Selection of (bio) indicators to assess effects of freshwater use in wetlands: a case study of s'Albufera de Mallorca, Spain

J. A. Veraart · R. S. de Groot · G. Perelló · N. J. Riddiford · R. Roijackers

Abstract Parc Natural s'Albufera de Mallorca is an internationally recognised resting area for a wide array of migratory birds, and like most wetlands it has many other ecological functions and socio-economic values. In the catchment, in which the wetland is situated, expanding tourism and intensification of agriculture place much pressure on a limited amount of freshwater. The freshwater supply to the wetland decreased due to water-extraction mainly driven by intensification of agriculture in the catchment. As a result saltwater intrusion increased since 1983–1985. This had considerable impacts on the ecological integrity of the wetland as reflected by changes in the state of the aquatic ecosystem. The distribution of submerged plants, less tolerant of salinity, declined or disappeared, while the distribution of species, known to prefer high salinity increased. As a contribution to the development of monitoring programs and management strategies that address both socio-economic and natural water demand, this article will formulate ecological criteria to assess the natural water demand by selection of (bio)indicators within the aquatic ecosystem.

Received: 13 October 2003 / Accepted: 5 April 2004
Published online: 13 May 2004

J. A. Veraart (✉)
Climate Change and Biosphere Research Centre,
Wageningen UR, p.o Alterra b.v.,
P.O. Box 47, 6700 AA Wageningen, the Netherlands
E-mail: jeroen.veraart@wur.nl

R. S. de Groot
Environmental Systems Analysis Group,
Wageningen University

G. Perelló · N. J. Riddiford
The Albufera International Biodiversity Group (TAIB),
Parc Natural s'Albufera de Mallorca

R. Roijackers
Aquatic Ecology and Water Quality Management Group,
Wageningen University

Keywords Freshwater availability · Biodiversity · Water quality · Indicators · Submerged macrophytes · s'Albufera de Mallorca

Introduction

In the Mediterranean region expanding tourism and the intensification of agriculture place considerable pressure on freshwater resources and coastal wetland ecosystems. These accumulating pressures may induce changes in ecological processes and biodiversity in coastal wetlands despite measures of protection and conservation (Santamaria and Amezaga 1999). These changes, in turn, threaten the continued availability of many ecological functions and associated socio-economic values to the local community and regional economy (de Groot 1992; IUCN 2000).

Here we present a case study of Parc Natural s'Albufera, a coastal wetland of 1,700 ha in the northeast of Mallorca, Spain (Fig. 1). The study is used to exemplify the impact of increasing pressures from agriculture and tourism on freshwater resources and biodiversity in Mallorca. In Mallorca 98% of the yearly available freshwater supply (infiltration of precipitation, 241 Hm^3yr^{-1})was used in 1998 (Salamanca and Rodríguez-Perea 1999). The Balearic government envisages that the current total water demand on Mallorca will increase to 255 Hm^3 yr^{-1} in 2002 and to 262 Hm^3 yr^{-1} in 2012 (Salamanca and Rodríguez-Perea 1999). It is clear that the average yearly groundwater recharge in Mallorca is lower than the anticipated future yearly freshwater demand.

The current Balearic policies try to satisfy the increasing water demand in two ways (DOT 1997):

- Increase water availability and develop new freshwater resources. For example, by increasing the capacity of desalinisation factories and import of freshwater from the Iberian Peninsula by boats (operacion Barca; GOB 1998).
- Optimise the recharge capacity of natural systems

IS48 (all variables in Hm^3yr^{-1}):

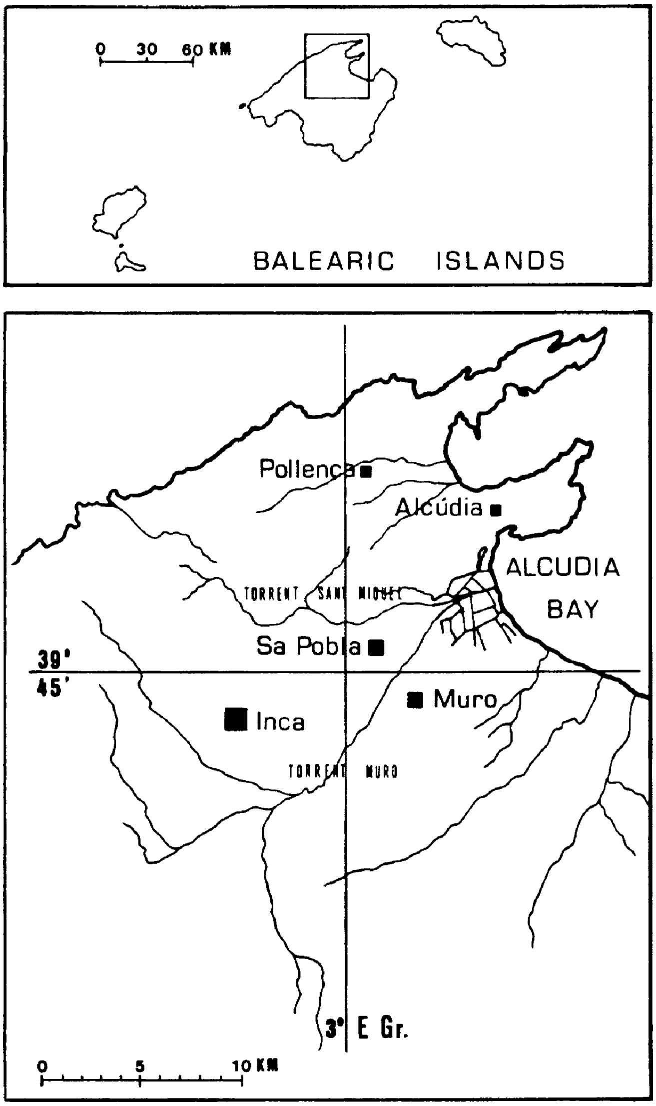


Fig. 1
Location of the s'Albufera natural park within its catchment area (640 km^2), source: Martínez-Taberner et al. (1990)

$$\text{Average groundwater recharge/Average water exploitation} > 1 \quad (1)$$

In the current sustainability indicator for water use [formula (1)] the effectiveness of the used policy strategy cannot be measured. Further, the indicator does not take into account that water is needed to maintain the ecological integrity of present ecosystems in the Balearic Islands: Coastal wetlands, like s'Albufera de Mallorca need water if they are to maintain all the ecological functions they provide. Ecosystem functions are defined as the capacity of natural processes and components to provide goods and services that satisfy human needs (directly and/or indirectly). Four types of ecological functions can be distinguished and are often classified (de Groot 1992; de Groot et al. 2000):

– Wetlands regulate water quantity and quality through storing water, reducing sediment loads and filtering chemicals out of the water (regulation functions);
– They provide refugia to many species of fish, birds and amphibians and their nursery grounds are essential to maintain food webs that form the basis of all productivity (habitat functions);
– They provide natural resources used in regional economy, eg. eel fishery in s'Albufera (production functions);
– They provide opportunities for (eco-)tourism, science and conservation-education (information functions).

Below a few of the ecological functions of s'Albufera Natural Park that are of particular relevance to this study are briefly described:

(a) Water regulation

s'Albufera is an important recharge area for the aquifer, which in turn is important to irrigation and drinking water production. A healthy (freshwater) wetland ecosystem reduces salt or brackish water intrusion into the groundwater.

(b) Refugium and nursery functions

s'Albufera has many ecological values, both at the regional/national level and internationally. The park is a refuge for several endemic species (eg. the fungus *Psathyrella halophila*) and nationally rare plant and animal species (eg. the orchid *Orchis laxiflora palustris* and the bat *Barbabastellus barbabastellus*). s'Albufera has internationally important breeding populations of several rare birds (eg. *Ardea purpurea, Botaurus stellaris, Acrocephalus melanopogon)* and recent studies have demonstrated that it has important populations of invertebrate species known from just a few specimens elsewhere (eg. The footman moth *Pelosia plumosa)* or not previously recorded in Europe (the tropical ephydrid *Zeros invenatus)*, plus a raft of plant and animal species considered threatened or endangered at the European or World level by various conventions or Red Data lists (Riddiford 2004). The wetland together with the coastal dunes represent two of the most endangered and declining ecosystems in the Mediterranean Basin (Vives 1996).
At a regional level s'Albufera enhances the biological diversity of Mallorca by providing a gradient of oligohaline to mixohaline aquatic habitats, which is hardly found elsewhere on the island.

(c) Water purification and sediment control

s'Albufera acts as a sink for agricultural runoff enriched with nitrogen and pesticides and runoff from sewage purification systems enriched with phosphates. The nutrients and pesticides are absorbed by aquatic vegetation or removed from the water column by sedimentation. This function is important for the marine ecosystem of Alcudia Bay and for drinking water quality. High nutrient loads from coastal waters are suspected to have a negative impact on the seagrass bed ecosystem in

Alcudia Bay (Whittingham 1999). The expansive *Posidonia oceanica* seagrass meadow found in the Alcudia Bay is well recognised for its role in sedimentary processes (Whittingham 1999); the species is endemic to the Mediterranean and the meadows support a high primary production (Marba and Duarte 1997). As a result of the role of the *Posidonia oceanica* seagrass meadow in sedimentary processes, the biotope provides an important hydrodynamic barrier, thus protecting the beaches and coastal dunes against erosion.

Approach

As a contribution to the development of monitoring programs and management strategies for sustainable water use, we will provide a method for the selection of (bio)indicators within the aquatic ecosystem to assess the natural water demand in future. We will demonstrate how the natural water demand and the current Balearic water resource policies can be implemented into an adjusted policy indicator for sustainable water use [formula (2)]: $IS48_{adj}$:

$$\frac{\text{Average groundwater recharge} + \text{Man - made water resources}}{\text{Average socio - economic water exploitation} + \text{Natural water demand}} > 1 \qquad (2)$$

all variables in Hm^3yr^{-1})
With the following constraints:

1. $IS_{adj}>1$;
2. The freshwater supply to ecosystems, like s'Albufera, should be optimised before man-made water freshwater resources are incorporated;
3. The indicator is calculated for a system with an ecological and socio-economic integrity, which is in agreement with the objectives of current EU directives for integrated water management (IUCN 2000).

The variables within the indicator [formula (2)] are calculated for the catchment in which s'Albufera Natural Park is situated. The catchment is seen as a socio-economic and ecological unity. The Driving force – Pressure – State – Impact – Response model (DPSIR:IUCN 2000) is used as a framework to analyse the links between changes in land use and population number and associated pressures on freshwater resources and changes in the state of the aquatic ecosystem in s'Albufera between 1983–1985 and 1994–1999.
These specific time periods (1983–1985 and 1994–1999) were chosen for two reasons: (1) availability of data, (2) the time periods are separated by two important with a high impact on the wetland ecosystem:

- Spain became a member of the European Union in 1986, which led to the further intensification of agricultural production in the catchment in which s'Albufera Natural Park is situated;
- A restoration project was carried out in the Natural Park in 1989

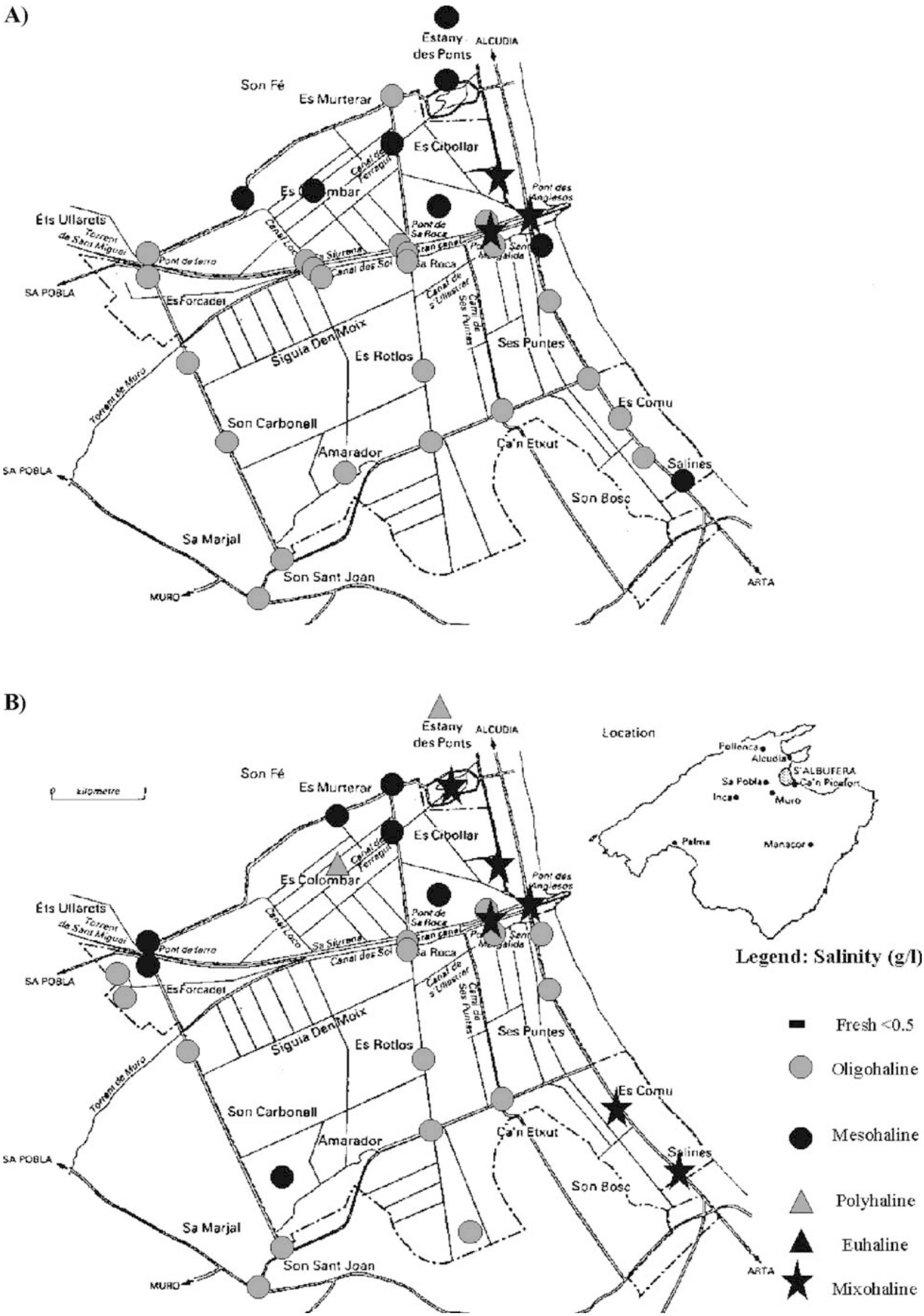
In the section below 'Changes in ecological and socio-economic setting in the s'Albufera catchment' the changes in nature conservation, land use, population and tourism numbers are described in the socio-economic and ecological setting of the catchment since 1983–1985 (driving forces). The pressures on the freshwater resources are assessed by estimating the yearly socio-economic water demand and the yearly recharge of the s'Albufera aquifer and is presented in the section 'Pressures on freshwater resources' The main abiotic and biotic state variables within the aquatic ecosystem in s'Albufera Natural Park are described and compared for the period 1983–1985 and 1994–1999 in the section 'State of the aquatic system'.

a) Comparison of abiotic state variables

Water quality data were available for the period 1983–1985 (Martínez-Taberner 1988). Monthly time series from 1994 to 1998 of salinity, conductivity, pH, O_2, and temperature data were available from the monitoring programme carried out by park staff (Conselleria de Medi Ambient, Ordenació del Territori i litoral 1999a). Additional water samples were taken in the summer of 1999. Samples were frozen and analysed for nitrite, nitrate and ortho-phosphate using a Skalar sanplus segmented flow analyser. Sampling sites in both periods are presented in Fig. 2

b) Comparison of biotic variables: fieldwork in 1999

Between April and August 1999 an inventory of aquatic vegetation, phytoplankton and zooplankton was carried out (Veraart 1999) in order to obtain insight into the actual state of the aquatic ecosystem. In this article a comparison is made between the inventory of the aquatic vegetation of the summer of 1999 and the inventory done in 1983–1985. The aquatic vegetation at the sampling sites (Fig. 3) was described on the basis of transects of approximately 5 meters. With the obtained vegetation data hierarchical cluster and correspondence analysis was done (Jongman et al. 1987). The sampling sites for aquatic vegetation included in this study for analysis were the same locations as the water quality and submerged vegetation was sampled in 1983–1985.
In the section 'Ecological criteria to assess the natural water demand' (bio)indicators are selected to assess the impact of socio-economic water use on the freshwater supply to the wetland . The proposed environmental policy indicator is calculated for both periods in the section 'Calculation of the sustainability indicator for water use'. The calculation is evaluated with the help of the selected bio-indicators. The presented method is evaluated in the 'Discussion' section below.


A)
B)
Estany des Ponts
ALCUDIA
Son Fé
Es Murterar
Es Cibollar
Es Colombar
Pont des Anglesos
Éts Ullarets
Torrent de Sant Miguel
Pont de ferro
SA POBLA
Es Forcadet
Siquia Den Moix
Es Rotlos
Ses Puntes
Es Comu
Son Carbonell
Amarador
Ca'n Etxut
Salines
Son Bosc
Sa Marjal
Son Sant Joan
MURO
ARTA
Torrent de Muro
Canal Loco
Canal des Sol
Sa Siurana
Gran canal
Sa Roca
Pont de Sa Roca
Canal de s'Ullastrar
Camí de Ses Puntes
kilometre
Location
Pollença
Alcudia
S'ALBUFERA
Sa Pobla
Ca'n Picafort
Inca
Muro
Palma
Manacor
Legend: Salinity (g/l)
Fresh <0.5
Oligohaline
Mesohaline
Polyhaline
Euhaline
Mixohaline

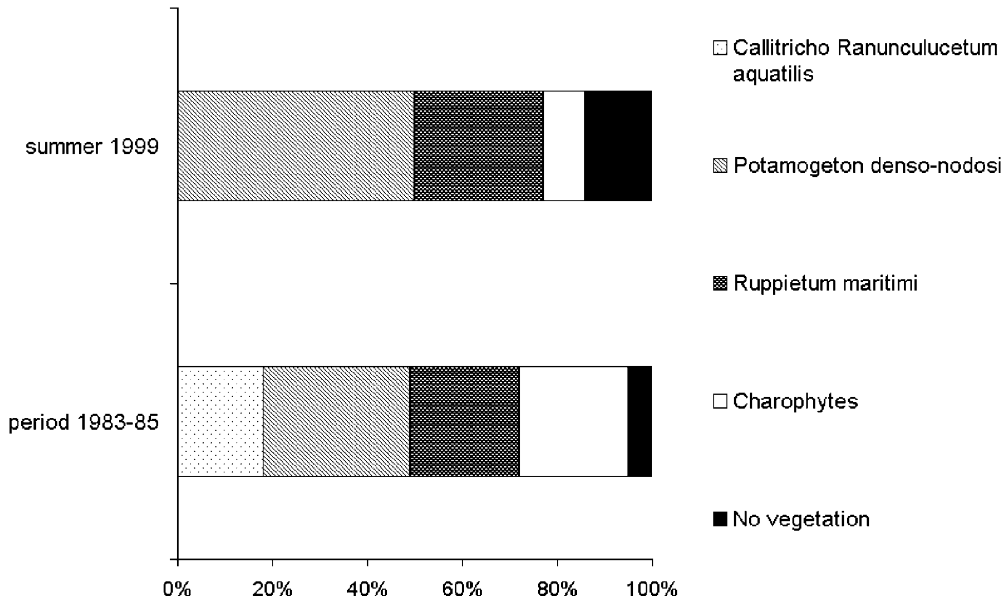


Fig. 3
Relative importance of each submerged vegetation community in the canals of the Albufera in 1983–1985 (Martínez-Taberner and Moyà 1993) and the summer of 1999 (based on 22 base-line locations in the canal system)

Results

Changes in ecological and socio-economic setting in the s'Albufera catchment

Management

The rehabilitation project carried out in1989 was intended to modify the physical, chemical and ecological characteristics of the wetland in such a way that the ecosystem would revert to into natural succession (Martinez-Taberner et al. 1990). The hydrological (a lotic habitat) and vegetation situation before restoration were a result of the drainage and agriculture during the past two centuries. The morphology and hydrology of the park prior to the drainage project of the 19th century served as a guide for restoration (a lentic habitat with many open water areas). After the restoration the open water area increased to 350 ha (20%) thus expanding the range of feeding habitats for waterbirds (Conselleria d'Agricultura Pesca 1989; Conselleria de Medi Ambient, Ordenació del Territori i Litoral 1999a). In the canal system a stagnant habitat was created by building dams, sluices and by restoring some canals to a more natural morphological state.

Inhabitants

The population living in the catchment and the coastal zone are categorised as: (1) permanent (local) inhabitants, (2) seasonal foreign inhabitants and (3) tourists. Foreign inhabitants own houses at Mallorca and stay there often the whole spring and summer. Demographic statistics (Ministerio de Agricultura Pesca y Alimentacion 1988; INE 1996) did not distinguish seasonal nor permanent inhabitants. The presented numbers in Table 1 were derived by extrapolation of available data (Veraart 1999).
It can be derived from Table 1 that the number of permanent inhabitants grew from 26 to 35% between 1986 and 1996. Tourist and seasonal inhabitant numbers grew from 21 to 38% (Table 1).

◄

Fig. 2A,B
Classification of sampling sites based on average conductivity, chlorinity and salinity in 83–85 (**A**: Martinez-Taberner 1988) and 94–98 (**B**: derived from monitoring data park staff). The method is based on salinity modifiers of Mediterranean wetlands (Farinha et al. 1996)

Land use

The wetland is bordered by agricultural fields on its west and southwest flanks, while in the north, urban and tourist developments extend to the border of the park (Fig. 1). The lowland catchment is the most intensively farmed on Mallorca because of the year-round access to groundwater close to the surface, the organically rich soils and the general absence of winter frosts (Earthwatch 1991). Cereals, potatoes, artichokes, onions and tomatoes are currently the principal cultivated crops. The crops are produced at small farms with a low input of machinery. The land use in the upland catchment (between Inca and Santa Maria) consists mostly of almond, olive and citrus orchards.

Table 1
Differences in population and tourist number between the period 1983–1985 and the period 1994–1999

	Period 1983–1985	Period 1994–1999
Local inhabitants	49,560–48,560[1]	65,545–62,545[2]
Seasonal inhabitants	1.000–2.000[3]	3,000–6,000[4]
Tourists	472,355–500,000[5]	600,000–650,000[6]

[1]Ministerio de Agricultura Pesca y Alimentacion (1988); [2]an exact growth cannot be given because Mallorcan demographic statistics do not separate seasonal and local inhabitants; [3] INE (1996); [4]it was assumed that growth rate of seasonal inhabitants was equal to the growth rate of tourist numbers; [5]it was assumed that 10% (the catchment is 10% of Mallorca's surface) of the total number of seasonal inhabitants (30,000–60,000) live in the catchment (Salamanca and Rodriguez-Perea 1999); [6]derived from Mata et al. (1997) and Conselleria d'Economia I Hisenda, direccio general d'Economia (1989)

Table 2
Surfaces (ha) of land use types in the s'Albufera catchment area in 1983–1985 and 1994–1998 and their relative importance (%). Source: Min. Agricultura, Pesca y Alimentacion (1988); INE (1996)

Land use	1983–1985	1994–1998
Intensive agriculture	15,808 (25%)	27,287 (42.7%)
Grassland	96 (0.1%)	96 (0.1%)
Vine yard	256 (0.4%)	256 (0.4%)
Fruit	24,000 (37.5%)	12,480 (19.5%)
Forest/scrubs/uncultivated*	23,872 (37.3%)	23,872 (37.3%)

*Uncultivated land was excluded in the representative Balearic statistics (INE 1996). It was assumed that the area for agricultural use (40.128 ha) did not increase after 1986. This assumption is in accordance with European Agricultural policy objectives (Diaz-Alvarez et al. 1994).

Land use changes in the period 1983–1985 and 1994–1999 are presented in Table 2. From Table 2 it is clear that intensive agriculture expanded at the expense of fruit cultivation.

Pressures on freshwater resources

The pressures on freshwater resources from increasing tourist and population numbers and land use change since 1983–1985 are presented in Table 3. Water demand (Table 3) by tourists and inhabitants in 1983–1985 and 1994–1998 were calculated by multiplying the tourist and (seasonal) inhabitant numbers (Table 2) with daily water use and days present. Seasonal foreign inhabitants (foreign people that own a house in Mallorca) and tourists use daily more water(160 l day^{-1}) compared to local inhabitants (130 l day^{-1}). It is assumed that local inhabitants, seasonal inhabitants and tourists are respectively 365, 150 and 14 days in average present. Custodio et al. (1989) estimated that agricultural water demand in the catchment was about 40 Hm3 $yr^{-}1$. We assumed this number as representative for the agricultural water demand in the period 1983–1985. Approximately 9,000 ha (14.1%) of the total catchment area was irrigated (Ministerio de Agricultura, Pesca y Alimentacion 1988). It was assumed that the area with irrigated agriculture was the same in the period 1994-1998. In average 8,000 m3 $ha^{-}1$ $yr^{-}1$ water was used in irrigated agriculture in the Balearics (Salamanca and Rodriguez-Perea 1999). The yearly agricultural water demand in the period 1994–1999 is estimated to be 9,000×8,000=72 Hm3 $yr^{-}1$ (Table 3). This is probably an under estimation as the area with irrigation probably increased because the area with intensive agriculture increased (Table 2).

Table 3 shows that the recharge in 1994–1998 only compensates for the extraction of water in the s'Albufera catchment in wet years. In dry years water demand exceeds the recharge based on estimated freshwater exploitation in the period 1994–1998. The water demand is in both periods mainly explained by agricultural practices. It can be derived from Table 3 that freshwater supply to the wetland is estimated to be between 16–36 Hm^3.yr in the period 1983–1985. In the period 1994–1999 freshwater supply to the wetland is estimated to be between 3–17 Hm^3.yr.

Assuming that saltwater intrusion will balance the water shortages in the aquifer this means that in dry years an additional 17–20 Hm^3 of marine water will enter the s'Albufera catchment in the current situation. This estimation of saltwater intrusion still includes mainly uncertainties, but it is probably an underestimation. We deduce this because while the input from adjacent aquifers has also decreased, in our balance model the input is assumed to be equal in both periods.

State of the aquatic system

The pressures described in the section 'Pressures on freshwater resources', have had a noticeable influence on the ecological situation in the study area. Below, two important environmental aspects (water biota and water quality) are described in some detail as basis for the selection of bio-indicators to formulate the natural water demand and to monitor future changes.

Aquatic biota

Submerged vegetation in 1999

A detailed description of the aquatic ecosystems of the marsh can be found in Veraart (1999). Based on physics and morphology three major habitats can be defined: permanent brackish lakes, temporary ponds and the canal system. Most important submerged species were, *Ruppia* sp.(2), *Lamprothamnium papulosum*, *Potamogeton pectinatus*, *Cladophora* sp., marine algae (Chlorophyceae, Rhodophyceae and Phaeophyceae) and *Cymodocea nodosa* (only present at Estany des Ponts). Temporary ponds near the coast were dominated by *Chara* sp., *Lamprothamnium*

Table 3
Yearly water recharge and water exploitation in the S'Albufera catchment in 1983–1985 and 1994–1999 and in the whole of Mallorca (in $Hm^{-3}yr^{-1}$)

Recharge		Exploitation	1983–1985	1994–1998	Mallorca 1998[2]
Adjacent aquifers	2–12[1]	Local inhabitants	2.35–2.30	2.97-3.11	62.7
Infiltration irrigation	10.8–12[1,2]	Seasonal inhabitants	0.02–0.05	0.07–0.14	
Infiltration precipitation	47–56[1]	Tourists	1.06–1.12	1.34–1.46	19.3
Salt water intrusion	??	Agriculture	40[5]	72[6]	154
		Outflow	0.1–0.8[3,4]	0.1–0.8[3,4]	
Total	60–80		44	77	236

Source: [1]Howe (1989); [2]Salamanca and Rodriguez-Perera (1999); [3]Juncosa (1991); [4]Wood (1989, 1990); [5]Custodio et al. (1989); [6]approximately 9,000 ha of the total catchment area was irrigated (Ministerio de Agricultura, Pesca y Alimentacion, 1988). In average 8,000 m^3 ha^{-1} yr^{-1} water was used in irrigated agriculture in the Balearics (Salamanca and Rodriguez-Perea 1999) *papulosum* and *Ruppia maritima*. The in 1989 created (temporary) open water areas in Sa Roca, Es Ras and Ses Puntes (Fig. 2) were dominated by *Zannichellia pedunculata* and *chara* sp. in 1999. *Potamogeton pectinatus, Myriophyllum spicatum, Chaetomorpha* sp., *Enteromorpha* sp. and *Najas marina* mainly dominated the aquatic vegetation within the canal system.

Differences between 1983–1985 and the summer of 1999

The submerged vegetation had a lower diversity at most of the sampling sites compared to 1983–1985. *Ceratophyllum submersum*, *Callitriche stagnalis*, *Ricciella fluitans*, *Lemna minor*, *Lemna gibba* and *Myriophyllum verticillatum* disappeared since the period 1983–1985, while these species were widely distributed in 1983–1985 (except *Myriophyllum verticilatum*). The average environmental tolerance (upper limit) for conductivity was estimated to be 3.8 $mScm^{-1}$ (*Callitriche stagnalis)* and 2.5 $mScm^{-1}$ *(Ceratophyllum submersum)* (derived from Martinez-Taberner and Moya 1991a, b; Martinez-Taberner and Moya 1993). Average conductivity was higher than these derived environmental tolerances in the period 1994–1999 at the sampling locations where these species disappeared. The distribution *of Ceratophyllum demersum* was decreased in the summer of 1999 compared to 1983–1985. At the locations where *Ceratophyllum demersum* was no longer present in 1999 average conductivity exceeded its derived environmental tolerance (5.9 $mScm^{-1}$) (Martinez-Taberner and Moya 1991a; Martinez-Taberner and Moya 1993). *Chaetomorpha* sp. was in the summer of 1999 widely distributed in the whole of s'Albufera, while in 1983–1985 it was only found in the seaward part of s'Albufera.

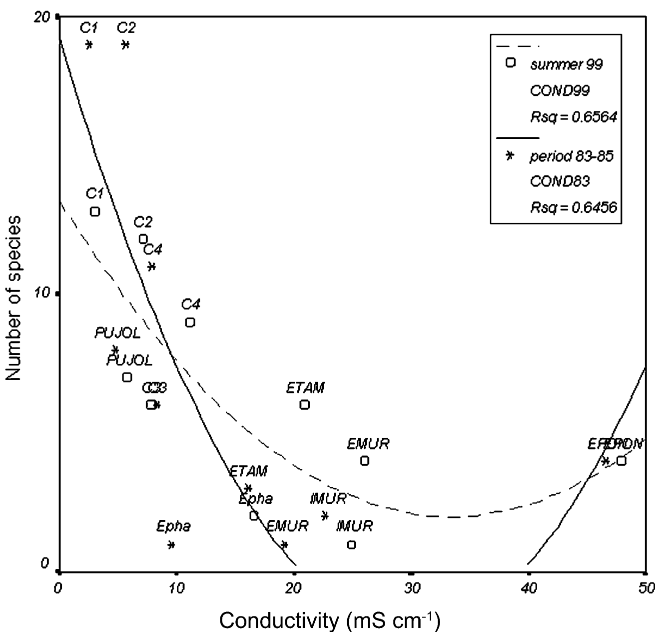


Fig. 4
Relationship between the number of species and the average measured conductivity ($mScm^{-1}$) at each location in 83–85 (derived from Martinez-Taberner 1988) and the summer of 1999 and quadratic regression lines with constants

Cymodocea nodosa was present in Estany des Ponts in the summer of 1999, while this species was not found in the period 1983–1985. Marine algae (Rhodophyceae and Phaeophyceae) were found at more sites near the coast. Principal component analysis and hierarchical cluster analysis showed that in 1983–1985 salinity was the most important factor that explained the distribution of aquatic vegetation (Martinez-Taberner 1988). Correspondence analysis with the field data of 1999 also pointed out that most of the variance was explained by salinity (Veraart 1999). Total variance explained was 41%, the first principal axis (13% explained variance) was assumed to be explained by salinity (Veraart 1999).
Martínez-Taberner (1988) identified four different aquatic vegetation communities for s'Albufera based on hierarchical cluster analysis. Three identified aquatic communities replaced each other with increasing salinity levels, i.e. *Callitricho Ranunculucetum aquatilis* (indicative species: *Callitriche stagnalis*), *Potamogetonetum denso-nodosi* (indicative species: *Potamogeton pectinatus*) and *Ruppietum maritimi* (indicative taxa *Ruppia* sp.). The fourth identified community was distinguished because of a clearly dominated and diverse charophyte community (indicative taxa: *Chara* sp.).
In 1999 the *Callitricho Ranunculucetum aquatilis* community was totally absent resulting in an increase of the *Potamogetonetum denso-nodosi* community (indication of salinization; Table 3). The number of locations without vegetation (turbid state) increased (Gran canal, coastal zone), while the number of locations dominated by charophytes was reduced (indication of eutrophication) (Veraart 1999).
The tolerance of the submerged aquatic vegetation for salinity expressed in species diversity is illustrated in Fig. 4. The highest number of species is found at sampling sites where the average conductivity was below 7 $mScm^{-1}$ ($\approx$ salinity 4.6 $g\ l^{-1}$), which were the oligohaline habitats (Fig. 2). In the brackish areas and temporary ponds species diversity is minimal. Only a few aquatic species are adapted to high fluctuations in salinity and desiccation in brackish waters with average conductivity between 7 and 30 $mScm^{-1}$ ($\approx$ 4.6<salinity<20.9 $g\ l^{-1}$) If the average conductivity became higher than 30–40 $mScm^{-1}$ (salinity $\approx$21–28 $g\ l^{-1}$), species diversity increased according to this conceptual model. The relationship in Fig. 4 confirms the idea of several authors (van Vierssen 1982; Santamaria

Table 4
Average conductivity (mS cm^{-1} in 1983–1985 and 1994–1998; differences in average conductivity (monthly data) at the sampling stations are tested with students t-test; canal system (n=11), temporary ponds (n=3), brackish lakes (n=3)

	1983–1985	1994–1998	Difference
Canal system	9.2±6.7	9.9±8.5	+7.6%*
	8.9±7	10.4±8.5	+17%***
Temporary ponds	15.1±5.4	18.4±2.7	+22%**
Permanent brackish lakes	27.3±16.8	31.6±14.3	+16%**

*** $\alpha<0.05$; **$0.05<\alpha<0.10$; * $0.10<\alpha<0.25$

et al. 1996) hypothesising that salinity governs the spatial distribution of the submerged plant communities in the Mediterranean, while factors affecting the light climate, seedbank and nutrient supply would determine the development of the macrophyte meadow.

All the results indicate that spatial differences in diversity were in the first place governed by salinity. The diversity was highest in the oligohaline habitats. In the brackish and ephemeral ponds diversity was minimal through the natural stress of high fluctuations in salinity and desiccation.

Water quality

In Fig. 2 sampling sites are marked based on salinity modifiers for Mediterranean wetlands. In 1983–1985 only conductivity and chlorinity was measured. Salinity was estimated by linear regression with the monthly salinity and conductivity data at Font de Son San Juan from 1994–1998. The number of mixohaline and euhaline habitats increased near the coast (Fig. 2). Average conductivity was respectively 17, 22 and 16% higher in the canal system (sampling sites in Canal de Sol excluded), the temporary ponds and the permanent brackish lakes (Table 4) in the period 1994–1998 compared to 1983–1985. At two sampling sites in canal del Sol salinity was 32–50% lower as a result of the construction of a sluice in 1989 (Veraart 1999).

Other water quality variables

The single measured sum nitrate/nitrite values in June 1999 ranged between 0.2 mg l^{-1} (Estany d'en Ponts) and 48.4 mg l^{-1} (Font de Son San Juan), while in 1983–1985 the sum nitrate/nitrite never exceeded 2.3 mg/l. As a result of seawater dilution the sum nitrate/nitrite values near the coast (Estany d'en Ponts were lower compared to the upper part of the s'Albufera (Font de Son San Juan) (Martínez-Taberner 1988). In the areas fed by the springs phosphorus concentrations were always below 0.05 mg l^{-1} in both 1983–1985 and in the summer of 1999. Highest average phosphorus concentrations (0.06–0.4 mg l^{-1}) were measured in the Gran Canal in 1983–1985. Single measured phosphorus concentrations in the Gran canal were between 0.1–0.16 mg l^{-1} in June 1999.

The average oxygen concentrations were at most of the sampling sites lower in the period 1994–1998 compared to 1983–1985 (Veraart 1999). Average oxygen concentrations ranged between 3 and 7 mg l^{-1} in 1994–1999 near the coast and in the Gran canal.

Ecological criteria to assess the natural water demand

The results from the previous sections show that freshwater supply to the wetland decreased due to the increased water exploitation in the s'Albufera catchment since 1983–1985. As a result saltwater intrusion increased since 1983–1985. This had an impact on (aquatic) biodiversity and is also a problem for the use of s'Albufera as a supplier of drinking water and irrigation water for agriculture (feed-back mechanism): a healthy (freshwater) wetland ecosystem reduces salt or brackish water intrusion into the groundwater. In this section indicators are selected to assess the impact of socio-economic water use in the catchment on the freshwater supply to the wetland.

Selection of *Ceratophyllum demersum*

Ceratophyllum demersum was selected as an indicator for changes in the freshwater supply to the wetland because past (Martinez-Taberner 1988), present (Veraart 1999) and predicted distribution after rehabilitation (Martinez-Taberner et al. 1992) is well documented. The distribution of *Ceratophyllum demersum* was calculated as a function of salinity and trophic state with use of a GIS model in order to estimate the impact of the rehabilitation measures in 1989 (Martinez-Taberner et al. 1992). The model predicted that the distribution of *Ceratophyllum demersum* would increase as a result of the rehabilitation measures. We hypothesize (derived from Bloemendaal and Roelofs 1988) that the distribution area of *Ceratophyllum demersum, Ceratophyllum submersum, Callitriche stagnalis, Ricciela fluitans* and *Lemna* sp. should have been larger due to the increased nitrogen loads but the distribution areas of these species became smaller or the species disappeared. We conclude that, despite rehabilitation measures and increased nitrogen loads (Veraart 1999), the distribution area of *Ceratophyllum demersum* has declined due to the impact of salinization. The distribution area of this species will increase under current trophic conditions if the freshwater supply to the wetland will be restored. The species is not suitable as a bio-indicator for the maintenance of biodiversity: eutrophication may result in *Ceratophyllum demersum* expanding and filling the entire water column at the expense of species that grow near the sediment, like charophytes (Bloemendaal and Roelofs 1988).

Selection of *Chaetomorpha* sp., *Cymodocea nodosa* and marine algae

Increased seawater intrusion explained why *Chaetomorpha* sp was widely distributed in the whole wetland in 1999 contrary to the period 1983–1985. At several places in the upper part of s'Albufera *Chaetomorpha* sp. filled almost the entire water column, while it was completely absent in 1983–1985 in this area of the wetland. This is explained by the combined impact of salinization and eutrophication. The presence of *Cymodocea nodosa* and marine algae (Rhodophyceae and Phaeophyceae) are indicative for the euhaline and mixohaline habitat in s'Albufera. The increased distribution area near the coast compared to 1983–1985 was indicative for permanent marine conditions during the growing season.

Table 5 presents a selection of (bio) indicators to assess the impact of salinization due to increased water exploitation on freshwater supply to the wetland. If Fig. 2 is compared with Fig. 4 it can be concluded that the salinity modifier for Mediterranean wetlands (Farinha et al. 1996) is not sensitive enough to measure the impact of salinization on submerged vegetation distribution within the salinity range of oligohaline habitats (0.5–5 mg l^{-1}). Species diversity within an oligohaline habitat with an average salinity of 0.5 mg l^{-1} is clearly different from an oligohaline habitat with an average salinity of 5 mg l^{-1}.

Table 5
Selection of bio-indicators to monitor the impact of water exploitation (salinisation) by agriculture and tourist developments on freshwater availability and aquatic biodiversity

Bio indicator	Environmental tolerance for		Sustainability criteria for ecosystem functions:
	Conductivity mS cm^{-1}	Salinity g l^{-1}	Freshwater supply
Ceratophyllum demersum	<5.9 ([1]	<1.8–3.6 ([2,3]	- If the spatial distribution area of this species increases this is indicative for increased fresh water supply to the wetland.
Chaetomorpha sp.	>3 ([2]	>2 ([2,3]	- If the spatial distribution area of these taxa increase this is indicative for increased seawater intrusion.
Marine Algae: 1) Rhodophyceae 2) Phaeophyceae	>38 ([2]	>33 ([2,3]	
Cymodocea nodosa	>42 ([2]	>29 ([2,3]	

[1]Martinez-Taberner and Moya (1993), [2]calculated with monitoring data 94–98 Park Staff, [3]regression equation: salinity=0.71*conductivity - 0.38 (r^2=0.77)

Calculation of the sustainability indicator for water use

We are able to calculate the IS_{adj} [formula (2)] if we assume that:

A) it is a Balearic environmental policy objective to restore the freshwater supply to the wetland to the same range of supply as in the period 1983–1985.
B) that the average freshwater supply to the wetland in 1983–1985 is equal to the natural water demand.
C) In the s'Albufera catchment no man-made water resources (desalinisation plants) are present.

>The average freshwater supply in the period 1983–1985 is estimated to be (16+36)/2=26 Hm^3 yr^{-1} (derived from minimal and maximal estimated freshwater supply in the section 'Pressures on freshwater resources'). Table 6 shows the calculation of IS [formula (1)] and IS_{adj} [formula (2)] based on the hydrological balance (Table 3) and above made assumptions.
Assumptions A and B on which basis IS_{adj} is calculated, can be argued:
It was an objective of the rehabilitation plan in 1989 to protect and to increase the "freshwater" habitat. If freshwater supply to the wetland did meet to the natural water demand in 1983–1985, such a rehabilitation objective was not formulated.
By using the average freshwater supply in 1983–1985 we do not take into account the large variability in meteorological conditions in the Mediterranean (wet and dry years), which is a natural characteristic. Mediterranean ecosystems should be able to deal with yearly variations in freshwater supply (robustness).
However, we think that it is valid to conclude that the natural water demand (or critical freshwater supply to the wetland) of s'Albufera is somewhere between the average freshwater supply (26 Hm^3 yr^{-1}) and the maximum supply in wet years (36 Hm^3 yr^{-1}) (Table 3). In future research uncertainties within the definition of the natural water demand could be reduced with the help of the presented ecological criteria in the section 'Ecological criteria to assess the natural water demand' in combination with a quantitative and qualitative hydrological study.

Table 6
Calculation of the sustainability of freshwater resource management in the Albufera catchment with and without taking into account the natural water demand

Period	IS	IS_{adj}
1983–1985	1.4–1.8	0.9–1.0
1994–1999	0.8–1.0	0.6–0.8

Discussion

The study concentrated on the role of the wetland as a freshwater supplier for human society in the catchment (agriculture, drinking water) and the necessary amount of freshwater in order to maintain ecological integrity and conservation values of s'Albufera.
The periods 1983–1985 and 1994–1999 were analysed and compared, this division was made because of data availability. Ideally a continuous time series would be preferred. However, despite the absence of a continuous time series, it is still interesting to compare these two time periods, because they are separated by two events, which have had a major influence on land use and nature conservation. In 1986 Spain became a member of the European Union, which led to the further intensification of agricultural production in the areas around s'Albufera Natural Park. In 1989, a rehabilitation project was carried out in the Natural Park
The changes within land use were of more importance in relation to the freshwater supply function of the wetland than the changes in population and tourist numbers and the restoration project. The potential positive impact of the construction of sluices and dams in the wetland in order to maintain freshwater were overshadowed by the increased freshwater demand by agriculture.
The increased freshwater exploitation in combination with increased fertiliser use may also explain the highly increased nitrogen concentrations within the wetland.
Other rehabilitation measures (eg. grazing management) resulted in an increase of biological diversity within the area. The creation of open water areas has resulted in an

increased number of breeding and feeding possibilities for waterfowl. These newly created temporal ponds, with low submerged species diversity (*Chara* sp. and *Zannichellia pedunculata*), represent a temporary nutrient rich oligo/mesohaline habitat (Veraart 2000) with a high ornithological value (Conselleria de Medi Ambient, Ordenació del territori I Litoral 1999a). The newly created ponds are fed by water originating from the wells, and the influence from the sea (nutrient dilution, high salinity) is lower compared to the already present ponds in 1983–1985. However, overgrazing may have negative impacts on the functional role of submerged vegetation for birds and on the distribution of rare terrestrial species (i.e. *Orchis palustris*). Cattle trampling may result into reduced light conditions, which has a negative impact on the development of the submerged vegetation. Ideally, grazing management should be based on ornithological, aquatic ecological, botanical and economical criteria in order to optimise biodiversity conservation.

We focussed on the impact of salinization on the freshwater supply function of the wetland and did not discuss other impacts on the state of the aquatic system related with land use change (eutrophication, pesticide use) and increasing population and tourist numbers (eg. changes in discharges of sewage). This focus was selected because the differences in species diversity within the submerged vegetation community were mainly explained by salinization. Differences in abundance of submerged species at several sampling sites, compared with 1983–1985, were also often explained by the combined impact of salinization and eutrophication. Species that grow near the sediment, like charophytes, have become less abundant at the expense of species that concentrate their biomass in the upper part of the water column (*Potamogeton pectinatus*, *Enteromorpha* sp.) or fill the entire water column (*Ceratophyllum demersum*). Long-term monitoring of abundance and diversity of the submerged vegetation community provide thus information of several impacts related with land use change and urbanisation.

In analysing the land use changes and the change in the water balance, some scaling problems occurred and assumptions had to be made caused by restrictions in data availability. For example, the data of 1983–1985 were derived from a regional source (Ministerio de Agricultura, Pesca y Alimentacion 1988), while the data representative for the period 1994–1998 had to be extrapolated from the Spanish national statistics office (INE 1996). It was assumed that within intensive agriculture, yearly water demand is the same of each type of cultivation, while in reality there might be some differences.

The presented changes in both human water use and freshwater supply to the wetland should therefore be seen as a 'best-case' scenario, rather than an exact prediction. Within this context the presented effects of these changes provide useful information to evaluate the sustainability of current tourist developments and land use in the s'Albufera catchment.

The above described constraints of data availability and scaling problems encountered by our study are, unfortunately, very common. Data collection and monitoring networks are often embedded in a fragmented institutional framework. In order to assess the impact of human society on freshwater resources we have to see a catchment as a socio-economic and ecological unity. Also from a scientific point of view integration of data collection is necessary. Only if chemical, hydrological and ecological monitoring programmes are integrated will it become possible to assess the vulnerability of ecological functions of wetlands to changes in pressures like, tourist numbers and land use change. It is also important that management objectives within the Park and policy objectives outside the park are linked with the monitoring programmes. The presented sustainability indicator for freshwater resource management in s'Albufera [formula (2)] offers a common framework to assess opportunities and constraints for linking socio-economic and conservation interests.

Acknowledgements The data in this article are largely based on fieldwork carried out by Veraart (1999) in spring/summer 1999. The authors would like to thank the staff of s'Albufera Parc Natural, The Albufera International Biodiversity Group, the Geography Department (Dr. M. Blazquez) and Limnology Department (Prof. Dr. Antoni Martinez and Prof. Dr. G. Moya) and the Department of Marine Sciences and Coastal Management of the University of Newcastle-Upon-Tyne (Miss E. Whittingham).

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