LIFE AGROWETLANDS II

Smart water and soil salinity management in agro-wetlands

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Scientific report

Monitoring project impact on the natural and semi-natural habitats, plant communities and water quality
Subaction C.2.1

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Introduction

The project area is located in a narrow strip of land between two large coastal brackish wetlands: “Valli di Comacchio” in the north and “Pialasse della Baiona” in the south (Fig. 1). This land strip includes a large cropland area close to the coast, where Agrowetlands II project was implemented, and is surrounded by several seminatural areas, mostly wetlands, that are protected and actively managed for nature conservation. The protection is due to the occurrence of one of the largest waterbirds population in Europe, occurring in the Po Delta, and of several habitats shortlisted in the Annex 1 of the Habitat Directive, mostly associated with brackish plant communities. In addition to the two largely protected brackish wetlands north and south of the cropland strip, the project area borders with “Valle della Canna” in the inland SW part of the project area, a large freshwater wetland belonging to “SCI/SPA IT4070001 Punte Alberete e Mandriole”. The project area finally includes the “SCI/SPA IT4070002 Bardello”, consisting of a large brackish wet meadow and the SCI “IT4070004 Pialasse Baiona, Risega and Pontazzo” that is a recent extension of the larger “Pialasse della Baiona” wetland to include abandoned crops under natural succession. The SCIs are managed by Parco Regionale del Delta del Po Nature Reserve (Po Delta Park).

1. SCI/SPA IT4070001 Punte Alberete e Mandriole
2. SCI/SPA IT4070002 Bardello
3. IT4070004 Pialasse Baiona, Risega and Pontazzo

Fig. 1. The project area

The marine intrusion in the ground water, due to the close proximity to the coastline, and the extension of large superficial brackish water bodies around and within the project area are a threat for the cropland. If freshwater water were not available for irrigation, this cropland would most likely evolve into a salt marsh. The threat posed by salinization here is therefore much stronger than the impact that fresh water irrigation, as experimented by the project in a few plots in this area, might have on brackish ecosystems.

To assess the impact that the irrigation practices experimented by the project had on the seminatural habitats, plant communities and water quality, there are therefore important factors that have to be considered, that are independent of the project actions and have a stronger impact than the project on the seminatural wetlands surrounding the project area, and can hide the effects of smart irrigation, especially during the short time project.

1) Brackish and saline seminatural wetlands are so large compared to the experimental fields in which the irrigation practices have been implemented that is very unlikely that the experimented irrigation can have modified habitats, plant communities and water quality in such water bodies.

2) Freshwater ecosystems are declining all over the world because of eutrophication, pollution, invasive species, unsustainable water use, modified flow, etc. The seminatural freshwater wetlands surrounding the project area are upstream of the project and are in a state of degradation. Merloni

and Piccoli (2007) documented the extinction of submersed and floating plant communities from these wetlands, and an excessive habitat fragmentation for wet meadows communities compared to their species inventories of 2001 (Merloni and Piccoli; 2001). These authors describe changes in water quality, especially in turbidity, organic solids concentration, and saltwater upspringing from the close brackish wetlands. Like in most eutrophicated wetlands in the world, the increase of nutrients has changed water chemistry and oxygenation status, and has facilitated the establishment of fast growing plants, like reeds, that have outcompeted oligo and mesotrophic communities, and established large monospecific stands. Eutrophicated wetlands tend to host the similar communities dominated by the common reed *Phragmites australis*, not only in the project area but all over the world (Eller et al. 2017). Despite the decrease in biodiversity, reeds habitats are important nesting sites for waterbirds, for this reason reeds dominated wetlands are conserved by the region Emilia-Romagna (Bassi et al. 2015, Regional Determinations no. 13910 of 31/10/2013 and no. 2611 of 9/3/2015), and are important habitats to conserve and manage for waterbirds life. The natural reversion to more diverse communities and species is very unlikely either in the short or long time. The beneficial or negative effects that irrigation might have had in such freshwater wetlands are therefore negligible in the time frame of the project and subordinate to the resolution of global environmental problems, the first of which is water eutrophication.

3) The seminatural wetlands within and surrounding the project area are managed for nature conservation (https://ambiente.regione.emilia-romagna.it/it/parchi-natura2000/rete-natura-2000/strumenti-di-gestione/misure-specifiche-di-conservazione-piani-di-gestione). The management consists in water regulation, periodic flooding and mowing for the conservation of wet meadows. Such a management is put in place during and at the end of the summer, and hides any possible effect that irrigation practices carried out during the summer may have had on plant communities and habitats that might have established after irrigation. In addition, the project area is also managed for agriculture, farming, irrigation, mechanization, hunting. Disturbance due to mowing is very intense, especially in the summer and in the autumn, and this limits the possibilities for wild plants communities to establish and communities to evolve within the project area, making the monitoring of irrigation effects challenging even in the cropland area.

For these reasons the environmental impact of the irrigation according to the DSS developed by the project on the seminatural wetlands defined in the project proposal is very uncertain, and definitely changes are not detectable during the project time. Our monitoring efforts were therefore diverted to the environment in the cropland area. We focused on the habitats that host wild plant communities in the crops landscape, including hunting wetlands, drainage channels and abandoned crops, that, on the small-scale, could directly experience some of the effects of irrigation, and are under the risk of salinization if irrigation were not performed.

Materials and Methods

The areas that were monitored during the project are indicated in Fig.2 and described in Annex 1.

Fig. 2. Sampling sites. The numbers refer to the sites described in Annex 1. Abandoned crops (A), channels (C), ditches (D), freshwater wetlands (W). REF.1 is the freshwater seminatural reference sites at Valle della Canna and REF.2 is the brackish seminatural reference site at Bardello.

We monitored water salinity, plants and invertebrate communities living in the substrate. The surveys were done in 2017, 2018 and 2019 as part of Agrowetlands monitoring activities and were object of two specific reports concerning the invertebrate communties (Zanni 2019) and water salinity and habitats (Ferroni 2019) that are synthesized here.

The closest SCI/SPA wetlands close to the project area were used as biodiversity references to compare our sites to, and identify the biodiversity potentially associated with our sites, that could be affected by irrigation. The SCI/SPA that are in the project area, or bordering with the project area, and were considered, are:

- "SCI/SPA IT4070001 Punte Alberete e Mandriole" is a system of freshwater wetlands. Valle della Canna is one such wetland bordering with the project area.
- "SCI/SPA IT4070002 Bardello" is a brackish meadow
- "SCI "IT4070004 Pialasse Baiona, Risega and Pontazzo" is a recent extension of the large "Pialasse della Baiona" wetland that includes crops that were abandoned from agriculture because of soil salinization

Salinity was measured monthly in the period February-November with a CTD-10 sensor (Decagon) that measures electric conductivity (EC). The probe was put in the water or in a jar water sample when the sites were not directly accessible. The measure was repeated in at least 3 different spots in the water, at a depth of at least 10-20 cm depending on water depth at the sampling sites, or at least 50 cm in the channels with higher flow.

The survey of the vegetation was done by inventorying the plant species occurring in the monitored areas. We referred to the annexes of the Habitat Directive 92/43 and to Bassi et al. (2015) to identify habitats as indicators of the biodiversity potentially associated with the habitats occurring in the project area, and

evaluate the evolution in the plant communities that could be affected by the irrigation practices suggested by the project.

The invertebrate community was sampled with the proportional multi-habitat method (Buffagni & Erba 2007), i.e. quantitative samples in 0.5 square meter-plots proportional to the number of microhabitats occurring in the sampled area, and within a reach of 15 m. A net of 500 µm mounted on a frame of 0,23x0,22m and an extendable pole of 4 m (Squbla Aquaculture) was used for scraping the bottom of the sediments to a depth of about 15 cm and the benthonic epiphytic community (Ghetti 1997). The microhabitats that were sampled are lime substrates with abundant organic matter and clay substrates, whereas the epiphytic community samples were obtained by scraping *Phragmites australis* stems, that was the most common and abundant species occurring at all sampling sites, upwards from the bottom. The net was emptied in 150 cc transparent lexan jars with removable bottom. The sampled invertebrates were identified alive whenever possible and stored in plastic jars and eppendorfs in 90% ethanol. In the lab, the samples were vacuum sieved through 500 µm nets to remove sediment and plant debris, and the animals were finally observed under the stereo-microscope. The cleaned samples were stained with Rose Bengal to facilitate sorting and identification operations. Identification was done with the support of taxonomic keys and could reach the family level. Given the low number of taxa that were sampled repeatedly through three years of project, and the high similarity of the communities sampled in the different sites, tested with the Bray-Curtis index (Bray & Curtis 1957), we realized that the index of Biological Integrity (ISI), as a measure of biological water quality, and as indicated in the project proposal, was a redundant indicator of the poor water conditions at the sampled sites.

Results and discussion

Freshwater wetlands or “chiari”

The Italian word “chiari” refers to clearings in the vegetation in which artificial freshwater wetlands have been realized to attract gambling birds for hunting. Such wetlands are important freshwater resources in the saline cropland, but are only temporary. They provide freshwater habitats to wildlife, increase the freshwater surfaces in the saline cropland area and buffer saline water intrusion in the water table. Because of the management exclusively addressed to the hunting activities, such wetlands are maintained wet only during the hunting season, i.e. in the autumn and in the winter, and dry out in the summer when their saline mitigation effects would be most needed.

The water in these wetlands is freshwater, however it can turn into brackish water with EC that can reach 6-7 dS/m in the months of September and October, depending on the inlet water, on evaporation that can still be very high when the wetlands are rewet, and the EC conditions and depth of the ground water at the end of the summer (Fig. 3).

Because of the long drought period, true aquatic vegetation (like hydrophytes) cannot establish permanently in these areas. In addition, vegetation is mown at the end of the summer, before the wetland are rewetted, limiting the establishment of aquatic plants further. The aquatic flora is very similar in all such wetlands and consists of a limited number of species (Table 1). The dominant resident species is *Phragmites australis* that can tolerate drought and moderate salinity (Eller et al. 2017). Other common plants species are rhizomatous species like *Scirpus sylvaticus* and *Schoenoplectus lacustris* that have underground organs to survive adverse conditions and mowing. Occasionally freshwater species like *Alysma plantago-aquatica, Butomus umbellatus, Ranunculus sceleratus* and even the hydrophyte *Glyceria fluitans* can be observed in such wetlands during the wet season, together with more salt-tolerant species like *Schoenus nigricans* and *Ranunculus peltatus*. Because of the dominance and permanence of *Phragmites australis* and other less frequent tall-statured grasses (*Typha latifolia*), the plant community of this habitat can be classified with the EUNIS code C3.2 “Water-fringing reedbeds and tall helophytes other than canes”.

Fig. 3. EC measured in some of the freshwater wetlands and ditches in the project area during the summer.

Only site 2b.W (Annex 1; Fig. 4) can be classified as a wet meadow dominated by *Eleocharis palustris* and other rushes (*Scirpus* and *Schoenoplectus spp*.). Despite the drought period, this habitat is quite stable, likely because the soil is kept humid by superficial ground water. This habitat benefits also from being in close proximity of another larger wetland, that attracts all attention as a hunting location.

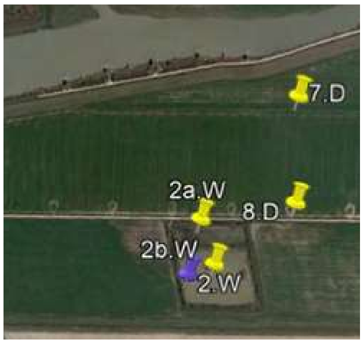

Fig. 4. Detail of sampling site 2.W. 2a.W is a wet meadow and 2b.W is a wetland.

The sites that we visited in Valle della Canna (SCI/ZPS IT4070001 Punte Alberete and Valle Mandriole) were more diverse in plant communities than those in the hunting wetlands within the project area. However the water-fringing reeds were the dominant habitat also here, at least in the closest part of the wetland to the cropland. The aquatic communities described by Merloni and Piccoli (2001) of submersed and floating macrophytes that have become quite rare in this wetland, including species like *Ceratophyllum demersum* that was once very common in this wetland (Merloni and Piccoli, 2007), have been replaced by the invasive water creeping *Ludwigia peploides* native to Central and South American, that was very abundant in our sampling sites especially in 2019. Valle della Canna also hosted a large stand of *Typha angustifolia* (Merloni and Piccoli, 2001) that the same authors could not find any more already in 2007 (Merloni and Piccoli, 2007).

Table 1. List of the plant species found in the freshwater wetlands, ditches and abandoned crops in the project area. The sites are very similar among each other and have a law number of species. The list is the sum of the species seen at all sampling sites throughout the project time. Bold species names refer to the most abundant species in these types of habitat.

Freshwater Wetlands	**Ditches**	**Abandoned crops**
Alisma plantago acquatica	*Althea officinalis*	*Arthrocnemum fruticosum*
Butommus umbellatus	***Arthrocnemum fruticosum***	***Aster squamatus***
Cynodon dactylon	*Aster squamatus*	*Aster tripolium*
Eleocharis palustris	*Aster tripolium*	*Atriplex* sp.
Glyceria fluitans	*Atriplex* sp.	*Elymus pycnanthus*
Phragmites australis	*Chenopodium* sp.	*Inula crithmoides*
Ranunculus peltatus	*Elymus repens*	*Inula viscosa*
Ranunculus sceleratus	*Inula crithmoides*	*Juncus acutus*
Schoenoplectus lacustris	***Phragmites australis***	***Phragmites australis***
Schoenus nigricans	***Portulaca oleracea***	*Puccinellia maritima*
Scirpus sylvaticus	*Sueda maritima*	***Salicornia* spp.**
Typha latifolia		*Suaeda maritima*

Like for the flora, the invertebrate community living in the sediment is similar in all wetland communities in the project area and very poor in species (Table 2). The invertebrates of the mud community belong to five generalist taxa: Physidae (Gastropoda), Tubificidae (Oligochaete worms), Chironomidae (Diptera, insects), Corixidae (Heteroptera, insects) and Coenagrionidae (Odonata, insects). These families can tolerate environmental stress, or are able to migrate when the conditions become limiting (like Corixidae) (Tamanini 1979). Chironomidae and Tubificidae can tolerate organic pollution and anoxic conditions (Campaioli et al. 1994). Physidae are represented in these wetlands by *Physella acuta*, an invasive species from South America (Vinarski, 2017). This contingent of species indicates ephemeral and disturbed habitats, and eutrophic water.

Table 2. Invertebrate taxa found in the sediment samples in freshwater wetlands, ditches and channels in the project area, relative to SCIs Valle della Canna (freshwater) and Bardello (brackish water) used as biodiversity references.

CLASS	ORDER	FAMILY	Freshwater wetlands	Ditches	Channels	Valle Canna (REF.1)	Bardello (REF.2)
INSECTA	COLEOPTERA	GYRINIDAE					x
		HYDROPHILIDAE	x				x
	ODONATA	ASCHENIDAE	x				x
		COENAGRIONIDAE	x			x	x
		LIBELLULIDAE	x			x	x
	DIPTERA	CERATOPOGONIDAE	x				x
		CHIRONOMIDAE	x	x	x	x	x
		CULICIDAE					x
		LIMONIIDAE				x	
		STRATIOMYIDAE					x
	HETEROPTERA	CORIXIDAE	x	x		x	x
		NOTONECTIDAE				x	x
		PLEIDAE				x	x
CRUSTACEA	ISOPODA	ASELLIDAE				x	x
	AMPHIPODA	CAMBARIDAE			x	x	
		GAMMARIDAE	x	x	x	x	x
	DECAPODA	PALAEMONIDAE				x	x
	OSTRACODA		x				
GASTROPODA	BASOMMATOPHORA	ANCYLIDAE				x	x
		PHYSIDAE	x			x	x
OLIGOCHETA	TUBIFICIDA	TUBIFICIDAE	x	x	x		x

The epiphytic invertebrate community sampled on *Phragmites australis* stems is richer in species than that in the sediment, however this community is very ephemeral as it disappears every time the vegetation is mown. The epiphytic community includes aquatic invertebrate taxa like Dytiscidae (Coleoptera), Libellulidae (Odonata) and Pleidae (Heteroptera), but includes also ubiquitous taxa like Anthomyiidae and Tipulidae (Diptera) and Elminthidae (Coleoptera) that contribute to increase the biodiversity, although are independent of wetlands ecosystems (Table 3).

The invertebrate community in the wetlands in the project area was not very different from that in Valle della Canna (SCI IT4070001 Punte Alberete, Valle Mandriole) throughout all project time. A few more taxa were found in Valle della Canna, however they are all generalist tolerant taxa like Notonectidae, Paleomonidae (Crustaceans) and Ancylidae (Gastropoda) or associated with eutrophic and anoxic waters like Limonidae (Diptera) and Asellidae (Crustaceans) (Campaioli et al., 1994). Interestingly the community of Valle della Canna was very similar to that of the wetland at site 1.W in the project area, in species composition and diversity. This however is not an indication of better environmental conditions at this site, but rather of disturbed and eutrophic conditions even at Valle della Canna.

The ecology of the invertebrate community sampled in Valle della Canna, as well as in the wetlands, along with the almost monospecific reed stands, indicate that the water conditions have been changing upstream of Valle della Canna since Merloni and Piccoli (2001), independently from the project activities, because of increasing eutrophication and introduction of invasive species. At the end of the summer 2019 Valle della Canna suffered also a severe event of botulism that lead to the death of thousands of aquatic birds. This prompts urgent measures by the Po Delta Park that manages such wetlands and by the Land Reclamation Authorities upstream of the water network to improve water quality and oxygenation status in the freshwater SCIs. Such measures would have a positive effect also on the freshwater quality in the wetlands in the project area.

Table 3. Epiphytic taxa found on *Phragmites australis* stems in freshwater wetlands, ditches and channels in the project area, relative to SCIs Valle della Canna (freshwater) and Bardello (brackish water) used as biodiversity references.

CLASS	ORDER	FAMILY	Freshwater wetlands	Ditches	Channels	Valle Canna (REF.1)	Bardello (REF.2)
INSECTA	EPHEMEROPTERA	BAETIDAE	x				
	COLEOPTERA	DYTISCIDAE	x				
		HALIPLIDAE	x				
		ELMINTHIDAE	x				
		HYDROPHILIDAE					x
	ODONATA	ASCHENIDAE	x				x
		COENAGRIONIDAE	x			x	x
		LESTIDAE					x
		LIBELLULIDAE	x			x	x
		PLATYCNEMIDIDAE					x
	DIPTERA	ANTHOMYIIDAE	x				
		CERATOPOGONIDAE	x				x
		CHIRONOMIDAE	x	x	x	x	x
		DIXIDAE					x
		EPHYDRIDAE					x
		LIMONIIDAE					x
		PSYCHODIDAE					x
		STRATIOMYIDAE					x
		TIPULIDAE	x				
	HETEROPTERA	CORIXIDAE	x	x	x	x	x
		NOTONECTIDAE				x	
		PLEIDAE	x			x	x
CRUSTACEA	ISOPODA	ASELLIDAE				x	x
	AMPHIPODA	CAMBARIDAE		x	x		
		GAMMARIDAE	x	x	x	x	x
	DECAPODA	PALAEMONIDAE			x	x	x
	OSTRACODA		x				
GASTROPODA	BASOMMATOPHORA	ANCYLIDAE				x	x
		PHYSIDAE	x			x	x
		PLANORBIDAE					x
OLIGOCHETA	TUBIFICIDA	TUBIFICIDAE	x	x	x		x

We could not see any direct impact of irrigation on the wetlands in the project area. At the time of the irrigation in 2019 the freshwater wetlands were dry, as well as all ditches close to the wetlands, and the wetlands were distant from the irrigated fields. On the contrary, such wetlands would have a positive effect on irrigation. A different management aimed at maintaining wetlands wet all year around would have positive effects both on irrigation management and biodiversity. Freshwater wetlands would feed groundwater with fresh water all year around and would create buffer zones to saline intrusion, that would contribute to protect soils from salinization, and would benefit agriculture. Superficial water in the wetlands would also be a source of freshwater for irrigation or for reducing irrigation water EC. Permanent water would finally create more diverse aquatic habitats than the existing ones, attracting birds and wild life, and would become refuges for aquatic plant species that are declining in all region, but were occasionally found in these wetlands like *Butomus umbellatus*, *Alisma plantago-aquatica* and the water buttercups (*Ranunculus* sp.).

The irrigation/drainage water network

The channels of the water network have a double function: 1) they transport fresh water for irrigation during the summer and the same channels drain the land during the winter (Cipolla et al. 2018; Lamberti et al. 2018). Because of soil salinization due to marine intrusion and the close proximity of the water table to the surface, the water that is drained from the cropland during the winter is saline, whereas the water that is transported for irrigation is freshwater. The irrigation water indirectly comes from the Po River and is managed by the Land Reclamation authorities to ensure irrigation to agriculture in all region during the dry summer months, and prevent flooding. The water network includes channels of different size, flow and water permanence time. The network is artificial and the channels have a different rank according to their bed size and functions. The primary channels maintain a certain flow all year around, minor channels and ditches reach out the crops and are, instead, filled up with water only when irrigation or drainage are necessary. Irrigation depends on the meteorological conditions and on crops water needs, for this reason the ditches among the crops are often dry during the summer and/or the winter. In addition, irrigation water is often transported through mobile tubes in the summer in order to reduce water loss by evaporation or soil absorbance.

To ensure water circulation all channels are mown once or even twice a year. The vegetation that grows along the shores is dominated by *Phragmites australis* in channels of all orders, and to a minor extent by *Arundo donax*. Both are rhizomatous fast-growing species that can tolerate disturbance associated with changes in water level and quality, and mowing of aboveground plants biomass.

Minor channels and especially ditches are used for water transport only seldom. Most of the year they are either dry or with little stagnating water. Water salinity depends on if they function as irrigation channels or drainage channels, however, if they are not replenished with water, they tend to accumulate the salt water drained from the fields, evaporate and dry out. The stagnating water exceeds 10 dS/m in EC in the month of February and EC can increases up to over 40 dS/M, with peaks of even 80 dS/m in some spots in the months of May and June (Fig. 3, site 9.D). In the warmest months of July and August EC increases further if water is still present or they dry out and are refilled with fresh irrigation water or drained from the irrigated crops. In the autumn EC is over 40 dS/m again. Ditches are the only habitats in the cropland that show the signs of salinization, for the presence of salt-tolerant plants established in the dry channel beds (Table 1).

The most common halophyte in these ditches is *Arthrocnemum fruticosum* sometimes intermingled by isolated patches of *Sueda maritima* and *Inula crithmoides*, and along the shores *Aster tripolium* can be very abundant in some spots, occasionally *Althea officinalis*. In recently disturbed ditches, the dominant species tends to be *Portulaca oleracea,* and in the paths there are patches of *Atriplex* spp. and *Chenopodium* spp. While *Portulaca oleracea* is an annual plant with wide ecological tolerance that is found in many different terrestrial habitats, often as a weed, the other species are specialized halophytes living in coastal marshes, and many of them are plants of habitat “1310 Salicornia and other annuals colonizing mud and sand” and

"1420 Mediterranean and thermo-Atlantic halophilous scrubs (*Sarcocornetea fruticosi*)" of Annex 1 of the Habitat Directive.
The invertebrate fauna of the ditches was not very different from that of higher ranking channels, did not change over the years of our monitoring, and, surprisingly, was not even different from that of the freshwater wetlands (Table 2). The most abundant taxa were Chironomidae, Tubificidae and Gammaridae. These families were represented in these channels by pollution- and anoxia-tolerant taxa, indicating that eutrophication and anoxia are more limiting conditions than salinity in the muds of the water network. In particular *Branchiura sowerbyi*, one of the most abundant Tubificidae taxa in these sediments, is an indicator of polluted water. In one of the largest channels, Canale Rivalone, individuals and exuvias of the invasive Louisiana red swamp crayfish, *Proacambarus clarkii* (Cambaridae), were sampled together with the mud, providing a second explanation for the low invertebrate diversity in the water network. The Louisiana crayfish prays on the invertebrate community and is highly resistant to environmental stress, including extreme temperatures, absence of water, high salinity, and the presence of pollutants, and has been thriving in the Po Plain water ways for more than 40 years (Gherardi, 2006). Surprisingly the epiphytic invertebrate community sampled on *Phragmites australis* stems was poorer in species than the one established in the sediment, likely for the frequent mowing of the shore vegetation to ensure water circulation in the channels all year around. The epiphytic community was represented by the same Chironomidae, Tubificideae and Gammaridae taxa (Table 3). Only Canale Rivalone had additional taxa, Corixidae and Palaemonidae. Palaemonidae includes salt-tolerant taxa, with marine and estuarine species. The same *Palaemon antennarius*, that is the most common freshwater shrimp in the Palaemonidae family, and found also in this area, is common also in estuaries and brackish conditions (d'Udekem d'Acoz 1999).
The draining ditches of the fields in which irrigation was performed in 2019, were colonized by *Portulaca oleracea* at the end of the summer. However, a larger area, that included also an organic soy crop that was not irrigated by the project, was invaded by this species. *Portulaca oleracea* is an annual fast growing C4 plant that can switch to CAM metabolism in draught conditions. These abilities make this species extremely competitive in disturbed and extreme habitats, including salinity, and is a weed for agriculture. Because of its larger distribution in the area than our experimental crop, and signs of recent human activities, the occurrence of this species in the ditches of the irrigated crop was likely associated with disturbance rather than irrigation. However, the transport and the movement of hose-reel irrigation machines to the field for our irrigation activities contributed to disturbance and to the establishment of this weed further. Bringing fresh water to the crops can be challenging in saline areas and the impact of the irrigation machinery that can be put in place can be also relevant.

Abandoned crops

Abandoned crops occur in the most southern part of the project area along River Lamone, that divides the cropland from the brackish wetland "Pialassa della Baiona" (Fig. 2, sites 31.A and 24.C). In its terminal estuarine course Lamone can reach very high EC (44 dS/m was measured in September 2019, 1,2 meters below water surface).
EC is very high in the waters that still drain and circulate in these abandoned crops. In September 2019 it was 33 and 24 dS/m in samples from two independent ditches in this area.
The vegetation is dominated by *Phragmites australis*, that shows high tolerance to brackish conditions in this area, and by halophytes (Table 1). Most saline and previously eroded soils, including also previous bare paths among crops, are covered by succulent mats of *Salicornia* spp. *Salicornia veneta* is a conservation priority species for the EU, and is shortlisted in annex II to the Habitat Directive. (as **Salicornia veneta*). Where the vegetation is more structured, *Salicornia* patches are intermingled with halophilous scrubs of *Artrochnemun fruticosum*, *Atriplex* and *Sueda* spp., and *Inula chritmoides*. Other haplophylous species present in this area are *Aster tripolium* and *Aster squamatus*, *Juncus acutus, Agropyron pycnanthus* and *Puccinellia maritima.* With the exception of *Aster squamatus,* several of these species are found in habitats "1310 Salicornia and other annuals colonizing mud and sand" and 1420 Mediterranean and thermo-Atlantic halophilous scrubs

(*Sarcocornetea fruticosi*)" protected by the Habitat Directive Annex 1, that appear as the natural succession stage of these young succulent communities. In abandoned crops such habitats are well established, abundant and vigorous and have been included in the larger "Pialasse della Baiona" brackish wetland south of the project as SCI "IT4070004 Pialasse Baiona, Risega and Pontazzo", managed by Delta del Po Park (nature reserve) (Piano Territoriale del Parco Regionale del Delta del Po, 2005).
Aster squamatus is an invasive species in Europe introduced from America. It thrives in ruderal habitats with low soil C/N ratio and moderate salinity (Sajna et al. 2014). Given its abundance in the abandoned crops and in some of our sampling sites along the ditches, as well as along the roads, this species is a threat for the evolution of these abandoned crops, but also for the evolution of all cropland in general, should agriculture be abandoned because of salinization. We found *Aster squamatus* also in the adjacent SCI IT4070002 Bardello, but the active management aimed at conserving brackish meadows from *Phragmites australis* expansion in this SCI, i.e. periodic flooding and mowing of the vegetation, indirectly controls also *A. squamatus* and other ruderal species that are also abundant in the abandoned crops (like *Inula viscosa*). The abandonment of agriculture, not accompanied by the establishment of nature protected areas and the application of conservation measures aimed at controlling invasive and ruderal species, could therefore lead to different coastal marshes from those currently protected in the SCIs, and would, at the same time, endanger the existing protected halophilous native communities in the SCIs (Green 2007; Feher 2008). These abandoned crops are too far from our irrigated fields in 2019 to have been impacted by irrigation. However, they show how the cropland would evolve without irrigation and freshwater wetlands.

Conclusive remarks and recommendations

The project area is threatened by salinization. This phenomenon is evident in the abandoned crops, in the ditches, and even from the weeds that can establish in disturbed patches. Irrigation, and even more, the smart irrigation practices proposed by the project are fundamental for maintaining agriculture in this area. The positive impact of irrigation is evident in the possibility as such of cultivating this area. The precision irrigation approach proposed by Agrowetlands to reduce irrigation to protect soils from salinization, and reschedule irrigation events based on crops water needs and freshwater availability, are of extreme importance to maintain healthy soils and productivity in the long term. However, because of the low amount of irrigated water, and the pilot stage of the project that tested smart irrigation according to the DSS developed by the project only in one crop in 2019, the regreening effects, or it is the case to say the "refreshing" effects, could not be observed within the project times. The intense management of the project area associated both with the agricultural activities and water circulation in channels and diches, did further contribute to hide possible effects of the irrigations on the seminatural habitats occurring among the fields. Such effects could have been seen, for example, in the ditches surrounding the irrigated crop, as the occurrence of freshwater plant and invertebrate species, and changes in the monitored communities. But ditches are kept mown to ensure water circulation, and the water that is drained from the crops is brackish, especially if the soil is not abundantly leached by irrigation. For these reasons the effects of irrigation are difficult, if not impossible, to be recorded in these ditches at this stage. Only pioneer and ruderal species with a broad ecological tolerance can colonize such habitats, even if it were freshwater, like *Portulaca oleracea*, that was weedy in the project area at the time of irrigation, and the invertebrate communities that we found that are typical of disturbed environments even at the sediment level.
Halophilous vegetation in other ditches that we visited was likely due to more saline, but also stable conditions, i.e. ditches that are rarely used to transport water. They collect leached brackish water from the crops and slowly evaporate. Salinity can become very high in the summer and only halophytes like *Artrochnemum fruticosum* can live in the muddy beds of such ditches. *Artrochnemum fruticosum* is a robust, perennial plant that can tolerate salt, draught and regrow after mowing. It was the most common species in these habitats and was abundant in the abandoned crops. We can't expect it to be outcompeted by other species in the agricultural area, as long as soils contain salt, even under full Agrowetlands irrigation regime.

Freshwater wetlands are an important and under-exploited resource to counteract salinization in this area. The current management, exclusively addressed to hunting activities, retains at least two ecosystem services that these wetlands could provide that could contribute, along with irrigation, to the "refreshing" of this area, and aid irrigation.

1)The change from temporary to permanent wetlands would create freshwater buffers in the soil and in the ground water (under the wetland) that would keep the salt away from the soil surface. It can be expected that this freshwater buffer would extend to a certain ray around the wetland protecting the soil from salinization. The area benefiting of the buffer effect depends on the size and the amount of water that is inlet into the wetland. As the farmers in this area are the last users of the water provided for irrigation before it is released to the sea, it could be worth to investigate possibilities to keep these existing wetlands wet all year around, and not only for hunting, and even enlarge them. Water supply to these wetlands would be a very limited extension of the service provided by the Land Reclamations Authorities (Consorzio di Bonifica Romagna Occidentale in this area). These wetlands could provide good quality water for irrigation, or the water could be used to reduce EC in the available irrigation water through dilution. The Life project WTORE2 (http://www.wstore2.eu/english.html) included the construction of a freshwater wetland in a similar coastal agricultural setting , not far from Agrowetlands project site, creating a freshwater storage for irrigation. This water constitutes an important available resource that, in the project area, is now wasted.

2) Permanent freshwater wetlands would also contribute to the "refreshing" of the agricultural area, would attract birds and wildlife, and would improve the connections among the SCIs sites of the Nature 2000 Network in this area. The establishment of permanent freshwater vegetation would also improve the water cleaning capacity of the wetlands, and as a result such wetlands would have better water quality than the water presently received for irrigation. Stabile habitats and cleaner water would also support more diverse and specialized invertebrate communities than the existing ones, and this would be a step forward in the direction of environmental requalification, despite the threats of salt and eutrophication.

All in all, a protocol for water management in this area under salinization, shared by farmers, water- and nature managers would improve water use efficiency, agriculture preconditions, and environmental quality. This constitutes a minor effort that can potentially be very beneficial.

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Annex 1. Some of the sampling sites monitored during the project.

Plants	Invert.	Ref.	Short description of the site		Coordinates
1.W	1.W		**Freshwater wetland** Reeds fringe dominated by *Phragmites australis*. Dry from June to August. Mown more than once a year.		44,577689 12,265853
2a.W	2.W		**Freshwater wetland** Reeds fringe with *Phragmites australis, Typha latifolia, Schoenoplectus lacustris, Juncus spp*. Dry in August. Mown once a year. Hunting hut.		44,571906 12,230346
2b.W			**Freshwater wetland** Wet meadow dominated by *Schoenus nigricans* and *Eleocharis palustris*. Mown once a year (*Phragmites australis*).		44,572705 12,229920
3a.W	3.W		**Freshwater wetland** Reed fringe dominated by Phragmites australis and to a minor extent by *Typha latifolia* and *Schoenoplectus lacustris*. Mown once a year. Hunting hut.		44,567503 12.234367

3b.W			**Freshwater wetland** Reed fringe dominated by *Phragmites australis* and to a minor extent by *Typha latifolia* and *Schoenoplectus lacustris*. Dry from April to August. Mown once a year. Hunting hut.		44,567872 12,235828
4.W			**Freshwater wetland** Reed fringe dominated by *Phragmites australis* and *Typha latifolia.* *Lotus corniculatus* covering wet area when dry. Dry from April to August. Hunting hut.		44.543122 12.255136
5.W			**Freshwater wetland** Reed fringe dominated by *Phragmites australis.* Dry from April to August. Hunting hut.		44,548631 12,265004
6a.W			**Freshwater wetland** Former quarry, today fish farm. Privately owned. Up to 6m depth. Reeds fringe dominated by *Phragmites australis* Unknown vegetation management.		44,563192 12,260258

6b.W			**Freshwater wetland** Former quarry, today fish farm. Privately owned. Reeds fringe dominated by *Phragmites australis* Unknown vegetation management.		44,564864 12,262894
6c.W			**Freshwater wetland** Former quarry, today fish farm. Privately owned. Reeds fringe dominated by *Phragmites australis* Unknown vegetation management.		44,566933 12,262414
7.D			**Ditch** Fringes of *Phragmites australis* along the shores. Mown frequently for water circulation		44,575054 44,574056
9.D			**Ditch** Fringes of *Phragmites australis* along the shores. Mown frequently for water circulation		44,575243 12,236989

16.D			**Ditch** Salt crusts in the area. Patches of *Arthocnemum fruticosum.*		44,552198 12,268676
17a.D	17.D		**Ditch** Fringes of *Phragmites australis* along the shores. Mown frequently for water circulation		44°34'23.02"N 12°16'25.22"E
	18.D		**Ditch** Fringes of *Phragmites australis* along the shores. Mown frequently for water circulation		44°34' 7.39"N 12°16'19.10"E
19a.D	19.D		**Ditch** Fringes of *Phragmites australis* along the shores. Mown frequently for water circulation		44°34'16.26"N 12°14'11.52"E

	20.D		**Ditch** Fringes of *Phragmites australis* along the shores. Mown frequently for water circulation		44°33'54.07"N 12°14'13.33"E
	21.C		**Channel** Fringes of *Phragmites australis* along the shores. Mown frequently for water circulation		44°34’28.56”N 12°14’38.13”E
	22.c		**Channel** Fringes of *Phragmites australis* along the shores. Mown frequently for water circulation		44°34'23.59"N 12°14'10.00"E
23a.C	23.C		**Channel** Fringes of *Phragmites australis* along the shores. Mown frequently for water circulation		44°32'29.97"N 12°15'35.78"E
31.A			**Abandoned crops** *Salicornia* spp. on the paths. Most abundant species *Phragmites australis* and *Aster squamatus* SCI IT4070004		44°31'46.87"N 12°15'46.41"E

		REF.1	**Valle della Canna** SCI/ZPS IT4070001 Freshwater *Ludwigia peploides* creeping in the water		44°32'45.50"N 12°14' 5.66"E
		REF.2	**Bardello (South)** SCI/ZPS IT4070002 Brackish water		44°31'53.06"N 12°14'10.70"E