt channel protecting the saltmarshes from fresh and seawater intrusions, low water level within the ponds, pumping, etc.), allowing the maintaining of the integrity of the sites but restricting its connectivity.

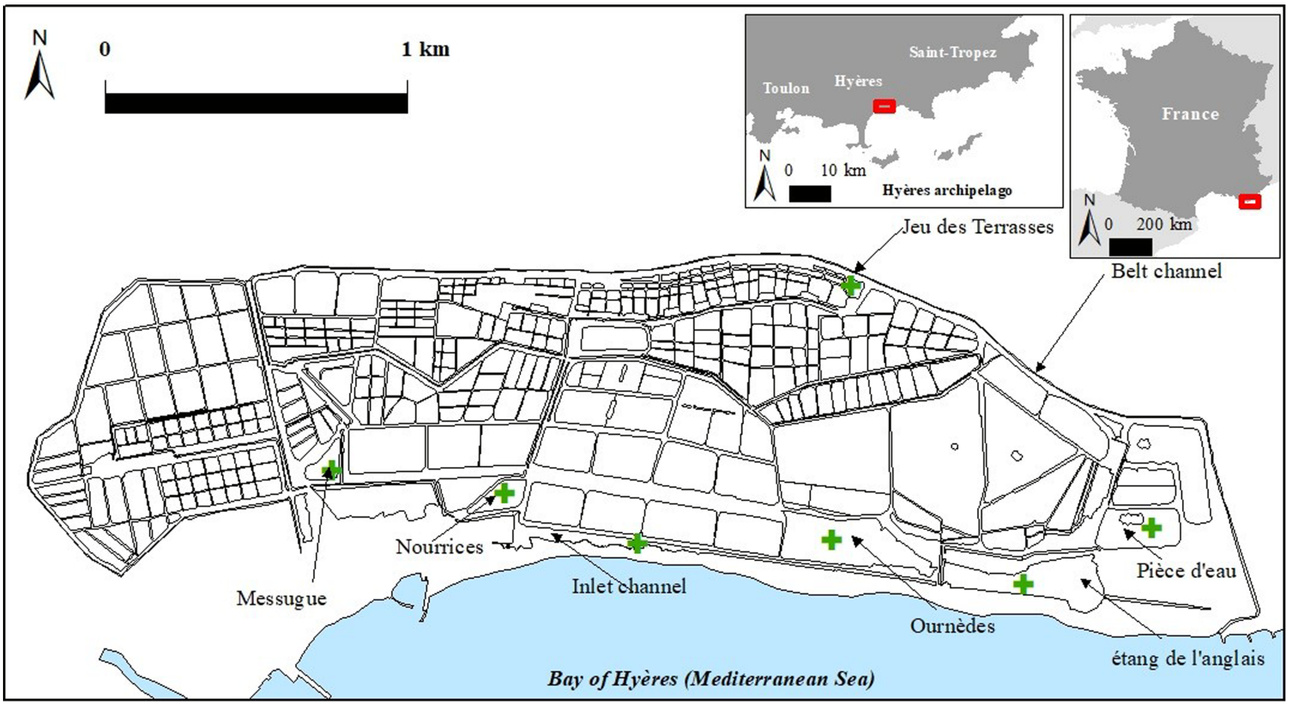


Fig. 3. – Toponymy within Vieux Salins site. Green crosses correspond to sampling sites for biometry analyses.

Table I. – Covering classes for the assessment of *Ruppia spiralis* cover.

Class	Cover (%)
0	0 %
1	0-1 %
2	1-5 %
3	5-25 %
4	25-50 %
5	50-75 %
6	75-100 %

The ecosystem engineer Ruppia spiralis: *Ruppia spiralis* Linnaeus ex Dumortier is characterized by a long, filiform and green stem. The ends of the leaves are regular and sharp with a diameter between 0.7 and 1.2 mm, the flower peduncle is very long (10-60 cm) and spiraled (Shili 2008). It is an annual/perennial species that grows in permanent and temporary lagoons and coastal brackish habitats. In France, *R. spiralis* spreads from the Mediterranean Sea to the Atlantic Ocean, the English Channel and the North Sea (Borel 2013). It is a euryhaline species able to withstand salinity ranging between 0 and 106 g/kg; its optimal growth occurs between 10 and 30 °C (Verhoeven 1980). This tolerance makes the species very competitive with other Magnoliophyta (Shili 2008). When drying occurs, the plant dies within a few days and only mature seeds survive. *Ruppia spiralis* vegetative phase starts in spring (April-May). After a few weeks, the flowers and fruits develop (May-July). Its regression starts from mid-summer (Shili 2008).

Data collecting and sampling: Data sampling has been held in May 2017, corresponding to both vegetative and flowering phase of *R. spiralis* meadow.

Mapping of *R. spiralis* meadow: covering (seven classes, Charpentier *et al.* 2003, Table I) has been visually assessed within all ponds and channels by foot or by kayak. The covering was then formatted in a Geographic Information System using ArcGIS® 10.5 software. The study site perimeter was previously digitized from the NGI's orthophotos (National Geographic Institute). Toponymy of main ponds and channel of both sites is presented in Figs 2 and 3.

Biometric analyses of *R. spiralis* were sampled at 11 sampling sites (4 at Salin des Pesquiers and 7 at Vieux Salins). On each sampling site, 3 replicates were sampled with a 20 cm × 20 cm frame (n = 33). The entire plant was sampled including roots and rhizomes until ~10 cm depth in the sediment. Analyses were held at the laboratory. After cleaning the samples from sediment and non-macrophyte organisms, flower and fruits were counted for each sample to estimate their density. Dry mass of epigenous (leaves, stem) endogenous (rhizomes, roots) of the plant and other macrophytes (*i.e.*, macroalgae) was measured after drying the samples 48 h at 70 °C. A Student's t-test was carried out to compare mean biomass of the two sites (Salin des Pesquiers and Vieux Salins).

RESULTS

Mapping of Ruppia spiralis

Based on the surface area of each pond and the median of the cover class assessed during the sampling, we estimated 50 ha and 14 ha of *Ruppia spiralis* meadow respectively within the Salin des Pesquiers and Vieux Salins. Within Salin des Pesquiers, its covering is heterogeneous (Fig. 4, Table I bis). In the belt channel, which delimits the perimeter of the Salin des Pesquiers, we can observe a variable covering that ranges from class 0 to class 5. The Étang Nord shows a 5-class cover (50-75 %). Areas with an intermediate rate of class 2, 3 and 4 (1-5 %, 5-25 % and 25 – 50 %) are at the mouth of the belt channel with an upward gradient that ranges from class 2 (1-5 %) to class 4 (25-50 %). *Ruppia spiralis* meadow of Étang Nord lives in association with another macrophyte such as *Acetabularia acetabulum* (Linnaeus) P.C. Silva.

The covering of *R. spiralis* within Vieux Salins is also heterogeneous and limited to some ponds (Fig. 5, Table I bis). The ponds with the maximal covering of 6 and 5 classes are: Pièce d'eau (class 6, 75-100 %), a channel that extends between the Pièce d'eau and the Ilotes (class 6, 75-100 %); the channel between Jeu des Terrasses and Jeu du Petit Conseiller (class 6, 75-100 %); a part of the channel between the Étang de l'Anglais and the Jeu du Bassin 2 (class 5, 50-75 %); the channels located between the Jeu du Grand Conseiller and Farnosi and the Estagnet represent water outlets to the sewers (channels collecting the salt water after its journey in the connected ponds); here the covering rate is class 5 (50-75 %). The areas with

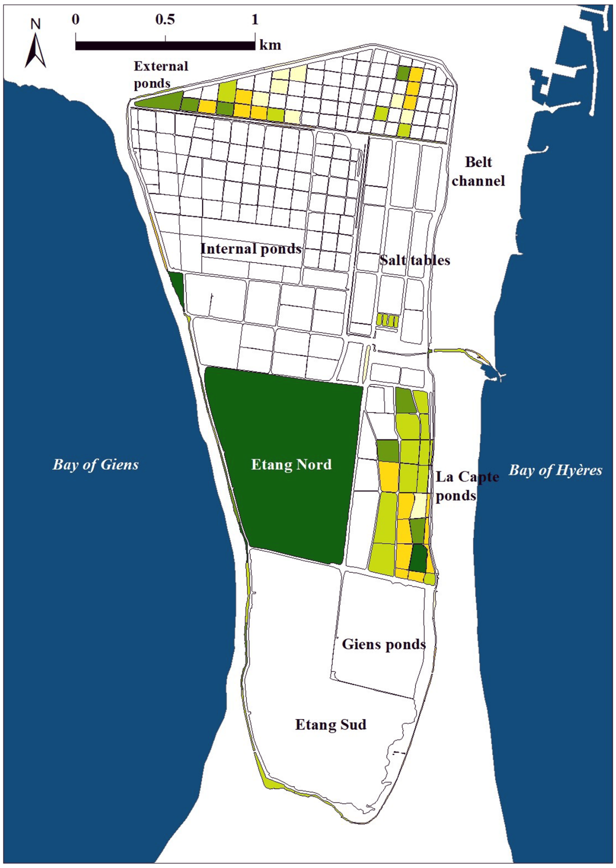
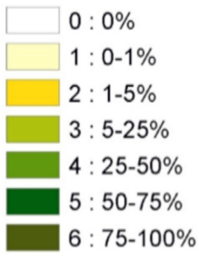


Fig. 4. – Covering classes of *Ruppia spiralis* at Salin des Pesquiers. The red circle corresponds to the location of *Lamprothamnium papulosum*.

Table I bis. – Colors of the covering classes of *Ruppia spiralis* used in Fig. 4 and 5.



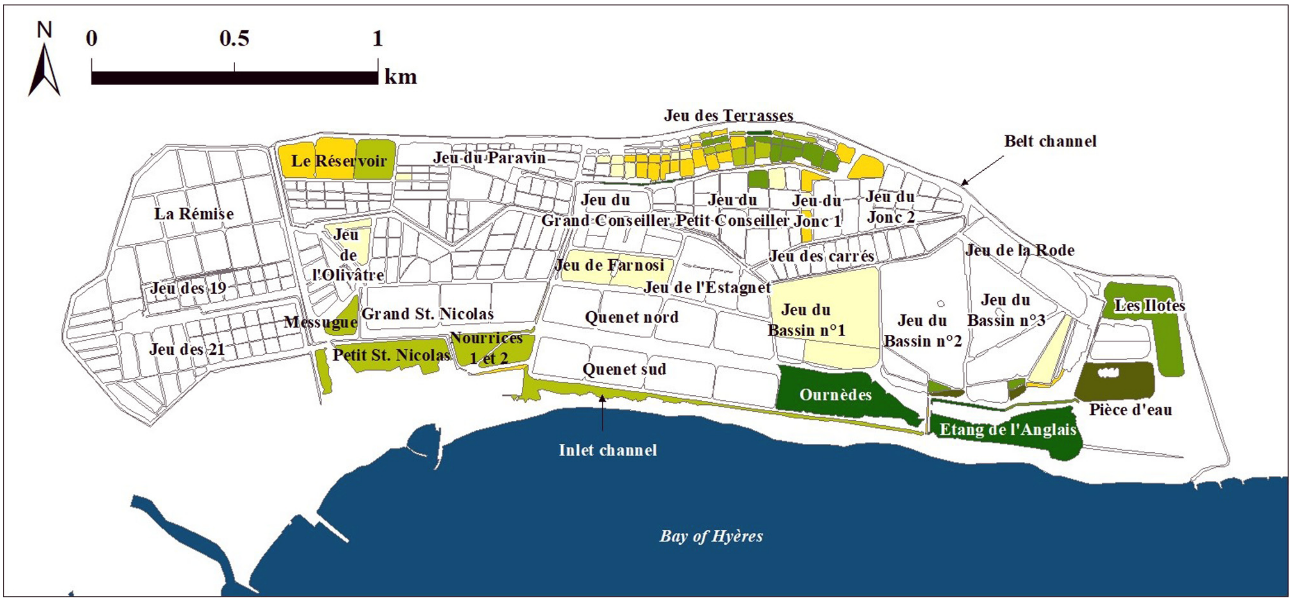


Fig 5. – Covering classes of *Ruppia spiralis* at Les Vieux Salins. The red circle corresponds to the location of *Zostera noltei*.

Table II. – Plant taxa recorded in saltmarshes of Hyères.

	Pesquiers					Vieux Salins		
Taxon	Étang Nord	Belt channel	External ponds	Salt tables	Nourrices	Étang de l'Anglais	Pièce d'eau	Belt channel
Acerabularia acetabulum	x							
Chaetomorpha linum	x	x		x	x			x
Cladophora sp.	x	x	x					x
Lophosiphonia obscura								x
						x		
Ruppia spiralis	x	x	x	x	x	x	x	x
Ulva rigida	x	x				x		x

Table III. – Biomass (gDW.m^{-2}) and flowers and fruits density (mean ± standard deviation) of *Ruppia spiralis* on the two sites (Salin des Pesquiers and Vieux Salins).

	Biomass	Flowers.m^{-2}	Fruits.m^{-2}
Salin des Pesquiers	65.6-267.2	1,017 ± 402	531 ± 630
Vieux Salins	97.2-557.5	1,613 ± 1,067	2,085 ± 1,639

an intermediate covering are the Ilotes (class 4, 25-50 %); Jeu de Terrasses (class 4, 25-50 %). A patch of *Zostera noltei*, Hornemann, was detected for the first time at the beginning of the inlet channel near the Nourrices 1 and 2, its covering is class 2 (red circle, Fig. 5).

Macrophytes community

The Macrophyte compartment is not very diversified; the most abundant taxa are *Chaetomorpha linum* (O.F. Müller) Kützing, *Cladophora* sp. and *Ulva rigida* C. Agardh (Table II). They are opportunistic species, which take advantage of high concentrations in nitrogen and phosphorus.

Of the 5 hydrophytic species identified by Borel (2013), only 2 were detected during the survey carried out in this work: *Ruppia spiralis* and *Lamprothamnium papulosum* (K. Wallroth) J. Groves. Several *Ruppia maritima* Linnaeus specimens were identified by Borel (2013), while no specimen was identified during this survey. In this regard, three assumptions can be made: (i) *R. maritima* meadow has regressed or disappeared due to too salinity and changes in water circulation, its optimum being 0.3-15 g/kg (Verhoeven 1980, Mannino *et al.* 2015); (ii) Borel (2013) allegedly confused *R. spiralis* with *R. maritima*; (iii) it may be that *R. maritima* was not found during our exploration. The criteria used for identification during our survey are those presented by Mannino *et al.* (2015): *R. spiralis* shows a regular and sharp apex, long leaves (15-17 cm), 4-6 carpels with a surface pollination while *R. maritima* has an irregular apex, short leaves (2-3 cm), 2 to 5 carpels and pollination occurs below the surface. These criteria were defined in 2015; they are more complete and they were not available at the time of Borel survey (2013).

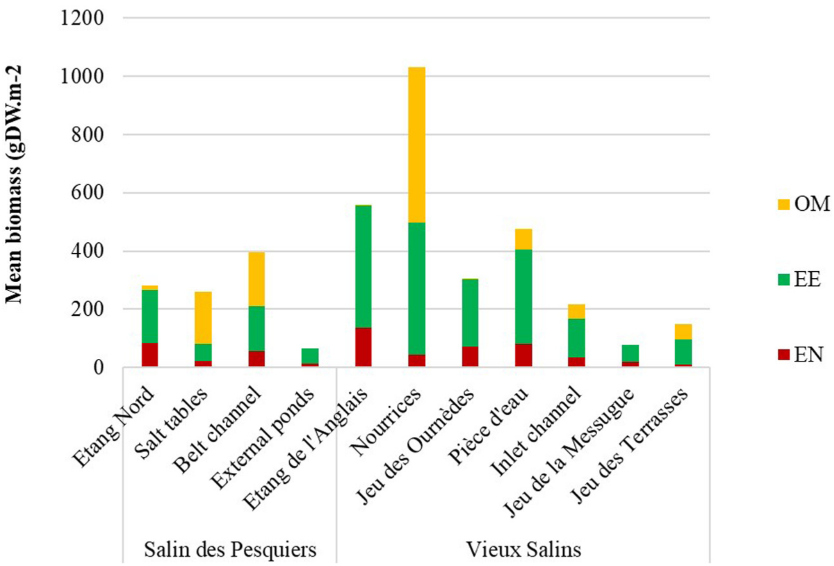


Fig. 6. – Biomass (gDW.m^{-2}) of *Ruppia spiralis* (EN = Endogenous; EE = Epigenous) and other Macrophytes (OM) measured in the different stations sampled in the saltmarshes of Hyères.

A green algae species (Characeae) of heritage value, *Lamprothamium papulosum,* has been identified in a salt swamp surrounded by *Salicornia* bushes within the Salin des Pesquiers (red circle, Fig. 4). *Lamprothamium papulosum* is a species adapted to brackish waters, it develops in a few months from spring, preferably close to the edge of ponds and close to freshwater arrival. Among the Characeae species, *L. papulosum* is the most tolerant species at high salinity levels, it germinates only if the salinity is less than 20. Reproduction cannot occur when salinity is up to 40 g/kg (Réseau Suivi Lagunaire 2011).

Mean dry biomass of *Ruppia spiralis* (including epigenous and endogenous biomass) ranges from

66 to 558 gDM.m^{-2} (Table III). The dry biomass is significantly higher in Vieux Salins (300 gDW.m^{-2}) than in Salin des Pesquiers (156 gDW.m^{-2}) (t test: p-value = 0.03). Endogenous and epigenous dry biomasses present different values according to sampling sites, respectively 8-136 gDW.m^{-2} and 54-454 gDW.m^{-2}. Other macrophytes biomass is also variable ranging from 0 to 535 gDW.m^{-2} (Fig. 6). The flowers and fruits density are also higher within Vieux Salins than Salin des Pesquiers (Table III).

DISCUSSION

Ruppia spiralis seagrass meadow within the saltmarshes of Hyères presents a good conservation status. Its relatively high mean biomass and overall covering correspond to the good health of this species, which find adapted conditions for its development. An increasing in the overall covering of *R. spiralis* meadow is also observed compared to Borel (2013) previous monitoring. However, *Ruppia spiralis* is a halophilous species, the only seagrass species that can thrive in such a range of salinity (*i.e.*, 0-106 g/kg). It seems important to consider that the highest abundance of a species does not indicate a climax configuration. A 100 % cover of *Ruppia spiralis* meadow could be linked to a lack of herbivorous at the scale of the saltmarsh ecosystem (*e.g.*, Anatidae). Moreover, herbivorous birds are known to contribute to the dissemination of submerged Magnoliophyta in other ponds (connected or not) thanks to the seeds contained in the feces (Clausen *et al*. 2002, Figuerola & Green 2002). In the case study of the saltmarshes of Hyères, the heterogeneous abundance of *R. spiralis* is linked to both artificialized water management and environmental condition; grazing by herbivorous birds has been observed on the field and Anatidae populations are known to be abundant in the area (Audevard 2017). The absence of other expected taxa such as *Zostera noltei* can be explained by both inadequate conditions (*e.g.*, high salinity, eutrophication) within the saltmarshes and the decreasing in the population at regional scale (Northwestern Mediterranean) (Pergent *et al*. 2014).

When comparing with other study cases of the Mediterranean Sea, mean biomass of *R. spiralis* within the saltmarshes of Hyères ranges among the highest value (Table IV). Consequently, we can consider that *R. spiralis* meadow within saltmarshes of Hyères is in good conservation status, although the associated plant communities are poorly diversified. Despite the good conditions, the ecosystem shows evidences of weakness, especially the fish compartment. The ponds that show potentially favorable features to increase the nursery role include: Étang Nord, belt channel (Salin des Pesquiers) and Nourrices, Petit Saint Nicolas, Jeu des Ournèdes, Étang de l'Anglais, Pièce d'eau, Ilotes (Vieux Salins) (Figs 2, 3), due to a widespread population of *R. spiralis*, their connection with open sea and the presence of several fish juveniles. However, the salinity and temperature measured in May 2017 show major values for Étang Nord (salinity greater than 60 g/kg). Such salinity range is not suitable for most fish species present in the saltmarshes of Hyères.

One of the objectives of the new management plan should be the maintaining of a salinity below 50 g/kg and a maximal temperature of 30 °C to limit the mortality of most juvenile species during the most critical period, between summer and fall. Even if *R. spiralis* can thrive in such euryhaline and eurytherm conditions (Verhoeven 1980), the enhancing of the nursery role and other lagoon functions of the saltmarshes of Hyères should be based on decreasing the maximum level of salinity. It is therefore important to ensure more regular water renewal for better oxygenation and to avoid too sudden variations in temperature and salinity, in order to promote the sediment mineralization and to limit opportunistic algal blooms such as *Chaetomorpha linum*, *Cladophora* sp. and *Ulva rigida*. In such ways, changes in macrophytes community could occur in a relative short period, conducing for example to the decreasing in halophilous species (*e.g.*, *Ruppia spiralis*) and the increasing in other macrophytes ecosystem engineers (*e.g.*, *Zostera noltei*, *Cymodocea nodosa* (Ucria) Ascherson, *Cystoseira barbata* (Stackhouse) C. Agardh).

CONCLUSION

The heterogeneous macrophyte communities within the saltmarshes of Hyères can be explained by the complex water circulation and the heterogeneous configura-

Table IV. – Dry mass (g.DW.m^{-2}) of *Ruppia spiralis* in other Mediterranean coastal lagoons and salt marshes.

Lagoons/saltmarshes	Biomass of *R. spiralis*	Sources
Camargue (France)	60-189	Verhoeven (1980)
Bahía del Fangar (Spain)	150-330	Calado and Duarte (2000)
Ichkeul Lagoon (Tunisia)	4-369	Casagranda and Boudouresque (2007), Shili (2008)
Smarlacca Valley (Italy)	52-411	Azzoni *et al.* (2001)
Hyères salt marshes	**66-558**	**Present work, Massinelli *et al.* (2017)**
Tancada, Ebro Delta (Spain)	61-656	Menéndez (2002)
Fra Ramon (Empordà, Spain)	95-802	Gesti *et al.* (2005)

tion of ponds and channels (depth, surface-area) of both sites (Salin des Pesquiers and Vieux Salins). *Ruppia spiralis* meadows present an overall good health status and dynamic, according to biometry descriptors and an increasing cover since the beginning of the environmental management in 2001.

These first data on the plant component of the ecosystem are the first step towards developing an ecosystem-based approach for saltmarshes of Hyères based upon a conceptual model of the socio-ecosystem (Massinelli *et al*. 2017, Astruch *et al*. 2019, 2020). This approach aims to improve the conservation and the management of the sites, taking into consideration the entire ecosystem rather than certain iconic taxa (Boudouresque *et al*. 2020), in the frame of the European Marine Strategy Framework Directive (MSFD) (Laffoley *et al*. 2004).

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