The aquatic beetles (Coleoptera) of the Parc Natural de s'Albufera de Mallorca, Balearic Islands

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SOCIETAT D'HISTÒRIA NATURAL DE LES BALEARS

Riddiford, N. J. and Foster, G. N. 2020. The aquatic beetles (Coleoptera) of the Parc Natural de s'Albufera de Mallorca, Balearic Islands. *Boll. Soc. Hist. Nat. Balears*, 63: 9-22. ISSN 0212-260X. e-ISSN 2444-8192. Palma (Illes Balears).

An investigation into the aquatic coleopteran fauna of the Parc Natural de s'Albufera de Mallorca in 2011-15 was compared with historical records prior to the 21st Century. Forty-nine taxa were encountered, 19 of them not previously recorded. They included several of a species cited only once before in Europe; a further 4 were confirmed or new species for the Balearic Islands. Locations were sampled in all parts of the Parc including sites for which historical data were available. The two sets of data revealed changes in species composition and abundance with losses post 20th C coinciding with deteriorated water quality. Socio-economic developments including intensive farming at the periphery, water treatment plants not keeping pace with a burgeoning human population and overabstraction of ground water during prolonged periods of drought were identified as contributing factors to increased eutrophication, salinisation and point source pollution. Radical catchment-wide measures are required to return the Albufera waters to favourable ecological condition. The study sets a repeatable baseline for monitoring ecosystem recovery.
Key words: *the Albufera de Mallorca, aquatic Coleoptera, monitoring, changes, water quality.*

ELS ESCARABATS AQUÀTICS (COLEOPTERA) DEL PARC NATURAL DE S'ALBUFERA DE MALLORCA, ILLES BALEARS. Una investigació sobre la fauna de coleòpters aquàtics de Parc Natural de s'Albufera de Mallorca en 2011-15 va ser comparada amb els registres històrics anteriors al segle XXI. Van ser registrats quaranta-nou tàxons, 19 d'ells no citats anteriorment. Aquests incloïen diverses espècies només citades anteriorment només una vegada a Europa; altres 4 van ser confirmades o noves per a les Illes Balears. Van ser mostrejades localitzacions de totes les parts de Parc, inclosos punts per als quals es disposava de dades històriques. Els dos conjunts de dades van revelar canvis en la composició i abundància d'espècies amb pèrdues posteriors a el segle XX, coincidint amb el deteriorament de la qualitat de l'aigua. El desenvolupament socioeconòmic basat en l'agricultura intensiva a la perifèria, les plantes de tractament d'aigua que no mantenen el ritme d'una població humana creixent i la sobre-extracció d'aigua subterrània durant períodes perllongats de sequera es van identificar com a factors contribuents a l'augment de l'eutrofització, la salinització i la contaminació de fonts puntuals. Es requereixen mesures radicals en tota la conca per tornar les aigües de l'Albufera a condicions ecològiques favorables. L'estudi estableix una línia de base repetible per monitoritzar la recuperació de l'ecosistema.
Paraules clau: *s'Albufera de Mallorca, coleòpters aquàtics, seguiment, canvis, qualitat de l'aigua.*

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Recepció del manuscrit: 19-febrer-2020; revisió acceptada:26-febrer-2020.

Introduction

Aquatic beetles are essential components of wetland ecosystems. Apart from their contribution, as grazers or predators, to ecosystem functioning they can also be used as bioindicators of water types and condition (Ribera *et al*., 1993). Because many have the power of flight, aquatic beetles have high potential mobility. Aquatic beetles have generalist species which cope with a range of water types and water quality (Denton, 2007). However, others have specific ecosystem requirements which restrict them to a much narrower range of habitats or conditions (Picazo *et al*., 2012). It can be assumed that changes, whether it be in vegetation, water type or water quality, will most strongly affect those species with narrow tolerance levels. Should changes occur, we may predict that water beetles capable of flight could adapt to that situation by dispersal to more suitable sites. This may, however, lead to a loss of species from part or all of the wetland. Such a loss has serious implications for a protected area whose ethos is to manage and conserve its biodiversity.

Recognising this dilemma, the Directorate of the The Albufera Natural Park, Mallorca requested The Albufera International Biodiversity group (TAIB) to incorporate a water beetle study in its long-term monitoring project *The Albufera Initiative for Biodiversity*. A series of objectives was identified: to assess the current status of the group within the Parc; to identify sources of historic information and publications; to evaluate changes which may have occurred; to investigate the communities of the various sites and habitats - such as canals and lagoons, coastal and interior locations; and to offer commentaries for each species on their ecological and conservation characteristics, particularly in relation to water quality.

The wetland of s'Albufera de Mallorca (hereafter shortened to *the Albufera*) has undergone a series of changes since the site was drained in the 19th century. That event was momentous for the Albufera, but the events of the last 30 years or so have contributed further marked changes to the habitats and water quality of the wetland. Management of the wetland has gone from agricultural and hunting/fishing exploitation to works related to environmental conservation; the inland periphery of the Parc has been turned over to intensive cultivation driven by large scale and continuing nitrogen-based agricultural chemical inputs to the land; an explosion of tourism has taken place along the coastal belt; high levels of water extraction from the catchment have coincided with periods of prolonged drought; and phosphate intrusion into the water bodies derives from water treatment plants of insufficient capacity to cope with the much larger input of waste water from a vastly increased population, particularly during the tourism season.

These events have contributed to major changes in water quality and aquatic habitats related especially to nutrient enrichment, saline intrusion and contamination from occasional and chronic waste water escapes.

How have these changes affected the aquatic environment? It is very difficult to assess this without recourse to previous data. By good fortune, we have access to historical information for the aquatic beetles. This has provided a starting point

from which to assess the current status of these groups.

Study area

The Albufera de Mallorca is the largest wetland in the Balearic Islands, Spain, and is separated from the sea by a belt of coastal dunes (Fig. 1). A total of 1688 ha, incorporating approximately 1450 ha of wetland and over 200 ha of dune, received designation as a *Parc Natural* by the Balearic Government in 1988.

The wetland zone comprises a complex network of canals – products of a failed attempt to drain the site in the 1860s (Picornell & Ginard, 1995) – extensive reed beds and shallow, open lagoons. The wetland is largely freshwater but with anomalies including extensive saltmarsh and saline lagoons in the north-east and a small set of abandoned salt pans in the south-east. An incomplete set of fossil dunes, remnants of an ancient coastline formed during the Riss glacial some 100,000 years before present, runs through the wetland parallel to the coast (Barceló & Mayol, 1980; Servera, 2004). This along with an intact band of coastal dunes, Es Comú (Fig. 1), and a strip of dune woodland on the southern border add diversity to the *Parc*. The entire area is flat and at or just above sea level. The *Parc*'s eastern boundary abuts Alcudia Bay, whose coastal strip has been heavily developed for tourism.

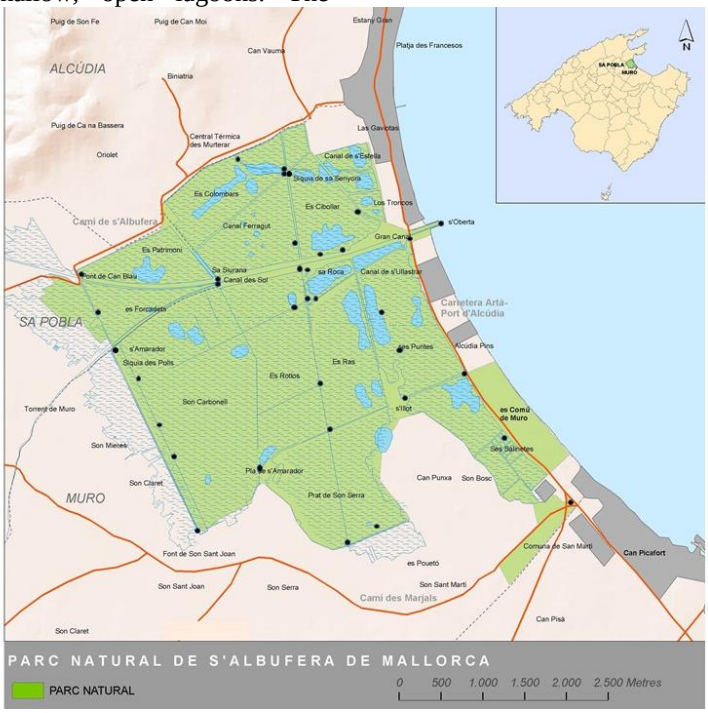

Fig. 1. The Parc Natural de s'Albufera, Mallorca, its regional context and locations sampled, 2010-2015.

Fig. 1. *El Parc Natural de s'Albufera, Mallorca, context regional i localitats mostrejades, 2010-2015.*

Methodology

The basis of the study was survey work in 2010-2015, combined with bibliographical research and reference to unpublished data and voucher material prior to those dates.

The primary survey was conducted between 18th May and 6th June 2010 and consisted of sampling as many sites as feasible throughout the Parc (Fig. 1) A second survey was conducted between 19th September and 16th October 2010 when sites not accessed during the spring were targeted. Repeat visits were also made to sites considered to be of high conservation or biodiversity interest. Less intensive sampling in spring and autumn 2011-2015, along with data collected during other fieldwork activities, added to the information base. Sampling was done using fine mesh nets, a weed drag, manual disturbance of the water edge and hand-searching through aquatic vegetation and debris. The information base was boosted by captures during normal light trapping activities for moths and in a Malaise Trap set alongside wetland habitats to intercept flying insects.

The main bibliographical resource was an unpublished list by GNF gathering together historical information relating to water beetles for all the Balearic Islands (Foster, 2008; and see Appendix 1 for dated sources). The list cited all known, verified records which for the Albufera ranged from 15th April 1900 to January 1994. The historical data extracted from that list was restricted to those locations considered with a reasonable level of confidence to fall within the study area. All study area locations listed in Foster (2008) were sampled at least once during the 2010 survey.

Voucher material captured during the survey period, 2010-15, were reviewed and determined by GNF, in a few cases following expert opinion from European specialists. Much of the material was subsequently deposited in the Parc's Bishop Laboratory collection.

The current data, defined as the period 2010-2015, and the historical records provide two datasets, which conveniently divide into pre-21st and post-20th century time blocks. The historical records are used as a baseline resource for assessing the current status of water beetles at the Albufera and changes which may have occurred.

Results

Prior to the current study, the species list for the Albufera was 43 from 8 families (Foster, 2008; Table 1). The current study recorded 49 taxa from 10 families, of which 19 taxa were additions. At the end of 2015 the total list of aquatic beetles known for The Albufera de Mallorca comprised 62 taxa from 11 families. Thirty (48%) species were recorded in both time periods and 70% of those recorded historically were re-found. The current study detected three extra families but failed to find Haliplidae.

Current and historical records are summarized in Table 1 below.

A total of 35 locations were sampled in the 2010 survey (Fig. 1). At least one water beetle was encountered at 22 (63%) of the sampling sites, spread widely throughout the Parc. Numbers varied but included 28 from four species at Prat de Son Serra, a location not known to have been sampled historically.

Historical data were far less precise for locations. The most imprecise were *Albufe-*

Table 1. Complete list of the Aquatic Beetles recorded from The Albufera de Mallorca.
Taula 1. *Llista completa dels escarabats aquàtics citats a s'Albufera de Mallorca.*
Note: 'Current' comprises 2010-15 records, supplemented by TAIB records from 2004 & 2005; 'Historical' are pre-21st Century (source: literature/G.N.Foster Balearic Checklist, 2008 unpublished)

Gyrinidae	Current	Historical
Gyrinus caspius Ménétries, 1832	**X**	**X**
Gyrinus urinator Illiger, 1836	**X**	**X**
Haliplidae		
Peltodytes rotundatus (Aubé, 1836)		**X**
Haliplus lineatocollis (Marsham, 1802)		**X**
Haliplus mucronatus Stephens, 1828		**X**
Noteridae		
Canthydrus diophthalmus (Reiche & Saulcy, 1855)		**X**
Noterus laevis Sturm, 1834	**X**	**X**
Dytiscidae		
Laccophilus hyalinus (De Geer, 1774)		**X**
Laccophilus poecilus Klug, 1834	**X**	**X**
Hydrovatus cuspidatus Kunze, 1818	**X**	**X**
Hyphydrus aubei Ganglbauer, 1892		**X**
Hygrotus parallellogrammus (Ahrens, 1812)		**X**
Bidessus pumilus (Aubé, 1838)	**X**	**X**
Hydroglyphus signatellus (Klug, 1834)		**X**
Hydroglyphus geminus (Fab., 1792)	**X**	
Nebrioporus ceresyi (Aubé, 1838)		**X**
Metaporus meridionalis (Aubé, 1836)	**X**	**X**
Hydroporus analis Aubé, 1838	**X**	
Hydroporus limbatus Aubé, 1838	**X**	**X**
Hydroporus tessellatus (Drapiez, 1819)	**X**	**X**
Liopterus haemorrhoidalis (Fab., 1787)	**X**	**X**
Agabus biguttatus (Olivier, 1795)	**X**	
Agabus bipustulatus (Linnaeus, 1767)	**X**	
Agabus conspersus (Marsham, 1802)	**X**	**X**
Agabus didymus (Olivier, 1795)	**X**	
Ilybius meridionalis Aubé, 1836	**X**	**X**
Rhantus suturalis (MacLeay, 1825)	**X**	**X**
Colymbetes fuscus (Linnaeus, 1758)	**X**	**X**
Hydaticus leander (Rossi, 1790)	**X**	**X**
Cybister lateralimarginalis De Geer, 1774	**X**	**X**
Eretes griseus Fabricius, 1781	**X**	**X**
Helophoridae		
Helophorus brevipalpis Bedel, 1881	**X**	
Helophorus fulgidicollis Motschulsky, 1860		**X**
Helophorus illustris Sharp, 1926	**X**	**X**
Hydraenidae		
Ochthebius deletus Rey, 1885	**X**	**X**
Ochthebius dilatatus Stephens, 1829	**X**	**X**
Ochthebius nanus Stephens, 1829	**X**	

Ochthebius subinteger Mulsant & Rey, 1861	**X**	
Ochthebius viridescens Ieniştea, 1988		**X**
Hydrophilidae		
Berosus hispanicus Küster, 1847	**X**	**X**
Berosus jaechi Schödl. 1991	**X**	**X**
Helochares lividus (Forster, 1771)	**X**	**X**
Paracymus aeneus (Germar, 1824)	**X**	**X**
Hydrophilus pistaceus Castelnau, 1840	**X**	**X**
Limnoxenus niger (Gmelin, 1790)	**X**	**X**
Enochrus ater (Kuwert, 1888)	**X**	**X**
Enochrus bicolor (Fab., 1792)	**X**	
Enochrus halophilus (Bedel, 1878)	**X**	
Enochrus melanocephalus (Olivier, 1792)	**X**	
Enochrus politus Küster, 1849		**X**
Enochrus segmentinotatus (Kuwert, 1888)	**X**	
Cymbiodyta marginella (Fab., 1792)	**X**	**X**
Coelostoma hispanicum (Küster, 1848)	**X**	**X**
Coelostoma orbiculare (Fab., 1775)		**X**
Cercyon subsulcatus Rey, 1885	**X**	
Scirtidae		
Contacyphon laevipennis (Tournier, 1868)	**X**	
Contacyphon lindbergi (Nyholm, 1948)	**X**	
Limnichidae		
Bothriophorus atomus Mulsant & Rey, 1852	**X**	
Heteroceridae		
Heterocerus fenestratus (Thunberg, 1784)	**X**	
Heterocerus flexuosus Stephens, 1828	**X**	
Heterocerus fossor Kiesenwetter, 1843	**X**	
Dryopidae		
Dryops algiricus (Lucas, 1849)	**X**	**X**

Note: Balfour-Browne (1979) reported *Ochthebius subpictus* under the name *O. mulleri*, describing it as very common in the Balearic Islands, particularly at the Albufera, based on specimens he collected himself. Jäch (1991) sank *muelleri* (=*O. subpictus* subspecies *deletus*) as a synonym of *subpictus*, which he recognised as having a wide distribution with two forms, intermediates of which occur in the Balearics. However, Jäch (2015) later accepted subspecies status for *deletus* and Villastrigo *et al*. (2018) reinstated it as a species distinct from *O. subpictus* on the basis of gene sequence data.

ra and *Albuferze* (Tenenbaum, 1915). *Alcudia* and *La Puebla* may have incorporated records from within study area boundaries but could refer equally to locations some distance away and thus were excluded from this study. The only sites of sufficient detail to allow some level of comparison were Es Colombars, Es Rotlos, Font de Son Sant Joan, Salinas (Ses Salinetes), Ses Puntes and Sa Roca. Tables 2a-2f compare those historical records with species found at the same six sites during the 2010 survey.

The location with the highest number of taxa historically was Ses Salinetes with 13 species. Ses Puntes with 11, Font de Son Sant Joan with 9 and Es Rotlos with 8 taxa contrasted with just 3 from Sa Roca and one from Es Colombars. The totals from the current survey were markedly lower at the

first three sites; two from Ses Salinetes, one from Ses Puntes, 1 from Font de Son Sant Joan. Other totals were 6 from Es Rotlos, 4 from Sa Roca and 3 from Es Colombars. In all cases, there was no or little species overlap with the historical record. The extent to which these are true comparisons is assessed in the Discussion section below.

Table 2. Taxa at six sites surveyed historically and for this study.
Taula 2. *Taxa citats a 6 localitats estudiades històricament i en el present treball.*

Table 2a. Es Colombars

Species	Current (at site)	Historical (at site)
Bidessus pumilus	X	
Berosus hispanicus		X
Enochrus bicolor	X	
Enochrus melanocephalus	X	

Table 2b. Es Rotlos

Species	Current (at site)	Historical (at site)
Laccophilus hyalinus		X
Laccophilus poecilus		X
Metaporus meridionalis		X
Liopterus haemorrhoidalis		X
Cybister lateralimarginalis	X	
Limnoxenus niger	X	X
Coelostoma hispanicum		X
Coelostoma orbiculare		X
Bothriophorus atomus	X	
Dryops algiricus	X	X

Table 2c. Font de Son Sant Joan

Species	Current (at site)	Historical (at site)
Gyrinus caspius		X
Gyrinus urinator		X
Peltodytes rotundatus		X
Haliplus lineatocollis		X
Haliplus mucronatus		X
Noterus laevis		X
Laccophilus hyalinus		X
Colymbetes fuscus		X
Ochthebius dilatatus	X	
Ochthebius deletus		X

Table 2d. Salinas (Ses Salinetes)

Species	Current (at site)	Historical (at site)
Hydroglyphus signatellus		X
Metaporus meridionalis		X
Hydroporus limbatus	X	X
Liopterus haemorrhoidalis		X
Agabus conspersus		X
Rhantus suturalis		X
Hydaticus leander		X
Ochthebius deletus		X
Berosus hispanicus		X

Berosus jaechi		**X**
Paracymus aeneus		**X**
Limnoxenus niger		**X**
Cymbiodyta marginella	**X**	
Dryops algiricus		**X**

Table 2e. Ses Puntes

Species	**Current (at site)**	**Historical (at site)**
Laccophilus poecilus		**X**
Metaporus meridionalis		**X**
Hydroporus tessellatus		**X**
Liopterus haemorrhoidalis		**X**
Rhantus suturalis		**X**
Helophorus illustris		**X**
Ochthebius dilatatus		**X**
Ochthebius deletus		**X**
Berosus hispanicus	**X**	
Paracymus aeneus		**X**
Limnoxenus niger		**X**
Dryops algiricus		**X**

Table 2f. Sa Roca

Species	**Current (at site)**	**Historical (at site)**
Gyrinus caspius	**X**	
Gyrinus urinator	**X**	
Noterus laevis		**X**
Hygrotus parallellogrammus		**X**
Agabus biguttatus	**X**	
Ilybius meridionalis	**X**	
Cymbiodyta marginella		**X**

Note: aquatic sampling only; excludes species entering Sa Roca light trap.

Discussion

The main objectives of the study were to ascertain the current status of water beetles in the wetland of the Albufera and compare it with previous knowledge of the group. The first was achieved by targeted sampling in 2010 and follow up studies in the following five years. Taxa were determined or verified by GNF with further opinion sought from other European experts for taxa he was unable to determine with confidence. The source for historical data was Foster (2008), an unpublished annotated list of all Balearic records, based on his own studies and an extensive literature search.

Our survey focused on adults. Apart from the very distinctive larva of *Cybister lateralimarginalis*, non-adult stages of aquatic Coleoptera at the Albufera are poorly known and larvae were not retained. Sampling in the current study was conducted in spring and autumn to cater for seasonal differences in life cycles. No sampling was done in summer or winter but January sampling in 1990 and 1994 (Foster, 2008) demonstrated that adults of some Dytiscidae were active then. Sampling was inclusive of all wet habitat types within the Parc boundaries. This included a series of tiny, shallow depressions in sea defence boulders at the tip of s'Oberta which provided an intermittent habitat for adult *Ochthebius deletus* and adult and larvae of

Ochthebius subinteger when filled with rain and/or coastal spray sea water.

The majority of captures were already known for the Balearic Islands (Valladares & García-Avilés, 1999; Ribera *et al*, 1997; Foster, 2008; Millán *et al*., 2014). Two, however, were new: *Contacyphon laevipennis* and *Contacyphon lindbergi*. Tenenbaum (1915) recorded *Cyphon ochraceus* Stephens from the Albufera, but, in the absence of vouchers, this name cannot safely be assigned to a *Contacyphon* species as currently understood. *Enochrus melanocephalus*, listed as "requiring confirmation" by Foster (2008), was confirmed. Three captures of the *Hydroporus planus* taxonomic group – incorporating *H. analis* Aubé and *H. decipiens* Sharp,(Fery & Petrov, 2005) – were determined as *H. analis* on the basis of the taxonomy of Fery & Petrov (2005). The *Cercyon* taxa are poorly known but *C. subsulcatus* may also be new. *Enochrus segmentinotatus* followed shortly after first citations for the Balearic Islands (Arribas *et al*., 2012). In all, the current study added 19 species to The Albufera de Mallorca biodiversity list (see Table 1).

The most notable of these was *Contacyphon lindbergi*. Previously known only from Algeria and Morocco, males were taken in a mercury vapour trap at Sa Roca during the nights of 30th September and 2nd October 2010, these, along with new records from Portugal (Klausnitzer, 2010; Foster & Riddiford, 2011), significantly extended the range into Europe. Further males were taken in the same trap on 24th October 2011, 11th September 2014 and three a week later on 18th September, while a female, probably this species, was taken on 28th September 2012. Like many water beetles capable of flight, it could be a migrant dispersing across the Mediterranean from North Africa. However, the series of records raises the strong possibility that this is a previously overlooked or recently established component of the Mallorcan water beetle community.

Amongst the other captures, *Cymbiodyta marginella* is considered to be rare in the Iberian context (Millán *et al*., 2005). It is therefore noteworthy that this species was recorded historically for the Albufera and we confirmed that it was still present during our study. It was found at five sample sites suggesting it is widespread and well established in the Parc, at least in the areas of fresher water.

Changes

Using the historical sources (Foster, 2008) to evaluate current status and change of the Albufera's aquatic beetle communities has many limitations. Disparate intensity of sampling effort weakens direct comparisons; and undated or locality deficient records limit the value of historic data in understanding change at specific sites. Many pre 2000 records refer generally to *Albufera*, *s'Albufera* or its Polish equivalent, *Albuferze* (Tenenbaum, 1915). These were useful in establishing what species had been encountered but little more. Fortunately, reference was made to six specific localities which were also sampled in the current study (Table 2a-f). In addition, dates were provided, giving a measure of intensity in terms of number of visits.

Despite the number of visits to the six sites being similar or greater in the current survey (Table 3), totals were markedly lower than historically at three sites: Ses Salinetes, Ses Puntes and Font de Son Sant Joan. At all sites, there was no or little species overlap with the historical record. This result suggests radical change and loss over the intervening period.

Table 3 Number of visits at six localities**.**
Taula 3. *Nombre de visites realitzades a 6 localitats.*

Site	Historical	Current
Es Colombars	1 (5 Jan 1994)	3
Es Rotlos	1 (6 Jan 1990)	5
Font de Son Sant Joan	2 (20 Jul & 28 Jul 1983)	3
Ses Puntes	1 (6 Jan 1990)	4
Ses Salinetes	1 (7 Jan 1990)	3
Sa Roca	1 (5 Jan 1994)	4

Since the Parc was declared, in 1988, the aquatic fauna (and flora) have had to contend with high eutrophication and increased salinisation of the Albufera waters – two major stresses in the ecosystem. A landmark study on macrophytes in the 1980s (Martínez Taberner, 1988) demonstrated that the process of eutrophication was already under way but a number of sites were still mesotrophic or even oligotrophic. By the last decade of the 20th century, the Parc's water quality monitoring data demonstrated this was no longer the case. Thus it seems likely that the major period of change has its roots in the 1980s.

The most significant events in the 1980s were:

1) major changes in agricultural land management after Spain entered the EU;
2) marked summer population increase as tourism grew.

With entry to the EU, access to better funding and modern agricultural methods saw large increases in the use of nitrogen-based chemical fertilisers in the farmland of Sa Pobla plain. During the same period, human population growth put more and more pressure on waste water treatment plants. The outcome has been excess nitrates and nitrites from farmland and phosphates from accidental waste water leakages (from hotels and inadequate sewage facilities) entering the hydrological system.

Agricultural and tourism intensification also resulted in higher demands on the aquifer. This coincided with periods of drought when below average rainfall was recorded in a number of years in the Albufera water catchment area. Lowering of the water table due to an imbalance between water extraction and recharge promotes saltwater intrusion from the sea and salinity levels rising as the aquifer's freshwater cap retreats (Galimont *et al*., 2003; Custodio, 2010; de Louw *et al*., 2011; Stofberg *et al*., 2017).

Over the course of the survey, a number of species were only taken in the light trap or Malaise trap. Thus we cannot be certain whether they were local or had flown in from farther afield. However, water beetles were not a major component of light trapping sessions away from the wetland in coastal Es Comú or Es Comú d'Abaix during and prior to this study (TAIB data, unpublished). This suggests that many of the captures within the wetland were on local dispersal flights.

The ability of most water beetles to disperse by flight means that they are able to colonise new sites and re-colonise sites from which they have previously been lost –provided the conditions which removed them in the first place have improved. Larvae are far more restricted in their ability to escape deteriorating conditions.

Only those already adapted to the new conditions (such as brackish-water species) and those with survival mechanisms allowing them to adapt to the changed conditions are able to persist. Those with low tolerance levels will be lost.

Improvement of water conditions for the benefit of aquatic Coleoptera and other components of the freshwater ecosystem will require catchment-wide measures, currently just at the planning stage (Maties Rebassa, Parc Director, *pers. comm.*). In the meantime, it is important to recognise and ensure the continued viability of those sites which still have an interesting fauna. The current study identified important refuge sites. They included the waters leading from Font de Son Sant Joan and freshwater pools at Son Serra. Both derive much of their water from the aquifer rather than surface run off.

Font de Son Sant Joan is mentioned in all the historic literature (e.g. Martínez Taberner, 1988) as a key site for rare aquatic biota, flora as well as fauna. This area remains of interest, in part because of stronger water movement into the parc than elsewhere and in part because it remains an area of relatively fresh water. We were not able to complete a full survey as an extensive pool, known to be the location for some of the important biota mentioned in the literature, is outside the Parc on private land. A survey of this pool is urgently needed but can only be achieved if official permission is sought and obtained.

Son Serra is an area of freshwater on the southernmost border of the Parc, some distance from the most intensive agricultural plots. There is not much standing water accessible, making it difficult to sample, but results indicate that this is another refuge area, at least for aquatic Coleoptera – with five species detected.

Further evidence of the relevance of water quality is gauged from a very small site at the edge of the Parc close to the roundabout on the outskirts of Ca'n Picafort. This small triangle of land was shallowly flooded in October 2010 and held three species of water beetle. The site was distant from agricultural land and canals feeding into the Parc and was thus fed directly from the groundwater. On subsequent visits the site was overgrown by dense *Phragmites* and open water was not found. However, this overlooked site could be returned to open water, at least at times of high groundwater levels, with careful management.

The site with the highest number of species historically was Ses Salinetes. This site has experienced greater ecological change than anywhere in the Parc. For the period 1950-1979 (Massutí *et al*., 2005) it was a site of commercial salt production and comprised a series of shallow pans filled with water pumped directly from the sea. With the demise of production the site very slowly reverted from hypersaline through brackish to its current state of largely fresh water. There was incursion too of emergent macrophytes though areas of shallow water were still present (in 2015). The northern pan remains without vegetation into current time but has suffered from frequent incursions of waste water from leaking pipes associated with coastal infrastructures and is heavily polluted – to the extent that water quality monitoring was suspended to protect the health of the monitoring team. Data suggest that the aquatic Coleoptera community was at its most diverse during the years of transition from saline to fresh and prior to the pollution events. A management regime which permanently addresses the problem of point source pollution and maintains areas of open water may yet return Ses

Salinetes to levels of diversity registered in 1990.

Some or all of the eleven species recorded historically at the Albufera but not during the current survey may still be present undetected. However, a brief assessment has been made of possible ecological requirements which may have affected their populations at the Albufera. Two species, *Graptodytes flavipes* and *Ochthebius viridescens*, may prefer more oligotrophic water conditions, though the latter also copes with brackish waters. Three species, may yet be found as they cope with brackish waters (*Dytiscus circumflexus* and *Ochthebius aeneus*) or saltmarshes (*Helophorus fulgidicollis*). The ecological requirements of the others (see Table 1) are insufficiently known to assess changes in water quality.

The future

One outcome from our aquatic beetle sampling has been the establishment of a named collection. This collection is lodged in the Bishop Laboratory at the Albufera to provide a resource for further studies including detection of new arrivals and re-locating species apparently lost.

It also forms a reference in support of repeat surveys. Our priority was to choose sites already established for other monitoring (e.g. water quality sampling points). In addition, we have extended these to include additional sites including all locations cited in the historical record. Sampling points were photographed and UTM references taken to aid re-location of sites in future repeat surveys.

The survey sets a baseline from which to measure future change in the Albufera water beetle community. However, the use of this group as indicators of water quality will only be effective if catchment-wide measures to return the Albufera waters to favourable conditon are enacted.

Conclusions

Our study increased the number of water beetles recorded at The Albufera de Mallorca by 50% (20 taxa). However, 11 species (18%) recorded historically were not found and there were some notable negative changes at sites monitored pre and post 2000. Our analysis suggests that declines and losses occurred, or were accelerated from the 1980s, by local changes including eutrophication related to agricultural intensification and increasing saline intrusion related to a lowering of the groundwater during a period of heightened demands on the aquifer. Maintaining the ecosystem in good hydrological balance is required to promote the maximum diversity of habitats and aquatic Coleoptera species. Current species include several known to cope well with brackish conditions. Access to oxygen is generally not as big a problem for this group though it may have an effect on some larvae. A bigger issue may be a reduction in submerged macrophytes, which provide an important micro-habitat for a number of species. Macrophyte species ill-adapted to eutrophication have been lost while the cover of remaining submerged vegetation has been compromised by the effects of suspended matter and phytoplankton reducing clarity and light penetration in the canals. The current study has set a repeatable baseline for water beetles to be used as indictors of ecosystem recovery. But this will only be of value if catchment-wide management measures are enacted to return The Albufera de Mallorca to favourable ecological condition.

Acknowledgements

We gratefully acknowledge Manfred Jäch, and Ignacio Ribera for advice on the determinations of difficult beetles; Pedro Abellán for advice on sources for the wider Iberian status of water beetles; the sampling teams of volunteers and supervising scientists from The Albufera International Biodiversity group, with special mention to the late Rob Strachan; and the Balearic *Conselleria de Medi Ambient* and Directorate of the *Parc Natural de s'Albufera de Mallorca* for their support and permission to operate in the *Parc*. Marina Pons and Macu Férriz are thanked for translations.

References

Arribas, P., Velasco, J., Abellán, P., Sánchez-Fernández, D., Andújar, C., Calosi, P., Millán, A., Ribera, I. & Bilton, D. T. 2012. Dispersal ability rather than ecological tolerance drives differences between lentic and lotic water beetles (Coleoptera: Hydrophilidae). *Journal of Biogeography*, 39: 984-994.

Balfour-Browne, J. 1979. Studies on the Hydraenidae (Coleoptera) of the Iberian Peninsula. *Ciênc. Biol. (Portugal)* (1978), 4: 53-107.

Barceló, B. & Mayol, J. 1980. *Estudio Ecológico de la Albufera de Mallorca*. ICONA/Departamento de Geografía, Universidad de Palma de Mallorca.

Cardrona, D. F. 1872. *Catálogo metódico de los Coleópteros de Menorca*. Mahón.

Custodio, E. 2010. Coastal aquifers of Europe: An overview. *Hydrogeology Journal* 18: 269-280.

de Louw, P. G. B., Eeman, S., Siemon, B., Voortman, B. R., Gunnink, J., van Baaren, E. S. & Oude Essink, G. H. P. 2011. Shallow rainwater lenses in deltaic areas with saline seepage. *Hydrol Earth Syst Sci.,* 15: 3659-3678.

Denton, J. 2007. *Water Bugs and Water Beetles of Surrey*. Surrey Wildlife Trust, Woking, Surrey, UK.

Fery, H. & Petrov, P. N. 2005. Nomenclatural, taxonomic and faunistic notes on selected species of *Hydroporus*. *Russian Entomological Journal*, 14: 251-262.

Foster, G. N. 2008. Balearic Checklist of Aquatic Coleoptera*. Unpublished.*

Foster, G. N. & Riddiford, N. J. 2011. *Cyphon lindbergi* Nyholm (Col., Scirtidae) new for Europe. *Entomologist's Monthly Magazine*, 147: 47-48.

Galimont, A., Candela, L., Barón, A. & González, C. 2003. *Evolución de la intrusión salina en el Llano de Inca-Sa Pobla, Mallorca*. Tecnología de la intrusión de agua de mar en acuíferos costeros: Países Mediterráneos, IGME Madrid.

Jäch, M. A. 1991. Revision of the Palearctic species of the genus *Ochthebius* Leach VI. The *marinus* group (Hydraenidae, Coleoptera). *Entomologica Basiliensia,* 14: 101-145.

Jäch, M.A. 2015. Hydraenidae. pp. 130-162 in Löbl, I. & Löbl, D. (eds). *Catalogue of Palaearctic Coleoptera. Volume* 2/1. *Hydrophiloidea-Staphylinoidea*. Leiden: Brill.

Klausnitzer, B. 2010. Neufunde von Scirtidae (Coleoptera) aus der Westpaläarktis und Ergänzungen zum "Catalogue of Palaearctic Coleoptera. Volume 3 (Scirtidae)" II. *Entomologische Nachrichten und Berichte* 54: 25-30.

Martínez Taberner, A. 1988. *Característiques Limnològiques de S'Albufera de Mallorca.* Tesi Doctoral, Departament de Biologia i Ciències de la Salut, Universitat de les Illes Balears, Palma.

Massutí, C., Rebassa, M. & Perelló, B. 2005. *Parc natural de s'Albufera de Mallorca: Guia de Passeig*. Conselleria de Medi Ambient, Govern de les Illes Balears.

Millán, A., Hernando, C., Aguilera, P., Castro, A. & Ribera, I. 2005. Los coleópteros acuáticos y semiacuáticos de Doñana: reconocimiento de su biodiversidad y prioridad de conservación. *Bol. Soc. Entom. Aragonesa*, 36: 157-164.

Millán, A., Sánchez-Fernández, D., Abellán, P., Picazo, F., Carbonell, J.A., Lobo, J.M. & Ribera, I. 2014. *Atlas de los Coleópteros acuáticos de España Peninsular*. Ministerio de Agricultura, Alimentacíon y Medio ambiente: Madrid.

Miller, K.B. 2002 Revision of the genus *Eretes* Laporte, 1833 (Coleoptera: Dytiscidae). *Aquatic Insects*, 24: 247-272.

Picornell, C. & Ginard, A. 1995. John Frederic Latrobe Bateman. *In:* S'Albufera de Mallorca. *Monografies de la Societat d'Història Natural de les Balears*, 4 (eds. Martínez, A. & Mayol Serra, J.). Editorial Moll, Palma de Mallorca.

Picazo, F., Millán, A. & Dolédec, S. 2012. Are patterns in the taxonomic, biological and ecological traits of water beetles congruent in Mediterranean ecosystems? *Freshwater Biology*, 57: 2192-2210. doi: 10.1111/j.1365-2427.2012.02859.x

Ribera, I. & Foster, G.N. 1993. Uso de Coleópteros acuáticos como indicadores biológicos. *Elytron*, 6**:** 61-75.

Ribera, I., Schödl, S. & Hernando, C. 1997. *Enochrus ater* (Kuwert) and *E. salomonis* (Sahlberg) (Coleoptera: Hydrophilidae), two widespread but overlooked species new to the European fauna. *Hydrobiologia*, 354: 183-188.

Rico, E. & García-Avilés, 1998. Distribution, Autecology and Biogeography of the Dryopidae and Elmidae (Coleoptera, Dryopoidea) in the Balearic Islands. *Graellsia*, 54: 53-59.

Servera, J. 2004. *Geomorfologia del Litoral de les Illes Balears*. Edicions Documenta Balear, Palma de Mallorca, Spain. ISBN: 8496376109.

Stofberg, S. F., Essink, G. H. P. O., Pauw, P. S, de Louw, P. G. B., Leijnse, A. & van der Zee, S. E. A. T. M. 2017. Fresh Water Lens Persistence and Root Zone Salinization Hazard Under Temperate Climate. *Water Resources Management*, 31: 689-702.

Tenenbaum, S. 1915. *Fauna koleopterologiczna wysp Balearskich*. 150 pp., Warsaw.

Villastrigo, A., Jäch, M. A., Cardoso, A., Valladares, L. F. & Ribera, I. 2018. A molecular phylogeny of the tribe Ochthebiini (Coleoptera, Hydraenidae, Ochthebiinae). *Systematic Entomology* doi: 10.111/syen.12318.

Whitehead, P. F. 1993. Observations on Coleoptera of Mallorca, Balearic Islands. *Boll. Soc. Hist. Nat. Balears*, 36: 45-56.

Valladares, L.F. & García-Avilés, J. 1999. Distribution, habitats and biogeography of four families of aquatic Coleoptera of the Balearic Islands (Spain), (Coleoptera: Hydraenidae, Helophoridae, Hydrochidae, Hydrophilidae). *Koleopterologische Rundschau*, 69: 187-206.

Appendix 1. Dated historical sources (from Foster, 2008 unpublished)

Apèndix 1. *Dates de fonts històriques (de Foster, 2008 sense publicar).*

leg. Thomas & Peacock (NHM) 15th April 1900
S. Tenenbaum, 15th June 1913; 15th July 1913
F. Balfour-Browne, 9th March 1935
C. Montes, 17th & 20th July 1983 (leg.; det. GNF)
G. N. Foster, 6th & 7th January 1990; 5th January 1994
P. F. Whitehead, 23rd & 25th October 1990 (Whitehead, 1993)