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Ecotones, ecoclines and eco-perturbations: the aquatic flora and fauna of the S'Albufera Natural Park, Majorca, a contribution and review

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Abstract: The S'Albufera Park in Majorca is protected nationally as a Natural Park, as an EU Special Protection Area for Birds (SPA) and as a Wetland of International Importance under the Ramsar Convention. This park is the most extensive area of marshlands in the Balearics at the brackish interface between seawater and freshwater inflow from the hinterland of Majorca. It is suggested that the whole marsh aquatic system is a saline freshwater gradient or ecocline containing a series of ecotones or sharp interfaces between different aquatic and terrestrial habitats changing with time and resulting in a dynamic niches for plants and animals leading to the rich biodiversity of the site. Here, we review some of the existing literature related to the site, particularly concerning the aquatic flora of the brackish water ecocline to which new data are added and the significance of these changing habitat interfaces i.e. ecotones in the present ecology and conservation of the Park.

Keywords: aquatic flora; ecotones; ecoclines; S'Albufera Natural Park; introduced species.

Introduction

The 1700ha of the S'Albufera Natural Park lie on the Bay of Alcudia on the northeast coast of Majorca. The park includes the most extensive marshlands in the Balearics, important not just for their international ornithological value but also for their rich biodiversity. This paper will briefly review ecological contributions to the Park as a whole but concentrating on the fresh water, brackish water, ecoclinal continuum and its contained ecotones, presenting new data to consolidate previous findings.

Ecotones can almost be all things to all men. Livingston in 1903 [1] described an ecotone as "a stress line connecting points of accumulated or abrupt change". Two years later Clements [2] noted the increased productivity of these "tension zones". By the 1950s Weaver and Albertson [3} had widened the ecotone concept to the landscape scale where two patches whit different ecological conditions meet. Natural changes resulting in an ecotonal edge effect may be the result changing geological or pedological conditions, salinity, topography or concomitant meteorological variation. Ecotones induced by human activity may be related to many factors including land reclamation, drainage, controlled burning, pollution, water abstraction or salination. Many ecotones are at least semi-stable in medium to long term but others may develop or be lost due to changing factors such as pollution, natural succession or hydroseral change. A characteristic of many ecotones is their increased internal biodiversity and productivity compared to the habitats they separate, this is frequently called the "edge effect" and the occupants "edge" species. However, in an estuarine or former estuarine system the abruptness of an ecotone is less marked and the gradual transition between saline and freshwater is better described as an ecocline [4], [5].

Albufera is effectively the ecocline between the fertile lands of the Inca-Sa Pobla Plain and the Bay of Alcudia at freshwater-saline interface (Figure.1). The S'Albufera Natural Park includes the largest and most important wetland in the Balearics protected not only by its Natural Park designation but also by being declared "a wetland of international importance" under the Ramsar Convention and an EU designated Special Protection Area. Originally, the present marshes were the catchment delta with an open estuary, but within the last 10,000 years an 8km sandbar has separated what are now the marshes from the sea. The marshes are then, on the macro scale, freshwater-sea water ecotone, a status complicated by the history of the site. Within the site, an ecotonal hierarchy is occurring, representing the terrestrial, riparian, aquatic transition; current and historic land use interfaces, saline transition, agro-chemical effects and other pollution. Some changes in the ecology are neither part of the ecocline nor areas of abrupt change as in ecotones.

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These changes are here designated eco-perturbations and include changes to the hydraulic architecture of the site as well as species appearing to fill niches created by change [6].

Figure 1. View over S'Albufera

S'Albufera has an annual rainfall averaging 630mm but, most of its inflow comes from the often periodic streams of the catchment mainly the Muro and Sant Miquel. providing up to 2400 m^3 per year, underground springs providing up to 3000 m^3 per year of fresh or slightly brackish water and infiltrating seawater. In Roman times the present area of the Albufera marshes had much open water, the estuary, connected to the sea, forming a natural harbour for the Imperial fleet and provided a rich supply of harvested birds for use locally and in Rome. Later the Moors knew the area as "al-buhayra" meaning lagoon and by the seventeenth century, land drainage and reclamation for agriculture began. By the eighteenth century, reclamation had produced a system of ponds, canals and infrastructure such as bridges which supported not just agriculture but also freshwater/saltwater fishery. In the mid nineteenth century, projects were undertaken to drain and reclaim the marshland firstly more minor canals and by the 1860s, the Grand Canal to take the two major water courses directly to the sea. By 1871, over 2000ha had been reclaimed but due to salination and reflooding only 400ha were of use to agriculture. Most areas were eventually abandoned and reverted to marsh. At the end of the nineteenth century, rice growing began but declined until today, it still is a very minor industry because of its rarity and of considerable market value. A factory called Celulosa Hispánica was operating on site from 1938 to 1966 to produce low grade packing paper using in part reeds (*Arundo donax* and *Phragmites australis*) and Great Fen-sedge and saw-sedge (*Cladium marismus*). However, chemical reagents from the factory polluted the canals causing significant deaths in the economically important eel population [6].

The Es Murterar Power Station adjacent to the Park is a 78MW coal fired installation which in the past used two ponds, Es Cibollar and Es Columars for water cooling. This had an inevitable effect on local aquatic ecology as, in the third quarter of the twentieth century, did the 14ha of saltpans at S'Illot. The level of pollution from the power station immediately north of the Park is unknown, but concern exists about the potential hazard of the electricity transmission lines from the station to birds.

The plants of the marshes had great economic importance. Reeds (Figure 2) provided materials for baskets, creels, broom handles, canes used in the orchards and saltpans, material for fencing, roofing, matting and even musical instruments. *Typha latifolia*, Reedmace or Greater Bulrush was widely used in chair making and the larger *Juncus* species (Rushes) were incorporated into fish traps, carpets and baskets. The latter being used to transport early season potatoes to Britain with 200,000 baskets reportedly produced for this purpose in 1932 [6].

Figure 2. Mist net ride through S'Albufera reed bed

Although there is some controlled fishing and harvesting of sedges and reeds, most activity on site revolves around the eco-tourist and conservation education with the surrounding agricultural land and coastal tourism resulting in the over use of ground water with an increased ingress of saltwater into the system and pollution from chemical residues of agricultural, domestic or industrial origin. S'Albufera is therefore an area in a state of constant flux largely due to constantly changing anthropogenic factors creating ecotonal instabilities in the fresh water salt water coastal ecocline.

Materials & Methods

As part of a more widespread ecological survey, the marshes were visited for several successive years in the period from late April to early May. During this period, we had the opportunity to take replicated water samples at equal intervals along the two main channels within the brackish water interface zone shown as A to F and G to M on Figure 3. Moreover, outlying samples for non-saline comparative purposes from a natural spring (point N) were also taken. A - F has some of its flow associated with the island's power station and passes close to former salt pans, now salt marsh. G - M is the main throughflow channel of the marshes. Because of the logistics of transportation to the UK for analysis, 5 x 250ml water samples were taken within plus or minus 5ml of the sample station, combined and then sub-sampled for analytical purposes. Samples were then deep frozen within three hours of collection and subsequently analysed by atomic absorption spectrophotometry (Perkin Elmer 703) for sodium (as a proxy for salinity), calcium, magnesium, and by colorimetry for nitrate nitrogen (Seal AutoAnalyser) by the Earth Sciences Analytical Laboratory at Cardiff University. Aquatic plants were sampled using a three pronged grab attached to a line. Plants were identified with chlorophyta kindly confirmed by J. A. Moore.

Figure 3. The S'Albufera marshes showing the end points of each transect, spring water sample (N) and vegetation features. Most of the unshaded areas within the marsh are dominated by reeds or sedges**.**

The sample from the spring at point N (Fig. 3) gave values for sodium of 750 ppm, Magnesium 115 ppm, Calcium 155 ppm, and nitrate Nitrogen 0.15 ppm. pH values measured at points G, J and M were 7.2, 6.8 and 8.1 respectively.

Results

Table. Distribution of dominant plants and elements along transect A – F

Sample points → Species ↓	A	B	C	D	E	F
Ruppia maritima / cirrhosa			■	■		■
Cladophera glomerata				■	■	
Chara vulgaris / hispida		■	■	■		
Zannichellia pedunculata			■			
Potamogeton pectinatus	■	■				
Nitrate N ppm	2.5	2.2	2.3	2.0	0.7	0.3
Sodium ppm	2100	1800	1900	2000	1700	1200
Calcium ppm	170	175	160	150	175	270
Magnesium ppm	110	100	170	160	130	170

Table 2. Distribution of dominant plants and elements along transect G – M

Sample points → / Species ↓	G	H	I	J	K	L	M
Entromorpha / Blidingia							■
Ruppia maritima / cirrhosa						■	■
Chaetomorpha linum					■	■	■
Cladophera glomerata			■	■	■	■	
Chara hispida				■	■		
Potamogeton pectinatus	■	■	■				
Potamogeton crispus		■					
Myriophyllum spicatum	■	■					
Nitrate N	12	3.1	2.5	2.0	2.6	2.1	1.1
Sodium ppm	1200	700	800	750	850	900	4000
Calcium ppm	300	150	110	150	160	180	340
Magnesium ppm	180	115	120	95	105	110	450

Discussion and Review

In 1989 *The Albufera Initiative for Biodiversity (TAIB)* was established to give support to the newly established *Parc Natural de s'Albufera*. With the collaboration of Earth-watch Europe from 1989 – 1997 plus the involvement of several eminent scientists, a sound baseline for the study of the biodiversity of the marshes was established and formally continued until TAIB funding ended in 2013 [7].

The basic results of the study show the gradual ecocline from fresh to salt water across the marsh. The aquatic and riparian flora is relatively well studied particularly by Martinez-Taberner with descriptions of the submerged and floating macrophytes in 1986 adding *Ceratophyllum submersum* and *Zannichellia pedunculata* to the Balearic flora[8]. In 1988 a survey of the Characeae (stoneworts) added *Chara aspersa, Chara major, Tolypella glomerata* and *Nitellopsis obtusa* to the island's flora in addition to the previously recorded *Chara canescens, C. connivens, C. galiodes, C. globularis, C. vulgaris,* and *Lamptothamnium papulosum* [9]. Other well recorded non-vascular plants include *Hildenbrandia rivularis, a* thalloid freshwater red alga, the mosses *Platyhypnidium ripariodes* and *Octodiceras fontanum.* Martinez-Taberner and Moya [10] used Principal Component Analysis (PCA) with 17 parameters to explore the relationship between the submerged vascular plants and water chemistry in S'Albufera. Their findings generally reflect the saline ecocline with *Ceratophyllum submersum* having low saline tolerance and *Ceratophyllum demersum* with a significant positive distribution in relation to nitrate concentration whereas *Ruppia cirrhosa and Ruppia maritime* var *brevirostris* are significantly associated with increased salinity, a property common to the autecology of all *Ruppia* species [11]. The analyses showed other species with a wide distribution in relation to these variables, notably *Myriophyllum spicatum, Najas marina, Potamogeton crispus, Potamogeton pectinatus* and *Zannichellia pedunculata.* The body of knowledge is still in enrichment concerning the aquatic flora of the Balearics particularly in relation to the genera *Potamogeton* and *Stuckenia* [12]. The species referred here and in other works earlier as *Potamogeton pectinatus* is now recognised as *Stuckenia pectinata* and together with *Potamogeton coloratus, Potamogeton crispus, Potamogeton nodosus* and *Potamogeton pusillus* are comprised in the known species of the Potamogetonaceae in Mallorca.

Interest in the hydrobiology of Mallorca dates back to at least the 1950s [13] but by the time Baron et al [14] investigated the hydrological conditions of this area they noted that, since the 1970s shallow irrigation wells have been replaced by deep drilled wells with more abstraction and more plans to meet the demands of tourism and urban areas [15]. Candela et al [16] have examined the combined effects of climate and management on the hydrological resources of the entire Inca-Sa Pobla hydrological region of the island relating the future demand of 14.8Mm^3/annum to the sustainable abstraction scenario of 8.1m^3/annum. This results in reduced ground water discharge to the Park and presumed increased sea water intrusion into the surface springs (“ullals”) (Figure 4) and, as we can note, “deep saline groundwater from the marshland is chemically and isotopically seawater”. Here then, localized salinity change over relatively short periods are likely to produce small local ecotones, possibly similar to the botanical response of road verges to deicing road salt in the UK. Although detailed data are not available, it is thought that increased saline run off from farmland is a result of increased irrigation and the consequent evaporative concentration of salt. Salt is not the only anthropogenic input into the marshes, as nitrogen and phosphorous leach from adjacent farmland and with elevated silica lead to eutrophication of water courses on the landward side of the marsh e.g. point G . These seasonal physico-chemical were followed in running waters of Albufera as nutrient enrichment increases phytoplankton as measured by Chlorophyll α, where the spatial and temporal distribution of phytoplankton were examined in these channels and in a separate report and shows the decline in chlorophyll α from the land towards the sea. This indicates a reduction in eutrophication reflected in a phytoplanktonic decline due, in part, was suggested, to the filtration properties of the coastal marshes probably including cation exchange[17,18].

Figure 4. Surface spring (Ullal), S.Albufera

In 1986 Martinez-Taberner published an aquatic example of contamination in the marshes and in 1990 discussed the limnological criteria for the rehabilitation of these coastal marshes[19]. Other more recent studies related to water contamination in the island come from Adrover concerned about the effects of two decades of waste water irrigation[20]. Rodriguez-Navas followed the pathways of pharmaceutical residues in the aquatic environment of Mallorca noting that treated domestic wastewater supplying some 30% of total water demand in Mallorca together with landfill leachates result in the introduction of pharmaceuticals to ground water aquifers [21]. An oil spill in June 2001 of 14,500 litres of low sulphur fuel into a salt water lagoon within the marsh illustrates the unpredictable nature of many pollution sources which in this case due to prompt remediation work resulted in “total recovery of the affected area”[22].

It is important for the Park and the wider environment that s’Albufera should act as a sink for the nitrogen and pesticides coming from agricultural activity as well as phosphates from sewage treatment. Some contaminants are removed by plants and others by sedimentation. The extensive and environmentally important *Posidonia oceanica* seagrass beds in Alcudia bay are adversely affected by high nutrient loads and their decline reduces not only their habitat value but also their protective effect for coastal dunes and beaches [23]. The littoral ecotone between the dunes and the sea where *Posidonia* remains, create the irregularities of contour allowing sand dune accretion, but beach management for tourists clears functional ecotone removing the sand gathering undulations.

The open water situation on the marshes has almost continually changed from extensive open water prior to the nineteenth century through steam powered hydraulic pump drainage in the 1860s and the reclamation of over 2000ha of dry land by 1871. Due to salinisation and reflooding, only a net gain of some 400ha drainage were left but, gradually more extensive vegetation was observed prior to restoration post Natural Park designation when open water areas increased to 350ha (29%) by late twentieth century. Largely because of the abstractive pressures on groundwater supplies and the resulting saltwater intrusions, the balance of salinity in the marshes have changed over time with a 16–22% increase in salinity in the canal system, temporary ponds and permanent brackish lakes between 1983-1985 and 1994–1998 [23]. Phosphate concentrations have little changed between the two periods whereas maximum nitrate/nitrite concentrations were considerably higher in 1999 at 48.4 mgl^{-1} compared to a maximum in 1983-1985 of 2.3 mgl^{-1}. These changes are reflected in species distribution. *Ceratophyllum demersum, C.submersum, Callitriche stagnalis Ricciela fluitans* and *Lemna minor* and *L. gibba* might have been expected to increase with increasing nitrogen levels but they did not, probably because of the concomitant increase in salinity. On the other hand, the increased salinity has favoured the spread of *the* Cladophoraceae throughout the marsh in places filling the water column *Cymodocea nodosa* (Slender sea grass) and some marine algae have increased in the seaward side of the marsh.

Eutrophication has increased the abundance of some species including *Typha domingensis, Typha angustifolia, Chaetomorpha, Cladophora, Enteromorpha intestinalis* and, in more anoxic conditions, *Spirogyra* [7]. Controlled grazing, creation of open water areas and modified canal flows have not only increased habitat diversity for wildlife but also created sharp ecotones between reed bed and water or grazed and ungrazed marsh. The biological description of such often temporary interfaces can change quite rapidly as with shallow waterbodies varying in salinity due to evaporation or impeded flows, resulting in modified water chemistry (op cit). Turbidity from cattle trampling and aquatic eutrophication also alters plant habitat by light attenuation. Bottom growing species such as charophytes will decline in such conditions whereas species of the upper water column such as *Enteromorpha* sp. and *Potamogeton pectinatus* gain advantage (op cit). The history of the marshes since at least the nineteenth century has been anthropogenic with concomitant continual ecotonal changes.

Of the approximately 29 species of fish utilising the ditches and canals, few complete their life cycles within freshwater systems such as the introduced three-spined sticklebacks (*Gasterosteus aculeatus*), mosquito fish (*Gambusia affinis*), bleak (*Alburnus alburnus*) and carp (*Cyprinus carpio*) [7]. Other species utilise the marshes for only part of their life cycles such as sea bass (*Dicentrarchus labrax*), m*ullet (Mugil spp),* red mullet *(Mullus spp),* gilthead bre*am (Sparus aurata)* and eel *(Anguilla anguilla).* Although these species are all still present. They occur in much smaller numbers than previous decades because of eco-perturbations due largely to physical changes, to water control regime in the marshes and the impact of tourist growth on the inshore breeding grounds of species which breed in the sea. In the 1940s, in a 5-6 night period, it is reported that seventeen tonnes of eels and 400-500 kilos of gilthead bream were caught in the marshes quantities unheard of in modern times[6].

I would suggest that some of the greatest eco-perturbations in the marshes have been the non-native species which have been added, particularly to the aquatic fauna. When I first visited the marshes in the mid 1980s as part of The British Trust for Ornithology's bird ringing teams quantifying the ornithological importance of the marshes, I noted numerous freshwater crayfish in fish traps in the ditches but was not able at that time to identify them. In the first edition of the S'Albufera Guidebook, the presence of only *Cambarus affinis* was reported which would now be designated as *Orconectes limosus* (the American spiny-cheek crayfish) (igure 5) [6]. This may or may not have been a correct designation of the species but on returning to the marshes in 1992, I was able to identify the crayfish exuviae which I collected from the ditches as *Procambarus clarkii* (American red swamp crayfish) a species of worldwide introduction and considerable economic value[24].

Figure 5. Fish and American red swamp crayfish in S'Albufera fish trap

In the 2006 edition of the Guidebook reference is made to the "recently introduced Louisiana crayfish"formal recognition of the presence of *P. clarkii*. It is probable that the presence of these crayfish may have increasingly important impacts on the ecology and economy of the marshes and their hinterland. Correia reported that in Portugal *P. clarkii* is considered a pest because it burrows into banks and levees causing damage and water loss in rice fields as well as damage to the rice plants themselves [25]. This could be a potential problem in s'Albufera but in Portugal and elsewhere it seems to play a key role in "terrestrial, riverine and trophic interactions since it is a prey item of diverse predators". In s'Albufera, Salazar found that cattle egrets (*Bulbulcus ibis*) and little egrets (*Egretta garzetta*) opportunistically fed on *P. clarkii* and it would seem likely that other species which Correia found to feed on these crayfish such as night heron (*Nycticorax nycticorax*), grey heron (*Ardea cinerea*) and purple heron (*Ardea purpurea*) and which pass through s'Albufera also utilise this food resource. Indeed, it is highly probable that many bottom feeding waterfowl, viperine snakes (*Natrix maura*) and piscivorous fish will also utilise the resource [26].

The clear eco-perturbations created by freshwater crayfish get more complex when other introductions to the s'Albufera fauna are considered. The European pond turtle (*Emys orbicularis*) (Figure 6), once exported in large quantities to mainland Catalonia from s'Albufera and Minorca, may itself be an ancient introduction, as is the case of the green (or Balearic) toad (*Bufo viridis*) [27]. S'Albufera may be adversely effected by more recent reptilian introductions of the American red-eared terrapin (*Trachemys scripta*) and possibly others of its genus together with Spanish pond turtle (*Mauremys leprosa*) [28]. Small crayfish may well form part of the diet of these reptiles but the situation regarding *E. orbicularis* was precised by Ayres as follows.

"The main problem in the natural park (for *E. orbicularis*) is the increasing populations of *Trachemys scripta* and other alien turtles, as well as the modifications of aquatic habitat caused by invasive exotic species (common carp, red-swamp crayfish)" [29,32.].

Figure 6. *Emys orbicularis* , S'Albufera

Conclusion

The freshwater to saltwater ecocline is usually a gentle gradient common to estuarine systems which will change with tide, time and human intervention. Within such a system are ecotones, sharper interfaces between habitats, infrequently developing characteristics not found on either side. These ecotones may be natural e.g. a freshwater spring issuing into a saline environment or due to human activity accentuation demarcating two habitats e.g. salt pans abutting non-saline habitat. However, the changing diversity of habitat fired largely by human intervention, creates and re-creates eco-perturbations some of which can almost be regarded temporal ecotones, Unoccupied niches created by spatial change into which highly adaptive species such as crayfish and terrapins easily slot. On the surface, the Natural Park's admirable work in creating and maintaining habitat and so increasing biodiversity is ironically aided by some invasive species changing trophic interactions grazing the aquatic flora and ultimately providing calories for top, particularly avian, predators together with visitor experience of the Park. Undoubtedly these marshes have been well studied and documented but theirs will undoubtedly be a continuing story of biological gain and loss in an ever changing environment

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