Universidad de Zaragoza

The habitats of the saline wetlands of Monegros, Spain, studied with field and remote sensing data

Los hábitats en las saladas de Monegros, España, estudiados con datos de campo y teledetección

Tesis doctoral

Manuela Domínguez Beisiegel

2010

AVANCES EN CIENCIAS AGRARIAS Y MEDIO NATURAL

Departamento de Agricultura y Economía Agraria

A Lucía....

La sabiduría suprema es tener sueños
bastante grandes para no perderlos de vista
mientras se persiguen
WILLIAM FAULKNER

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RESUMEN

Los humedales salinos o "saladas" de Bujaraloz-Sástago, en la comarca de Monegros, son biotopos de gran singularidad. Se enmarcan en un paisaje árido y de escasa vegetación, característico de la llanura cerealista, determinado por la aridez del clima, la fisiografía, el sustrato lítico y los suelos, junto a la multisecular presión antrópica. El paisaje recuerda a algunas regiones africanas, y es muy raro en Europa. Los hábitats existentes en las saladas tienen gran interés recogido en documentos administrativos y en publicaciones científicas y de organizaciones ecologistas. Distintos autores han citado en las saladas especies, tanto vegetales como animales, endémicas, raras, o de gran interés biogeográfico, subrayando su atractivo como consecuencia de la confluencia de distintos factores ambientales.

En los últimos cien años parte de las saladas han desaparecido o su extensión se ha recortado debido a la intensificación agraria. A partir de los años 80 del siglo pasado, la tendencia se exacerbó por una agricultura cerealista de secano subvencionada por la Política Agraria Común; más recientemente las desapariciones han aumentado con la transformación en regadío, aún no culminada. Hoy, muchos de los hábitats considerados de interés prioritario por las políticas ambientales de la Unión Europea están amenazados.

Se desconoce cuál puede ser el destino de estos humedales y si la alteración del régimen hidrológico va a motivar su desaparición o un cambio de hábitats debido a la estrecha relación de las especies actuales con las características físicas del medio, principalmente la elevada salinidad, la acusada aridez y la inundación intermitente. Pese a la existencia de diferentes figuras de protección, por ejemplo las ZEPA's, la inexistencia de una cartografía detallada y los vacíos de la normativa legal, ponen en situación de gran fragilidad a estos espacios, cuyo medio natural no atiende a delimitaciones administrativas. Es evidente la necesidad de documentar estos humedales y su vegetación levantando una cartografía que permita estudiar su dinámica y la de sus hábitats.Con este objetivo:

(i) se ha elaborado una cartografía de las diferentes etapas de la evolución de las saladas y los desencadenantes de su desaparición ligados a hitos históricos. La cartografía de humedales proporciona un inventario completo para las fechas 1927,

1957, 1984 y 2008, y los calificativos con los que se reconocen en los documentos más antiguos.

(ii) se ha formado una cartografía, actualizada y a escala detallada, de la vegetación. Para la nomenclatura de los hábitats se ha utilizado la Directiva hábitats y la leyenda CORINE adaptada a Aragón. Esta cartografía no es un mero inventario de especies sino un instrumento para la gestión y seguimiento, pues permite superponer los límites legales de protección a fin de conocer los hábitats amenazados por actuaciones como la transformación en regadío.

(iii) partiendo del conocimiento de los hábitats y especies vulnerables de interés, su recubrimiento y extensión, se han examinado algunos condicionantes ecológicos de *Arthrocnemum macrostachyum*, uno de los halófitos más característicos de las saladas. Para ello se ha muestreado y analizado la distribución de *A. macrostachyum* a lo largo de distintos puntos seleccionados en relación a sus características edáficas.

(iv) por último, las prospecciones de campo, el conocimiento del medio y la cartografía de hábitats ha servido como base para estudiar las características espectrales de los principales estados superficiales del suelo de las saladas. A tal fin se han tomado datos radiométricos para caracterizar los ambientes y poderlos relacionar con imágenes de diferente resolución espacial y espectral proporcionadas por los satélites Quickbird, Aster y Landsat. Esto ha permitido evaluar la radiometría de campo como herramienta para cartografiar los estados superficiales en humedales salinos de interior.

El estudio de los estados superficiales y de los hábitats a partir de la exploración y observaciones de campo, los muestreos, el inventario y la cartografía detallada de la presente Tesis constituyen fuentes básicas para el conocimiento de los humedales de Monegros, los instrumentos metodológicos desarrollados se pueden aplicar fácilmente, para su evaluación, en otros humedales salinos de regiones áridas.

El empleo de herramientas básicas de trabajo como los Sistemas de Información Geográfica (SIG) y la teledetección, con imágenes de sensores de gran resolución, espaciales o aeroportados, serán claves en la gestión y el seguimiento de estos ambientes. Como se ha demostrado, todo ello aumenta sustancialmente la información disponible, mejorando su calidad, y reduciendo costes. Los SIG y tecnologías asociadas pueden también cubrir el flanco de la divulgación, uno de los pilares básicos para la protección de la Naturaleza.

ABSTRACT

The saline wetlands or "saladas" of Monegros (NE Spain) are unique biotopes within an arid landscape with scarce vegetation, a plain cropped with rainfed winter cereal, obtaining poor or nil yields in many years. This landscape results from the aridity, the physiography, the lithology, and the soils, together with the multi-secular human pressure. This landscape, very rare in Europe, remembers some African desertic regions. The high interest of the habitats in the saladas has been recognized in administrative documents as well as in many scientific publications and in manifests from ecology activists. In the saladas, several authors have recorded animal and vegetal species qualified as endemic, rare or of biogeographical interest. Most of these authors have shown the ecological value of these species as result of several stressing environmental factors.

In the last hundred years, some saladas have disappeared. The extent of many others has decreased because of the agricultural pressure. Fro the 80's of he 20th Century, this trend was exacerbated by the increase of surface sown with rainfed barley or durum to earn subsidies. More recently the destruction of saladas has increased by the installation of irrigation districts, still not finished. Today, many habitats considered of prioritary interest by the environmental policies of the European Union are threatened.

The fate of these wetlands is unknown, but the alteration of the hydrological regime will probably result in their disappearance or in a dramatic change of habitats. The present species of living organisms are possible because of the high salinity, the aridity and the intermittent inundation. In spite of the several legal conservation measures, as the SPA's, the lack of detailed maps and the gaps in the protection rules put these wetlands in a fragile situation. The environment can not be divided by administrative boundaries. These wetlands and their vegetation need to be recorded and mapped to allow the study of their dynamics.

With his purpose:

(i) the several steps of he evolution of the saladas have been mapped, and the causes of disappearance linked to historical milestones. The map of saladas gives inventories for the years 1927, 1957, 1984 y 2006, and the qualifiers applied to the saladas in the oldest documents.

(ii) an updated cartography of vegetation at a detailed scale, has been produced. The habitats have been named according to the Habitats Directive and the CORINE legend adapted for Aragón. This cartography is not a simple list of species but, as included in a GIS, a tool for management and monitoring. It allows superseding the borders of the legal protection areas on the habitats map to know the habitats threatened by new irrigation districts or other activities.

(iii) the edaphic conditions for an outstanding halophyte of the saladas (*Arthrocnemum macrostachyum*), have been examined based on the knowledge of the vulnerable plant habitats and species, their cover density and extent. For this purpose, soil has been sampled in selected points and the distribution of *A. macrostachyum* analyzed against the edaphif characteristics.

(iv) field prospections and knowledge of the environment together with the habitats map, have enabled to undertake the study of spectral characteristics for the main "états de surface" of the saladas'. Several environments have been characterized by taking radiometric measurements in order to find relationships with images of different spectral and spatial resolutions acquired by the satellites Aster, Landsat, and Quickbird. An evaluation of field radiometry as a tool for mapping the "états de surface" in inland saline wetlands has been obtained.

The study of the "états de surface" and the habitats throughout field work and observation, sampling, inventory and detailed mapping accomplished in this Thesis, are basic information sources for the saline wetlands of Monegros. Moreover, the methods developed can be easily applied, for their evaluation, in other saline wetlands of arid regions.

The use of basic tools, like GIS and remote sensing with satellite or airborne images of high resolution, will be the key for management and monitoring of the studied environments. As has been demonstrated, all these tools dramatically increase the amount and quality of available information with costs reduced. Last but not least, GIS and associated technologies can be instrumental for vulgarisation, a cornerstone for nature protection.

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CHAPTER 1. Introducción

1. JUSTIFICACIÓN

En el centro de la depresión del Ebro, en los municipios de Bujaraloz, Peñalba y Sástago, se localiza el conjunto endorreico de humedales salinos del sur de Monegros, conocidos localmente como saladas o saladares (Figura 1). Las saladas, en un paisaje agrícola condicionado por la aridez y las oscilaciones térmicas, han sido objeto de numerosos estudios científicos y de divulgación. Esos estudios han reconocido la singularidad de los procesos químicos y edáficos en las saladas, la hidrología y la geomorfología, así como la fauna, flora, y vegetación. Con todo ello, estos hábitats se pueden calificar como ambientes relictos.

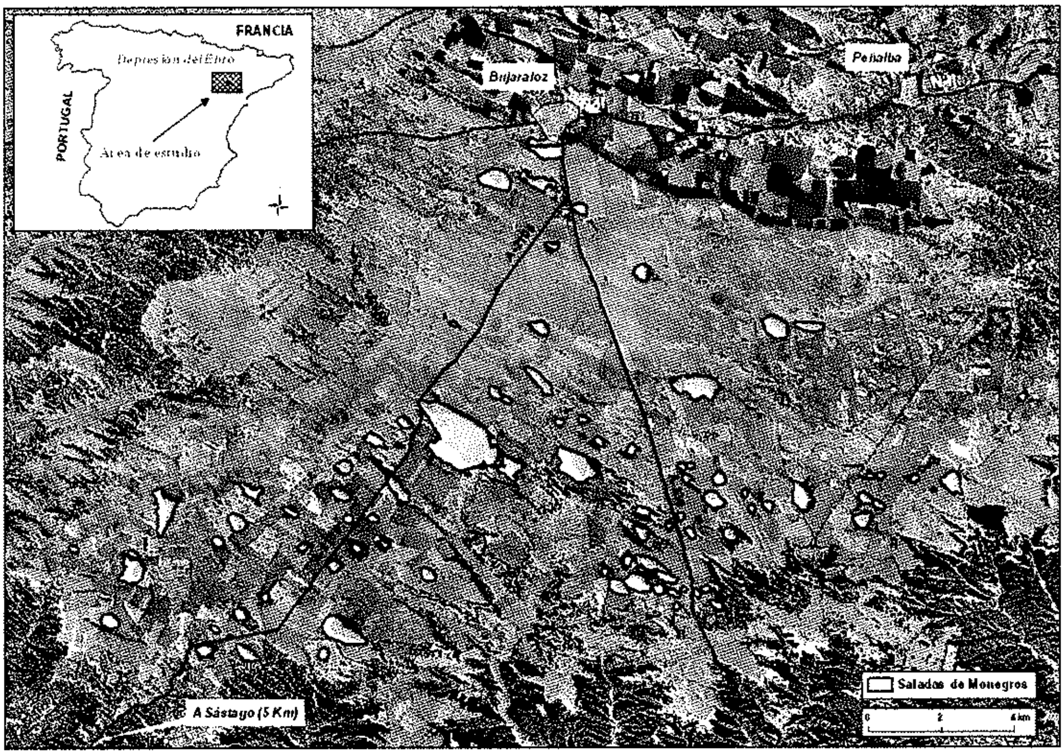

Figura 1. Localización del área de estudio; al norte en gama de verdes, el actual regadío y los humedales sobre el secano en transformación. Al sur del área de estudio destaca la vegetación en las cabeceras de los barrancos del escarpe sobre el Ebro. (Ortofoto del PNOA, 2006).

La agricultura tradicional en Monegros es de secano, basada en la cebada como principal y casi único cultivo. En Bujaraloz y Sástago, los subsidios de la Política Agraria Común (PAC), añadieron el trigo duro al estar subvencionado este cultivo sólo en la provincia de Zaragoza. El impulso de las subvenciones de la PAC, extendió el cereal de invierno a todas las zonas cuya roturación (Molero y Blanché, 1986) no queda impedida por el relieve u otros factores adversos a la entrada de maquinaria. En zonas llanas, como la plataforma endorreica, la vegetación espontánea se ha visto reducida a las saladas y los lindes de los campos. Los cultivos extensivos son hábitat de especies como *Circus cyaneus, Otis tarda, Tetrax tetrax, Burhinus oedicnemus, Pterocles orientalis, P. alchata* o *Calandrella rufescens* incluidas por su grado de amenaza en la Lista Roja de los vertebrados de España. El área de estudio se está transformando en regadío con el fin de incrementar su rentabilidad agrícola. La transformación (Real Decreto 1676/86 de 1 de agosto) empezó tras el bloqueo durante más de diez años de los fondos de la Unión Europea para el Plan transformación debido a una queja de activistas del ecologismo.

Las saladas ocupan posiciones topográficas bajas, en depresiones cerradas y fondos de val, albergando plantas adaptadas a la alta salinidad y otras condiciones extremas. Muchos de los organismos propios de estos ambientes podrían desaparecer simplemente por la dulcificación de las aguas inducida por los retornos del regadío, según señaló el estudio de impacto elaborado por el Instituto Pirenaico de Ecología (CSIC). Otras modalidades de presión humana, como vertidos del despedregado de los campos o de escombros, nueva red viaria, conducciones de agua de riego y drenaje, polígonos industriales, etc. amenazan parte de estos hábitats. Pese al interés de estos humedales salinos continentales, inexistentes en otros países de Europa, se ha consumado ya la destrucción total de algunas de las saladas.

La diversidad del ecosistema con numerosas especies y endemismos, junto con su singularidad geológica y paisajística, llevó a 483 investigadores e instituciones científicas de 35 países a firmar el Manifiesto Científico por los Monegros (Melic y Blasco, 1999) en apenas dos meses. Esto contribuyó a la inclusión de parte de las saladas en la Red Natura. En el año 2000, el Gobierno de Aragón aprobó el Lugar de Interés Comunitario (LIC) "Monegros", y la Zona de Especial Protección para las Aves (ZEPA) "La Retuerta y Saladas de Sástago". La ZEPA abarca algunas saladas, muchas de ellas próximas a los límites del regadío, y deja fuera otras consideradas en buen estado de conservación (Castañeda y Herrero, 2008). El día dos de octubre de 2009, el Gobierno de Aragón solicitó la inclusión de parte de los saladares de Monegros en la Lista de Humedales del Convenio Internacional de Ramsar. La superficie propuesta coincide parcialmente con los límites del LIC Monegros.

El Convenio Ramsar ha reconocido la importancia de los inventarios nacionales de humedales para conformar medidas para su conservación y uso racional (Secretaría de la Convención de Ramsar, 2007). Uno de los objetivos de la Directiva Hábitats de la Unión Europea es proteger la biodiversidad a través de la conservación de los hábitats (Council Directive 92/43/EEC). Hay pocos inventarios y mapas de hábitats a escala detallada en humedales salinos de interior, de ahí la necesidad de generar estudios para conocer su evolución y poder caracterizar y cuantificar sus estados superficiales, tan variables en estos ambientes. Muchos humedales se han perdido durante el último siglo por la presión humana (Davis y Froend, 1999; Tiner, 2002) y especialmente por la intensificación agrícola. Cartografiar estos humedales y sus hábitats a escala adecuada y según las normas europeas adaptadas a nuestro territorio, permitirá monitorizar cambios ambientales debidos al regadío u otras intervenciones y facilitará la conservación de los hábitats.

Los sistemas de información geográfica (SIG) resultan útiles para analizar los cambios ocurridos a largo plazo (Aspinall, 1993). Thomson et al. (2007) utilizaron la fotografía aérea y la metodología CORINE para monitorizar los cambios en lugares de la Red Natura 2000 en un área de 30 × 30 km. Boteva et al. (2004) inventariaron y cartografiaron la conservación de los hábitats Natura 2000 en Creta a escala 1:5000. Otros estudios combinan el SIG con distintas técnicas para la evaluación y mapeo de la vegetación (Ringrose et al., 1998; Tappeiner et al., 1998; Draper et al., 2003; Bock, 2003; Carlson et al., 2004). Piernik (2003) cartografió en Polonia la vegetación halófila de interior como indicadora de la salinidad edáfica. Hay estudios de las relaciones entre la vegetación y su entorno en zonas costeras de España (Álvarez-Rogel et al., 2000) y otras regiones áridas (Waisel, 1969; Ringrose et al., 1998; Feoli et al., 2002; Harris, 2001; Khan y Beenna, 2002).

Con el desarrollo de técnicas y aplicaciones de la teledetección, se ha incrementado el uso de imágenes de satélite de alta resolución para estudios a escalas detalladas. Durante los últimos años está siendo reconocida la importancia de la teledetección en el mapeo y cuantificación de la cubierta de vegetación (Xiao, 2005) y de sus hábitats (Keramitsoglou et al., 2005; Kobler et al., 2006) en ambientes áridos y semiáridos; en la actualidad se está usando para detectar cambios (Elmore et al., 2000; Camacho et al., 2004; Schmid et al., 2005), para monitorizar procesos de desertificación (Collado et al., 2002; Awad Khiry, 2007; Khaznadar et al., 2009) y de degradación de humedales (Koch, 2000; Schmid et al., 2004; Castañeda y Herrero, 2008).

2. ANTECEDENTES

Los primeros estudios publicados sobre las comunidades vegetales de las saladas datan de mediados del siglo pasado. Sappa y Rivas Goday (1952) presentan algunas especies de las márgenes de las saladas, caso de *Artemisia herba-alba* o *Lygeum spartum*. Posteriormente, Braun-Blanquet y Bolòs (1958) citan especies y comunidades halófilas en la salada de La Playa y cerca del núcleo de Bujaraloz, incluyéndolas en su inventario florístico de saladares de la Depresión del Ebro. Algunos trabajos inéditos, emprendidos por diferentes Administraciones para evaluar el impacto ambiental de la instalación de nuevos regadíos en Monegros II, hacen referencia al interés de la vegetación.

El estudio multidisciplinar del CSIC-MOPU coordinado por Pedrocchi (1989), presenta un estudio detallado de la flora y vegetación de las saladas llevado a cabo en campo entre enero y junio de 1988. Paralelamente, el Gobierno de Aragón estudió la vegetación de las saladas durante un año incluyendo una cartografía detallada, en un estudio del que únicamente se ha dispuesto del pliego de condiciones; dicho estudio incluía una propuesta de actuaciones sobre perímetros de protección por la incidencia de las obras infraestructura hidráulica y transformación al regadío. Otros autores se han centrado en la hidrogeología, elaborando un modelo conceptual y numérico del flujo subterráneo (García-Vera, 1996; Samper y García-Vera, 1998).

Molero y Blanché (1998) citan, para la comarca de Monegros, cerca de un millar de especies, de las cuales un 8% son endemismos ibéricos y un 3% se consideran endemismos monegrinos. Pedrocchi (1998) describe los dominios, detalla catenas de vegetación en los saladares, y elabora un catálogo con ejemplos de plantas endémicas o de especial interés biogeográfico para ilustrar la singularidad florística de Monegros. En él incluye otras Clases y Alianzas, además de las reconocidas con anterioridad por Braun-Blanquet y Bolòs (1958). Entre otros trabajos inéditos posteriores referentes a la vegetación de las saladas está el de Cervantes y Sanz (2002), que localizan tres especies amenazadas (*Halopeplis amplexicaulis*, *Microcnemum coralloides* y *Senecio auricula*) en un estudio promovido por la Subdirección del Medio Natural del Gobierno de Aragón dentro de su Plan para la Conservación de la Biodiversidad.

Al mismo tiempo, el "Estudio de Impacto Ambiental del Plan Coordinado de Obras del Modificado de la 1ª parte, 2ª fase (sectores VIII-A y IX-A), y de la 2ª parte, 1ª fase (Sectores XI-A y XIII-A) de la Zona regable de Monegros II", incluye una tabla con la vegetación endémica clasificada según grado de amenaza por la Unión Internacional para la Conservación de la Naturaleza, UICN (Comisión Técnica Mixta, 2002). El estudio destaca la presencia de: *Halopeplis amplexicaulis, Ruppia, Juniperus thurifera, Microcnemum coralloides, Senecio auricula, Limonium costae* y *Ferula loscosii*. Otras destacables son *Aizoon* sp. y *Cressa cretica*. Dicho estudio cita la especie amenazada Senecio auricula en Gramenosa y Zaborros, esta última salada destruida por las obras del regadío; en Salineta, no incluida en la Red Natura 2000, cita *Halopeplis amplexicaulis*, considerada en claro peligro de extinción y valorada por su interés como especie muy rara.

Estudios más recientes acerca del régimen hídrico de las saladas a partir de datos de campo y de satélite muestran la relación de la presencia de agua con las precipitaciones y la evaporación (Castañeda y Herrero, 2005) y la dinámica de las aguas subterráneas (Castañeda y García-Vera, 2008). Esto, junto con el reconocimiento de especies de interés dentro de la Red Natura 2000 (Domínguez et al., 2006) y la actual desaparición de humedales y de gran parte de su vegetación (Domínguez y Castañeda, 2008) hace necesario levantar una cartografía y establecer indicadores que sirvan para diagnosticar la vulnerabilidad de estos humedales (Castañeda y Herrero, 2008) y asegurar su conservación.

3. OBJETIVOS

Hasta la fecha no se cuenta con cartografía temática detallada y completa de los humedales salinos del sur de Monegros. El objetivo de esta tesis es caracterizar las saladas y sus hábitats a partir de información retrospectiva, y datos actuales de terreno y procedentes de la teledetección. El estudio de la heterogeneidad espacial y temporal de los estados superficiales de los humedales y los hábitats que los componen servirá de base y para detectar posibles cambios y/o alteraciones presentes y futuros.

En la tesis se pretende integrar la teledetección y los sistemas de información geográfica relacionando la información de campo con los datos de radiometría e imágenes satelitales. Con ello se quiere facilitar una herramienta para la cartografía de las saladas y la detección de cambios tanto de la distribución como del porcentaje de de la vegetación natural. Para este propósito se han definido los objetivos que se detallan a continuación:

1. Cartografiar e identificar los cambios espacio-temporales de las saladas a partir de mapas topográficos, fotografías aéreas, ortofotos, y otros documentos procedentes de estudios inéditos.
2. Cartografiar y caracterizar los hábitats de las saladas y estudiar sus patrones espaciales organizando esta información en un SIG.
3. Estudiar el vínculo entre los rasgos edáficos de un hábitat específico predominante de estos humedales y su distribución.
4. Estudiar el comportamiento espectral de los hábitats a diferentes escalas y relacionarlo con las imágenes de satélite para la obtención de una cartografía de vegetación a priori.

4. PRESENTACIÓN Y ESTRUCTURA DE LA TESIS

La tesis se ha organizado en cinco capítulos, el primero es la introducción y el último las conclusiones generales. El resto de capítulos se relaciona con cada uno de los objetivos anteriormente especificados:

- *Capítulo II. Ochenta años de evolución de los humedales salinos de interior.*

El inventario, el estudio retrospectivo, y el conocimiento de la tendencia evolutiva de los humedales salinos de Monegros son clave para su conservación y gestión. Su caracterización histórica en el marco paisajístico que los engloba permitirá definir los factores de transformación del paisaje, de los hábitats naturales y de su homogeneización.

El objetivo es obtener un inventario histórico de estos humedales prestando especial atención a los cambios de extensión y a la modificación de los márgenes. Para ello se ha recopilado y tratado documentación histórica: ortofotomapas del año 1927 de la Confederación Hidrográfica de Ebro, fotografías aéreas de 1957 y de 1984, y ortofotos de 2006. Esta información se ha georreferenciado e incorporado a un SIG junto a datos espaciales, generados a posteriori, sobre comunidades vegetales y rasgos edáficos. Ello permitirá analizar espacialmente los datos y contrastarlos con información histórica para conocer la evolución de los humedales en relación a distintos hitos históricos.

- *Capítulo III. Patrones espaciales de los hábitats Natura 2000 en los humedales salinos de Monegros Sur.*

Las condiciones microclimáticas, topográficas y edáficas de los humedales de Monegros han favorecido la diversidad florística. Se prevé la desaparición de las comunidades de halófitos más interesantes y la sustitución de la vegetación por otra más banal y mejor adaptada a la humedad (Pedrocchi, 1998). Ello hace necesario disponer de información actualizada para prevenir posibles impactos y afectaciones irreversibles para la flora y la vegetación.

El objetivo es crear un Sistema de Información Geográfica que englobe todos los humedales de Monegros, con los diferentes hábitats, su caracterización y situación frente a las nuevas delimitaciones finales del regadío y a las nuevas figuras de protección (ZEPAS y PORN). Este permitirá no sólo almacenar la información georreferenciada de las comunidades vegetales o de las especies de interés, sino también combinarla con otros datos almacenados (suelos, aguas,..), generar mapas y analizarlos a fin de poder caracterizar estos humedales y mejorar su gestión.

Para ello se ha emprendido la cartografía de la vegetación de las saladas y de las plantas protegidas o de especial interés sobre ortofoto digital. Esta información se ha georreferenciado e incorporado a un SIG. Las unidades cartografiadas se basan en los biotopos CORINE adaptados a la vegetación presente en Aragón y las leyendas estándar de hábitats de Interés Comunitario.

- *Capítulo IV. Los suelos de Arthrocnemum macrostachyum en los humedales salinos de Monegros.*

La vegetación de las saladas está adaptada a la sucesión de episodios de sequía e inundación y a condiciones de gran salinidad. La quenopodiácea *Arthrocnemum macrostachyum* destaca en el paisaje como resistente a la salinidad y encharcamiento, en un grado superior a *Suaeda vera*, otro halófito también muy característico. La distribución estratégica de *A. macrostachyum* le concede un papel muy significativo en la ecología de los fondos de las saladas. El objetivo de este trabajo es relacionar la distribución espacial del hábitat más destacado de estos saladares con los rasgos de la superficie de los suelos donde se asienta y describir la organización de la superficie del suelo y su posible influencia en la implantación de la vegetación.

➤ *Caracterización espectral de los estados de superficie de los humedales salinos de Monegros.*

Los cambios de la cubierta de vegetación pueden ser relativamente rápidos en estos humedales. La superficie del suelo, incluyendo la vegetación, es heterogénea. La vegetación, expuesta a condiciones extremas, se distribuye influenciada por la microtopografía, humedad y salinidad. La reflectancia, medida por un sensor terrestre o espacial, depende de las especies de plantas y su estado fenológico; muchas veces la vegetación senescente o seca tiene una respuesta espectral similar a la del suelo desnudo. El suelo también presenta diferentes estados en función de la humedad y de la presencia de eflorescencia. Algunos autores han señalado la dificultad de estimar cubierta vegetal en zonas áridas debido a las particulares características de la vegetación y de la superficie del suelo (Huete et al., 1985; Huete et al., 1985; Smith et al. 1990; Escafadal y Huete, 1991). Por ello se ha medido la reflectancia de diferentes estados de la superficie del suelo y la vegetación (humedad, eflorescencia, vegetación verde o senescente, etc.).

El objetivo de este trabajo es desarrollar una metodología para discernir el comportamiento espectral de la superficie del terreno teniendo en cuenta la variabilidad del suelo y la vegetación, y establecer una relación con la reflectancia obtenida de las imágenes de alta resolución.

Para ello se han tomado medidas radiométricas junto a parámetros biofísicos de los humedales salinos de Monegros. A partir de estos datos ha emprendido una metodología que permite clasificar la imagen relacionando los estados superficiales del suelo y los valores digitales de la imagen.

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CHAPTER 2. Eighty years' evolution of arid inland saline wetlands

1. INTRODUCTION

The saline wetlands scattered across the region of Monegros, NE Spain, have attracted attention from scientists and environmental authorities because of the rarity and isolation of these habitats, which host protected halophytes, extremophile microbes and invertebrates, as well as other forms of life, some of them endemic. Maintaining the equilibrium between agriculture and environmental protection is a concern in this strategic region located in the central Ebro Valley. Traditionally, Southern Monegros has been an arid area with barley as the only feasible crop, with very low or nil yields in many years. In the last 25 years, a major source of income for farmers has been agricultural subsidies, especially for durum wheat. Pressurized irrigation systems using Pyrenean water will increase yields and diversify crops. The ongoing works and the resulting change in the hydric regime threaten the present saline habitats and may well result in the disappearance of a unique set of saline wetlands in Western Europe. The risks have been stressed by authors such as Pedrocchi (1998), Melic and Blasco (1999), Domínguez et al. (2006), and Castañeda and Herrero (2008).

The Ramsar Convention highlighted the interest of wetland inventories in order to design policies and measures for their conservation and wise use, and established the List of Wetlands of International Importance on the basis of ecological, biological, limnological and hydrological criteria. The wetlands proposed for inclusion in this list must be representative, rare, or unique, or host species that are endangered or important for biodiversity. Moreover, all wetlands needed for aquatic bird life in any season must be included.

The Ramsar wetlands classification system (Ramsar Convention Secretariat 2006) allows a basic description of the main habitats, but does not fit all the habitats contained in the different wetlands (Zalidis et al. 1996; Costa et al. 1996). The present study, adapted to our saline wetlands in an arid region, takes into account straightforward features: size, morphology, the occurrence of halophytes, and the hydric regime. The uniqueness of the saladas depends on their biogeographic setting. The saladas could be included in the Ramsar checklist because they host plants included in the Catalogue of Threatened Species of Aragón (CTSA) and the Habitats Directive (Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora), the cornerstone of Europe's nature conservation policy. The saladas also contain Special Protection Areas (SPAs) for birds and Special Areas of Conservation

(SACs). Moreover, some salada habitats absent in Directive 92/43 are in the draft of the official checklist of habitats of Aragón (Benito et al. 2009).

Few saladas disappeared under traditional Monegros agriculture, which was well adapted to this arid milieu. The set-aside of the fields surrounding the saladas could help establish climax vegetation, but the impact on the saladas seems unclear, as their status is related to the agroecological conditions as a whole (Naveh 1994).

The inventory, retrospective study, and knowledge of the evolutionary trends of the saladas of Monegros are keystones for their conservation and management. Characterizing them at different dates in their landscape framework will make it possible to define the factors driving transformation associated with landscape fragmentation and habitat homogenization (Forman and Godron 1986). In this way, the number of saladas and their degree of degradation provide criteria for assessing their conservation status. Both can be deduced from our knowledge of the landscape and the available digital information, with the necessary concurrence of GIS (Turner 1989). Field surveys guided by aerial photographs and topographic maps are classical tools for land resources inventories. GIS makes it possible to create, stock, manage, analyze, and display spatial data from different sources. The development of GIS, improvements in the quality and availability of satellite images, together with the advances in techniques in information extraction, now make the task of gathering information and producing inventories easier.

We analyze the landscape components using a GIS to obtain maps illustrating the landscape changes. Our georeferenced data base, with maps from 1927, 1957, 1984, and 2007, has allowed us to reconstruct the evolution of the landscape and its causes.

The aim of this article is to give an integrated overview of the saline wetlands located in the south of Monegros, Spain, explaining the present landscape components by means of historical milestones. For this purpose, we establish two partial objectives: (i) historical reconstruction and updating of the inventory of saladas, and (ii) identification and assessment of spatio-temporal changes from 1927 until now. Our main tools are photointerpretation and GIS.

2. STUDY AREA

2.1 Geographical setting and physical environment

The saline wetlands of Monegros, or saladas, are endorheic depressions resulting from karstic and eolic action. This constellation of wetlands is developed on a Tertiary structural platform in the center of the Ebro valley (Figure 1), between 320 and 417 m above sea level.

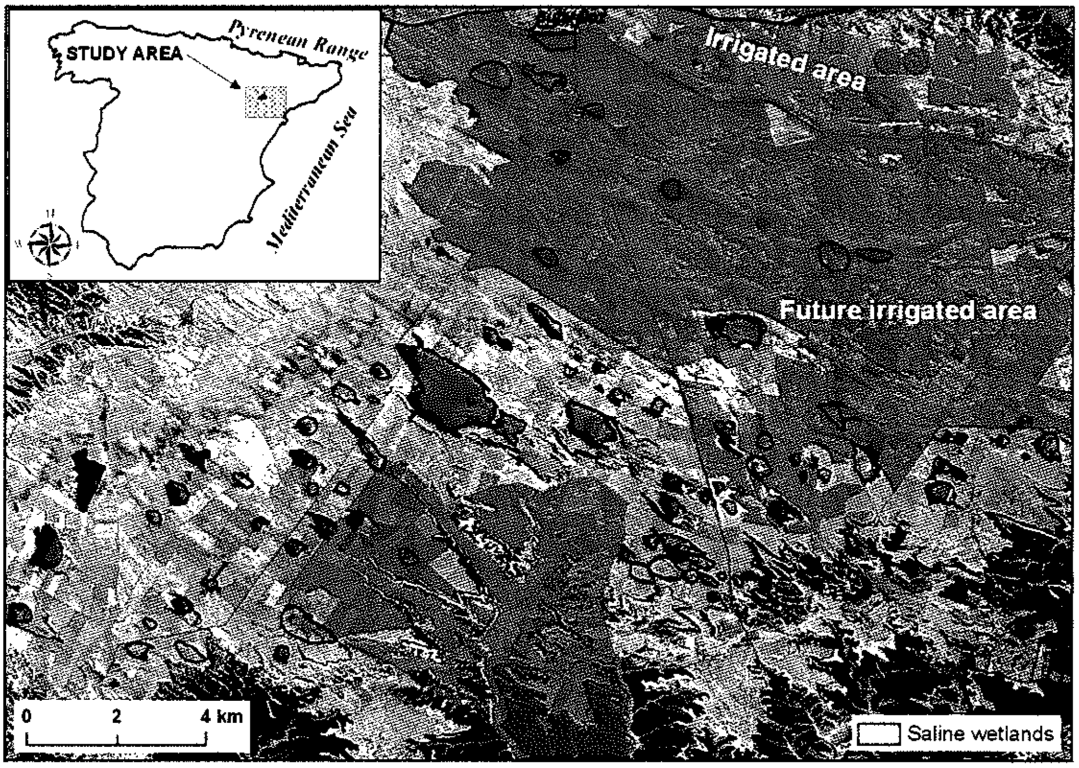

Figure 1. Saladas of Monegros over drawn in a RGB composition of an ASTER image from July 5, 2005. Actual irrigation appears in red color and future irrigation in blue.

2.2 Landscape

Dryland agriculture is the outstanding feature of the Monegros landscape, a broad plain with smooth undulations, depressions and vales with longitudinal slopes between 2% and 5%. The growth of winter cereal in the plain, plus the saladas' hydric regime and the associated facies (Castañeda et al. 2005), result in a distinct seasonality marked by drastic changes of landscape color, mainly between spring and summer.

Gardens are absent because of the arid climate and the scarcity of springs. Winter cereal and extensive lamb-grazing on the fallows, and also in the unharvested cereal fields in the frequent dry years, determine the appearance of the landscape. Some rare vineyard and olive tree plots are scattered among the cereal fields. Since the mid-20th century, the loss of traditional activities such as shepherding (De los Ríos 1982) has modified the landscape.

Since the mid-1990s, pressurized irrigation in the north of our study area has maintained alfalfa, corn, and other irrigated crops, allowing for new agro-industries around the urban area of Bujaraloz. Intensive farms and alfalfa dehydration factories are very conspicuous buildings in this horizontal landscape. In the south, the saladas are scattered between barley and durum cultivated in fields with high surface stoniness.

The saladas vary in size and in shape from subcircular to elongate with predominant NW-SE orientation and alignment. The bottoms are occasionally flooded with shallow salty water, or the muddy soil is covered by ephemeral saline effloresceces and algal mats. Most inner bottoms are bare, with external fringes of perennial shrubs and small annual plants, adapted to the high soil and water salinity. The escarpments, which are lighter in color, bear gypsophilous plants.

The grain-growing dry steppe is characterized by light colors because of the abundance of gypsum and calcium carbonate, and the scarcity of organic matter. Trees are absent, but idle and scrub lands are frequent, interspersed with small, isolated dry stone buildings or 'mases'. Most of them are ruined, but are now considered important for the survival of protected birds. New irrigation districts have been developed on these dry lands, and works for others are in progress.

The landscape color and patterns changed between the introduction of agricultural machinery in the mid-20th century and the land systematization prior to irrigation. Many saladas were invaded by cultivation, and much land was plowed and leveled, leading to marked changes in the landscape. For years, the bottoms and escarpments of saladas have been used for stone dumping, and the new linear infrastructures are producing more modifications.

Plot merging and leveling for irrigation, plus other work on pipe networks, drainage ditches, pumping stations and minor service roads, modify the relief. This fact, plus the return flows from irrigation, may lead to the disappearance of the protected halophytes, with a false positive effect of increasing biomass and birds, as has already happened at Lake Sariñena, 30 km to the north of our study area.

3. MATERIAL AND METHODS

3.1 Material

For recognizing, drawing and inventorying saladas, we used topographic maps, aerial photographs and orthophotographs, unpublished documents, and data bases from previous studies referenced in Castañeda (2002, page 33).

The main documents were: (i) the 1927, 1929, 1950, 1952, and 2004 editions of the sheets 413-Gelsa and 414-Bujaraloz of the National Topographic Map of Spain at a scale of 1:50 000; (ii) black and white photomaps from the 1927 flight by the Confederación Sindical Hidrográfica del Ebro, i.e. the Ebro Basin Water Authority (now the Confederación Hidrográfica del Ebro, or CHE); contact prints from flight B from 1956 and 1957 by the US Air Force; and from the photogrammetric flight of the Instituto Geográfico Nacional between 1981 and 1984; (iii) color orthophotographs from the 2006 flight by the National Aerial Orthophotography Plan (PNOA, by its Spanish name). Moreover, photographs from the 'Interministerial Flight' (1977-1979), even though incomplete for our study area, allowed some verification.

The 1927 flight was intended to cover all lands dominated by the irrigation canal network then in service and by the projected canals distributing irrigation water from the dams due to be built in the Pyrenean rivers to the mouth of the River Ebro into the Mediterranean. The Ebro Basin Water Authority contracted the flight and the related works to the Compañía Española de Trabajos Fotogramétricos Aéreos (CETFA) in one of the earliest non-military applications of aerial pictures. CETFA used a Zeiss 24 × 30 cm camera with a focal distance of 50 cm flying at 2500 m elevation, each shot covering 1 km^2. Tilt was corrected with a restitution instrument. The contact prints and negatives are not available, only the photomaps at a scale of 1:10 000, digitized by the CHE (http://oph.chebro.es/fotoplanos.htm).

The 1956-57 aerial photographs were taken by the US Air Forces flying over Spain. Each sheet of the National Topographic Map (about 500 km^2) is covered by 4 or 5 tracks with 12-19 photographs each; the scale of the contact prints is about 1:33 000.

The 1981-1984 flight at a scale of 1:30 000 was intended to produce a map of crops and land use for Spain. Each sheet of the National Topographic Map is covered by 4 or 5 tracks with 12 to 14 photographs each. Most photographs of our study area were taken in 1981, except for the 413 sheet.

The orthophotographs by the PNOA at a scale of 1:30 000 were taken with a differential GPS, obtaining digital orthophotographs with a 0.5 m pixel and 2 m altimetric accuracy (Arozarena and Villa 2004).

Of the existing inventories of saladas compiled by Castañeda and Herrero (2008), we used as a reference the inventory of Balsa et al. (1991) and their location sketch. This inventory contains the greatest number of saladas, and its sketch is very useful in spite of the lack of coordinates. We also used the georeferenced database of the saladas' vegetation (Domínguez et al. 2006) at scales from 1:2000 to 1:6000.

3.2 Technical procedures

We used a digital mosaic georeferenced at the University of Lérida from 46 photomaps from 1927. Fixing the deformations detected in the 1927 photomaps was possible during the georeferencing process thanks to the short range of elevations (from 320 to 417 m above sea level) in the platform hosting the saladas.

The 44 contact prints from the 1957 USAF flight at a scale of 1:33 000 were scanned with 800 dpi resolution and georeferenced maintaining their original dimensions. The smaller saladas are represented by a minimum of 4 pixels. We produced digital copies with a 1 m pixel as a compromise to avoid both information losses and inflating the data processing. For each contact print, we used from 6 to 12 control points for georeferencing on the PNOA orthophotograph. The technical parameters for orthorectification were not available; fiducial marks were never visible, and often the same applies to the flight altitude; only the flight direction was used. A second degree polynomial was applied to achieve an allowable adjustment correcting the linear patters of the scanner; resampling was done using the nearest-neighbor technique.

The 46 digital photographs from 1981-1984 were georeferenced on the PNOA orthophotographs with more than 20 control points in each photograph.

The georeferenced mosaics of the photomaps from 1927, the photographs from 1957 and 1981, and the PNOA orthophotographs from 2006, were photointerpreted on screen. This interpretation was based on geometric criteria, plus image texture, grey level, and color.

The geometric criteria were shapes clearly associable with saladas, in general elongated (playa-lakes) or subcircular (clotas or hoyas), and aligned with a preferred NW-SE orientation. The minimum accepted map delineation is one that allows the detection of small saladas in the cartographic documents, working with a scale better than 1:30 000. The main textural criteria were the occurrence of natural vegetation on escarpments and bottoms, and the dumping of boulders. The color or tonal criteria give an account of the occurrence of salt efflorescences and soil moisture in changing irregular surface patches of variable extent and shape. Only the PNOA orthophotographs contain chromatic information.

These observations were checked and completed by photointerpretation of stereoscopic pairs of contact prints from 1957. The sketch by Balsa et al. (1991) made it possible to locate in the mosaics of 1957 and 1927 those saladas that cannot be seen in the most recent orthophotograph. The delimitation of saladas derived from the vegetation data base of Domínguez et al. (2006) has been used to draw a reference map on the PNOA orthophotograph.

The presence of 'old' saladas in the PNOA orthophotographs has been checked, also using field observations on the occurrence of halophytic vegetation, geomorphic features such as depressions or escarpments, or color changes at the soil surface.

A geodatabase has been created incorporating the toponymy from historical and present sources and inventories. We assign to each salada the name given in Balsa et al. (1991); if this author did not name or recognize a salada, we use the name of a nearby site, well or road appearing on the oldest available photomap or topographic map.

Each of the four resulting maps is one layer of the geodatabase. These layers are arbitrarily named M1927A, M1957A, M1984A, and M2006A, because updating can be foreseen if better photograms from the same or other flights become available, or documents from any other source are exhumed. Those saladas detected at one date but not at another later date are qualified as having disappeared between these two dates, while those not detected at one date but detected at some later date are qualified as recovered. Of course, these qualifiers can change if new cartographic documents or other information become available.

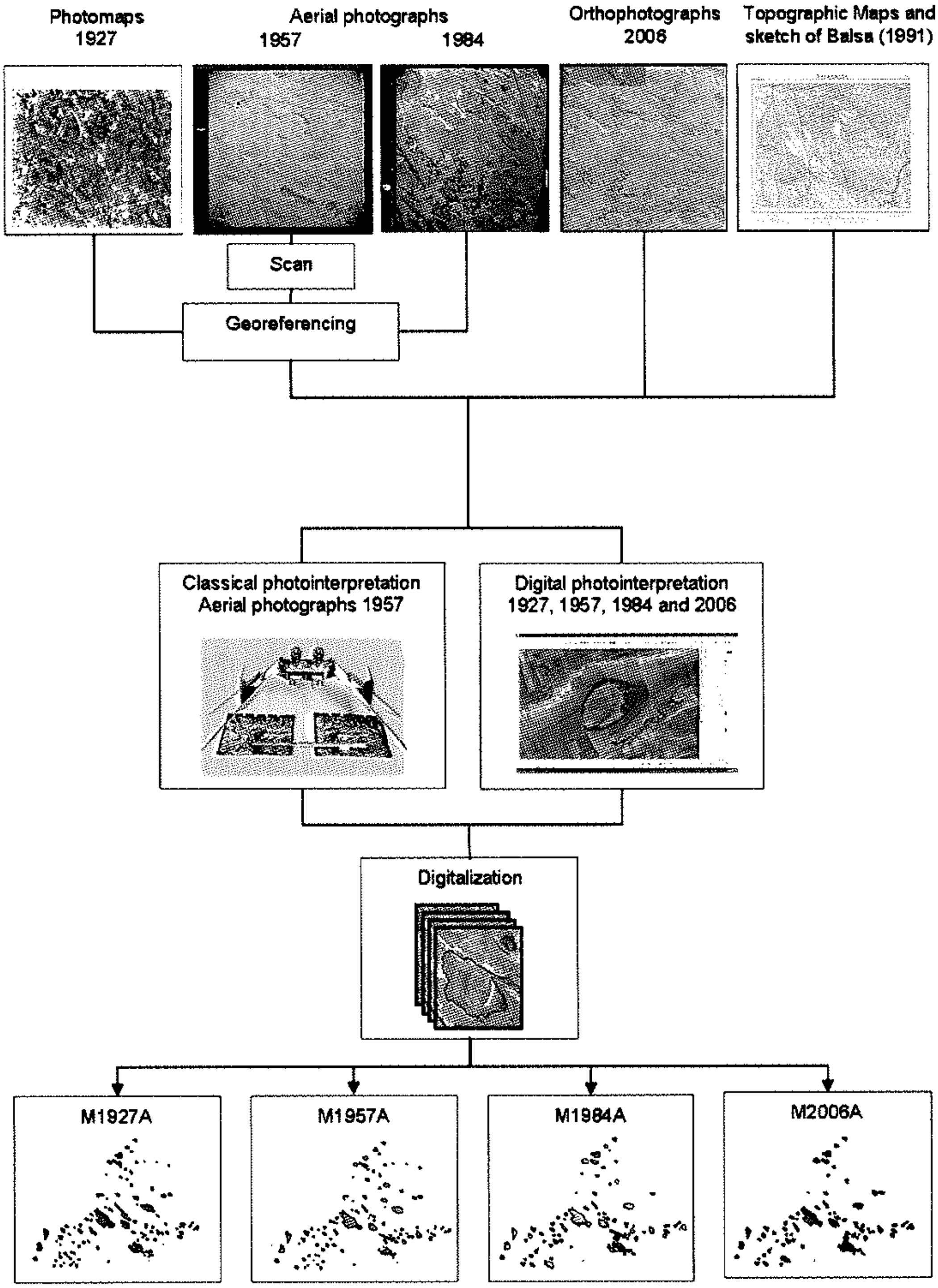

Figure 2. Steps of the data gathering and processing.

4. RESULTS AND DISCUSSION

4.1 The saladas in 1927, 1957, 1984, and 2006

The detailed information and planimetry provided by the aerial photographs have been invaluable for the retrospective study of saladas and their surrounding landscape. The studied dates are good bench marks for relevant landscape changes: the year 1927 was prior to agricultural mechanization; 1957 was at the end of the famine following the Spanish Civil War (1936-39) and the beginning of agricultural mechanization; the years 1984 to 2006 display the changes associated with agricultural intensification, the Common Agricultural Policy (CAP), and the introduction of irrigation.

From the four maps of saladas (Figure 3), M1927A contains 136 saladas; M1957A contains 115; M1984A contains 101; and M2006A contains 96 saladas, the lowest number from the four dates. It must be stressed that the most recent inventory is the most detailed because of the possibility of checking in the field, the available vegetation map (Domínguez et al. 2006), and the color and resolution of the orthophotographs from 2006. The total number of different detected saladas is 144, including those coincident and those exclusive to each date.

The quality of the cartographic documents hampered recognition of shapes and textures denoting saladas. Delineation was conditioned by the differences in scales and the geometric deformations of the historical cartographic documents, mainly in those from 1927 and 1957; for this reason, the saladas' borders on the four layers (M1927A, M1957A, M1984A, and M2006A) cannot be used for the automatic measuring of changes in extension. This kind of problem in comparing flights from different times has been pointed out by other authors (Cardenal et al. 2008), even for more recent documents or aerial photographs.

Layer M2006A contains 88 of the 99 saladas inventoried by these authors; the difference may be due to the disappearance of some of them but also to the field recognition criteria. The textural and grey level criteria plus the toponymy found in the photomaps from 1927 produced layer M1927A. Of the 136 saladas of this layer, 82 are coincident with the saladas of Balsa et al. (1991); of the remaining 54, only 16 were not recognized at any other date. The 21 saladas recorded by these authors with the generic name 'clota', plus the 54 new saladas, have been designated with the toponym of the older document, i.e., the photomaps of 1927. In the absence of a name in these photomaps, we take the names from nearby land features such as wells (pozo), corrals, roads, or isolated buildings (mas, venta).

Layer M1957A results from classical photointerpretation based upon textural and tonal criteria. The 115 saladas of this layer include 78 of those inventoried by Balsa et al. (1991); three of these saladas —Hoya de Correo, Balsa de Gros, and Hoyo de Benamud— were not identified in M1927A. Moreover, 85 of the saladas inventoried by these authors have been recognized among the 101 saladas contained in layer M1984A.

If the four maps are compared, 11% of the saladas occur at only one date, most of them in the photomaps from 1927; 24% occur at two dates; 62% at three dates. Only 55% occur at the four dates: those of bigger size, or playa-lakes, and hoyas or clotas greater than 20 ha. Moreover, those clotas < 10 ha with closed escarpments also occur at the four dates (Figure 3).

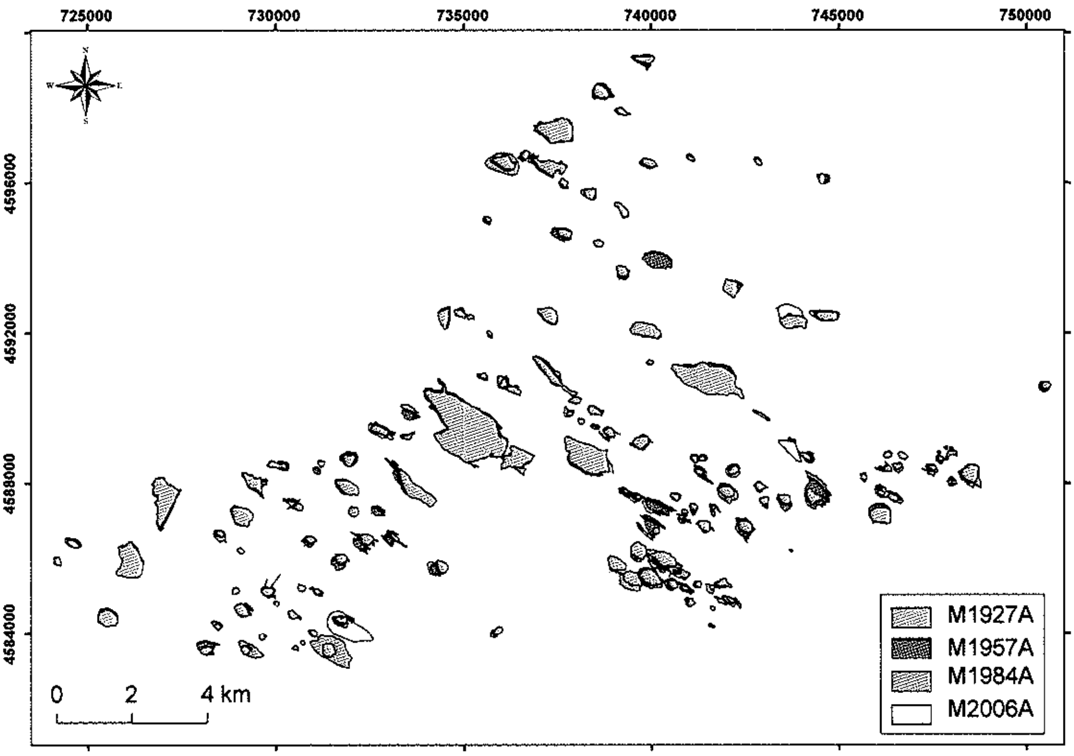

Figure 3. Maps of the saline wetlands inventory.

4.2 Extent, shape, and confinement of saladas

The location and toponymy of the saladas were contrasted for all the sources consulted, and both ambiguities and discrepancies between sources recorded. The reference documents were the inventory and sketch by Balsa *et al.* (1991), but all the names of saladas found in the topographic maps and photomaps were incorporated into the GIS. We recorded eight different terms used to designate the saladas: balsa, clota, hoya, hoyo, laguna, saladar, salina, and pozo. These are usually accompanied by a second word which frequently refers to the owner's family name, alias or job; for this reason some of them differ between dates. The generic terms refer to the morphology and confinement of the depression (clota, hoya, hoyo), the size and occurrence of water (laguna), their use as a saltern (saladar, salina), and the proximity of a water supply (balsa, pozo), key for the survival of humans and livestock. In the map M2006A, the names of 36% of the saladas incorporate terms such as hondonada, clota, hoya, or hoyo referring to a depression, while 16% evoke the occurrence of water or salts, such as laguna or salina.

Figure 4 displays the extent of saladas grouped according to the qualifiers of Balsa *et al.* (1991), or M2006A for those not inventoried by these authors. The size ranges from 1.2 to 29.8 ha for clotas, and from 5.2 to 56.2 ha for hoyas, suggesting that these names refer more to the shape and the confinement by escarpment than to the size.

Commonly, the escarpments of clotas are more abrupt and closed than in hoyas; clotas are often located in the SE of the study area, while hoyas are more common in the SW. The terms 'hoya' and 'hoyo' are used for depressions with smooth borders that are in general drier than the others. No relationship was found between the size of clotas and their geographical location or the preservation of their escarpment, but invasion by crops is more frequent at hoyos and hoyas because of the open morphology of their escarpments.

The laguna, saladar and salina types are the largest saladas, their sizes being similar in range if we exclude La Playa. While not abundant, these are the most persistent types. Many suffer degradation over time, much more often due to the dumping of boulders or debris than as a result of agricultural invasion. The terms 'pozo' (well) and 'balsa' (artificial pond), related to landscape elements close to the salada, are not represented in Figure 4.

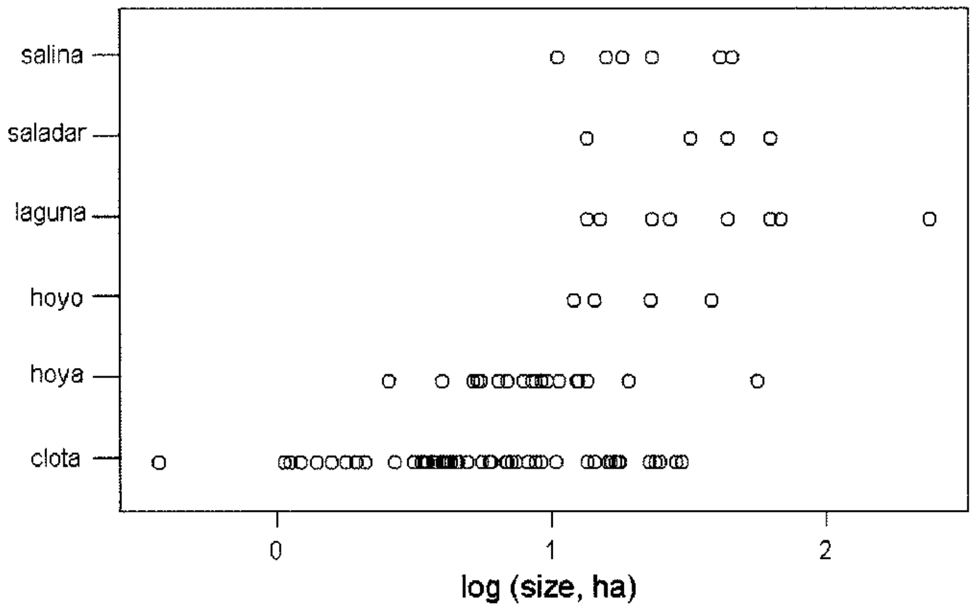

Figure 4. The qualifiers of saladas against the decimal logarithm of their surface extend.

4.3 Persistence and disappearance of saladas

The analysis of qualitative changes shows frequently alternating land uses. This fact, plus the limitations of photointerpretation due to the low quality of old documents, explains the appearance of new saladas in maps M1957A, M1984A, and M2006A (Table 1).

The number of saladas that have disappeared would be, at the minimum, the difference between those detected at the earlier date and those concurrent with them at the following dates. When talking about saladas that have disappeared or recovered, it must be stated whether we are referring only to the concurrent saladas or to all the saladas detected at each date. The following two tables show both numbers. Table 1 displays the number of saladas detected at each date, and how many of them persist at each later date. Table 2 displays the recovered saladas and the net differences; all are negative and account for saladas that have disappeared.

Some saladas that appear to be plowed or cultivated at one date appear with natural vegetation at a later date. Irrespective of surface area, we qualify these saladas as recovered; if the contrary happens, we consider the salada to have disappeared.

From 1927 to 2006, at least 47 saladas were lost; 50% in 1957 and 37% since the introduction of CAP. The greatest number of saladas was detected in the photomaps from 1927 (Table 1); the 16 saladas identified only in the 1927 photomaps are located mainly in the south of the study area. Of the 136 saladas detected in 1927, 111 were also seen in 1957; of these, 84 persisted in 1984, and of these 77 persisted in 2006. The number of saladas in M2006A is 29% lower than in M1927A.

Of all the time intervals under consideration, the greatest decrease in the number of saladas happened between 1927 and 1957 (Table 1). Most of the saladas recognized in 1957 are coincident with those of 1927, except Hoyo de Benamud, Hoya de Correo I, Yesera I, and Balsa de Gros. These four saladas are regarded as recovered, subject to the discovery of new maps or other documents with additional information.

Between 1957 and 1984, 27 saladas disappeared, 26 of which were identified on the aerial photomaps of 1927. In 1984, 13 saladas were recovered. Hoya de Correo II was recognized for the first time in the photographs of 1984.

Table 1. Number of saladas detected at each date, and saladas persistent between maps from different dates.

Detected saladas		Number of persistent saladas		
Map	**Number**	**M1957A**	**M1984A**	**M2006A**
M1927A	136	111	93	89
M1957A	115		88	84
M1984A	101			93
M2006A	96			96

Table 2. Number of saladas that recovered (light grey) and disappeared (dark grey) between pairs of maps from the four dates.

	M1927A	**M1957A**	**M1984A**	**M2006A**
M1927A		4	8	7
M1957A	-21		13	12
M1984A	-35	-14		3
M2006A	-40	-19	-5	

Even though the most intense landscape changes happened from 1984 to 2006, the number of saladas that disappeared is the lowest (Table 2). Moreover, 3 saladas (Corral Nuevo I, Corral Nuevo III, and Saladar de Don Roque) that were plowed or cultivated in 1984 were recognized in 2006.

If we look at the net differences between the saladas that disappeared and recovered between the dates (Table 2), the disappearance of saladas has decelerated in recent years: 21 from 1927 to 1957, 14 from 1957 to 1984, and 5 from 1984 to 2006 (Table 2). These figures include the balance of disappeared and recovered saladas, such as Hoya del Correo and Balsa de Gros, which were cultivated in 1927 and recovered in 2006; or, by contrast, Hoyo de Botones, Hoyo del Lugar, or Clota del Saso, which were visible in 1927 and cultivated in 2006.

Many saladas have been lost over the 80 years covered by our study. Moreover, their identification has been difficult because of the great variability in their conservation status. In spite of the low level of agricultural mechanization during the first 30 years, the saladas were modified and their number decreased due to the strong agricultural pressure. The pressure continued in the following 50 years, increasing the cultivated surface through the elimination of natural vegetation. However, some saladas have recovered. As an illustration, in the last 20 years only 8 saladas have disappeared, and 3 were recovered, as against 25 that disappeared and 4 that recovered between 1927 and 1957. The increase in recovered saladas may be a false impression produced by the quality of the more recent documents.

Figure 5 shows an example of the change in land use between 1927 and 1957. Bare soils and brush in 1927 (Figure 5a) located among cultivated lands were broken up (Figure 5b). The increase in low-productivity cultivated surfaces preceded the disappearance of many saladas by the plowing of their escarpments, and sometimes also the bottoms, to earn subsidies.

Superimposing our maps on the Spanish Farming Land Geographical Information System (SIGPAC), and from the 2005-2006 alphanumerical data from the GIS for Herbaceous Crops of the Spanish Ministry of Agriculture, Fisheries and Food, we ascertained that the 31 saladas that disappeared from 1957 until 2006 formed part of 137 farming plots (belonging to 17 farming polygons) with a total surface area of 1373 ha. Of this surface, 133 ha belonged to saladas: 22 clotas, and 9 hoyos or hoyas. SIGPAC qualifies 93% of the surface of these saladas as arable land, and the remaining 7% as idle land, roads, or water bodies. About 44% of the arable surface of the saladas was fallow in 2005-2006; 34% is of unknown use; and 11% is cultivated with durum or barley. Set-aside is a requirement in order to earn the single CAP payment only for 4% of the surface area occupied by the 31 saladas that have disappeared. The remaining arable land (7%) is alfalfa and voluntary set-aside lands.

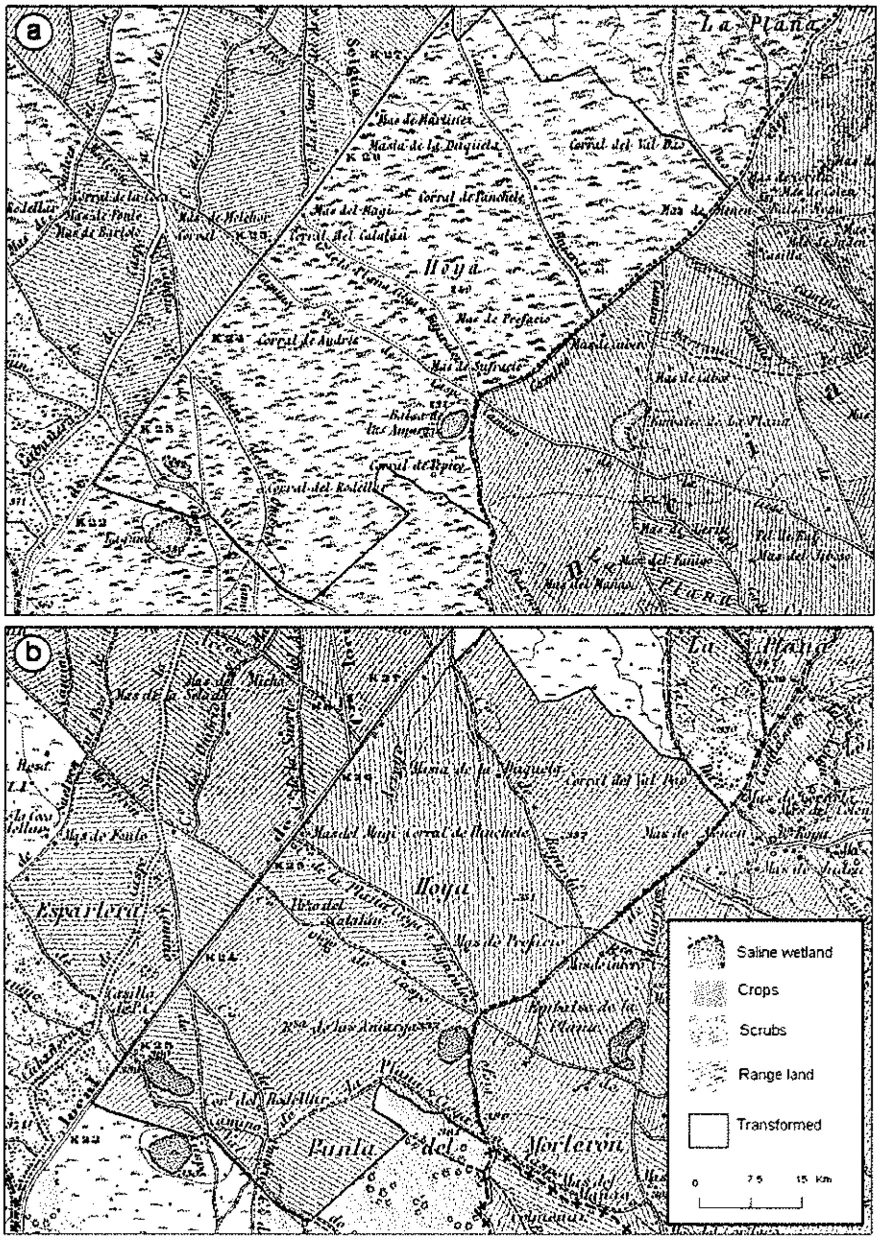

Figure 5. Sheet number 414 of the National Topographic Map, edition of 1927 (a) and 1957 (b). We enclose in a red line the area changed from brush and idle land to rainfed cereal.

4.4 Landscape assessment

Historical documents note the landscape changes in Monegros, referring to the elimination of vegetal cover (De Asso 1789). In 1927, rainfed winter cereal crops were the main landcover (Figure 6a). De los Ríos (1982) reports that on the small terraces, easily recognized in photomaps, the irregular yield becomes nil in the drier years. Both cultivated and idle lands show uniform textures and light colors in the aerial photographs, but agricultural fields can be recognized by their elongated and rectangular shapes. Fields and small roads were adapted to the gentle reliefs and to the slopes of vales, and the escarpments of clotas and hoyas remain unplowed.

Agricultural intensification in Spain started around 1950, but mechanization, the introduction of the moldboard plow, and fertilizers were late coming to Monegros (Castelló 1984). No relevant changes in the fields' morphology or in the escarpments of saladas can be seen in 1957 (Figure 6b). Only some fields at the bottom of the vales were plowed. Other fields contain aligned points corresponding to vineyards or to trees such as olive or almond, which are now very rare in the study area.

The texture and grey level in the aerial photographs are very similar for fallow and winter cereals in Monegros. If the day of the flight is unknown we only have an idea about the general status of the landscape, but it is impossible to ascertain whether a particular field was cultivated. Figure 6b is dominated by homogeneous textures and light grey tones related to the flight date (July 28, 1956) just after the harvest, which finished before July 15 in this area. Dark tones at the bottom of saladas are due to moisture. The absence of whitish spots representing salt efflorescences can be attributed to a wet season or occasional rain. The vegetation of the saladas shows an irregular mottled texture, and seems undisturbed. The roads, which are quite straight and light in tone, have not changed.

During the 1960s and 1970s the human pressure increases. The fields are more regular and bigger in extent; the relief is smoothed to gentle slopes, close to plain (Figure 6c). Heavy machinery extensively brings pieces of limestone and gyprock strata to the surface. The boulders are stocked either in piles spread in the fields, or at the borders of the fields; if a salada is close, the boulders are dumped at the bottom. More recently, surface stones are crushed. Some saladas close to the urban area of Bujaraloz have disappeared, filled up with debris and earth, or their vegetation has changed from halophilous to nitrophilous under the influence of animal farm leachates or other residues.

In the 1980s the irrigation planned by a law from 1915 reached our study area, which was declared "irrigable of national interest" (Royal Decree 371/1985). A complaint from ecological activists filed in Brussels stopped the irrigation works for 11 years and reduced to a half the surface of the study area to be irrigated. The land systematization process prior to irrigation lasted until 2005, as can be seen in the Official Bulletin of Aragón (BOA 7/9/2005). Now the main landscape alterations come from the works for irrigation water distribution and drainage ditches (Figure 6c). Moreover, the new roads are much broader than the old ones, and make a more orthogonal network. The old network is still partially existent. Some saladas interrupt the network of field borders and roads. The surface occupied by saladas decreased (Figure 6c), and the escarpments of some saladas became vestigial. Natural vegetation is often confined to the steeper escarpments and the bottoms, where plowing is difficult. At times, moisture or low productive spots suggest a salada that has disappeared, as is the case with Hoyo del Lugar (Figure 6).

Most saladas that disappeared as a result of agricultural pressure were located at the south of the study area, where saladas were more abundant. As an example of the evolution of saladas, Figure 7 shows that of nine saladas seen in the 1927 photomap, three have disappeared in 1957, three more in 1984, and one in 2006. Often, moisture, salt efflorescences, or remaining natural vegetation on the escarpments (Figure 7d) serve as a reminder of an old salada. Not all saladas have disappeared, but most of them have had their borders altered with time. This is illustrated by Figure 7, which shows how the extent of Hoya de los Aljeces has decreased, and its escarpments have been smoothed by the elimination of man-made terraces. Borders and bottoms of saladas have undergone on-and-off cultivation and abandonment because of their low profitability, even though subsidies provide incentives for plowing.

Most changes became more intense from the 1950s following the introduction of machinery for plowing more land (Figure 7b). Many saladas disappeared after changes in relief as a result of movements of earth to merge small fields; this is the case with Clota del Piriquet and Hoya del Pansero. Figure 7c shows that before the introduction of CAP the cultivated surface was enlarged to increase cereal cultivation. The mottles seen in 1984 are piles of boulders, which have remained until now (Figure 7d).

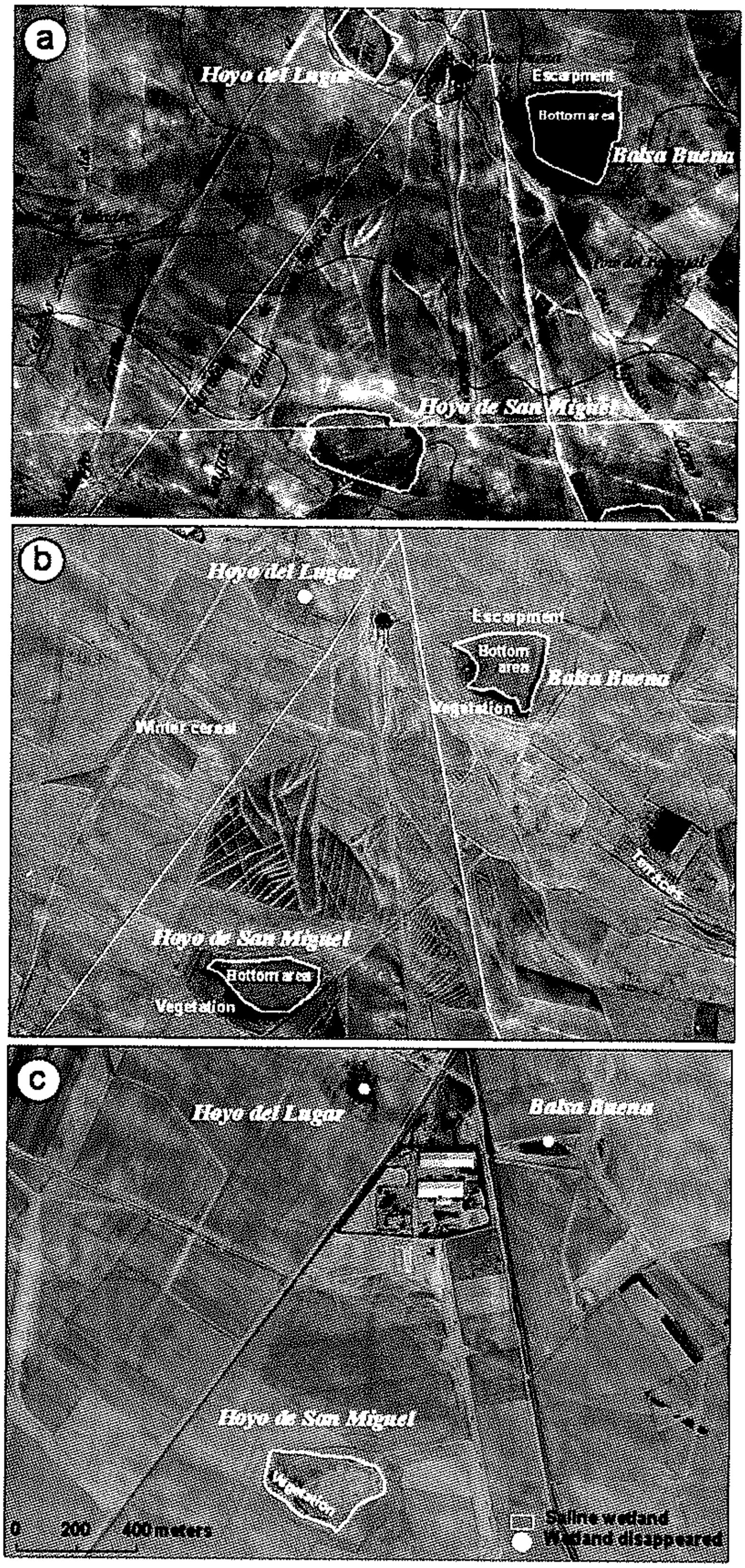

Figure 6. Example of landscape changes from 1927 to 2006. Photomap of 1927 (a) aerial photograph of 1957 (b), and PNOA ortophotograph from 2006 (c).

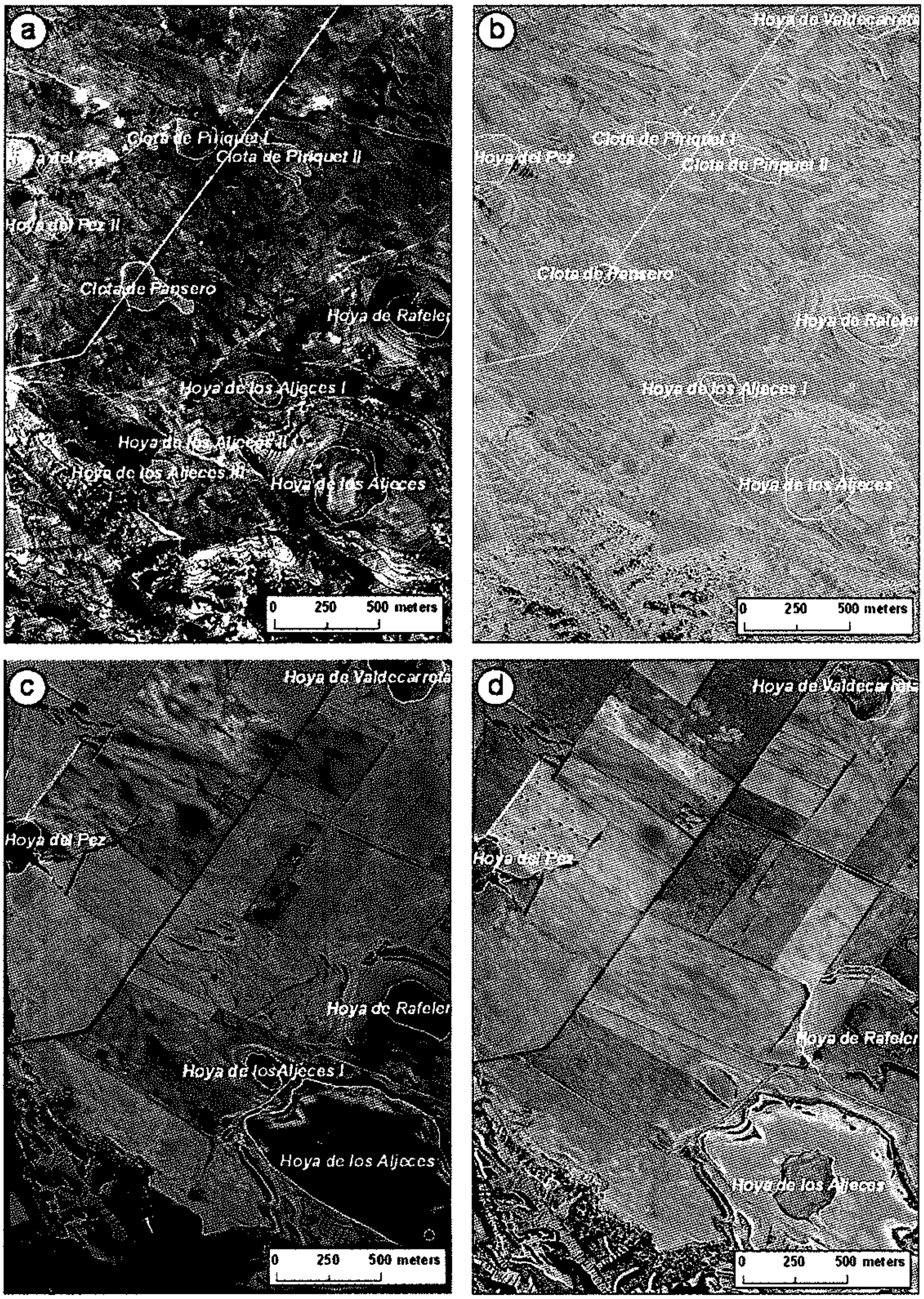

Figure 7. Changes produced in 1927 (a), 1957 (b), 1984 (c) and 2006 (d).

Figure 8 shows the changes undergone by Salobral, a salada close to the urban area of Bujaraloz. Most of the natural vegetation was preserved in 1956 (Figure 8a), as shown by mottled textures in the west of the salada. The eastern escarpment still has terraces, and the salada is crossed by minor roads. The bare bottom is dry and probably has salt efflorescences. In the east of the salada field limits fade due to the monotonous grey colors; the texture in some fields could be due to vineyard or olive trees. The orthophotograph from 2006 (Figure 8b) shows evidence of major alterations. The salada is flooded by effluents from the surrounding intensive animal farm and irrigated lands, and the roads have disappeared. Dumped debris covers the natural vegetation and half the bottom.

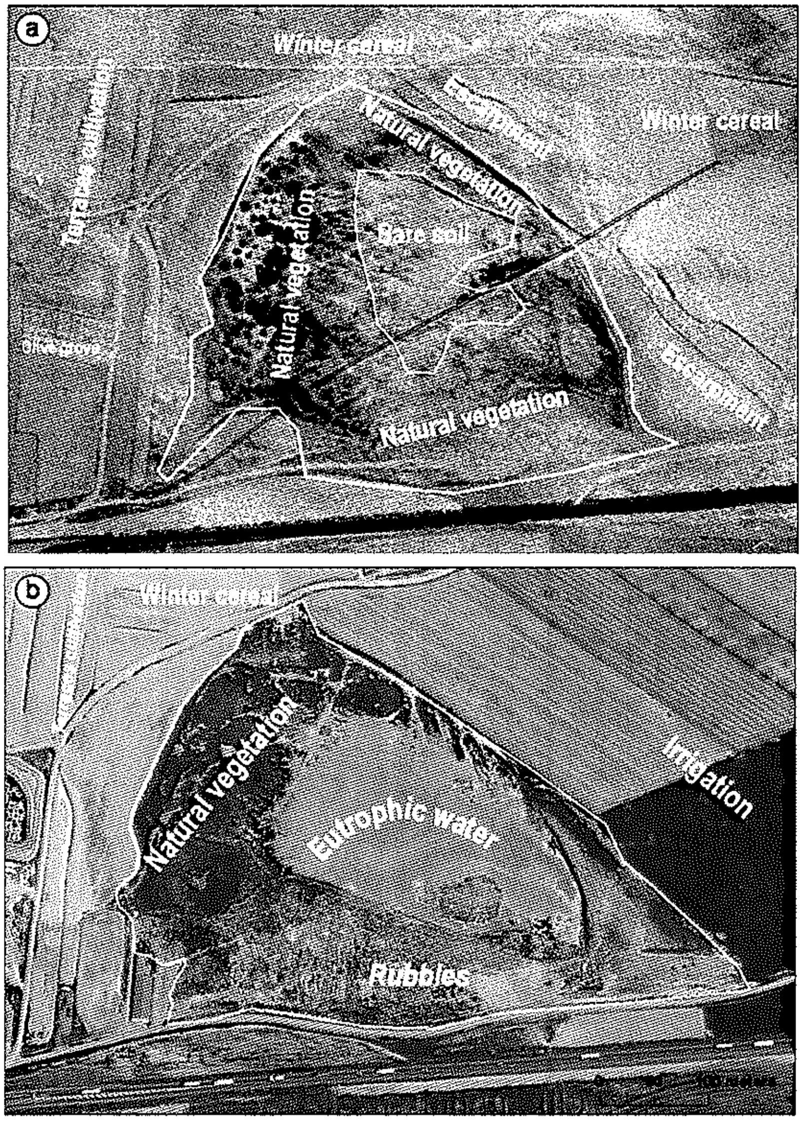

Figure 8. Changes in Salobral from the aerial photograph of 1956 (a) to the orthophotograph of 2006 (b).

Some outstanding changes are the direct destruction of saladas by roads and water pipes associated with the introduction of irrigation, as is the case with Hoyo Garra

(Figure 9), which disappeared between 1984 and 2006. In Figure 9a the salada is surrounded by fallow and recently plowed fields of winter cereal crops. The borders of the salada are outlined by natural vegetation that is dark grey in color, while the soil is bare in the central area. Figure 9b shows the new field pattern after land systematization and the complete disappearance of the salada after the construction of the drainage ditch. The color and texture of the sprinkler-irrigated fields to the north of the ditch are very different from the rainfed fields to the south.

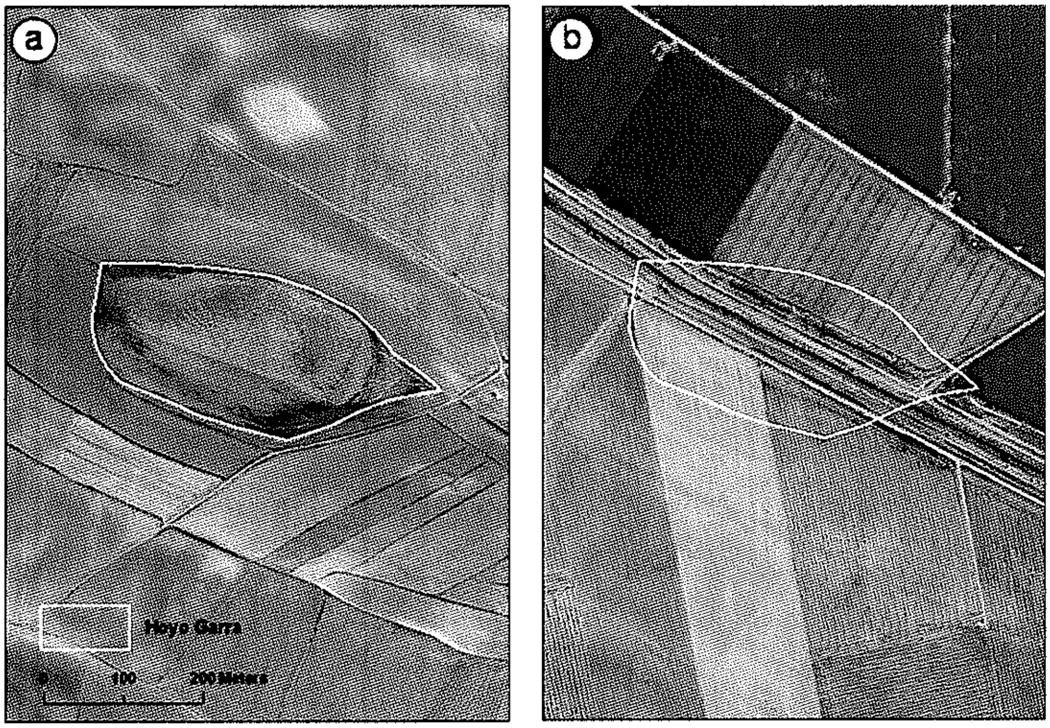

Figure 9. Aerial photograph of 1981 (a) and orthophotograph of 2006 (b) showing the destruction of Hoyo Garra by a drainage ditch. Green area in (b) is under irrigation.

The inverse evolution is rare. As an example, the bottom of Benamud is occupied by several cultivated fields in 1927 (Figure 10a), whereas in 2006 there is bare soil and natural vegetation (Figure 10b). The proximity to the urban area of Bujaraloz and easy access may have fueled cultivation, with subsequent abandonment because of low profitability due to soil salinity. The traces of cultivation, still visible in 1956, have disappeared by 2006, and the natural vegetation is in the process of recovering. However, other saladas not plowed in 1956, such as Hoyo Botones, are plowed in 2006 (Figure 10).

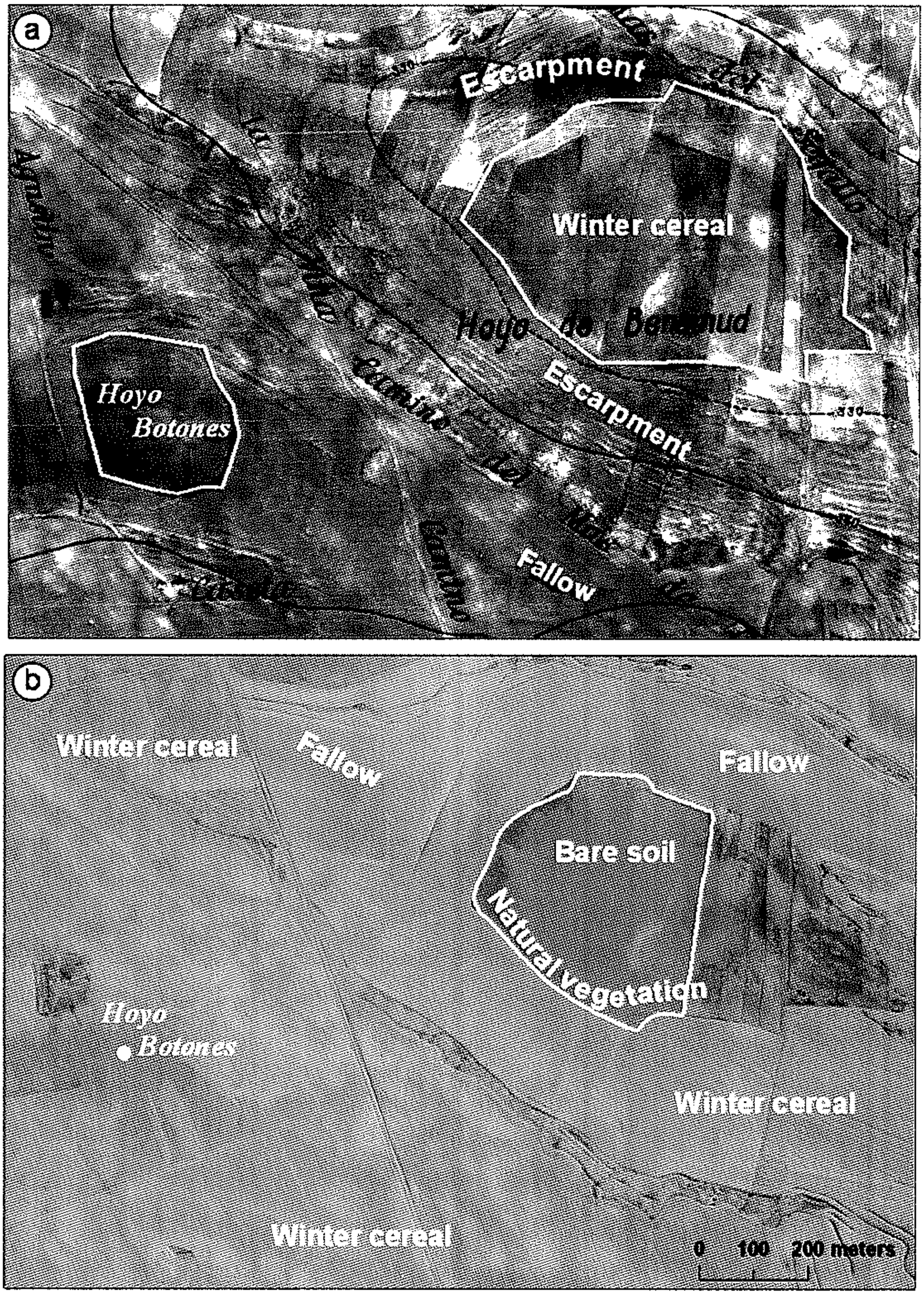

Figure 10. Salada Benamud in 1927 (a) and 2006 (b).

Figure 11 shows another example of clotas recovering from 1984 to 2006. In 1984, the two saladas Corral Nuevo I and Corral Nuevo III were plowed and with stockpiles of an unknown material, whereas in 2006 both bottoms look abandoned, with natural vegetation recovering. The light tones are spots of shallow gypsum or salt efflorescences, both resulting in low cereal yields.

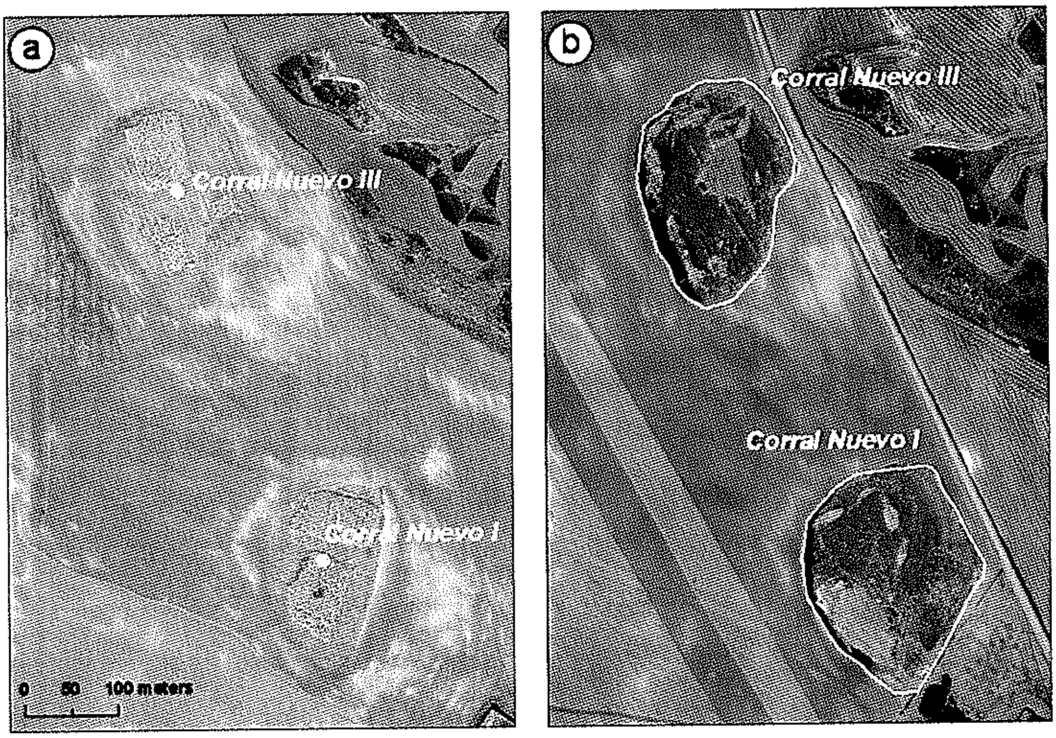

Figure 11. Clotas Corral Nuevo I and III in 1984 (a), and 2006 (b).

The intermittence of agricultural use and abandonment has transformed the mosaic landscape of 1927. The great diversity of textures produced by traditional agriculture, evident in aerial photographs, denotes different kinds of habitats contrasting with the homogeneity of winter cereal crops. The mosaic has been reorganized into big plots suitable for the mechanized cultivation of winter cereals. Now these plots are being put under sprinkler irrigation.

On the other hand, agriculture in Monegros has been revolutionized since the 1980s (García 2006) by CAP subsidies permitting cultivation in spite of the low yields. This policy does not help the conservation of saladas.

5. CONCLUSIONS

We have inventoried 140 saladas at four dates within an eighty-year span. In the earliest year, 1927, we identify 136 saladas; others have been identified in 1957, 1984, and 2006. The map M2006A contains 96 saladas, most of them surrounded by or very close to irrigated or irrigable lands.

The changes in land use have resulted in an increase in plowed land, changes in the cultivation patterns, and the alteration of saladas. The maximum decrease in the number of saladas happened between 1927 and 1957, due to the plowing of new land; the overall landscape morphology was unaltered however. Agricultural mechanization and intensification have been modifying the landscape since 1957, with many of the saladas' escarpments smoothed and then cultivated, as well as some bottoms. Some saladas have later been abandoned because of low profitability.

Photointerpretation allows an understanding of the landscape changes over the 80-year span studied, and provides depictions of landscape patterns and their past and present relationships with the saladas. The old photographic flights have been crucial for the retrospective study of saladas; conversely, their usefulness would be increased by restoring the film or paper support and making available the flight date. Data treatment and analysis by GIS have been key to the quantitative analysis.

Our georeferenced database can be enlarged with other data layers obtained by photointerpretation, and with biodiversity maps. This would provide basic information supporting the proposal for inclusion in the Ramsar list.

The acquisition of information from photographs and maps produced during an 80-year span is restricted by flaws in the conservation of the documents, differences in scale, geometric deformations, and the lack of flight data. These flaws have been admissible because our aim was more to locate, identify, and assess the conservation of saladas than to produce accurate delimitation and planimetry. However, in order to improve the accuracy and reliability of the historical inventories, we recommend the restoration of the original paper or film supports and the publication of available flight data such as the date, camera or altitude.

The four maps of saladas and their future updates will help monitoring and management. A sustained loss of these wetlands can be foreseen given the current conditions of the saladas and their location in the face of present and future irrigated lands, their infrastructures and effluents. This is the case with some saladas that are already degraded or destroyed, while low agricultural productivity and the alternation of land uses have allowed the recovery of other saladas.

Overall, in the last 25 years the landscape has changed its appearance. The arid rainfed agricultural fields, scattered with saladas over the course of a thousand-year equilibrium, are becoming bigger fields, often owned by agricultural companies; the backbone of this new landscape is provided by irrigation water.

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CHAPTER 3. The threatened inland saline habitats of Monegros mapped with a dedicated CORINE legend

1. INTRODUCTION

Wetlands are waterlogged or inundated areas hosting high biodiversity. The ecological value of the inland saline wetlands has been stressed by several authors and by the Ramsar Convention (Ramsar Convention Secretariat, 2007). A methodology to depict the changes produced in wetlands has been developed (McCauley et al, 2005; Rebelo et al., 2007; Castañeda et al., 2008) though indicators of wetland condition based on soil, hydrology and vegetation are needed. Habitats mapping at an adequate scale is not frequent in the wetland studies, while it is needed to protect the biodiversity and to evaluate the management practices. The anthropic activities affect the spatial patterns of soil properties (Cohen et al., 2008) and vegetation (Liu and Cameron, 2001). Halophytes have a relevant role in saline wetland ecosystems, specially the perennial scrubs of chenopodiaceae, like as *Suaeda vera* or *Arthrocnemum macrostachyum.*

Vegetation maps are needed to assess changes in wetlands. Moreover, a map of habitats at adequate scale is required to meet the European Directives on biodiversity and habitats conservation. The integration of data in a GIS is common to monitor habitats and to analyze long term changes (Aspinall, 1993). Thomson et al. (2007) used aerial photography and CORINE legend to monitor historic changes in UK Natura 2000 sites at local scale, in an area 30 × 30 km. Boteva et al. (2004) inventoried and mapped the of Natura 2000 habitats in Creta at scale 1:15000. Other studies combined GIS with different techniques for evaluating and mapping vegetation (Ringrose et al., 1998; Tappeiner, et al. 1998; Bock, 2003; Draper et al., 2003; Carlson et al, 2004).

Piernik (2003) mapped inland halophilous vegetation as indicator of soil salinity in Poland; more frequent are the studies of vegetation-environment relationships in coastal areas (marshes) in Spain (Alvarez-Rogel et al., 2000; 2001) and other arid regions (Waisel, 1969; Ringrose et al., 1998; Feoli et al., 2001; Harris, 2001; Khan and Beenna, 2002). Few maps of habitat have been conducted at a detailed scale on inland saline wetlands for their monitoring and for biodiversity assessment purposes (Costa et al., 1996; Farina et al., 1996; Finlayson et al., 2002; Herrero et al., 2005).

Up to now, the vegetation of the saladas in Monegros has not been mapped at detailed scale though several authors have stressed its interest. The vegetation of this semiarid area was described in the pioneer and extensive study of Braun-Blanquet and Bolòs (1958). Blanché and Molero (1986) studied the environmental conditions of halophytes and xerophytes of the largest saladas (playa-lakes) describing new syntaxa and suggesting measures for their conservation. Molero et al. (1989) recognized, in an unpublished study, the singularity and diversity of the flora and reported more than 800 taxa. These authors mapped 102 endemic species on a UTM 10 × 10 km grid and mapped vegetation based on photointerpretation of 1:30000 scaled aerial photography acquired in November 1981 and September 1984. They agreed with previous studies in considering the vegetation of the area of semidesert type. Herrero (1982, 2008) interpreted the halophytes distribution in several saline wetlands in the Ebro Valley from an edaphic perspective in relation with soil salinity. Marín (1982) described the occurrence of a Hepatic species in three saladas and Pedrocchi (1998) described the dominions of the vascular flora in Monegros at landscape scale and the vegetation of some playa-lakes. Sanz et al. (1996) and Cervantes and Sanz (2002) located, on a kilometric grid, three threatened halophytes (*Microcnemum coralloides, Halopeplis amplexicaulis, Senecio auricula*) in the largest playa-lakes.

The aim of this article is to depict and analyze the distribution of habitats in the saladas of Monegros. For this purpose, the field data gathered with a legend based on CORINE biotopes and Habitats Directive have been integrated in a Geographic Information System (GIS). The georeferenced database will help to monitor changes and alterations in the habitats.

2. STUDY AREA

2.1 Features of conservation interest

In the center of the Ebro basin, the saline wetlands or "saladas" of southern Monegros are located in gentle depressions, scattered in a structural Tertiary platform which ranges in elevation from 320 m to 417 m a.s.l. The Miocene strata are lying almost horizontal and are limestone, lutites, and gypsum, the latter increasing to the west (Salvany et al., 1996). Limestone and gypsum strata outcrop at the border of the depressions, in escarpments ranging from 1 m to 20 m high. The saladas have a karstic and aeolian origin and a close connection with the saline groundwater. As discharge wetlands, they are intermittently waterlogged or inundated.

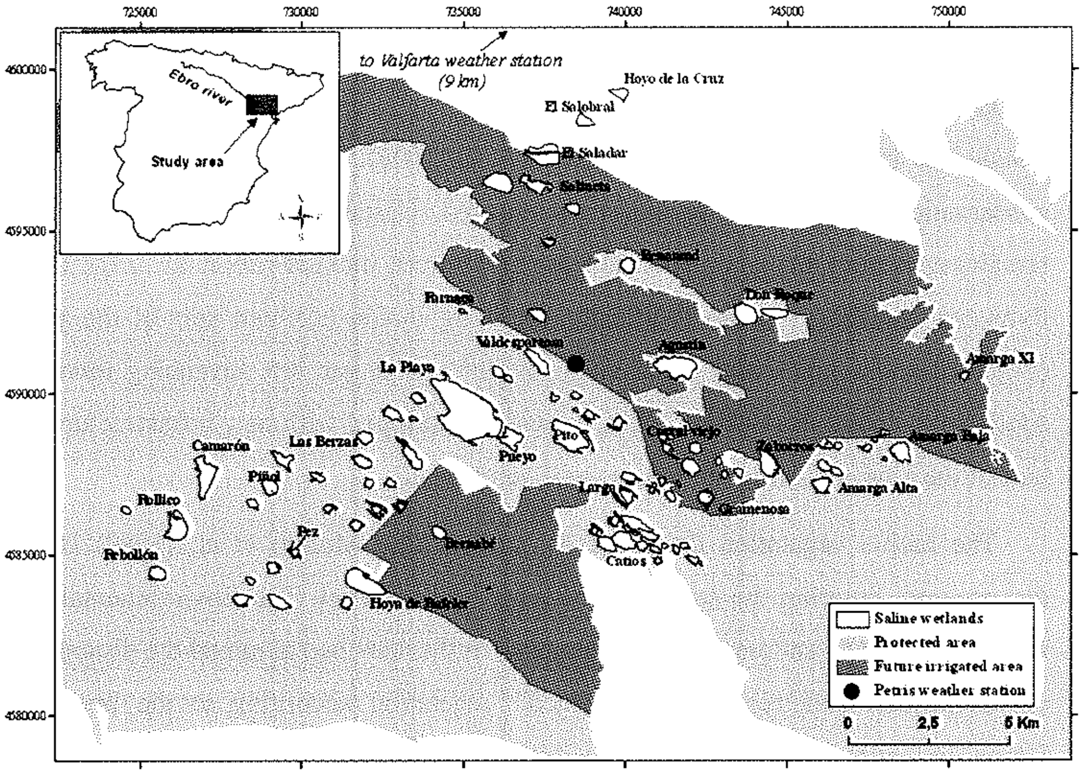

Figure 1. Location of the Monegros saline wetlands.

The saladas are isolated on an agricultural landscape where winter cereal alternates with fallow land. At present, the size and shape of the fields are regular and squared due to recent land consolidation. The agricultural invasion of marginal lands to earn subsidies from the Common Agricultural Policy has smoothed the escarpments of many saladas. The stoniness of the field's urfacel is related to practices like deep plowing or the crushing of the rock fragments brought to the surface. Frequently, soils are shallow, gypseous or calcareous, with low organic matter content. Soil maps are not available.

The platform enclosing the saladas has a surface extent of 350 km^2. About a half (Figure 1) is protected under two European directives: 52% of the platform surface extent is Special Protection Area (SPA) for birds (Council Directive 79/409/EEC), and 46% is a proposed Site of Community Interest (SCI) (Council Habitats Directive 92/43/EEC) to be included in the Mediterranean region of European Natura 2000 network because of its biodiversity interest. According to the CORINE Land Cover 2000, the saline wetlands occupy 1.25% of the total surface extent of the SCI, coded as ES2430082, and a similar percent of the SPA for birds, coded as ES0000181 (http://portal.aragon.es/portal/page/portal/MEDIOAMBIENTE/MEDIONATURAL/BIODIVERSIDAD/REDNATURA/).

Both delimitations, almost coincident (Figure 1), enclose 75 from the 96 saladas inventoried in 2007 (Domínguez and Castañeda, 2008). Not all saladas in good state of conservation are included in the protected area (Castañeda and Herrero, 2008). The remaining area is being transformed for agriculture intensification by irrigation with Pyrenean waters. Irrigation is already operating in the northern part of the platform (Figure 1), and pipes and other irrigation infrastructures are advancing towards the south. In the next years about 11000 ha will be equipped with new infrastructures and a half of the area enclosing the saladas will be irrigated.

The native vegetation described by authors like Molero et al. (1989) is almost disappeared, favoring the streaming of loose soil material. The Environmental Impact Assessment (EIA) endorsed by governmental authorities had assumed the disappearance of halophytes, endemic and "threatened" vegetation according to the International Union for Conservation of Nature (IUCN) standards (Comisión Técnica Mixta, 2002).

Nowadays, the vegetation associated to the saladas is restricted to their fringes or bottoms, and always occupies low-lying positions —depressions and flat-bottomed valleys— in the landscape. Therefore, a strong impact is expected in these habitats by flooding with non-saline and polluted water from the return flows of surrounding irrigated land. Other alterations can be expected, especially next to the new intensive animal farms. Due to the foreseeable enlargement of the flood periods, the communities of halophytes will be spoiled and substituted by hygrophytes and nitrophilous communities. This is the case of Chiprana, a permanent saline wetland (Ramsar site) located less than 20 km far from our study area receiving fresh and polluted return flows from irrigated land during the last decades (Valero-Garcés et al., 2000).

2.2 Climate

Monegros is one of the most arid lands of Europe according to its evaporative deficit (Herrero and Snyder, 1997). The aridity contrasts with the presence of wetlands, fed to a large extent by the saline groundwater (Samper and García-Vera, 1998). The thermal regime is continental Mediterranean, with a mean annual temperature of 14.4

°C. Winter and summer are long due to the thermal inertia of the interior areas; spring and autumn are short, and thermal oscillation is strong.

The average precipitation in the last 20 years is 350 mm, according to the records of Petris and Valfarta weather stations. Rainfall is scarce and irregular. Monthly maximum occurs in spring (May-June) and autumn (September-October). The minimum is recorded in summer (July-August) and winter (January-February). The mean annual ET_0 reaches 1225 mm at the nearby Bujaraloz weather station (Martínez-Cob *et al.*, 1991) producing an important hydric deficit, accentuated by the frequent NW-prevailing dry wind.

Figure 2 shows the monthly rains from January 2004 toAugust 2007. The maximum monthly rain is 102.6 mm in September 2006. Monthly rains were < 10 mm in three months every year, irrespective of the season. In the four years, the field surveys were accomplished between May and July, the season coincident with maximum development of perennial halophytes. Monthly rains were very irregular during the survey and previous months. The mean monthly precipitation during the field campaigns was 46.3 mm in 2004, 34.2 mm in 2005, 27.5 in 2006 and 15.7 in 2007, according to the records of Valfarta Weather Station.

May 2005 and April 2007 were the most suitable months for the occasional apparition of pioneer annuals as *Halopeplis amplexicaulis* or *Salicornia ramosissima.*

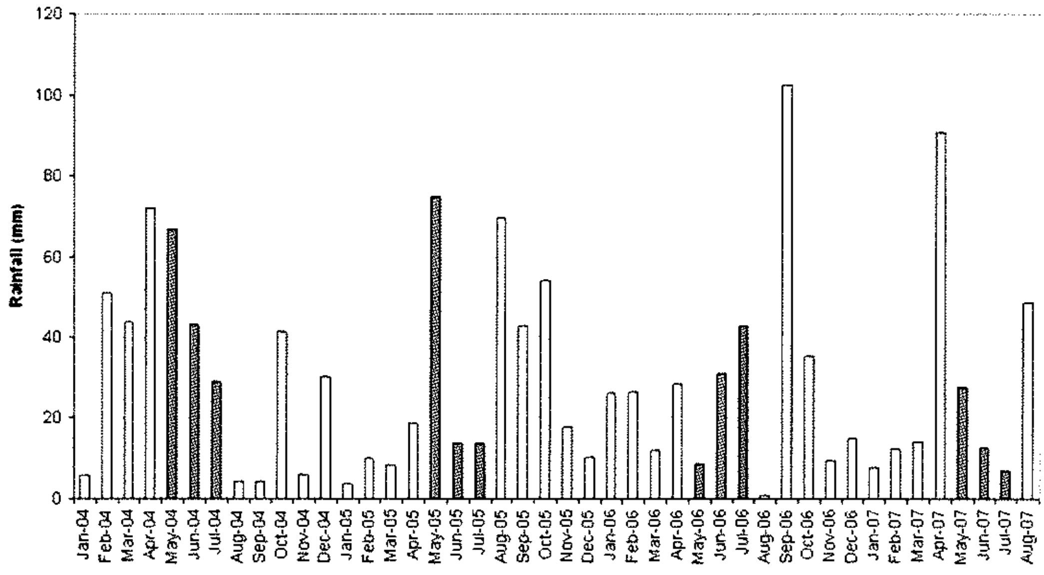

Figure 2. Monthly rains registered in Valfarta Weather Station, for the period from January 2004 to August 2007. In grey, months of field sampling.

3. MATERIALS AND METHODS

3.1 Field sampling

In this study we take as reference 94 saladas from our catalog (Domínguez and Castañeda, 2008) with a surface extent ranging from > 1 ha to > 200 ha. Two consecutive cartographic bases were used for the field survey of vegetation: (1) the black and white orthophotographs of Spanish "SIG Oleícola", flown in 1997, and (2) the color orthophotographs of "SIGPAC" (Spanish Farming Land Geographic information System) with several flight dates, from 1999 to 2003.

The vegetation was recognized and mapped by botanists from the University of Lérida, during the growing seasons of 2004, 2005, 2006 and 2007, from May to July (Figure 3). The survey followed the methodology of the Project Habitats (Rivas-Martínez, 1994; Vigo, 1998) based on the classical method of Braun-Blanquet (1979). This methodology provided a characterization of natural environment based on floristic, physiognomic and ecologic similarities.

The delineations established in the field were habitats characterized by the floristic composition and a visual estimation of plant cover. The endangered or threatened species and those of special biogeographic interest were noted. A GPS (Global Positioning System) helped the drawing of delineations and location of species of interest. The habitat delineations were drawn in the field on printed orthophotographs at scale between 1:2000 and 1:6000, depending of the salada size (Figure 3).

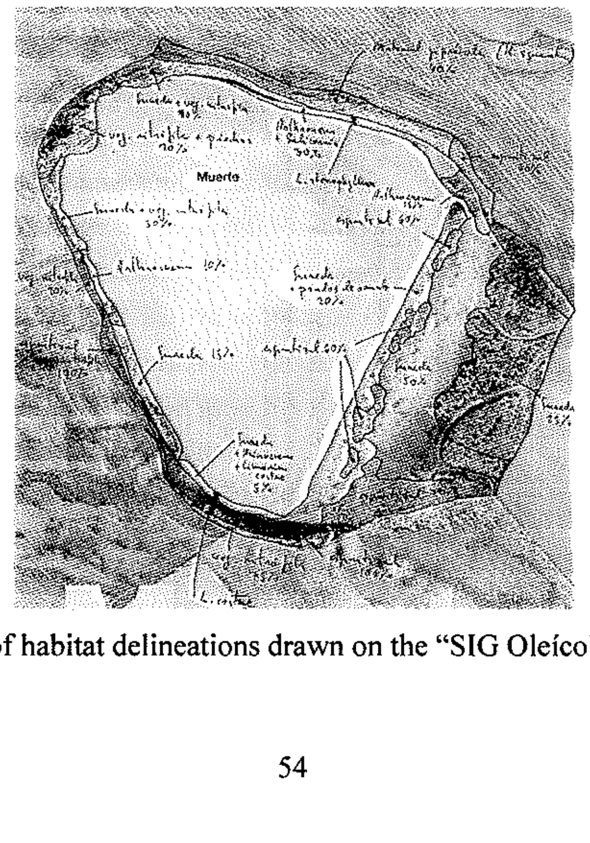

Figure 3. Example of habitat delineations drawn on the "SIG Oleícola", Hoya Correo II.

3.2 Field data standardization

The List of Habitats of Aragón (LHA) established by Benito (2009) was the reference for standardizing the field descriptions. This list will is being developed as the base for the forthcoming official Map of Habitats of Aragón. The LHA, adapted from CORINE biotopes manual (European Community, 1991), establishes a hierarchical classification of biotopes or habitats with a brief description of them. This manual arose from the necessity of characterizing the habitats for inventory and conservation purposes in a European context. The CORINE classification is based on the physiognomy, plant dominance, ecological conditions, and biogeography. Most biotopes are defined by their vegetation; however the flexible interpretation of the manual, adapted tor each country or region, allows for consideration of biotopes other than vegetation.

We also established the correspondence with the List of Habitats of Community Interest (LHCI). This list is a technical tool to identify the habitats abided by conservation measures, the special areas catalogued as SCI, to be included in the Natura 2000 network. The LHCI is published in the successive Interpretation Manuals of European Union Habitats (European Commission, 2007), and emanates from the Habitats Directive (Directive Council 92/43/CEE of 21 May 1992) on the conservation of natural habitats and wild fauna and flora, OJ L206, 22.07.92).

3.3 Database and Geographic Information System (GIS)

Field data were transferred to a digital base (Figure 4) using ArcGIS v.9. The 94 field maps were scanned and georeferenced taking between four and sixteen control points, depending on their size and relief. The habitat delineations and the punctual data were digitized on screen producing two separate graphical layers, respectively, and a parallel database with alphanumeric information was created. The graphical and alphanumerical data were linked, and processing errors were verified and corrected. This procedure was dynamic and opened for updating taking into account that the habitat composition can change along time.

We integrated different layers in our GIS, including administrative limits and delimitations of interest provided by the Departments of Environment of the Government of Aragon, such as the Natural Resources Plan, Special Protection Areas for Birds, and Sites of Community Interest. The available geological maps (Salvany et al., 1996), topographic information (http://sitar.aragon.es/) were also incorporated.

For each habitat delineation, the georeferenced database stores (1) the field description based on the surface extent and density of the vegetation (Figure 4), (2) the code of the List of Habitats of Aragón (LHA); and (3) the code of Habitats of Community Interest (LHCI) if contained in the interpretation manual (European Commission, 2007).

The GIS produced a map of habitats for each salada. The LHA legend was adopted for these maps since it is conceived to generate a continuous map of Aragón. At present, only a part of the LHA habitats has their corresponding LHCI. A spatial analysis of the saladas and the habitats was performed by means of Spatial and geostatistical analyst extension and Patch Analyst tool, both implemented in ArcGIS v.9 (ESRI, Redlands, California).

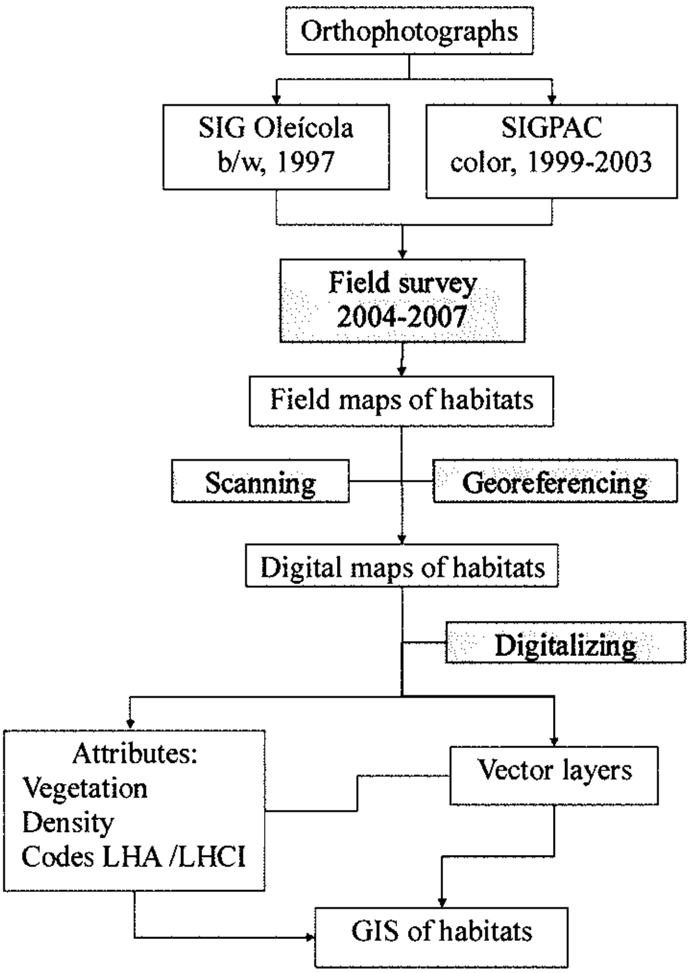

Figure 4. Simplified schema showing the process to obtain the database and the maps of habitats.

4. RESULTS AND DISCUSSION

4.1 Saladas attributes

Taking into account the generic qualifier of the saladas recorded in our catalog, we observe that the salada category laguna and the southern largest clota are spread along a mayor axis in NE-SW direction according to the common tectonic (Arlegui et al., 2003) and wind direction of the Ebro valley. The roundness index, established as the relation between the length and the area of each salada, varies from 6.2 to 0.4. This index is very small (< 1.5) for the categories laguna, salina and saladar, and the highest values (> 4) correspond to the saladas qualified as clotas. The roundness decreases exponentially with the size (Figure 5a) and there is not a clear relationship between roundness and elevation though in general, the most rounded saladas, which are the smallest ones, have a higher altitude, > 335 m (Figure 5b).

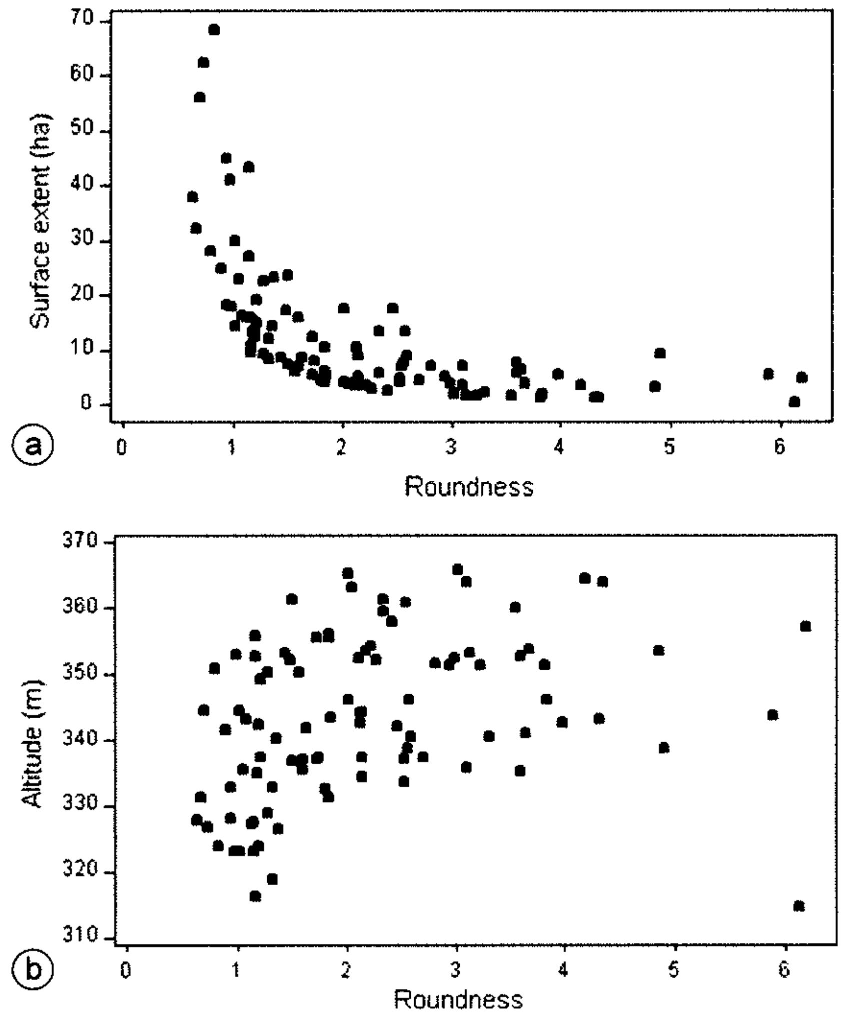

Figure 5. Roundness of the saladas plotted against their size (a) and elevation (b).

The distribution of the saladas elevation for each category (Figure 6) shows that the largest saladas, qualified as lagunas, salina, and saladar, are in lower positions. This is in accord with their close connection with the groundwater, which favors the capillary rising, producing a more frequently flooding and high salinity.

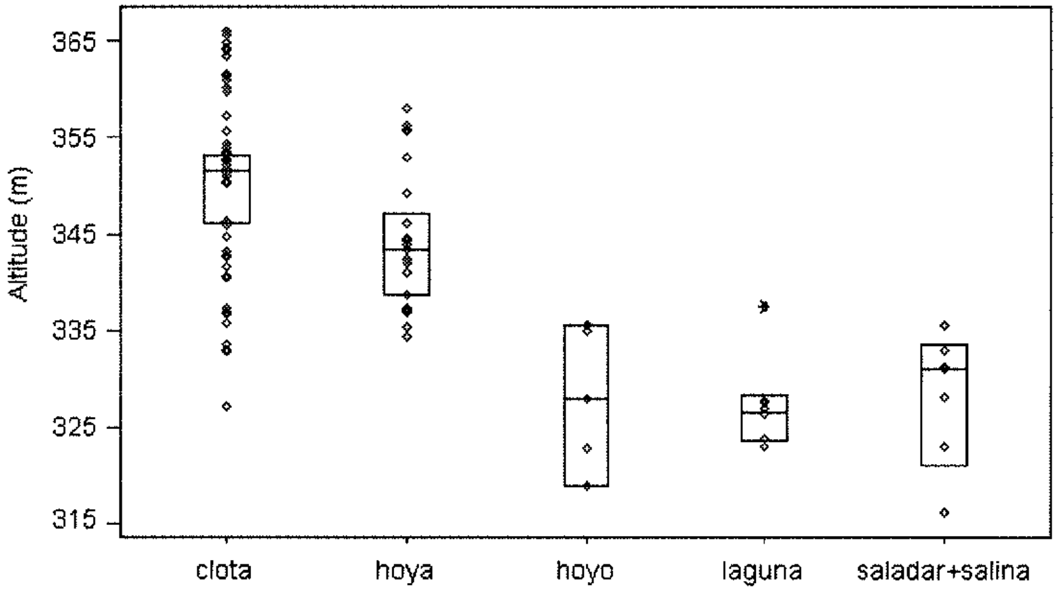

Figure 6. The altitude (m a.s.l.) of the saladas grouped by their qualifier. Boxes show the first and third quartiles, and the median.

Although the gypsum unit occupies a low estratigraphic position in the endorheic platform (Salvany et al., 1996), the saladas occur, at different elevations, the 66% in gypsum strata and 22% in limestone strata (Figure 7). The presence of limestone and lutite layers of variable thickness interbedded with the gypsum beds make difficult to differentiate a single substrate for each salada. However, we have observed some relationship between the saladas' kind and their bedrock. About 10% of saladas, mainly those qualified as hoyos are in the northern lutites whereas the saladas most frequently flooded, i.e. lagunas and salinas, usually occur on gyprock except Salineta. Most clotas are excavated in limestone. The elongated lagunas are on gyprock, and represent an advanced stage of karstification, according to the conceptual genetic model of Sánchez et al. (1998).

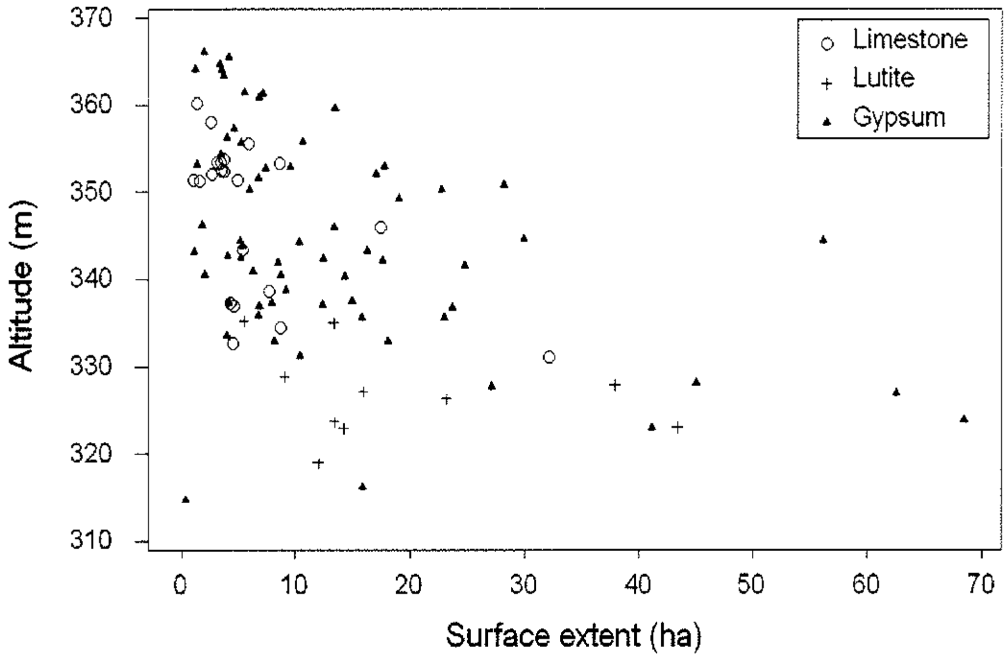

Figure 7. The saladas size, excepting La Playa, plotted against their elevation using different symbol for each lithology.

4.2 The variable composition of the habitat delineations

A total of 1068 habitat delineations were drawn in 94 of the 96 preserved saladas with different conservation status. The extent of the surface mapped is 1600 ha. The delineations size ranges from 0.5 ha of *Tamarix* in Amarga Alta to 196 ha of saline bare soil in La Playa. The results of our vegetation survey are in good agreement with the geographical sketch of Balsa et al. (1991).

A total of 36 standard LHA-habitats were found (Table 1). Each LHA-habitat was delineated as a separate map unit whenever possible; however, the complex arrangement of the vegetation, the occurrence of areas with mixed communities or biotopes, and the small surface extent of some of them according to the scale of the survey, did not always allow for a separate demarcation of every LHA-habitat. For this reason, a delineation can be a composition of 1 to 5 LHA-habitats, ranked in the field after the surface extent and the structure of the plants' community. These ranks are shown at the five last columns of Table 1. The bulk density cover of the delineations ranges from 10% to 100%, with 85% delineations ≥ 50% density cover.

Table 1. The 36 LHA-habitats found in the saladas: code, name, and ranks of their occurrence in the 1068 habitat delineations.

LHA-habitat code	**LHA-habitat name**	**Occurrences in the five possible ranks at the delineations**				
		1st	**2nd**	**3rd**	**4th**	**5th**
14.1	Mud flats and sand flats (Saline bare soils)*	17	1			
15.1141	*Microcnemum* swards	2	9	1		
15.1142	Iberian Interior *Salicornia* swards	7	5	4		
15.1143	Iberian glasswort swards (*Halopeplis amplexicaulis*)*	10	5		1	
15.12	Halonitrophiluous *Frankenia* communities	15	39	9		
15.51	Mediterranean Salt meadows	12	1	1		
15.54	Interior Iberian salt Pan meadows	7	22	3	1	
15.57	Saltmarsh couch-wormwood stands	8	9	7		
15.613	Glaucous glasswort thickets	88	2	1		
15.6151	Interior Woody seablite scrubs	218	58	8	1	1
15.6152	Interior glaucous glasswort scrubs	4	8	2	1	

Table 1 (cont). The 36 LHA-habitats found in the saladas: code, name, and ranks of their occurrence in the 1068 habitat delineations.

LHA-habitat code	LHA-habitat name	Occurrences in the five possible ranks at the delineations				
15.6153	Interior creeping glasswort scrubs	6				
15.721	Ebro sisallares	117	54	10		
15.8113	Sea lavender salt steppes (*Limonium sp. pl*)*	3	10	1	1	
15.81131	Sea lavender salt steppes (*Limonium sp. pl*)*		1			
15.8213	Esparto salt steppes (*Lygeum spartum*)*	26	8	2		1
15.921	*Gypsophila hispanica* garrigues	35	12	1		
15.922	*Helianthemum squamatum* garrigues	1	6	3		1
15.925	Central iberian gypsum scrubs (*Rosmarimus*)*	6	2			
23.12	Charophyte algal carpets		1			
23.211	Tasselweed communities	1				
32.1321	Inland *Juniperus Oxicedrus* arborescent matorral		1			
32.136	*Juniperus thurifera* arborescent matorral		1	1		
32.2191	Thermo-mediterranean brushes, tickets and health-garrigues	18	24	2	2	
32.42	Rosemary garrigues	65	27	2		
34.511	Retuse torgrass swards	6	19	18	1	
34.621	Iberian esparto steppes	157	12	1	4	
42.8417	Iberian alepo pine forest (*Pinus Halepensis*)*	1				
44.81342	Saline *Tamarix canariensis* stands	17				
53.112	Dry *Phragmites* beds	3	4			
82.32	Extensive cultivation (Dry cereal)*	115				
82.5	Crops (Pile of stones of the fields)*	4				
86.413	Hard stone quarries		1			
86.42	Slag heaps and other detritus open spaces	39	43	29	8	
87.21	Ruderal communities	60	117	26	2	
89.23	Industrial lagoons and ornamental ponds		1			

All LHA-habitats occur at the 1st or the 2nd position in the ranking, denoting their relevance for saladas vegetation mapping. Delineations with a single LHA-habitat are > 50% with 1216.9 ha, and are spread in 91 saladas. The number of delineations decreases as the number of LHA-habitats for each delineation, i.e. the degree of complexity, increases (Table 2). We have found a high number of different compositions, especially in the delineations composed by 2 and 3 LHA-habitats (Table 2), 218 different compositions irrespective of their surface extent or cover density. This complexity illustrates how intricate is the distribution of vegetation.

Table 2. Attributes of the delineations: number of LHA-habitats, surface extent, number of delineations and different LHA compositions found.

Number of LHA-habitats in each delineation	Surface extent of delineations		Number of saladas	Delineations		Number of different LHA compositions found
	(ha)	%		Number	%	
1	1216.9	76	91	565	52.9	29
2	285.8	17.9	90	371	37.7	89
3	84.8	5.4	65	110	10.2	79
4	8.7	0.5	22	19	1.7	18
5	3.9	0.2	3	3	0.2	3

Table 3 shows how many LHA-habitats occur in each rank. The surface extent of each component, calculated from its percent, illustrates the amount on information which would be lost if the number of LHA-habitats allowed for each delineation would be reduced. As examples, with only one LHA-habitat per delineation, 1491 ha can be accurately mapped (Table 3); on the other hand, if we discard the 5th component, i.e. with four LHA-habitats per delineation, only 3.9 ha of the map would be affected, in 3 delineations (Table 2). This analysis provides useful criteria for vegetation surveys at different scales in this or similar complex environments.

Table 3. The five possible ranks the 36 LHA-habitats occupy in the delineations.

Ranks of LHA-habitats in the delineations	Number of different LHA-habitats in each rank	Surface extent of each component (ha)
1st	30	1490.6
2nd	30	93.7
3rd	21	14.1
4th	10	1.3
5th	3	0.4

A total of 218 different combinations of LHA-habitats have been found (Table 2, last column), irrespective of their percent cover. Table 4 shows the ten most frequent combinations ranked by surface extent (Table 4, 6th column). The most extended LHA-habitats are not those occurring in more delineations. As an example, LHA 14.1 "Saline bare soil" is the second habitat in surface extent, but the thirteen in frequency occupying a large part of the bottom of 15 saladas (Table 5). LHA 34.621 "Iberian esparto steppes" is disseminated in 157 delineations and occurs in 52 wetlands although only represents < 3% of the 1600 ha inventoried. "Extensive cultivation of dry cereal" (LHA 82.32) is the most extended habitat, often destroying the smoothed borders of the saladas and the less saline bottoms. It increases the lost of saladas and habitats.

The halophytes *A. macrostachyum, Suaeda vera, Frankenia pulverulenta,* and *Hordeum marinum* stand out because of their extent and frequency. They are represented in the following habitats: 15.613 (Glaucous glasswort thickets), 15.6151 (Interior woody seablite scrubs), 15.6151 + 15.12 (Interior woody seablite scrubs + Halonitrophilous communities) and 156151 + 87.21 (Interior woody seablite scrubs + Ruderal communities).

Table 4. The ten most representative compositions of LHA-habitats: number of delineations, rank of each habitat, and surface extent. The last column is calculated taking into account the density cover of the habitat delineations.

Number of delineations	**Ranks of LHA-habitats in the delineations**					**Surface extent**	
	1st	**2nd**	**3rd**	**4th**	**5th**	**Delineations (ha)**	**Habitats (ha)**
112	82.32					528.65	528.65
15	14.1					381.20	380.84
57	15.613					86.65	34.98
24	15.6151	15.12				79.49	46.23
60	15.6151					61.82	30.12
61	15.6151	87.21				47.31	34.23
106	34.621					41.16	30.97
49	15.721					39.03	24.72
4	82.5					17.32	17.32
23	15.721	87.21				16.82	11.37

Taking apart La Playa, with more than 200 ha and 53 delineations, there is not a lineal relationship between the number of delineations and the salada size (Figure 8). The size of the saladas with > 30 delineations ranges between 30 ha and 80 ha. In contrast, some saladas have a relatively large size, > 40 ha, and less than 15 delineations. This is the case of Saladar, Larga and Rafeler.

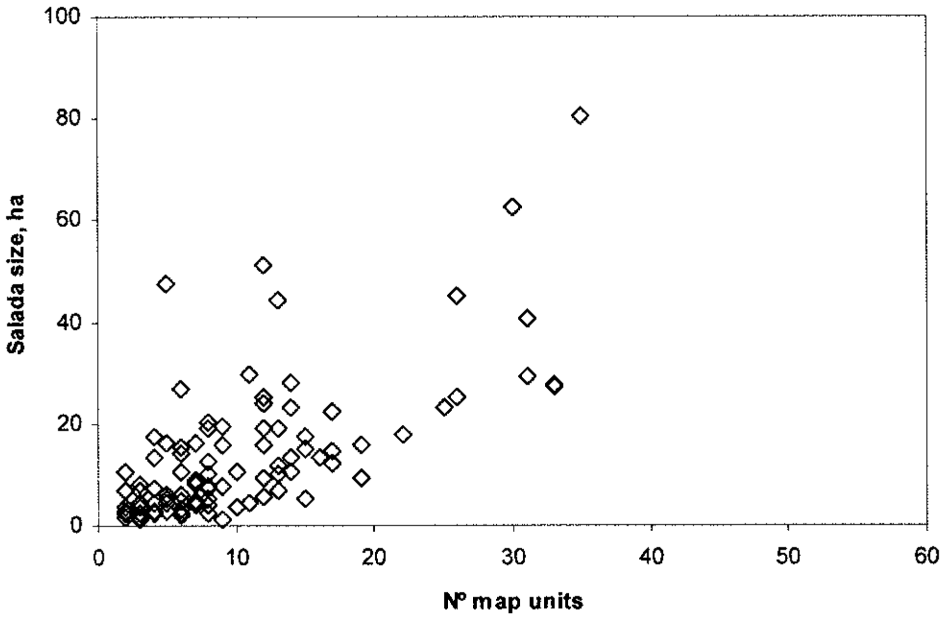

Figure 8. Scatterplot showing the number of delineations in each salada against its size.

4.3 Representative LHA-habitats

From the 94 saladas, fifteen (Table 5) have "Saline bare soils" (LHA 14.02) which totalizes a 29% of the surface mapped. Computing the surface extent of this habitat in each salada, the minimum is 2.1 ha in Cruz and the maximum, 196 ha in La Playa (Table 5). "Saline bare soils" cover > 75% of the salada surface extent in Camarón, Guallar, La Playa, Muerte, Piñol, Rollico, and Salineta. These saladas are temporally waterlogged, and host annual plants such as *Salicornia ramosissima, Microcnemum coralloides* and *Halopeplis amplexicaulis*; often, they have algal mats or salt crust. Figure 9 shows examples of this habitat in Pito and Salineta.

Table 5. Saladas with "Saline bare soils" (LHA 14.02) and its surface extent.

Salada	**Surface extent LHA 14.02**	
	ha	**% relative to the salada extent**
Amarga Alta	8.1	37.2
Amarga Baja	2.7	15.3
Camaron	34.6	84.2
Cruz	2.1	29.2
Guallar	9.0	75.4
La Playa	196.1	89.5
Muerte	10.9	78.3
Pez	5.1	69.2
Piñol	10.6	81.2
Pito	36.9	58.7
Pueyo	13.5	67.3
Rebollon	6.8	65.3
Rollico	25.0	78.0
Salineta	19.4	87.6
Salobral	2.2	28.0

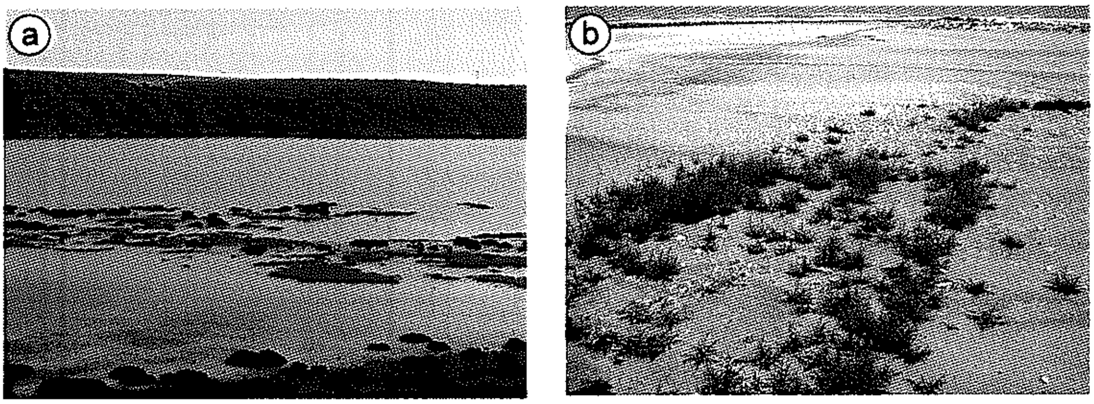

Figure 9. (a): "Saline bare soils" habitat in Pito, partially covered by *Halopeplis amplexicaulis*, in December 2006; at the background, the talus with gypsophiles. (b): Salicornia ramosissima growing in a part of the "Saline bare soils" habitat in Salineta, next to the salt crust and the brine, in June 2006.

"Extensive cultivation, dry-cereal" (LHA 82.32) is the most representative habitat according to their extent, with 42% (529.68 ha) of the habitats extent, and 61% of the vegetation. This habitat has been mapped in 75 saladas, entering the hoyas and clotas, less inundated and with smoothed edges, and extending to the escarpments and edges of the playa-lakes.The habitat "Interior woody seablite scrubs" (LHA 15.6151), formed by *Suaeda vera* (Figure 10a), is the third in extension (117.28 ha). With a surface extent of

54.8 ha, *S. vera* covers 48.2% of the surface mapped, occurs in 64 saladas, with a density cover ranging from 60% to 80%.

The following halophyte habitat in extension is "Glaucous glasswort thickets" (LHA 15.613), formed by *Arthrocnemum macrostachyum* (Figure 10b). *A. macrostachyum* is less common than *S. vera* and is usually located in very saline and intermittently waterlogged soils conterminous to the "Saline bare soils". *A. macrostachyum* and *S. vera* often occur together in several conditions of soil moisture and salinity.

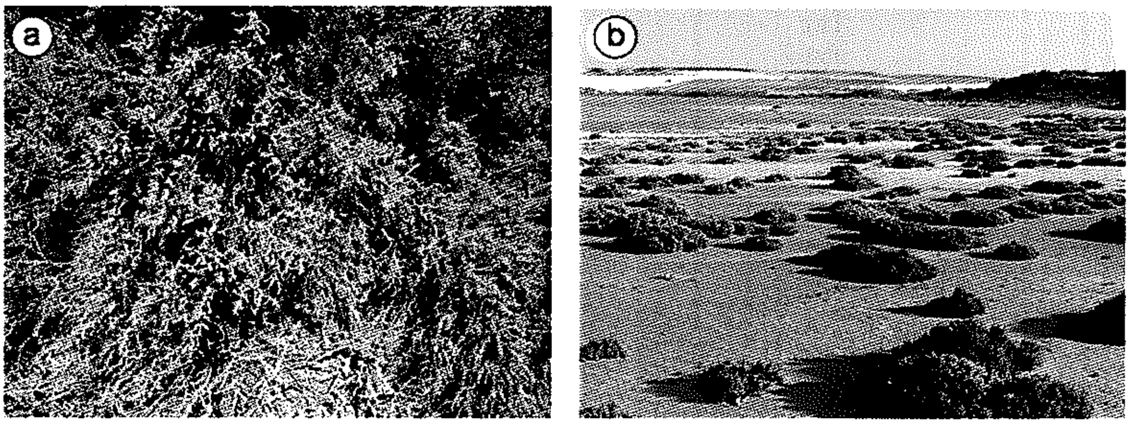

Figure 10. *Suaeda vera* in Farnaca (a) and *Arthrocnemum macrostachyum* in Rollico (b)

The habitat "Ebro sisallares" (LHA 15.721) is very common in the Ebro basin. It is associated to halo-nitrophilous scrubs with dominance of *Salsola vermiculata* (sisallar), *Artemisia herba-alba, Kochia prostrata,* and *Atriplex halimus*. This habitat, with a density cover ranging from 60% to 80%, has been mapped at the southeast of the studied area, in the gypsum and limestone escarpments of 52 saladas.

The habitat "Iberian esparto steppes" (LHA 34.621) is mainly formed by *Lygeum spartum* (Figure 11a). It is the sixth in surface after "Ebro sisallares", being located at the south of the study area, in the escarpments of the saladas, associated to "Rosemary garrigues" (LHA 32.42, with 19.9 ha).

The remaining habitats have less of 18 ha, including annual halophytes with scarce density. This is the case of "*Microcnemum* swards" (LHA 15.1141) (Figure 11b) located in inundated areas in Pez; the "Tasselweed communities" (LHA 23.211) of *Ruppia maritima* in Amarga Alta; "*Helianthemum squamantum* garrigues" (LHA 15.922) in

Catio II; and "Dry *Phragmites* beds" (LHA 53.112) on rarely inundated soils in Cruz and Salineta.

Table 6. The 1st LHA-habitat with the number of delineations and their surface extent. The surface of the habitat is calculated taking into account the density cover of the delineations.

1st LHA-habitat		**Delineations**		**Habitat**
Code	**LHA**	**Number**	**Surface extent (ha)**	**ha**
14.1	Mud flats and sand flats (Saline bare soils)*	17	384.42	383.04
15.1141	*Microcnemum* swards	2	0.16	0.03
15.1142	Iberian Interior *Salicornia* swards	7	5.85	1.57
15.1143	Iberian glasswort swards (*Halopeplis amplexicaulis*)*	10	6.16	1.94
15.12	Halonitrophiluous *Frankenia* communities	15	4.42	1.50
15.51	Mediterranean Salt meadows	12	2.47	1.86
15.54	Interior Iberian salt Pan meadows	7	4.69	2.43
15.57	Saltmarsh couch-wormwood stands	8	3.50	2.99
15.613	Glaucous glasswort thickets	88	111.36	41.89
15.6151	Interior Woody seablite scrubs	218	243.08	117.28
15.6152	Interior glaucous glasswort scrubs	4	1.87	0.82
15.6153	Interior creeping glasswort scrubs	6	1.23	0.35
15.721	Ebro sisallares	117	81.08	42.86
15.8113	Sea lavender salt steppes (*Limonium sp.* pl)*	3	0.94	0.21
15.8213	Esparto salt steppes (*Lygeum spartum*)*	26	11.66	4.49
15.921	*Gypsophila hispanica* garrigues	35	15.94	7.56
15.922	*Helianthemum squamatum* garrigues	1	0.30	0.15
15.925	Central iberian gypsum scrubs (*Rosmarinus*)*	0	5.77	2.60
23.211	Tasselweed communities	1	0.01	0.01
32.2191	Thermo-mediterranean brushes, tickets and health-garrigues	0	19.66	8.56
32.42	Rosemary garrigues	1	38.13	19.96
34.511	Retuse torgrass swards	6	3.41	2.15
34.621	Iberian esparto steppes	2	62.42	40.04
42.8417	Iberian alepo pine forest (*Pinus halepensis*)*	1	0.58	0.58
44.81342	Saline *Tamarix canariensis* stands	17	1.15	0.74
53.112	Dry *Phragmites* beds	3	0.42	0.42
82.32	Extensive cultivation (Dry cereal)*	115	534.68	529.68
82.5	Crops (Pile of stones of the fields)*	4	17.32	17.32
86.42	Slag heaps and other detritus open spaces	39	9.95	8.07
87.21	Ruderal communities	60	27.45	17.18

(*) Class name burrowed from the upper hierarchic level because the LHA class is not incorporated to the CORINE biotopes manual (2005). In brackets, our specific habitat name.

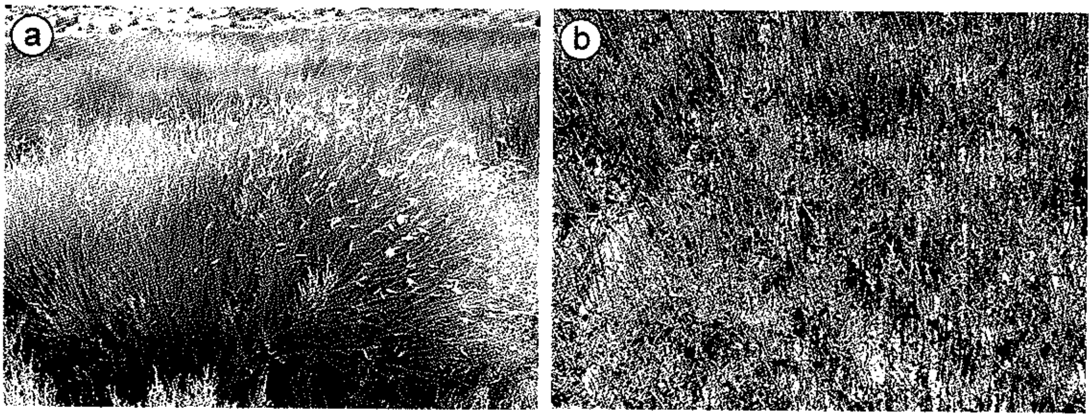

Figure 11. *Lygeum spartum* (a) and *Microcnemum coralloides* (b).

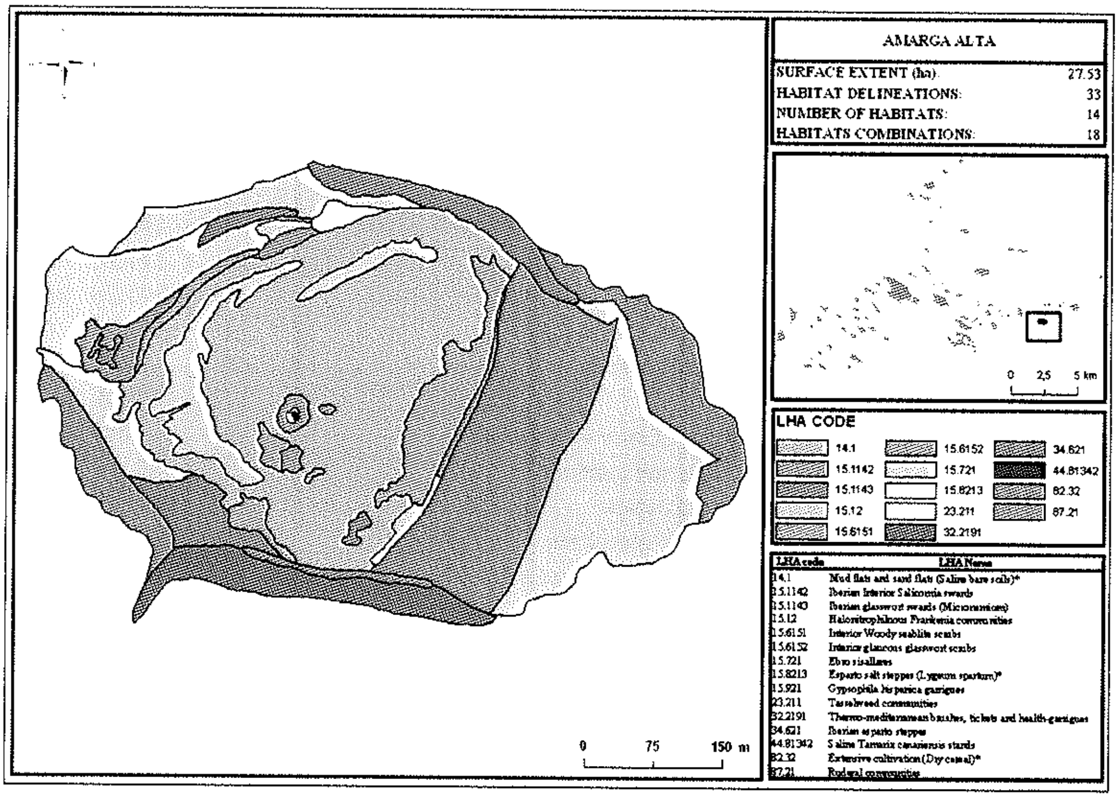

Figure 12. Examples of LHA map of Amarga Alta.

4.4 Minor LHA-habitats

Minor LHA-habitats are considered those occurring in the habitat delineations at the second, third, fourth and fifth rank position. The 2nd LHA-habitat of the delineations (Table 7) is the 23.9% of the surface mapped (383.1 ha) and the 4.8% of the habitats inventoried (60.4 ha). Six of them are new: (1) *Limonium sp.* (Figure 13a), (2) Charophyte algal carpets, (3) Inland *Juniperus oxicedrus* arborescent matorral, (4) *J. thurifera* arborescent matorral, (5) Hard stone quarries, and (6) Industrial lagoons and ornamental ponds. These six new habitats summarize < 1 ha and six delineations in five saladas, and happens together with *A. macrostachyum*, *Suaeda vera* and *Gyspsophila hispanica*.

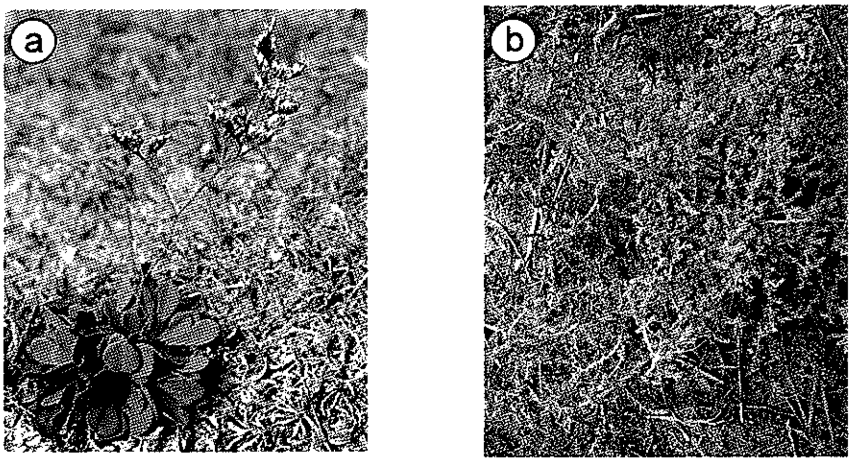

Figure 13. *Limonium* sp. (a) and *Frankenia pulverulenta* (b).

The LHA-habitat "Ruderal communities" (LHA 87.21) stands out because of the frequency (117 delineations) and surface extent, 15.5 ha. This habitat happens in 47 saladas, especially in the southeast of the study area.

The habitat "Halonitrophilous *Frankenia* communities" (LHA 15.12), with plant species such as *Frankenia pulverulenta* (Figure 13b) and *Hordeum marinum*, is one of the most frequents, occurring in 39 delineations and 28 saladas; although its density cover is very low (from 10% to 20%) and suposses the 16% of the 2nd LHA-habitat surface.

"Interior woody seablite scrubs" or *Suaeda vera* (LHA 15.6151) occurs in 58 delineations, though its surface extent is only 5.2 ha. "Ebro sisallares" (LHA 15.721) and "Slag heaps and other detritus opens spaces" (LHA 86.42) have scarce extension (1.24 ha) but is conspicuous because of its occurrences in the border of the saladas.

Table 7. The 2nd LHA-habitat with the number of delineations and their surface extent. The surface of the habitat is calculated taking into account the density cover of the delineations.

2nd LHA-habitat		**Delineations**		**Habitat**
Code	**LHA**	**Number**	**Surface extent (ha)**	**ha**
14.1	Mud flats and sand flats (Saline bare soils)*	1	0.35	0.02
15.1141	*Microcnemum* swards	9	1.67	0.07
15.1142	Iberian Interior *Salicornia* swards	5	2.05	0.43
15.1143	Iberian glasswort swards (*Halopeplis amplexicaulis*)*	5	5.65	0.40
15.12	Halonitrophiluous *Frankenia* communities	39	102.52	9.61
15.51	Mediterranean Salt meadows	1	1.86	0.30
15.54	Interior Iberian salt Pan meadows	22	31.44	5.42
15.57	Saltmarsh couch-wormwood stands	9	4.51	1.17
15.613	Glaucous glasswort thickets	2	1.73	0.40
15.6151	Interior Woody seablite scrubs	58	26.60	5.26
15.6152	Interior glaucous glasswort scrubs	8	5.51	0.80
15.721	Ebro sisallares	54	28.06	5.76
15.8113	Sea lavender salt steppes (*Limonium sp.* pl)*	10	2.90	0.11
15.81131	Sea lavender salt steppes (*Limonium sp.* pl)*	1	0.09	0.00
15.8213	Esparto salt steppes (*Lygeum spartum*)*	8	4.52	0.63
15.921	*Gypsophila hispanica* garrigues	12	3.33	0.71
15.922	*Helianthemum squamatum* garrigues	6	1.89	0.17
15.925	Central iberian gypsum scrubs (*Rosmarimus*)*	2	1.04	0.31
23.12	Charophyte algal carpets	1	3.04	0.91
32.1321	Inland *Juniperus oxicedrus* arborescent matorral	1	0.05	0.00
32.136	*Juniperus thurifera* arborescent matorral	1	0.29	0.01
32.2191	Thermo-mediterranean brushes, tickets and health-garrigues	24	13.69	2.67
32.42	Rosemary garrigues	27	22.33	4.70
34.511	Retuse torgrass swards	19	8.57	1.31
34.621	Iberian esparto steppes	12	8.27	1.57
53.112	Dry Phragmites beds	4	0.80	0.20
86.413	Hard stone quarries	1	0.79	0.55
86.42	Slag heaps and other detritus open spaces	43	12.25	1.24
87.21	Ruderal communities	117	85.28	15.46
89.23	Industrial lagoons and ornamental ponds	1	2.06	0.21

(*) Class name burrowed from the upper hierarchic level because the LHA class is not incorporated to the CORINE biotopes manual (2005). In brackets, our specific habitat name.

The 3rd LHA-habitat component of the delineations (Table 8) is less than 1% of the saladas surface extent. Its surface extent is not representative. The habitats "Ruderal communities", "Iberian interior *Salicornia* swards" (Figure 14), "Halonitrophilous *Frankenia* communities", "Slag heaps and other detritus open spaces" and the "Retuse torgrass swards" (dry grass *Brachypodium retusum* with therophytes), range in extent from 1 ha to 2.3 ha. The fourth and fifth LHA-habitat have scarcely representation.

Table 8. The 3rd LHA-habitat with the number of delineations and their surface extent. The surface of the habitat is calculated taking into account the density cover of the delineations.

3rd LHA-habitat		Delineations		Habitat
Code	LHA	Number	Surface extent (ha)	ha
15.1141	*Microcnemum* swards	1	0.17	0.00
15.1142	Iberian interior *Salicornia* swards	4	6.45	1.01
15.12	Halonitrophiluous *Frankenia* communities	9	18.38	1.28
15.51	Mediterranean salt meadows	1	1.17	0.19
15.54	Interior Iberian salt pan meadows	3	1.82	0.21
15.57	Saltmarsh couch-wormwood stands	7	2.68	0.38
15.613	Glaucous glasswort thickets	1	1.70	0.17
15.6151	Interior woody seablite scrubs	8	4.49	0.35
15.6152	Interior glaucous glasswort scrubs	2	0.87	0.12
15.721	Ebro sisallares	10	9.92	0.84
15.8113	Sea lavender salt steppes (*Limonium sp.* pl)*	1	0.15	0.00
15.8213	Sea lavender salt steppes (*Limonium sp.* pl.)*	2	0.66	0.06
15.921	*Gypsophila hispanica* garrigues	1	0.26	0.02
15.922	*Helianthemum squamatum* garrigues	3	0.91	0.08
32.136	*Juniperus thurifera* arborescent matorral	1	0.54	0.04
32.2191	Thermo-mediterranean brushes, tickets and health-garrigues	2	0.93	0.11
32.42	Rosemary garrigues	2	0.18	0.02
34.511	Retuse torgrass swards	18	14.27	1.51
34.621	Iberian esparto steppes	1	0.43	0.07
86.42	Slag heaps and other detritus open spaces	29	19.69	2.37
87.21	Ruderal communities	26	11.69	1.59

(*) Class name burrowed from the upper hierarchic level because the LHA class is not incorporated to the CORINE biotopes manual (2005). In brackets, our specific habitat name.

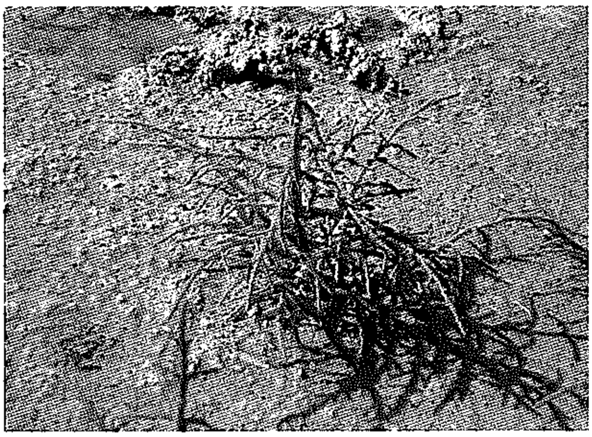

Figure 14. *Salicornia ramosissima*

4.5 Habitats distribution in the saladas

The number of LHA-habitats in each salada is related to its extent (Figure 15). The smallest saladas have less number of habitats. As examples of extreme cases, the saladas Larga, Rafaler and Saladar, with 40-50 ha, have < 15 habitats whereas Amarga Alta, Pueyo and Amarga Baja have high habitats diversity (> 30 habitats) against their size, 25-30 ha. A 58% of the saline wetlands have < 10 habitats and a surface extent < 25 ha. Only 9.6% saladas have > 25 ha, and are formed by a variable number of habitats, from 11 to 53.

In general, clotas are the smallest saladas, with few habitats though of high ecological value. As example, they present annual species like *Microcnemum coralloides* and *Halopeplis amplexicaulis*. The largest saladas, such as La Playa and Pito, have a high number of delineations (53 and 35, respectively) despite the high proportion occupied by "Saline bare soil". Agustín, that stands out by its vegetated bottom despite its considerable size (68 ha), hosts only 11 LHA-habitats.

Saladar, Corral Viejo II, Benamud and Pedregal have few habitats ranging from < 1 ha to 16 ha in surface extent. Thirty-three habitats in Amarga Alta and Baja, twelve in Fonda II, and thirteen habitats in Ceferino IV have a mean size of < 0.5 ha.

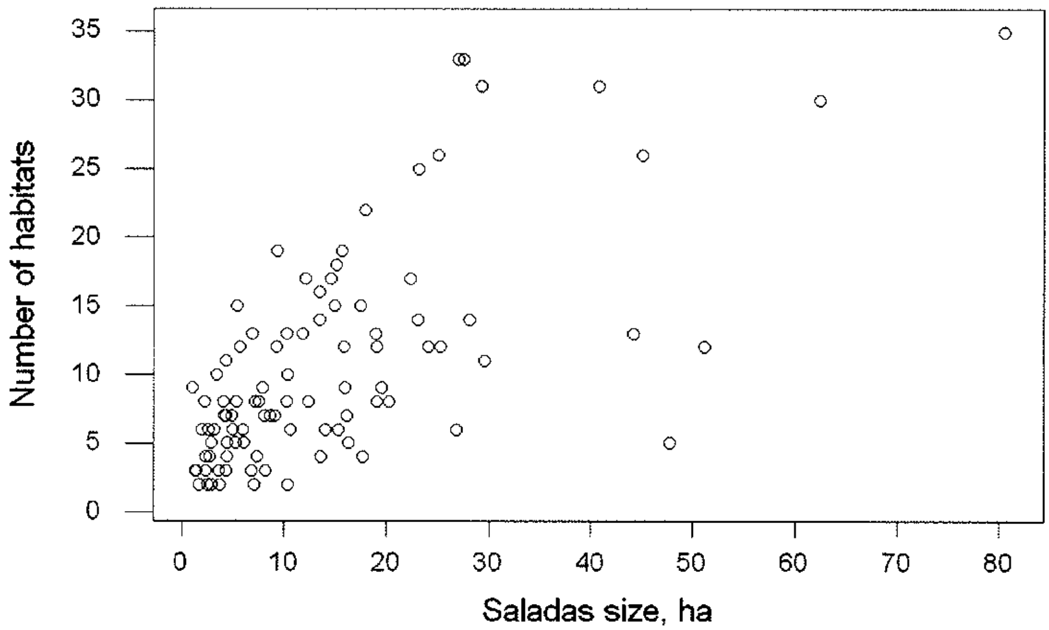

Figure 15. The number of LHA-habitats plotted against the surface extent of each salada.

A wide range (20% to 100%) of vegetation densities has been found in the 1068 delineations (Figure 16). La Playa, Salineta, Pueyo, and Rafeler were the saladas with the higher number of delineations having > 80% of density cover. Most of them are halophytes and esparto steppes.

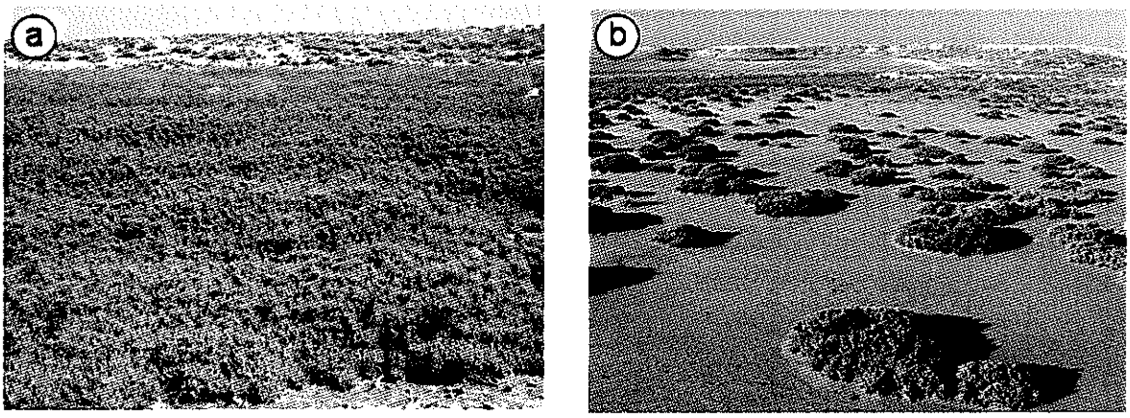

Figure 16. Examples of different density cover: (a) High density cover in La Playa and (b) Sparse clumps of *A. macrostachyum* Rollico.

4.6 Protected habitats: List of Habitats of Community Interest (LHCI)

The Habitats of Community Interest (LHCI) extend on 524.7 ha. Three of the nine LHCI-habitats mapped are of priority interest (Table 9). The remaining 67.2% surface, though not considered by European Directive, includes habitats of ecological interest. As an example, four wetlands have piles of stones (LHA 82.5) occupying more than 25% of the salada; these piles could be considered as a new habitat for *A. macrostachyum* as shown by field observations. Another example is the "Saline bare soil" (LHA 14.1) whose salinity and moisture variations control the distribution of halophytes; moreover, these bare soils host extremophilous microbes, algae and aquatic organisms when inundated. Another issue not considered by most protection policies is the unique mineral and edaphic objects occurring in these athalassohaline environments.

The habitat "Mediterranean and thermo-Atlantic halophilous scrubs" (LHIC 1420) is the most frequent, occurs in 65 saladas and extends on 66.3% of the surface inventoried. The second habitat in extension and occurrence in the delineations is "Halonitrophilous scrubs (*Pegano-Salsoletea*)" (LHIC 1430), mapped in 51 saladas at the southeast area. It is less than a half of the surface occupied by the habitats and the 3% of the total surface inventoried. The habitat "Arborescent matorral with *Juniperus spp.*" (LHIC 5210) occurs only in the escarpments of ten saladas at the southeast.

Table 9. The LHCI-habitats: code and description; number of delineations and their surface extent; surface of the habitat, in ha and in percent on the delineation surface extent, and number of saladas where they occur.

LHIC-habitat		**Delineations**		**Habitat**		**Saladas**
Code	**Name**	**Number**	**Surface extent (ha)**	**ha**	**%**	**Number**
1310	Salicornia and other annuals colonising mud and sand	34	16.59	5.05	2.1	8
1410	Mediterranean salt meadows (*Juncetalia maritimi*)	27	10.66	7.28	3.0	12
1420	Mediterranean and thermo-Atlantic halophilous scrubs (*Sarcocornietea fruticosi*)	316	357.5	160.3	66.3	65
1430	Halo-nitrophilous scrubs (*Pegano-Salsoletea*)	117	81.08	42.86	17.7	51
1510*	Mediterranean salt steppes (*Limonietalia*)	29	12.60	4.69	1.9	14
1520*	Iberian gypsum steppes (*Gypsophiletalia*)	42	22.01	10.31	4.3	25
5210	Arborescent matorral with *Juniperus spp.*	18	19.66	8.56	3.5	10
6220*	Pseudo-steppe with grasses and annuals of the *Thero-Brachypodietea*	6	3.41	2.15	0.9	4
92D0	Southern riparian galleries and thickets (*Nerio-Tamaricetea*)	17	1.15	0.74	0.3	11

*: Priority habitat

The remaining habitats are mainly annuals halophytes (LHIC 1310), in particular Chenopodiaceae of the genus *Salicornia* or grasses located in periodically inundated muds and *Juncus maritimus* (LHIC 1410).

From the priority habitats, the LHIC 1510 “Mediterranean salt steppes (Limonietalia)”, contains associations with rosette-forming perennial plants (*Limonium* spp.) or esparto grass (*Lygeum spartum*), and occurs in the fringes of saladas, soils temporarily permeated (though not inundated) by brines and subject to extreme summer drying, with occurrence of salt efflorescence. It happens in 14 saladas of the southeast area together with *Halopeplis amplexicaulis* (Figure 17a), *Limonium spp., Lygeum spartum, Microcnemum coralloides*, and *Senecio auricula* (Figure 18b). The second priority habitat is LHIC 6220 “Pseudo-steppe with grasses and annuals of the Thero-Brachypodietea” is sparsed in the talus of four saladas (Table 9). The third priority habitat, LHIC 1520, "Iberian gypsum steppes (Gypsophiletalia)", has only 10.3 ha though it occurs in 25 saladas, located in their gypsum-rich escarpments.

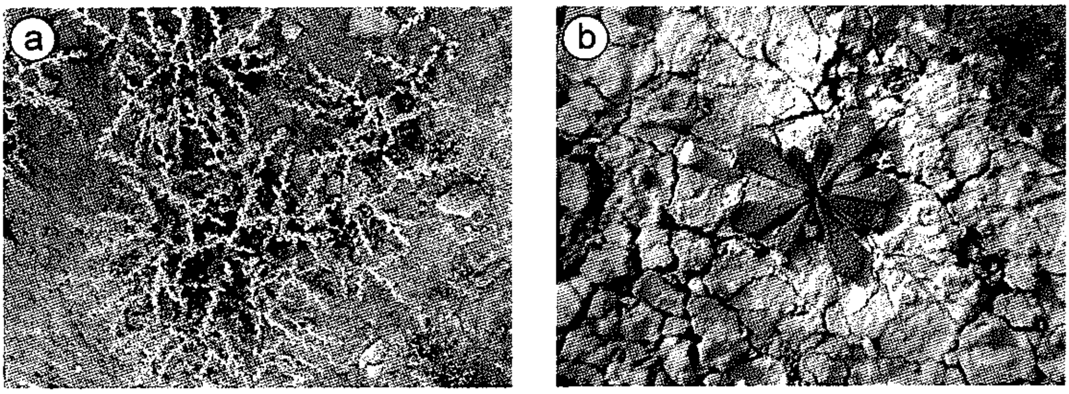

Figure 17. *Halopeplis amplexicaulis* (a) and *Senecio auricula* (b)

Regarding the LHIC-habitats occurrence in each salada (Table 10), the most frequent are LHICs 1420, 1430, and 1520, which occur in 67%, 54% and 26% saladas, respectively. A 7% saladas studied have LHA-habitats not included in the LHIC.

The spatial analysis performed with GIS gives a list of LHA-habitats and LHIC-habitats. These lists are needed for monitoring, protection and law enforcement, and their usefulness can be judged also under the biogeographical or conservationist point of views.

Table 10. Distribution of LHIC-habitats in each salada.

Salada		LHCI-habitat								
Name	**ha**	**1310**	**1410**	**1420**	**1430**	**1510***	**1520***	**5210**	**6220***	**92D0**
Agustín	62.52			x	x	x	x			
Alforjeta I	3.18	x		x						
Alforjeta II	2.68			x						
Aljeces	9.32			x	x					
Amarga Alta	27.53	x		x	x	x		x		x
Amarga Baja	29.3	x	x	x	x			x		
Amarga I	7.17			x	x				x	
Amarga II	5.98				x					
Amarga IV	4.33			x	x					
Amarga V	4.85		x	x	x					
Amarga VIII	1.06	x		x	x					x
Amarga X	5.47		x	x	x					
Amarga XI	2.26		x		x					
Amarga XII	2.84									
Balsa Valdejuanico	20.28			x						
Balsa Buena	7.04			x			x			
Benamud	26.82		x	x	x		x			
Bernabé	10.68									
Cabrero I	3.72				x					
Cabrero II	2.33							x		
Cabrero III	4.12			x	x					
Calabacera	16.32									
Camarón	45.08		x	x	x	x				
Catio I	17.68							x		
Catio II	28.09						x	x		
Ceferino I	7.91				x					
Ceferino II	5.72				x			x		
Ceferino III	3.46				x					x
Chamarqueta	2.9			x						
Chelader I	4.47						x			
Chelader III	2.51									
Clotetes	1.46			x						
Corral Nuevo II	4.09			x	x					
Corral Nuevo III	2.57			x	x					
Corral Nuevo I	6.1			x						
Corral Viejo I	19.09			x			x			
Corral Viejo II	10.4				x					
Correo I	6.89				x					
Correo II	7.38				x		x			
Cruz	12.08	x	x	x	x					
Cucaracha I	4.3				x					

Table 10 (cont.). Distribution of LHIC-habitats in each salada.

Salada		LHCI-habitat								
Name	**ha**	**1310**	**1410**	**1420**	**1430**	**1510***	**1520***	**5210**	**6220***	**92D0**
Cura	5.01			x	x					
Don Roque	14.06			x	x					x
Escobedo	19.51	x		x	x					
Farnaca	13.44		x	x		x				
Fonda I	24.12			x	x	x				
Fonda II	1.32					x				
Fonda III	1.97				x					
Fonda IV	10.24									
Fuesas I	13.61				x		x			
Gancho	8.67			x			x			x
Gramenosa	25.05			x	x	x	x	x		
Gros	15.35				x					
Guallar	14.97			x			x			
Herrero I	10.4			x	x	x		x		
Hoya Pez	10.49			x	x					
Jimena I	7.57				x		x			
La Playa	239.89			x	x		x			
Larga	51.1				x		x	x		
Lifonser	14.57			x	x	x		x		
Muerte	17.97			x			x			
Navarro	16.1			x						x
Nieves	17.54			x	x	x	x			
Pecado	11.88			x	x					x
Pelada	8.17									
Piñol	15.66			x			x			
Pitamar I	3.59									
Pitamar II	2.34									x
Pito	80.48			x	x	x				
Pueyo	27.05	x		x	x		x			
Rafeler	44.18			x		x			x	
Ramilla	4.37			x			x			
Rebollón	15.84	x		x						x
Rollico	40.81	x		x			x			
Rozas	6.82			x						
Saladar	47.73			x						
Salina Pez	9.34	x		x	x	x	x			
Salineta	23.19	x	x	x	x	x				
Salobral	13.51		x	x						
San Miguel	5.29			x						
Serafín	10.24		x		x		x			

Table 10 (cont.). Distribution of LHIC-habitats in each salada.

Salada		**LHCI-habitat**								
Name	**ha**	**1310**	**1410**	**1420**	**1430**	**1510***	**1520***	**5210**	**6220***	**92D0**
Serón II	4.44			x						x
Valdao	9.09	x		x						
Valdecarretas	15.98			x						
Valdefrancín I	25.27			x						x
Valdespartosa	22.39			x	x					
Villa	12.43			x			x			
Vinagrero I	23.12			x			x		x	
Vinagrero II	19			x	x		x			
Viuda del Vacar	19.05		x	x	x					
Yesera I	5.39			x	x					
Yesera II	8.06			x						
Yesera III	1.72									
Zaborros	29.58			x	x				x	

4.7 Plant species of biogeographical interest

From 19 inventoried plant species of biogeographic interest (Table 11), eleven are listed in the Catálogo de Especies Amenzadas de Aragón (C.EE.AA.) http://portal.aragon.es/portal/page/portal/MEDIOAMBIENTE/MEDIONATURAL/BIODIVERSIDAD/Catalogo_especies. Eighteen of them occur < 1500 m far from the new irrigated area, and eleven in irrigated land. *Ferula loscosii* is an endangered species located near to the irrigation; other plants considered of special interest as *Boleum asperum* or *Thymus loscosii* are inventoried in one or two saladas included in the irrigation with the consequent danger of disappearance.

The irrigation can destroy approximately 177 ha of the mapped LHA-habitats surface extent (Figure 18) distributed in 100 delineations, 51% LHIC-protected habitats, and 1.4% LHIC-priority. Within the new irrigated land, LHA 15.6151 ("Interior Woody seablite scrubs") occurs in eleven saladas (mainly in Salineta and Farnaca), being the most frequent (34 delineations) and extended (41%) LHA-habitat. The second in extension is the LHA 82.32 or "Extensive cultivation" formed by dry cereal (14 delineations) occupying 34% of the new irrigated land. Most of this cereal, commercially unprofitable and often not harvested, is sown to earn subsidies.

Table 11. Plants of biogeographical interest, with their correspondence in C.EE.AA. and their location respect to the future irritation.

Plant species or association	Category in C.EE.AA.	Distance from the new irrigated land		Occurrence in wetlands
		< 1 km	within	
Arthrocnemum macrosthachyum		x	x	Agustín, Camarón, La Playa, Muerte, Pez, Piñol, Pito, Pueyo, Rollico
Boleum asperum	Of special interest		x	Gramenosa
Cressa cretica		x		Rebollón, Valdefrancín
Ferula loscosii	Endangered	x		Catio I, Catio II, Ceferino I, Ceferino II, Ceferino III, Cura, Gros, Fonda I, III, IV, Gros, Herrero, Larga
Frankenia thymifolia		x	x	Bernabé, Gancho
Halopeplis amplexicaulis	Sensible	x	x	Amarga Alta, Guallar, Gramenosa, La Playa, Pez, Pito, Pueyo, Rebollón, Rollico.
Jurinea pinnata		x	x	Amarga I, II, Fonda IV, Fuesas II, Guallar, Gramenosa, Nieves, Pitamar, Ramilla
Juniperus thurifera	Of special interest	x		Albacar, Berzas, Camarón, Piñol, Rebollón, Serafín, Valdefrancín
Limonietum		x		Herrero II, Valdespartosa
Limonium costae		x	x	Agustín, Aljeces, Berzas, Chamarqueta, Camarón, Gramenosa, Guallar, Muerte, Piñol, Salineta, Sueltas, Vinagrero II
Limonium delicatulum subsp. latebracteatum		x	x	Agustín, Herrero, Pito, Pueyo, Valdespartosa, Salineta
Limonium stenophyllum	Sensible	x		Camarón, La Playa, Muerte, Pito, Pueyo, Rollico
Microcnemum coralloides	Sensible	x	x	Amarga Alta, Amarga Baja, Berzas, Chamarqueta, Guallar, Muerte, Pez, Pueyo, Valdespartosa.
Ruppia maritima	Vulnerable	x		Amarga Alta
Senecio auricula	Vulnerable	x		Pito
Tamarix boveana	Vulnerable	x		Piñol
Thymus loscosii	Of special interest	x	x	Catio II, Gramenosa, Gros, Herrero, Larga, Lisonfer, Nieves, Pitamar, Valdespartosa
Thymus zygis	Of special interest	x	x	Benamud

4.8 LHA-habitats against new irrigated lands

The surface extent of the LHA-habitats inventoried (29 habitats) located < 1 km apart from the new irrigated land (Figure 18) is about 60% (959 ha) included in 608 delineations. This surface is 41% of the LHIC protected habitats, with 2.5% priority. The extensive cultivation (LHA 82.32) and LHA 15.6151 ("Interior Woody seablite scrubs") are again the most extended, with 41% and 22% surface extent, respectively. LHA 15.6151 has the higher number of delineations (145 delineations) distributed in 42 saladas. The third habitat in extent is Saline bare soils (LHA 14.1) with 84 ha or 8.7%. About 70% extent of the 29 habitats is < 500 m far from new irrigated lands (423 delineations).

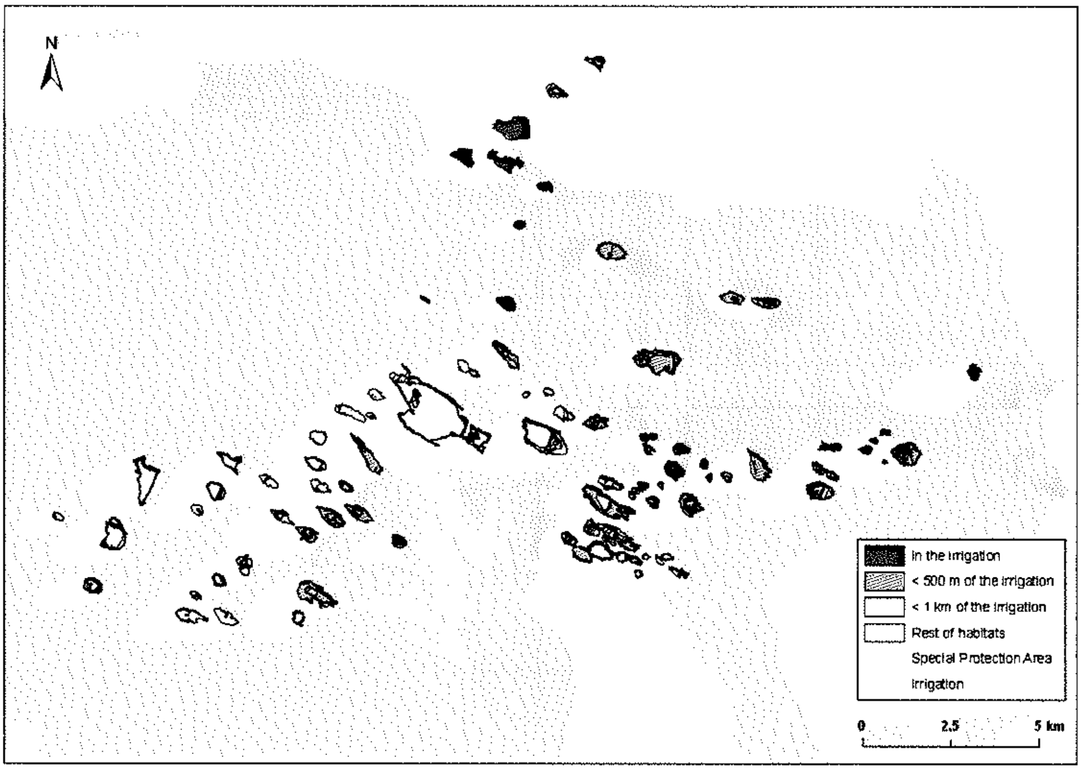

Figure 18. LHA-habitats grouped by their distance to the new irrigated area.

5. CONCLUSIONS

For the first time, a vegetation map of the saline wetlands of Monegros at detailed scale and incorporated to a GIS has been produced, giving an effective representation of the total and protected habitats of the saladas. GIS will facilitate the inclusion of the saladas vegetation in the forthcoming Map of Habitats of Aragón at 1:25.000 scale. Our map shows the distribution of habitats considered in the Directive 97/62/CEE, some of them as priority.

The map of habitats and associated database provide the distribution of the most representative plant communities, and catalogued species of special interest. Habitats protected by the European legislation cover 33% of our LHA-habitats map (2.4% priority and 30.4% non priority). The remaining 67% of the map includes plant communities with species of biogeographical interest not yet catalogued.

The standard functions of GIS and associated data bases enable for analysis and updating, and hopefully will help the nature protection, including prevention and law enforcement measures. One immediate application should be the evaluation of the effects of the new irrigation schemes, which can "digest" 20% of the vegetation and 8% of the habitats protected by European laws, in terms of surface extent.

The database structures the standard components (LHA-habitats) of the habitats delineations, their size, description and percent cover. The GIS can be easily updated in contents and structure to incorporate future changes in the vegetation composition extent, and classification. The integration of this map with images and territorial delimitations facilitate the knowledge and analysis of the wetlands evolution. For the near future, lost of high-priority habitats after the European legislation can be foreseen from the data presented.

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CHAPTER 4. Surface traits of soils of Arthrocnemum macrostachyum in Monegros, Spain

1. INTRODUCTION

The stem succulent halophyte *Arthrocnemum macrostachyum* (Moric.) Moris *in* Moris & Delponte) is a perennial Chenopodiaceae whose shrub formations have been included by geobotanists in the class *Thero-Salicornietea* (Rivas-Martínez *et al.*, 2002), *Suaedetum* Association, and the *Arthrocnemetosum macrostachii* Subassociation (Braun-Blanquet and Bolòs, 1958). *Arthrocnemum macrostachyum* (*A.m.*) occurs in Spain along the sea shore and in inland saline wetlands, as is the case in Monegros in northeastern Spain. In this region, the habitats of *A.m.* are muddy and saline soils seasonally or occasionally flooded with brine. These habitats are now threatened by some agricultural activities, and specifically by the foreseeable change of the hydrological cycle resulting from a decrease in the salinity of soils and brines due to water coming from conterminous newly irrigated lands.

The Habitats Directive (Council Directive 92/43/EEC, O.J. L206 22.07.92), the European legislative instrument in the field of nature conservation, takes inland halophytes into consideration. The EUR27 version of the *Interpretation Manual of European Union Habitats* (Council Directive 2006/105/EC, OJ L363, p. 368 20.12.2006), adopted by the Habitats Committee in April 2007, includes halophytes in coastal environments and also in inland Mediterranean habitats, such as our study area. In the *Coastal and halophytic habitats* category, *A. macrostachyum* is represented in habitats 1410 and 1420, occurring mainly in salt marshes and salt meadows.

Almost 25% of Ramsar sites are inland saline environments (Jellison, 2005), and their ecological value as habitat for migratory and nesting populations of birds has been widely recognized. In Spain, the main inland habitats for halophytes are saline wetlands located in Tertiary Depressions under arid or semiarid conditions and endhoreic hydrologic settings (Herrero, 1982, 2008; Comín *et al.*, 1991; Anento *et al.*, 1997; Cirujano and Medina, 2002; Domínguez *et al.*, 2006). Intermittent inundation and the soil salinity gradient are the key factors, at the local scale, in the distribution of the vegetation. Moreover, water in inland saline wetlands can reach higher salinity than that in coastal lagoons or marshes, as is the case in Spain in Monegros and other areas.

In Monegros, the bare soil in the saline wetlands recognized as *playa-lakes* (Castañeda *et al.*, 2005) is intermittently waterlogged with salty water. *A.m.* is the most salt-resistant perennial vascular plant living in these conditions. At the bottom of the playa-lake, this plant is distributed in fringes of variable cover density controlled by the microtopography, salinity and water ponding, which provide microhabitats that differ in moisture and salinity from the conterminous bare soil (Callaway, 1994). It is physical factors like drought, flooding and soil salinity rather than intraspecific competition that inhibit *A.m.* growth (Gul and Khan, 1999). *A.m.* plant cover and branching are more inhibited by flooding frequency than by salinity increases (Gul and Khan, 1998). The adaptations of this plant to salinity and other stressing factors (Gul and Khan, 2008), as well as its role in soil formation through organic matter production, dust-trapping, rooting, and providing conditions for the life of other organisms, are not well known.

A.m. clumps have a radial growth leading to a centrifugal gradient of density and size of both aerial shoots and branches within each clump, which is associated with a hummock shaped like a nebkha that disappears with the ageing and death of the clump (Sadek and El-Darier, 1995). Seeds are needed for dissemination and to ensure genetic variability, but germination is a critical step in plants that are under stress. The germination conditions of *Arthrocnemum* have been studied in the laboratory by Pujol *et al.* (2000), Rubio-Casal *et al.* (2003), Herranz *et al.* (2004), Khan *et al.* (2006), Vicente *et al.* (2007), and Khan and Gul (2008). In these studies, which were conducted in Petri dishes, different combinations of saline stress were imposed and it was determined that germination gradually decreased with increasing salt concentrations. The salt tolerance of *A.m.* for survival and for reproduction differs. Khan and Gul (2002), using NaCl solutions, demonstrated the high tolerance of *A.m.* They found that maximum leaf and root succulence occur with a 400 mM NaCl solution (30 dS m^{-1}, according to the NyPa® scale, www.nypa.com.au), and decrease at very high salinity. Germination, conditioned by the thermoperiods at high salinity, tolerated up to 1000 mM of NaCl solution (seawater is 600 mM according to the NyPa® scale), though with a very low germination rate (3%).

Herranz *et al.* (2004) reported positive effects following the submission of seeds of *A.m.* to high salinity, with > 50% germination recovery for those seeds which had been exposed to hypersaline solutions. This is the phenomenon of salt stimulation, defined by Woodell (1985) as an enhanced rate of germination after pre-treatment in salt water. In most of these species, the higher the salinity during pre-treatment, the higher the germination after transfer to fresh water. This behavior is well adapted to the typical episodic successions of dryness and waterlogging or flooding by occasional rains. Also, several authors reviewed by Khan and Gul (1998) stressed the occurrence of polymorphism in seeds of a number of halophytic species and mention the hypothesis of selection by different salinity levels at the sites where these plants grow.

Gul and Khan (2008) report the dominance of five species of halophytes, one of them *A.m.*, in coastal vegetation in Pakistan. As they confirmed in the laboratory, the high tolerance of *A.m.* for soil salinity was related to the high calcium content of the soils, since they are developed in calcareous materials. A similar consideration applies in Monegros, because gypsum ($CaSO_4 \cdot 2H_2O$), which is much more soluble than calcium carbonate, is ubiquitous and is a major component of many soils. The soils of *A.m.* in Spain have been studied in Mediterranean coastal marshes by Álvarez-Rogel *et al.* (2001), and in saline wetlands of the central (Molina *et al.*, 2001) and southeastern Iberian Peninsula (Esteve-Chueca, 1972). The temporal oscillations of soil electrical conductivity in the extract of saturated paste under *A.m.* from one *salada* of Monegros (Herrero, 2008) range from about 30 dS m^{-1} to 80 dS m^{-1} in the upper 20 cm of the soil, and Ochoa (1988) gives average data.

Most of the studies conducted on physiology of salt tolerant plants (Gibbs and Greenway, 2003; Barrett-Lennard, 2003) and on plant-soil relationships (Barrett-Lennard and Malcolm, 1999; Bazihizina *et al.*, 2009) consider several of the various plant-stressing factors and the concept of non-uniform salinity in the root zone. Fewer works are available on highly salt tolerant plants, which often have few if any commercial uses, like *A.m.* In this article we study only the salinity-related issues of the soils where *Arthrocnemum macrostachyum* lives, in Monegros, Spain.

Our aim is to characterize prominent soil surface features related to the occurrence of this plant, and to show that the self-organization of the soil in a tessellated surface horizon provides two different environments for seed germination and plant establishment.

2. STUDY AREA

Our research was conducted in seven of the saline wetlands located in southern Monegros, Spain (Figure 1), which are locally named *saladas*. They are scattered in gentle depressions in an agricultural landscape in a platform between 320 m and 417 m a.s.l. The platform ends to the south in an escarpment of more than 100 m on the Ebro River.

The rocks are horizontal strata of alternating limestone, gypsum, and lutite, with gypsum becoming more abundant from east to west (Salvany *et al.,* 1995). These materials were deposited in an endohreic lacustrine environment during the Miocene, and the saladas are the remains of those ancient endhoreic and arid conditions, similar to the current African or Asian sebkhas and pans.

Monegros is one of the most arid regions in Europe (Herrero and Snyder, 1997), with a mean annual precipitation of 350 mm in the last 20 years, according to the data from the Petris (Figure 1) and Valfarta weather stations; the latter, 11 km north of the former, provides automatic records from 2004. The mean annual ET_0 is 1225 mm (Faci and Martínez-Cob, 1991) resulting in a significant mean annual water deficit. The soil temperature and moisture regimes in Monegros are thermic and aridic, respectively, according to the definitions of Soil Survey Staff (1999). These conditions plus the frequent strings of dry years explain the poor yields of winter cereals —the only feasible crop in the non-irrigated lands— in most years. Subsidies are a major income source for rainfed agriculture.

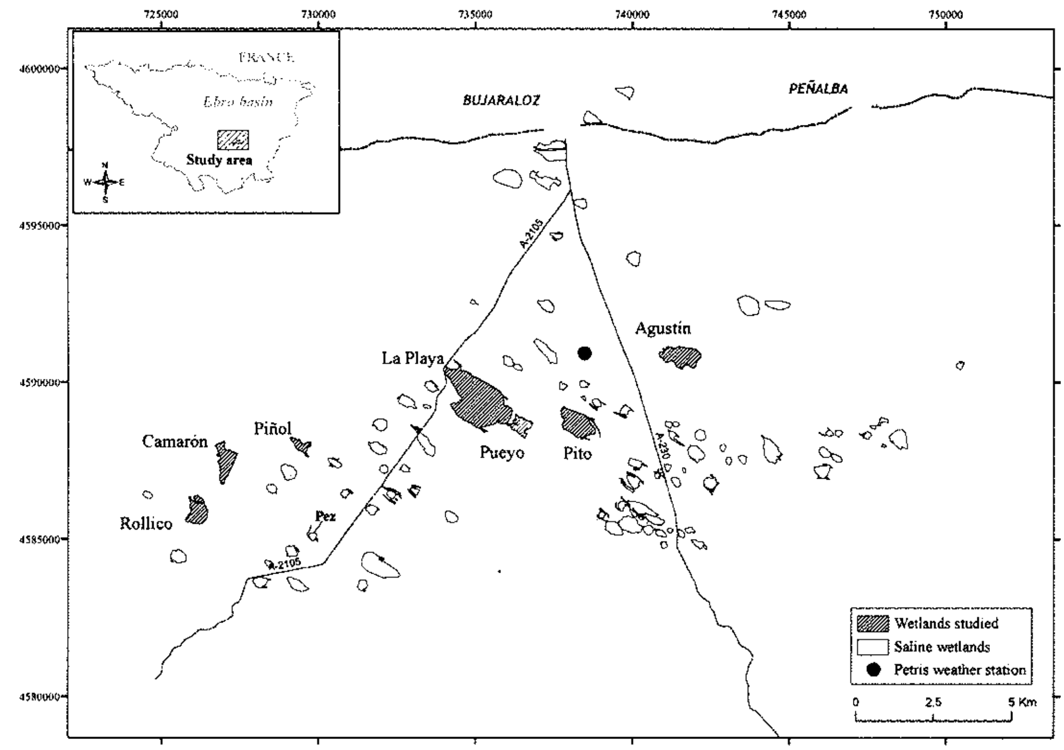

Figure 1. Location of the main saline wetlands in Monegros, Spain.

The surface stoniness of many soils surrounding the saladas is related to the deep plowing which is practiced in order to retain the scarce rains. Boulders are traditionally removed and often dumped in the saline wetlands, destroying and suffocating vegetation, though young *A.m.* plants have pioneered the base of stabilized dumps. On-site stone crushing by special machinery has become frequent in recent times.

Early studies of the vegetation of the Ebro valley (Braun-Blanquet and Bolòs, 1958; Blanché and Molero, 1986; Molero *et al.*, 1989) have stressed the singularity of the halophytic communities. Its ecological interest (Vigo, 1998), recognized in Directive 92/43/EEC of the European Union, is now acknowledged in Spanish environmental laws. Molero *et al.* (1989) established more than 70 plant associations, with 14 of them considered as exclusive to Monegros and adjacent territories. They classified *A.m.* as vulnerable because of the strong disturbances of its habitats, mainly by intensifying agricultural activities. Twenty years later, the major threat is the destruction of whole wetlands by new irrigation infrastructures —roads, pipelines, pumping stations, drainage trenches— and the alteration of habitats (Castañeda and Herrero, 2008). Moreover, irrigation will change the hydrological regime and the ionic composition of waters; this plus pollution will destroy the natural vegetation, as has already happened in several saline wetlands close to our study area.

The contrasting halophilous vegetation in the saladas is related to the microclimatic, topographic and edaphic conditions. Halophilous vegetation occurs at the bottom of many saladas, but those most frequently inundated have a bare bottom, with halophytes limited to the salada fringes, which are free of long inundation periods. The distribution of *A.m.* in the playa-lakes is key in the biological interactions with physical factors that control zonation patterns (Pennings and Callaway, 1992).

The inner bare bottom which is occasionally or seasonally flooded is bordered by a fringe of *A.m.* along with pioneer annual communities including species like *Halopeplis amplexicaulis, Limonium stenophyllum,* and *Frankenia pulverulenta.* The next fringe, rarely flooded, is formed by *Suaeda vera*, often accompanied by annual halophytes. The outer part of the salada bottom, which is never flooded and has less soil moisture, can be occupied by nitrophilous and halo-nitrophilous plants, or it is plowed and planted with cereal crops for subsidies. Dwarf secondary calcicolous and gypsophilous shrubs occupy the escarpment around the saladas, in soils subject to very dry summers.

The occurrence of *A.m.* is correlated to highly saline soils with a shallow water table and intermittent floods. The dissolution of salts from the rocks and the low transmissivity of the aquifer (Samper and García-Vera, 1998) determine a hypersaline water table, with the bottoms of the wetlands acting as discharge areas where these salts are evapoconcentrated. Bottoms are intermittently flooded by brine with up to 200 g L^{-1} of salt (Samper and García-Vera, 1998), with large variations. In the dry periods capillary ascent is responsible for high salinities in the soil and for surface efflorescences. Few halophytes can live in these harsh conditions, *A.m.* being the only perennial plant at the fringes closest to the intermittently flooded bottoms.

3. MATERIAL AND METHODS

3.1 Field sampling

Our sampling is based on a previous survey of *A.m.* made between 2004 and 2006 (Domínguez *et al.*, 2006) and ongoing fieldwork. According to the data analysis, *A.m.* occurs in 11 saladas (Table 1) as the dominant species of European Commission habitat 1420, i.e. "Mediterranean and thermo-Atlantic halophilous scrubs" (European Commission, 2007).

Table 1. Saladas, number of habitat map delineations containing *A. macrostachyum*, area (ha), and the ranges of plant cover and *A. macrostachyum* cover in each salada.

Salada		Map delineations with *A.m.*		% plant cover		% *A.m.* cover	
Name	ha	Number	ha	Min.	Max.	Min.	Max.
Agustín	62.5	11	41.8	10	80	7	68
Aljeces	9.3	2	0.1	30	30	15	27
Camarón	45.1	10	6.9	10	90	6	90
Farnaca	13.4	1	0.2	10	10	10	10
La Playa	239.9	20	30.0	10	80	9	70
Muerte	18.0	3	0.4	10	30	10	18
Pez	9.3	2	0.1	10	50	10	50
Piñol	15.7	7	2.7	20	80	20	80
Pito	80.5	10	12.4	10	60	9	40
Pueyo	27.1	11	7.2	10	60	10	51
Rollico	40.8	13	11.3	15	100	15	70

The saladas Aljeces, Farnaca, Muerte, and Pez were discarded since they have few map delineations, with total extent < 1 ha. The seven selected saladas (Table 2) are representative of the full range of percent cover of *A.m.*, from < 10% to 90%. A total of 33 sites, from bare soil to 90% cover of *A.m.*, were sampled, ranging in elevation from 323.1 to 337.5 m above sea level. Based on maps of the habitats at scales ranging from 1:2000 to 1:6000 (Domínguez *et al.*, 2006), we sampled from 3 to 8 sites in each salada. Table 2 also shows the occurrence of vegetation other than *A.m.*

Table 2. Saladas studied with their survey dates, sampling sites, percent of *A. macrostachyum* (*A.m.*) and other associated covers, and elevation range of sampling sites in each salada.

Salada	Site	*A.m.* cover (%)	Other covers (%)	Elevation range (m)
Agustín 28-07-2006 13-12-2006	AGU1	0	44 *Suaeda vera*	0.53
	AGU2	25	46 *Suaeda vera*	
	AGU3	35		
	AGU4	10		
Camarón 28-07-2006 13-12-2006	CMR1	35	15 *Lygeum spartum*	1.15
	CMR2	90		
	CMR3	0	Bare soil	
	CMR4	30		
	CMR5	70		
La Playa 24-07-2006 12-12-2006	LPL0	56	24 *Suaeda vera*	0.74
	LPL1	60		
	LPL2	70		
	LPL3	70		
	LPL4	0	Bare soil	
	LPL5	40		
	LPL6	0	Bare soil	
	LPL7	50		
Piñol 28-07-2006 13-12-2006	PNL1	60		0.97
	PNL2	80		
	PNL3	35		
Pito 26-07-2006 14-12-2006	PTO1	30		1.69
	PTO2	10		
	PTO3	18		
	PTO4	40		
Pueyo 26-07-2006 12-12-2006	PYO1	30		0.48
	PYO2	0	Bare soil	
	PYO3	10		
	PYO4	10		
Rollico 28-07-2006 13-12-2006	RLL1	18	8 *Halopeplis amplexicaulis*	1.45
	RLL2	0	Bare soil	
	RLL3	70	30 *Suaeda vera*	
	RLL4	40		
	RLL5	60		

In order to gather soil data for all vegetation densities in each salada, we adopted a transect strategy wherever suitable, or else surveyed around the bottom, depending on the distribution of *A.m.* (Figure 2). Our survey strategy was intended to sample sites in a way that would enable us to relate plant cover to the physical and chemical characteristics of the soils in each salada. For this reason, the final sampling decisions were made in the field, and the sampling sites were located with GPS. Other soil characteristics such as the presence of salt efflorescence and desiccation polygons delimiting tessellae were also recorded. Elevations were extracted from DTM.

At each sampling site we took three soil samples: (i) from 0 to 15 cm depth; (ii) the top surficial layer naturally separated in tessellae from the underlying soil, in a degree related to the precedent weather; and (iii) the soil below the (ii) sample, up to 15 cm depth. The three samples were named: 0-15, T (top), and BT (below top).

Samples BT and T were taken less than 0.5 m from the samples 0-15. Samples 0-15 and BT were taken with an Eijkelkamp auger with a diameter of 7 cm, whereas sample T was taken with the fingers or with the help of a knife. All of the samples were introduced in polyethylene bags and hermetically sealed and were transported the same day to our laboratory.

In order to study seasonal variations, two sampling campaigns were conducted, from 24 to 28 July 2006, and from 12 to 14 December 2006, in the summer and winter seasons, respectively. A total of 99 soil samples were taken in each sampling campaign. The rainfall at the Petris weather station (Figure 1) in July 2006 was 43 mm, more than twice the average for this month in recent years. Furthermore, 7.2 mm of precipitation was recorded during the sampling campaign, with rain prints as the only field evidence. December 2006, on the other hand, was very dry, with only 15 mm, half the monthly average for this month in the 1984-2006 period. During the December sampling campaign only 1 mm of precipitation was recorded.

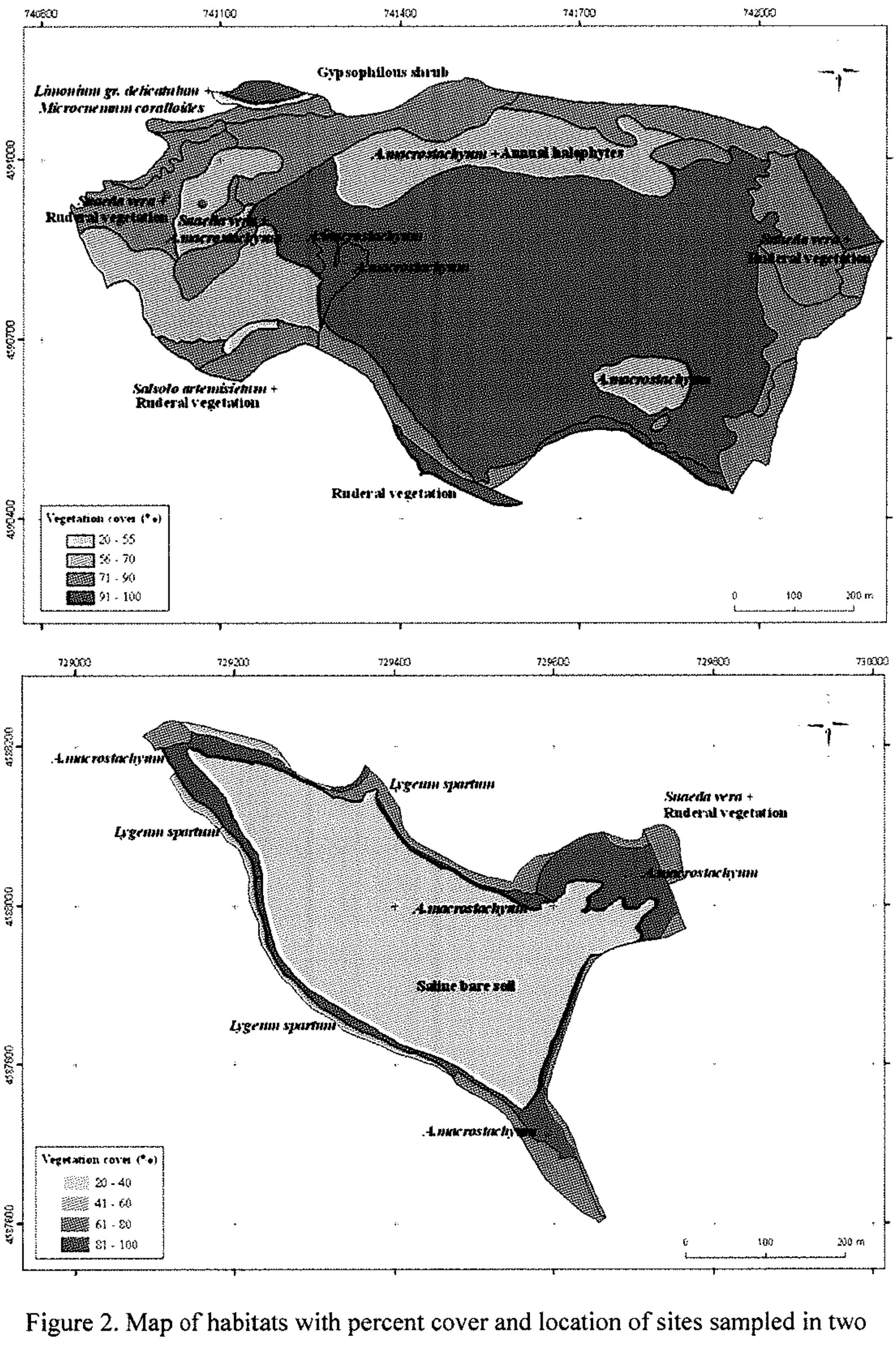

Figure 2. Map of habitats with percent cover and location of sites sampled in two saladas: (a) NW-SE transect sampled in Agustín and (b) randomly sampled sites in Piñol.

At each site we recorded the soil temperature at a depth of 15 cm, as representative of the roots' thermal conditions. Photographs of the vegetation and field notes helped in recording the conditions at each site. The field and laboratory determinations are summarized in Table 3.

Table 3. Determinations in the field and laboratory, indicating the sampled soil layers in the field surveys.

Depth		July	December
	Field determinations		
0-15	Soil temperature	x	x
	Thickness of the T layer	x	x
	Laboratory determinations		
0-15	Gravimetric moisture	x	x
T		x	x
BT		x	x
0-15	CE1:5 and CE1:10	x	x
T		x	x
BT		x	x
0-15	Munsell color	x	
T		x	
BT		x	
0-15	SO_4^{2+}, Cl^-, Ca^{2+}, Mg^{2+}, Na^+, K^+	x	
T		x	
BT		x	
0-15	Calcium carbonate equivalent, Total N, Organic matter, NO_3^-	x	
0-15	Gypsum	x	
BT		x	

3.2 Laboratory methods

The actual gravimetric soil moisture was measured in a way that avoided the loss of the constitutional water of gypsum (Herrero *et al.*, 2009). The samples were weighed in the closed polyethylene bags immediately upon their arrival to the lab; then the bags were opened to allow air drying at room temperature for one week; then the samples were placed for two weeks in a ventilated oven with a temperature not above 32 °C. The dry weight of the samples ranged from 90 g to 945 g and the average weight of the bags (5.72 g) was used as a uniform tare when calculating the actual moisture.

The color of both the air-dried and the wet soil samples was determined in the lab using Munsell charts (Munsell Color, 1988). Soil pH was determined by pH-meter in an aqueous 1:2.5 soil-to-water dilution.

The electrical conductivity was measured in extracts with the ratios soil:water of 1:5 (EC1:5) and 1:10 (EC1:10) for all samples, and expressed in dS m^{-1} at 25 °C. Soil salinity appraisal by the standard agricultural method of saturated paste extract was intended by the United States Salinity Laboratory Staff (1954) for soils with salt contents well under the EC attained in the saladas bottoms, and does not give results which are representative of the conditions of these soils, which are often flooded with brine. Moreover, as saturation extracts produce neutral ionic pairs, EC in these extracts is a weak estimator of ionic content. We deemed a 1:10 dilution ratio better suited to our study, but we also prepared 1:5 extracts as a more standard ratio that would allow comparisons with the results of other authors.

Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, SO_4^{2-}, and NO_3^{-} were titrated in 1:10 soil-to-water ratio extracts of the July samples. Calcium and magnesium were determined by atomic absorption spectrophotometry, and sodium and potassium by flame absorption photometry, with a Perkin-Elmer 2380 spectrophotometer. Chloride was determined with an electrode connected to an ORION EA-920 ion analyzer. Sulfate was determined by molecular absorption spectrophotometry according to Nemeth's method using a SP6-200 PYE UNICAM spectrophotometer; and nitrate by colorimetry with a Bran-Luebbe AA3 automated analyzer. The quality of the EC and ion determinations was checked by scatter plots and correlation coefficients between these parameters.

The organic matter content was determined with a Spectronic 20 colorimeter by oxidation of the organic carbon with potassium dichromate in a sulfuric environment using $AgNO_3$ to avoid the interference of Cl^{-}. Total nitrogen was determined by Kjeldahl's method and equivalent calcium carbonate (ECC) with a Bernard calcimeter. The gypsum content was determined by thermogravimetry following the method of Artieda *et al.* (2006).

3.3 Data treatment

The data were managed with spreadsheets and the statistical package Minitab. The distributions are represented by boxplots, following Chambers *et al.* (1983). Smoothing by LOWESS lines was used to graphically summarize the relationship between salinity measures on the two dates, without fitting a specific model. We used the central and dispersion measures of salinity, soil moisture, major ions concentration, organic matter, and gypsum content to depict the distribution of these parameters in relation with *A.m.* cover. ARC GIS v.9 was used to draw the maps of habitats and to organize the geographical data.

4. RESULTS AND DISCUSSION

4.1 Vegetation

Habitats where *A.m.* is dominant occur in saladas located at the center and southwest of the endorheic platform. They developed in the Intermediate Lacustrine Unit (Salvany *et al.*, 1995) which contains gypsum and limestone with intercalations of lutite. Most of them are playa-lakes, ranging from 16 ha to 240 ha, with a bare bottom that is occasionally flooded. Their vegetation fringes occupy between 20% and 50% of the total salada extent; Agustín is the only salada whose bottom is almost entirely vegetated (Table 4). *A.m.* was not inventoried as a dominant habitat in the northern saladas, which developed in the lutites of the Superior Lacustrine Unit (Salvany *et al.*, 1995).

Table 4. Saladas sampled, total vegetation extent and percent of *A. macrostachyum* extent.

Salada			**% *A.m.* habitat**	
Name	**Vegetation** ha	**Vegetation** %	**Over the total vegetation extent**	**Over the total salada extent**
Agustín	62.5	100.0	66.8	66.8
Camarón	10.5	23.3	65.4	1.5
La Playa	43.1	20.0	69.7	12.5
Piñol	5.0	32.1	54.6	17.5
Pito	44.0	54.7	28.1	15.4
Pueyo	13.5	50.1	52.9	26.5
Rollico	15.8	38.8	71.3	27.6

In the playa-lakes studied, the habitat of *A.m.* is more than 50% of the vegetation extent except in Pito, where *A.m.* is only 28% of the vegetation. The occurrence of *A.m.* is not related to salada size, salada shape, or to the vegetation extent. Within each salada, the maximum occurrence of *A.m.* is usually located at the foot of northern escarpments or protected by the adjacent hills, in lees from the frequent northwest wind.

The plant cover percent reached 100% only in Rollico. Total coverage by *A.m.* is rarely attained (Figure 3). Maximum coverage occurs at Camarón, 90%, and Piñol, 80%. The Camarón, La Playa, and Rollico saladas were sampled in a wide range of plant cover densities, from 0% to 70% and 90%; whereas Pito, Pueyo, and Piñol had the smallest ranges. Piñol was the only salada where we took no samples in bare soil, because the muddy conditions on the sampling dates hampered our entering the salada. This fact draws attention to a possible bias in data from soil sampling by pits or augering when these methods do not work in muddy or flooded conditions (Herrero, 2008, page 101).

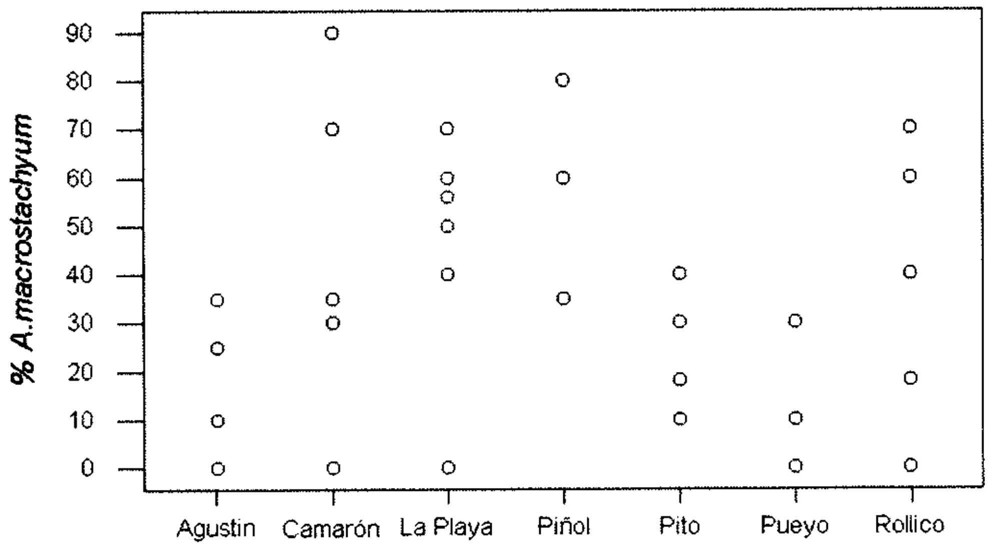

Figure 3. Percent cover of *A. macrostachyum* at the sites studied in each salada.

Apart from the cover density of *A.m.* (Table 2), which was used as the main criterion to select the sampling sites at the scale of the habitat map, local variations of greenness, homogeneity, and structure were observed. The height of the plants varied up to 40 cm, and formed round clumps up to 150 cm in diameter. Desiccation polygons of variable size (from 15 cm to 30 cm) were usual in all the saladas, despite the recent rains, and the efflorescences associated with them were concentrated around the plants' bases. In Pito, *A.m.* decreased in coverage and size from the salada border to the center. Further away, a fringe of younger (bigger and greener) plants showed that *A.m.* had advanced toward the bottom. In La Playa, areas of dead clumps denoted a change to unfavorable edaphic or biological conditions. The best developed cover of *A.m.* occurred in Rollico, where clumps were dome-shaped with a concentric distribution of plants from successive years, the younger surrounding the older. In Piñol, small new clumps of *A.m.* pioneered the old stone dumps on the salada bottom.

Figure 4 shows the distribution of the sampling sites. The elevation range between contiguous *A.m.* sites was always < 0.5 m. The Agustín (Figure 4a), Camarón (Figure 4b), and Pueyo (Figure 4f) transects included from 2 to 4 sites and have different orientations, depending of the arrangement of the fringes. Their distance from the border of the salada ranged from 70 m in Camarón to 400 m in Agustín. The other sites sampled are arranged parallel to the edges of the saladas (Figures 4c, 4d, 4e, 4g) and can include some isolated growths of *A.m.* (Figures 4d, 4f).

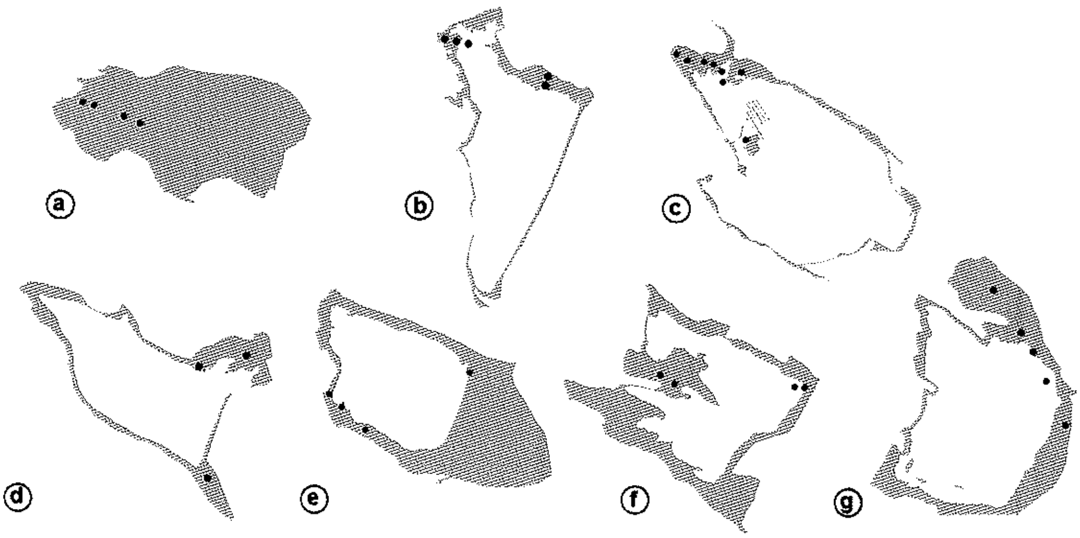

Figure 4. Saladas studied, with different scale factors, showing the vegetation extent (in grey) and the location of sampling sites (black dot): a) Agustín; b) Camarón; c) La Playa; d) Piñol; e) Pito; f) Pueyo; g) Rollico.

4.2 Soil surface organization

The polygonal decimetric pattern of the T layer can persist even after small showers, occasional floodings (Figure 5a), or submersion under water driven by the wind (Figure 5b), i.e., the crack and tessellae pattern can survive waterlogging and drying. After drying, salt can accumulate in the cracks, sometimes surpassing the high sides of the tessellae (Figure 5c). In these conditions, germination can be easier on the tessellae (Figure 5d) than in the cracks. Conversely, with no salt accumulation, the cracks could be a friendlier environment for germination and plant establishment in terms of moisture and temperature.

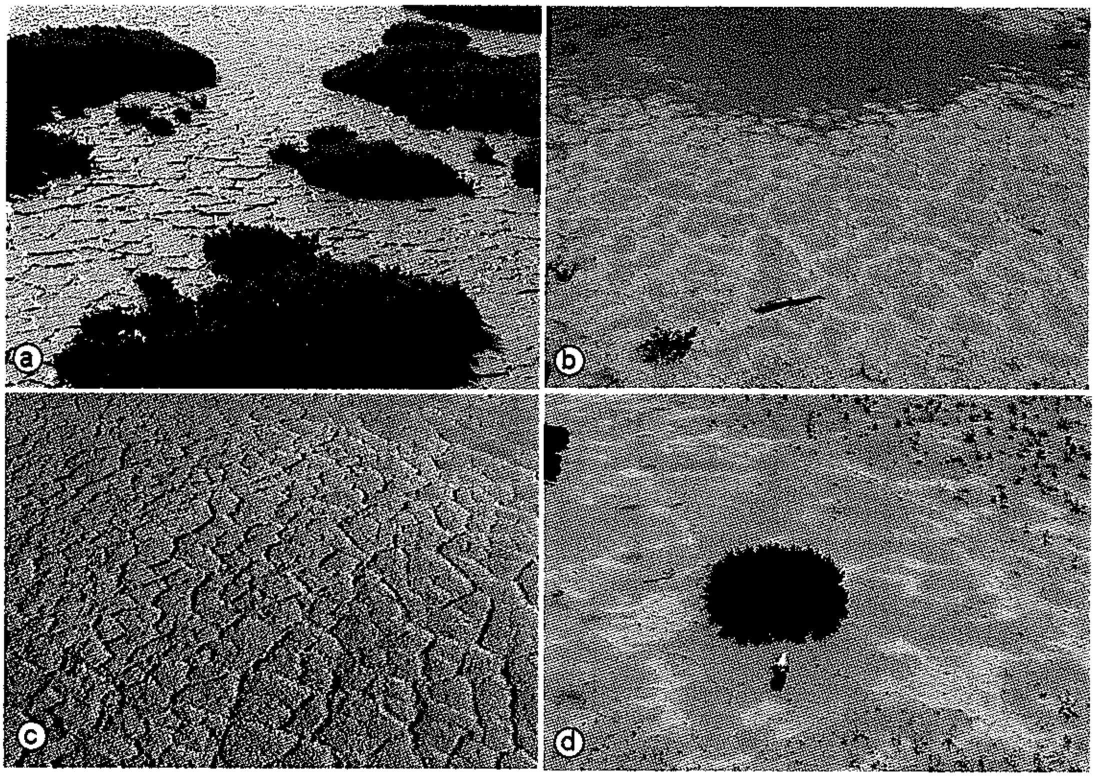

Figure 5. Different views of the soil surface in the saladas. All of them show the polygonal pattern with different development of tessellae. In a) the pattern survives inundation, in b) and c) salts concentrate in cracks, in d) plantules grow preferentially on the tessellae.

The T layer thickness ranged from 0.3 cm to 2 cm, and in general was greater in July, except in Pueyo. Cracks between the tessellae, most of which have no continuity in the underlying soil material, can be more than 1 cm wide (Figure 6a). The thickness of T and the ease with which it separates from BT differ among sites even within the same salada.

At the sites with the best developed tessellae (Figure 6a), the ease with which the tessella could be lifted with the fingers and inspection of the T and BT contact surfaces suggest that the tessella lies in partial or total discontinuity with BT, which would render capillary ascent into the tessellae difficult or impossible. The best developed tessellae were found in Agustín (Figure 6a), where the OM content is > 2%. In other circumstances, the T layer can still be separated from BT, though tessellae are poorly developed (Figure 6b). The distribution of efflorescences is not homogeneous, and occasionally, a millimetric saline crust results in a mulching (Figure 6b).

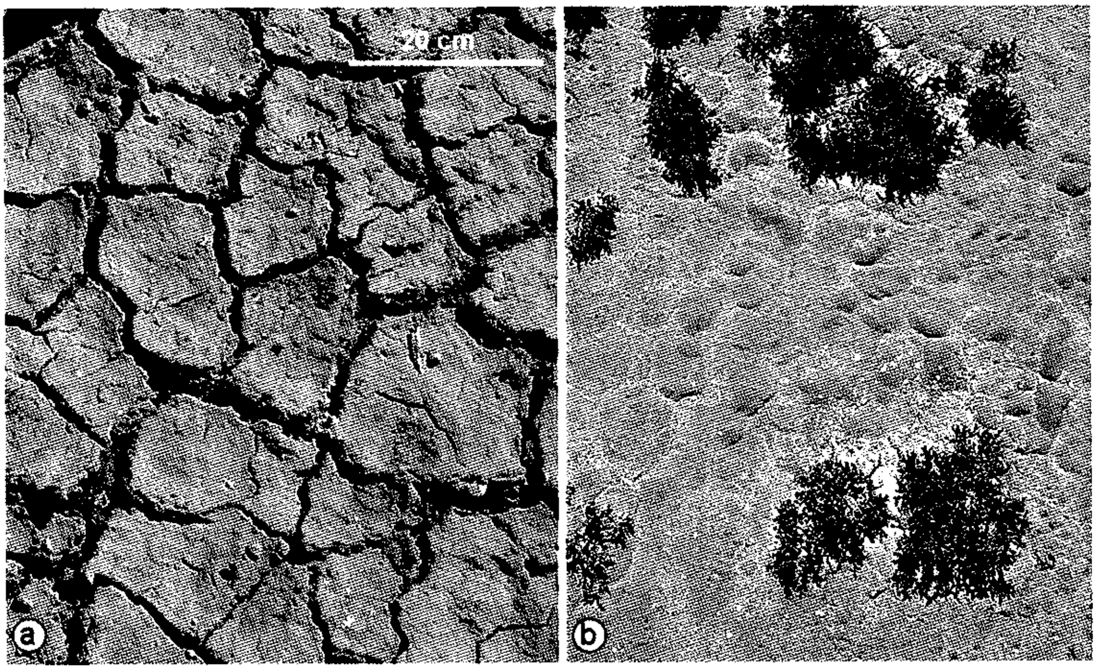

Figure 6. (a): Discontinuous mulch in AGU3, made by curled desiccation tessellae easily separable from the BT layer. (b): Continuous mulch in LPL5 with dome structures related to gas expulsion from sapropelic BT, highlighted by millimetric (low-lying) thin efflorescence.

A model of the soil surface organization based on our field observations is sketched in Figure 7. Of course, all intermediate situations can occur, and changes may happen in short time spans associated with weather and daily cycles. These changes affecting the water and salts dynamics at a centimetric scale can be decisive for favoring seed germination and the establishment of plantules in one location or another. The differences in salinity between the T and BT layers have been confirmed by our measurements of soil salinity in both layers.

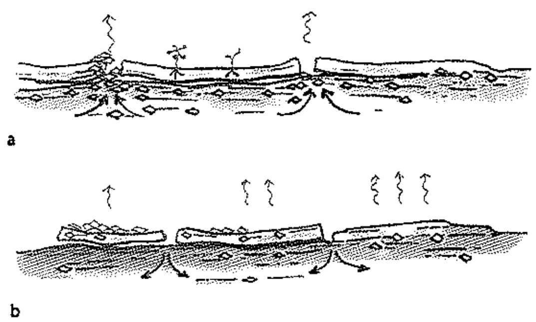

Figure 7. Schematic profile of the soil surface in the bottom of the saladas, showing different degrees of discontinuity between the T and BT layers. Arrows indicate capillary flow of water rich in salts (curved) and water evaporation (undulating). Salts are symbolized by small lozenges. In a) salt content increases more in BT than in T, whereas in b) the contrary occurs.

4.3 Soil color

Color is an easily determined characteristic that can be related to the chemical or physical conditions of the soil. In our environment the soil has a high gypsum and calcium carbonate content (Figure 8a); these two components together account for more than half of the weight of the soil in 70% of the samples (Figure 8b). This fact in addition to the intermittent bright salt efflorescences made the color of most dry samples much whiter than the available chips for field color description in the Munsell charts. This lack of adequate chips, which has been stressed by Herrero and Schoeneberger (2007), severely limited the recording of soil color. Only two hues (10YR and 2.5Y) were described in the moist and dry soil samples. In spite of the layering (Figure 9), the colors determined in the 0-15 ground samples are light: almost all dry samples have a value between 6 and 8, and a chroma value of 2. At each site the T and BT colors are similar, suggesting a similar bulk composition in spite of the natural discontinuity between them.

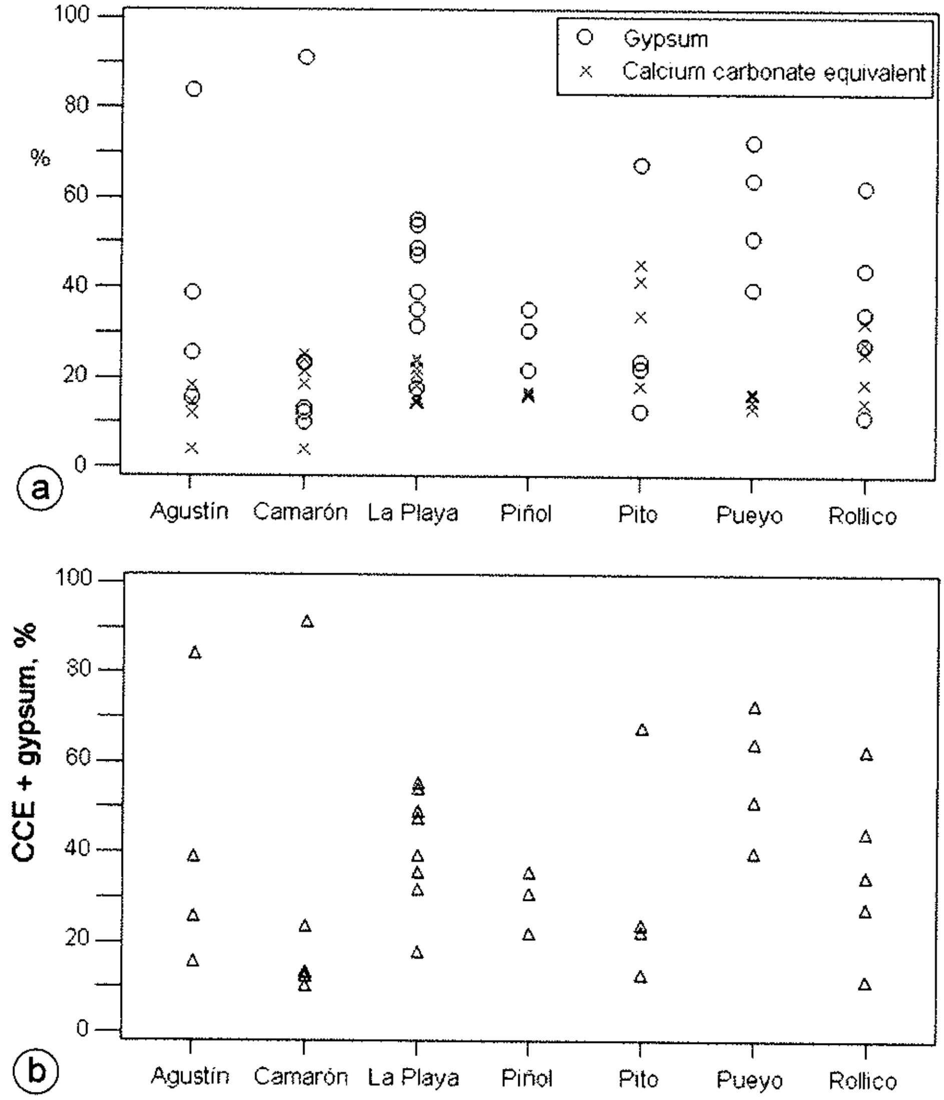

Figure 8. Percent calcium carbonate equivalent (CCE) and gypsum in the seven saladas studied, and sum of CCE plus gypsum. Both computed for the 0-15 cm depth interval.

In most sampling sites a net change of color occurs beneath the upper 5 cm of soil, from a dark highly organic soil to white or pinkish gypseous material. Moreover, frequent discontinuous centimetric bands occur in the upper 15 cm (Figures 9a and 9b). In the bottom of some saladas, a dark layer some cm thick occurs under the soil surface, a sapropel which is evidence of a persistent reducing environment. This sticky material (Figure 9c) is due to a concentration of organic matter (Pueyo, 1978, page 24), often associated with dead roots of *A.m.*

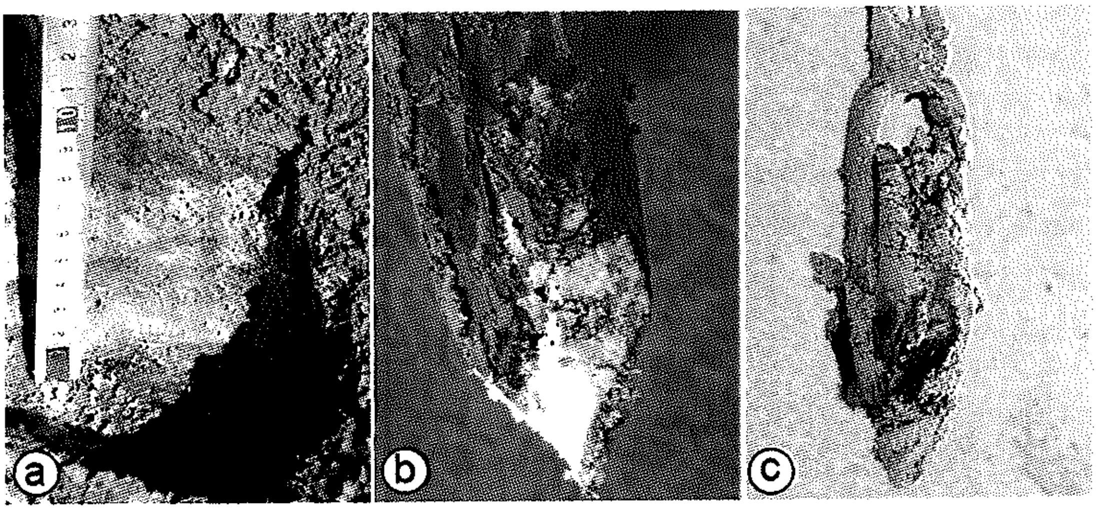

Figure 9. (a): White and pinkish soil underlying a dark surface layer in CMR1. (b): Auger sample with gypsum accumulation (BT layer) in LPL4. (c): sample with sapropel mixed with a brownish BT layer in LPL6.

In the dry season the soil surface has patches of contrasting colors because efflorescences with changing appearances occur either around the plants or associated with microtopographical features. In rainy weather, salts are dissolved and can move downward in the soil; the surface color then becomes more homogeneous and darker, and the texture is sticky. These quick changes in soil appearance, together with the contrasting pale colors of the vegetation in winter and the lively colors in summer, plus the flooding episodes, were summarized in the facies concept by Castañeda et al. (2005).

4.4 Soil temperature and moisture

The general soil regimes of temperature and moisture of Monegros do not to apply to the saladas, because the soils there are often waterlogged or moist, with only an indirect relationship with the weather (Castañeda and García-Vera, 2008). The soil temperatures and moistures recorded at the sites studied show large variations depending on season, time of the day (from 8 a.m. to 4 p.m. in our samplings), and state of the surface. Soil temperature is more variable in the dry season; the range during our sampling dates was 14°C (from 21.6°C to 35.7°C), whereas in the wet season it did not exceed 4°C (from 5.6°C to 9°C). Soil moisture ranged from 4.7% to 29.2% in our July measurements, whereas in December it ranged from 11.0% to 34.7% in spite of the drying effect of the winds. These measurements, though they do not record the winter or summer extremes, suggest the role of water as a buffer for soil temperature.

The duration of each salada survey ranged from less than 1 hour in Piñol and Pueyo to more than 4 hours in La Playa (Table 5), in July. The soil temperature increased throughout the day, especially in July (Figure 10a) from 21.6°C to 35.7°C, with a range of 14.1°C. In December, the soil temperature variation was very low, from 5.6°C to 9°C, a range of 3.4°C.

In some saladas the soil temperature differs from one site to another, in both July and December. Even taking into account the time lag between temperature measurements in each salada (Table 5), there is not a clear relationship between temperature and soil moisture, except in Agustín and at some sites in Camarón and La Playa, in July (Figure 10b).

Table 5. Time lag between the first and the final temperature measurements in each salada.

Salada	Time lag (hours:minutes)	
	July	**December**
Agustín	1:00	0:58
Camarón	1:24	1:00
La Playa	**4:05**	2:28
Piñol	0:47	**0:33**
Pito	2:27	1:46
Pueyo	0:57	0:46
Rollico	1:25	1:09

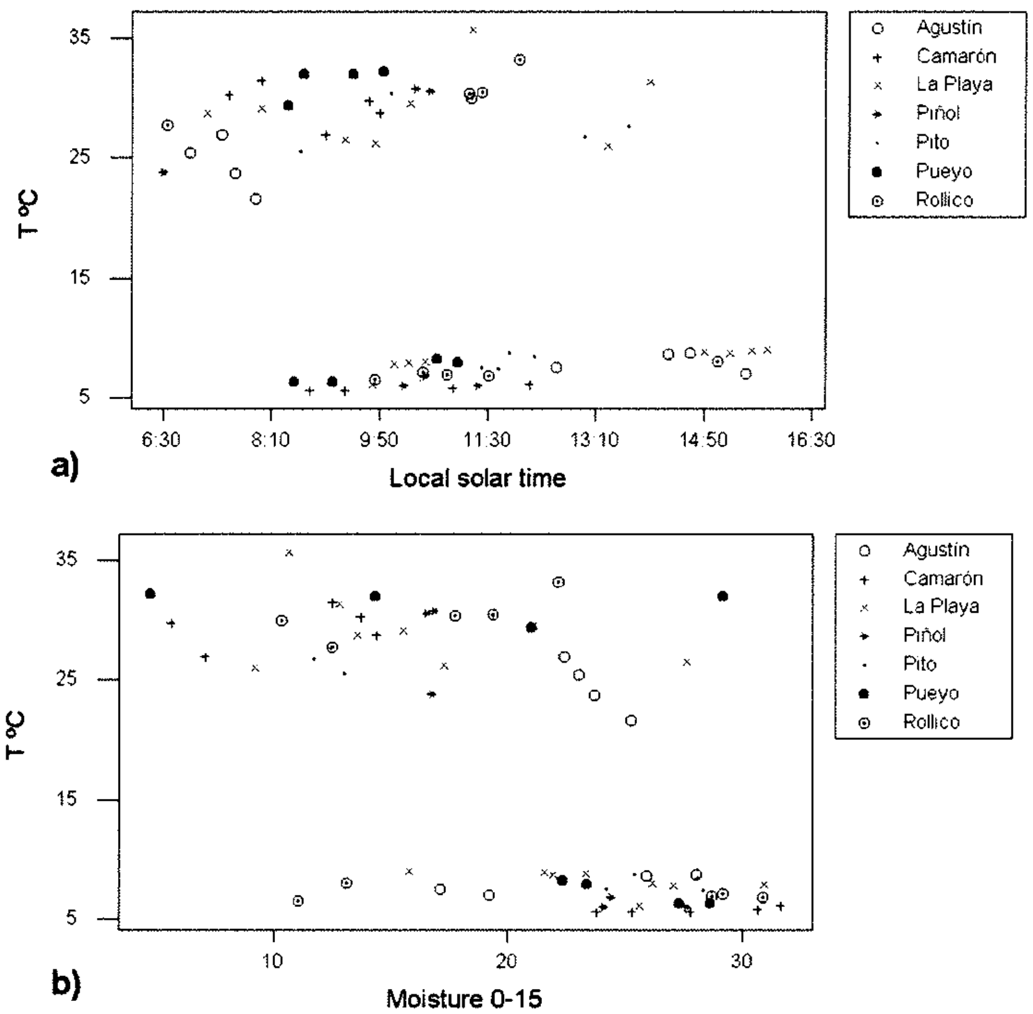

Figure 10. (a): Soil temperature recorded at each site and its solar time, in December (lower series) and July (upper series). (b): Relationship between temperature and gravimetric moisture in the 0-15 cm layer for all the sites.

The distributions of soil moisture for the three sampled depths (Figure 11) show a clear difference between July and December. As expected, this seasonal difference is greater for the T layer. The moisture range in the BT layer is less than in the T layer in both seasons; moreover, the difference between the July and December medians is smaller in BT than in T. The range and median in BT are very similar to those of the 0-15 layer in both seasons. This result stresses the need to sample the upper tessellae separately in order to study the soil conditions for the plants growth, especially for germination.

In July, the T layer attained total dryness while the BT layer retained some moisture, about 5%; the maximum moisture recorded was 38% and 33% for the T and

BT layers, respectively. In December, the T layer had a broad range of moisture, from about 11% to > 50%, even though no rain was recorded in the area; while the BT moisture is more homogeneous, with the smallest moisture range of all computed depth intervals and seasons.

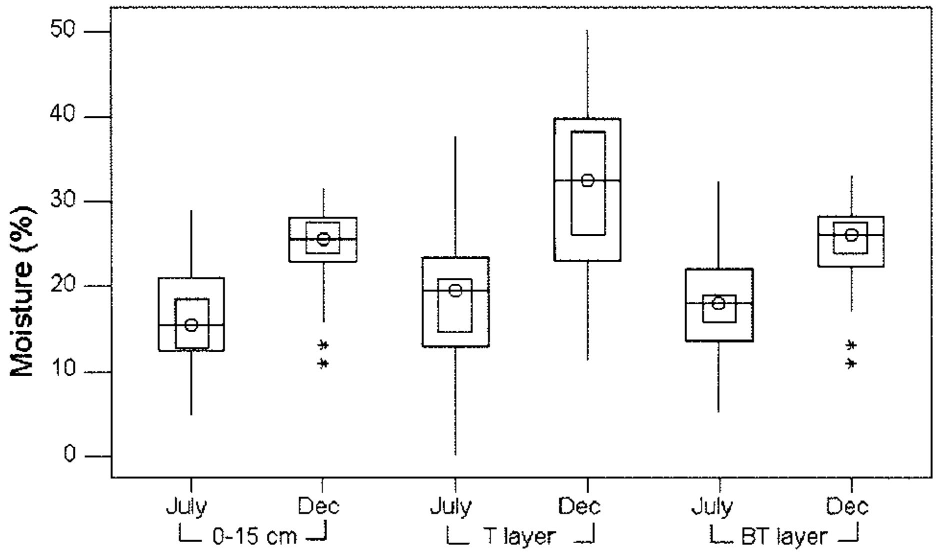

Figure 11. Boxplots of gravimetric moisture measured in July and December for the three sampling depths, 0-15 cm, T, and BT.

The LOWESS lines in Figure 12 show the overall difference in soil moisture between the July and December samplings. As expected, this difference is greater for the T layer (Figure 12a) and much smaller for BT (Figure 12b), illustrating the mulching effect of the T layer. The LOWESS lines for 0-15 (Figure 12c) also show the seasonal difference in soil moisture, but the mulching effect of the T layer remains hidden. The soil moisture of the T layer varies greatly among different sites, even in the same salada (Figure 12a). This variability is similar for July and December, being in December always higher than in July for almost all sites in the three sampling depths. The December moisture of the T layer is lower than the July moisture for two sites of Rollico; of these, only RLL5 retained this difference in the BT layer (Table 6), with no apparent relation with topography or site location.

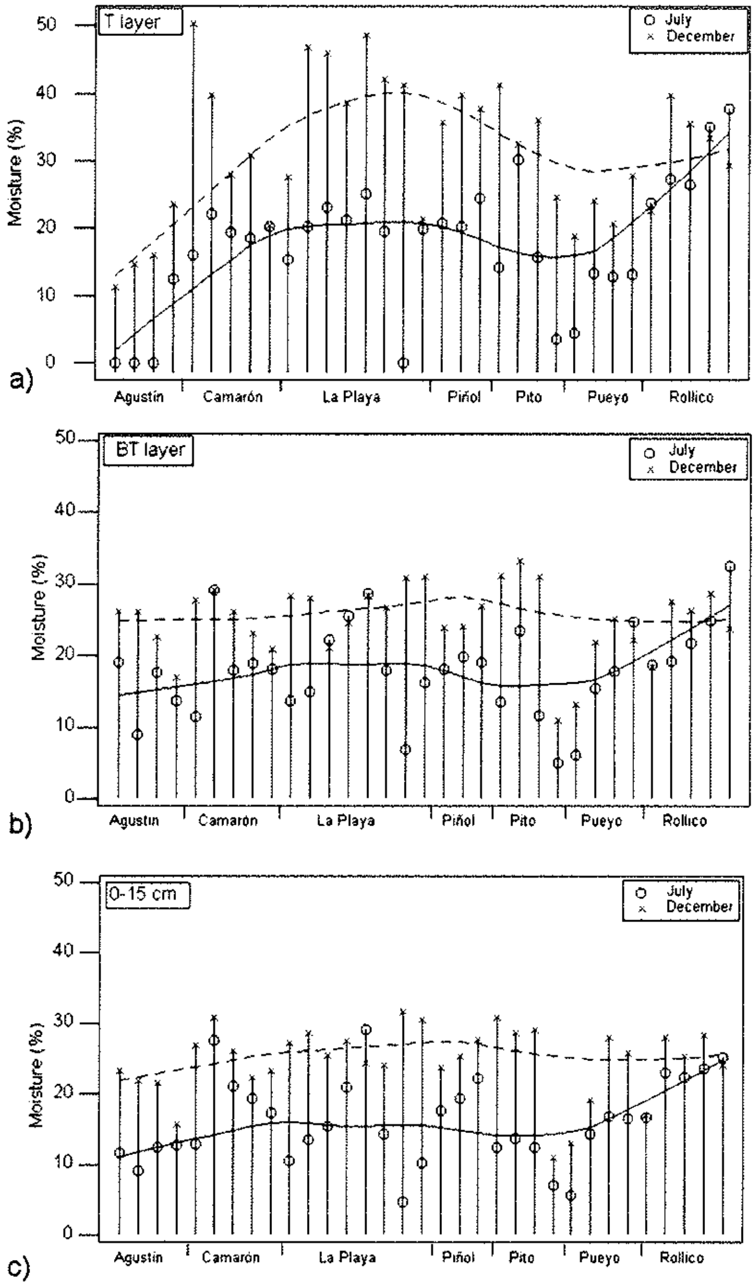

Figure 12. Soil moisture in July and December for the three sampling layers. The solid line curve is for the smoothed July distribution; the dashed line is for December.

In the T layer, the lowest moisture values belong to Agustín and the highest to La Playa and Piñol. LPL6 is the site with the largest seasonal difference, followed by CMR1. However there is no similarity between these sites since CMR1 is located at the salada edge, while LPL6 is far from the salada border. Both sites have relatively low salinity, 3.0 dS m^{-1} and 5.6 dS m^{-1}, respectively, and very low Mg content. CMR1 has gypseous soil (> 90% gypsum) with a 35% *A.m.* density, and LPL6 is bare soil with 54% gypsum.

There is no seasonal variation of moisture in some sites of Camarón, Rollico, and La Playa (Figure 12), and again no common features were observed in their soil composition. At some sites moisture was higher in July than in December (Figure 12), probably due to groundwater discharge. However, a continuous survey would be needed to confirm this hypothesis.

In the Rollico salada, the flattened LOWESS lines of Figure 12b indicate the moisture uniformity between saladas in the BT layer, especially in December. The lack of parallelism and the distance between LOWESS lines reveals the still noticeable influence of summer evaporation at this depth, and the homogenizing effect of winter. The much more undulated LOWESS lines for the T layer (Figure 12a) illustrate the concentration of soil moisture variations in this mulching layer.

Differences in moisture variability between July and December at different depths can be related to surface factors like evaporation and local surface flows, and also to groundwater dynamics associated with the permeability of the highly fractured bedrock and subsurface flows. Rains previous to the field surveys were not a factor in the moisture variability. During the three days before the July survey only 3 mm were recorded, much less than the daily July evaporation. No rains fell in the month before the December survey.

4.5 Soil salinity

Khan and Gul (2002) in their study of the germination of *A.m.* reported the same range of soil salinity (22 dS m^{-1} to 68 dS m^{-1}) and moisture (19% to 33%) measured by Gul (1993, in Khan and Gul, 2002, page 353), though they fail to state the water to soil ratio in which the electrical conductivity and ionic concentrations were measured, hampering comparisons with our data. The same authors, in a laboratory test, refer to the salinity of laboratory solutions as NaCl mM.

Table 6 displays the regression equations of EC1:5 on EC1:10 for the different sampling dates and depths, showing the stability of these relationships along all groupings, and the quality of the EC measurements.

Table 6. Relationship of EC1:5 with EC1:10, both in dS m^{-1}, for different groupings of the soil samples according to data and depth.

Sampling month	Computed depth, cm	No. of samples	EC1:5 = $a + b \times$ EC1:10			
			a	b	R^2	SE, dS m^{-1}
July	All	99	-1.38	1.81	99.5	0.66
December		99	-0.87	1.76	99.4	0.38
July + December		198	-1.21	1.80	99.5	0.54
July	T	33	†-1.11	1.79	99.6	0.92
December		33	-0.78	1.74	99.6	0.38
July + December		66	-1.13	1.79	99.6	0.71
July	0-15	33	-2.04	1.88	99.4	0.44
December		33	-1.14	1.81	99.1	0.35
July + December		66	-1.50	1.83	99.2	0.43
July	BT	33	-1.43	1.81	98.8	0.50
December		33	-1.18	1.80	98.8	0.38
July + December		66	-1.24	1.80	98.8	0.45

Significance levels for all parameters are $p < 0.001$, except for † where $p = 0.001$.

The scatter plot of Figure 13 depicts the relationship between EC1:10 and EC1:5, and the different distribution in the July and December samplings. The maximum EC attained in July is almost twice that in December, in both EC1:5 and EC1:10, in accordance with the high correlation between the two salinity measures (Table 5). The maximum December EC1:10 and EC1:5 did not exceed 13.4 dS m^{-1} and 22.9 dS m^{-1}, respectively, whereas the maximum July values reach 26.9 dS m^{-1} and 46.6 dS m^{-1}. The minimum values are lower in July: 0.4 dS m^{-1} in both soil-to-water ratios.

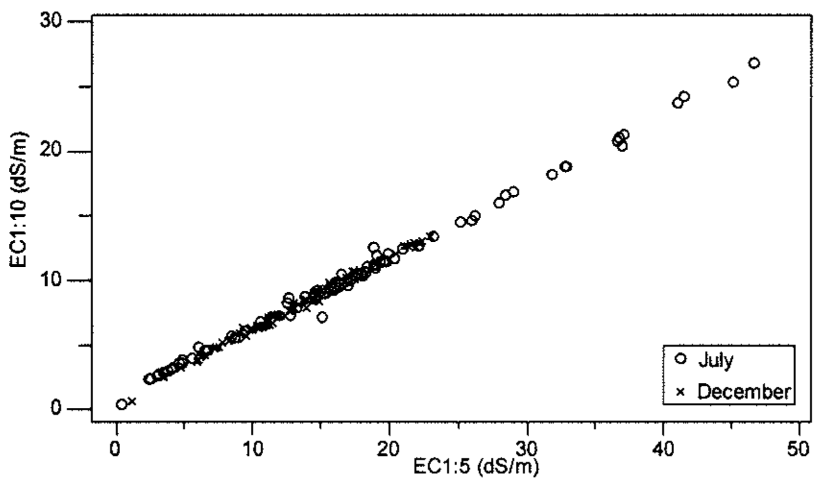

Figure 13. Scatter plot of EC1:10 and EC1:5 for the two dates using all samples.

The matrix of the Pearson product-moment correlation coefficients between EC1:5, EC1:10, and main ions in the 1:10 soil extracts in the 99 samples of July (Table 7) shows the coherence of these determinations.

Table 7. Matrix of correlation coefficients for EC1:5, EC1:10 and several ions in the 1:10 extract. The computed major cations are $Ca^{2+} + K^{+} + Na^{+} + Mg^{2+}$.

	EC1:5	**EC1:10**	**Cl^-**	**Na^+**	**Mg^{2+}**	**SO_4^{2-}**	**$Cl^- + SO_4^{2-}$**
EC1:10	0.998						
Cl^-	0.965	0.962					
Na^+	0.981	0.981	0.927				
Mg^{2+}	0.817	0.828	0.695	0.782			
SO_4^{2-}	0.852	0.863	0.706	0.865	0.938		
$Cl^- + SO_4^{2-}$	0.982	0.987	-	0.969	0.888	-	
Major cations	0.984	0.988	0.915	-	-	0.920	0.994

P = 0.000 for all cases.

NO3- content was not computed because this ion was titrated only in 33 samples (0-15 cm depth) and because it yielded values < 0.20 meq L-1 in all samples but one, which yielded 0.67 meq L-1. These values were deemed negligible in comparison with the other ionic contents. The high correlation coefficient between EC1:10 and EC1:5 suggests that the occurrence of neutral ionic pairs, a major concern with extracts of highly saline soils, is not significant in the 1:5 and 1:10 soil-to-water ratio samples of our soils. This is confirmed by the similar values in columns 2 and 3 in Table 9, i.e., between the ions determined in the 1:10 extracts, and the EC in both extracts. Greater differences are found in Mg^{2+} and SO_4^{2-}, and Mg^{2+} followed by SO_4^{2-} are the ions that yielded the smallest correlations with both EC1:5 and EC1:10. Sodium and chloride are the ions that contribute most to salinity. The high correlation coefficients between ions and EC1:10 allow estimations of individual ions from EC measurements, which will reduce lab workload in future salinity studies of these soils. Our further examination of salinity distribution will be based on EC1:10.

The distributions of EC1:10 for all samples and for each sampled depth are shown split by dates in Figure 14. The first two boxplots illustrate the same distribution as the vertical axis in Figure 13, showing the significant difference between the medians in July and December when all samples are computed. The values > 14.5 dS m^{-1} in the first boxplot of Figure 14 includes the outliers and come from the T layer sampled in July. This sampling (July, T) has the widest range, from 0.40 dS m^{-1} to 26.9 dS m^{-1}, followed by the December sampling of the T layer, which ranges from 0.60 dS m^{-1} to 13.4 dS m^{-1}. As expected, the salinity ranges in BT are smaller than those of the T layer at the same dates, with the difference greater in July. The two last boxplots in Figure 14 show somewhat intermediate values in comparison with the two other depths sampled, again illustrating that relevant information has been lost in the 0-15 cm sampling, which mixes the tessellated horizon with the underlying soil material.

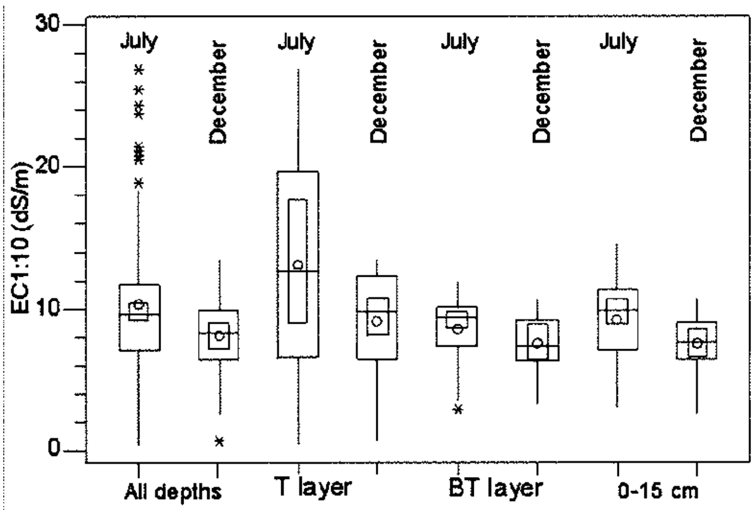

Figure 14. Boxplots of EC1:10 in July and December for all samples, for the T layer, the BT layer, and the 0-15 cm layer.

Figure 15 displays the EC1:10 of the soil samples taken at each date in the 33 sites. Figure 15a shows the strong variability of salinity in T, both at individual sites and in the general distribution, as shown by the wide separation between the two LOWESS lines. Figure 15b shows much less variability in BT both at individual sites and in the general distribution, as shown by the fact that the LOWESS lines are much closer and more parallel than in Figure 15a. The T layer also acts as mulch for salinity, and the overall salinity of BT is very similar in July and December. Finally, the results in Figure 15c are somewhat intermediate, as expected for the 0-15 layer.

Comparison of Figure 15c with 15a and 15b illustrates again the loss of information incurred if soil salinity is reported for the upper soil layer routinely sampled with an auger, a common practice in soil salinity studies focusing on the stock of salts in the soil.

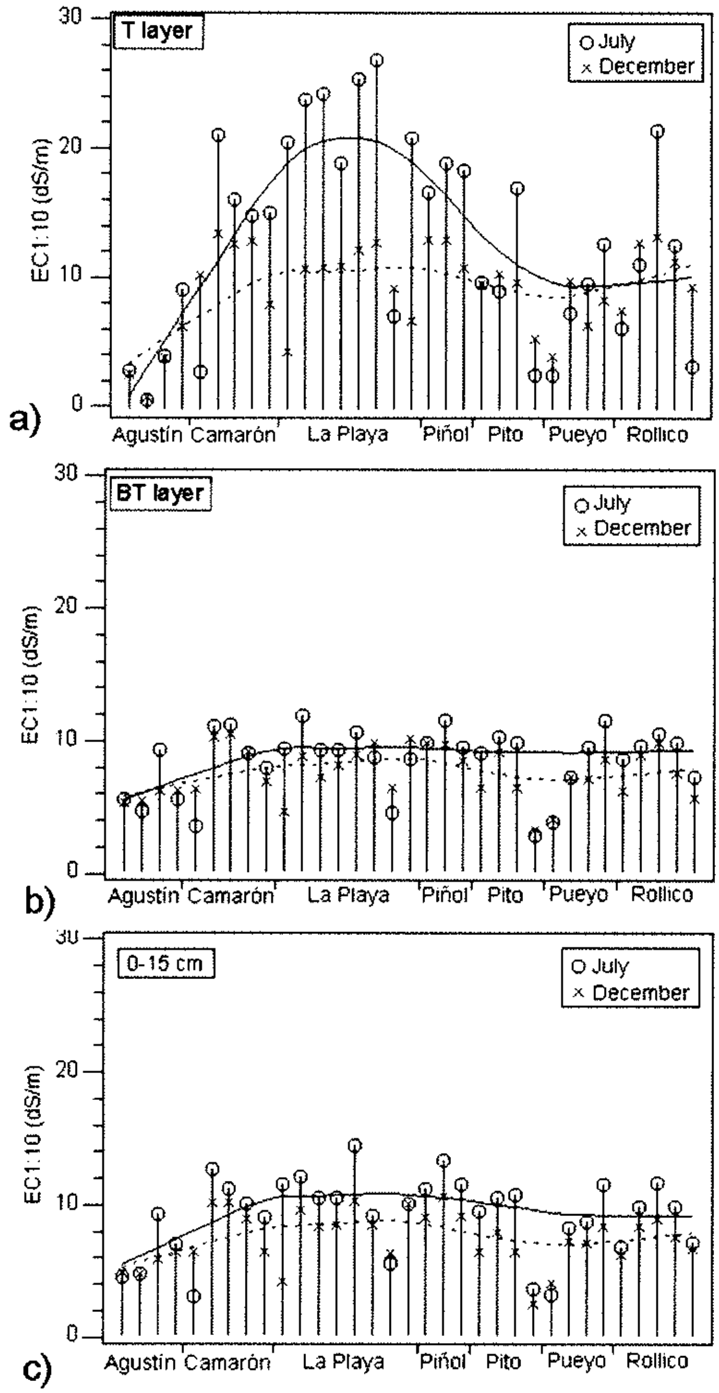

Figure 15. EC1:10 in July and December for the three sampling depths. The solid line curve is for the smoothed July distribution, the dashed line is for December.

The scatter plot of salinity for the layers T and BT (Figure 16) shows that 10 of the 33 points sampled in July have EC1:10 in the BT layer greater than that in the T layer, and these salinities are equal at one point. In December, the salinity of BT surpasses that of T at 9 points. Overall, a third of the sampled points had less salt in the T layer than in the BT layer either in July and December.

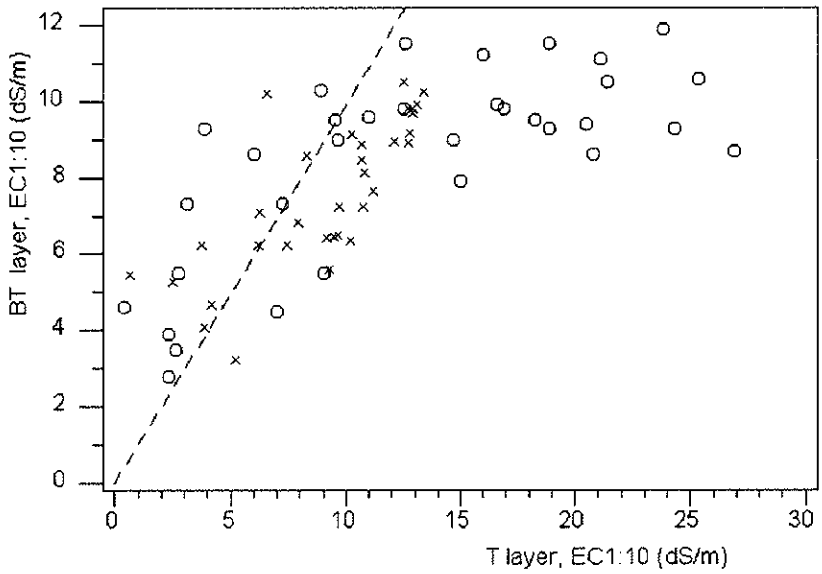

Figure 16. Dispersion diagram of CE1:10 in the BT layer against the T layer in July (circles), and December (crosses). Dashed line is x = y.

Several *A.m.* sites have July EC1:10 > December EC1:10 in the T, BT, or 0-15 layers (Figure 15). The greatest differences in EC1:10 between July and December occur in La Playa (ranging from 8 dS m-1to 16 dS m-1), followed by Camarón, Piñol and Pito. The smallest differences occur in Agustín for all the depths. CMR1, LPL6, and PYO1 are the only sites with higher December EC1:10 for the three sampling depths, with the maximum in Camarón in the T layer, with almost 8 dS m-1.

In general, the July EC1:10 is higher than that in December, as expected. The contrary occurs at ten sites in the T layer (Figure 15a); and at nine sites in the BT layer (Figure 15b). In the 0-15 layer, CMR1 still had lower salinity in July than in December; a very slight difference was also computed for AGU1, LPL6, and PYO1. These differences do not show any relationship with location within the salada or with relative elevation. In the two sampling dates, the tessellae could provide a germination bed which was less saline than BT. The suitability of a layer for seed establishment is also determined by other factors like soil moisture. As an example, at 24 of the 33 sites, December moisture in the T layer is more than 10% higher than July's, and only three sites (RLL1, RLL4, and RLL5) have July moisture higher than December's. Moreover, the higher December moisture is not associated with higher salinity. Of course other factors beyond the scope of this investigation should also be considered.

This seasonal and spatial variability of EC in the different sampling depths shows the variability and unpredictability of soil conditions relevant to plant growth, and especially to germination. This variability can be associated with physical processes like the evapoconcentration of groundwater discharge in the bottom of the saladas, though the influence of biological processes has been not studied. At a metric and decametric scale, "similar" variability of vertical salinity stratification was observed by Samper and García-Vera (1998), and was found to be related to permeability and hydraulic conductivity changes and dissolution processes more than to evaporation.

Variations of soil microtopography due to the modification of the saladas' escarpment, bottom, or dune (lunette), together with changes of land use in their surroundings, affect the hydrology by diverting or concentrating water flows. Due to the close connection of salada habitats with water dynamics, these changes are producing and will continue to produce an adjustment of the saline habitats which was not predicted or considered by those who planned the irrigation and other civil works.

In the field, the T layer often looks like a tessellated horizon with centimetric cracks which end at the underlying BT layer (Figures 6a and 7). Seeds can fall into the cracks which in some circumstances would be favorable environments for germination in terms of temperature, sun exposure, moisture, or salt content. The tessellae can provide a more suitable environment in other moments or circumstances, as is the case if evapoconcentration at the tessellae stopped after the loss of capillary contact with the underlying soil (Figure 7), with greater amounts of salt in the bottom of the centimetric cracks.

4.6 Chemical characteristics

The median pH of the 33 samples from a depth of 0 to 15 cm is 8.77, and ranges from 7.94 to 9.00. The value 7.94 is the only outlier; all of the others are ≥ 8.35, and 20 samples have pH values between 8.70 and 8.90. According to Soil Survey Staff (1996, pp. 618-32), three of these samples are moderately alkaline, and all of the others are strongly alkaline. An inadequate availability of several elements for plants can be surmised, which would increase the salinity stress on plants and other organisms.

Gypsum and calcium carbonate are ubiquitous in the soils of Monegros due to the parent material. All of the *A.m.* sites sampled have similar CCE except AGU4 and CMR1, both of which are in gypseous soils. However, *A.m.* sites differ in gypsum content (Figure 8a), even in the same salada in the T and the 0-15 layers (Figure 17a).

In general, gypsum content in the T layer was lower than in the 0-15 layer on the dates of the survey (Figure 17a), whereas salinity behaves in opposite way (Figure 17b), according to the much lower solubility of gypsum in comparison with the other salts contained in the soil.

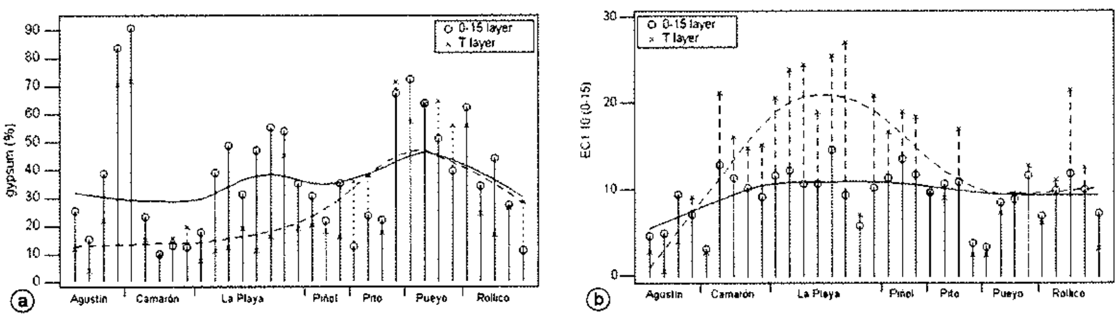

Figure 17. Gypsum content (a) and EC1:10 (b) in July at each *A.m.* site for the two layers: 0-15 (circles), and T (crosses). The curved lines are for the smoothed distributions of the 0-15 layers (solid) and the T layers (dashed).

Sites with gypsum > 70% occur in Agustín (AGU4 = 84%), Camarón (CMR1 = 91%), and Pueyo (PYO1 = 73%), and all of them have *A.m.* with densities < 40%. Their relative locations inside the salada also differ. The Agustín site is located towards the center of the salada, whereas in Camarón and Pueyo these *A.m.* sites are near the edge of the salada, in the northern escarpment and the eastern dune, respectively. Gypsum content, ranging from 10% to 91% in the 0-15 layer, is not related with *A.m.* cover or with total vegetation cover (Figure 18). Coverages of up to 50% of *A.m.* occur over the full range of gypsum content, and only soils with < 40% gypsum reach the denser *A.m.* coverages.

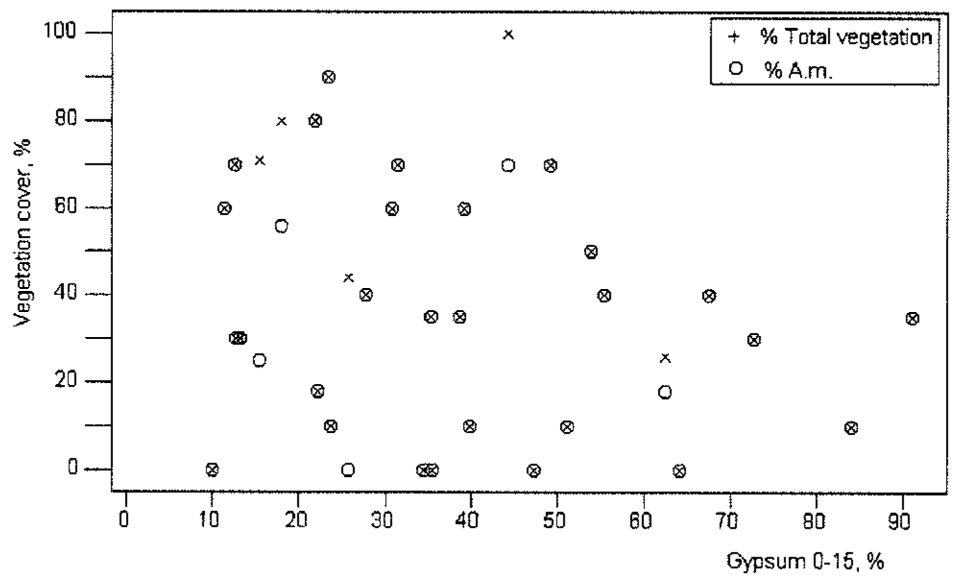

Figure 18. Scatter plot of *Arthrocnemum macrostachyum* and total vegetation coverages on the gypsum content in the 0-15 layer.

The *A.m.* sites of Agustín, La Playa, and Rollico have the highest contents of OM. No relation has been found between OM content and *A.m.* distribution. A close relationship was found (R^2 = 0.94) between OM and N content, with a C/N ratio of 6.8, indicating an advanced humification.

Cl and Na show a high correlation with EC1:10, with r equal to 0.96 and 0.98, respectively (Table 7). The most harmful ions for plants, Cl, Na, and Mg, show higher average contents in the T layer. These ions are the originators of the occasional efflorescences that were sampled with the T layer, as is show by the maximums in Table 8. However, the crystals of the efflorescences do not contribute to the actual salinity of the soil solution. Ion concentrations determined in diluted extracts are valuable for measuring the stock of salts, but less reliable as measures of the true stress supported by organisms, a classic problem in soil science.

Table 8. Maximum and mean values of Cl^-, Ca^{2+}, K^+, Na^+, Mg^{2-}, SO_4^{2-} (meq L^{-1}) in 1:10 ratio soil:water extracts of the T and BT layers in July.

Ion	T		BT	
	Max.	Mean	Max.	Mean
Cl^-	182.0	89.3	82.4	54.0
Ca^{2+}	50.7	33.9	41.8	35.7
K^+	5.9	2.6	3.6	2.4
Na^+	258.8	84.8	75.7	54.4
Mg^{2+}	140.8	39.3	67.4	21.4
SO_4^{2-}	236.4	81.7	108.6	65.2

Maximum values of Mg occur in the *A.m.* sites of Agustín and Piñol, and maximum SO_4 in Agustín and La Playa. In July, Agustín soil samples indicate that Mg, SO_4, Na, Cl accumulate in BT. Conversely, salts concentrate in the T layer in Camarón, La Playa, and Pito. In Pueyo and Rollico it depends on the site. The variable composition of soil in the *A.m.* sites sampled is comparable to the variability of playa-lake brine for major and minor elements (Pueyo, 1979). Variation in the physical and chemical characteristics of groundwater was also reported by Samper and García-Vera (1998), even over short distances. Moreover, as calcium carbonate and gypsum are the major components of most of the soils in the saladas (Figure 8), the capacity for ion retention is very low, allowing quick changes in soil solution composition by brine inundation or by rain. This can explain why bare soil sites (CMR3, LPL4, LPL6, and PYO2) did not show, at least during our samplings, physical or chemical characteristics that were unsuitable for *A.m.* growth or different from those of *A.m.* sites. The same reasoning can explain why sites like CMR1 (91% gypsum 0-15), PTO4 (68% gypsum 0-15) and PYO1 (73% gypsum 0-15) have low salinities (EC10 from 3.0 to 3.6 dS m^{-1}), but *A.m.* coverages ranging from 30% to 40%.

The Shoeller-Berkaloff diagram (Figure 19) illustrates again the similarities and differences between all of the *A.m.* sites based on the ionic content of 1:10 soil extracts in July. Almost all of the sampled soils can be grouped in the upper part of the diagram, with a moderate range for all of the analyzed ions. Mg is the most variable component of this homogeneous group. In the lower part of the diagram, seven *A.m.* sites are distinguished from the group by their less saline T layer. Salt content variability is lower in the BT layer. Almost the same sites that differ by their T layer composition also differ in their BT layer, though these divergences in composition are less marked.

In the T layer, La Playa has the highest salt content of all sites, including bare soil; in general, the Agustín sites differ from the rest, in one layer or in both (T and BT). PYO2, PTO4, CMR1, stand out for their low salinity, with less variability in BT. These three sites have high gypsum content and low moisture, and thus support the association of fast changes in salt content with high gypsum content.

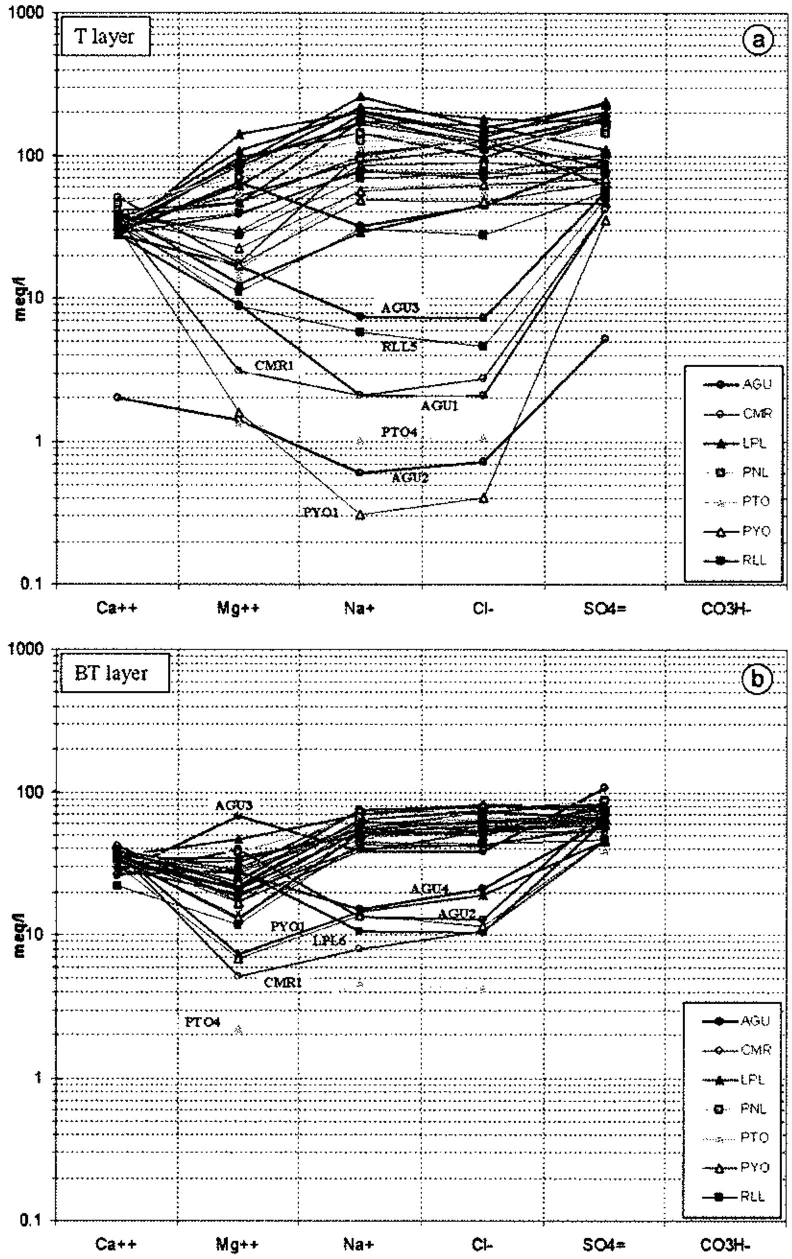

Figure 19. Schoeller-Berkaloff diagrams of each sampling site for the T (a) and BT layers (b). Only sites with divergent composition are labelled.

4.7 *A. macrostachyum* distribution and soil characteristics in each salada

In this section we portray the *A.m.* distribution in each salada in relation with topography and sampling site location, soil moisture, pH, salinity (CE1:10 dS m^{-1}), OM, gypsum, and relevant ions.

4.7.1 Agustín

This is the only salada studied with an *A.m.* habitat that extended over the central part of the bottom, though with differences in density. The *A.m.* habitat is the most important in terms of surface extent, similar to that in La Playa and Camarón (Table 4). Along the studied transect, *A.m.* density increases from AGU1 to AGU3 as pH and topography decrease. Then, *A.m.* density decreases at the inner site, AGU4, also highly saline but more often flooded and with high gypsum content. Maximum *A.m.* density occurs where salinity, Mg, and SO_4, are high.

In this salada *A.m.* soil reaches the maximum values of OM, Mg, and SO_4 of all of the samples analyzed. Moisture is relatively low, but is higher in the inner sites, and does not have a continuous gradient along the transect.

4.7.2. Camarón

The *A.m.* habitat, 65% of the vegetation cover, is restricted to the escarpment and northern salada fringe (Figure 4b), and has been degraded by stone dumping in the southern area. The variation of *A.m.* density towards the center of the salada differs between the NW-SE and N-S transects: it decreases along the former but increases along the latter. This difference cannot be attributed only to the elevation range, which is lower in the N-S transect (Figure 20). The differences in soil composition are attributed to the different rocks outcropping along the escarpment.

In the N-S transect, CMR1 soil has half the moisture of CMR2 and > 90% gypsum, the highest gypsum content of all the sites sampled, contrasting with the low gypsum content of the *A.m.* soil along the NW-SE transect. CMR1 is the only site with inappreciable Mg; moreover, it has the lowest salinity (3 dS m^{-1}) and OM of all the sites sampled. This composition contrasts with its vegetation density (50%) and 35% of *A.m.* cover. Soil moisture always increases towards the center of the salada.

4.7.3. La Playa

The vegetation surface extent is only 20% of this playa-lake (Table 4), with one of the highest percentages of *A.m.* habitat. Soil moisture in *A.m.* sites does not show a direct relationship to the microtopography (Figure 20), but rather to the proximity to the northern channel (Figure 4c). From the two bare soil sites sampled at the mouth of the channel, LPL4 stands out with the highest moisture and salinity of all sites sampled, and also a high K content attributable to runoff from cultivated lands. Meanwhile, the nearby LPL6 has the lowest salinity of all La Playa sites, 5.6 dS m^{-1}, and a noticeably lower level of Mg. Annual halophytes (*Halopeplis amplexicaulis*) occasionally pioneer this barren area.

A.m. reaches its maximum extent and density along the northwest edge of the salada, opposite the more frequently inundated area to the east. Gypsum content ranges from 18% to 56% and increases to the east, from LPL0 to LPL6. OM decreases in the same direction, while the density of *A.m.* does not show a direct relationship with these gradients or with topography (Figure 20). Probably factors such as microrelief, runoff and sediments entering through the channel, plus stone dumping and shepherding, provide different textural, chemical and hydrological conditions along the studied edge, resulting in a variety of subenvironments for *A.m.* growth.

4.7.4. Piñol

Vegetation extent is small, only 5 ha, mostly restricted to the salada escarpment; the northern road invades the edge of the salada, affecting the vegetation and water flows. Nonetheless, *A.m.* reaches a significant density, surpassed only by that in Camarón. The three sites sampled have the highest pH values of all sites, with the maximum in PNL1 (pH = 9), and a relatively homogeneous composition: OM ranging from 1.18% to 1.32%, very high salinity, and medium-low gypsum content. The maximum percent of *A.m.* coverage, 80%, occurs in PNL2, where SO_4, Mg, and salinity are maximum (13.4 dS m^{-1}), and gypsum is minimum, about 20%.

4.7.5. Pito

The vegetation covers about 55% of the salada, the highest percentage of the playa-lakes studied after that in Agustín. However, *A.m.* habitat is only 28% of the vegetation surface extent, the lowest percentage (Table 4), with a medium-low density, between 10% and 40%.

The sites PTO1 to PTO3, which are aligned along the southwestern edge (Figure 4), have similar soil compositions, with an average soil moisture of about 13%, 8.67 pH, and salinity of 10.3 dS m^{-1}. The increase in *A.m.* density in PTO1 coincides with a more moist area and very vigorous clumps. In PTO3, Mg is twice that in PTO1, and the site has the highest elevation but not the lowest *A.m.* density (18%) and clumps smaller than in PTO1.

The maximum *A.m.* coverage of this salada, 40%, occurs in PTO4, at the eastern edge (Figure 21). This site differs from the other sites sampled, with half of the average moisture, low salinity (3.6 dS m^{-1}) and Mg content (4.5 meq L^{-1}); meanwhile the gypsum content is high, up to 70%, contrasting with the average of southwestern *A.m.* sites, < 20%.

4.7.6. Pueyo

Vegetation occupies 50% of the playa-lake surface and *A.m.* habitat is 53% of the vegetation cover. The sites sampled here, even if located on opposite edges (Figure 4g), show the smaller elevation range (Table 2) which indicates the extreme flatness of the playa-lake surface. The soil composition of bare soil site, PTO2, does not differ from that of the vegetated sites. Mg increases and gypsum decreases in the western edge, between PYO3 and PYO4, though the density of *A.m.* cover does not change.

Much as in Pito, in the eastern site of Pueyo, in PYO1, the maximum *A.m.* cover (30%) coincides with the lowest salinity (3.2 dS m^{-1}), K^+, and Mg^{2+} percentages, and high gypsum (> 70%). These eastern sites, PTO4 and PYO1, also have in common a very low soil moisture, 7.1% and 5.6%, respectively. In contrast, maximum *A.m.* cover occurs at the highest elevation in Pueyo and at the lowest elevation in Pito.

4.7.7. Rollico

A.m. habitat is about 71% of the total vegetation extent, the maximum of all the playa-lakes studied (Table 4). Together with La Playa and Camarón, the Rollico sites display a great variability of *A.m.* densities, and include an area with 100% vegetation cover.

The soil composition of the five *A.m.* sites sampled, which are in a line along the northeastern edge of the salada (Figure 4), shows two different gradients: one is unidirectional and other is symmetrical with respect to the central site, RLL3. Soil moisture, OM, and gypsum show a unidirectional pattern whereas salinity has a symmetrical pattern, perhaps more related to topography (Figure 20) and inundation frequency.

Soil moisture ranges between 17% and 25%, increasing to the north together with OM; gypsum decreases to the north from about 63% to 12%. A vegetation density of 100% and 70% *A.m.* cover occur in the middle, RLL3, together with minimum pH, and maximum salinity, about 12 dS m^{-1}, K^+, and Mg^{2+} content, 3.4 and 38.8 meq L^{-1}, respectively. In July the brine almost reached the site, but its several decimeters of elevation above the waterlogged bottom and the gypsum content probably favor the halophytes.

4.8 Patterns of *A. macrostachyum* occurrence across the saladas studied

We have not found a regular or systematic pattern in the spatial arrangement of *A.m.*, its density of cover, or the soil properties analyzed. In general, *A.m.* density and plant size decreased with distance to the salada border and with the occurrence of runoff channel outlets. Different *A.m.* densities can be found at the lowest topographic positions (Figures 20 and 21).

No gradient of pH was observed from the border to the bottom of the salads, or related to *A.m.* cover. pH increases along the Agustín transect but decreases slightly along the Piñol and Pueyo transects, and along the N-S transect of Camarón.

Soil moisture increases from the border to the bottom in Camarón, Agustín, and Pito. In Rollico, moisture increases towards the north; in La Playa moisture increases to the east and especially at the runoff channel mouth. Salinity and OM increase with moisture; also Mg increases with moisture, except in Agustín, which stands out for its high Mg content, followed by Piñol. The broadest range of soil moisture occurs in La Playa, whereas Agustín and Pito have the smallest moisture range and the minimum values.

There is no clear relationship between *A.m.* density and differences in OM content. The OM content of bare soils differs between saladas, ranging from 0.32% to 1.35%. The highest percentages occur in Agustín and La Playa (LPL0), in livestock paths.

Soils with maximum *A.m.* percent cover are rich in Mg (above 40 meq L^{-1}) in Camarón, La Playa, Piñol, and Rollico. AGU3 is an exception, with a medium density of *A.m.*, 35%, and maximum Mg (and also SO_4). High *A.m.* density, > 70%, occurs in soils with low gypsum, ≤ 50%. At the only site with 100% vegetation cover (RLL3, 70% *A.m.* and 30% *Suaeda vera*), gypsum is about 45%. High *A.m.* cover is associated with high salinity, between 10 dS m^{-1} and 13 dS m^{-1}, and SO_4, from 50 to 100 meq L^{-1}.

Gypsum-rich soils, > 50%, have *A.m.* cover ≤ 40%. Within each salada, the relationship between gypsum and maximum *A.m.* cover differs. At Camarón, La Playa, Piñol, and Rollico, maximum *A.m.* matches maximum salinity and low gypsum content; the contrary occurs in Pito and Pueyo, with medium *A.m.* density and gypsum > 70%. These discrepancies may be related to the effects of gypsum on the soil's hydrologic properties and ion retention.

A.m. sites with salinity > 10 dS m^{-1} have densities ≥ 70%, moisture between 10% and 30%, and gypsum content < 50%. Moreover, *A.m.* plants grow in nebkhas, creating a microtopography which provides subenvironments differing in moisture and salinity from the surrounding soil.

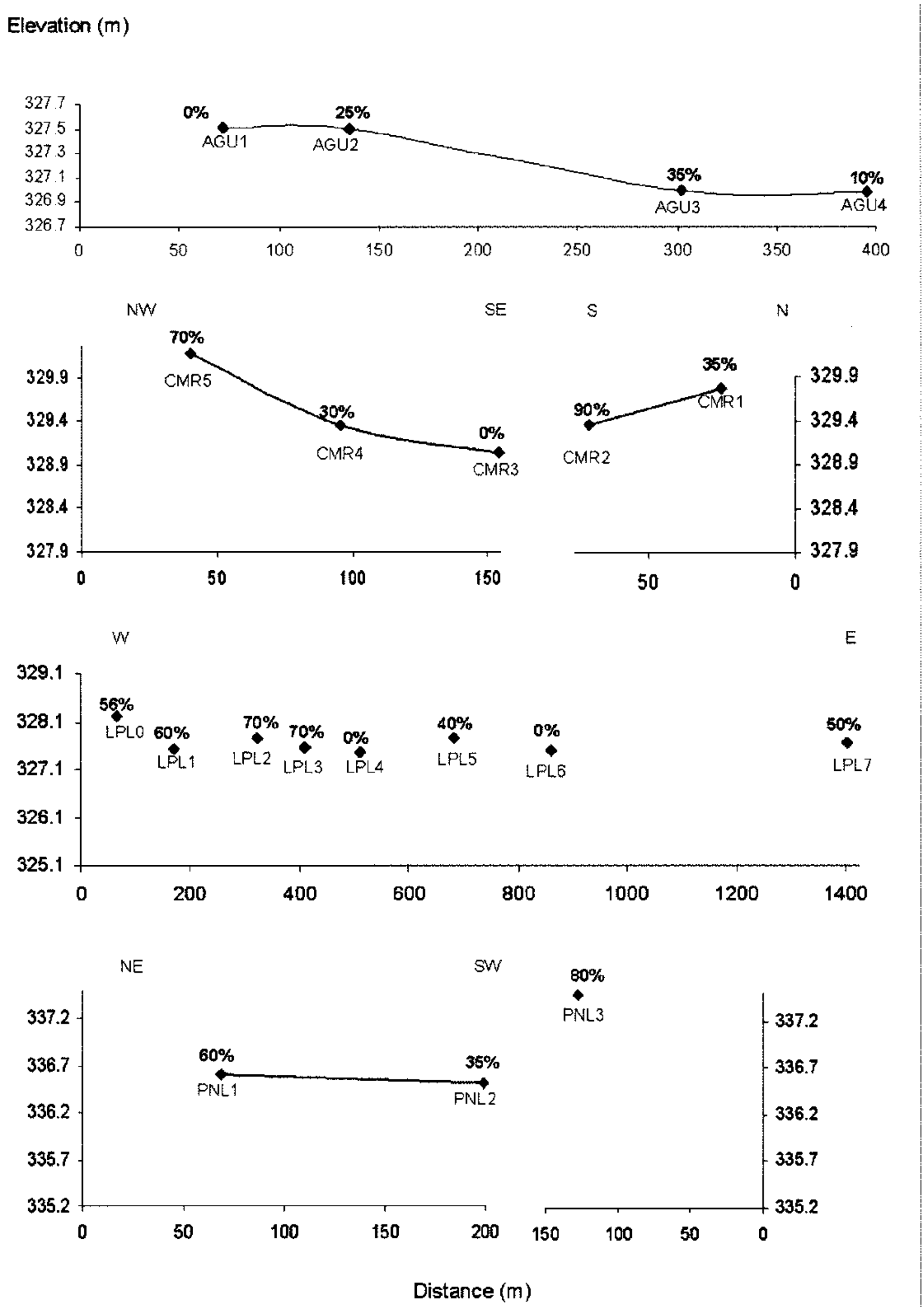

Figure 20. Transects (solid line) and randomly sampled points, with their elevations and distances from the salada edge, and the *Arthrocnemum macrostachyum* percent. The minimum Y-axis value is the elevation of the salada bottom. See Table 2 for the saladas' names.

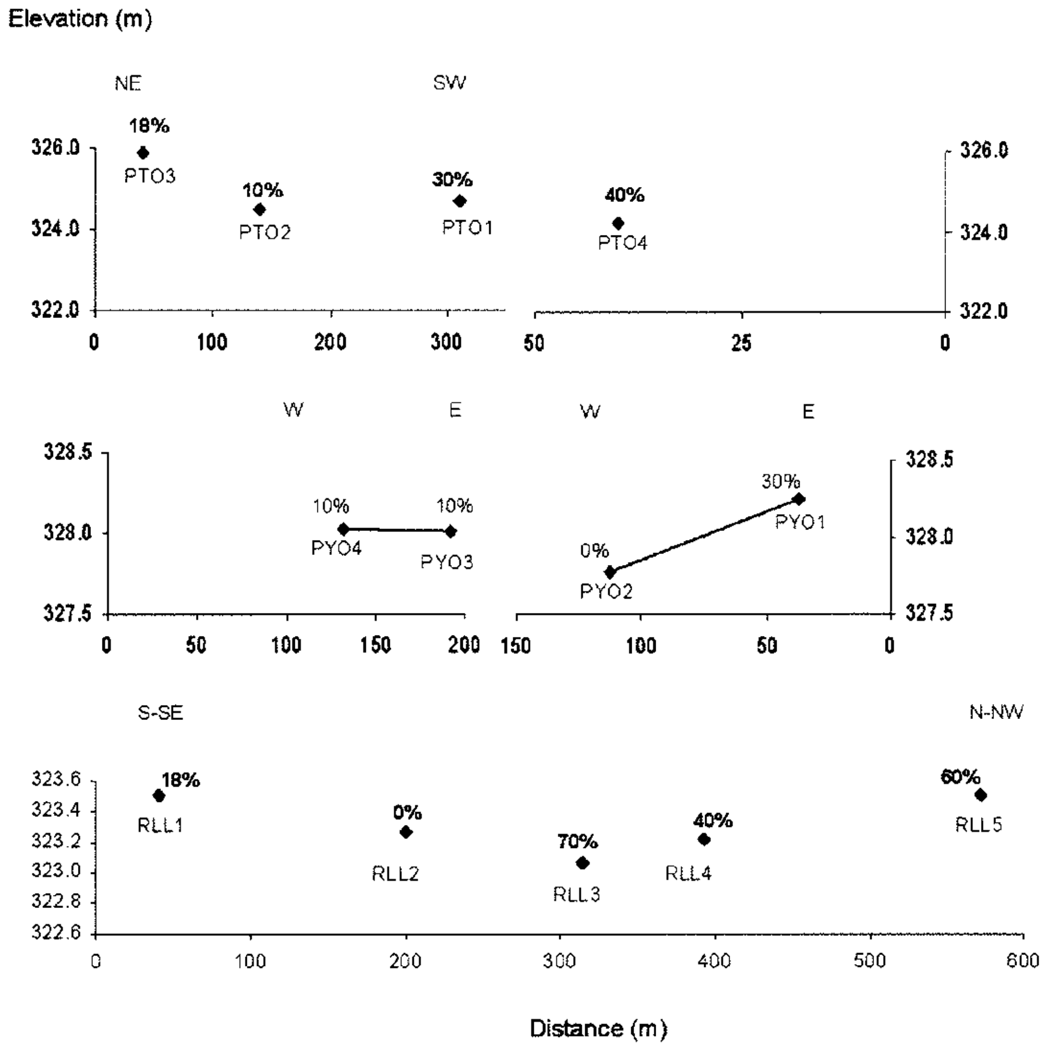

Figure 21. Transects (solid line) and randomly sampled points, with their elevation and distance measured from the salada edge, and the *Arthrocnemum macrostachyum* percent. The minimum Y-axis value is the salada bottom elevation. See Table 2 for the saladas names.

5. CONCLUSIONS

The playa-lakes studied, intermittently waterlogged with salty water, are suitable environments for *Arthrocnemum macrostachym.* The field survey has provided new information about the soils of *A. macrostachyum* and their seasonal variability. The different conditions of salinity and moisture in the tessellated top soil and the underlying soil layer have been studied for the first time, and have been confirmed by lab analyses. The findings of this study, conducted on seven representative saline wetlands, go beyond the soil salts stock approach, and are especially relevant for the knowledge and protection of these unique wetlands which are of high ecological interest.

A.m. lives on soils that show a wide range of conditions in salinity, moisture, and mineral composition and these conditions vary among sites, saladas, seasons, and soil depths. The distribution of *A.m.* density along the fringes of the saladas shows a complex relationship with the distance to the salada border, the microtopography, and the local hydrology. All these factors influence moisture and salts availability for plants.

The EC of 1:10 soil-to-water extracts is a good predictor of major ion content. In general, maximum *A.m.* density occurs in highly saline soils with low gypsum content, high Mg, and variable moisture. The mulching effect of the T layer is illustrated by the greater seasonal variability of moisture and salinity in comparison with the BT layer; this result also stresses the importance of sampling the upper tessellae separately to know the soil conditions for plantules. The upper tessellate horizon is usually more saline in July than December; however, the T layer offers a wider range of salinity, including some sites with less salinity than in BT.

The peripheral environments of playa-lake bottoms are variable and complex. The differences found in soil composition, based upon major ions, do not seem to be decisive for *A.m.* distribution. Physical soil characteristics, salinity and moisture are probably important enough to overcome chemical differences. Moreover, the effects of brine- or water-logging frequency and duration are not well known for soils very rich in gypsum and calcium carbonate. This makes it difficult to model the relationships of salinity and other soil characteristics with *A.m.* density and distribution.

If soil salinity studies are to be used by botanists to assess the conditions of seed germination, it is essential to observe the differences in salt content between the available substrates for germination. Germination in the cracks or on the tessellae could provide different survival probabilities that could themselves be related to the seed dimorphism of some halophytes. We hope that this hypothesis will inspire field or pot trials or at least lab experiments mimicking the soil surface.

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CHAPTER 5. Spectral characterization of the surface conditions in the saline wetlands of Monegros, NE Spain

1. INTRODUCTION

A goal of European Habitats Directive is to protect the biodiversity through the conservation of habitats (Council Directive 92/43/EEC). This task requires data about the distribution of habitats and their conservation status. The Earth Observation Techniques can provide useful data for mapping habitats (Keramitsoglou *et al.*, 2005; Boyd *et al.,* 2006; Kobler *et al.*, 2006) and assessing the vegetation cover (Wang *et al.*, 2004; Xiao and Moody, 2005; Wang *et al.*, 2007).

Remote sensing has been used to estimate the vegetation changes (Adams *et al.*, 1995; Elmore *et al.*, 2000; Roberts *et al.*, 2002; Camacho-De Coca *et al.*, 2004; Schmid et al., 2005; Adamo and Crews-Meyer, 2006), to monitor desertification processes (Collado *et al.*, 2002; Awad-Khiry, 2007; Khaznadara and Griffiths, 2008) and to assess wetlands degradation (Schmid *et al.*, 2004; Castañeda and Herrero, 2008).

Although the availability of very high-resolution satellite imagery has increased, a large number of studies quantify the vegetation cover by means of vegetation indexes based upon Landsat images and field surveys (Ishiyama *et al.*, 1997; Elmore *et al.*, 2000; Xiao and Moddy, 2005; Guerschman *et al.*, 2009). Duchemin *et al.* (2006) showed that the improvement of spatial resolution of Quickbird images resulted in a better relation between satellite and field data, compared with Landsat images. Quickbird images offer a good option for plant cover estimation (Laliberte *et al.*, 2005) and vegetation mapping provided their high spatial resolution (Kobler *et al.,* 2006). However, their spectral range, restricted to the visible and near infrared, limits the study of plant cover, for which the difference between near and middle infrared is crucial (Chuvieco, 2002).

Vegetation indexes such as NDVI (Normalized Difference Vegetation Index) and classification techniques are used to map vegetation though they seem not useful in sparsely vegetated areas (Huete *et al.*, 1984, 1985; Ustin *et al.,* 1986; Escadafal and Huete, 1991). In these conditions, satellite data include the soil background, resulting in a mixture of soil and vegetation in different proportions and geometries (Adams et al., 1993). To overcome this difficulty, other techniques such as Linear Spectral Mixture Analysis approach (LSMA) have been used to classify multispectral and hyperspectral satellite imagery (Ustin *et al.*, 1999; DeFries *et al.*, 2000; Theseira *et al.*, 2002; Lu *et al.*, 2003). Laliberte *et al.* (2004) combined object analysis and segmentation of aerial photos to study the changes of the vegetation cover in New Mexico during a long period. Similar techniques are applied to determine the percent cover of green fraction, senescent vegetation, and bare soil from digital ground photographs giving good results to classify the vegetation cover of satellite images, and to determine changes over a period (Jonckheere *et al.*, 2005; Laliberte *et al.*, 2007).

Several efforts have been made to establish a relationship between satellite data and vegetation cover, type, and phenological state (Smith *et al.*, 1990; Zhang *et al.* 2007). Glenn *et al.* (2008) established the relationship between the vegetation indexes of the canopies extracted from high-resolution aerial images (pixel of 0.3 m) and the fractional vegetation cover of species with different leaves in shapes and angles. Results showed that the fraction of green cover could be estimated through aerial photography or directly by field measures, despite the LAI variations among species and along the growing season. Maas (1998) studied the effect of the camera point of view on the reflectance of the vegetation, observing a decrease of reflectance as the shadow between plants increases.

Mapping and estimating vegetation cover in arid areas could be difficult due to the characteristics of the vegetation and the reflectance of soil background (Huete *et al.*, 1985; Huete and Jackson, 1987; Smith et al., 1990; Escafadal and Huete, 1991; Elmore *et al.*, 2000). Todd and Hoffer (1998) studied the specific influence of soil background reflectance to estimate the vegetation cover. Frequently, vegetation cover is overestimated because the high reflectivity of the soil (Xiao and Moody, 2005) masks the weak spectral response of sparse vegetation. Huete *et al.* (1985) and Elmore *et al.*, (2000) analyzed the influence of soil brightness in the NDVI at low percent cover of vegetation. Montandon and Small (2008) showed that NDVI of soils is often underestimated in areas with sparse vegetation, resulting in overestimation of the vegetation fraction. These authors suggested local estimations of NDVI for soil and vegetation avoiding the use of global values.

The aim of this work is to develop a methodology for the monitoring of the vegetation associated to the saline wetlands of Monegros using remote sensing. For this purpose, we study the spectral characteristics of soils and vegetation and we establish the relationship between green cover and spectral data collected using both satellite and proximal sensors.

2. STUDY AREA

Sebkha is a suitable term to designate some of the saline wetlands of the south of Monegros. They are playa-lakes and close saline depressions scattered in an agricultural landscape in central Ebro basin (NE Spain). Tens of saline wetlands are located between latitudes 41° 31' 15" N and 0° 16' 38", an almost flat area ranging from 320 m to 417 m a.s.l. The inventoried wetlands occupy about 1600 ha (Figure 1).

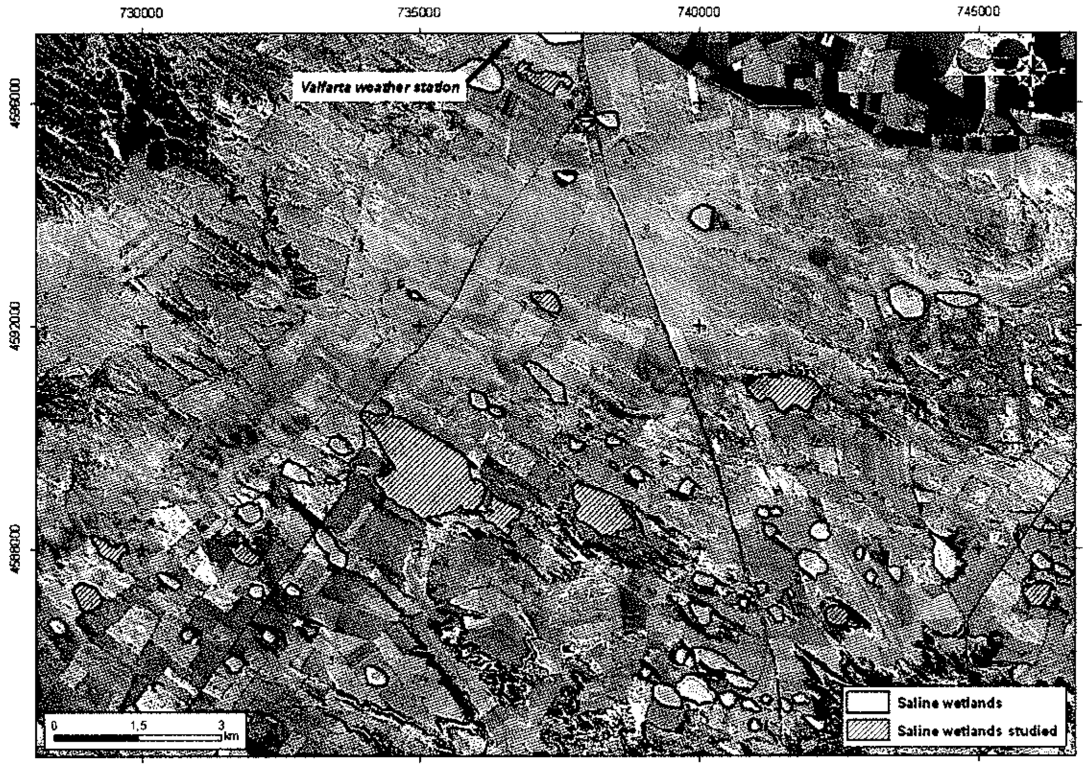

Figure 1. The saline wetlands studied in 2007and 2008 are highlighted on orthophotographs of 2006. The currently irrigated land is in dark green in the northeast.

The climate is Mediterranean-continental and the area is one of the most arid regions in Europe (Herrero and Snyder, 1997) due to the rains scarcity and irregularity. Summer is the season with maximum temperature and minimum rainfall. The mean monthly rainfall from January 2007 to August 2008 was 27.8 mm, with the minimum in September 2007 (0 mm) and the maximum (130 mm) in May 2008 (Figure 2). The minimum temperature, reached in January 2007, was -10.2 °C; the maximum, 38.3 °C, was reached in August 2007. The summer temperature was higher in 2008.

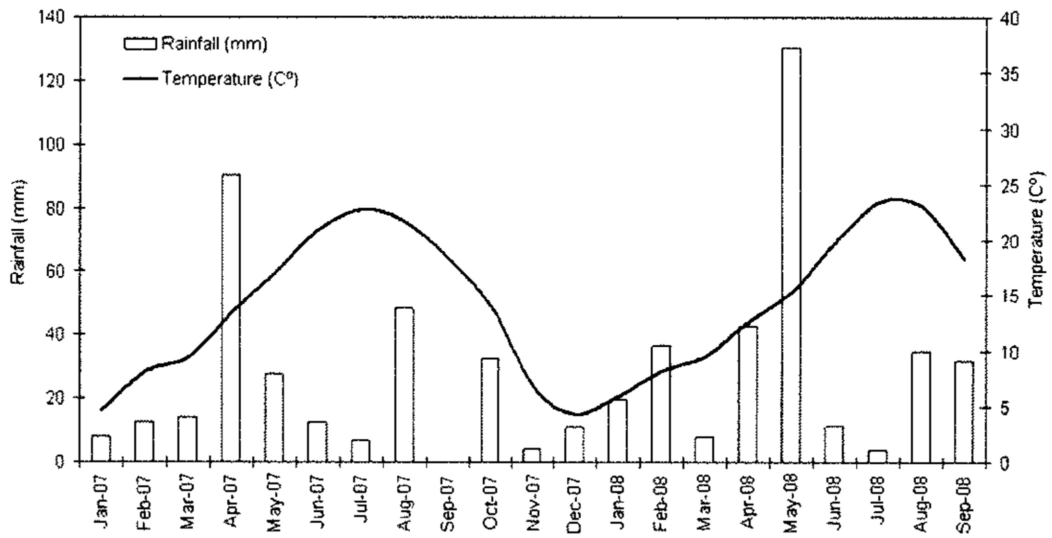

Figure 2. Monthly rainfall (bars) and temperature (line) from January 2007 to September 2008.

Saline wetlands are connected with hypersaline aquifers (Samper and García-Vera, 1998; Castañeda and García-Vera, 2008) and undergo drought, waterlogging, and high salinity, crucial factors in the distribution of the vegetation (Pennings and Callaway, 1992). The vegetation, restricted to the borders of the saline wetlands, spreads out in fringes conditioned by the soil microtopography, moisture and salinity. The percent cover of vegetation is heterogeneous and includes patches of sparsely vegetated areas, densely vegetated spots, and bare areas, which exhibit frequent changes of soil surface appearance.

The vegetation includes endemic species and habitats protected by European laws. The most prominent halophytes are *Arthrocnemum macrostachyum* (Figure 3a) and *Suaeda vera*. Gypso-halophytic vegetation (*Lygeum spartum*) occupies high topographic positions, in the escarpments of the depressions, whereas halo-nitrophilous vegetation (*Salsola vermiculata*) can appear in the bottom. Annual halophytes such as *Halopeplis amplexicaulis* frequently pioneer the bottoms. The plants appearance depends on their phenological state and the previous rains; their greenness is always darker than that of surrounding crops.

The soil surface is prone to frequent changes due to the occurrence of water, algal mats, efflorescence and salt crust (Figure 3b). Organic matter, moisture, and composition are the main factors affecting soil color (Kondrateyev and Fedchenko, 1983).

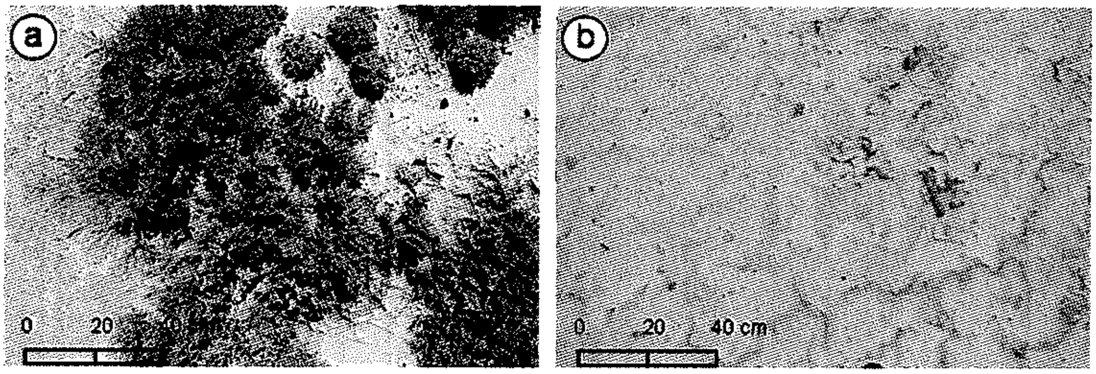

Figure 3. Two looks of the ground: (a) sparse vegetation and (b) bare soil with salt crust and algal mats.

3. MATERIAL AND METHODS

3.1 Satellite imagery and ancillary data

The acquisition of two Quickbird images, planned about one year before July 2007 and 2008, was scheduled in the season when perennial halophytes reach maximum activity. Due to the Quickbird width-imaging swath, limited to 16.5 km, three satellite passes acquired in two dates (spanning 18 days) were required to catch the entire study area in July 2007 (Table 1). We reduced the study area to match only one Quickbird pass in 2008 survey, avoiding possible discrepancies in spectral values, nadir angle, pixel size, and soil surface conditions between the three scenes. The high demand on Quickbird images delayed the acquisition with the inconvenient of some rains in the area between field data collection and image acquisition in 2008 survey.

We exploited ASTER and Landsat 5TM summer images (Table 1) to compare with Quickbird results. Rainfall from "Valfarta" weather station (Figure 1), the nearest automatic station belonging to the SIAR network (www.mapa.es/siar/), was gathered to know the soil surface conditions.

Table 1. Characteristics of the images employed in the study.

Image data	Satellite						
	Quickbird				ASTER	Landsat 5TM	
Acquisition date	2007			2008	2007	2007	2008
	July, 11		July, 29	August, 28	July, 11	August, 4	July, 21
Acquisition time	11:15:50	11:15:52	11:15:55	11:19:11	10:56:29	10:25	10:25
Part of the study area imaged	North	South-west	East	Center	Complete scene	Complete scene	
Nadir angle (degrees)	12.9	13.4	2.3	24.5	2.8	nd	nd
Format delivery	GeoTiff				HDF-EOS	CEOS	
Quantization levels (data type)	16 bits				8 bits		
Correction Level	Standard2a				Sensor radiance 1B	System corrected 1A	
Spectral range used*	VIS, NIR				VIS, NIR, SWIR/MIR		
No bands used	4 (3 VIS, 1 NIR)				9 (2 VIS, 1 NIR, 6 SWIR)	6 (3 VIS, 1 NIR, 2 MIR)	
Spatial resolution (m)	2.44–2.88 (VIS and NIR)				15 (NIR) 30 (SWIR)	30	
Area of original scene (km^2)	91.59	138.9	28.8	68.9	60 × 60	180 × 180	

*Thermal band of ASTER and TM sensors were not used in this work

3.2 Sites selection and sampling

We conducted two field surveys before the two Quickbird image acquisitions. We used as basic document the georeferenced database of vegetation (Domínguez et al., 2006) which fits the CORINE biotopes standard (European Commission, 1991) adapted to our region (Benito et al., 2009). The Quickbird image of 2007 helped for the selection of sampling points in 2008. We took the final decision in the field.

We sampled 11 wetlands (Agustín, Amarga Alta, Farnaca, Gramenosa, Guallar, La Playa, Muerte, Piñol, Pito, Pueyo, and Salineta), 10 in 2007 and 6 in 2008; 4 of them were surveyed in both years (Table 2). Their size ranges from 134 ha to 240 ha, and summarize 23 habitats, with saline bare soils, *A. macrostachyum*, and *Suaedetum Braun-blanquetii* as the most representative from the point of view of the surface extent. We sampled points deemed as representative of the covers to be discriminated by remote sensing, i.e., soils with different moisture and efflorescence conditions, and representative plants *—Arthrocnemum macrostachyum, Suaeda vera, and Lygeum spartum—* with different percent cover.

Table 2. Sampled components and features of the soil surface, wetlands where they were collected, and number of points and transects in each of them. Coordinates and complementary data from each point are listed in Appendix I.

<table>
<tr><th colspan="3">Component / Feature</th><th rowspan="2">Salada</th><th colspan="3">No. of points (P) and transects (T) containing the specific feature</th></tr>
<tr><th>Primary</th><th>Secondary</th><th>Specific</th><th>P 2007</th><th>P 2008</th><th>T 2008</th></tr>
<tr><td rowspan="12">Vegetation</td><td rowspan="10">Halophytic vegetation</td><td>A. macrostachyum</td><td>Agustín, La Playa, Pito, Pueyo</td><td>13</td><td>21</td><td>4</td></tr>
<tr><td>Halopeplis amplexicaulis</td><td>Amarga Alta, La Playa</td><td>9</td><td>-</td><td>-</td></tr>
<tr><td>Suaeda vera</td><td>Agustín, Amarga Alta, Farnaca, Guallar, Gramenosa, Muerte, Pito, Salineta</td><td>22</td><td>37</td><td>5</td></tr>
<tr><td>Microcnemum coralloides</td><td>Salineta</td><td>3</td><td>-</td><td>-</td></tr>
<tr><td>Salicornia ramosissima</td><td>Amarga Alta, Salineta</td><td>4</td><td>-</td><td>-</td></tr>
<tr><td>Juncus maritimus</td><td>Salineta</td><td>1</td><td>2</td><td>1</td></tr>
<tr><td>Phragmites australis</td><td>Pito</td><td>-</td><td>3</td><td>1</td></tr>
<tr><td>Salsola kali</td><td>Salineta</td><td>1</td><td>-</td><td>-</td></tr>
<tr><td>Limonium sp.</td><td>Agustín</td><td>2</td><td>-</td><td>-</td></tr>
<tr><td>Lygeum spartum[1]</td><td>Agustín, Amarga Alta, Gramenosa, Muerte, La Playa, Pueyo, Pito, Salineta</td><td>20</td><td>5</td><td>1</td></tr>
<tr><td rowspan="2">Calcicolous scrub</td><td>Rosmarinus officinalis</td><td>La Playa</td><td>2</td><td>-</td><td>-</td></tr>
<tr><td>Thymus vulgaris</td><td>Salineta</td><td>1</td><td>-</td><td>-</td></tr>
<tr><td rowspan="6">Soil</td><td rowspan="3">Dry</td><td>Efflorescence</td><td>All</td><td>20</td><td>30</td><td>8</td></tr>
<tr><td>Desiccation polygons</td><td>Agustín, La Playa, Piñol, Pito, Salineta</td><td>10</td><td>14</td><td>2</td></tr>
<tr><td>Sapropel</td><td>Guallar, Salineta</td><td>2</td><td>5</td><td>1</td></tr>
<tr><td rowspan="3">Moist</td><td>Saturated soil</td><td>Salineta</td><td>3</td><td>5</td><td>1</td></tr>
<tr><td>Saturated soil + sapropel</td><td>Salineta</td><td>1</td><td>9</td><td>2</td></tr>
<tr><td>Salt crust</td><td>Salineta</td><td>4</td><td>-</td><td>-</td></tr>
<tr><td colspan="3">Water</td><td>Amarga Alta, Salineta</td><td>3</td><td>-</td><td>-</td></tr>
</table>

[1] This species considered halophytic if occurring at the salada bottom.

In 2007 (26, 27 and 28 June) we measured pure samples of soil or vegetation. We randomly selected from 4 to 34 points at each salada, summarizing a total of 144 points (Table 2). The reflectivity was recorded with the multispectral radiometer CropScan

MSR16R, in 16 wavebands ranging from 450 nm to 1750 nm. The device, held 1.5 m above the terrain (Figure 4a), recorded also the level of the incident radiation, and the temperature of the radiometer.

In 2008 (15, 18 and 23 July) we located from 2 to 5 transects in each salada summarizing 18 transects whose length ranged from 24 m to 150 m. From 5 to 10 points were collected in each transect totalizing 98 sampling points. We collected data when the soil features ("les états de surface") changed, following both the ecological and the remotely sensed approach. We recorded a continuum spectrum, from 200 nm to 1100 nm, with the Spectroradiometer OceanOptics HR2000CG-UV-NIR. Its optimum optical resolution is 1.0 nm full width at half maximum (FWHM). The readings were calibrated with a 50% (grey) Spectralon reflectance standard panel (Labsphere, Inc.). The device, fixed in a tripod with a constant height of 1.3 m, recorded a nadir lecture of a 57.6 cm-diameter sized terrain surface (Figure 4b). For each point we measured: (1) the reference standard panel used to convert data in reflectance, (2) the dark current associated to the thermal component of the signal to be subtracted to the readings, and (3) the ground measure. An example of transects is given in Figure 5.

A total of 242 points were sampled in the two years for their spectral study in the visible and infrared espectra. All the measures were systematically collected from 11 a.m. to 15 p.m. and out of solar noon to avoid the shadows as much as possible. Readings were georeferenced using a Global Positioning System (SYS ON CHIP) with 5 m accuracy.

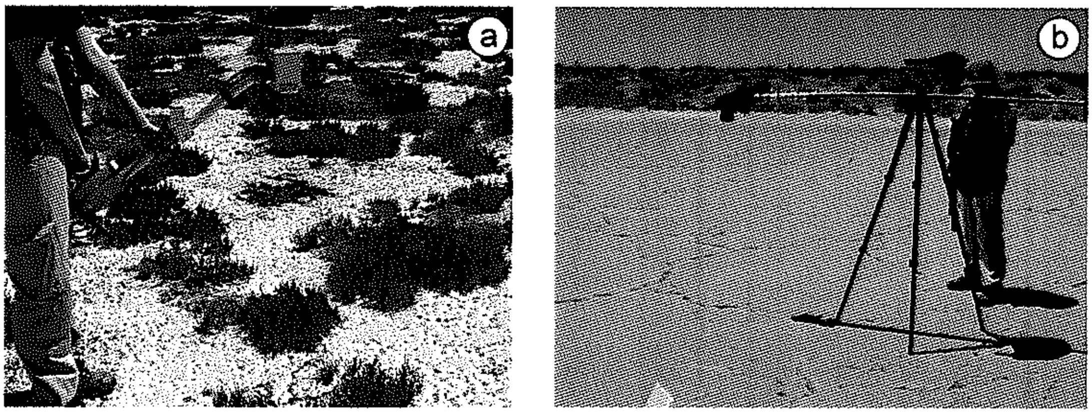

Figure 4. Spectrometers used in the 2007 campaign, CropScan (a) and that of 2008, OceanOptics (b).

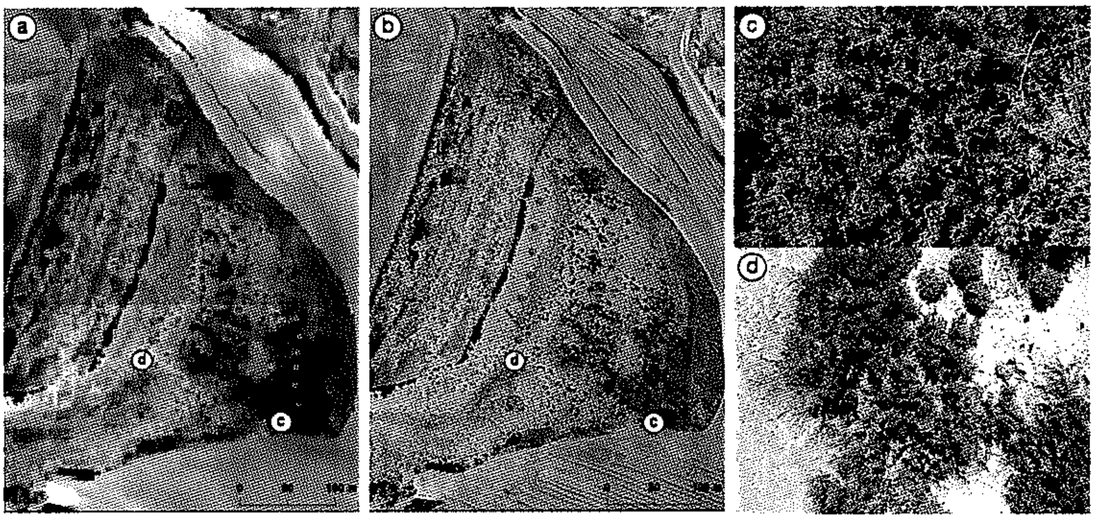

Figure 5. Example of two transects (green points) in Pito on the 432 Quickbird image (a) and Orthophoto (b). The first transect was located in a densely vegetated area (c), and the second in a sparsely vegetated area (d).

3.3 Ground photographs processing and auxiliary field data.

Photographs of the ground were taken with a digital camera (Reflex Nikon D50) simultaneously to each spectral measure. In 2007 survey we took an oblique photography; in 2008 survey we fixed the camera in the tripod to take a vertical photograph with similar field of view than the spectrometer. We assigned the maximum focal aperture (18 mm) obtaining a picture representing 167 cm × 111 cm of ground surface.

We have derived the percentage of each component of our photographs using Can-Eye free software developed by INRA (http://147.100.66.194/can_eye/). Can-Eye processing has been often used to characterize the structure of crops (Baret et al., 2004), which have a high and relatively homogenous greenness. Due to the characteristics of our vegetation, we have computed the percent cover of vegetation by selecting the green and yellow-green parts, i.e. green and senescent vegetation. For this purpose we classified the photographs in five classes: green vegetation, senescent vegetation, trunks, bare soil, and mixed (Figure 6). The later class included shadows and pixels not incorporated in the previous classes. The percent cover of "green" vegetation or fCover (Kallel et al., 2007) estimated from the ground photographs was later related to the NDVI.

Previously to the classification, an adjustment of the field of vision of both devices, the digital camera and the spectrometer, was performed by calculating the distance between the centre of the radiometric measure and the focal centre of the camera.

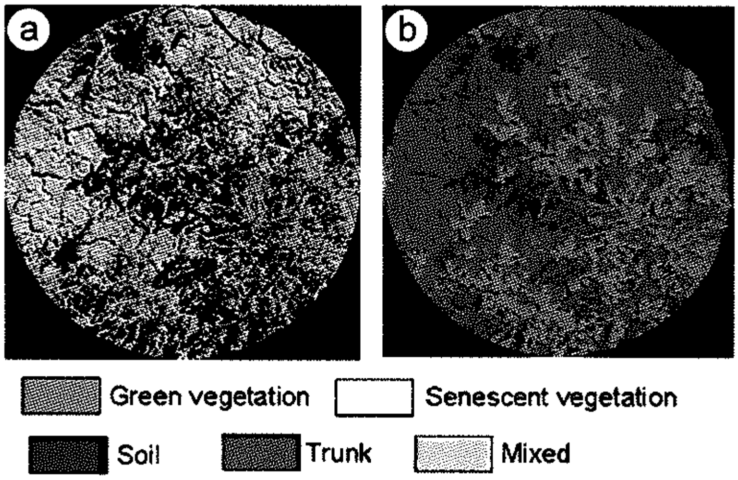

Figure 6. (a): Photograph of a sampled point (field of vision adjusted). (b): CanEye classification in five classes.

We also recorded the plant cover by visual estimation and the soil color by means of the Munsell chart. A soil sample of the surface (< 2 cm) was taken in each transect to obtain the gravimetric moisture and the color under dry and moist conditions.

3.4 Spectral data processing

3.4.1. Remotely sensed data

Image processing included radiometric, atmospheric and geometric corrections. Atmospheric of the Top of Atmosphere (TOA) and radiometric corrections were made using ACORN5 software (ImSpec, USA) based in a MODTRAN4 (MODerate resolution atmospheric TRANsmission) algorithm (Anderson et al., 2000). We applied the geometric correction using as the reference document the orthophotographs from 2006 with a pixel of 0.5 m. We took 20 or more ground control points (GCP) and we used a second order polynomial equation and the nearest neighbor resampling method to rectify the images, yielding root mean square errors < 0.5 pixel.

The homogeneity of the mosaic composed by three 2007 Quickbird images was verified by selecting invariant areas. We obtained a determination coefficient, R^2, of 0.99 between the acquisitions from the same day, and 0.97 between images from two days, probably due to the 11.1 degrees of difference in view angle (Table 1). We preserved the original values of each image because we considered that the reflectance variations were not significant and no rains happened in the area during the time spanning between the images acquisitions.

The image QBwetland was created by masking the image values outside of the wetlands using the silhouette of our wetlands inventory. The NDVI of QBwetland, named forward $NDVI_{QB}$, was calculated.

3.4.2. Proximally sensed data

The reflectance of only four CropScan channels (485, 561, 660 and 830 nm) was directly compared with that of the corresponding Quickbird bands. However, all the CropScan channels were used for analyzing the spectral behavior of the covers.

Row data from OceanOptics were pre-processed using SAMS software (Spectral Analysis Management System, http://www.cstars.ucdavis.edu/software-sams.htm). Developed by CSTARS (Center for Spatial Technologies and Remote Sensing, Davis, California), this software eased the visualization of spectral data and allowed for a preliminary sorting and processing of the spectral signatures. The pre-processed continuum spectra, exported to the ENVI (Research Systems Inc., 2000) spectral library, were sampled into the Quickbird discrete bands using the Spectral Library Resampling tool. In order to adjust the different sensitivity of OceanOptics and Quickbird sensors at near-infrared spectral range, we tested different filters. We reduced the fourth bandwidth (NIR) to the range 775-795 nm to eliminate noisy absorption values. A spectral library was created.

The $NDVI_{fs}$ index (NDVI from field sampling data) was calculated and verified according to the field descriptions, ground photographs, and gravimetric moisture data. Inconsistencies or errors such as negative values were eliminated.

3.4.3. Remote versus proximal spectral data

To compare the *QBwetland* images to each other, and with field spectral data, we took into account that different soil surface conditions can occur due to weather. The rainfall recorded in the precedent month to the image date was 27.6 mm in 2007 and

11.4 mm in 2008 (Figure 2), and the month with maximum mean evapotranspiration was June in 2007 and July in 2008. In addition, the considerable amount of rain recorded the day before the satellite pass in 2008 (Figure 7) produced significant differences in soil moisture and occurrence of efflorescence.

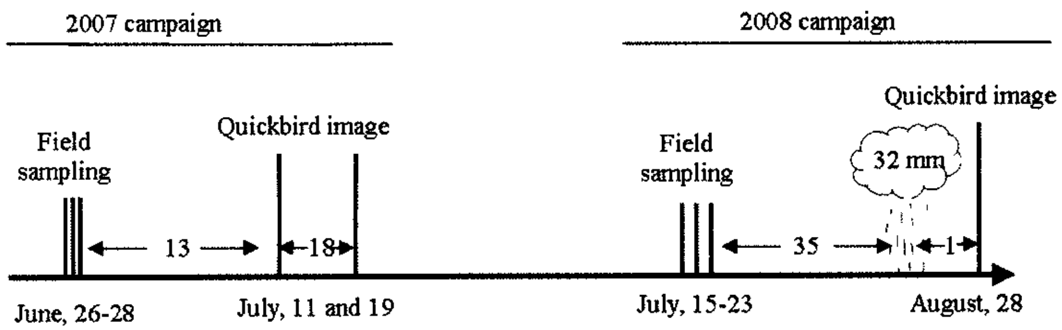

Figure 7. Time line schema (not to scale) showing the distribution of sampling and image acquisition dates. Days between dates are indicated.

Another factor limiting the radiometric comparison is the vegetation patterns and characteristics. The intricate distribution of vegetation, the small size of many habitats, and the sparse vegetation, made difficult to find invariant regions of quality required to establish the radiometric relationships between the two *QBwetland* images and the field sampling.

Since the color of halophytes changes with the species and the season, we measured their reflectance taking into account their phenological state (green, senescent, dry, and dead) and type (species). The phenological state varied depending on the species and the rains, especially for pioneer annual halophytic plants like *Halopeplis amplexicaulis* and *Microcnemum coralloides*.

We checked the radiometric homogeneity of the field points on the *QBwetland* image and their correspondence with field descriptions. We considered this homogeneity as an indication of the purity of the sample. We selected only the most homogeneous points containing vegetation or bare soil, i.e. the pure points.

The methodology is shown in the schema of Figure 8, which connects the different sources of data and its processing.

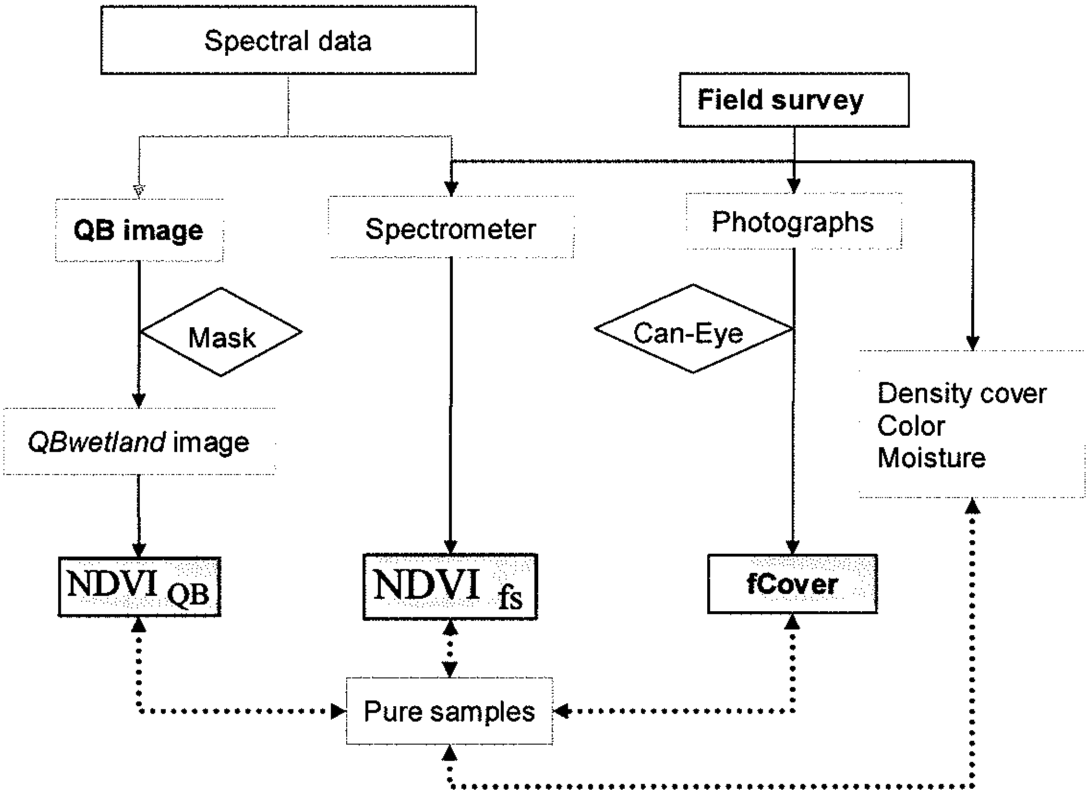

Figure 8. Schema of the methodology applied to process spectral and field data.

4. SPECTRAL CHARACTERISTICS OF SOIL AND VEGETATION

Field surveys showed that vegetation varies in height, percent cover and phenological state; some plants are widely distributed and others, like some pioneers, are restricted to small areas. The distribution of the vegetation depends on the soil moisture, plant salt tolerance, and topographic position. The greenness of the halophytes and xerophytes is heterogeneous, even with maximum phenological activity, and frequently green, senescent, and dry parts occur in the same plant.

The density of the vegetation depends on the vegetation type and size. Vegetated areas with maximum density are not common. Due to the variability of soil and vegetation at the scale of sampling, each transect can be considered distinctive because the same features cannot be reproduced in other transect or salada. The spectral signatures were interpreted by means of the ground truth (photographs) and the reflectance of pure samples. A qualitative analysis of the contribution and weight of the different components (Table 3) to the total reflectance measured in each transect and point was performed.

4.1 Bare soil

We recorded the spectral characteristics of the bare soil in most studied saladas. The bare soil had very different looks (Table 3) depending on the salada and even within the same salada. The soil moisture and color changed in short distances during the daily dry-wetting cycles, associated to the occurrence of ephemeral efflorescence and algal mats, microtopography, and shadows. Soil surface frequently exhibited light colors related to the soil composition and efflorescence occurrence, making difficult the assignment of Munsell colors. Figure 9 shows the CropScan reflectance of the soil features sampled and photographs of Figure 11 illustrate them.

Table 3. Different features and conditions of the soils studied with spectrometer, their field description and photograph identification in Figure 11.

Soil		Field description	Photograph
Feature	**Condition**		
Wetness	Dry	Occasionally, desiccation polygons	Figure 11d
	Moist	Some water content (< 20%). Matt soil surface	-
	Saturated	Much water content (> 20 %). Glossy / bright soil surface	Figure 11b
Salts	Salt crust	Relatively consistent crust that crack under walk	Figure 11a
	Dry soil + efflorescence	White powdery efflorescence over dry soil, with brightness depending of the amount of salts	Figure 11c
	Moist soil + efflorescence	Very bright efflorescence (salt crystals are visible) over moist dark soil	-
Biological layer / sapropel	Dry	Dry sapropelic soil	Figure 11f
	Moist	Moist sapropelic soil	Figure 11e

Saladas bottom remains wet in spite of the scarce rains, high evaporation and desiccating winds. Soil moisture was an important factor from the spectral point of view because (1) moist soils are darker than dry soils, and (2) moisture absorbs the radiance masking other characteristics of soil.

In summer, the soil surface partially dries and efflorescences dramatically increase the soil brightness. Soils covered with a white salt crust have a relatively high reflectance, rising from the visible (VIS) to the near infrared (NIR) with a strong decrease, around 40%, in the medium infrared (MIR) (Figures 9 and 11a), probably due to the absorption of water associated to hygroscopic salts. In moist conditions, soil with efflorescence differs in overall magnitude of reflectance (Figure 9) and in the lower decreasing of MIR reflectance, around 10%.

The efflorescence maintains the VIS and NIR reflectance of soils above that of other type of soils, except if saturated (Figure 9 and 11b), with similar strong MIR decreasing. Therefore, salts are a dominant factor providing higher reflectance against simply dry soils.

The continuous increasing of reflectance from VIS (8%) to MIR (> 40%) is a unique spectral feature of dry soils without efflorescence (Figure 9). Its magnitude depends on soil color, which in turn varies with the soil composition. The high soil content in calcium carbonate and gypsum contributes to the bright color, partially darkened with other components such as organic matter and clays. The desiccation polygons decrease the soil reflectance due to the shadows between cracks and the dark color of the underlying soil.

Other aspects frequently ignored in spectral studies of saline wetlands are the biological components forming crust or thin layers (West, 1990) whose pigments are spectrally active under certain environmental conditions and can be confused with soil (Karneli and Tsoar, 1994). In the saladas studied, a sapropelic layer of millimetric thickness, resulting from accumulation and decomposition of organic mater, can occur under anaerobic conditions (Pueyo, 1979). Apart from its rotten smell, this soil component exhibits a unique black color influencing the soil reflectance. Due to the continuous drying-wetting cycles occurring at the saladas bottom, the sapropelic material is reworked with other soil components, such as the algal mats and salts, becoming a component of surface soil both in dry and moist conditions (Figures 11e, f).

The sapropelic component is a dominant feature from the spectral point of view producing a much lower reflectance at VIS, NIR, and MIR than any type of soil. According to Zhang et al. (2007), the sapropelic soil has low reflectance with a flat shape, especially between green and red. This distinctive spectrum (Figure 9) is similar in shape and magnitude to the spectra of dark biological crust studied by these authors.

The high value of MIR reflectance of dry soils (Figure 11d) contrasts with the MIR decreasing of salt crust (Figure 11a) and sapropelic soil (Figure 11e).

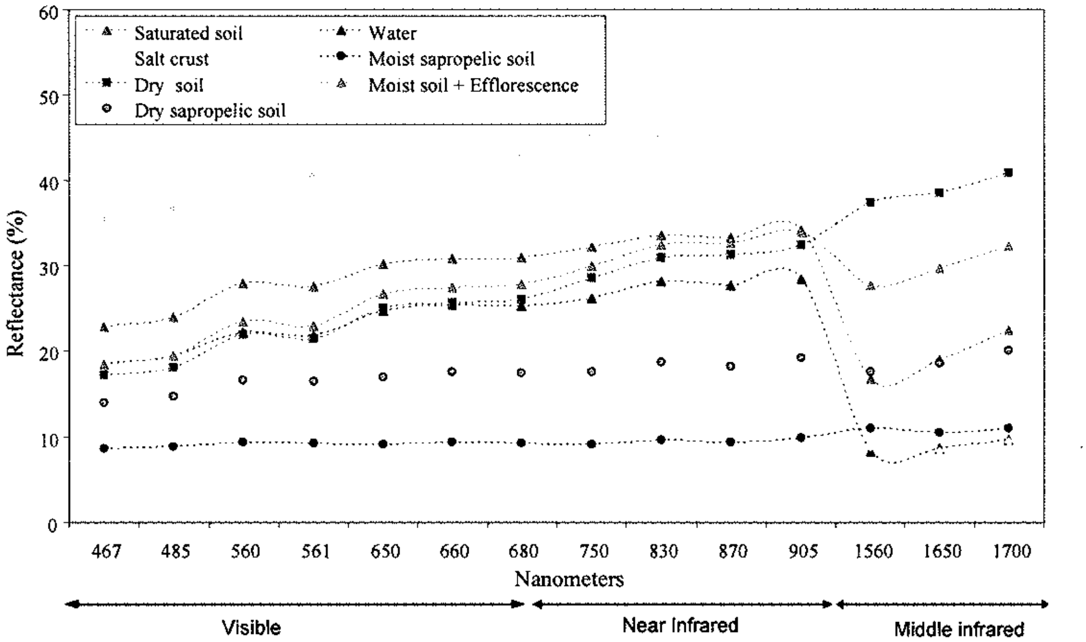

Figure 9. Spectral reflectance of sampled soils.

The reflectance of moist and dry soil also decreases to the half in sapropelic soil (Figure 10), whose behaviour is similar to the shadows. Although these soils have distinct spectral features, the small surface extent where these soils occur hampers their detection by remote sensing as proposed by Zhang et al. (2007).

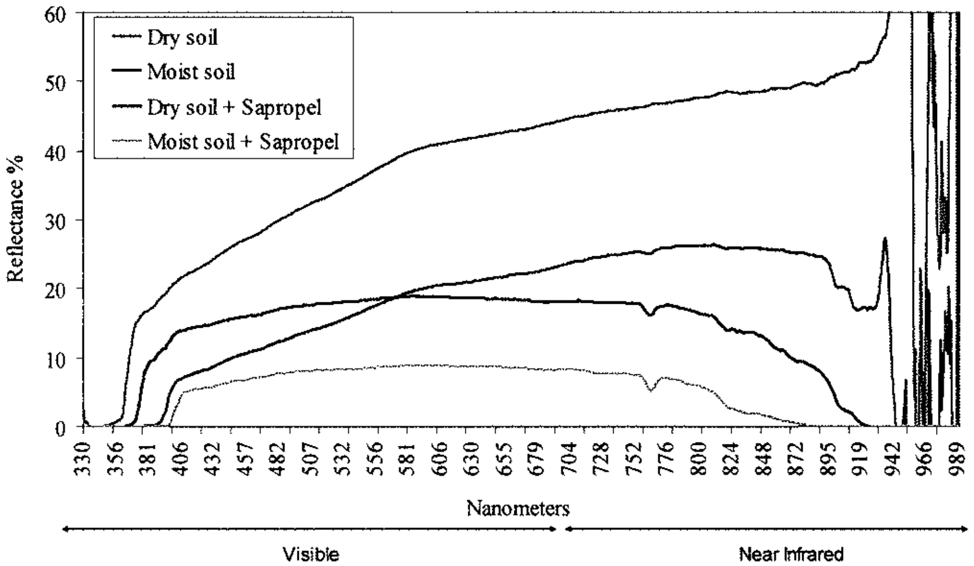

Figure 10. Reflectance of dry and moist soil with and without sapropelic component sampled with OceanOptics.

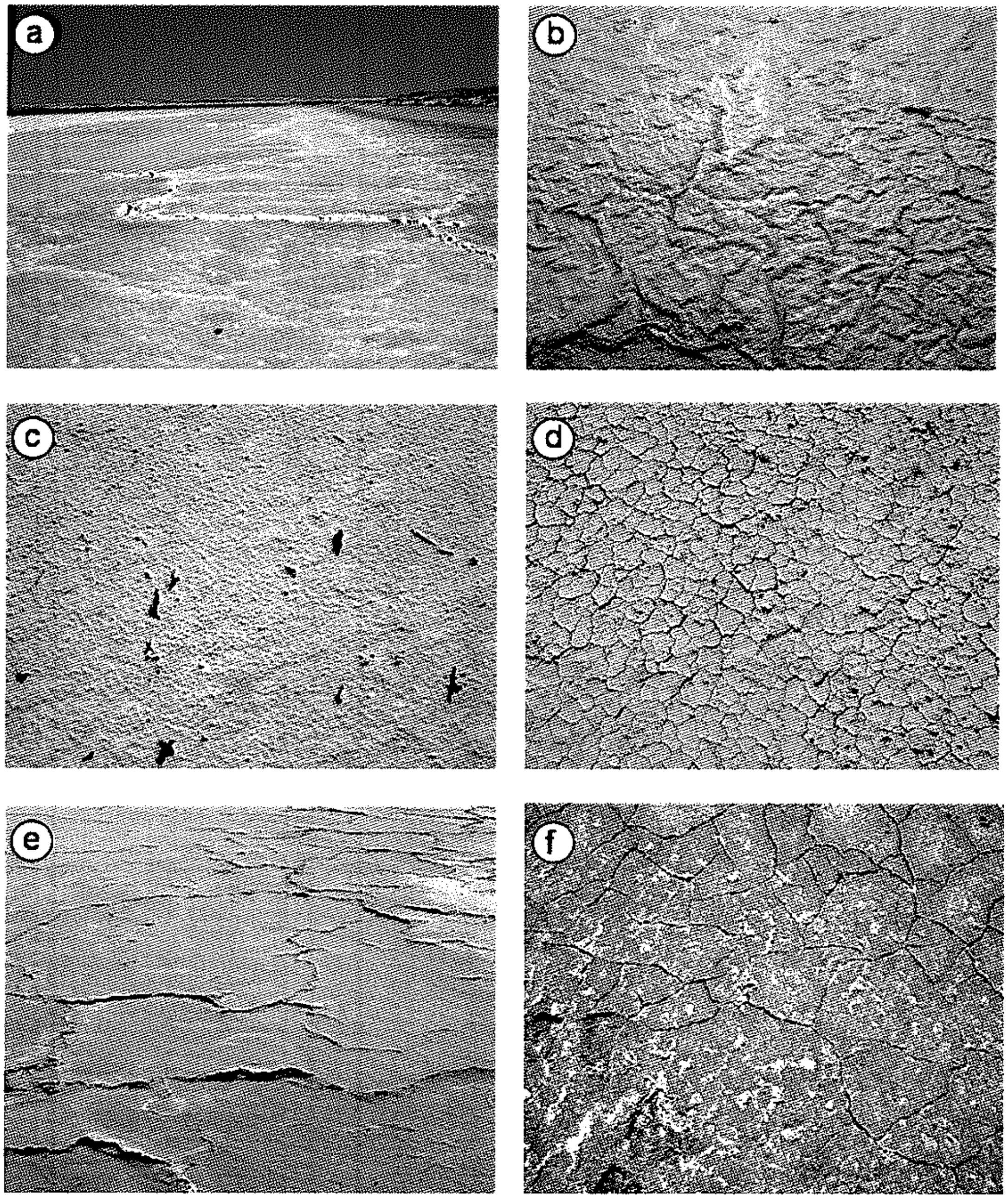

Figure 11. Photographs of soils sampled at the bottom of the wetlands: (a) salt crust, (b) saturated soil, (c) dry soil with efflorescence, (d) dry soil without efflorescence, (e) moist sapropelic soil (and salt crust), and (f) dry sapropelic soil.

Figure 12 shows the NIR against the RED reflectance values for dry and moist bare soils. Despite the great heterogeneity of sampled soils, the measurements, made under similar solar illumination, depict a soil line with a clear threshold (about 30% NIR or RED) separating dry from moist soils.

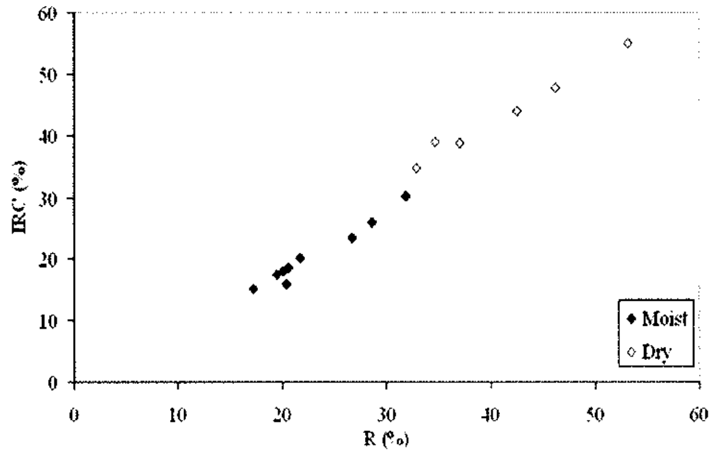

Figure 12. Scatterplot with NIR against RED (R) reflectivity for sampled points on dry and moist soils.

4.2 Vegetation

The low percent cover of the vegetation conditioned its spectral study. Moreover, the halophytes are only partially and temporarily green (Escadafal, 1994), giving a low spectral signal. Tueller (1987) and Smith et al. (1990) noted that in areas with less than 30%-40% of percent cover, the sensitivity of the NDVI to the soil background restricts the estimation of green cover. In the studied wetlands, maximum density of green vegetation is about 75%, with frequent occurrence of efflorescence and moisture on the soil surface.

Figure 13 shows the CropScan reflectance of different plants at different percent cover. The spectral signatures illustrate the mixture of components in some of the points sampled. They include bare soil and several plants (*Suaeda vera, Arthrocnemum macrostachyum, Lygeum spartum and Juncus maritimus*) with variable density, from 30% to 100%, based on visual estimation. In general, this vegetation is characterized by a VIS reflectance < 10%, and NIR reflectance > 10%. This low reflectance can be related to the absorption of the pigments in succulent stems (chlorophylls, xanthophylls and carotenoids). Halophytic vegetation stems have a cellular structure organized in pores where plants accumulate salts or ashes that increase or reduce the reflectance against other plants (Salisbury et al. 1992). In the June campaign, the plants had a dark green color that did not produce noticeable peaks of reflectance in the green band because of the absorption of the chlorophyll.

The VIS reflectance increases with the decrease of the density cover from 100% to 30%, producing spectra similar to that of bare soil. This fact justifies the use of a specific methodology adapted to our field features in order to estimate the percent cover of this dark green and sparse vegetation.

The reflectance of green vegetation was minimum around 420 nm, 490 nm and 670 nm, and maximum around 550 nm, though these values depend on the concentration of pigments in the leaf (Renz, 1999). The loss of chlorophyll increases the VIS and NIR reflectance. Chlorophylls stop to absorb at the wavelength interval 670-780 nm (red edge) and during senescence they degrade and caretenoids become the main pigment, producing the yellow color of the leaf. Senescent and dead vegetation have brown pigments, their reflectance decreases between 750 nm and 400 nm and the spectral signature becomes flat.

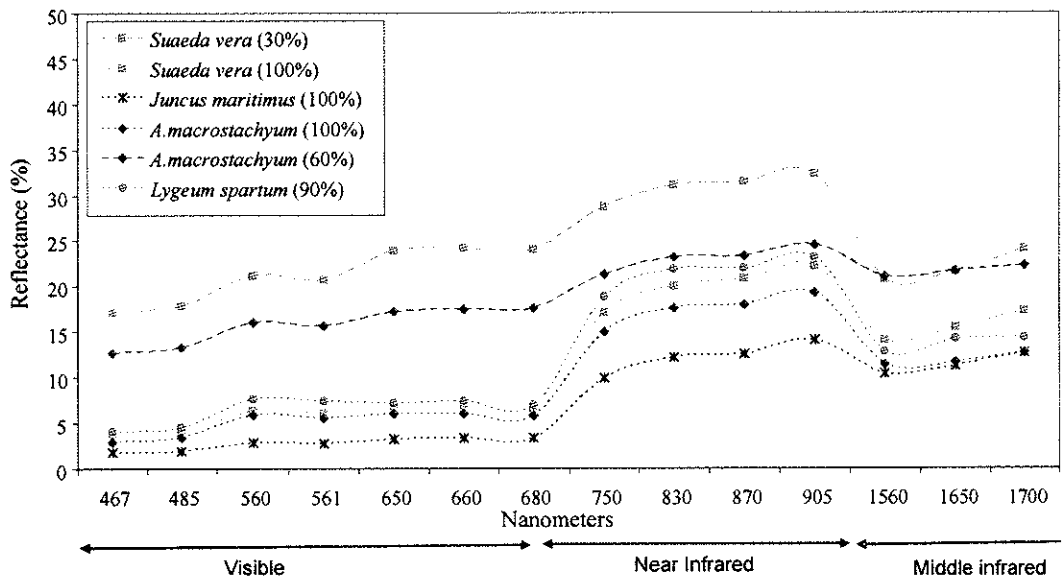

Figure 13. Reflectance (CropScan) of the plants sampled with different percent cover.

The spectrometer registered the reflectance of green and yellow-green parts of the vegetation; since it does not include the reflectance of dry plants, the results did not give a measure of the total biomass. For this reason, the spectrometer measures underestimated the density of vegetation observed in the field due to (1) the frequent occurrence of dry and dead plants (yellow and grey color), and (2) the lack of coincidence of maximum vigor between annual and perennial plants due to different plant establishment. Moreover, the greenness of the vegetation was related to the meteorological conditions during previous months, especially rainfall distribution; in this sense, we observed greenness differences being the vegetation much drier in 2008 that in 2007.

Figure 14 shows the spectral reflectance of plants sampled the same day and with maximum coverage excepting for annual species as *Salicornia ramosissima*, which hardly reached a high percent cover. The plants with similar spectral signature showed differences related to their different proportion of green parts in the plant. In general, the halophytes sampled had a 20% difference between VIS and NIR reflectance, excepting for *Juncus maritimus*, without the peak of reflectance in the green band, and with scarce variability along the spectral range due to the dry and senescent vegetation.

In spite of its low density cover, hypersaline plants such as *Salicornia* has a high variability of reflectance, especially between NIR and MIR (Figure 14). Figure 15d shows this plant with a vigorous state, characteristic of the dry season for some plants adapted to saline conditions. Frequently, plants were located on patches where efflorescence accumulated, providing a falsely increased reflectance.

Despite the differences in color, morphology, and density cover, *Lygeum spartum*, *Microcnemum coralloides*, and *Salsola kali* have similar spectra. *Suaeda vera* has a high proportion of dry and senescent vegetation, resulting in a short difference between NIR and MIR reflectance. Detailed field reflectance measurements have given similar shaped spectra, though with different proportion of the green component.

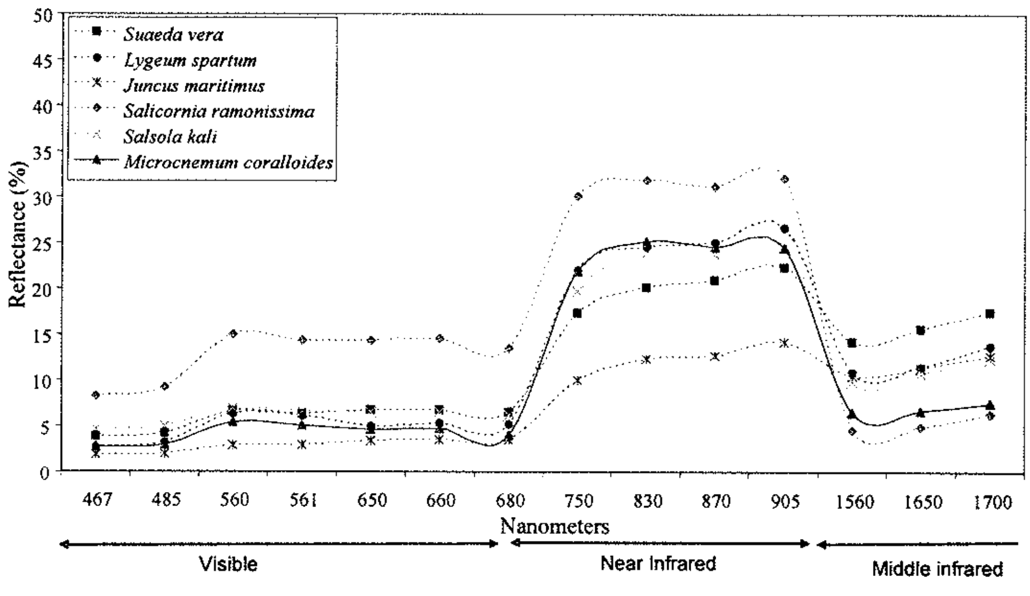

Figure 14. Spectral reflectance of the plants sampled with CropScan.

Figure 15 shows oblique photographs of the species sampled with CropScan in June, 2007. Different vigorous species are shown in Figure 15a, 15b, and 15d. Figure 15c present *Salsola kali* influenced by light color of grey. In Figure 15d the reflectance is a mixture of *Salicornia*, soil moisture, algae and efflorescence. *Suaeda vera* (Figure 15e) and *Juncus maritimus* (Figure 15f) have the greater proportion of senescent and dry vegetation, in grey colors.

The occurrence of moisture and organic matter in the soil, or a thin sheet of water covering the vegetation, make difficult the interpretation of the spectra. Moisture masks the occurrence of sparse vegetation. Decaying and dry vegetation have greater influence on soil spectra than green vegetation; dead vegetation spectra can be confused with that of soil because of the flat signature increasing from VIS to MIR.

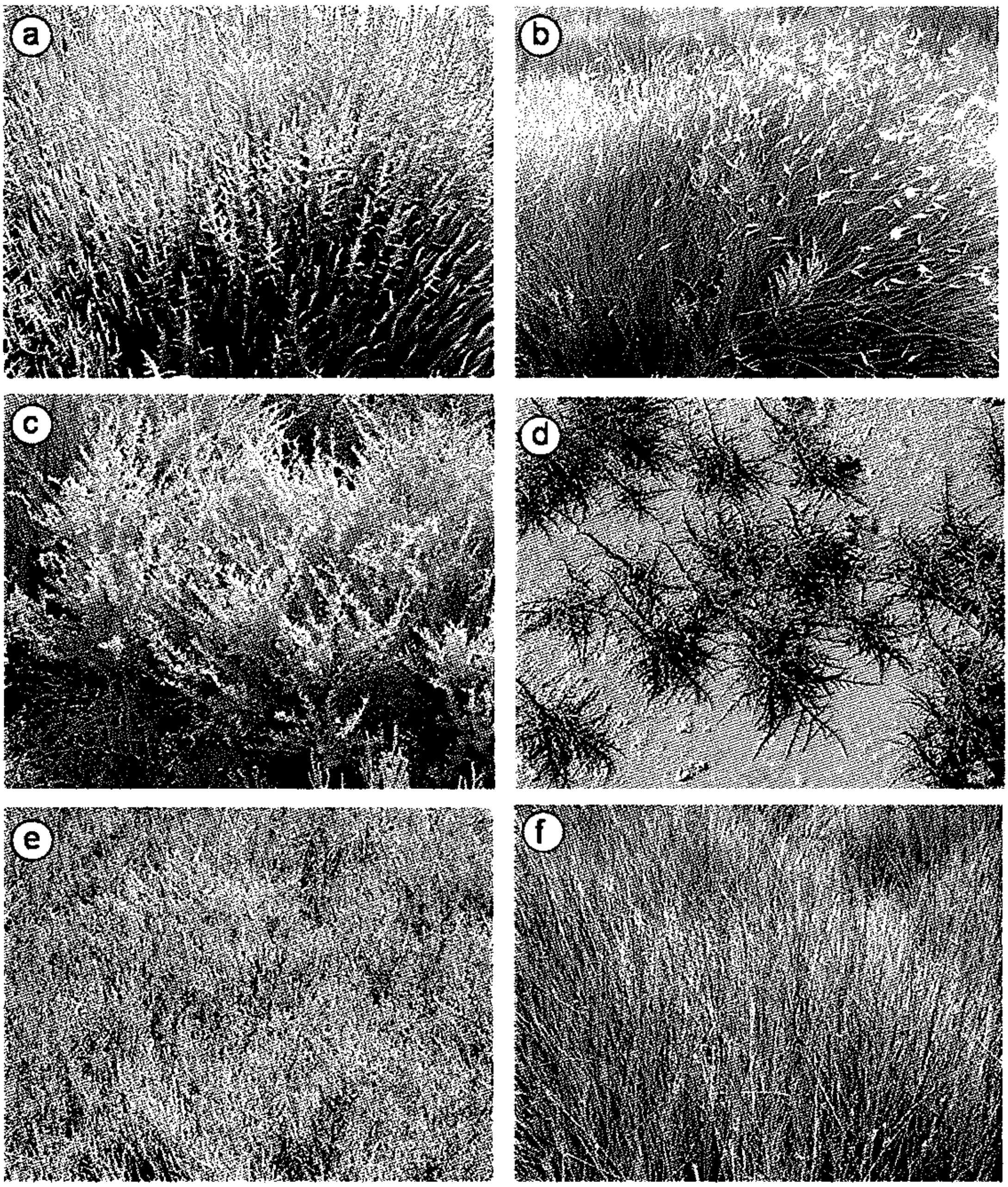

Figure 15. (a) *Microcnemum coralloides*, (b) *Lygeum spartum*, (c) *Salsola kali*, (d) *Salicornia ramosissima*, (e) *Suaeda vera* and (f) *Juncus maritimus*.

5. SPECTRAL INDEXES AND SURFACE CHARACTERISTICS

5.1 Normalized vegetation index and soil line

The NDVI, the normalized difference between the reflectance of infrared and red bands, is the most frequently used index used to study the phenological state of the vegetation. However, it has the disadvantage of its sensibility to the soil background reflectance (Huete, 1988) masking the vegetation in areas with densities $< 50\%$, common in our study area. Moreover, the overall reflectance of most sampled points is $< 20\%$.

The spectral reflectance of the soils is similar in red (RED) and NIR bands. In moist soils the reflectance decreases in RED and NIR, whereas in dry soil the reflectance increases in both bands. In order to differentiate vegetation from soils we calculated the soil line (Baret et al., 2002) using the OceanOptics measures. The soil line separates in the upper part the vegetation and other points with NIR > RED (Figure 16); the larger is the distance of the upper points to the soil line, the denser is the vegetation cover.

Richardson and Wiegand (1977) formulated the Perpendicular Vegetation Index, which measure the quantity of vegetation by taking the perpendicular distance from a point to the soil line. From our soil line, we obtained as Perpendicular Vegetation Index the value: $PVI = 0.8841 \times NIR - R + 2.84$

Most vegetated points were near the soil line (Figure 16) and their vegetation result underestimated. This result indicates that this index results inadequate due to the low-density cover and the dark green of our vegetation.

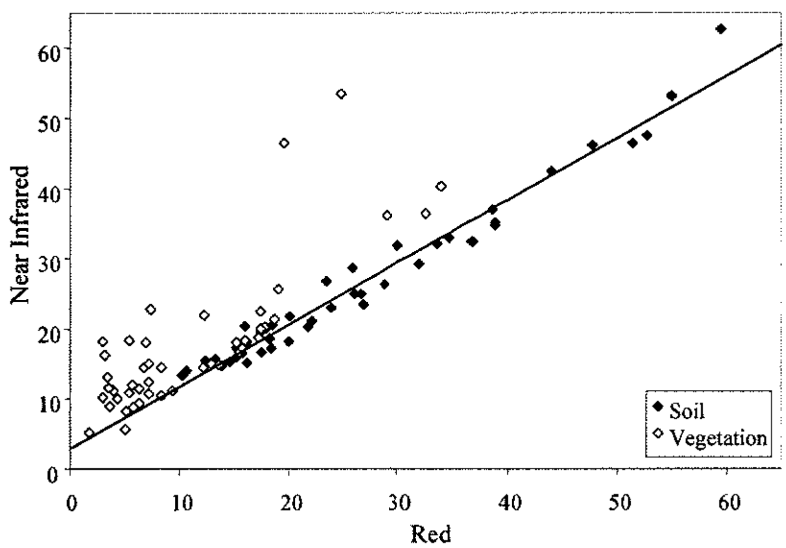

Figure 16. Soil line obtained from field-measures spectral data in 2008.

In general, it is assumed that NDVI equal to 0.2 establishes a limit between soil and vegetation. According to this threshold, only 27 from the 45 vegetated points sampled can be considered "spectrally true" vegetation, and the remaining vegetated points should be considered as bare soil. This limit seems to be unsuitable for sparsely vegetated areas, whose plants exhibit dark green color. Moreover, the analysis of spectral data together with field photographs confirms that senescent vegetation (yellow-green colored) contribute in part to the NDVI.

To found a relationship between vegetation cover and NDVI for our vegetation, we have modeled the regression of fCover values extracted from CanEye on NDVI extracted from spectrometer. We measured in the field, over dry and moist soil, the reflectance of control samples with known percent cover, 0%, 25%, 50%, and 100% (Figure 17).

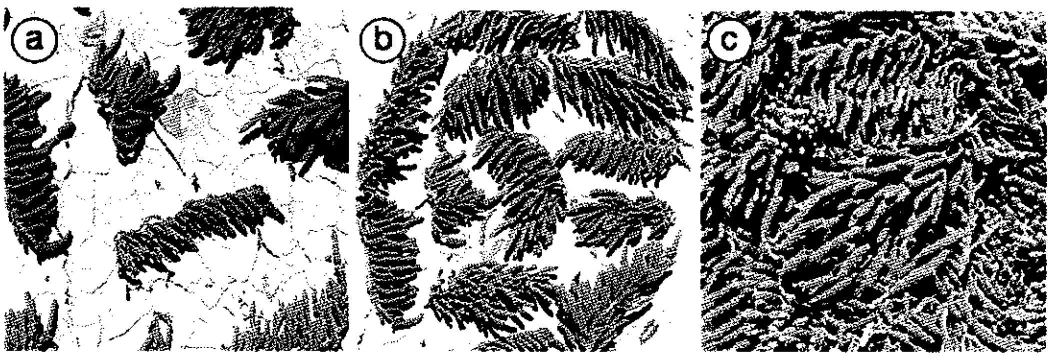

Figure 17. Control samples of *A. macrostachyum* with different percent cover: (a) 25%, (b) 50%, and (c) 100%.

The reflectance of the maximum vegetation cover, 100%, ranges from 5% in R band to 30% in NIR band (Figure 18), giving NDVI equal to 0.7. The reflectance increases with the decreasing of vegetation density though the shape of the spectral signature remains.

The reflectance of vegetation decreases with the increasing of soil moisture. This decreasing is stronger for low-density covers affecting to the entire spectrum. Figure 18 shows that with a density cover of 100% the moisture only concerns the NIR reflectance; whereas with 25%, the moisture produces a decreasing of VIS and NIR reflectance in a half.

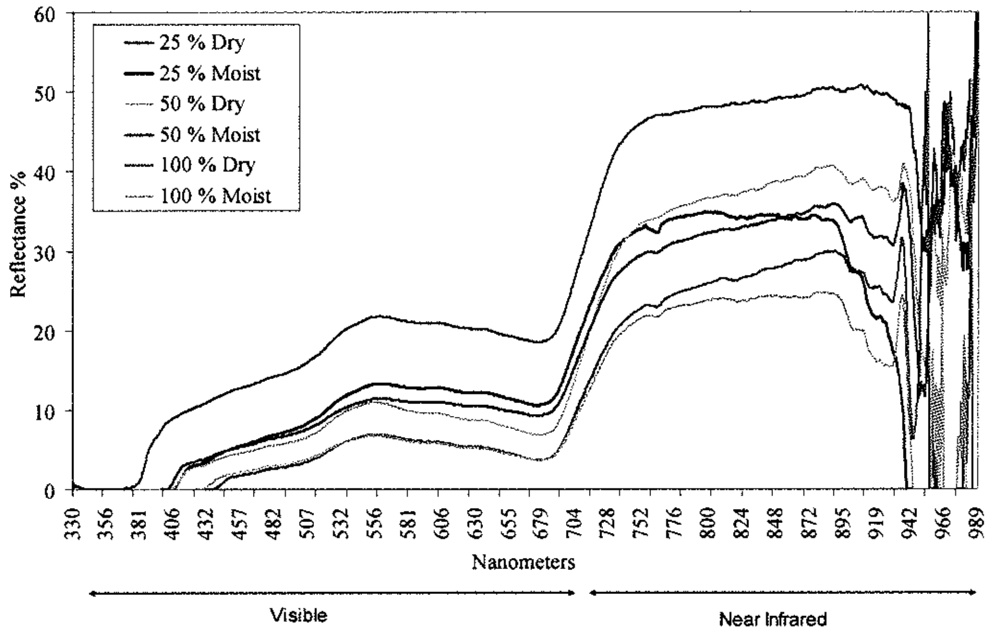

Figure 18. Reflectance of vegetation with different density cover, and with dry and moist soil.

5.2 NDVI versus green cover fraction

The fraction cover (fCover) and the density of green vegetation are related to the NDVI and could be estimated by this index. However, the estimation of vegetation by means of spectral data is conditioned by the typology (halophytes, gypsophytes, etc.) and the photosynthetic state of the vegetation. The trunks and the dry and senescent parts of the plants are low- and non-photosynthetic elements of the biomass. The increase of reflectance produced by the occurrence of this "non-green" biomass and light-colored plants like *Lygeum spartum* could be mistaken by an increasing reflectance of the soil background, as demostrated by CanEye classifications, which also mistook this vegetation for bare soil.

Taking into account this unpredictability of NDVI values (i.e., interpreted as different "états de surface") we have established the relationship between the fCover derived from CanEye classification and NDVI from the OceanOptics survey, for every sampling point. Three different methods were applied, by computing (1) the green vegetation of control samples prepared in the field with known percent covers of vegetation, 0%, 25%, 50%, and 100%; (2) the green fraction from sampling points. (3) the green and yellow-green fraction of sampling points.

Figure 19 illustrates the three regressions obtained. The yellow-green fraction or senescent vegetation includes dry and dead vegetation, largely represented in our sampling points. Very yellow vegetation was not included because it was not chlorophyllic and did not contribute to the NDVI but to the bare soil spectra.

The first relationship, the approach of the modeled density, provides the stronger correlation, with $R^2 = 0.91$, followed by the relationship derived from the sum or green and yellow-green fraction, with $R^2 = 0.90$. The NDVI was slightly correlated to the green cover, yielding $R^2 = 0.71$. From these relationships and the slopes of the regression lines we extract two observations. First, the spectrometer measures overestimate NDVI due to the contribution of the soil background, with a high reflectance in NIR; second, CanEye classifications underestimate the green vegetation fraction even if computed as also the yellow-green fraction. This loss of biomass is due to the masking effect of shadows together with the difficulty of classifying the wide range of green and yellow-green hues in the photographs. Despite this fact, we have considered that the fraction cover formed by green plus yellow-green vegetation is suitable for remote sensing detection as it fits best the general spectral behavior of our vegetation.

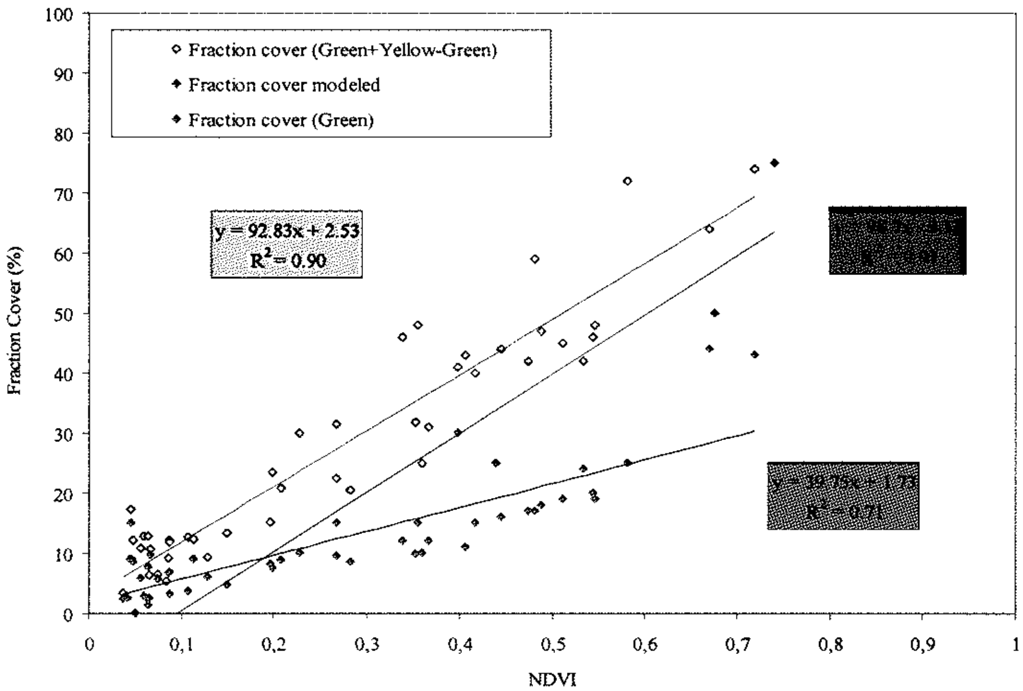

Figure 19. Regressions of fCover on NDVI, for modeled (in red), green (in green) and green plus yellow-green (in grey) fCover.

5.3 Indexes to distinguish vegetation and soils

The field spectral measures used to quantify the fCover were strongly affected by the soil brightness. With similar density of vegetation, the dark soils give lower NDVI values (Huete et al., 1985). In this sense, the Redness Index (RI) developed by Escadafal (1993) in arid lands, measures the saturation of soil color by means of the difference between the green (G) and red (R) bands (R-G/R+G).

The relation of RI and NDVI indicates the influence of the type of plant or the dominance of the vegetation against the soil (Figure 20). *Suaeda vera* and *Lygeum spartum* were distributed in all the range while *A. macrostachyum* concentrates in two different groups: the first group, with minimum NDVI and maximum RI, corresponds to dry and dispersed shrubs; the second group, with NDVI > 0.4 and RI < 0, corresponds to dense areas and greener plants.

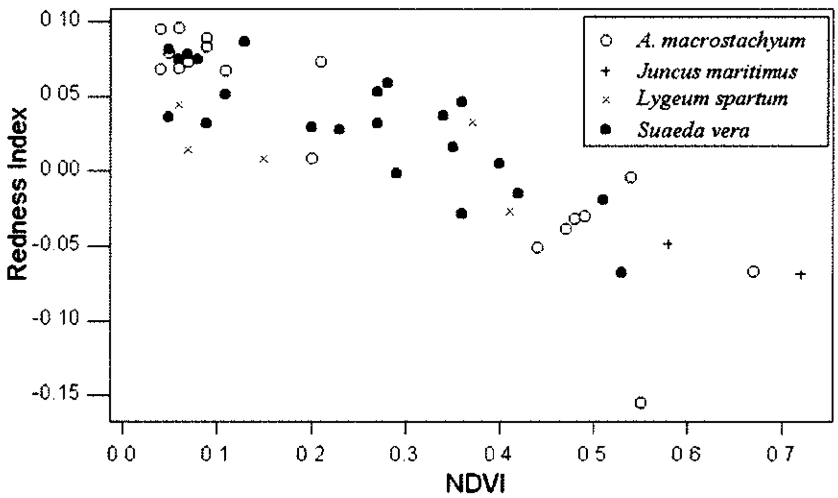

Figure 20. Scatter plot of RI and NDVI indexes for different plant species.

In contrast with RI, the Brightness Index (BI), also utilized in arid lands and defined as BI = $(G^2 + R^2 + NIR^2)^{1/2}$ (Escadafal and Bacha, 1996), allows establishing a reflectivity value of 35% as a threshold to separate bare soil and vegetation (Figure 21). BI < 35% identifies the sparse vegetation whereas BI for bare soil varies from 35% to 50%. BI decreases with soil moisture and increases with the occurrence of efflorescence or salt crust, despite the water content of salts.

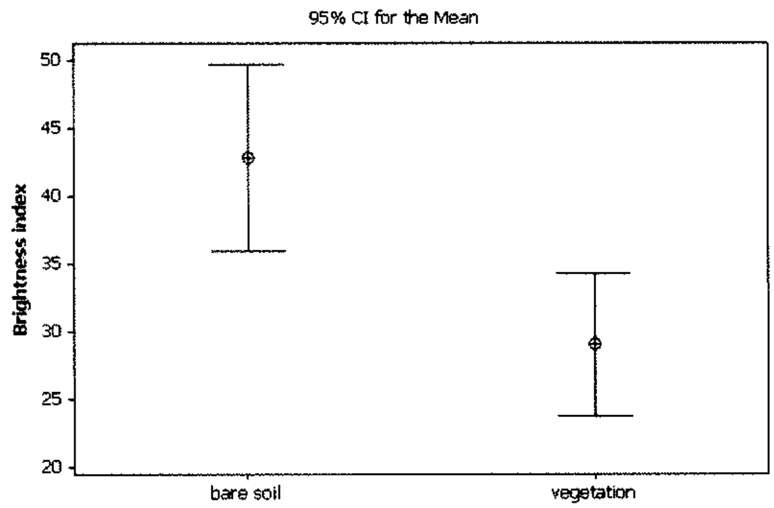

Figure 21. BI values distribution within a confidence interval of 95%, for bare soil and vegetation. The mean is also indicated.

BI index also shows differences in the spectral behavior of plant species (Figure 22). Halophytes such as *A. macrostachyum* and *Suaeda vera* clearly differ from other plants. Their low chlorophyll concentration decreases the VIS reflectance absorption and the RED boundary value resulting in BI < 30%, except if efflorescence occurs. BI is very high for *Lygeum spartum*, from 30% to 65%, giving similar values to the soil, in agreement with the yellow and grey colors observed in the field. *Juncus maritimus* had a very dark green providing a small range and BI values, from 15% to 20%. An additional factor influencing the BI values is the proportion of shadows produced by their branches and intertwines stems, being *Lygeum spartum* less affected.

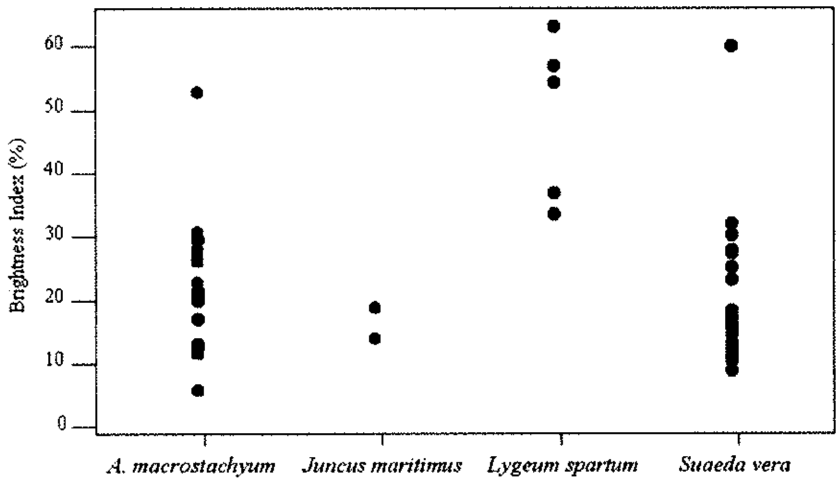

Figure 22. BI of different species studied.

To improve separation of plant species we put in regression BI on the color index (CI), defined as (R – G)/(R + G) (Houssa et al., 1996). Figure 23 shows that *Suaeda vera* is dispersed whereas *A. macrostachyum* concentrates from 10% to 30% of BI and between 0.15 and 0.35 of CI. The dark green colored plants like *Juncus maritimus* have high CI (> 0.39) and low BI (< 20%). The low variability of *Lygeum spartum*, around 0.2 CI, contrasts with its high BI and reflectance values. Bare soils, not represented in Figure 23, have a wide range of BI (20%-100%) and low values of CI (< 0.15), corresponding to the Munsell colors 10YR and 2.5Y.

RI, BI, and CI indexes allow studying the influence of the type of vegetation or its dominance, and are suitable to separate soil and vegetation. However, they are not useful to differentiate species of halophytes.

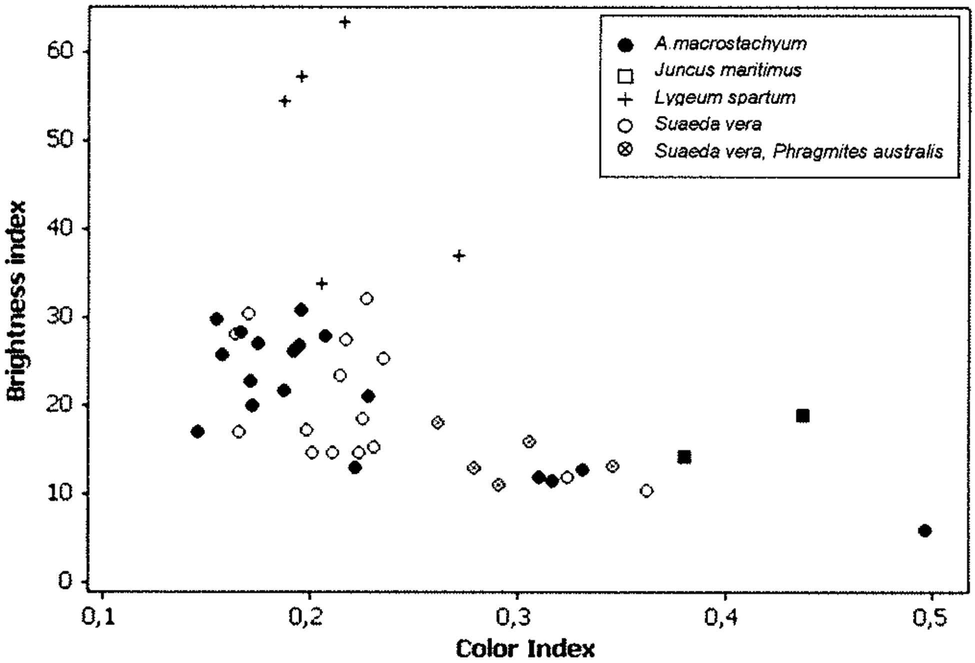

Figure 23. Scatter plot of BI and CI indexes for different plant species.

6. PROXIMALLY VERSUS REMOTELY SENSED SPECTRA

6.1 The mean signature of transects

Each transect surveyed in 2008 has been characterized by its mean spectral signature, obtained by computing the mean reflectance of each band, in all of the points of the transect. Figure 24a shows the mean spectral signature of bare soil transects T4 and T5 sampled in Agustín. The reflectance ranges from 20% to 30% in T4, and from 30% to 60% in T5. Photographs representative of these transects together with soil samples corroborate these differences. In T4, 8.4% of moisture results from the mixture of dry and moist soil with some efflorescence (Figure 24b); meanwhile, the dry soil homogeneously cover with efflorescence (Figure 24c) gives 4.2% of moisture in T5. This difference in moisture produces a decreasing of reflectance of 21% for band 4.

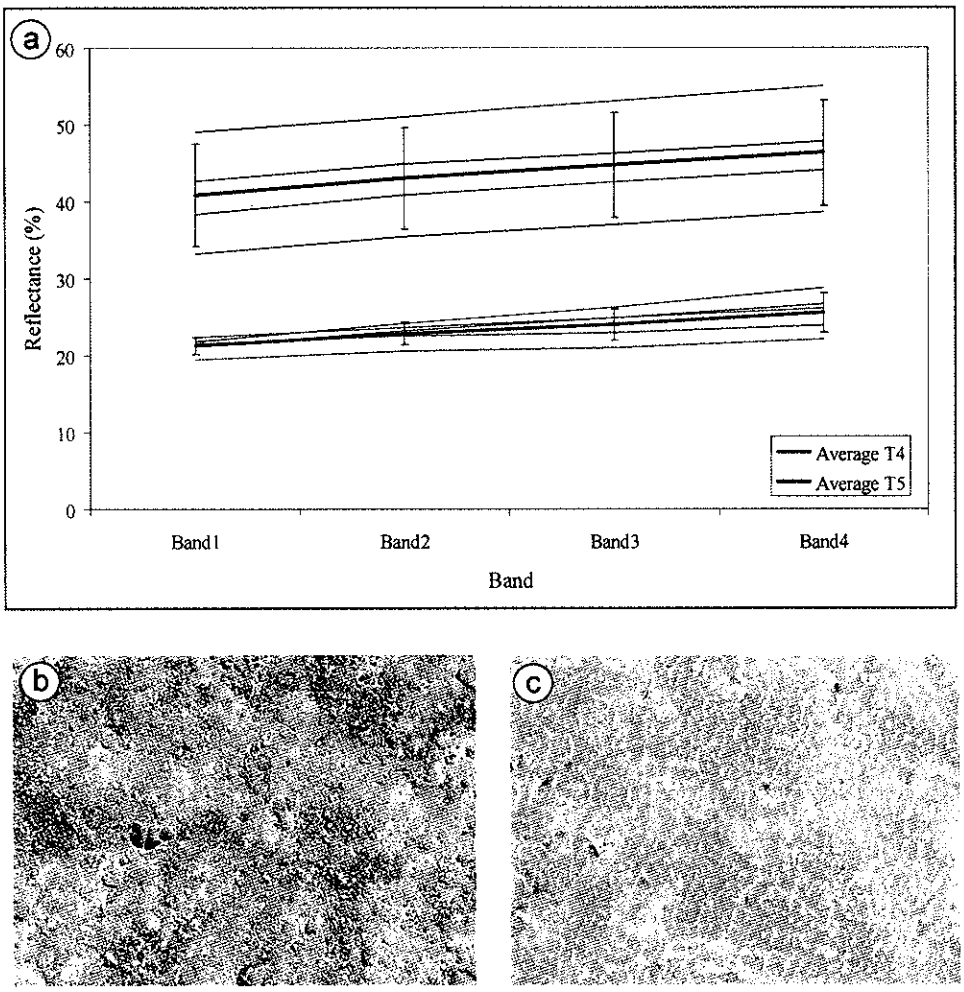

Figure 24. Reflectance of bare soil transects T4 and T5, in Agustin (a). The mean spectral signature (thick solid line) is represented together with the standard deviation in each band (vertical bars). Photographs are sampling points of T4 (b) and T5 (c).

Figure 25a shows the mean signature of T2, a densely vegetated transect in Farnaca. As shown by the different slopes the nine spectra have between B3 and B4, this heterogeneous transect includes points with different "états de surface". The mean reflectance is very low due to the shadows of the branches and the dark color of algal mats and soil. Band band 4 has the maximum value, < 16%. The relatively high band 4 / band 3 ratio indicates the dominance of the vegetation with different density (Figures 25b, and 25c).

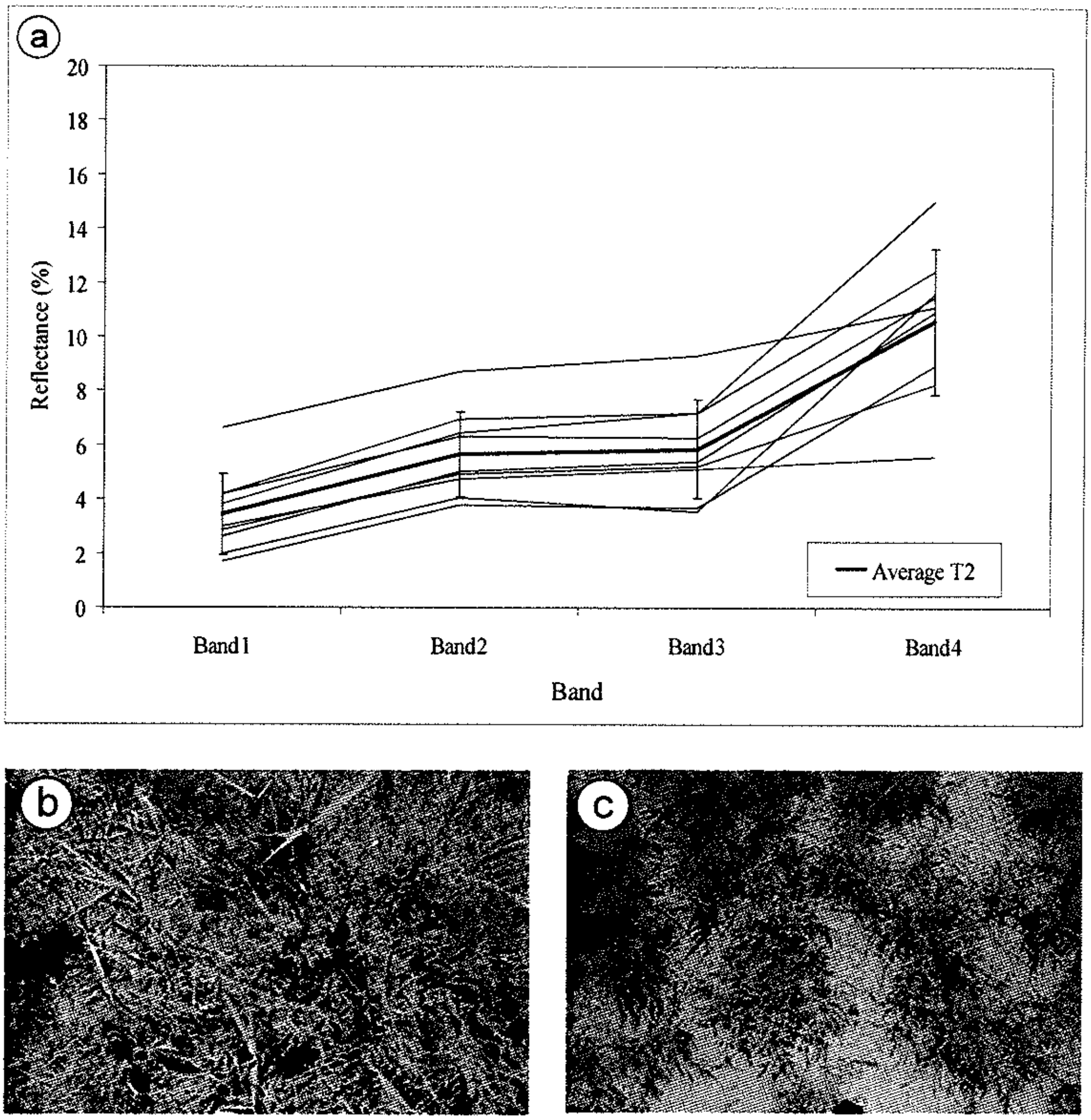

Figure 25. Reflectance of the 9 sampled points of the transect T2 in Farnaca (a); the mean reflectance (thick solid line) is represented together with the standards deviation (vertical bars). Vigorous vegetation including *Phragmites australis* with shadows (b) and a mixture of senescent and dry vegetation and bare soil (c).

The vegetated transect T2 of Agustín is a mixture of 5 points of bare soil and 2 points of vegetation. Bare soil points (Figure 26a, b) have flat signatures and the highest reflectance, from 10% to 20%. The low density of vegetation (Figure 26c) increases the difference of reflectance between points. The resulting mean signature is more characteristic of a dry soil. This underestimation of vegetation illustrates the difficulty of having well represented all the components of the soil surface (Table 3), and justifies the amount of points sampled in this study.

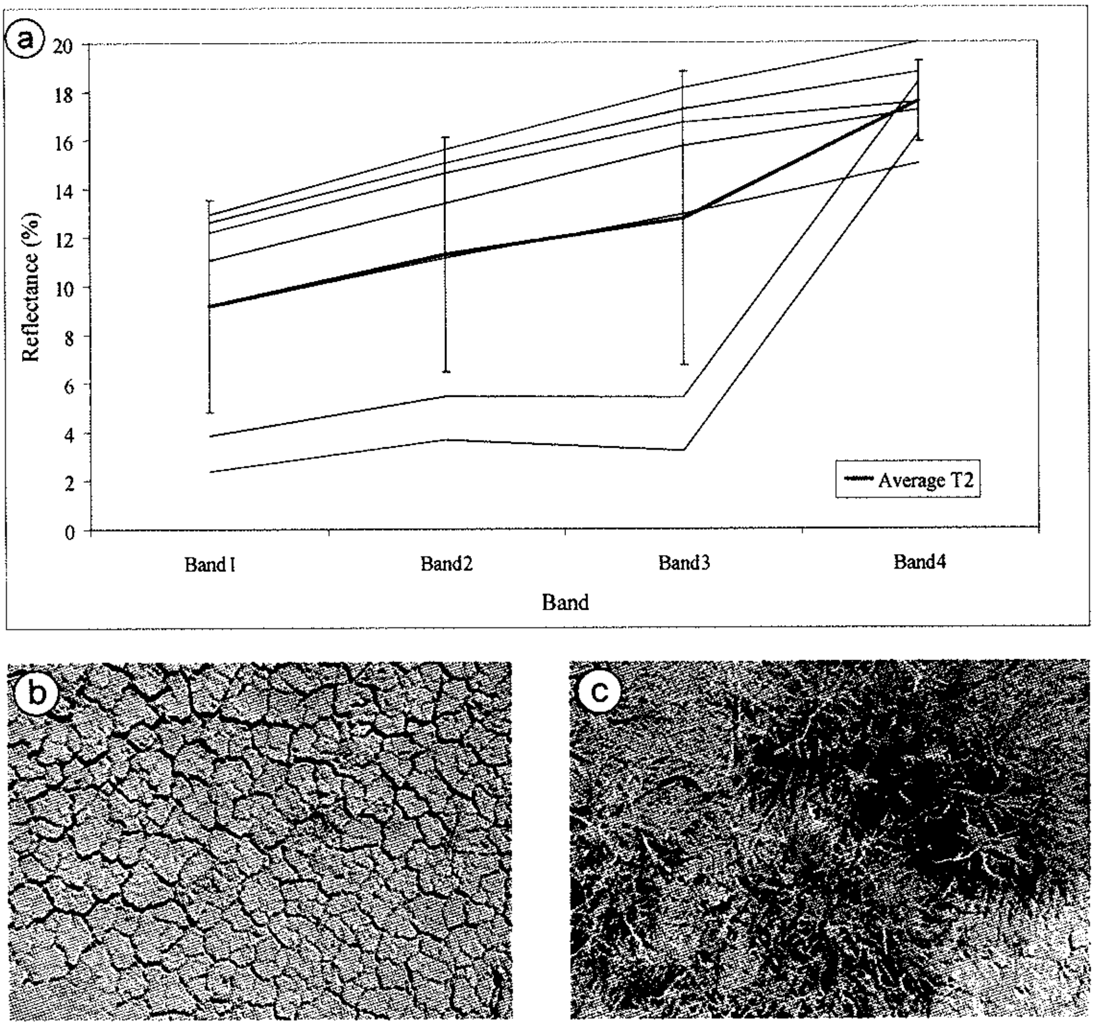

Figure 26. Spectral signatures of the points in the transect T2 of Agustín with standard deviation (a). Dry bare soil with desiccation polygons (b) and *A. macrostachyum* with dead plants and bare soil as background (c).

Figure 27a represents the reflectance of the transect T2 sampled in Pito, formed by dry bare soil (Figure 27b) and halophytic vegetation with a maximum cover of 35% (Figure 27c). The reflectance of the transect varies from < 5% to > 35%, and the standard deviation is very high. The vegetation was very vigorous; however, due to its low density the mean signature of the transect is dominated by soil reflectance.

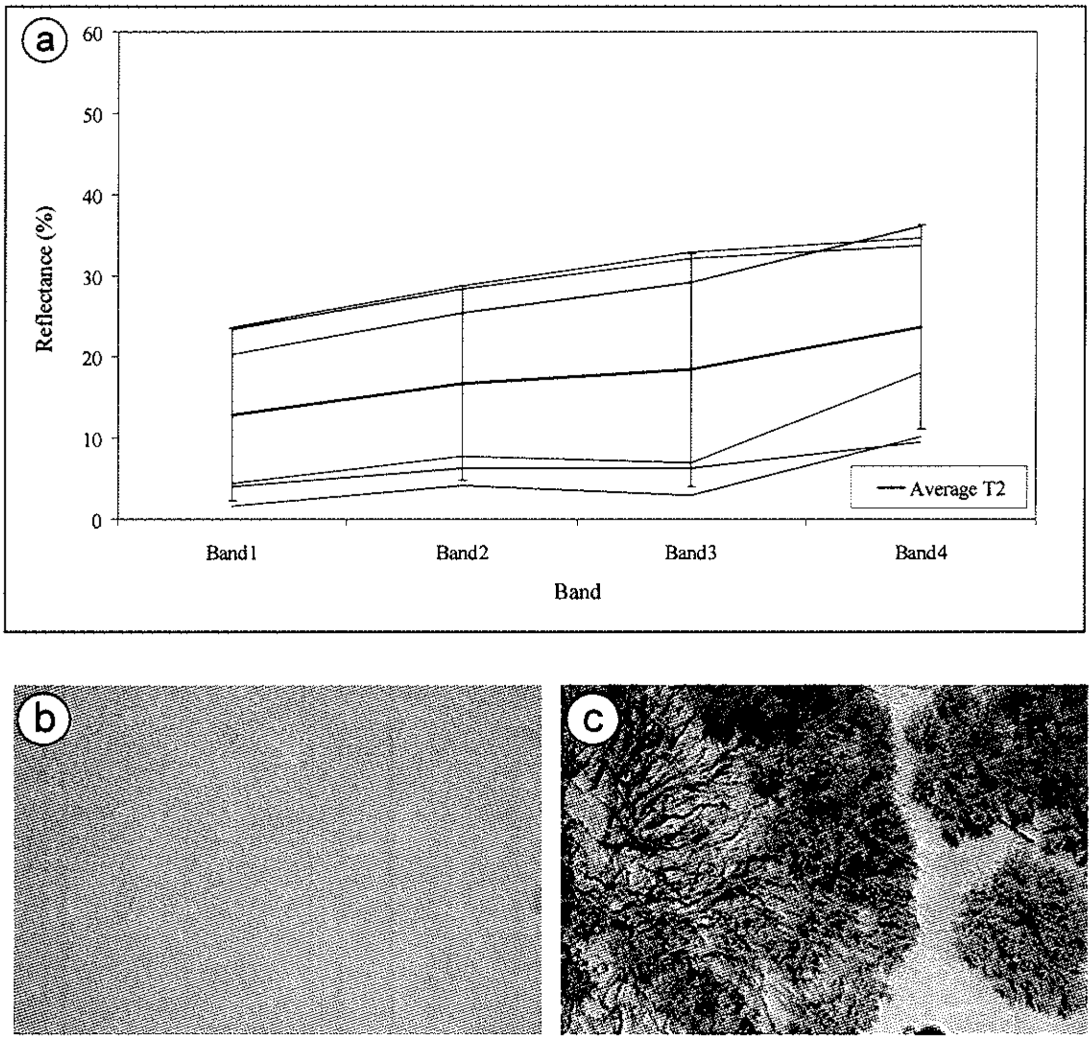

Figure 27. Spectral signatures of T2 in Pito (a). Dry bare soil (b) and *A. macrostachyum* with 35% percent cover (c).

These examples allow analyzing the suitability of using an averaged reflectance to characterize these environments and to relate the ground-based spectral measures with the satellite images. Our analysis forces to consider each component of the transect individually to compare it with high-resolution images.

6.2 The effect of spatial resolution on spectral characterization of "états de surface"

The reflectance of each pixel in the satellite images results from the contribution of different soil and vegetation conditions. The effects of spatial and spectral resolution on the identification of vegetation were analyzed by comparing Landsat (30-m pixel, 6 bands VIS-MIR) and ASTER (15-30-m pixel, 9 bands VIS-MIR) summer images (Table 1) with Quickbird (2.4-m pixel, 4 bands, VIS-MIR) and field spectral data. The dry summer in 2007, with absence of rains before the capture of these images, guaranteed similar dry soil surface conditions for all data sources.

NDVI derived from Landsat and ASTER images were put in regression on NDVI derived from Quickbird for the points surveyed in 2008 (Figure 28). ASTER and Quickbird data show a good determination coefficient, R^2 = 0.9, whereas Landsat relationship severely drops. This good correlation indicates the suitability of ASTER images to study the sparse vegetation. Probably, its wider spectral information (more bands) compensates its medium spatial resolution. ASTER performs better the ability to discriminate moisture, both from vegetation and soil, because of the amount of infrared spectral information provided by its seven bands (Table 1).

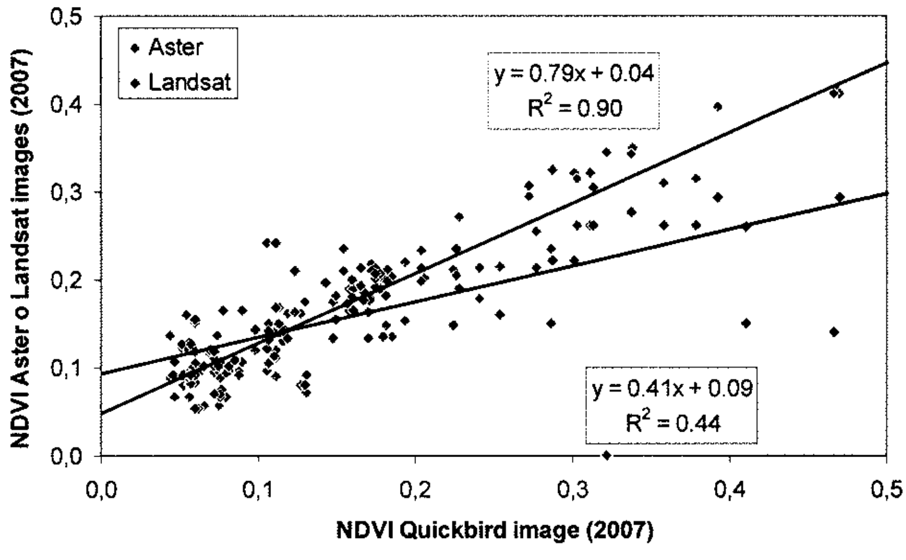

Figure 28. Correlation of NDVI extracted from ASTER and Landsat images on NDVI extracted from Quickbird image, in 2007.

Bare and scarcely vegetated surfaces with a NDVI ranging from 0.0 to 0.2 are the best correlated. As vegetation density increases, NDVI > 0.2, the Quickbird image detects better the vegetation due to its high spatial resolution. The schema of Figure 29 shows the dependence of the spectral dominance on the pixel size. Small patches of low-density vegetation surrounded by bare soil are identified with Quickbird but not with ASTER images. In these cases, the resulting ASTER reflectance is similar to that of bare surfaces.

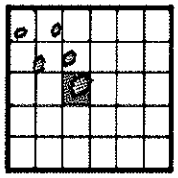

Figure 29. Schema showing the vegetation (green) and bare soil (white) components of one ASTER pixel with the Quickbird pixel size overlaid. In red, the only Quickbird pixel with vegetation as the dominant component.

6.3 Relationships between Quickbird images and field spectra

The relationship between the Quickbird reflectance in 2007 and in 2008 is an indicator of the spectral changes occurring between the two surveys. For the points sampled with OceanOptics in 2008 (Figure 30), we obtained a determination coefficient of 0.84 denoting a good correlation. The higher reflectance of bands 2 to 4 in 2007 is probably due to the dry surface confirmed by the rainfall records, whereas in 2008 the soil was moist. Due to 32 mm registered between the field survey and the satellite data acquisition in 2008, the surface conditions of field sampling in 2008 matches better that of 2007 image date.

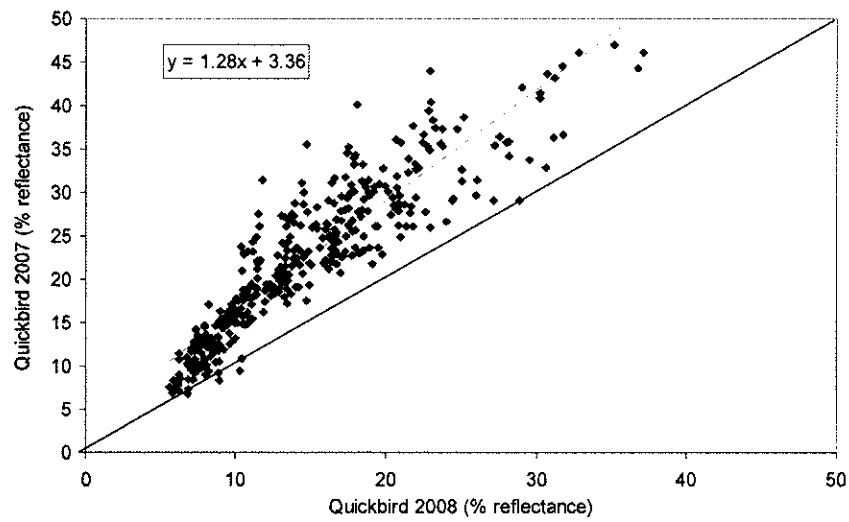

Figure 30. Regression of Quickbird reflectance in 2007 on that of 2008.

Regarding the relationship between field and image data, we have taken into account the different scale of the two spectral data sources. The transects sampled in 2008, with a length ranging from 24 m to 85 m, can extend along more than five Quickbird pixels, three or four ASTER pixels, and one or two Landsat pixels. The area represented by each Quickbird pixel (5.76 m^2) is almost 9 times the area measured in the field with the spectrometer (0.62 m^2). For these reasons, and taking into account the large variability observed, we did not apply the spectral mean of each transect but the spectra of individual points sampled along the transect.

The relationships between the spectrometer and the Quickbird reflectances were established using a 3 × 3-pixel window in order to reduce the incertitude of possible errors from the GPS used in the field survey and from image georeferencing. The regression of the averaged 3 × 3 window reflectance on the central pixel reflectance yielded a R^2 of 0.99 for bands 1, 2, and 3; and 0.98 for band 4, indicating the sensitivity of this band to local changes in vegetation or soil moisture.

Table 4 summarizes, for each band, the regressions of field spectral data (2008) on the Quickbird images of 2007 and 2008. R^2 is higher for band 3 and decreases for band 4 in both years. The low R^2 for bands 1 and 2 in 2008 is attributed to the differences in soil moisture; the low correlation of band 4 in both years is in agreement with the different phenological state of the vegetation derived from the annual distribution rains of rains.

Table 4. Regressions of the field reflectance measured with OceanOptics in 2008 on the Quickbird images in 2007 and 2008. Equations are y=ax+b, being a the slope and b the offset.

Quickbird	2007			2008		
Band	a	b	R^2	a	b	R^2
1	1.12	- 7.19	0.55	0.16	7.42	0.39
2	1.22	- 6.32	0.54	0.22	8.23	0.42
3	1.37	- 7.55	0.55	0.28	9.94	0.43
4	1.20	- 14.84	0.38	0.22	16.34	0.26

A low correlation (Figure 31) is obtained between the OceanOptics data and the Quickbird reflectance in 2007 and 2008. The determination coefficient R^2 is slightly higher in 2007 because of the dry conditions of field survey and image acquisition dates. In 2008, the rainfall reduced the Quickbird reflectance of the soil and vegetation against the dry conditions of OceanOptics data.

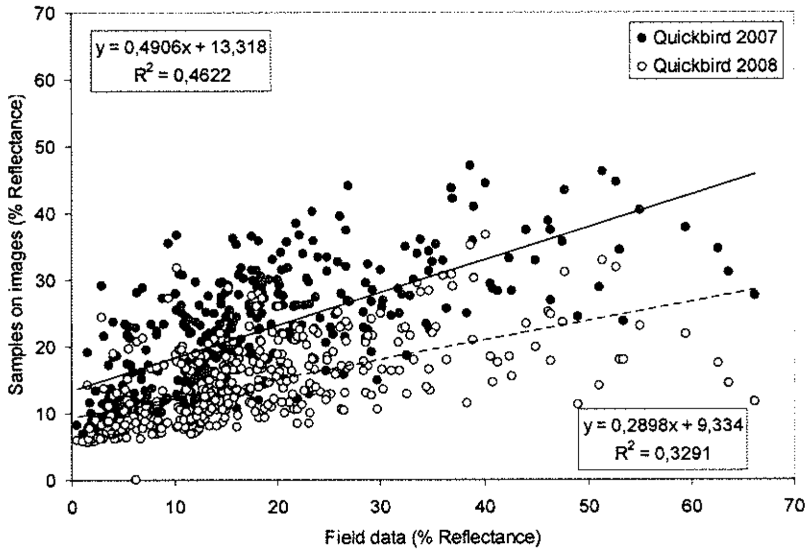

Figure 31. Scatter plot of the OceanOptics reflectance and that of the Quickbird images in 2007 and 2008.

6.4 Spatial-temporal characteristics of the reflectance in sebkhas

The reflectance of bare soil undergoes spatial and temporal changes caused by the occurrence of moisture, efflorescence spots of variable extent, algal mats, and salt crusts. Soil features are strongly conditioned by the microtopography, the water distribution within the wetlands, and the wind. Soil moisture presents a gradation from the edge of the wetland towards the bottom area. The morphology of the edge, varying from a net escarpment to a smooth slope in continuity with the crops, also conditions the vegetation and the soil features distribution. The bottom is occasionally waterlogged, inundated with a thin sheet of water, or is oozing water. These covers correspond to the *Water* and *Watery Ground* facies differentiated by Castañeda *et al.* (2005) using spectral data from Landsat images. Surface salt crusts and efflorescences are ephemeral and common in low areas.

We have related field data with Quickbird data from 2007 and 2008. Although field data were not collected simultaneously to the image acquisitions, the absence of rain records in the weather stations of the area guaranteed in 2007 similar soil surface conditions between dates. The irregular and stormy character of the summer rains registered in 2008 can explain the differences in reflectance observed between the north and south of the study area. The northern wetlands, such as Salineta, depict a more pronounced reflectance decreasing due to the soil moisture caused by local rains.

The band 4 is appropriate to illustrate the reflectance variation along selected transects. Figure 32 illustrates the variations of band 4 reflectance in Salineta NW-SE transect. It includes the bottom and the adjacent agricultural area behind the escarpment, used as fallow land in the date of the survey. The two spectral profiles of 2007 and 2008 represent dry and humid conditions, respectively. The reflectance variability is higher in dry than in humid year. In general, reflectance decreases towards the bottom excepting for the presence of salt crust and efflorescence patches. In 2007, several absorption peaks can be related to the algae occurrence near the escarpment, between the salt crust and the moist soil.

The most significant feature is the large difference in the bottom reflectance, between the two years. In 2007 reflectance > 50% in the salt crust (Figure 34a), whereas in 2008 the water happens at the same location. The reflectance increases towards the edges due to the decreasing of soil moisture and the occurrence of white soil (gypsum-rich dry soil).

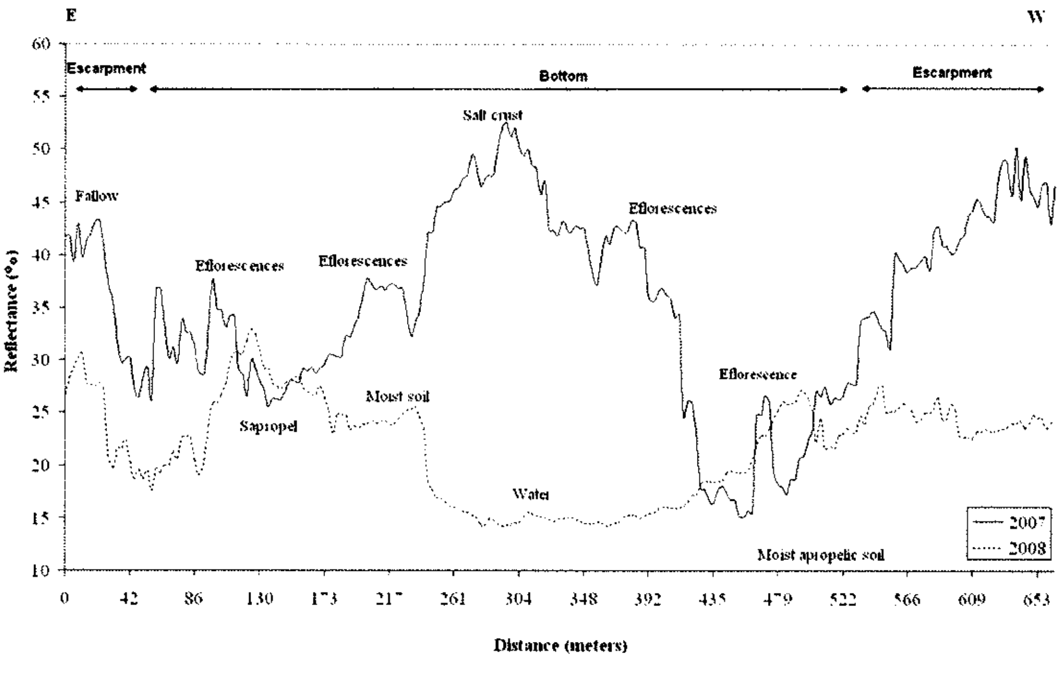

Figure 32. Reflectance of band 4 extracted from the Quickbird images of 2007 and 2008, along a NW-SE transect in Salineta.

The transect 653 m long located in Pito (Figure 33) extends from the NW edge with fallow land towards the SE vegetated area with sparse *Suaeda vera*. In the center of the transect, the playa soil is saturated, moist or with efflorescence. Similar to Salineta, the soil surface was dryer in 2007 than in 2008. Reflectance varies depending on soil color (probably related to gypsum content) and the absorption of vegetation. Two different areas are distinguished: (1) the mud flat with moist soil (corresponding to the Wet Ground facies in Castañeda et al., 2005) with similar reflectance in both years. (2) the dry flat with efflorescence and more variable reflectance, especially in 2007, with a series of absorption peaks of algae pigments. These algae develop between the desiccation polygons, are dark and have similar reflectance to halophytes (Figure 34b). At the SE end of the transect Arthrocnemum macrostachyum scrubs (decreasing reflectance) alternate with efflorescence, about 45% of reflectance.

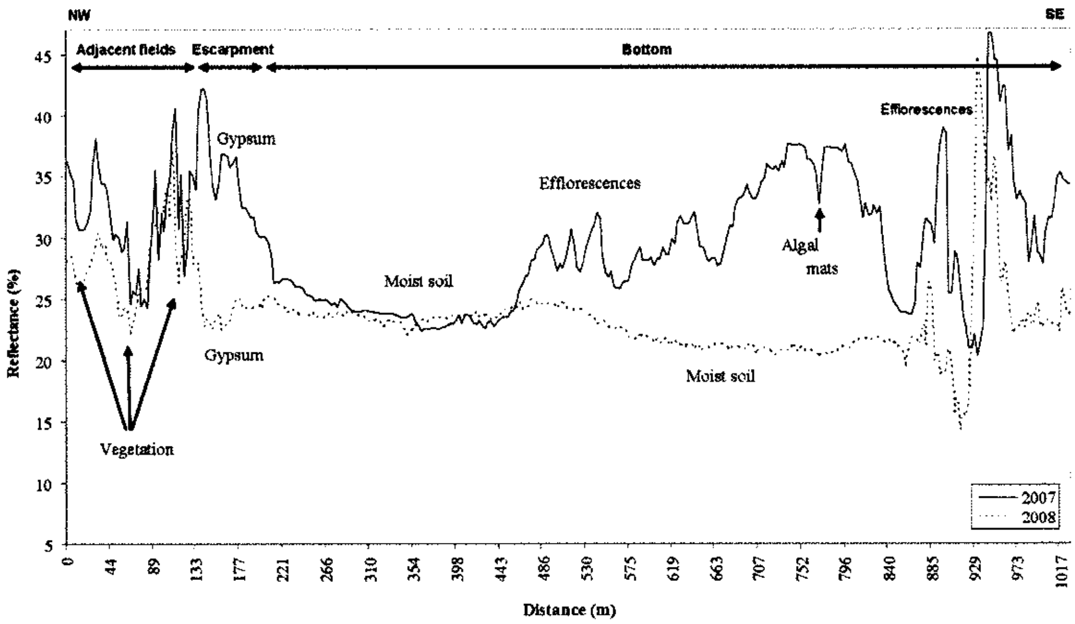

Figure 33. Reflectance in band 4 extracted from Quickbird images of 2007 and 2008, along a transect located in Pito.

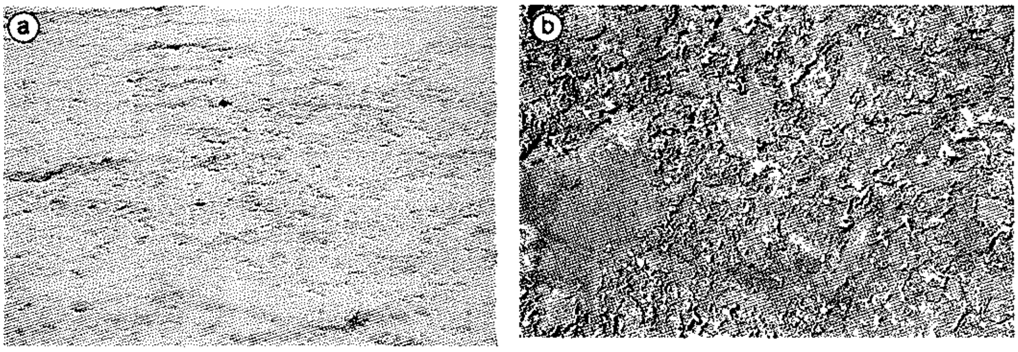

Figure 34. Salt crust in Salineta (a) and algal mats in Pito.

The remaining wetlands do not exhibit large reflectance changes in band 4, except the general decrease in 2008. This difference, computed in a transect of Agustín, ranges from 10% to 15% (Figure 35). Greatest spatial variation of reflectance occurred in 2007, related to bare soil, efflorescence or vegetation. The low reflectance of halophytes at the bottom strongly differs from that of gypsophytes located at the escarpment, with higher reflectance.

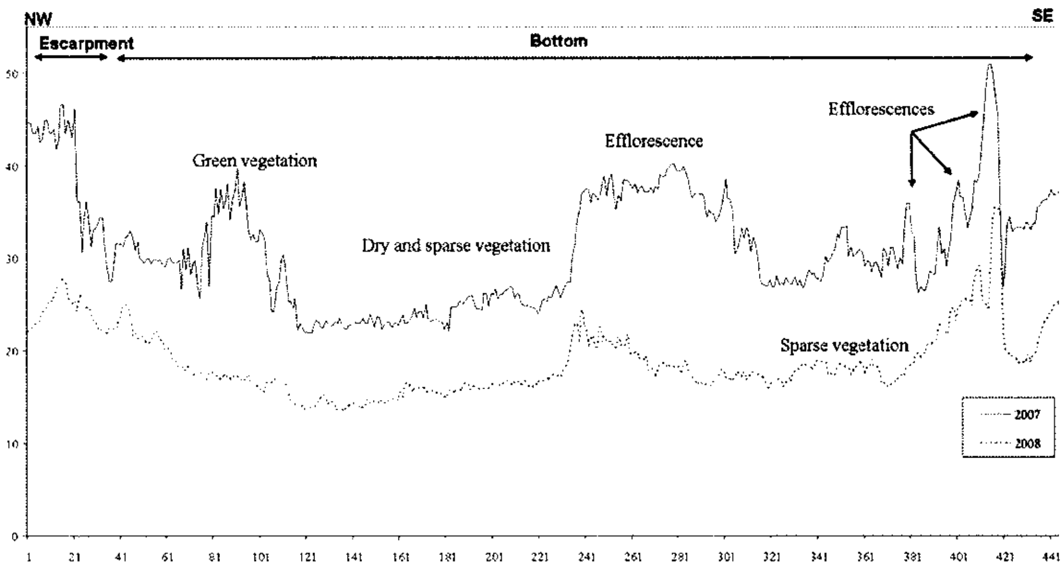

Figure 35. Reflectance of band 4 extracted from the Quickbird images of 2007 and 2008, along the transect of Agustín.

Figure 36 shows a EW transect in Farnaca 1301 m long. Dry and moist soils occur with algal mats and dark soil. The difference of reflectance values between 2007 and 2008 is about 5%-10% at the bottom. At the escarpments, calcareous or gypseous materials covered with vegetation show a larger difference between the two years.

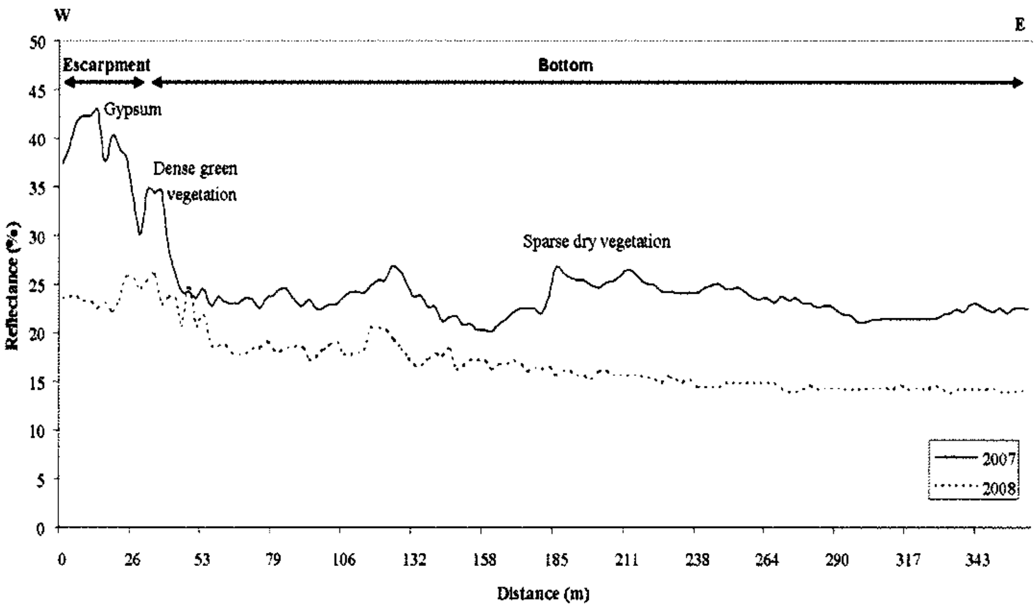

Figure 36. Reflectance of band 4 extracted from the Quickbird images of 2007 and 2008, along the transect in Farnaca.

The transect WE in Guallar (Figure 37) extends along 600 m, from the bare bottom towards the escarpment. Reflectance difference ranges from 2% to 30% depending on the moisture and the occurrence of efflorescence or white soil (gypseous). Moist soil with low reflectance occurs in lowlying areas. In 2007, the algal mats reduce the reflectance around the playa bottom. In the escarpment, the gypsum-rich bare soils alternate with gypsophytes increasing the reflectance in both years.

In general, dry years have larger variation in reflectance than moist years. The variation of reflectance depends on four main factors: (1) the soil moisture, (2) the kind of vegetation, (3) occurrence of efflorescence, and (4) algal mats.

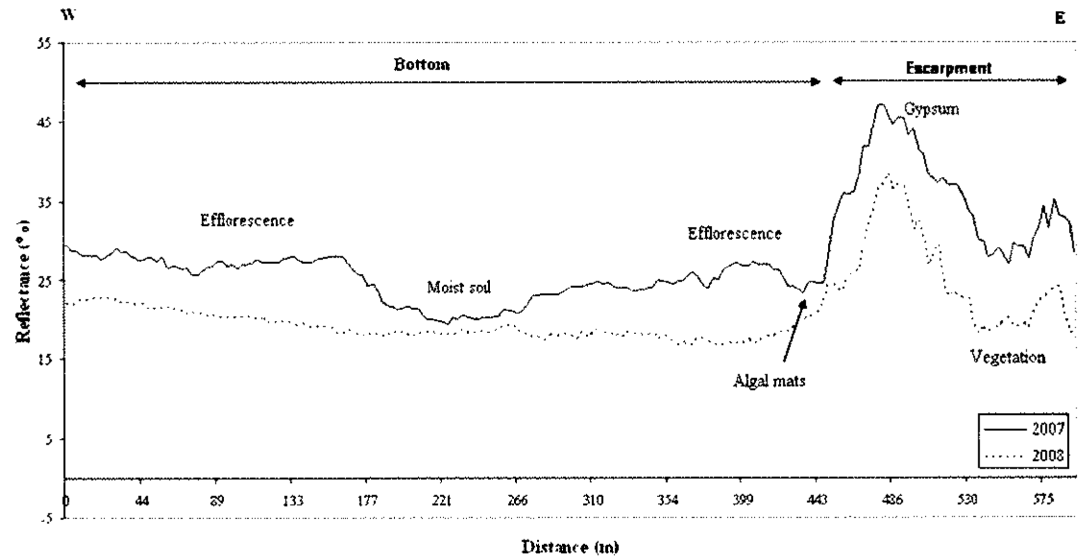

Figure 37. Reflectance of band 4 extracted from the Quickbird images of 2007 and 2008, along the transect located in Guallar.

7. SATELLITE DERIVED MAPS

The fraction of the "green" vegetation, fCover image, was derived from the QBwetland image by applying two equations. In one hand, we put in regression the fCover of pure sampled points obtained by means of CanEye on the NDVI calculated from spectrometer data, $NDVI_{fs}$, obtaining a good correlation with $R^2 = 0.97$ and the equation [1]:

$$fCover = 119.6 \times NDVI_{fs} - 6.34 \quad [1]$$

In the other hand, we put in regression $NDVI_{QB}$ from the image and $NDVI_{fs}$ from the field data, obtaining a coefficient of determination $R^2 = 0.99$, and the equation [2]:

$$NDVI_{fs} = 1.84 \times NDVI_{QB} - 0.15 \quad [2]$$

By relating 1 and 2 equations we obtained the fCover image or $fCover_{QB}$ by applying [1] and [2] equations:

$$fCover_{QB} = 119.6 \times (1.84 \times NDVI_{QB} - 0.15) - 6.34 \quad [3]$$

The resulting fCover image of wetlands has a continuum range of values. To obtain discrete classes of the vegetation based on its density we applied a decision tree method of classification. By integrating the $fCover_{QB}$ and $NDVI_{fs}$ in the classification tree (Figure 37), we classified the vegetation in terms of density, and the bare soil in terms of moisture; we separate also the water.

The $fCover_{QB}$ and $NDVI_{fs}$ images, named b1 and b2 in Table 5, were the input data. In the first step, soil and vegetation were segregated, using as threshold the nodes fCover > 0% and fCover < 0%. Table 5 summarizes the classes, subclasses, and thresholds (nodes) employed in the classification.

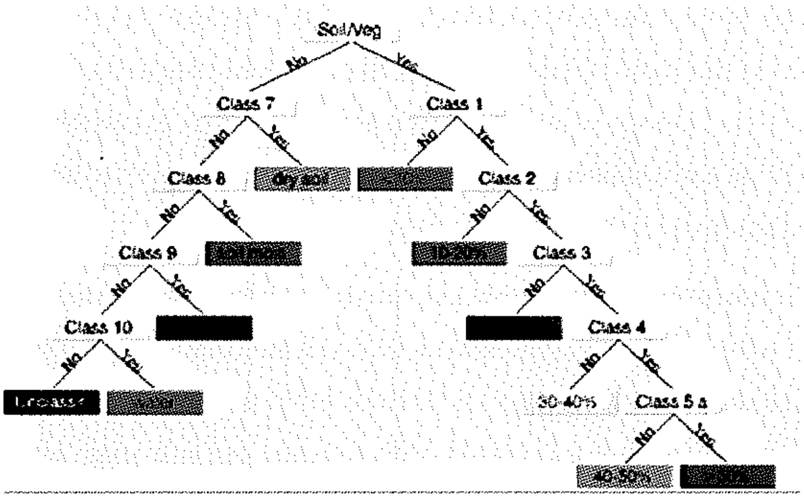

Figure 38. Decision tree sketch created to classify the QBwetlands image.

Table 5. Classes and nodes of the decision tree classification. Input data: b1 = $fCover_{QB}$, and b2 = $NDVI_{fs}$. GT: major, LE: minor.

Feature	Range (%)	Class name	Threshold (node) of ENVI decision tree-classification structure
Vegetation	Density cover		b1 GT 0
	<10	Rare vegetated	b1 GT 10
	10-20	Very sparse vegetated	
	20-30	Sparse vegetated	b1 GT 20
	30-40	Medium sparse vegetated	b1 GT 30
	40-50	Low densely vegetated	b1 GT 40
	>50	Dense vegetated	b1 GT 50
Soil	Gravimetric moisture		b2 LE 0.05 and b2 GT 0
	0	Dry soil	b2 GT -0.05
	< 20	Moist soil	b2 GT -0.3
	> 20	Saturated soil	b2 GT -0.5
Water	-	Water	b2 LE -0.5

The low-density cover of the vegetation and the high variability of its spectral response made difficult to establish the density thresholds by means of remotely sensed data. We established 10 classes: six classes of vegetation, from rare vegetated to dense vegetated, three classes of soil moisture, and water. The distribution of the classes of vegetation density shows a high coincidence with the delimitations of vegetation derived from the map of habitats given by botanists; however, the vegetation data from Quickbird is always lower in density.This disagreement is explained by the different method of estimation. The density cover obtained from ground photographs includes the photosynthetic (green and yellow-green) vegetation, whereas the visual estimation of density cover in the field includes also dry and senescent vegetation. This vegetation, even if part of the biomass, is spectrally similar to soil and is frequently included in the reflectance of the soil background. Therefore, the fCover image does not include all the biomass, excluding dry and senescent vegetation.

The soil classes are: (1) Saturated soil, for soil moisture greater than 20%, (2) Moist soil for soils with < 20% moisture; and (3) Dry soil for soils with gravimetric moisture equal to 0. Regarding the remaining soil features listed in Table 3, different features can give similar spectral response or NDVI. Efflorescence and salt crust decrease the NIR reflectance due to the water content in the salts, producing a negative NDVI. Both features result in spectral signatures similar to that of water or saturated soil. White soils rich on carbonates or gypsum can be mistaken for efflorescence, making difficult to interpret the reflectance or NDVI, especially of points with a mixture of vegetation and soil. Taking into account that our aim is to discriminate vegetation, we have not differentiated the occurrence of efflorescence and salt crust, which therefore can be included in Dry soil and Moist soil classes. In future works, these difficulties should be overcome with dedicated surveys of bare surfaces and by improving the image classification of soils (for example, by masking the vegetation).

Figures 38 to 43 display the classified fCover image of selected saladas with representative vegetation density covers. The maps of vegetation and the orthophotographs are showed together. We have applied a continuous green-to-red scale, which includes the whole range of vegetation density cover and bare soils. Maps also display the delimitations of vegetation established by the botanists during the 2004-2007 campaigns.

In La Playa (Figure 39), soil and vegetation distribution are in good agreement in the classified image and the orthophotograph. The greatest vegetation density cover, dense vegetated, produces the darkest areas in the orthophotograph. Red, orange and yellow colors in the map correspond to some groups of shrubs also visible in the orthophotograph. We observe a gradation of density cover related to the microtopography: the lowest vegetation density occurs near the bare soil, where the high moisture and salinity are limiting factors. A gradation of soil moisture is inferred, from the edges to the bottom. The ortophoto depicts in similar light color both the bare soil and the very sparse vegetation. The map of vegetation underestimate the density cover in this area, mapped as rare vegetated class, < 10% of density cover.

Figure 40 shows Salineta, characterized by its high variability due to frequent flooding and high salinity. In the southeast, the dense vegetated class corresponds to the habitat delineation mapped with 80%-90% of density cover. In the southern part, the dense vegetated class gradually decreases the density cover from the centre to soil which has white color (bare soil) in the orthophotograph (Figure 40b). As for the soil classification, the salt crust and efflorescence seen in the orthophotograph are not classified due to the masking effect of the moisture.

Salobral, degraded by the human pressure due to its proximity to the urban area, has an important density cover of halo-nitrophilous vegetation, especially in the north and west. The bare bottom is recognized in the orthophotograph (Figure 41b) and classified as moist soil and saturated soil (occasionally with water in other season). This wetland experiences a great variation of water occurrence along the year.

Farnaca (Figure 42) and Piñol (Figure 43) illustrate the good adjustment between the habitats drawn in the field by the botanists and the fCover image. Farnaca shows a gradation of vegetation density, from dense vegetated to rare vegetated, in the western area. In Piñol, the distribution of vegetation along the salada edge matches the delimitations of the habitats delineation map. However, in Farnaca the bottom is delimited with a 35% of vegetation, visible as sparse shrubs in the orthophotograph, but corresponds to the very sparse vegetated with 10% vegetation. This disagreement can be explained by the dry conditions of the vegetation during the field survey, underestimating the total biomass by spectral measures.

Figure 44 is an example of wetland invaded by crops. The classified image is a good identifier for the shrubs grouped close to the wetland edge. These groups are classified with high coverage as dense vegetated class and the cultivated areas are classified as dry soil.

The methodology employed, based on field and remote spectral data, is useful to extract the ranges of green vegetation percent cover from the satellite images. The resulting map of vegetation enables for simultaneous vegetation monitoring in a large number of wetlands, helping for the field surveys.

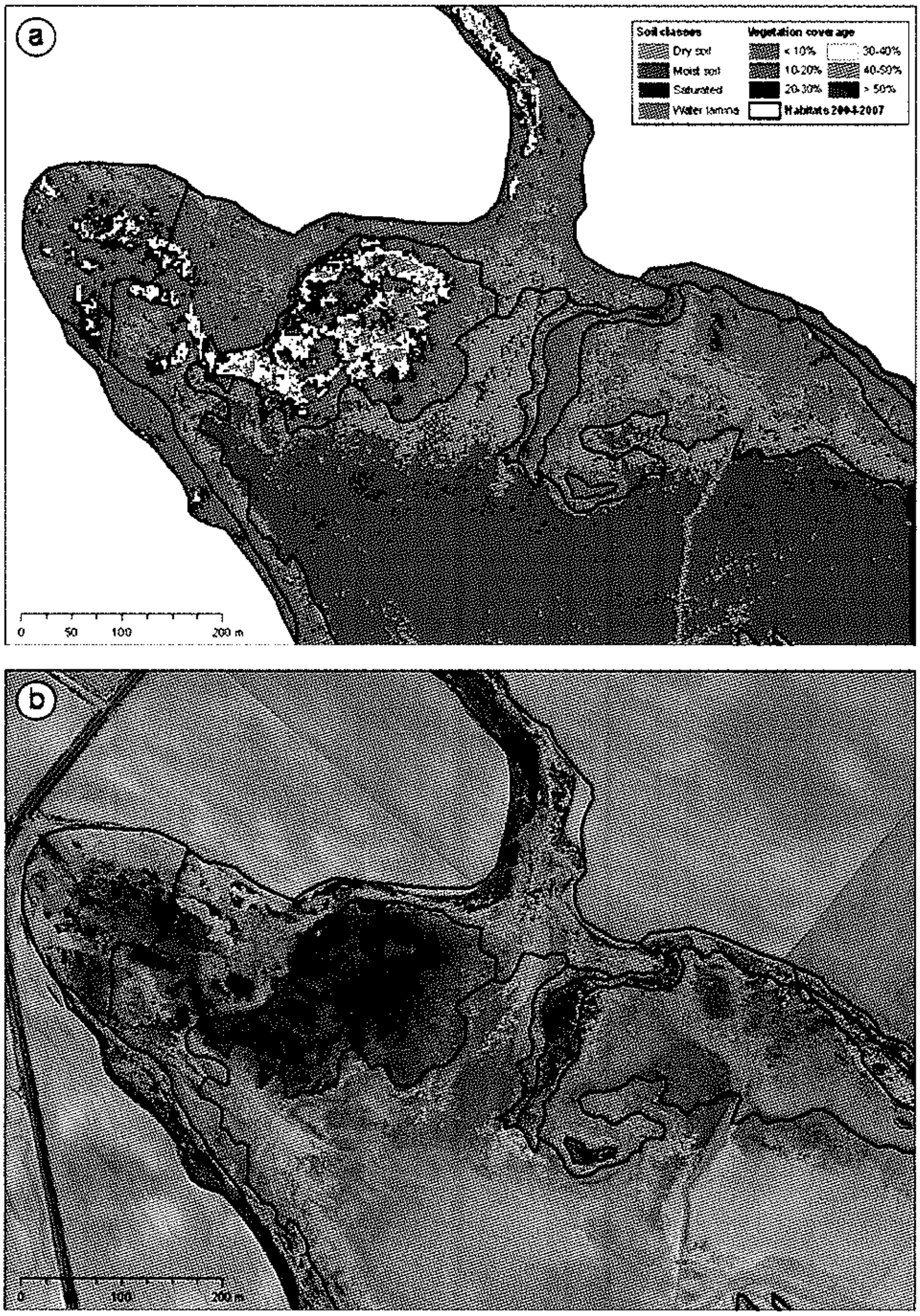

Figure 39. Northwest part of La Playa: (a) percent cover of vegetation and (b) orthophotograph from 2006.

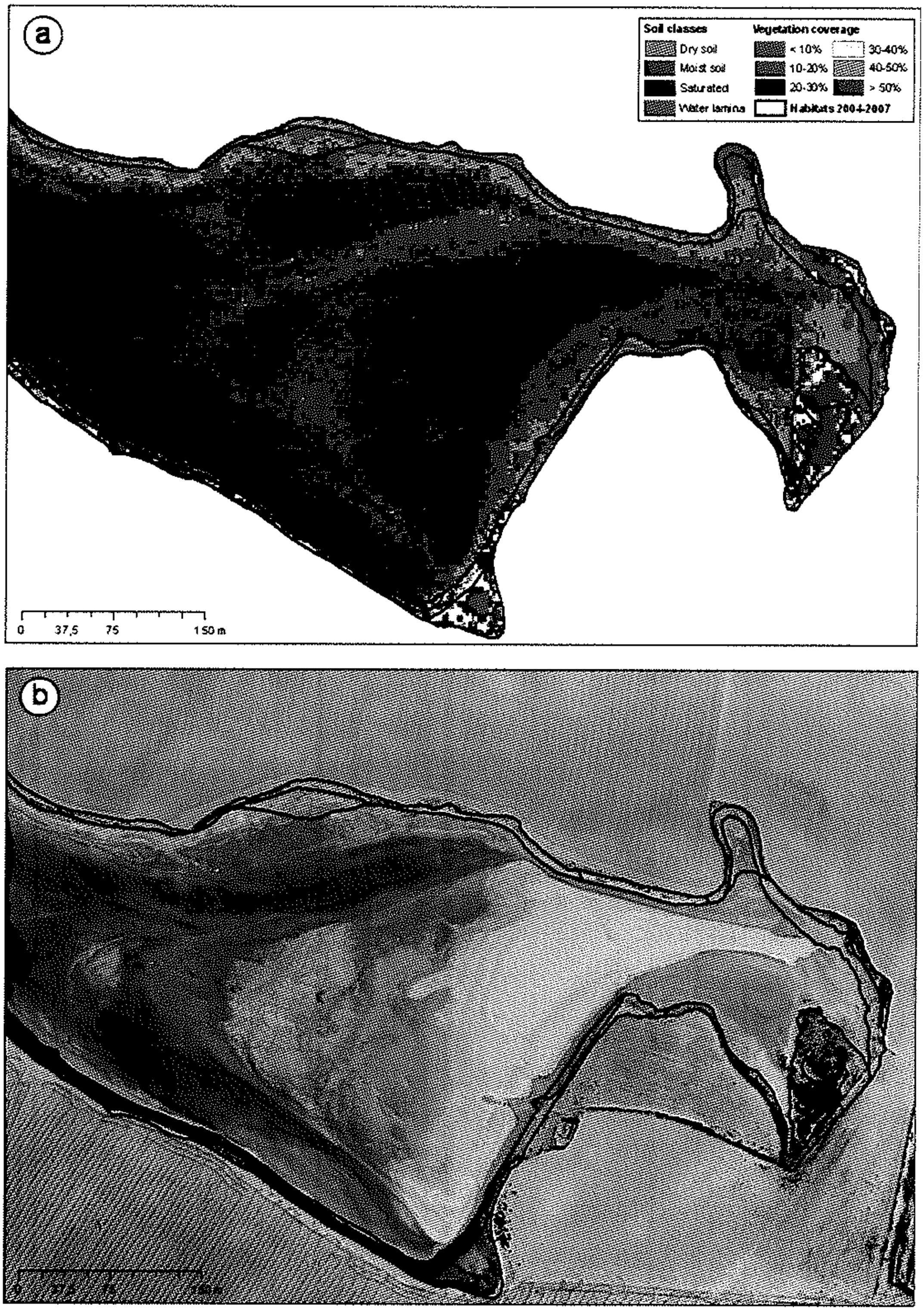

Figure 40. Percent cover of vegetation of Salineta (east part) (a) and orthophotograph from 2006 (b).

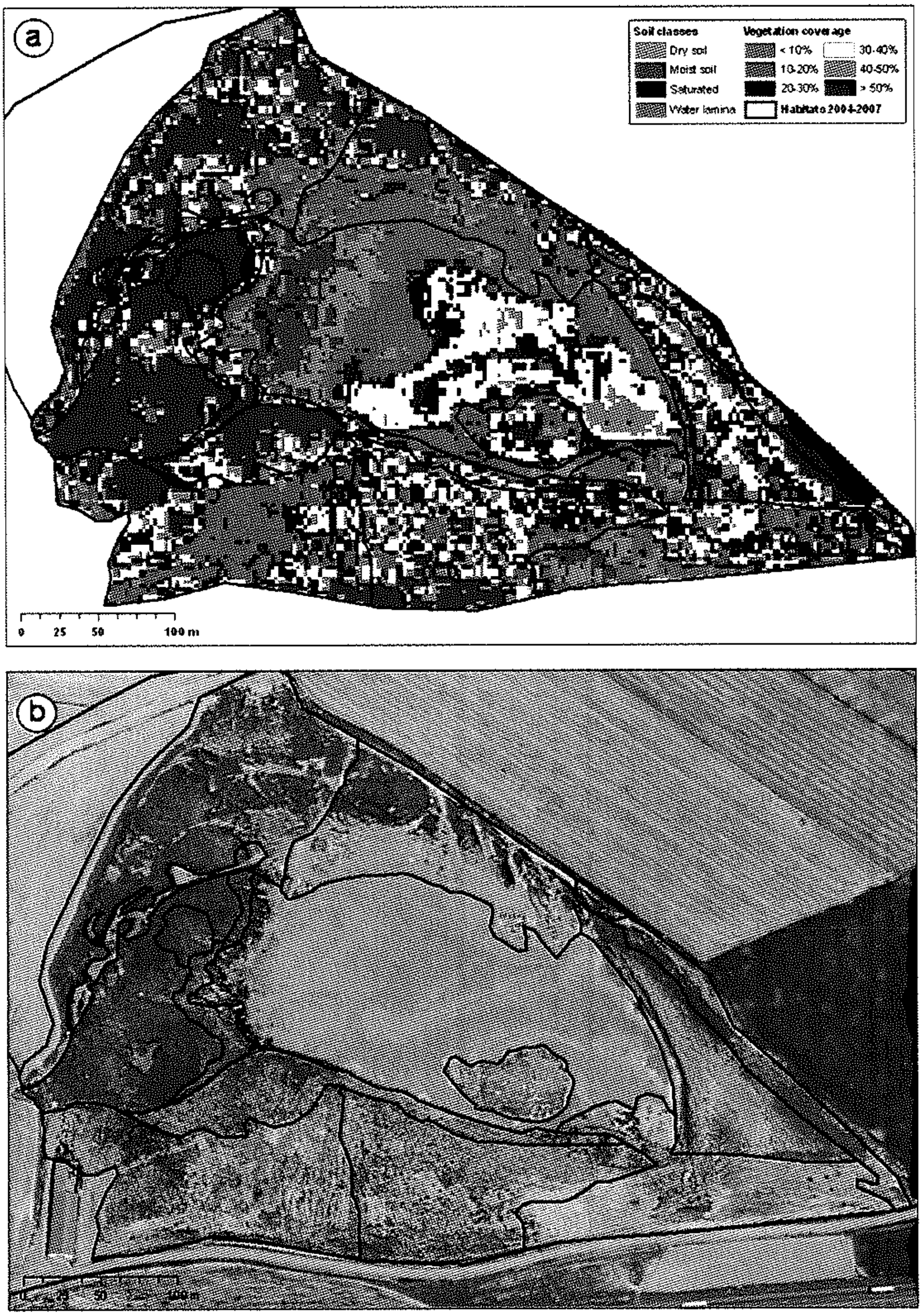

Figure 41. El Salobral: (a) percent cover of vegetation and (b) orthophotograph from 2006.

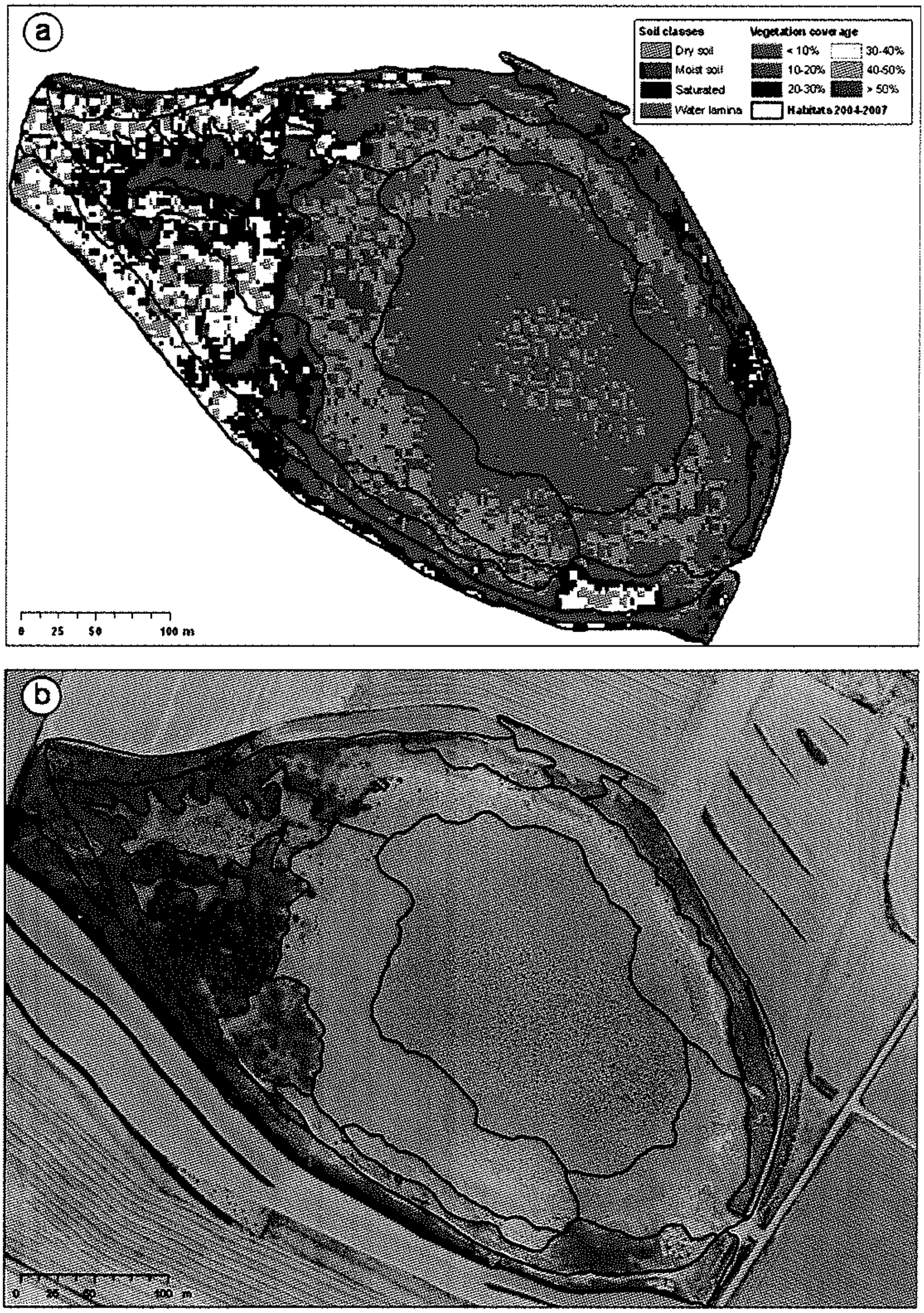

Figure 42. Farnaca: (a) percent cover of vegetation and (b) orthophotograph from 2006.

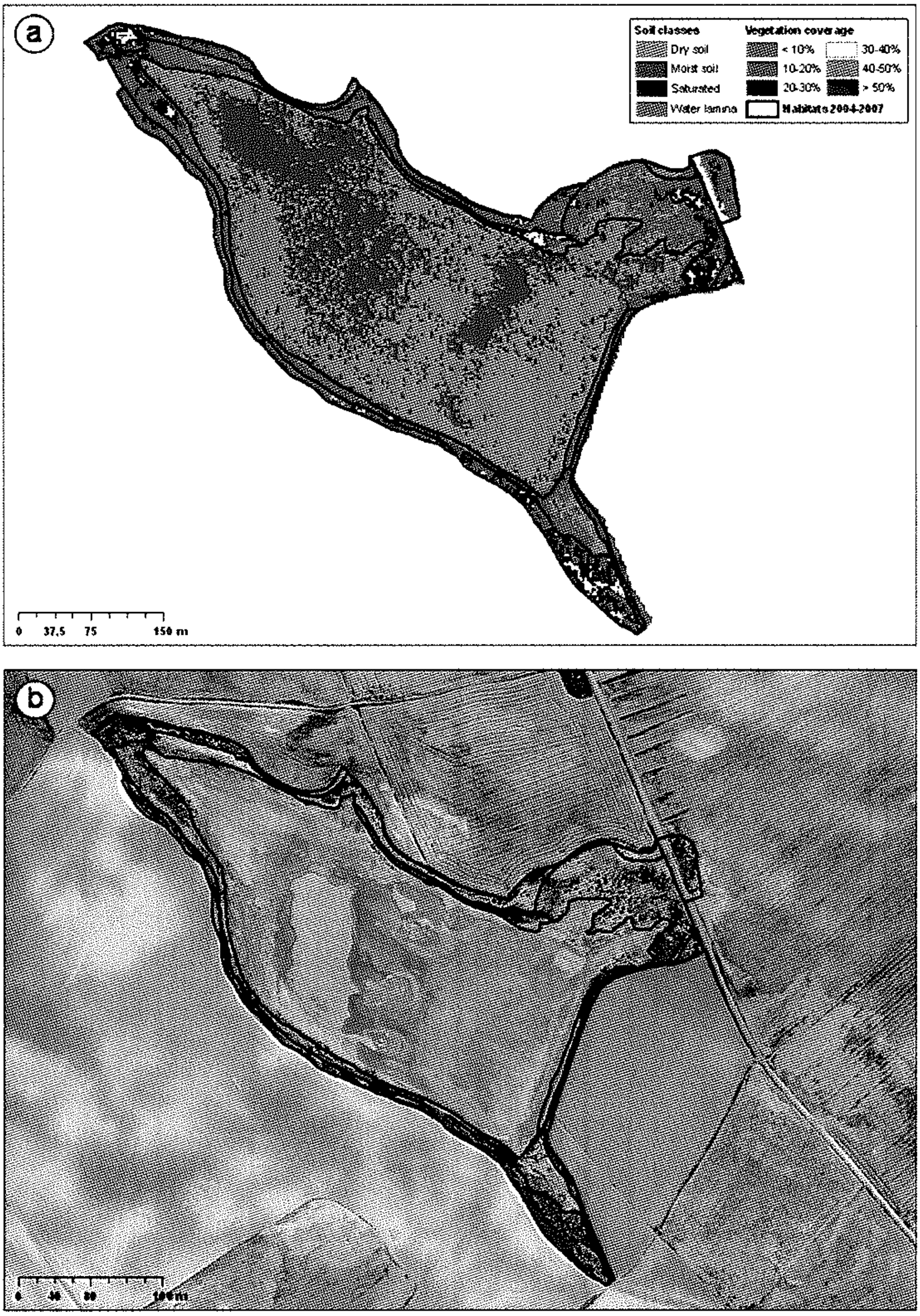

Figure 43. Piñol: (a) percent cover and (b) orthophotograph from 2006.

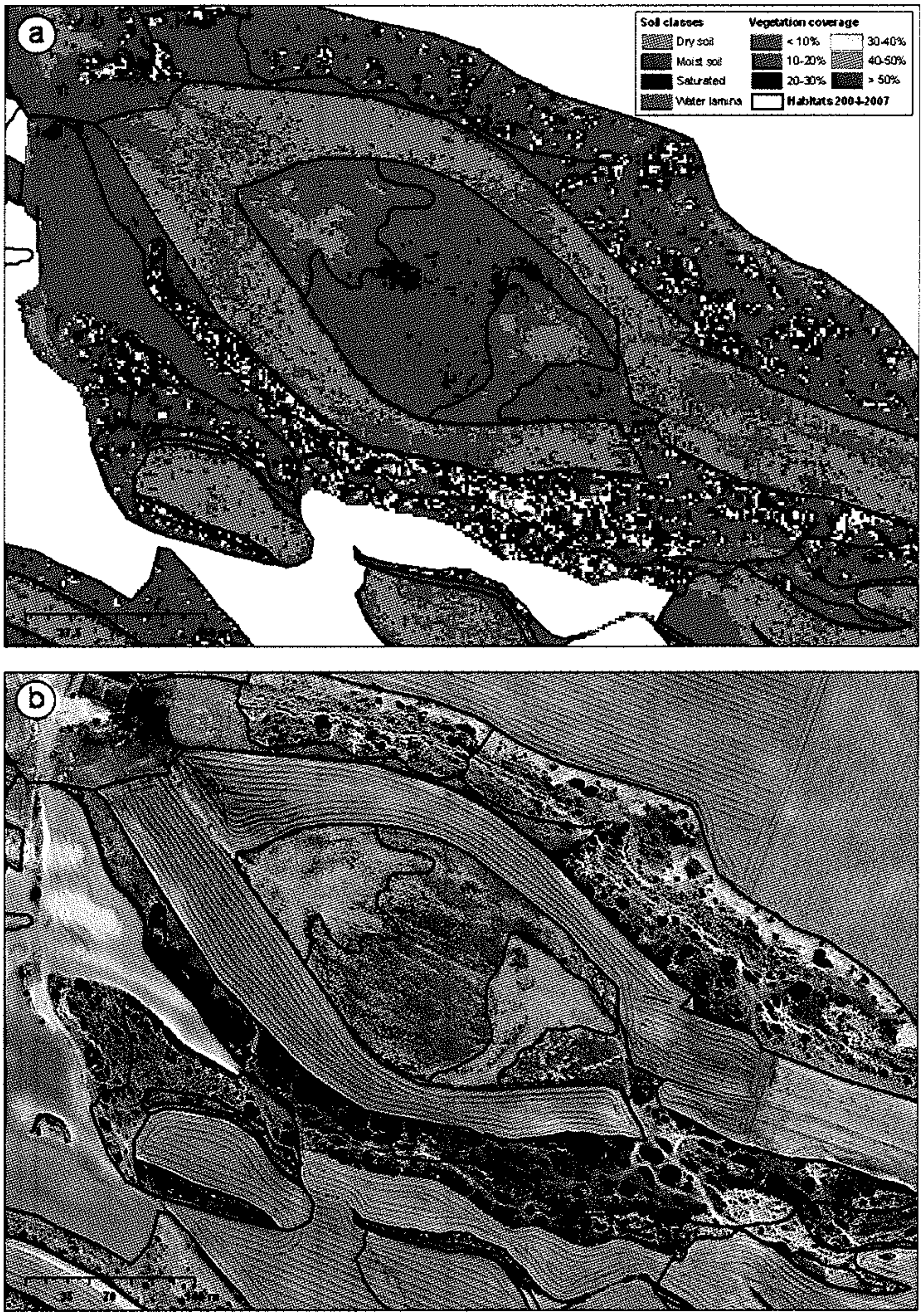

Figure 44. Clota Fonda cultivated: (a) percent cover of vegetation and (b) orthophotograph from 2006.

8. CONCLUSIONS

We have developed a methodology for the study of the vegetation in sebkhas using remote sensing. Our approach integrates spectral data from field measures and from satellite sensors, taking into account differences in spatial and spectral resolution. The high variability of surface conditions, and their unpredictability, make difficult to interpret the image spectra as well as to determine their temporal changes. The auxiliary data are crucial for the validation of the spectral measures, especially the ground photographs and the soil surface descriptions. The spectrometer measures have been contrasted with Quickbird, ASTER and Landsat images, obtaining the best relationship for Quickbird and ASTER images.

The spectra of the main components of the soil surface and the different "états de surface" of the sebkhas have been studied. A spectral library was created to help in the characterization of the different phenological states of the vegetation and the soil moisture. The vegetation density, type, and its phenological state together with the soil moisture and color, occurrence of efflorescences, sapropelic layer, and shadows are the main factors conditioning the reflectance variations of the surface.

Collecting field data about soil and vegetation is essential in the validation and classification of multispectral images. The spectral data of ground surveys and images must assemble similar surface conditions though they concern to the same or different date.

The classification of the ground photographs using Can-Eye was adequate if adapted to the characteristics of the sparse vegetation. Green and yellow-green parts of the plant must be considered in the vegetation indexes in order to obtain good relationships. The response of the vegetation to different spectral indexes helps in the identification of the components contributing to the reflectivity within the satellite pixel. The NDVI and Brightness Index were the most suitable to discriminate vegetation and soil.

The high variability of the soils and vegetation in the saladas is a limiting factor to select homogeneous areas. The low-density, scarcity, and the mixture of dry, senescent and green parts in the plant, contribute to the low spectral response of the vegetation. Only the pure pixels allowed for a good relationship between the NDVI's obtained from field and satellite data. The decision tree method classifies the vegetation density and separates different soil moisture conditions. The resulting vegetation image gives the distribution of the vegetation (green fraction cover) density cover though it underestimates the total biomass.

Remote sensing integrated with field data enables the study and monitoring of the vegetation in arid environments. To improve the spectral study of the vegetation is advisable the use of the middle infrared spectrum. The implementation of this method together with classification methods oriented to objects and the use of high-resolution panchromatic bands can be of interest in the delimitation of vegetation and soil features.

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CHAPTER 6. Conclusiones y consideraciones finales

Aunque cada uno de los capítulos incluye sus propias conclusiones y consideraciones, a continuación se presenta un epígrafe con un resumen de las mismas. Por último se expondrán unas líneas futuras de investigación y unas recomendaciones surgidas durante la elaboración de la presente tesis doctoral.

1. CONCLUSIONES Y CONSIDERACIONES FINALES

Se han inventariado 144 saladas, de las cuales 136 se han identificado en los fotomapas de 1927. Entre 1927 y 2006, la introducción de la maquinaria y la intensificación agrícola han producido importantes cambios en los usos del suelo y patrones de cultivo. Se han suavizado las formas del paisaje y con ello, los escarpes de los humedales facilitando la alteración de los hábitats que los componen. La escasa productividad derivada de la salinidad de los fondos ha llevado al abandono de algunas de las saladas que se cultivaban, reocupadas en la actualidad (96 saladas) por vegetación natural; otras se siguen cultivando. Los Sistemas de Información Geográfica (SIG) han sido clave para integrar la información correspondiente a cada una de las fechas de vuelo estudiadas (1927, 1957, 1984, y 2006). También han servido para el análisis cuantitativo.

La utilidad de las fotografía aéreas más antiguas ha quedado limitada por su estado de conservación y también por las diferencias de escala y las deformaciones geométricas. Todo ello ha obstaculizado la delineación exacta de los bordes, impidiendo cuantificar de forma más detallada los cambios de tamaño de los humedales a lo largo del tiempo. Los cambios acaecidos en el paisaje a lo largo de un periodo de 80 años se han estudiado gracias a la fotointerpretación. Los cuatro mapas formados (M1927A, M1957A, M1984A y M2006A) permitirán el seguimiento y gestión de los humedales en su localización estratégica respecto al regadío.

Se ha incorporado al SIG una cartografía de la vegetación de las saladas a escala detallada elaborada en campo. Esto ha facilitado el representar los hábitats protegidos teniendo en cuenta las políticas de conservación plasmadas en la Directiva Hábitats. Para levantar el mapa de hábitats, la Administración aragonesa ha adaptado esa Directiva estableciendo unos hábitats estándar en su Lista de Hábitats de Aragón (LHA), a los cuales se atiene nuestra cartografía.

La base de datos de la presente Tesis recoge las comunidades de plantas más representativas y su extensión a fin de facilitar su seguimiento. El 33% de los hábitats cartografiados está considerado para su protección según la legislación Europea, el resto incluye plantas de interés biogeográfico todavía no catalogadas. El mapa de hábitats producido consta de 1068 recintos compuestos por entre uno y cinco hábitats estándar, quedando cartografiada la mayor parte de la superficie con dos componentes. Los fondos salinos (LHA 14.02) de los humedales suponen uno de los hábitats de mayor extensión (29%) y son más del 75% de la superficie en 7 de las 15 saladas donde se ha cartografiado. El cultivo extensivo de cereal de secano (LHA 82.32) ha invadido 75 de los 96 humedales inventariados y supone el 40% del total de hábitats cartografiados. Los siguientes hábitats más representativos son los compuestos por halófitos, sobre todo *Suaeda vera* (LHA 15.6151) y *Arthrocnemum macrostachyum* (LHA 15.613). El regadío puede destruir unas 177 ha de vegetación de las 1600 ha totales cartografiadas, y el 51% de los hábitats considerados por la Directiva Europea. La mayoría de estos hábitats llevan halófitos u otras plantas de especial interés localizadas en 11 humedales dentro del regadío y en 8 a menos de 1500 m.

En las prospecciones de campo se ha tomado información estacional de los suelos donde se asienta *Arthrocnemum macrostachyum*. Se han estudiado las condiciones de humedad y salinidad de la superficie del suelo, muestreando la capa natural de los primeros centímetros del suelo, fácilmente separable, y la capa inmediatamente inferior hasta los 15 cm de profundidad. *A. macrostachyum* se desarrolla sobre suelos con amplios intervalos de salinidad, humedad y composición mineral. Tanto el contenido de sales como el de humedad varían de manera estacional y espacial en relación a la distancia a los bordes y la microtopografía. *A. macrostachyum* suele implantarse en suelos muy salinos, con variado contenido de yeso y con mucho magnesio. Aunque a grandes rasgos la distribución de la salinidad y la humedad, y sus cambio estacionales, condicionan la presencia de estos halófitos, las propiedades físicas del suelo junto a su teselado pueden restringir o favorecer su establecimiento y desarrollo, según interacciones complejas.

Finalmente, se presenta la metodología desarrollada para monitorizar cambios en la vegetación de estos ambientes de "sebkha" a través de la teledetección. El muestreo de campo, basado en medidas espectrales y de propiedades del suelo, es fundamental para evaluar la utilidad de los datos satelitales de diferente resolución espacial. La reflectancia medida con espectrorradiómetros ofrece información detallada sobre las variadas respuestas de los diferentes estados del suelo y las plantas. El análisis de las fotografías y las descripciones asociadas ha sido fundamental para interpretar los valores espectrales debido a la heterogeneidad de los estados superficiales del suelo y el diferente estado fenológico de la vegetación. La validación de los datos satelitales mediante los espectros de campo se ha completado explorando la capacidad de diferentes índices específicos de medios áridos.

Este tratamiento integrado ha permitido extraer de las imágenes Quickbird la distribución de la vegetación "verde" y su densidad relativa. Con ello, se confirma la utilidad de los satélites de alta resolución espacial para reconocer la vegetación de ambientes semiáridos y facilitar su seguimiento. Los cambiantes estados de humedad del suelo y la presencia de eflorescencias son factores limitantes al enmascarar o resaltar las propiedades espectrales de la vegetación.

2. FUTURAS LÍNEAS DE INVESTIGACIÓN Y RECOMENDACIONES

La elaboración de la presente Tesis ha generado futuras líneas de trabajo dentro de los distintos campos de investigación explorados. Entre ellos ya se ha iniciado el empleo de la radiometría de campo y la teledetección con imágenes de alta resolución espacial. La viabilidad de esta línea la apoya el interés y relativo bajo coste de las herramientas de cartografía espacial a distancia en el seguimiento de humedales y de sus hábitats. Dada la distribución de los hábitats en los humedales de medio árido, y el continuo y rápido cambio de los estados superficiales, las imágenes ópticas de alta resolución espacial son una fuente de información insustituible.

Este tipo de técnicas deben de desarrollarse para mejorar las relaciones entre la realidad de campo y la componente espacio-temporal. Es importante destacar que el tiempo transcurrido entre la toma de la imagen de satélite y la de los datos de campo limita el establecimiento de relaciones debido a la variación radiométrica inducida por cambios meteorológicos u otros. En esta línea convendría desarrollar una metodología fundamentada en un mejor conocimiento de los procesos que afectan a la componente suelo y estudiar con detalle su variabilidad espectral. Así, sería interesante cuantificar la influencia de la humedad y la aparición de eflorescencia en la reflectancia de la superficie del suelo medida en campo y en la imagen de satélite, para comprender el comportamiento espectral del suelo a escalas de detalle y mejorar su clasificación.

Persiguiendo este mismo objetivo, sería de interés un estudio detallado de los factores y componentes que afectan a la respuesta espectral de la vegetación, que limitan la diferenciación de especies y, en ocasiones, favorecen su confusión con el suelo. Habría que incluir, además, la variable estructural y direccional de la luz que afecta a la producción de sombras. El estudio espectral de la vegetación debería hacerse mediante sensores que incluyan el espectro del infrarrojo medio para registrar el estrés hídrico de la vegetación senescente o no fotosintética.

En cuanto a la clasificación de imágenes, deberían aplicarse técnicas como la orientada a objetos, capaz de integrar en la clasificación criterios geométricos e incluso capas de información vectorial, aspectos que complementan los criterios espectrales en zonas de vegetación dispersa. La incorporación en el SIG de herramientas que permitan modelizar la respuesta espectral de la vegetación, basadas en datos de campo y de teledetección, permitiría establecer una relación entre la información espacial y las características del suelo y la vegetación, capaz de mejorar el seguimiento y caracterización espacio temporal de estos ambientes.

Sería necesaria una cartografía detallada del suelo, geología y geomorfología de las saladas. Habría que mejorar el conocimiento de la relación entre hábitats y factores fisiológicos como la humedad y la salinidad del suelo.

Sería conveniente continuar actualizando datos e integrarlos en el Sistema de Información Geográfica generado para las saladas. Para mejorar la calidad de los inventarios históricos sería imprescindible la restauración de los vuelos fotogramétricos en papel o película y su publicación.

ANEJO 1.Capítulo II

Table A1. Inventory of the saladas and their occurrence in the different dates.

	Date of the inventory			
Saladas	**1927**	**1957**	**1984**	**2006**
Alforjeta I	x	x	x	x
Alforjeta II	x	x	x	x
Amarga Alta	x	x	x	x
Amarga Baja	x	x	x	x
Amarga I	x	x	x	x
Amarga II	x	x	x	x
Amarga III	x	x		
Amarga IV	x		x	x
Amarga V	x	x	x	x
Amarga VI	x	x	x	x
Amarga VII	x	x	x	x
Amarga VIII	x	x	x	x
Amarga IX	x	x	x	x
Amarga XIII	x	x	x	x
Amarga X	x			
Amarga XI	x			
Amarga XII	x			
Balsa Buena	x	x	x	x
Balsa de Gros		x	x	x
Balsa del Horno	x	x	x	x
Balsa Mas del Senén	x	x	x	x
Chamarqueta	x	x	x	x
Clota del Mas del Labrador	x	x		
Clota Berchel	x	x		
Clota Calvera	x	x		
Clota Catio I	x	x	x	x
Clota Catio II	x	x	x	x
Clota de Calabacera I	x	x	x	x
Clota de Calabacera II	x	x		
Clota de Ceferino II	x	x	x	x
Clota de Ceferino III	x	x	x	x
Clota de Gancho	x	x	x	x
Clota de Herrero I	x	x	x	x
Clota de las Barreras	x			
Clota de las Fuesas I	x		x	x
Clota de las Fuesas II	x	x	x	x
Clota de las Fuesas III	x			
Clota de las Nieves	x	x	x	x
Clota de Lifonser	x	x	x	x
Clota de Pansero	x	x		
Clota de Piriquet I	x	x		
Clota de Piriquet II	x	x		
Clota de Escobedo	x	x	x	x

Table A1 (cont.). Inventory of the saladas and their occurrence in the different dates.

Saladas	1927	1957	1984	2006
Clota de Serón I	x		x	x
Clota de Val Dao	x	x	x	x
Clota de Velilla	x			
Clota de Zaborros	x	x	x	x
Clota del Cabrero I	x		x	x
Clota del Cabrero II	x		x	x
Clota del Cabrero III	x	x	x	x
Clota del Ceferino I	x	x	x	x
Clota del Ceferino II	x	x	x	x
Clota del Chelader I	x	x	x	x
Clota del Chelader II	x	x		
Clota del Chelader III	x	x	x	x
Clota del Cura	x	x	x	x
Clota del Fraile	x	x		
Clota del Mas de Ganino	x			
Clota del Mas de la Talagueta	x	x		
Clota del Mas del Navarro	x	x	x	x
Clota del Mas del Pecado	x	x	x	x
Clota del Mas del tío Remigio	x	x		
Clota del Mudo	x			
Clota del Saso	x	x		
Clota del Saso Pito	x	x		
Clota del Tío Mariano Sena I	x	x	x	
Clota del Tío Mariano Sena II	x	x	x	
Clota Fonda I	x	x	x	x
Clota Fonda II			x	x
Clota Fonda III			x	x
Clota Jimena I	x		x	x
Clota Jimena II	x			
Clota Muchón	x	x		
Clota Pelada	x	x	x	x
Clota Pelada II	x	x		
Clota Ramilla	x	x	x	x
Clota Roya	x			
Clota Val del Pino	x			
Clota Yesera I	x	x	x	x
Clota Yesera II	x	x	x	x
Clota Yesera III				x
Clota Yesera IV		x	x	x
Corral Nuevo I	x	x		
Corral Nuevo II	x	x	x	x
Corral Nuevo III	x	x		
El Clot	x	x	x	
El Saladar	x	x	x	x
El Salobral	x	x	x	x
Hoya de Bernabé	x	x	x	x
Hoya de Catalino	x	x		

Table A1 (cont.). Inventory of the saladas and their occurrence in the different dates.

Saladas	1927	1957	1984	2006
Hoya de Corral Viejo I	x	x	x	x
Hoya de Corral Viejo II	x	x	x	x
Hoya del Correo I		x	x	x
Hoya del Correo II			x	x
Hoya de la Balsa Valdejuanico	x	x	x	x
Hoya de la Cucaracha I	x	x	x	x
Hoya de la Villa	x	x	x	x
Hoya de los Aljeces	x	x	x	x
Hoya de los Aljeces I	x	x	x	
Hoya de los Aljeces II	x			
Hoya de los Aljeces III	x			
Hoya de los Planas del Pez I	x			
Hoya de Piñol	x	x		
Hoya de Rafeler	x	x	x	x
Hoya de Rozas	x	x	x	x
Hoya de San Miguel	x	x	x	x
Hoya de Santiago	x			
Hoya de Serafín	x	x	x	x
Hoya de Valdecarreta	x	x	x	x
Hoya de Valdefrancín	x	x	x	x
Hoya del Codino	x			
Hoya del Pez	x	x	x	x
Hoya del Pez II	x			
Hoya del Vinagrero I	x	x	x	x
Hoya del Vinagrero II	x	x	x	x
Hoyo del Lugar	x	x	x	x
Hoyo de Benamud		x	x	x
Hoyo de Botones	x	x	x	
Hoya de Gramenosa	x	x	x	x
Hoyo de la Cruz	x	x	x	x
Hoyo de la Farnaca	x	x	x	x
Hoyo de la Viuda del Vacar	x	x	x	x
Hoyo de Rechina	x	x		
Hoyo de Valdespartosa	x	x	x	x
Hoyo del Lugar	x	x		
Hoyo Figuera	x	x		
Hoyo Garra	x	x	x	
La Salineta	x	x	x	x
Laguna de Guallar	x	x	x	x
Laguna de La Playa	x	x	x	x
Laguna de Pito	x	x	x	x
Laguna de Pozo Agustín	x	x	x	x
Laguna de Pueyo	x	x	x	x
Los Clotetes	x	x	x	x
Pitamar I	x		x	x
Pitamar II	x		x	x
Pozo Agustín III	x	x		

Table A1 (cont). Inventory of the saladas and their occurrence in the different dates.

Saladas	**1927**	**1957**	**1984**	**2006**
Saladar de Don Roque	x	x		
Salina de la Muerte	x	x	x	x
Salina de Piñol	x	x	x	x
Salina del Camarón	x	x	x	x
Salina del Pez	x	x	x	x
Salina del Rebollón	x	x	x	x
Salina del Rollico	x	x	x	x
Total	**136**	**115**	**101**	**96**

ANEJO 2.Capítulo IV

Table A2.1. Data of the *Arthrocnemum macrostachyum* soils sampled in July 2006.

Sample	Deep (cm)	Munsell color		Moisture	Temp.	EC, dS m^{-1}		meq L^{-1}							CCE (%)	Gypsum (%)	Total nitrogen (%)	Organic carbon (%)	Organic matter (%)
		Dry	Wet	(g/100g)	(°C)	1:5	1:10	Cl^-	Ca^{2+}	K^+	Na^+	Mg^{2+}	SO_4^{2-}	NO_3^-					
LPL0	0 to 15	10YR 6/3	10YR 4/3	10.60	35.70	19.30	11.46	73.02	30.76	1.76	86.63	26.36	104.97	0.08	24.20	17.82	0.19	1.28	2.20
LPL0	T	10YR 6/3	10YR 3/3	15.26		36.90	20.50	112.78	28.69	2.81	194.88	61.12	175.56			7.62			
LPL0	BT	10YR 6/2	10YR 3/3	13.76		15.60	9.40	53.44	32.14	1.56	62.64	21.37	74.02						
LPL1	0 to 15	10YR 6/2	10YR 3/3	13.54	28.80	19.90	12.10	82.83	33.98	1.40	80.27	44.01	99.79	0.08	21.93	39.16	0.11	0.79	1.36
LPL1	T	10YR 6/2	10YR 3/3	20.16		41.00	23.80	145.32	32.78	2.76	205.32	108.01	202.34			11.30			
LPL1	BT	10YR 7/2	10YR 4/3	14.97		19.10	11.90	82.36	35.93	1.76	69.16	46.32	79.26						
LPL2	0 to 15	10YR 7/3	10YR 4/3	15.52	29.20	16.50	10.50	67.06	31.78	1.14	62.46	39.51	106.06	0.03	18.34	49.04	0.08	0.61	1.05
LPL2	T	10YR 6/2	10YR 4/2	23.15		41.50	24.30	136.12	28.49	2.69	200.53	140.75	236.42			12.38			
LPL2	BT	10YR 6/2	10YR 4/3	22.24		14.80	9.30	53.95	33.08	1.18	49.59	34.80	77.51						
LPL3	0 to 15	10YR 7/3	10YR 5/3	21.01	29.40	18.00	10.50	55.28	29.16	1.20	70.11	40.30	113.29	0.02	23.72	31.39	0.13	0.72	1.24
LPL3	T	10YR 6/2	10YR 3/3	21.24		32.90	18.90	97.24	27.94	2.33	143.11	95.51	183.63			19.36			
LPL3	BT	10YR 6/2	10YR 3/3	25.53		15.10	9.30	50.10	31.14	1.74	55.24	32.91	81.32						
LPL4	0 to 15	10YR 7/2	10YR 4/2	29.17	32.00	25.10	14.50	111.50	39.05	3.56	101.92	35.66	81.64	0.08	14.98	47.20	0.10	0.43	0.74
LPL4	T	10YR 6/2	10YR 3/3	25.17		45.10	25.40	181.97	35.08	5.86	219.67	81.19	168.87			11.30			
LPL4	BT	10YR 7/2	10YR 5/3	28.67		18.30	10.60	74.62	38.32	2.89	64.38	21.86	65.87						
LPL5	0 to 15	10YR 7/2	10YR 5/3	14.32	32.00	15.90	9.20	58.96	33.85	1.21	57.70	23.08	77.66	0.04	14.65	55.35	0.07	0.42	0.72
LPL5	T	10YR 6/2	10YR 4/2	19.64		46.60	26.90	157.74	30.94	4.09	258.82	86.30	227.29			16.43			
LPL5	BT	10YR 7/2	10YR 5/3	18.04		13.80	8.70	52.83	33.98	1.87	51.76	20.88	64.89						
LPL6	0 to 15	2.5Y 7/2	2.5Y 6/2	4.73	32.20	8.50	5.60	31.72	37.55	1.17	26.78	8.50	49.63	0.01	15.50	53.89	0.05	0.32	0.55
LPL6	T	2.5Y 7/2	2.5Y 6/2	0.00		11.40	7.00	45.99	38.97	1.20	29.14	12.50	47.09			45.18			
LPL6	BT	2.5Y 7/2	2.5Y 6/2	6.94		6.60	4.50	19.28	38.02	0.97	14.44	7.29	45.72						

Table A2.1 (cont.). Data of the *Arthrocnemum macrostachyum* soils sampled in July 2006.

Sample	Deep (cm)	Munsell color		Moisture	Temp.	EC, dS m^{-1}		meq L^{-1}							CCE (%)	Gypsum (%)	Total nitrogen (%)	Organic carbon (%)	Organic matter (%)
		Dry	Wet	(g/100g)	(°C)	1:5	1:10	Cl^-	Ca^{2+}	K^+	Na^+	Mg^{2+}	SO_4^{2-}	NO_3^-					
LPL7	0 to 15	2.5Y 6/2	2.5Y 3/2	10.33	30.00	17.00	10.10	66.15	37.78	2.90	69.65	16.37	61.78	0.05	20.75	35.38	0.11	0.63	1.08
LPL7	T	2.5Y 6/2	2.5Y 3/2	19.83		36.60	20.80	162.51	37.28	5.70	174.00	46.97	109.23			19.16			
LPL7	BT	2.5Y 6/2	2.5Y 3/2	16.23		14.50	8.60	53.50	34.83	2.40	51.76	12.74	59.71						
PTO1	0 to 15	2.5Y 6/2	10YR 5/2	12.49	27.70	16.20	9.50	71.98	41.09	2.66	64.07	13.33	60.60	0.02	45.27	12.65	0.08	0.50	0.87
PTO1	T	2.5Y 7/2	10YR 5/2	14.10		17.00	9.60	65.13	37.38	2.56	58.29	15.75	60.47			36.33			
PTO1	BT	2.5Y 7/2	10YR 5/2	13.60		15.30	9.00	59.39	35.83	2.76	56.98	13.08	58.80						
PTO2	0 to 15	2.5Y 6/2	2.5YR 4/2	13.69	30.30	17.60	10.50	72.41	39.19	2.94	69.87	13.89	53.04	0.03	34.22	23.65	0.08	0.53	0.92
PTO2	T	2.5Y 7/2	2.5YR 4/2	30.23		14.70	8.90	55.65	35.48	2.53	52.20	13.94	60.93			38.16			
PTO2	BT	2.5Y 7/2	2.5YR 4/2	23.50		18.00	10.30	71.07	37.62	3.43	63.51	14.97	61.92						
PTO3	0 to 15	2.5Y 6/2	2.5YR 4/2	12.47	31.50	18.20	10.70	75.35	41.41	2.87	66.70	24.72	57.13	0.11	41.49	22.14	0.08	0.46	0.80
PTO3	T	2.5Y 6/2	2.5YR 4/2	15.75		29.00	16.90	127.40	36.78	4.58	114.84	52.73	96.91			17.77			
PTO3	BT	2.5Y 6/2	2.5YR 4/2	11.60		16.70	9.80	67.97	38.32	2.86	59.59	15.61	61.24						
PTO4	0 to 15	2.5Y 7/2	2.5Y 6/2	7.09	26.90	4.90	3.60	10.77	33.99	0.76	10.74	4.53	47.75	0.01	18.34	67.53	0.04	0.21	0.36
PTO4	T	2.5Y 7/2	2.5Y 6/2	3.49		2.50	2.30	1.07	30.84	0.23	1.04	1.34	35.52			71.62			
PTO4	BT	2.5Y 7/2	2.5Y 6/2	5.04		3.40	2.80	4.25	31.79	0.41	4.67	2.24	39.48						
PYO1	0 to 15	2.5Y 7/2	2.5Y 6/2	5.62	29.80	4.10	3.20	7.27	33.40	0.30	7.52	4.81	46.69	0.01	14.84	72.67	0.06	0.23	0.40
PYO1	T	2.5Y 7/2	2.5Y 6/2	4.44		2.40	2.30	0.40	31.34	0.05	0.31	1.59	35.52			57.54			
PYO1	BT	2.5Y 7/2	2.5Y 6/2	6.20		5.60	3.90	11.65	30.94	0.54	13.81	6.85	46.78						
PYO2	0 to 15	2.5Y 7/2	2.5Y 6/2	14.37	28.80	12.60	8.30	44.78	37.58	1.41	41.25	13.44	58.17	0.05	16.45	64.12	0.04	0.19	0.32
PYO2	T	2.5Y 7/2	2.5Y 6/2	13.37		15.10	7.20	47.96	33.58	1.18	49.15	16.95	65.04			63.79			
PYO2	BT	2.5Y 7/2	2.5Y 6/2	15.38		12.00	7.30	41.95	34.98	1.28	42.63	13.37	59.56						

Table A2.1 (cont.). Data of the *Arthrocnemum macrostachyum* soils sampled in July 2006.

Sample	Deep (cm)	Munsell color		Moisture	Temp.	EC, dS m^{-1}		meq L^{-1}							CCE (%)	Gypsum (%)	Total nitrogen (%)	Organic carbon (%)	Organic matter (%)
		Dry	Wet	(g/100g)	(°C)	1:5	1:10	Cl^-	Ca^{2+}	K^+	Na^+	Mg^{2+}	SO_4^{2-}	NO_3^-					
PYO3	0 to 15	2.5Y 7/2	2.5Y 6/2	16.86	30.80	14.50	8.70	59.19	36.85	2.40	55.05	16.54	62.16	0.01	13.28	51.13	0.07	0.47	0.80
PYO3	T	2.5Y 6/2	2.5Y 5/2	12.88		16.10	9.50	62.26	37.38	2.07	56.55	22.34	68.75			65.00			
PYO3	BT	2.5Y 6/2	2.5Y 5/2	17.76		15.80	9.50	61.68	35.73	2.53	61.77	16.71	66.71						
PYO4	0 to 15	2.5Y 6/2	2.5Y 5/2	16.55	30.60	19.80	11.50	80.80	40.54	3.15	75.90	25.76	59.34	0.02	16.73	39.74	0.08	0.45	0.78
PYO4	T	2.5Y 6/2	2.5Y 5/2	13.18		18.90	12.60	89.26	37.72	2.35	84.82	29.29	81.39			56.00			
PYO4	BT	2.5Y 6/2	2.5Y 5/2	24.69		19.50	11.50	80.44	38.62	2.79	75.69	23.22	75.91						
RLL1	0 to 15	2.5Y 7/2	2.5Y 5/2	16.75	23.80	10.60	6.80	40.71	36.78	1.58	35.99	14.39	57.20	0.15	14.37	62.49	0.06	0.45	0.78
RLL1	T	2.5Y 7/2	2.5Y 5/2	23.85		9.40	6.00	27.67	32.29	0.92	30.80	11.05	55.91			55.92			
RLL1	BT	2.5Y 7/2	2.5Y 5/2	18.72		12.70	8.60	53.67	35.93	1.74	47.41	18.11	62.15						
RLL2	0 to 15	2.5Y 6/2	2.5Y 4/2	23.03	25.40	16.30	9.80	73.67	38.91	2.75	63.12	20.01	67.03	0.08	27.79	34.36	0.07	0.51	0.89
RLL2	T	2.5Y 6/2	2.5Y 4/2	27.27		19.00	11.00	75.10	37.62	2.33	69.60	27.75	75.30			24.73			
RLL2	BT	2.5Y 7/2	2.5Y 5/2	19.20		16.20	9.60	63.40	36.58	3.38	54.37	18.60	63.52						
RLL3	0 to 15	10YR 7/2	10YR 4/2	22.44	26.90	20.40	11.70	83.84	38.07	3.35	70.17	38.80	76.23	0.12	18.86	44.21	0.08	0.62	1.08
RLL3	T	10YR 7/2	10YR 4/2	26.40		37.00	21.40	128.35	32.14	4.83	173.13	84.98	175.56			16.99			
RLL3	BT	10YR 7/2	10YR 4/2	21.79		17.40	10.50	73.19	38.37	2.79	56.55	28.18	66.78						
RLL4	0 to 15	10YR 7/2	10YR 4/2	23.70	23.70	16.80	9.90	71.30	36.50	2.57	60.42	29.29	81.13	0.05	25.57	27.59	0.10	0.74	1.28
RLL4	T	10YR 7/2	10YR 4/2	35.15		21.00	12.50	75.93	32.39	2.69	77.43	39.32	103.00			26.58			
RLL4	BT	10YR 7/2	10YR 4/2	24.92		16.10	9.80	62.84	36.68	2.38	54.81	26.81	70.36						
RLL5	0 to 15	10YR 6/3	10YR 4/3	25.24	21.60	11.40	7.10	41.03	31.89	2.28	41.40	13.22	62.05	0.05	32.42	11.38	0.16	1.12	1.93
RLL5	T	10YR 7/3	10YR 5/3	37.81		4.00	3.10	4.60	35.58	0.87	5.80	8.70	50.43			28.55			
RLL5	BT	10YR 6/2	10YR 4/3	32.53		12.80	7.30	43.96	22.26	2.30	44.80	11.74	47.09						

Table A2.1 (cont.). Data of the *Arthrocnemum macrostachyum* soils sampled in July 2006.

Sample	Deep (cm)	Munsell color		Moisture	Temp.	EC, dS m^{-1}		meq L^{-1}							CCE (%)	Gypsum (%)	Total nitrogen (%)	Organic carbon (%)	Organic matter (%)
		Dry	Wet	(g/100g)	(°C)	1:5	1:10	Cl^-	Ca^{2+}	K^+	Na^+	Mg^{2+}	SO_4^{2-}	NO_3^-					
CMR1	0 to 15	10YR 8/2	10YR 7/3	13.01	25.50	3.80	3.00	5.76	32.34	0.19	3.70		41.63	0.07	3.97	91.04	0.04	0.20	0.35
CMR1	T	10YR 7/2	10YR 5/3	16.02		3.00	2.60	2.73	35.93	0.23	2.09	3.10	42.52			72.00			
CMR1	BT	10YR 8/2	10YR 7/3	11.55		4.60	3.50	10.70	37.97	0.26	7.91	5.13	46.17						
CMR2	0 to 15	2.5Y 6/2	2.5Y 4/2	27.63	26.50	22.10	12.70	88.47	35.28	3.47	84.62	41.01	96.30	0.10	18.53	23.29	0.16	1.01	1.74
CMR2	T	2.5Y 6/2	2.5Y 4/2	22.15		36.70	21.10	122.31	33.48	4.63	166.17	91.07	192.60			15.13			
CMR2	BT	2.5Y 6/2	2.5Y 5/2	29.19		18.40	11.10	72.54	35.43	2.86	73.95	29.04	84.43						
CMR3	0 to 15	10YR 6/2	10YR 5/3	21.15	29.60	18.80	11.20	78.49	32.21	3.03	64.09	21.72	58.59	0.14	25.09	10.02	0.13	0.78	1.35
CMR3	T	10YR 6/2	10YR 5/3	19.42		27.90	16.00	132.02	41.47	3.45	99.18	46.73	81.69			9.97			
CMR3	BT	10YR 6/2	10YR 5/3	18.00		19.10	11.20	78.57	37.08	2.79	74.82	23.96	74.70						
CMR4	0 to 15	10YR 6/2	10YR 5/3	19.39	30.40	17.20	10.10	74.85	31.98	2.92	55.10	23.46	72.10	0.19	21.36	13.15	0.14	0.97	1.67
CMR4	T	10YR 6/2	10YR 5/3	18.53		26.00	14.70	111.56	38.22	3.25	91.35	51.25	92.65			15.73			
CMR4	BT	10YR 6/2	10YR 5/3	18.99		14.50	9.00	57.54	32.88	2.35	52.63	20.76	65.19						
CMR5	0 to 15	10YR 6/2	10YR 5/3	17.28	26.20	15.20	9.00	69.57	42.08	0.87	51.61	14.03	51.96	0.67	24.01	12.43	0.14	0.79	1.37
CMR5	T	10YR 6/2	10YR 5/3	20.26		26.20	15.00	126.43	50.70	0.97	102.66	17.63	62.83			19.89			
CMR5	BT	10YR 6/2	10YR 5/3	18.21		13.30	7.90	52.49	41.82	1.10	38.71	17.05	53.17						
PNL1	0 to 15	10YR 6/2	10YR 5/3	19.38	30.40	19.00	11.20	77.55	42.17	3.44	71.28	27.11	63.49	0.03	16.97	30.69	0.11	0.69	1.18
PNL1	T	10YR 6/2	10YR 5/3	20.23		28.40	16.60	131.53	45.86	4.99	93.09	70.50	96.30			20.43			
PNL1	BT	10YR 6/2	10YR 5/3	19.83		16.80	9.90	65.39	39.37	3.07	60.03	24.00	69.30						
PNL2	0 to 15	10YR 6/2	10YR 5/3	22.17	30.50	23.20	13.40	91.21	36.25	4.22	85.14	58.12	91.26	0.06	16.02	21.84	0.14	0.76	1.32
PNL2	T	10YR 6/2	10YR 5/3	24.43		32.70	18.90	119.89	33.88	5.17	143.55	81.85	154.42			18.00			
PNL2	BT	10YR 6/2	10YR 5/3	19.06		19.30	11.50	77.00	37.38	3.63	66.99	37.92	87.17						

Table A2.1 (cont.). Data of the *Arthrocnemum macrostachyum* soils sampled in July 2006.

Sample	Deep (cm)	Munsell color		Moisture	Temp.	EC, dS m^{-1}		meq L^{-1}							CCE (%)	Gypsum (%)	Total nitrogen (%)	Organic carbon (%)	Organic matter (%)
		Dry	Wet	(g/100g)	(°C)	1:5	1:10	Cl^-	Ca^{2+}	K^+	Na^+	Mg^{2+}	SO_4^{2-}	NO_3^-					
PNL3	0 to 15	10YR 6/2	10YR 5/3	17.72	33.20	19.70	11.60	76.21	36.83	2.87	73.93	36.26	70.04	0.00	16.30	35.30	0.11	0.70	1.21
PNL3	T	10YR 6/2	10YR 5/2	20.71		31.80	18.30	122.45	34.23	4.37	128.32	84.81	145.29			16.29			
PNL3	BT	10YR 6/2	10YR 5/2	18.12		16.30	9.50	60.45	34.58	2.70	54.59	28.56	72.80						
AGU1	0 to 15	10YR 5/2	10YR 4/2	11.72	26.70	6.50	4.50	10.27	29.43	1.02	10.11	27.65	70.70	0.10	12.00	25.56	0.18	1.22	2.10
AGU1	T	10YR 5/2	10YR 4/2	0.00		3.10	2.70	2.09	27.74	0.73	2.11	9.02	42.37			11.88			
AGU1	BT	10YR 5/2	10YR 4/2	19.01		8.90	5.50	12.83	26.20	1.72	13.44	39.11	77.67						
AGU2	0 to 15	10YR 4/1	10YR 4/2	9.18	26.00	6.00	4.80	10.96	28.42	1.09	11.17	32.46	83.61	0.13	14.65	15.43	0.24	1.62	2.79
AGU2	T	10YR 4/1	10YR 4/2	0.00		0.40	0.40	0.73	2.00	0.73	0.60	1.39	5.29			3.99			
AGU2	BT	10YR 5/2	10YR 4/2	8.94		6.70	4.60	10.34	26.55	1.73	10.64	28.25	63.67						
AGU3	0 to 15	10YR 6/2	10YR 5/2	12.42	27.60	14.80	9.30	42.11	29.76	3.39	39.75	74.41	140.51	0.02	18.43	38.69	0.09	0.53	0.92
AGU3	T	10YR 5/2	10YR 4/2	0.00		4.90	3.80	7.30	27.84	1.44	7.46	16.82	56.06			21.95			
AGU3	BT	10YR 6/2	10YR 4/2	17.71		15.10	9.30	39.05	27.05	2.96	39.06	67.37	108.55						
AGU4	0 to 15	10YR 8/2	10YR 7/2	12.78	31.40	11.40	7.00	33.40	32.46	2.73	24.57	41.48	82.05	0.02	4.25	83.96	0.04	0.20	0.35
AGU4	T	10YR 8/2	10YR 7/2	12.50		15.40	9.00	44.53	29.14	3.54	32.10	64.33	94.71			70.77			
AGU4	BT	10YR 7/2	10YR 4/2	13.71		8.70	5.50	21.09	30.19	2.07	15.23	27.12	62.91						

Table A2.2. Electrical conductivity of the *Arthrocnemum macrostachyum* soils sampled in December 2006.

Sample	Depth interval	CE 1:5	CE 1:10
LPL0	T	6.47	4.16
LPL0	BT	7.2	4.68
LPL1	T	17.5	10.67
LPL1	BT	14.7	8.87
LPL2	T	17.3	10.75
LPL2	BT	12.1	7.25
LPL3	T	17.8	10.8
LPL3	BT	13.4	8.14
LPL4	T	20.5	12.07
LPL4	BT	14.6	8.95
LPL5	T	21.3	12.69
LPL5	BT	15.6	9.8
LPL6	T	14.8	9.12
LPL6	BT	10.8	6.42
LPL7	T	11.3	6.57
LPL7	BT	17.5	10.22
PTO1	T	15.9	9.44
PTO1	BT	10.6	6.46
PTO2	T	17.1	10.25
PTO2	BT	15.8	9.14
PTO3	T	16.1	9.63
PTO3	BT	10.5	6.49
PTO4	T	7.8	5.17
PTO4	BT	4.7	3.24
PYO1	T	6.0	3.82
PYO1	BT	6.1	4.09
PYO2	T	16.2	9.7
PYO2	BT	11.8	7.24
PYO3	T	9.8	6.21
PYO3	BT	11.1	7.11
PYO4	T	13.0	8.25
PYO4	BT	14.4	8.57
RLL1	T	11.9	7.41
RLL1	BT	10.43	6.24
RLL2	T	21.1	12.71
RLL2	BT	14.6	8.92
RLL3	T	22.4	13.1
RLL3	BT	16.1	9.9
RLL4	T	19.0	11.16
RLL4	BT	12.8	7.64
RLL5	T	14.7	9.24

Table A2.2 (cont.). Electrical conductivity of the *Arthrocnemum macrostachyum* soils sampled in December 2006.

Sample	Depth interval	CE 1:5	CE 1:10
RLL5	BT	9.5	5.61
CMR1	T	16.5	10.16
CMR1	BT	10.8	6.36
CMR2	T	22.9	13.4
CMR2	BT	17.1	10.27
CMR3	T	21.9	12.55
CMR3	BT	18.2	10.53
CMR4	T	21.5	12.79
CMR4	BT	15.8	9.16
CMR5	T	13.0	7.92
CMR5	BT	11.2	6.85
PNL1	T	22.1	12.93
PNL1	BT	17	9.82
PNL2	T	21.8	12.92
PNL2	BT	16.5	9.68
PNL3	T	17.9	10.7
PNL3	BT	13.8	8.46
AGU1	T	3.4	2.46
AGU1	BT	8.2	5.28
AGU2	T	1.1	0.6
AGU2	BT	8.3	5.46
AGU3	T	5.9	3.72
AGU3	BT	9.3	6.24
AGU4	T	9.7	6.19
AGU4	BT	9.9	6.25

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Table A3.1. Points sampled in 2007 with CropScan, sampling date, point description and percent cover of vegetation.

Sample	Date	Description	Vegetation %	Soil %
LPL1	26-Jun-2007	Bright green dwarf plants of *A. macrostachyum*	97	3
LPL2	26-Jun-2007	Moist soil with efflorescence	0	100
LPL3	26-Jun-2007	Bare soil with desiccation polygons and efflorescence	0	100
LPL4	26-Jun-2007	Dry vegetation + bare soil with polygons and efflorescence	60	40
LPL5	26-Jun-2007	*Lygeum spartum*	80	20
LPL6	26-Jun-2007	Stones	0	100
LPL7	26-Jun-2007	*A. macrostachyum* + bare soil	70	30
LPL8	26-Jun-2007	*Halopeplis amplexicaulis*	5	95
LPL9	26-Jun-2007	Dry *Halopeplis amplexicaulis*	60	40
LPL11	26-Jun-2007	Bare soil with efflorescence and stones	0	100
LPL12	26-Jun-2007	Elevated area + dry vegetation and soil with polygons of desiccation	10	90
LPL13	26-Jun-2007	Elevated area + dry vegetation and soil with polygons of desiccation	80	20
LPL14	26-Jun-2007	*Lygeum spartum*	75	25
LPL15	26-Jun-2007	*Rosmarinus* on the escarpment	20	80
LPL16	26-Jun-2007	*Rosmarinus* on the escarpment	70	30
AGU1	26-Jun-2007	Field, dry and stony	10	90
AGU2	26-Jun-2007	*Suaeda vera* + stones	70	30
AGU3	26-Jun-2007	*Suaeda vera* + stones + lichen	80	20
AGU4	26-Jun-2007	*Suaeda vera* + stones + lichen	80	20
AGU5	26-Jun-2007	*Lygeum spartum*	80	20
AGU6	26-Jun-2007	*A. macrostachyum* + dry soil with efflorescence and domes	20	80
AGU7	26-Jun-2007	*A. macrostachyum* + grey dry bare soil	10	90
AGU8	26-Jun-2007	Bare soil with desiccation polygons	0	100
AGU9	26-Jun-2007	*A. macrostachyum* + dry soil with efflorescence and domes	10	90
AGU10	26-Jun-2007	*A. macrostachyum* + dry soil with efflorescence and domes	30	70
AGU11	26-Jun-2007	Elevated area, bare soil with efflorescence	0	100
AGU12	26-Jun-2007	Dry bare soil	20	80

Table A3.1 (cont). Points sampled in 2007 with CropScan radiometer, sampling date, point description and percent cover of vegetation.

Sample	Date	Description	Vegetation %	Soil %
AGU13	26-Jun-2007	*Limonium* + *Suaeda vera* + Dry soil with polygons	85	15
AGU14	26-Jun-2007	*Limonium delicatulum* on bares soil with efflorescence	50	50
AGU15	26-Jun-2007	*Suaeda vera* on the escarpment	90	10
AA1	27-Jun-2007	*Quercus ilex*	80	20
AA2	27-Jun-2007	Bare soil	0	100
AA3	27-Jun-2007	*Halopeplis amplexicaulis* + Bare soil with efflorescence	10	90
AA4	27-Jun-2007	*Suaeda vera* + stones	10	90
AA5	27-Jun-2007	*Halopelis amplexicaulis*	75	25
AA6	27-Jun-2007	*Salicornia ramosissima*	80	20
AA7	27-Jun-2007	Bare soil with efflorescence	0	100
AA8	27-Jun-2007	*Salicornia ramosissima* + *Halopeplis amplexicaulis*	80	20
AA9	27-Jun-2007	*Salicornia ramosissima*	10	90
AA10	27-Jun-2007	Bare soil	0	100
AA11	27-Jun-2007	Bare soil	0	100
AA12	27-Jun-2007	Water sheet	0	100
AA13	27-Jun-2007	*Tamarix sp.*	100	0
AA14	27-Jun-2007	*Halopeplis amplexicaulis*+ *A. macrostachyum*	0	100
AA15	27-Jun-2007	Bare soil	10	90
AA16	27-Jun-2007	*Halopeplis amplexicaulis*	0	100
AA17	27-Jun-2007	*Halopeplis amplexicaulis*	10	90
AA18	27-Jun-2007	Bare soil	0	100
AA19	27-Jun-2007	Stones with gypsum	0	100
AA20	27-Jun-2007	*Lygeum spartum*	90	10
AA21	27-Jun-2007	*Pinus*	80	20
PTO1	27-Jun-2007	*Lygeum spartum*	70	30
PTO2	27-Jun-2007	*Suaeda vera*	70	30
PTO3	27-Jun-2007	*A. macrostachyum*	30	70

Table A3.1 (cont.). Points sampled in 2007 with CropScan, sampling date, point description and percent cover of vegetation.

Sample	Date	Description	Vegetation %	Soil %
PTO4	27-Jun-2007	*A. macrostachyum*	30	70
PTO5	27-Jun-2007	*Suaeda vera*	30	70
PTO6	27-Jun-2007	*Suaeda vera*	40	60
PTO7	27-Jun-2007	Dry soil with desiccation polygons	0	100
PTO8	27-Jun-2007	*Lygeum spartum*	40	60
PTO9	27-Jun-2007	Dry vegetation + *Frankenia pulverulenta*	80	20
PTO10	27-Jun-2007	*Lygeum spartum*	80	20
PTO11	27-Jun-2007	Bare soil + Dry *Halopeplis amplexicaulis*	0	100
PTO12	27-Jun-2007	Dry bare soil	0	100
PTO13	27-Jun-2007	*Suaeda vera* + Bare soil	40	60
GRM1	27-Jun-2007	Harvested field	50	50
GRM2	27-Jun-2007	Fallow	60	40
GRM3	27-Jun-2007	*Suaeda vera*	60	40
GRM4	27-Jun-2007	*Suaeda vera*	20	80
GRM5	27-Jun-2007	Dry vegetation	10	90
GRM6	27-Jun-2007	*Suaeda vera* + Bare soil with efflorescene	40	60
GRM7	27-Jun-2007	*Tamarix sp.*	100	0
GRM8	27-Jun-2007	*Lygeum spartum*	80	20
GRM9	27-Jun-2007	Dry vegetation	70	30
LPL1	28-Jun-2007	*A. macrostachyum* + bare soil with efflorescence	60	40
LPL2	28-Jun-2007	Moist soil with efflorescence	0	100
LPL3	28-Jun-2007	Bare soil with efflorescence	0	100
LPL4	28-Jun-2007	Yellow - green *A. macrostachyum*	95	5
LPL5	28-Jun-2007	*Lygeum spartum*	70	30
LPL6	28-Jun-2007	Moist soil with efflorescence	0	100
LPL7	28-Jun-2007	Bare soil	0	100

Table A3.1 (cont.). Points sampled in 2007 with CropScan, sampling date, point description and percent cover of vegetation.

Sample	Date	Description	Vegetation %	Soil %
LPL8	28-Jun-2007	Green *Halopeplis amplexicaulis*	20	80
LPL9	28-Jun-2007	Dry *Halopeplis amplexicaulis*	50	50
LPL10	28-Jun-2007	Bare soil with efflorescence	0	100
LPL11	28-Jun-2007	Moist soil with polygons of desiccation	0	100
LPL12	28-Jun-2007	Dry soil with stones	0	100
LPL13	28-Jun-2007	*	*	*
LPL14	28-Jun-2007	Dry soil + *Suaeda vera*	3	97
MTE1	28-Jun-2007	Dry *Suaeda vera*	75	25
MTE2	28-Jun-2007	Dry bare soil	0	100
MTE3	28-Jun-2007	Dry bare soil	0	100
MTE4	28-Jun-2007	*Lygeum spartum*	70	30
MTE5	28-Jun-2007	*Suaeda vera* + dry soil	40	60
MTE6	28-Jun-2007	Bare soil with efflorescence and domes	0	100
MTE7	28-Jun-2007	Bare soil with efflorescence and domes	0	100
PNL1	28-Jun-2007	Field, dry and stony	75	25
PNL2	28-Jun-2007	Gypsum	0	95
PNL3	28-Jun-2007	Green *A. macrostachyum*	90	10
PNL4	28-Jun-2007	Dry soil with polygons	0	100
PNL5	28-Jun-2007	Dry soil with efflorescence	0	100
PNL6	28-Jun-2007	Dry soil with died vegetation	5	95
PYO1	28-Jun-2007	*A. macrostachyum* + bare soil	70	30
PYO2	28-Jun-2007	*Lygeum spartum* + Dry soil	90	10
PYO3	28-Jun-2007	Moist soil	80	20
PYO4	28-Jun-2007	Dry soil with efflorescence	0	100
PYO5	28-Jun-2007	Dry soil with efflorescence	0	100
SAL1	28-Jun-2007	*Suaeda vera* + Gypsum	98	2
SAL2	28-Jun-2007	*Suaeda vera* + Bare soil with efflorescence	40	60

Table A3.1 (cont.). Points sampled in 2007 with CropScan, sampling date, point description and percent cover of vegetation.

Sample	Date	Description	Vegetation %	Soil %
SAL3	28-Jun-2007	Bare soil with efflorescence	0	100
SAL4	28-Jun-2007	Bare soil with stones and dry suaeda vera	2	98
SAL5	28-Jun-2007	*Lygeum spartum*	20	80
SAL6	28-Jun-2007	Moist bare soil	5	95
SAL7	28-Jun-2007	Moist and dark soil with efflorescence	0	100
SAL8	28-Jun-2007	Moist soil with salt crust	0	100
SAL9	28-Jun-2007	Saturated soil and salt crust	0	100
SAL10	28-Jun-2007	Dry vegetation on escarpment and white soil	5	95
SAL11	28-Jun-2007	Saturated soil and salt crust	0	100
SAL12	28-Jun-2007	Moist soil with efflorescence and stones	0	100
SAL13	28-Jun-2007	Red *Suaeda vera* on bare soil with efflorescence	30	70
SAL14	28-Jun-2007	*Salicornia ramosissima* (15 cm) on water lamina with yellow soil	20	80
SAL15	28-Jun-2007	*Salsola kali*	0	100
SAL16	28-Jun-2007	Red *Suaeda vera* on bare soil with efflorescence	5	95
SAL17	28-Jun-2007	Moist soil with orange color	2	98
SAL18	28-Jun-2007	Suaeda vera on bare soil with efflorescence	40	60
SAL19	28-Jun-2007	*Juncus maritimus*	0	100
SAL20	28-Jun-2007	Green *Suaeda vera*	98	2
SAL21	28-Jun-2007	*Microcnemum coralloides* (red)	90	10
SAL22	28-Jun-2007	Soil with efflorescence and desiccation polygons	0	100
SAL23	28-Jun-2007	*Microcnemum coralloides* (green)	95	5
SAL24	28-Jun-2007	*Microcnemum coralloides* (green and dry)	95	5
SAL25	28-Jun-2007	Moist soil with efflorescence	0	100
SAL26	28-Jun-2007	*Lygeum spartum* + *Suaeda vera*	100	0
SAL27	28-Jun-2007	Dry soil with desiccation polygons	0	100
SAL28	28-Jun-2007	Field	90	10
SAL29	28-Jun-2007	Green *Suaeda vera* on field	70	30

Table A3.1 (cont.). Points sampled in 2007 with CropScan, sampling date, point description and percent cover of vegetation.

Sample	Date	Description	Vegetation %	Soil %
SAL30	28-Jun-2007	Saturated soil and salt crust	0	100
SAL31	28-Jun-2007	Dry soil with algal mats	0	100
SAL32	28-Jun-2007	Dry soil with algal mats	0	100
SAL33	28-Jun-2007	Green *Suaeda vera*	100	0
SAL34	28-Jun-2007	*Thymus vulgaris* + Bare soil	80	20
CMR1	28-Jun-2007	Bare soil with desiccation polygons	0	100
CMR2	28-Jun-2007	*A. macrostachyum*	98	2
CMR3	28-Jun-2007	Dry sandy soil	0	100
CMR4	28-Jun-2007	Moist soil with desiccation polygons and efflorescence	0	100

Table A3.2. Points sampled with OceanOptics in vegetated areas.

Sample	Description level 1	Description level 2	Description level 3	Location
Pto1	*Lygeum spartum, Frankenia thymifolia* + *Suaeda vera*	Perennial halophilous grasses	Sparse vegetation	Elevated area of the dune, soils with desiccation polygons, dry and light color
Pto2	*Lygeum spartum, Frankenia thymifolia* + *Suaeda vera*	Perennial halophilous grasses	Sparse vegetation	Elevated area of the dune, soils with desiccation polygons, dry and light color
Pto3	*Suaeda vera*	Perennial halophilous grasses	Sparse vegetation	Elevated area of the dune, soils with desiccation polygons, dry and light color
Pto4	*Lygeum spartum, Frankenia thymifolia* + *Suaeda vera*	Perennial halophilous grasses	Sparse vegetation	Elevated area of the dune, soils with desiccation polygons, dry and light color
Pto6	*Lygeum spartum*	Perennial halophilous grasses	Sparse vegetation	Elevated area of the dune, soils with desiccation polygons, dry and light color
Pto7	Dense mixed green and senescent *A. macrostachyum*	Halophytic vegetation	Very sparse vegetation	Lateral leeward of the dune. Darker, saline and moist soils and very bare soil
Pto8	*A. macrostachyum* alternated with dry soil and branches	Halophytic vegetation	Very sparse vegetation	Lateral leeward of the dune. Darker, saline and moist soils and very bare soil
Pto10	*A. macrostachyum* alternated with dry and sandy soil	Halophytic vegetation	Very sparse vegetation	Lateral leeward of the dune. Darker, saline and moist soils and very bare soil
Pto11	Bare soil with senescent vegetation	Halophytic vegetation	Very sparse vegetation	Lateral leeward of the dune. Darker, saline and moist soils and very bare soil
Ipl1	Stunted and senescent *A. macrostachyum* alternating with polygonal soil with	Halophytic vegetation	Very sparse vegetation	Fringe vegetation
Ipl2	Green and senescent *A. macrostachyum* on soil with efflorescence	Halophytic vegetation	Very sparse vegetation	Fringe vegetation

Table A3.2 (cont.). Points sampled with OceanOptics in vegetated areas.

Sample	Description level 1	Description level 2	Description level 3	Location
lpl3	Dry *A. macrostachyum* on soil with efflorescence in the polygons and moisture	Halophytic vegetation	Very sparse vegetation	Fringe vegetation
lpl6	Soil with efflorescence in polygons and a shrub of *A.m.*	Halophytic vegetation	Very sparse vegetation	Fringe vegetation
lpl7	Green and senescent *A. macrostachyum* with dead vegetation on bare soil	Halophytic vegetation	Very sparse vegetation	Fringe vegetation
lpl8	Dense green and senescent *A. macrostachyum* on dry bare soil	Halophytic vegetation	Sparse vegetation	Fringe vegetation
lpl9	Dense green and senescent *A. macrostachyum* on dry bare soil	Halophytic vegetation	Sparse vegetation	Fringe vegetation
lpl10	Dense green and senescent *A. macrostachyum* on dry bare soil	Halophytic vegetation	Sparse vegetation	Fringe vegetation
lpl11	Dense green and senescent *A. macrostachyum* on dry bare soil	Halophytic vegetation	Sparse vegetation	Fringe vegetation
agu2	Dry bare soil with desiccated polygons and *Suaeda vera*	Dry halophytic vegetation	Very sparse vegetation	Fringe vegetation
agu3	Dry bare soil with desiccated polygons and *Suaeda vera*	Dry halophytic vegetation	Very sparse vegetation	Fringe vegetation
agu5	Dry bare soil with desiccated polygons and *Suaeda vera*	Dry halophytic vegetation	Very sparse vegetation	Fringe vegetation
agu6	Dry bare soil with desiccated polygons and *A. macrostachyum*	Dry halophytic vegetation	Very sparse vegetation	Fringe vegetation
agu7	Dry bare soil with desiccated polygons and *A. macrostachyum* with senescent vegetation	Dry halophytic vegetation	Very sparse vegetation	Fringe vegetation

Table A3.2 (cont.). Points sampled with OceanOptics in vegetated areas.

Sample	Description level 1	Description level 2	Description level 3	Location
agu8	Dry bare soil with desiccated polygons and *A. macrostachyum* with senescent vegetat	Dry halophytic vegetation	Very sparse vegetation	Fringe vegetation
agu10	Dry bare soil with desiccated polygons and *A. macrostachyum*	Dry halophytic vegetation	Very sparse vegetation	Fringe vegetation
agu11	Dry bare soil with desiccated polygons and *A. macrostachyum*	Dry halophytic vegetation	Very sparse vegetation	Fringe vegetation
sal1	Dry and green vegetation: *Suaeda vera* and nitrophilous	Halophytic vegetation	Sparse vegetation	Fringe vegetation
sal2	Green vegetation *Suaeda vera* and nitrophilous	Halophytic vegetation	Sparse vegetation	Fringe vegetation
sal3	*Suaeda vera* and *Juncus maritimus*	Halophytic vegetation	Sparse vegetation	Fringe vegetation
sal4	*Suaeda vera* and *Juncus maritimus*	Halophytic vegetation	Sparse vegetation	Fringe vegetation
sal5	*Suaeda vera* and *Juncus maritimus*	Halophytic vegetation	Sparse vegetation	Fringe vegetation
sal6	*Suaeda vera* and *Juncus maritimus*	Halophytic vegetation	Sparse vegetation	Fringe vegetation
far7	Vigorous and dense halophytic vegetation	Halophytic vegetation	Sparse vegetation	Fringe vegetation
far8	Vigorous and dense halophytic vegetation	Halophytic vegetation	Sparse vegetation	Fringe vegetation
far9	Vigorous and dense halophytic vegetation	Halophytic vegetation	Sparse vegetation	Fringe vegetation
far10	Vigorous and dense halophytic vegetation	Halophytic vegetation	Sparse vegetation	Fringe vegetation

Table A3.2 (cont.). Points sampled with OceanOptics in vegetated areas.

Sample	Description level 1	Description level 2	Description level 3	Location
far11	Vigorous and dense halophytic vegetation	Halophytic vegetation	Sparse vegetation	Fringe vegetation
far12	Vigorous and dense halophytic vegetation	Halophytic vegetation	Sparse vegetation	Fringe vegetation
far13	Vigorous and dense halophytic vegetation	Halophytic vegetation	Sparse vegetation	Fringe vegetation
far14	Vigorous and dense halophytic vegetation	Halophytic vegetation	Sparse vegetation	Fringe vegetation
far15	Vigorous and dense halophytic vegetation	Halophytic vegetation	Sparse vegetation	Fringe vegetation
gll1	*Suaeda vera* in dry soil with desiccated polygons	Dry halophytic vegetation	Sparse vegetation	Lateral leeward of the dune.
gll2	*Suaeda vera* in dry soil with desiccated polygons	Dry halophytic vegetation	Sparse vegetation	Lateral leeward of the dune.
gll3	*Suaeda vera* in dry soil with desiccated polygons	Dry halophytic vegetation	Sparse vegetation	Lateral leeward of the dune.
gll4	*Suaeda vera* in dry soil with desiccated polygons	Dry halophytic vegetation	Sparse vegetation	Lateral leeward of the dune.
gll5	*Suaeda vera* in dry soil with desiccated polygons	Dry halophytic vegetation	Sparse vegetation	Lateral leeward of the dune.
gll7	Dry soil with scattered *Suaeda vera*	Dry halophytic vegetation	Very sparse vegetation	Elevated area of the dune

Table A3.3. Sampled points with OceanOptics in bare soil areas.

Sample	Description level 1	Description level 2	Description level 3	Location
Pto9	Bare soil	Dry bare soil	Bare soil, efflorescence +	Lateral leeward of the dune. Darker, saline and wet soils and very bare soil
Pto12	Bare soil	Dry bare soil	Bare soil, efflorescence +	Lateral leeward of the dune. Darker, saline and wet soils and very bare soil
Ipl4	Soil with rest of vegetation, moisture and efflorescence	Dry bare soil	Bare soil, efflorescence +	Fringe vegetation
Ipl12	Sandy soil with polygons of desiccation Efflorescence in top layer	Saturated soil	Bare soil, polygons, efflorescence	Bottom area
Ipl13	Sandy soil with polygons of desiccation. Efflorescence in top layer	Saturated soil	Bare soil, polygons, efflorescence	Bottom area
Ipl14	Sandy soil with polygons of desiccation. Efflorescence in top layer	Saturated soil	Bare soil, polygons, efflorescence	Bottom area
Ipl15	Sandy soil with polygons of desiccation. Efflorescence in top layer	Saturated soil	Bare soil, polygons, efflorescence	Bottom area
Ipl16	Sandy soil with polygons of desiccation. Efflorescence in top layer	Saturated soil	Bare soil, polygons, efflorescence	Bottom area
agu4	Dry bare soil with desiccated polygons and *Suaeda vera*	Dry bare soil	Bare soil, polygons	Fringe vegetation
agu9	Dry bare soil with desiccated polygons and *A. macrostachyum*	Dry bare soil	Bare soil, polygons	Fringe vegetation
agu12	Dry bare soil with desiccated polygons	Dry bare soil	Bare soil, polygons	Fringe vegetation
agu13	Bare soil with efflorescence and some moisture	Salt efflorescence soil	Bare soil, efflorescence +	Bottom area
agu14	Bare soil with efflorescence and some annuals	Salt efflorescence soil	Bare soil, efflorescence +	Bottom area

Table A3.3 (cont). Sampled points with OceanOptics in bare soil areas.

Sample	Description level 1	Description level 2	Description level 3	Location
agu15	Bare soil with efflorescence and some moisture	Salt efflorescence soil	Bare soil, efflorescence +	Bottom area
agu16	Bare soil with efflorescence and some moisture	Salt efflorescence soil	Bare soil, efflorescence +	Bottom area
agu17	Bare soil with efflorescence and some moisture	Salt efflorescence soil	Bare soil, efflorescence ++	Bottom area
agu18	Bare soil with efflorescence and spot of moisture	Salt efflorescence soil	Bare soil, efflorescence ++	Bottom area
agu19	Bare soil with efflorescence and moisture	Salt efflorescence soil	Bare soil, efflorescence ++	Bottom area
agu20	Bare soil with efflorescence and moisture	Salt efflorescence soil	Bare soil, efflorescence ++	Bottom area
agu21	Bare soil with efflorescence, moisture and *A. macrostachyum*	Salt efflorescence soil	Bare soil, efflorescence ++	Bottom area
agu22	Bare soil with efflorescence and moisture	Salt efflorescence soil	Bare soil, efflorescence ++	Bottom area
agu23	Bare soil with efflorescence and moisture	Salt efflorescence soil	Bare soil, efflorescence ++	Bottom area
agu24	Bare soil with efflorescence and moisture	Salt efflorescence soil	Bare soil, efflorescence +++	Bottom area
agu25	Bare soil with efflorescence and moisture	Salt efflorescence soil	Bare soil, efflorescence +++	Bottom area
agu26	Bare soil with efflorescence and moisture	Salt efflorescence soil	Bare soil, efflorescence +++	Bottom area
sal7	Moist soil with superficial efflorescence	Salt efflorescence soil	Bare soil, efflorescence ++, algal mats	Bottom area

Table A3.3 (cont). Sampled points with OceanOptics in bare soil areas.

Sample	Description level 1	Description level 2	Description level 3	Location
sal8	Moist soil with superficial efflorescence	Salt efflorescence soil	Bare soil, efflorescence ++, algal mats	Bottom area
sal9	Moist soil with superficial efflorescence	Salt efflorescence soil	Bare soil, efflorescence ++, algal mats	Bottom area
sal10	Moist soil with superficial efflorescence	Salt efflorescence soil	Bare soil, efflorescence ++, algal mats	Bottom area
sal11	Moist soil with superficial efflorescence	Salt efflorescence soil	Bare soil, efflorescence ++, algal mats	Bottom area
sal13	Bare soil with sapropel	Salt efflorescence soil	Bare soil, efflorescence +++, sapropel	Bottom area
sal14	Bare soil with sapropel	Salt efflorescence soil	Bare soil, efflorescence +++, sapropel	Bottom area
sal15	Bare soil with sapropel	Salt efflorescence soil	Bare soil, efflorescence +++, sapropel	Bottom area
sal16	Bare soil with sapropel	Salt efflorescence soil	Bare soil, efflorescence +++, sapropel	Bottom area
gll6	Dry soil with scattered *Suaeda vera*	Dry bare soil	Bare soil, efflorescence +	Elevated area of the dune
gll8	Dry soil with scattered *Suaeda vera*	Dry bare soil	Bare soil, efflorescence +	Elevated area of the dune
gll9	Dry soil with scattered *Suaeda vera*	Dry bare soil	Bare soil, efflorescence +	Elevated area of the dune
gll10	Dry soil with scattered *Suaeda vera*	Dry bare soil	Bare soil, efflorescence +	Elevated area of the dune
gll11	Dry bare soil with efflorescence and sapropel	Salt efflorescence soil	Bare soil, desiccation polygons, sapropel	Bottom area
gll12	Dry bare soil with efflorescence and sapropel	Salt efflorescence soil	Bare soil, desiccation polygons, sapropel	Bottom area
gll13	Dry bare soil with efflorescence and sapropel	Salt efflorescence soil	Bare soil, desiccation polygons, sapropel	Bottom area
gll14	Dry bare soil with efflorescence and sapropel	Salt efflorescence soil	Bare soil, desiccation polygons, sapropel	Bottom area
gll15	Dry bare soil with efflorescence and sapropel	Salt efflorescence soil	Bare soil, desiccation polygons, sapropel	Bottom area

Table A3.4. Vegetation points sampled with OceanOptics, Munsell color, gravimetric moisture and percent of every cover (CanEye).

Sample	Point description	Munsell	Gravimetric Moisture	% Soil	Green vegetation	Senescent (Yellow-greens)	Trunk	Mixed	Green + Senescent
Pto1	*Lygeum spartum*	10YR 7/2	0.00	1.90	12.00	0.19	34.00	34.00	31.00
Pto2	*Lygeum spartum*	10YR 7/3	0.00	3.30	2.50	3.90	67.00	24.00	6.40
Pto3	*Lygeum spartum*	10YR 7/4	0.00	6.00	11.00	32.00	32.00	18.00	43.00
Pto4	*Lygeum spartum*	10YR 7/5	0.00	15.00	4.70	8.60	0.05	71.00	13.30
Pto6	*Lygeum spartum*	10YR 7/7	0.00	1.20	5.80	5.10	55.00	33.00	10.90
Pto7	*A. macrostachyum*	2.5YR 7/2	0.00	35.00	19.00	29.00	5.90	12.00	48.00
Pto8	*A. macrostachyum*	2.5YR 7/3	0.00	60.00	8.11	7.00	8.00	17.00	15.11
Pto10	*A. macrostachyum*	2.5YR 7/5	0.00	10.00	16.00	28.00	18.00	27.00	44.00
Pto11	*A. macrostachyum*	2.5YR 7/6	0.00	74.00	3.70	2.60	10.00	8.90	12.60
lpl1	*A. macrostachyum*	10YR 3/3	15.57	62.00	1.40	0.86	8.30	27.00	2.26
lpl2	*A. macrostachyum*	10YR 3/4	15.57	16.00	6.90	5.20	26.00	46.00	12.10
lpl3	*A. macrostachyum*	10YR 3/5	15.57	88.00	6.62	2.60	0.07	2.90	9.22
lpl6	*A. macrostachyum*	10YR 3/8	15.57	67.00	2.40	0.88	4.10	26.00	3.28
lpl7	*A. macrostachyum*	10YR 3/2	12.24	52.00	2.80	10.00	21.00	14.00	12.80
lpl8	*A. macrostachyum*	10YR 3/3	12.24	17.00	8.90	12.00	13.00	49.00	20.90
lpl9	*A. macrostachyum*	10YR 3/4	12.24	11.00	18.00	29.00	7.40	35.00	47.00
lpl10	*A. macrostachyum*	10YR 3/5	12.24	3.50	17.00	42.00	7.30	30.00	59.00
lpl11	*A. macrostachyum*	10YR 3/6	12.24	6.80	17.00	25.00	9.00	42.00	42.00
agu2	*Suaeda vera*	2.5YR 5/3	2.18	41.00	10.00	15.00	0.62	33.00	25.00
agu3	*Suaeda vera*	2.5YR 5/4	2.18	74.60	9.70	0.90	1.70	13.10	10.60
agu5	*Suaeda vera*	2.5YR 5/6	2.18	67.00	7.60	5.30	1.10	20.00	12.90
agu6	*A. macrostachyum*	10YR 7/2	0.44	3.20	44.00	20.00	15.00	18.00	64.00
agu7	*A. macrostachyum*	10YR 7/3	0.44	7.90	20.00	26.00	21.00	25.00	46.00
agu8	*A. macrostachyum*	10YR 7/4	0.44	60.00	2.50	0.02	5.00	33.00	2.52
agu10	*A. macrostachyum*	10YR 7/6	0.44	39.00	5.60	0.93	4.80	49.00	6.53
agu11	*A. macrostachyum*	10YR 7/7	0.44	52.00	8.90	0.04	7.40	32.00	8.94

Table A3.4 (cont). Vegetation points sampled with OceanOptics, Munsell color, gravimetric moisture and percent of every cover obtained from CanEye.

Sample	Point description	Munsell color	Gravimetric Moisture	Percent cover					
				Soil	Green vegetation	Senescent vegetation	Trunk	Mixed	Green + Senescent
sal1	*Suaeda vera*	2.5Y 4/2	8.14	10.00	9.50	22.00	28.00	30.00	31.50
sal2	*Suaeda vera*	2.5Y 4/2	8.14	5.10	19.00	26.00	21.00	29.00	45.00
sal3	*Suaeda vera*	2.5Y 4/2	8.14	3.50	30.00	11.00	27.00	29.00	41.00
sal4	*Juncus maritimus*	2.5Y 4/2	8.14	0.84	25.00	47.00	0.90	26.00	72.00
sal5	*Juncus maritimus*	2.5Y 4/2	8.14	0.25	43.00	31.00	6.20	19.00	74.00
sal6	*Suaeda vera*	2.5Y 4/2	8.14	53.00	8.50	12.00	6.50	20.00	20.50
far7	*Suaeda vera*	10YR 6 or 5/2	2.03	*	*	*	*	*	*
far8	*Suaeda vera, Phragmites australis*	10YR 6 or 5/3	2.03	0.07	24.00	18.00	20.00	38.00	42.00
far9	*Suaeda vera*	10YR 6 or 5/4	2.03	35.00	3.10	8.80	4.00	50.00	11.90
far10	*Suaeda vera*	10YR 6 or 5/5	2.03	1.50	15.00	25.00	8.20	50.00	40.00
far11	*Suaeda vera, Phragmites australis*	10YR 6 or 5/6	2.03	73.00	15.00	7.50	0.24	4.50	22.50
far12	*Phragmites australis*	10YR 6 or 5/7	2.03	0.93	15.00	2.40	53.00	28.00	17.40
far13	*Suaeda vera, Phragmites australis*	10YR 6 or 5/8	2.03	0.55	12.00	34.00	15.00	38.00	46.00
far14	*Suaeda vera, Phragmites australis*	10YR 6 or 5/9	2.03	2.50	9.80	22.00	34.00	32.00	31.80
far15	*Suaeda vera, Phragmites australis*	10YR 6 or 5/10	2.03	1.80	10.00	20.00	29.00	38.00	30.00
gll1	*Suaeda vera*	10YR 7/2	4.36	14.00	15.00	33.00	3.40	34.00	48.00
gll2	*Suaeda vera*	10YR 7/3	4.36	33.00	9.00	3.40	41.00	14.00	12.40
gll3	*Suaeda vera*	10YR 7/4	4.36	60.00	8.50	3.70	7.60	20.00	12.20
gll4	*Suaeda vera*	10YR 7/5	4.36	41.00	7.50	16.00	0.43	35.00	23.50
gll5	*Suaeda vera*	10YR 7/6	4.36	60.00	6.00	3.30	5.80	25.00	9.30
gll7	*Suaeda vera*	10YR 7/3	0.08	0.80	3.70	1.60	2.50	12.00	5.30

Table A3.5. Soil points sampled with OceanOptics, Munsell color and moisture.

Sample	Point description	Munsell color	Moisture
Pto9	Bare soil, efflorescence +	2.5YR 7/4	0.00
Pto12	Bare soil, efflorescence +	2.5YR 7/7	0.00
lpl4	*A. macrostachyum*	10YR 3/6	15.57
lpl12	Bare soil, polygons, efflorescence	10YR 5/2	23.70
lpl13	Bare soil, polygons, efflorescence	10YR 5/3	23.70
lpl14	Bare soil, polygons, efflorescence	10YR 5/4	23.70
lpl15	Bare soil, polygons, efflorescence	10YR 5/5	23.70
lpl16	Bare soil, polygons, efflorescence	10YR 5/6	23.70
agu4	Bare soil, polygons	2.5YR 5/5	2.18
agu9	Bare soil, polygons	10YR 7/5	0.44
agu12	Bare soil, polygons	10YR 7/8	0.44
agu13	Bare soil, efflorescence +	2.5Y 6/2	5.78
agu14	Bare soil, efflorescence +	2.5Y 6/3	5.78
agu15	Bare soil, efflorescence +	2.5Y 6/4	5.78
agu16	Bare soil, efflorescence +	2.5Y 6/5	5.78
agu17	Bare soil, efflorescence ++	2.5Y 6/6	5.78
agu18	Bare soil, efflorescence ++	2.5Y 6/7	4.20
agu19	Bare soil, Efflorescence ++	2.5Y 6/8	4.20
agu20	Bare soil, efflorescence ++	2.5Y 6/9	4.20
agu21	Bare soil, efflorescence ++	2.5Y 6/10	4.20
agu22	Bare soil, efflorescence ++	2.5Y 6/11	4.20
agu23	Bare soil, efflorescence ++	2.5Y 6/12	4.20
agu24	Bare soil, efflorescence +++	2.5Y 6/13	8.40
agu25	Bare soil, efflorescence +++	2.5Y 6/14	8.40
agu26	Bare soil, efflorescence +++	2.5Y 6/15	8.40
sal7	Bare soil, efflorescence ++, algal mats	2.5Y 5/3	16.05
sal8	Bare soil, efflorescence ++, algal mats	2.5Y 5/4	16.05

Table A3.5 (cont.). Vegetation points sampled with OceanOptics, Munsell color and moisture.

Sample	Point description	Munsell color	Moisture
sal9	Bare soil, efflorescence ++, algal mats	2.5Y 5/5	16.05
sal10	Bare soil, efflorescence ++, algal mats	2.5Y 5/6	16.05
sal11	Bare soil, efflorescence ++, algal mats	2.5Y 5/7	16.05
sal13	Bare soil, efflorescence +++, Sapropel	2.5Y 4/0	23.95
sal14	Bare soil, efflorescence +++, Sapropel	2.5Y 4/1	23.95
sal15	Bare soil, efflorescence +++, Sapropel	2.5Y 4/2	23.95
sal16	Bare soil, efflorescence +++, Sapropel	2.5Y 4/3	23.95
gll6	Bare soil, efflorescence +	10YR 7/2	0.08
gll8	Bare soil, efflorescence +	10YR 7/4	0.08
gll9	Bare soil, efflorescence +	10YR 7/5	0.08
gll10	Bare soil, efflorescence +	10YR 7/6	0.08
gll11	Bare soil, algal mat, polygons, sapropel	2,5Y 4/2	19.91
gll12	Bare soil, algal mat, polygons, sapropel	2,5Y 4/3	19.91
gll13	Bare soil, algal mat, polygons, sapropel	2,5Y 4/4	19.91
gll14	Bare soil, algal mat, polygons, sapropel	2,5Y 4/5	19.91
gll15	Bare soil, algal mat, polygons, sapropel	2,5Y 4/6	19.91

Table A3.6. Reflectance of points sampled in 2007 with CropScan.

	467	485	560	561	650	660	680	750	830	870	905	1560	1650	1700
LPL1	5.65	6.21	9.51	9.06	9.67	9.60	9.09	20.45	23.55	23.70	25.48	14.23	16.12	17.71
LPL2	14.23	15.09	17.58	17.58	20.46	21.02	21.26	22.88	24.72	24.65	26.18	27.00	29.45	32.51
LPL3	18.07	19.56	24.61	24.57	29.72	30.50	31.07	33.92	36.71	36.79	39.09	48.14	50.69	54.71
LPL4	12.29	13.14	16.43	16.21	18.80	19.15	19.43	23.70	25.96	26.31	27.82	29.62	30.87	34.04
LPL5	6.77	7.36	9.80	9.54	11.30	11.50	11.50	17.12	19.39	19.62	21.04	24.57	27.74	31.15
LPL6	19.98	21.52	25.49	25.39	29.62	30.46	30.87	33.60	36.61	36.69	39.05	35.54	38.55	42.54
LPL7	14.87	15.78	18.68	18.46	20.94	21.34	21.59	25.20	27.40	27.81	29.09	27.08	27.63	30.05
LPL8	13.22	13.97	16.90	16.70	19.32	19.55	19.40	24.02	26.09	26.13	27.25	26.78	27.98	31.34
LPL9	20.70	21.57	23.80	23.71	25.78	26.33	26.19	28.60	30.31	29.93	31.27	30.55	32.89	36.56
LPL10	15.96	16.80	19.47	19.47	22.06	22.75	22.89	24.09	25.73	25.54	27.01	27.26	29.64	33.44
LPL11	20.62	21.50	24.14	24.08	26.46	27.07	26.99	28.29	29.96	29.54	31.05	31.78	34.20	38.62
LPL12	22.33	23.68	28.56	28.35	32.59	33.13	33.28	34.88	37.15	37.12	38.63	47.33	49.53	54.69
LPL13	9.42	10.09	12.66	12.46	15.72	15.99	15.98	20.59	23.93	24.88	26.59	33.79	36.42	40.29
LPL14	6.85	7.75	10.64	10.79	11.41	12.37	12.17	18.59	21.34	20.43	23.28	24.36	27.11	28.99
LPL15	18.19	19.90	25.61	25.82	28.21	29.59	30.28	35.88	38.76	38.04	41.38	43.56	46.38	50.92
LPL16	13.73	14.99	19.44	19.28	24.03	24.72	25.13	29.81	33.45	34.02	36.36	43.57	47.40	51.74
AGU1	19.54	20.73	24.98	24.82	29.26	29.92	30.23	32.64	35.91	36.12	38.07	45.49	49.85	55.26
AGU2	6.18	6.62	9.02	8.80	10.26	10.48	10.19	18.13	21.54	21.96	24.03	21.36	24.73	27.87
AGU3	4.92	5.43	7.85	7.80	8.85	9.21	8.91	17.88	21.31	21.71	24.16	18.88	22.45	25.59
AGU4	11.63	12.38	15.65	15.48	17.35	17.55	17.81	22.46	24.98	25.58	27.39	29.63	32.05	36.22
AGU5	6.13	6.70	10.05	9.67	11.17	11.27	10.91	19.45	21.70	21.91	23.24	20.64	23.84	27.13
AGU6	37.55	38.58	40.90	40.99	41.59	42.13	41.80	42.42	44.08	43.17	44.89	30.66	32.67	36.05
AGU7	12.01	12.75	15.16	15.05	16.53	16.80	16.81	18.09	20.22	20.46	21.96	25.53	27.81	30.50
AGU8	12.79	13.58	16.11	15.94	17.54	17.81	17.77	18.83	20.69	20.65	21.94	25.49	27.72	30.37
AGU9	17.78	19.25	22.63	22.90	23.13	24.32	23.52	32.05	35.60	34.57	38.10	27.40	31.53	34.82
AGU10	40.60	42.15	46.40	46.32	46.54	47.32	47.54	50.28	50.70	50.65	52.36	34.34	35.60	40.83
AGU11	40.30	42.08	45.30	45.27	47.47	48.14	47.50	47.96	49.44	48.19	50.19	30.84	34.38	39.66
AGU12	13.63	14.54	17.80	17.63	19.77	20.06	20.08	22.47	24.53	24.68	26.22	29.04	30.98	34.94

Table A3.6 (cont.). Reflectance of points sampled in 2007 with CropScan.

	467	485	560	561	650	660	680	750	830	870	905	1560	1650	1700
AGU13	11.08	11.99	15.65	15.46	19.55	19.99	20.39	27.64	31.78	32.94	35.80	34.67	37.87	43.31
AGU14	17.12	18.71	22.96	23.10	24.40	25.27	25.44	38.25	39.58	40.28	42.10	25.98	27.68	31.78
AGU15	6.96	7.58	10.12	9.98	11.93	12.21	12.38	18.79	21.91	22.70	24.73	29.47	31.67	35.35
AA1	2.57	2.91	6.03	5.62	4.39	4.55	4.25	24.40	26.52	28.16	29.78	13.98	14.78	15.84
AA2	22.37	23.95	29.21	29.13	34.06	34.73	34.82	37.36	39.84	39.54	41.39	45.77	49.95	51.88
AA3	14.30	15.22	18.32	18.21	22.17	22.74	23.09	26.25	29.50	29.89	31.86	31.89	35.16	36.77
AA4	8.21	8.75	11.43	11.22	12.85	13.05	12.76	20.11	22.85	23.57	25.26	23.53	25.98	27.78
AA5	14.04	14.57	17.39	17.13	17.28	17.49	17.04	26.45	28.08	27.59	28.73	18.74	20.32	22.07
AA6	14.52	15.12	17.35	17.19	18.40	18.71	18.60	22.65	24.11	23.94	24.97	19.75	20.63	22.15
AA7	14.21	14.85	17.05	17.05	18.69	19.01	18.98	20.38	21.46	21.31	22.32	19.34	20.43	21.78
AA8	16.39	17.51	21.10	20.90	21.82	22.48	21.68	32.75	34.88	34.88	36.06	21.07	23.91	26.20
AA9	4.77	5.25	7.64	7.39	8.96	9.21	9.29	13.78	16.05	16.26	17.35	20.17	22.64	25.17
AA11	4.94	5.26	7.90	7.66	7.91	7.99	8.02	19.49	21.46	21.95	24.36	18.42	18.47	21.03
AA12	33.30	34.55	37.57	37.54	39.77	40.44	40.36	41.22	42.73	42.36	43.66	26.75	30.75	35.19
AA13	5.02	6.19	13.08	12.08	11.50	11.23	8.88	14.79	14.15	10.84	10.28	2.58	3.42	2.01
AA14	4.31	4.75	10.61	9.43	6.10	5.86	4.69	39.94	47.86	47.93	48.23	13.13	15.20	17.47
AA15	33.85	35.26	38.76	38.81	41.44	42.19	42.29	43.30	44.94	44.55	46.26	25.61	30.19	34.67
AA16	16.86	17.55	21.11	20.86	21.68	22.01	21.68	32.89	35.12	34.72	36.08	24.39	26.13	28.12
AA17	16.14	16.93	20.22	20.10	21.33	21.78	21.59	29.13	31.06	30.61	31.97	24.98	26.64	28.57
AA18	12.53	13.11	15.45	15.49	17.28	17.83	17.81	19.95	21.31	21.21	22.25	20.51	20.51	21.98
AA19	16.89	17.82	23.06	22.71	25.76	26.15	26.12	37.88	40.78	40.89	42.44	34.75	38.05	42.03
AA20	24.67	25.90	29.86	29.92	33.81	34.65	35.11	36.94	39.43	39.22	41.21	35.27	40.09	45.66
AA21	34.03	35.75	40.85	40.65	44.91	45.72	45.62	46.80	48.43	46.69	47.65	15.75	20.83	26.67
PTO1	5.31	5.85	8.54	8.46	9.53	10.03	9.28	19.59	23.31	23.00	24.87	14.77	21.10	25.24
PTO2	3.81	4.03	5.15	5.02	5.99	6.22	5.98	8.96	11.24	10.60	11.82	10.83	16.06	19.31
PTO3	2.72	3.01	4.46	4.42	4.75	4.93	4.82	10.68	13.00	12.96	14.62	8.84	11.41	13.98
PTO4	5.00	5.91	9.00	9.34	8.35	9.35	9.32	16.54	18.93	17.80	20.45	11.10	14.07	17.54
PTO5	14.26	15.27	20.05	19.88	23.31	23.88	23.83	26.54	29.67	30.07	32.02	32.91	38.15	45.89

Table A3.6 (cont.). Reflectance of points sampled in 2007 with CropScan.

	467	485	560	561	650	660	680	750	830	870	905	1560	1650	1700
PTO6	5.11	5.46	7.72	7.39	8.95	9.08	8.93	14.11	16.27	16.40	17.35	14.96	19.59	23.34
PTO7	20.76	22.02	27.43	27.24	31.34	31.89	32.67	35.44	38.59	39.57	41.15	45.21	49.95	58.89
PTO8	11.47	11.78	15.03	14.63	16.79	16.84	17.00	23.67	26.25	27.48	28.58	27.44	30.47	36.03
PTO9	9.45	10.57	13.91	14.27	14.37	15.58	15.53	21.80	24.06	23.54	26.31	21.52	25.47	29.98
PTO10	5.77	6.36	9.15	8.96	10.63	10.85	10.86	15.89	17.81	18.03	19.15	18.82	23.29	27.31
PTO11	16.05	16.79	19.56	19.46	21.48	22.00	21.79	23.03	24.63	24.23	25.21	22.72	27.48	32.23
PTO12	24.45	25.64	29.74	29.59	32.32	32.97	32.95	34.02	36.06	35.67	36.82	28.30	35.20	42.84
PTO13	14.07	14.91	18.68	18.53	22.59	23.16	23.95	27.32	31.39	32.40	34.55	27.87	34.20	41.73
GRM1	13.03	15.30	22.41	22.29	30.83	32.00	33.31	38.14	42.80	43.66	47.06	42.89	47.10	50.67
GRM2	4.92	5.46	8.55	8.17	8.98	9.08	8.83	22.35	25.38	25.79	27.16	14.28	16.63	18.62
GRM3	7.73	8.63	11.91	11.81	16.11	16.65	17.43	21.16	24.85	26.21	28.77	34.43	38.15	40.91
GRM4	17.70	19.01	24.64	24.35	30.11	30.74	30.98	36.52	39.50	39.68	41.96	49.33	53.37	57.52
GRM5	4.95	5.46	7.95	7.73	8.29	8.48	8.46	17.29	19.91	20.59	22.50	19.46	21.68	24.37
GRM6	13.24	14.26	18.68	18.50	20.93	21.41	21.58	26.73	29.73	30.01	32.68	35.96	39.43	43.77
GRM7	15.11	16.34	20.37	20.04	24.84	25.38	25.60	29.14	32.01	32.35	34.92	37.36	40.73	44.78
GRM8	6.44	7.06	9.74	9.69	11.40	11.81	11.58	21.51	24.51	25.16	27.32	22.39	24.64	28.70
GRM9	6.14	6.54	11.05	10.24	9.29	9.00	7.77	26.31	31.93	31.03	31.57	15.98	20.97	22.54
LPL1	12.74	13.41	16.09	15.71	17.26	17.53	17.71	21.39	23.31	23.40	24.62	21.11	21.77	22.34
LPL2	14.94	15.97	19.77	19.33	23.26	23.75	24.21	26.46	28.80	29.13	30.67	37.65	40.50	42.11
LPL3	24.62	25.38	28.11	27.34	30.78	31.07	30.99	32.29	33.94	33.96	34.72	36.05	38.67	40.19
LPL4	3.04	3.46	5.98	5.65	6.10	6.12	5.82	15.00	17.71	18.04	19.39	11.49	11.71	12.74
LPL5	6.13	6.63	8.70	8.44	10.05	10.39	10.50	13.96	15.97	15.90	17.25	23.06	26.49	28.70
LPL6	9.77	10.32	12.29	12.08	13.95	14.38	14.58	15.89	17.26	17.33	18.41	20.03	20.57	21.32
LPL7	12.52	13.27	15.67	15.41	17.66	18.12	18.32	19.47	20.77	20.69	21.63	22.53	24.46	26.55
LPL8	13.45	14.30	17.81	17.28	18.74	19.05	18.81	26.46	28.56	28.22	29.19	26.26	28.33	30.55
LPL9	12.61	13.42	16.60	16.24	19.02	19.22	19.26	23.56	25.40	25.59	26.48	27.69	28.91	31.92
LPL10	21.00	21.90	24.62	24.26	26.63	27.10	27.13	28.17	29.48	29.11	30.09	30.59	33.29	36.43
LPL11	11.85	12.67	15.43	15.24	17.56	18.02	18.18	19.35	20.73	20.59	21.58	26.23	28.37	30.96

Table A3.6 (cont.). Reflectance of points sampled in 2007 with CropScan.

	467	485	560	561	650	660	680	750	830	870	905	1560	1650	1700
LPL12	15.10	16.49	20.68	20.41	23.98	24.78	25.71	28.44	30.68	31.16	33.34	34.21	36.79	40.98
LPL13	10.37	11.12	13.89	13.60	15.75	16.01	16.37	20.15	22.41	23.33	24.75	33.69	35.71	38.84
LPL14	21.74	23.21	28.58	27.94	32.34	32.57	33.03	35.06	37.34	37.62	39.17	47.88	50.29	56.34
MRT1	11.18	11.93	15.21	14.79	17.96	17.99	18.36	22.67	25.07	26.12	27.49	35.21	38.31	39.80
MRT2	23.37	25.60	33.90	33.27	41.91	42.73	43.65	46.90	49.93	49.94	52.39	56.14	62.78	66.80
MRT3	32.37	35.05	44.04	43.23	50.04	50.81	51.49	54.06	56.00	55.73	57.92	55.26	62.26	69.72
MRT4	6.46	7.41	11.35	10.87	12.59	12.90	13.12	19.99	21.53	21.96	23.24	21.95	24.96	27.82
MRT5	17.26	18.61	23.59	23.00	25.44	25.80	25.89	31.96	34.71	35.68	37.43	34.77	39.87	44.40
MRT6	20.08	21.29	25.04	24.63	27.19	27.68	27.63	28.69	29.68	29.31	30.40	18.66	22.48	26.17
MRT7	19.28	20.14	23.27	22.84	25.03	25.39	25.17	26.57	27.39	26.92	27.96	25.06	27.49	29.95
PNL1	24.55	25.47	28.13	27.70	29.21	29.65	29.29	30.54	31.24	30.63	31.75	28.93	31.70	35.16
PNL2	10.26	11.30	15.80	15.15	18.84	19.11	19.30	28.89	32.98	33.76	35.40	33.18	37.90	40.06
PNL3	18.46	19.38	21.61	21.30	23.30	23.71	23.69	25.35	28.54	29.43	31.65	23.53	29.76	35.29
PNL4	4.01	4.60	7.80	7.48	7.62	7.66	7.31	16.63	19.11	19.19	20.68	12.84	13.94	15.12
PNL5	23.44	25.32	32.55	32.04	37.97	38.69	39.08	40.87	42.78	42.39	43.80	51.43	55.35	59.24
PNL6	21.86	22.88	26.53	26.31	28.95	29.57	29.87	30.81	31.72	31.12	32.27	33.55	36.36	39.69
PYO1	24.64	25.38	27.96	27.68	29.09	29.70	29.85	30.28	30.81	30.42	30.99	32.58	34.86	38.37
PYO2	4.07	4.58	7.66	7.37	7.13	7.45	6.91	18.88	21.83	21.97	23.18	12.80	14.16	14.27
PYO3	5.15	5.69	8.92	8.56	9.74	10.06	9.82	16.57	19.04	18.50	20.16	19.84	22.79	23.71
PYO4	25.87	27.35	32.56	31.85	34.95	35.67	35.46	36.96	40.29	40.83	42.35	46.17	51.08	54.36
PYO5	12.23	12.85	15.69	15.37	16.87	17.25	17.13	18.88	21.00	21.42	22.51	22.80	24.50	25.59
SAL1	4.21	4.56	6.75	6.46	6.69	6.94	6.73	16.10	18.27	19.08	19.73	11.17	13.64	16.28
SAL2	14.19	14.76	17.42	17.15	18.56	19.28	19.32	23.24	24.79	24.74	25.71	18.89	21.31	24.84
SAL3	21.66	22.62	25.95	25.46	28.15	29.04	28.99	30.30	32.14	31.91	32.81	27.70	30.34	33.63
SAL4	15.93	16.94	20.45	20.09	22.85	23.69	23.84	27.36	30.13	30.20	31.89	27.25	29.49	32.33
SAL5	16.28	17.39	22.44	21.71	24.85	25.63	25.41	33.52	36.79	37.23	38.59	40.08	41.88	46.36
SAL6	24.65	25.94	30.10	29.52	33.16	34.14	34.18	35.66	37.91	37.63	38.64	35.81	38.25	41.81
SAL7	13.96	14.74	16.59	16.45	16.96	17.59	17.38	17.57	18.65	18.12	19.18	17.55	18.57	20.09

Table A3.6 (cont.). Reflectance of points sampled in 2007 with CropScan.

	467	485	560	561	650	660	680	750	830	870	905	1560	1650	1700
SAL8	37.00	38.39	43.27	42.69	46.10	47.45	46.72	47.64	48.09	46.79	46.92	11.34	12.14	14.38
SAL9	18.45	19.41	22.16	21.84	24.60	25.42	25.22	26.20	28.11	27.67	28.44	8.27	8.57	9.60
SAL10	17.12	18.07	21.93	21.36	24.98	25.61	26.07	28.51	30.85	31.30	32.34	37.37	38.44	40.80
SAL11	11.66	12.78	16.77	16.48	20.06	20.74	20.75	23.84	26.41	26.52	27.72	13.54	17.11	20.20
SAL12	18.40	19.48	23.42	22.95	26.64	27.38	27.79	29.86	32.39	32.60	33.84	27.60	29.61	32.22
SAL13	10.84	11.48	14.57	14.29	17.47	17.84	18.03	24.07	26.91	27.65	28.79	19.33	20.27	22.60
SAL14	8.13	9.02	14.89	14.19	14.21	14.44	13.43	29.95	31.77	31.03	31.94	4.39	4.75	6.21
SAL15	4.55	4.84	6.91	6.48	6.34	6.37	6.07	19.66	23.88	23.75	24.53	9.81	10.68	12.19
SAL16	4.28	4.66	7.90	7.47	7.63	7.65	7.14	20.12	23.00	23.65	25.28	13.06	13.93	15.83
SAL17	13.24	14.54	23.71	22.82	24.46	24.36	21.00	32.03	33.24	32.65	33.87	5.81	6.71	8.99
SAL18	17.24	17.93	21.29	20.71	24.03	24.28	24.11	28.75	31.09	31.56	32.28	20.71	21.75	24.11
SAL19	1.76	1.87	2.84	2.76	3.26	3.38	3.36	9.91	12.20	12.53	14.12	10.40	11.17	12.61
SAL20	5.29	5.72	8.81	8.44	9.16	9.31	8.67	20.61	23.73	23.53	25.45	14.18	15.00	17.06
SAL21	5.18	5.51	7.20	7.20	9.16	9.40	8.99	18.90	21.64	21.74	23.42	10.01	9.81	11.14
SAL22	34.98	36.50	41.31	40.65	43.36	44.12	44.12	44.73	46.68	45.98	47.00	36.60	37.50	41.35
SAL23	2.63	2.92	5.34	5.01	4.51	4.61	3.96	21.83	25.08	24.48	24.43	6.37	6.60	7.42
SAL24	4.02	4.28	5.65	5.55	6.85	7.00	6.84	12.31	14.26	14.36	15.47	10.58	10.56	11.93
SAL25	22.75	23.91	27.93	27.47	30.09	30.79	30.84	32.06	33.49	33.22	34.12	16.62	18.93	22.44
SAL26	2.60	3.13	6.27	6.08	4.87	5.27	5.11	21.96	24.57	24.97	26.62	10.77	11.35	13.73
SAL27	28.35	29.84	34.62	34.01	36.59	37.26	37.09	38.27	40.20	39.60	40.85	49.25	51.09	54.83
SAL28	8.16	9.13	13.08	12.80	16.88	17.58	18.11	21.79	25.51	26.22	28.47	34.57	37.18	40.66
SAL29	6.77	7.44	10.82	10.50	11.99	12.32	12.46	20.12	23.65	24.10	26.04	25.41	25.70	28.61
SAL30	35.52	36.67	41.03	40.55	43.51	44.54	42.93	45.29	45.21	43.24	42.99	8.66	8.24	9.29
SAL31	11.96	12.56	13.80	13.65	13.96	14.32	14.21	14.37	15.29	15.01	15.86	16.32	17.43	19.16
SAL32	8.62	8.87	9.34	9.27	9.09	9.32	9.21	9.14	9.58	9.37	9.86	10.90	10.49	10.96
SAL33	3.76	4.06	6.48	6.14	6.58	6.65	6.35	17.17	20.01	20.87	22.25	14.10	15.48	17.36
SAL34	12.51	13.15	16.33	15.79	17.73	17.88	17.78	24.82	27.78	28.41	29.79	31.54	33.11	36.00
CMR1	14.47	15.50	19.81	19.37	23.76	24.19	24.60	26.89	29.23	29.73	30.81	37.67	40.39	44.56

Table A3.6 (cont.). Reflectance of points sampled in 2007 with CropScan.

	467	485	560	561	650	660	680	750	830	870	905	1560	1650	1700
CMR2	16.26	17.63	23.48	23.13	28.54	29.29	29.87	32.23	34.67	34.99	36.54	45.80	49.15	51.66
CMR3	3.35	3.75	6.74	6.36	6.36	6.32	6.10	16.29	19.03	19.60	21.02	11.24	11.46	12.63
CMR4	15.00	16.05	20.82	20.47	24.55	25.07	25.63	27.57	29.63	29.60	30.98	41.43	43.25	46.61

Table A3.7. Reflectance of vegetated points measured in 2008 with OceanOptics espectroradiometer, average of the transect, and NDVI, SAVI and IPV indexes.

Sample	Band 1	Band 2	Band 3	Band 4	Avge. Band1	Avge. Band2	Avge. Band3	Avge. Band4	NDVI	SAVI	IPV
Pto1	15.95	23.17	24.77	53.46	14.88	22.07	22.92	36.65	0.37	0.55	27.49
Pto2	12.31	18.15	18.70	21.31					0.07	0.10	4.44
Pto3	13.39	20.64	19.58	46.40					0.41	0.61	25.84
Pto4	10.88	18.68	19.01	25.67					0.15	0.22	8.02
Pto6	21.88	29.73	32.54	36.41					0.06	0.08	5.55
Pto7	1.55	4.10	3.00	10.22	12.88	16.77	18.39	23.69	0.55	0.79	8.52
Pto8	4.03	6.22	6.33	9.43					0.20	0.29	4.87
Pto10	4.38	7.70	6.96	18.10					0.44	0.65	11.98
Pto11	20.33	25.42	29.11	36.08					0.11	0.16	8.29
Ipl1	11.96	14.67	17.79	20.24	10.37	12.73	15.21	17.45	0.06	0.10	4.30
Ipl2	8.30	10.27	12.14	14.47					0.09	0.13	4.19
Ipl3	10.22	12.67	15.16	18.01					0.09	0.13	4.65
Ipl6	10.50	12.81	15.51	16.72					0.04	0.06	3.20
Ipl7	11.53	14.06	16.14	18.17	4.91	7.02	7.73	11.42	0.06	0.09	3.92
Ipl8	3.05	5.01	5.80	8.84					0.21	0.30	4.81
Ipl9	1.95	4.13	3.89	11.29					0.49	0.71	8.68
Ipl10	0.61	1.94	1.82	5.19					0.48	0.67	5.11
Ipl11	2.00	4.31	3.99	11.17					0.47	0.69	8.48
agu2	4.53	6.18	6.78	14.41					0.36	0.53	8.87
agu3	12.37	14.91	17.44	19.91					0.07	0.10	4.31
agu5	11.52	13.81	16.05	18.25					0.06	0.09	4.07
agu6	2.40	3.68	3.22	16.25	9.17	11.28	12.77	17.58	0.67	0.98	13.65
agu7	3.84	5.47	5.43	18.35					0.54	0.80	13.55
agu8	12.63	15.03	17.25	18.74					0.04	0.06	3.45
agu10	9.14	11.15	12.92	15.00					0.07	0.11	3.97
agu11	11.04	13.39	15.71	17.21					0.05	0.07	3.45

Table A3.7 (cont). Reflectance of vegetated points measured in 2008 with OceanOptics espectroradiometer, average of the transect, and NDVI, SAVI and IPV indexes.

Sample	Band 1	Band 2	Band 3	Band 4	Avge. Band1	Avge. Band2	Avge. Band3	Avge. Band4	NDVI	SAVI	IPV
sal1	5.28	7.83	8.35	14.46	3.77	6.32	6.46	16.75	0.27	0.39	7.52
sal2	4.55	7.65	7.37	22.76					0.51	0.75	15.74
sal3	2.22	4.30	4.35	10.10					0.40	0.58	7.22
sal4	1.55	3.81	3.46	13.05					0.58	0.85	10.61
sal5	1.17	3.42	2.98	18.24					0.72	1.05	15.62
sal6	7.87	10.89	12.25	21.87					0.28	0.42	10.63
far7	4.18	6.31	6.29	11.47	3.45	5.66	5.87	10.59	0.29	0.43	6.72
far8	1.99	4.05	3.54	11.62					0.53	0.77	9.27
far9	6.65	8.72	9.30	11.10					0.09	0.13	3.72
far10	1.72	3.79	3.68	8.95					0.42	0.60	6.78
far11	3.82	6.46	7.19	12.43					0.27	0.39	6.76
far12	3.00	4.74	5.10	5.59					0.05	0.07	2.56
far13	2.62	5.01	5.40	10.93					0.34	0.49	7.01
far14	4.20	6.94	7.17	15.00					0.35	0.52	9.05
far15	2.85	4.91	5.19	8.25					0.23	0.33	4.83
gll1	3.71	6.03	5.70	11.98	6.64	9.30	10.44	14.13	0.36	0.52	7.68
gll2	5.19	7.50	8.32	10.43					0.11	0.17	4.00
gll3	8.79	11.54	13.59	14.94					0.05	0.07	3.32
gll4	4.58	6.81	7.23	10.79					0.20	0.29	5.28
gll5	10.95	14.62	17.40	22.52					0.13	0.19	6.65
gll7	23.55	29.23	33.95	40.22					0.08	0.13	7.67

Table A3.7 (cont). Reflectance of soil points measured in 2008 with OceanOptics espectroradiometer, average of the transect, and NDVI, SAVI and IPV indexes.

Sample	Band 1	Band 2	Band 3	Band 4	Avge. Band1	Avge. Band2	Avge. Band3	Avge. Band4	NDVI	SAVI
Pto9	23.62	28.78	32.86	34.67					0.03	0.04
Pto12	23.36	28.39	32.10	33.64					0.02	0.03
lpl4	11.04	13.02	15.18	16.18					0.03	0.05
lpl12	10.34	12.69	14.76	13.87					-0.03	-0.05
lpl13	10.56	13.06	15.28	14.62	11.98	14.46	16.55	15.93	-0.02	-0.03
lpl14	14.09	16.50	18.52	18.25					-0.01	-0.01
lpl15	11.27	13.79	15.95	15.16					-0.03	-0.04
lpl16	12.02	14.48	16.46	15.70					-0.02	-0.03
agu4	12.53	14.96	17.26	18.44					0.03	0.05
agu9	12.93	15.59	18.14	19.99					0.05	0.07
agu12	12.21	14.64	16.71	17.50					0.02	0.03
agu13	22.99	26.47	29.21	31.93	30.00	32.11	34.04	35.80	0.04	0.07
agu14	17.48	20.86	23.38	26.85					0.07	0.10
agu15	66.09	63.67	62.63	59.46					-0.03	-0.04
agu16	17.25	19.22	20.31	21.78					0.03	0.05
agu17	26.18	30.33	34.69	38.95					0.06	0.09
agu18	21.14	23.18	24.87	26.67	25.89	27.53	28.86	30.43	0.03	0.05
agu19	19.42	20.54	21.04	22.14					0.03	0.04
agu20	21.52	22.56	22.99	23.93					0.02	0.03
agu21	21.87	24.20	26.25	28.79					0.05	0.07
agu22	22.33	23.66	24.88	26.09					0.02	0.04
agu23	49.04	51.01	53.12	54.99					0.02	0.03
agu24	38.38	40.83	42.46	43.98	38.10	40.37	41.88	43.47	0.02	0.03
agu25	33.24	35.38	36.97	38.66					0.02	0.03
agu26	42.68	44.91	46.20	47.75					0.02	0.02
sal7	14.47	17.61	19.50	17.45	14.63	17.75	19.83	17.85	-0.06	-0.08
sal8	12.57	15.44	17.26	15.18					-0.06	-0.10
sal9	15.08	18.32	20.58	18.53					-0.05	-0.08

Table A3.7 (cont). Reflectance of soil points measured in 2008 with OceanOptics espectroradiometer, average of the transect, and NDVI, SAVI and IPV indexes.

Sample	Band 1	Band 2	Band 3	Band 4	Avge. Band1	Avge. Band2	Avge. Band3	Avge. Band4	NDVI	SAVI
sal10	16.08	19.42	21.72	20.12					-0.04	-0.06
sal11	14.94	17.99	20.08	17.98					-0.06	-0.08
sal13	28.64	31.06	31.82	30.06	25.21	26.95	26.88	23.86	-0.03	-0.04
sal14	26.53	28.41	28.62	25.92					-0.05	-0.07
sal15	20.48	21.51	20.43	15.99					-0.12	-0.18
sal16	25.18	26.82	26.65	23.46					-0.06	-0.09
gll6	24.79	30.20	35.05	38.98	27.83	33.68	39.07	44.04	0.05	0.08
gll8	34.84	41.33	47.53	52.77					0.05	0.08
gll9	34.52	40.64	46.39	51.41					0.05	0.08
gll10	21.46	26.97	32.42	36.85					0.06	0.10
gll11	12.16	14.60	15.67	13.27	11.96	14.03	14.52	11.43	-0.08	-0.12
gll12	11.42	13.48	14.01	10.68					-0.13	-0.20
gll13	11.05	13.00	13.42	10.22					-0.14	-0.20
gll14	13.06	15.10	15.49	12.33					-0.11	-0.17
gll15	12.11	13.95	14.01	10.68					-0.14	-0.20

Table A3.8. Reflectance and NDVI of the points sampled with OceanOptics on the Quickbird, Landsat, and Aster images of 2007.

	QUICKBIRD					LANDSAT							ASTER			
	Band 1	Band 2	Band 3	Band 4	NDVI	Band 1	Band 2	Band 3	Band 4	Band 5	Band 6	NDVI	Band 2	Band 3 (Red)	Band 4 (nir)	NDVI
pto1	10.68	13.13	16.25	23.61	0.18	9.42	14.14	16.15	21.17	31.34	23.66	0.13	16.00	16.88	25.49	0.20
pto2	9.71	11.87	14.76	21.22	0.18	9.42	14.14	16.15	21.17	31.34	23.66	0.13	16.45	18.14	27.27	0.20
pto3	12.22	15.05	18.93	26.77	0.17	9.42	13.44	14.48	22.20	32.28	24.00	0.21	15.55	16.13	25.14	0.22
pto4	11.80	14.41	18.01	24.77	0.16	9.76	14.49	16.43	22.89	33.92	26.05	0.16	15.55	16.63	24.43	0.19
pto5	12.34	15.60	19.15	26.47	0.16	9.76	14.49	16.43	22.89	33.92	26.05	0.16	15.55	16.63	24.43	0.19
pto6	12.08	14.89	18.61	25.68	0.16	11.10	15.18	17.82	25.63	33.92	29.13	0.18	18.46	19.15	28.69	0.20
pto7	19.09	23.62	29.07	36.69	0.12	16.12	21.11	23.39	30.43	37.91	28.79	0.13	27.61	26.95	35.45	0.14
pto8	18.41	22.79	28.07	35.40	0.12	16.12	21.81	23.11	30.78	37.91	28.11	0.14	26.72	26.19	35.09	0.15
pto9	17.99	22.54	27.61	34.17	0.11	16.12	21.81	23.11	30.78	37.91	28.11	0.14	27.17	26.70	36.16	0.15
pto10	18.61	23.33	28.70	35.82	0.11	16.95	24.60	27.01	33.86	39.32	27.76	0.11	25.83	26.70	35.45	0.14
pto11	17.57	21.76	26.63	32.89	0.11	17.12	24.94	27.29	34.89	40.73	27.76	0.12	25.83	26.70	35.09	0.14
pto12	18.32	22.77	27.77	33.82	0.10	16.45	22.50	25.34	33.86	40.26	28.11	0.14	25.83	26.70	34.02	0.12
pto13	19.32	23.67	29.34	36.37	0.11	14.11	21.46	23.11	30.09	38.15	28.79	0.13	25.38	27.20	35.45	0.13
lpl1	11.96	14.66	17.83	29.12	0.24	10.59	15.88	17.26	26.66	24.77	18.52	0.21	23.82	24.43	35.09	0.18
lpl2	10.21	12.54	14.93	26.34	0.28	10.59	15.88	17.26	26.66	24.77	18.52	0.21	16.89	16.63	27.98	0.25
lpl3	12.89	15.79	19.00	28.80	0.20	10.76	15.53	17.26	25.97	28.29	21.26	0.20	16.89	17.39	26.20	0.20
lpl4	13.25	16.01	19.51	27.75	0.17	10.76	15.53	17.26	25.97	28.29	21.26	0.20	17.34	18.14	27.98	0.21
lpl5	13.21	16.70	20.87	30.86	0.19	13.77	18.32	22.84	31.12	33.69	25.37	0.15	18.23	18.14	28.34	0.22
lpl6	12.43	15.48	19.11	30.15	0.22	14.94	20.06	25.62	34.55	40.26	31.53	0.15	17.34	18.65	28.69	0.21
lpl7	10.96	13.67	16.56	27.80	0.25	15.28	22.50	27.01	37.30	42.84	31.53	0.16	16.89	17.64	27.27	0.21
lpl8	11.41	14.20	17.14	27.27	0.23	12.77	17.28	21.16	31.12	28.76	20.92	0.19	14.66	15.63	27.27	0.27
lpl9	8.36	10.40	11.89	24.05	0.34	8.75	12.74	13.36	23.57	22.18	15.44	0.28	13.54	12.10	25.14	0.35
lpl10	8.27	10.01	11.56	23.34	0.34	8.75	12.74	13.36	23.57	22.18	15.44	0.28	13.54	12.10	24.78	0.34
lpl11	8.99	10.82	12.48	24.32	0.32	8.08	11.00	21.17	21.17	18.66	13.04	0.00	14.43	12.61	25.85	0.34
lpl12	14.87	17.23	20.80	24.88	0.09	12.60	15.18	16.43	22.89	27.35	19.89	0.16	23.82	23.18	28.69	0.11
lpl13	18.80	21.53	25.42	29.70	0.08	12.60	15.18	16.43	22.89	27.35	19.89	0.16	24.93	23.68	28.69	0.10

Table A3.8 (cont.). Reflectance and NDVI of the points sampled with OceanOptics on the Quickbird, Landsat, and Aster images of 2007.

	QUICKBIRD					LANDSAT							ASTER			
	Band 1	**Band 2**	**Band 3**	**Band 4**	**NDVI**	**Band 1**	**Band 2**	**Band 3**	**Band 4**	**Band 5**	**Band 6**	**NDVI**	**Band 2**	**Band 3 (Red)**	**Band 4 (nir)**	**NDVI**
lpl14	18.21	21.03	24.96	28.80	0.07	15.61	20.06	21.72	26.66	32.28	23.66	0.10	26.27	25.19	30.47	0.09
lpl15	17.72	20.53	24.37	28.30	0.07	15.61	20.06	21.72	26.66	32.28	23.66	0.10	30.96	29.72	33.31	0.06
lpl16	23.77	27.30	31.71	36.16	0.07	15.61	20.06	21.72	26.66	32.28	23.66	0.10	30.96	29.72	33.31	0.06
agu1	10.29	12.76	15.70	23.70	0.20	8.75	12.74	13.92	20.83	27.11	20.23	0.20	15.55	15.63	25.14	0.23
agu2	10.47	12.98	16.16	23.35	0.18	8.75	12.74	13.92	20.83	27.11	20.23	0.20	15.77	16.13	24.78	0.21
agu3	12.44	15.25	18.89	25.90	0.16	9.92	14.49	16.15	22.89	32.51	24.00	0.17	17.34	18.90	26.92	0.18
agu4	12.57	15.81	19.83	28.02	0.17	9.92	15.18	16.98	24.26	33.69	24.68	0.18	19.57	20.41	29.40	0.18
agu5	13.18	16.26	20.60	29.48	0.18	11.10	15.53	17.54	26.66	33.22	24.34	0.21	21.58	21.67	31.89	0.19
agu6	13.42	17.12	21.56	30.68	0.17	11.43	15.88	17.54	26.66	33.69	23.66	0.21	20.69	21.16	31.18	0.19
agu7	13.77	17.44	21.70	30.58	0.17	9.76	14.83	16.98	22.20	29.70	21.60	0.13	20.47	21.41	29.76	0.16
agu8	12.45	15.44	18.87	27.18	0.18	10.93	15.88	17.26	24.94	31.34	24.00	0.18	18.46	19.40	26.20	0.15
agu9	14.59	18.28	22.48	29.97	0.14	10.09	14.49	15.59	23.23	29.46	23.31	0.20	17.34	17.64	26.20	0.20
agu10	12.01	14.97	18.14	24.40	0.15	10.59	15.88	16.98	22.20	28.99	20.57	0.13	17.79	17.89	25.49	0.18
agu11	13.17	16.11	19.47	26.30	0.15	11.10	17.28	16.98	23.23	29.23	20.92	0.16	18.68	18.14	26.20	0.18
agu12	12.80	15.84	19.11	24.83	0.13	20.63	25.99	27.85	33.52	28.76	19.20	0.09	34.09	36.26	41.85	0.07
agu14	31.39	35.56	40.09	44.03	0.05	18.96	25.99	27.29	33.86	30.87	19.89	0.11	34.09	34.75	39.71	0.07
agu15	27.60	31.11	34.56	37.71	0.04	16.45	23.90	23.11	30.43	30.17	20.57	0.14	32.30	31.48	37.58	0.09
agu16	26.15	29.96	34.02	38.35	0.06	15.61	22.85	22.00	30.09	29.70	20.57	0.16	30.74	29.72	36.87	0.11
agu17	22.99	26.87	31.14	35.74	0.07	15.45	22.85	23.67	30.09	35.33	24.68	0.12	30.74	29.97	37.94	0.12
agu18	22.08	26.27	31.30	37.29	0.09	17.12	23.55	25.62	30.78	29.70	20.92	0.09	30.52	29.47	35.80	0.10
agu19	23.26	27.55	31.77	36.67	0.07	17.29	23.90	24.79	31.46	31.34	21.60	0.12	30.96	29.21	35.80	0.10
agu20	22.92	26.15	29.58	33.33	0.06	18.29	23.55	25.90	31.12	28.52	20.23	0.09	29.85	30.47	37.58	0.10
agu21	21.01	24.28	27.86	32.33	0.07	15.11	21.11	23.67	31.12	37.44	27.08	0.14	30.07	31.73	38.65	0.10
agu22	23.18	27.33	33.27	39.43	0.08	16.12	22.16	23.67	29.40	30.64	27.08	0.11	30.07	30.98	38.65	0.11
agu23	24.35	28.78	34.34	40.43	0.08	17.62	22.16	24.23	29.75	28.05	20.92	0.10	31.19	31.23	37.94	0.10
agu24	24.88	28.66	33.22	37.42	0.06	16.12	23.55	26.18	33.18	35.57	23.31	0.12	28.06	29.21	39.71	0.15

Table A3.8 (cont.). Reflectance and NDVI of the points sampled with OceanOptics on the Quickbird, Landsat, and Aster images of 2007.

	QUICKBIRD					LANDSAT							ASTER			
	Band 1	Band 2	Band 3	Band 4	NDVI	Band 1	Band 2	Band 3	Band 4	Band 5	Band 6	NDVI	Band 2	Band 3 (Red)	Band 4 (nir)	NDVI
agu25	30.06	35.28	42.11	46.96	0.05	18.12	23.55	25.90	33.18	30.87	20.23	0.12	26.27	27.45	37.94	0.16
agu26	28.28	32.74	38.71	43.27	0.06	18.46	25.29	26.46	34.21	30.64	20.23	0.13	32.08	33.24	37.94	0.07
sal1	10.75	13.72	16.29	29.40	0.29	14.27	20.06	21.72	29.40	21.95	14.75	0.15	16.22	18.90	30.47	0.23
sal2	8.56	11.15	12.61	30.15	0.41	14.27	20.06	21.72	29.40	21.95	14.75	0.15	15.10	17.89	30.47	0.26
sal3	7.26	9.25	10.07	27.87	0.47	11.10	14.49	15.31	28.03	21.71	13.38	0.29	15.55	12.61	30.47	0.41
sal4	7.52	9.54	10.91	25.04	0.39	11.10	14.49	15.31	28.03	21.71	13.38	0.29	14.66	12.10	27.98	0.40
sal5	6.86	8.48	9.41	26.12	0.47	11.10	14.49	15.31	28.03	21.71	13.38	0.29	12.65	12.10	29.05	0.41
sal6	6.77	8.38	9.49	26.10	0.47	9.92	17.97	20.89	27.69	26.18	18.52	0.14	12.65	12.10	29.05	0.41
sal7	26.52	29.86	32.90	36.45	0.05	15.28	20.06	21.72	28.03	22.89	13.38	0.13	28.06	25.69	32.96	0.12
sal8	20.72	23.04	26.02	29.15	0.06	15.28	20.06	21.72	28.03	22.89	13.38	0.13	27.84	26.19	31.89	0.10
sal9	19.84	22.65	26.08	29.12	0.06	15.61	20.76	22.84	27.35	23.59	14.07	0.09	28.06	26.70	32.25	0.09
sal10	19.84	22.72	26.21	29.64	0.06	22.81	29.83	32.03	35.58	22.65	13.73	0.05	28.06	26.70	32.25	0.09
sal11	21.13	24.26	27.86	31.39	0.06	22.81	29.83	32.03	35.58	22.65	13.73	0.05	27.84	28.21	33.31	0.08
sal13	21.17	24.60	28.60	31.36	0.05	18.63	24.25	26.46	31.81	21.95	16.81	0.09	30.96	30.98	37.22	0.09
sal14	21.46	25.13	29.46	32.71	0.05	18.63	24.25	26.46	31.81	21.95	16.81	0.09	29.85	30.22	35.45	0.08
sal15	21.93	26.00	31.43	35.18	0.06	18.63	24.25	26.46	31.81	21.95	16.81	0.09	31.19	32.23	37.94	0.08
sal16	22.74	26.84	31.89	35.74	0.06	19.13	25.29	28.13	33.86	21.01	15.78	0.09	31.19	32.23	37.94	0.08
far2	13.17	15.44	17.87	22.40	0.11	11.60	15.88	16.43	22.20	28.52	21.94	0.15	17.79	17.14	24.07	0.17
far3	13.04	15.39	17.95	22.78	0.12	11.93	15.88	17.26	22.54	29.70	23.31	0.13	17.56	17.39	24.07	0.16
far4	13.10	15.38	18.03	23.27	0.13	12.94	17.28	20.05	23.57	30.64	24.34	0.08	17.79	17.64	24.43	0.16
far5	13.29	15.65	18.25	23.70	0.13	12.94	17.28	20.05	23.57	30.64	24.34	0.08	17.79	17.64	25.14	0.18
far6	14.65	17.13	20.14	25.79	0.12	13.94	17.28	18.94	29.06	36.50	30.16	0.21	20.02	20.66	28.69	0.16
far7	8.05	9.84	11.77	21.92	0.30	9.42	12.74	13.92	21.86	25.94	18.18	0.22	12.87	12.36	24.07	0.32
far8	7.74	9.78	11.58	22.09	0.31	8.08	11.35	11.97	20.48	25.47	16.47	0.26	12.87	12.36	24.07	0.32
far9	7.93	10.14	12.32	23.04	0.30	8.08	11.35	11.97	20.48	25.47	16.47	0.26	12.42	12.36	23.72	0.31
far10	7.98	10.00	12.17	23.27	0.31	8.08	11.35	11.97	20.48	25.47	16.47	0.26	12.42	12.61	23.72	0.31

Table A3.8 (cont.). Reflectance and NDVI of the points sampled with OceanOptics on the Quickbird, Landsat, and Aster images of 2007.

	QUICKBIRD					LANDSAT							ASTER			
	Band 1	Band 2	Band 3	Band 4	NDVI	Band 1	Band 2	Band 3	Band 4	Band 5	Band 6	NDVI	Band 2	Band 3 (Red)	Band 4 (nir)	NDVI
far11	8.45	10.44	13.27	23.19	0.27	7.25	11.35	11.41	21.51	25.71	16.47	0.31	12.87	13.11	24.07	0.29
far12	7.32	9.24	10.84	22.92	0.36	8.08	11.35	11.97	20.48	25.47	16.47	0.26	12.42	12.10	23.01	0.31
far13	7.13	9.05	10.54	23.38	0.38	8.08	11.35	11.97	20.48	25.47	16.47	0.26	12.42	12.36	23.72	0.31
far14	7.90	9.84	11.77	22.01	0.30	8.08	11.35	11.97	20.48	25.47	16.47	0.26	12.42	12.36	23.72	0.31
far15	8.34	10.27	12.06	21.81	0.29	9.42	12.74	13.92	21.86	25.94	18.18	0.22	13.09	12.10	23.72	0.32
gll1	12.99	16.22	21.18	29.66	0.17	9.92	15.53	18.66	26.66	37.44	28.11	0.18	18.23	20.66	30.11	0.19
gll2	13.58	17.20	22.20	30.96	0.16	10.43	17.28	18.38	28.37	34.86	28.11	0.21	18.23	19.65	29.05	0.19
gll3	11.64	14.48	18.56	28.02	0.20	10.43	17.28	18.38	28.37	34.86	28.11	0.21	18.46	19.15	28.69	0.20
gll4	11.79	15.10	19.39	30.73	0.23	11.10	17.28	18.66	30.09	36.74	27.42	0.23	18.46	19.40	29.40	0.20
gll5	14.56	18.82	24.84	33.88	0.15	11.10	17.28	18.66	30.09	36.74	27.42	0.23	18.90	19.90	30.47	0.21
gll6	20.48	25.76	32.70	40.88	0.11	14.94	19.02	20.05	32.83	38.62	28.79	0.24	28.73	29.47	36.87	0.11
gll7	22.68	28.49	35.91	44.33	0.10	14.94	19.02	20.05	32.83	38.62	28.79	0.24	31.86	33.24	40.42	0.10
gll8	22.39	28.18	35.63	44.52	0.11	14.94	19.02	20.05	32.83	38.62	28.79	0.24	31.86	34.00	40.78	0.09
gll9	23.33	29.27	37.30	46.14	0.11	16.12	24.60	27.57	35.92	37.68	24.34	0.13	34.09	35.00	43.27	0.11
gll10	21.11	26.74	34.90	43.61	0.11	17.96	25.29	27.29	38.32	43.08	31.53	0.17	31.63	33.49	42.56	0.12
gll11	17.64	20.25	23.57	27.48	0.08	12.60	18.32	21.44	24.94	23.36	15.10	0.08	23.59	23.18	28.69	0.11
gll12	16.17	19.01	22.24	26.10	0.08	12.94	18.67	20.05	22.89	21.01	15.78	0.07	23.15	23.18	27.98	0.09
gll13	16.29	18.88	21.93	25.50	0.08	12.94	18.67	20.05	22.89	21.01	15.78	0.07	23.82	23.18	28.69	0.11
gll14	16.78	19.48	22.55	26.22	0.08	12.94	16.58	18.38	21.17	19.84	12.70	0.07	23.59	23.18	27.63	0.09
gll15	16.07	18.68	21.69	25.04	0.07	12.94	16.58	18.38	21.17	19.84	12.70	0.07	22.92	22.42	27.98	0.11

Table A3.9. Reflectance and NDVI of the points sampled with OceanOptics, on the Quickbird and Landsat images of 2008.

	QUICKBIRD					LANDSAT						
	Band 1	**Band 2**	**Band 3**	**Band 4**	**NDVI**	**Band 1**	**Band 2**	**Band 3**	**Band 4**	**Band 5**	**Band 6**	**NDVI**
pto1	7.95	9.93	11.89	17.97	0.20	9.62	12.95	15.53	25.62	31.98	25.69	0.25
pto2	7.45	9.22	10.66	16.24	0.21	9.62	12.95	15.53	25.62	31.98	25.69	0.25
pto3	8.06	9.92	12.08	17.76	0.19	11.48	14.36	18.07	29.44	35.54	27.77	0.24
pto4	7.54	9.25	11.15	15.84	0.17	12.16	15.42	19.20	31.87	36.25	29.85	0.25
pto5	7.47	9.28	10.98	16.08	0.19	12.16	15.42	19.20	31.87	36.25	29.85	0.25
pto6	8.43	10.52	12.82	17.93	0.17	10.80	15.42	17.23	28.05	32.69	25.69	0.24
pto7	14.25	18.90	24.37	31.73	0.13	12.50	21.08	21.18	27.36	36.49	27.77	0.13
pto8	12.64	0.00	20.66	27.17	0.14	16.40	24.26	26.26	34.65	41.48	30.55	0.14
pto9	13.25	17.02	21.59	28.16	0.13	16.40	24.26	26.26	34.65	41.48	30.55	0.14
pto10	12.92	16.69	21.21	27.94	0.14	16.57	25.32	27.67	35.00	40.53	31.24	0.12
pto11	14.72	19.13	23.97	30.55	0.12	16.91	24.96	27.11	34.31	41.72	31.94	0.12
pto12	13.70	17.74	22.60	29.51	0.13	15.72	23.55	25.13	32.92	41.01	30.55	0.13
pto13	14.95	19.48	24.40	31.11	0.12	12.67	21.08	20.90	28.05	38.87	28.47	0.15
lpl1	7.07	8.62	10.09	16.20	0.23	12.84	17.19	21.18	30.83	25.08	17.37	0.19
lpl2	6.82	8.14	9.52	15.39	0.24	12.84	17.19	21.18	30.83	25.08	17.37	0.19
lpl3	7.83	9.49	11.44	16.54	0.18	10.97	14.36	17.23	25.62	29.12	17.37	0.20
lpl4	8.65	10.70	13.34	18.12	0.15	9.78	14.72	16.66	24.58	30.79	21.19	0.19
lpl5	8.41	10.37	12.99	17.71	0.15	12.16	16.13	19.48	28.40	28.88	21.19	0.19
lpl6	8.97	11.18	14.02	19.16	0.16	10.97	16.84	18.36	25.97	27.93	21.53	0.17
lpl7	6.76	8.03	9.68	14.83	0.21	8.77	13.30	14.12	22.49	24.84	18.06	0.23
lpl8	6.19	7.38	8.22	13.29	0.24	8.43	11.54	13.28	21.10	21.99	16.33	0.23
lpl9	5.80	6.86	7.36	13.34	0.29	7.58	14.01	12.15	20.41	20.09	14.60	0.25
lpl10	5.90	7.00	7.71	13.48	0.27	7.58	14.01	12.15	20.41	20.09	14.60	0.25
lpl11	6.21	7.29	8.10	13.55	0.25	8.77	13.66	12.71	21.45	22.70	16.33	0.26
lpl12	10.82	13.47	17.00	20.98	0.10	9.62	14.72	16.10	21.10	25.56	18.06	0.13
lpl13	10.59	13.34	16.76	20.93	0.11	9.62	14.72	16.10	21.10	25.56	18.06	0.13

Table A3.9 (cont). Reflectance and NDVI of the points sampled with OceanOptics, on the Quickbird and Landsat images of 2008.

	QUICKBIRD					LANDSAT						
	Band 1	Band 2	Band 3	Band 4	NDVI	Band 1	Band 2	Band 3	Band 4	Band 5	Band 6	NDVI
lpl14	10.49	13.21	16.68	20.84	0.11	10.80	15.42	16.66	21.80	26.98	18.06	0.13
lpl15	10.60	13.26	16.86	20.75	0.10	10.80	15.42	16.66	21.80	26.98	18.06	0.13
lpl16	10.41	13.06	16.63	20.66	0.11	10.80	15.42	16.66	21.80	26.98	18.06	0.13
agu1	7.22	8.39	9.96	14.10	0.17	11.65	18.25	18.92	31.18	38.63	28.12	0.24
agu2	7.04	8.52	10.31	14.32	0.16	11.65	18.25	18.92	31.18	38.63	28.12	0.24
agu3	7.77	9.30	11.42	15.43	0.15	23.36	34.51	40.37	50.99	58.84	49.27	0.12
agu4	8.50	10.51	13.15	17.24	0.13	23.36	34.51	40.37	50.99	58.84	49.27	0.12
agu5	8.83	10.83	13.56	17.42	0.12	12.16	16.84	18.92	26.66	34.83	31.94	0.17
agu6	8.87	11.10	13.76	19.23	0.17	11.48	15.78	18.64	25.62	33.88	31.94	0.16
agu7	9.64	11.96	15.04	20.71	0.16	11.65	18.25	19.77	26.31	37.92	29.85	0.14
agu8	8.67	11.04	13.45	18.31	0.15	10.80	16.84	18.07	24.92	35.54	28.47	0.16
agu9	9.10	11.34	13.91	18.83	0.15	10.63	15.42	16.94	23.88	33.64	27.08	0.17
agu10	8.48	10.10	12.39	16.61	0.15	9.78	14.36	16.10	23.88	32.93	25.00	0.19
agu11	8.29	10.23	12.34	16.15	0.13	9.62	14.01	15.25	22.49	32.21	24.65	0.19
agu12	8.36	10.40	12.56	16.33	0.13	10.80	14.72	16.38	22.49	28.88	22.57	0.16
agu14	11.79	14.77	18.06	22.90	0.12	9.95	14.36	16.38	22.84	30.55	24.31	0.16
agu15	11.56	14.40	17.43	21.78	0.11	10.12	16.13	17.51	24.58	32.93	26.04	0.17
agu16	11.59	14.58	17.91	23.06	0.13	15.04	21.08	22.87	28.75	32.93	24.65	0.11
agu17	10.58	13.49	16.42	20.95	0.12	15.04	21.43	23.72	30.14	35.54	24.65	0.12
agu18	11.50	14.39	18.37	23.74	0.13	15.55	20.72	22.87	29.79	31.98	23.61	0.13
agu19	10.85	13.76	17.31	22.49	0.13	14.37	21.08	22.31	28.05	32.69	24.31	0.11
agu20	10.57	13.37	17.07	21.92	0.12	14.53	19.66	20.05	27.01	30.55	22.23	0.15
agu21	10.48	13.12	17.00	21.50	0.12	15.04	21.08	22.59	28.75	30.31	20.49	0.12
agu22	11.15	13.93	17.91	22.80	0.12	15.89	21.08	22.59	28.40	28.65	19.45	0.11
agu23	11.14	14.00	17.97	22.93	0.12	15.89	21.08	22.59	28.40	28.65	19.45	0.11
agu24	11.43	14.54	18.49	23.30	0.11	13.35	23.55	21.74	27.01	34.35	23.27	0.11

Table A3.9 (cont). Reflectance and NDVI of the points sampled with OceanOptics, on the Quickbird and Landsat images of 2008.

	QUICKBIRD					LANDSAT						
	Band 1	Band 2	Band 3	Band 4	NDVI	Band 1	Band 2	Band 3	Band 4	Band 5	Band 6	NDVI
agu25	17.87	22.74	28.94	35.11	0.10	15.04	22.84	25.41	28.75	36.02	23.61	0.06
agu26	15.44	19.83	25.14	31.12	0.11	16.57	20.72	26.54	33.96	37.44	26.04	0.12
sal1	6.23	8.01	8.96	22.00	0.42	13.18	22.84	28.52	31.87	26.98	18.41	0.06
sal2	6.33	8.32	9.64	20.14	0.35	13.18	22.84	28.52	31.87	26.98	18.41	0.06
sal3	5.85	7.29	8.11	18.81	0.40	12.16	21.78	24.85	31.87	37.44	27.43	0.12
sal4	5.60	7.04	7.93	18.53	0.40	12.16	21.78	24.85	31.87	37.44	27.43	0.12
sal5	5.79	7.21	8.20	19.31	0.40	12.16	21.78	24.85	31.87	37.44	27.43	0.12
sal6	6.82	8.89	10.32	21.32	0.35	10.97	17.90	19.77	37.09	30.55	22.92	0.30
sal7	13.89	17.65	22.15	27.48	0.11	13.69	18.60	20.90	26.66	23.42	15.64	0.12
sal8	14.47	18.22	22.92	28.83	0.11	13.69	18.60	20.90	26.66	23.42	15.64	0.12
sal9	13.51	17.16	21.83	27.11	0.11	14.03	20.02	21.18	27.01	22.70	15.29	0.12
sal10	12.97	16.47	20.86	25.96	0.11	16.74	21.43	22.31	28.75	22.70	14.94	0.13
sal11	12.98	16.61	20.85	26.04	0.11	16.74	21.43	22.31	28.75	22.70	14.94	0.13
sal13	12.94	16.39	20.54	24.98	0.10	15.04	21.08	22.59	29.44	23.65	17.72	0.13
sal14	12.99	16.31	20.47	25.02	0.10	15.04	21.08	22.59	29.44	23.65	17.72	0.13
sal15	11.56	15.13	18.85	17.47	-0.04	15.72	23.20	24.85	29.79	21.51	15.98	0.09
sal16	12.84	16.71	20.70	22.42	0.04	15.72	23.20	24.85	29.79	21.51	15.98	0.09
far2	7.48	9.04	10.53	14.11	0.15	10.80	15.07	16.10	21.45	27.22	21.19	0.14
far3	7.72	9.31	10.91	14.63	0.15	10.80	15.42	16.10	21.45	27.93	21.53	0.14
far4	7.79	9.32	10.98	14.85	0.15	11.48	15.78	16.66	22.84	29.12	22.23	0.16
far5	7.95	9.69	11.42	15.66	0.16	11.48	15.78	16.66	22.84	29.12	22.23	0.16
far6	7.97	9.74	11.45	16.00	0.17	12.50	17.54	17.51	25.62	31.26	24.31	0.19
far7	6.17	7.58	8.56	15.91	0.30	8.09	11.89	11.58	20.75	22.94	16.68	0.28
far8	6.18	7.67	8.52	16.32	0.31	7.41	10.83	10.73	20.06	22.70	15.29	0.30
far9	6.14	7.67	8.53	16.75	0.33	7.41	10.83	10.73	20.06	22.70	15.29	0.30
far10	6.13	7.78	8.81	17.28	0.32	7.41	10.83	10.73	20.06	22.70	15.29	0.30

Table A3.9 (cont). Reflectance and NDVI of the points sampled with OceanOptics, on the Quickbird and Landsat images of 2008.

	QUICKBIRD					LANDSAT						
	Band 1	**Band 2**	**Band 3**	**Band 4**	**NDVI**	**Band 1**	**Band 2**	**Band 3**	**Band 4**	**Band 5**	**Band 6**	**NDVI**
far11	6.84	8.64	10.03	18.39	0.29	7.07	10.48	10.73	21.10	22.70	15.98	0.33
far12	6.88	8.86	10.43	19.73	0.31	7.41	10.83	10.73	20.06	22.70	15.29	0.30
far13	6.24	7.99	8.92	18.52	0.35	7.41	10.83	10.73	20.06	22.70	15.29	0.30
far14	6.17	7.77	8.84	16.46	0.30	7.41	10.83	10.73	20.06	22.70	15.29	0.30
far15	6.08	7.49	8.29	16.76	0.34	10.46	12.95	14.69	22.49	25.32	18.76	0.21
gll1	7.40	9.52	11.47	18.92	0.25	9.95	14.72	18.64	28.75	34.35	24.31	0.21
gll2	7.53	9.81	11.70	19.56	0.25	9.45	14.36	17.23	27.01	36.25	27.77	0.22
gll3	7.03	9.10	10.78	18.43	0.26	9.45	14.36	17.23	27.01	36.25	27.77	0.22
gll4	7.25	9.23	11.08	19.97	0.29	10.97	14.36	19.48	28.40	36.25	26.04	0.19
gll5	7.95	10.52	13.63	21.47	0.22	10.97	14.36	19.48	28.40	36.25	26.04	0.19
gll6	12.67	16.57	22.00	30.22	0.16	17.59	27.79	28.52	39.52	37.68	24.65	0.16
gll7	16.48	21.65	28.12	36.70	0.13	17.59	27.79	28.52	39.52	37.68	24.65	0.16
gll8	13.31	17.51	23.58	31.68	0.15	13.01	20.37	20.33	28.40	25.32	17.02	0.17
gll9	13.88	18.50	24.66	32.78	0.14	13.01	20.37	20.33	28.40	25.32	17.02	0.17
gll10	12.86	17.08	22.86	30.67	0.15	13.69	22.49	24.28	35.35	27.22	18.06	0.19
gll11	10.43	13.22	16.42	20.30	0.11	12.33	16.48	17.79	21.45	22.23	15.29	0.09
gll12	10.28	12.93	16.00	19.41	0.10	12.33	16.48	17.51	20.75	22.23	15.29	0.08
gll13	10.09	12.34	14.94	17.74	0.09	11.65	16.13	17.51	20.41	21.51	15.29	0.08
gll14	9.89	12.08	14.54	17.47	0.09	11.65	16.13	17.51	20.41	21.51	15.29	0.08
gll15	9.99	11.97	14.30	17.38	0.10	11.65	16.13	17.51	20.41	21.51	15.29	0.08

Table A3.10. Reflectance and NDVI of the points sampled with CropScan, on Quickbird and Landsat of 2007.

	QUICKBIRD					ASTER				LANDSAT						
	Band 1	**Band 2**	**Band 3**	**Band 4**	**NDVI**	**Band 2**	**Band 3**	**Band 4**	**NDVI**	**Band 1**	**Band 2**	**Band 3**	**Band 4**	**Band 5**	**Band 6**	**NDVI**
agu1	19.26	23.58	29.46	37.71	0.12	31.86	36.76	45.04	0.10	16.79	22.85	26.18	35.24	40.73	31.87	0.15
agu2	14.04	17.11	21.32	31.08	0.19	21.81	20.66	29.76	0.18	10.93	16.23	19.77	27.69	36.74	26.39	0.17
agu3	14.51	17.58	21.92	31.45	0.18	21.81	20.66	29.76	0.18	10.93	16.23	19.77	27.69	36.74	26.39	0.17
agu4	15.34	19.01	23.38	33.15	0.17	21.81	20.66	29.76	0.18	10.93	16.23	19.77	27.69	36.74	26.39	0.17
agu5	12.86	15.89	19.87	26.93	0.15	18.01	18.14	27.27	0.20	12.94	16.58	17.26	28.37	34.39	24.68	0.24
agu6	16.08	19.05	22.56	29.18	0.13	19.35	19.40	26.56	0.16	11.43	16.58	18.66	24.94	30.17	21.60	0.14
agu7	21.80	25.13	28.88	35.17	0.10	22.48	20.66	28.69	0.16	13.10	18.32	19.77	26.32	29.23	20.92	0.14
agu8	14.49	16.98	19.84	24.20	0.10	18.46	18.90	25.85	0.16	12.43	16.93	18.10	24.26	30.40	22.63	0.15
agu9	15.45	18.39	21.64	27.38	0.12	21.14	20.66	28.69	0.16	13.44	19.72	21.16	27.69	32.04	23.66	0.13
agu10	15.71	18.74	21.89	28.61	0.13	23.82	22.42	30.83	0.16	12.94	18.32	19.21	25.29	30.40	21.94	0.14
agu11	29.11	33.46	38.04	42.75	0.06	32.08	32.23	39.36	0.10	20.63	25.99	27.85	33.52	28.76	19.20	0.09
agu12	13.59	16.60	19.72	25.68	0.13	21.81	21.16	28.34	0.15	11.10	17.28	16.98	23.23	29.23	20.92	0.16
agu13	15.34	19.03	24.16	33.26	0.16	21.36	22.67	32.25	0.17	11.10	15.53	17.54	26.66	33.22	24.34	0.21
agu14	15.72	19.23	24.37	34.47	0.17	20.47	19.40	31.18	0.23	12.60	16.58	18.66	30.78	35.10	24.68	0.25
agu15	12.67	15.57	20.12	29.27	0.19	18.23	20.16	29.05	0.18	11.43	17.28	20.61	26.32	36.50	27.42	0.12
lpl1	13.91	17.10	21.18	29.52	0.16	17.12	17.64	28.34	0.23	10.76	15.53	17.26	25.97	28.29	21.26	0.20
lpl2	14.63	17.36	21.13	27.14	0.12	23.37	24.94	33.31	0.14	11.10	17.28	17.26	24.26	31.11	24.34	0.17
lpl3	14.64	18.60	23.19	32.14	0.16	19.35	16.88	27.98	0.25	11.10	17.28	17.26	24.26	31.11	24.34	0.17
lpl4	9.62	11.84	14.00	23.55	0.25	16.67	18.14	27.63	0.21	10.76	14.83	16.15	24.60	24.06	17.15	0.21
lpl5	17.27	20.68	25.71	32.95	0.12	22.03	23.68	32.25	0.15	13.27	19.02	23.11	30.43	33.45	22.63	0.14
lpl6	11.85	14.06	16.78	24.74	0.19	14.21	13.86	24.43	0.28	11.93	19.02	20.89	26.66	29.93	20.92	0.12
lpl7	9.73	11.61	13.59	23.19	0.26	16.45	15.88	26.20	0.25	8.58	13.09	13.08	20.48	20.78	13.73	0.22
lpl8	24.87	28.50	33.55	38.07	0.06	34.09	34.00	38.29	0.06	19.80	28.43	29.80	34.55	40.26	32.56	0.07
lpl9	25.05	28.68	33.75	38.32	0.06	34.09	34.00	38.29	0.06	19.80	28.43	29.80	34.55	40.26	32.56	0.07
lpl11	20.90	24.54	29.11	34.15	0.08	26.05	27.96	34.38	0.10	19.80	25.99	27.01	32.49	35.57	27.76	0.09
lpl12	17.08	20.45	25.13	31.48	0.11	22.03	22.67	28.69	0.12	16.62	22.50	24.23	29.06	36.50	27.76	0.09

Table A3.10 (cont.). Reflectance and NDVI of the points sampled with CropScan, on Quickbird and Landsat of 2007.

	QUICKBIRD					ASTER				LANDSAT					
	Band 1	**Band 2**	**Band 3**	**Band 4**	**NDVI**	**Band 2**	**Band 3**	**Band 4**	**NDVI**	**Band 1**	**Band 2**	**Band 3**	**Band 4**	**Band 5**	**Band 6**	**NDVI**
lpl13	19.14	23.03	28.28	34.43	0.10	25.83	24.18	30.11	0.11	16.62	22.50	24.23	29.06	36.50	27.76	0.09
lpl14	18.87	23.19	29.64	38.19	0.13	23.37	26.19	36.51	0.16	15.78	23.90	26.46	35.58	44.25	32.56	0.15
lpl15	19.18	23.93	30.34	38.72	0.12	23.37	26.19	36.51	0.16	15.78	23.90	26.46	35.58	44.25	32.56	0.15
lpl16	18.37	22.41	28.35	36.26	0.12	23.37	26.19	36.51	0.16	15.78	23.90	26.46	35.58	44.25	32.56	0.15
pto1	14.70	18.45	23.41	31.09	0.14	19.13	20.66	30.47	0.19	13.77	19.02	21.44	30.78	39.79	30.85	0.18
pto2	15.28	19.31	24.37	32.15	0.14	19.13	20.66	30.47	0.19	13.77	19.02	21.44	30.78	39.79	30.85	0.18
pto3	16.98	21.52	27.35	34.49	0.12	22.92	24.94	31.89	0.12	13.44	20.06	22.84	30.43	41.44	32.56	0.14
pto4	18.20	22.67	28.03	35.88	0.12	26.05	26.95	35.45	0.14	16.95	22.16	24.23	31.81	37.21	28.79	0.14
pto5	17.93	22.33	27.52	35.70	0.13	25.83	26.70	35.45	0.14	16.95	24.60	27.01	33.86	39.32	27.76	0.11
pto6	20.07	25.33	30.87	38.19	0.11	27.61	26.70	35.45	0.14	17.12	24.94	27.29	34.89	40.73	27.76	0.12
pto7	20.17	24.90	30.62	38.83	0.12	23.37	25.94	34.02	0.13	15.61	22.16	25.06	33.52	43.08	29.82	0.14
pto8	18.04	21.83	27.27	34.74	0.12	24.93	24.94	35.45	0.17	15.11	20.76	23.39	32.49	40.26	27.08	0.16
pto9	14.06	16.91	20.63	27.58	0.14	24.93	26.70	33.67	0.12	14.78	20.06	23.11	30.78	36.97	24.34	0.14
pto10	17.64	21.63	26.41	33.67	0.12	24.93	23.93	34.74	0.18	11.60	16.93	18.38	25.63	32.51	21.60	0.16
pto11	17.18	20.25	24.22	30.08	0.11	20.91	21.67	28.69	0.14	13.44	19.37	20.61	25.29	28.29	17.84	0.10
pto12	16.94	19.99	23.40	26.59	0.06	25.60	25.44	31.18	0.10	13.44	20.06	21.44	26.66	28.29	17.84	0.11
pto13	16.64	20.05	24.99	32.39	0.13	22.25	23.18	31.89	0.16	13.77	18.67	20.89	29.06	35.10	22.29	0.16
grm1	17.24	23.80	33.98	45.91	0.15	27.61	32.23	43.62	0.15	12.10	16.23	19.77	31.81	40.97	30.16	0.23
grm2	16.31	21.27	28.90	40.05	0.16	24.26	24.18	36.51	0.20	13.44	20.41	24.23	34.55	45.90	35.64	0.18
grm3	16.23	20.69	25.69	34.50	0.15	23.37	24.18	32.96	0.15	12.10	17.28	19.77	28.72	40.50	31.53	0.18
grm4	17.54	22.10	28.07	36.83	0.13	22.48	23.18	33.31	0.18	12.10	17.28	19.77	28.72	40.50	31.53	0.18
grm5	15.07	19.11	24.32	33.78	0.16	19.80	20.66	32.25	0.22	11.26	17.62	20.33	28.37	38.62	29.48	0.17
grm6	14.82	18.90	23.25	35.01	0.20	20.24	20.91	32.96	0.22	10.93	15.53	16.71	28.03	30.40	21.26	0.25
grm7	15.85	20.30	25.13	36.71	0.19	19.57	19.40	32.25	0.25	10.93	15.53	16.71	28.03	30.40	21.26	0.25
grm8	15.51	20.05	24.76	36.39	0.19	18.46	18.39	31.18	0.26	10.93	15.53	16.71	28.03	30.40	21.26	0.25
grm9	11.33	14.82	18.34	31.45	0.26	16.89	17.39	30.47	0.27	8.92	14.14	16.15	27.00	31.11	19.89	0.25

Table A3.10 (cont.). Reflectance and NDVI of the points sampled with CropScan, on Quickbird and Landsat of 2007.

	QUICKBIRD					ASTER				LANDSAT						
	Band 1	Band 2	Band 3	Band 4	NDVI	Band 2	Band 3	Band 4	NDVI	Band 1	Band 2	Band 3	Band 4	Band 5	Band 6	NDVI
aa1	8.15	10.49	13.23	24.29	0.29	19.13	21.92	36.16	0.25	14.78	23.55	28.41	38.67	51.53	38.04	0.15
aa2	16.34	20.27	25.89	34.98	0.15	22.92	25.19	34.02	0.15	16.95	20.76	24.79	34.55	34.86	24.34	0.16
aa3	14.70	17.83	23.02	29.58	0.12	21.58	23.68	32.96	0.16	16.95	20.76	24.79	34.55	34.86	24.34	0.16
aa4	21.76	26.94	33.54	43.41	0.13	20.69	24.68	30.11	0.10	14.78	18.67	22.00	31.12	31.34	22.97	0.17
aa5	13.02	16.59	21.01	29.22	0.16	21.58	25.69	30.83	0.09	12.94	16.58	19.49	28.37	24.53	17.15	0.19
aa6	12.73	15.41	18.93	24.14	0.12	26.72	25.44	31.54	0.11	10.59	15.18	16.43	22.20	26.41	18.18	0.15
aa7	11.57	14.64	17.83	23.79	0.14	23.15	22.42	31.18	0.16	11.10	15.18	16.98	23.23	24.53	16.12	0.16
aa8	10.42	12.89	15.85	20.62	0.13	27.61	26.95	34.74	0.13	11.10	15.18	16.98	23.23	24.53	16.12	0.16
aa9	11.24	14.04	18.09	22.74	0.11	25.16	24.18	30.47	0.12	10.59	15.53	17.54	23.91	25.24	18.18	0.15
aa10	9.97	12.48	16.17	22.24	0.16	23.37	23.68	33.31	0.17	10.76	15.88	17.54	24.26	29.23	21.60	0.16
aa11	13.79	17.63	22.57	30.12	0.14	25.38	27.45	36.16	0.14	11.76	16.93	18.94	28.37	25.94	19.55	0.20
aa12	10.91	14.07	17.65	28.32	0.23	25.38	27.45	36.16	0.14	11.26	17.62	18.66	26.66	26.41	19.55	0.18
aa13	8.63	12.15	13.80	19.80	0.18	25.38	27.45	36.16	0.14	11.26	17.62	18.66	26.66	26.41	19.55	0.18
aa14	14.45	18.62	22.32	30.38	0.15	27.61	28.21	35.09	0.11	11.26	17.62	18.66	26.66	26.41	19.55	0.18
aa15	11.23	13.99	17.51	25.38	0.18	26.50	27.70	36.51	0.14	11.76	16.93	18.94	28.37	25.94	19.55	0.20
aa16	14.47	18.20	23.40	31.55	0.15	26.50	27.70	36.51	0.14	11.76	16.93	18.94	28.37	25.94	19.55	0.20
aa17	13.67	17.44	22.24	30.84	0.16	26.50	25.19	31.18	0.11	10.93	15.18	17.26	25.97	28.05	20.23	0.20
aa18	6.99	9.09	11.06	20.86	0.31	24.49	25.69	34.38	0.14	14.44	18.32	22.00	29.40	29.70	21.26	0.14
aa19	9.35	12.19	15.42	25.78	0.25	24.49	25.44	32.60	0.12	14.44	18.32	22.00	29.40	29.70	21.26	0.14
aa20	7.98	10.07	12.38	18.85	0.21	12.65	13.86	24.43	0.28	13.10	17.97	20.89	28.72	39.09	30.50	0.16
aa21	15.88	20.16	24.94	31.52	0.12	17.34	16.38	26.20	0.23	8.75	12.39	12.81	23.57	30.17	22.97	0.30
2lpl1	15.39	18.25	22.11	29.01	0.13	25.16	23.68	36.51	0.21	15.95	22.50	27.57	37.98	40.03	29.48	0.16
2lpl2	13.27	16.65	20.51	29.93	0.19	17.56	16.63	26.56	0.23	10.76	14.83	16.15	24.60	24.06	17.15	0.21
2lpl3	13.70	16.63	20.38	26.32	0.13	22.03	22.42	31.89	0.17	11.10	17.28	17.26	24.26	31.11	24.34	0.17
2lpl4	18.77	21.90	26.32	31.46	0.09	19.57	17.64	25.14	0.18	10.26	16.93	16.71	23.57	27.35	20.92	0.17
2lpl5	14.83	17.83	21.47	30.16	0.17	22.03	23.68	32.25	0.15	13.27	19.02	23.11	30.43	33.45	22.63	0.14

Table A3.10. (cont.). Reflectance and NDVI of the points sampled with CropScan, on Quickbird and Landsat of 2007.

	QUICKBIRD					ASTER				LANDSAT						
	Band 1	**Band 2**	**Band 3**	**Band 4**	**NDVI**	**Band 2**	**Band 3**	**Band 4**	**NDVI**	**Band 1**	**Band 2**	**Band 3**	**Band 4**	**Band 5**	**Band 6**	**NDVI**
2lpl6	9.98	11.71	13.64	23.95	0.27	16.67	16.38	25.14	0.21	8.58	13.09	13.08	20.48	20.78	13.73	0.22
2lpl7	14.90	17.52	21.09	25.11	0.09	18.68	18.14	25.49	0.17	9.25	12.05	13.08	21.17	21.48	15.78	0.24
2lpl8	21.95	25.44	30.14	36.10	0.09	29.40	28.46	32.25	0.06	18.63	25.64	27.85	32.83	36.74	29.48	0.08
2lpl9	24.82	28.32	32.95	37.64	0.07	32.30	31.73	36.16	0.07	19.80	28.43	29.80	34.55	40.26	32.56	0.07
2lpl10	19.34	22.41	26.70	31.18	0.08	29.85	30.47	35.45	0.08	20.30	28.43	30.08	34.21	39.56	32.90	0.06
2lpl11	19.49	22.60	26.86	31.68	0.08	26.27	26.45	31.54	0.09	17.96	23.55	25.90	30.09	34.16	26.39	0.07
2lpl12	22.00	25.78	30.45	35.23	0.07	24.26	25.94	31.54	0.10	17.96	23.55	25.90	30.09	34.16	26.39	0.07
2lpl13	18.97	22.86	27.76	33.64	0.10	25.83	24.18	30.11	0.11	16.62	22.50	24.23	29.06	36.50	27.76	0.09
2lpl14	16.27	19.62	23.96	30.82	0.13	25.83	24.94	30.83	0.11	16.62	22.50	24.23	29.06	36.50	27.76	0.09
Mte1	17.94	23.33	30.26	40.34	0.14	25.83	27.96	36.87	0.14	13.10	20.41	23.39	32.83	41.90	30.50	0.17
Mte2	19.68	25.80	34.57	44.03	0.12	26.72	29.21	38.29	0.13	14.11	20.41	23.67	32.83	39.09	28.11	0.16
Mte3	17.07	21.79	27.76	37.51	0.15	23.82	25.69	34.74	0.15	12.60	18.32	23.67	32.83	32.98	26.39	0.16
Mte4	17.13	21.40	25.87	33.43	0.13	24.26	24.43	34.38	0.17	15.28	21.46	28.13	35.58	36.74	23.66	0.12
Mte5	19.27	23.53	27.93	35.76	0.12	27.39	27.45	36.16	0.14	15.45	23.20	24.23	32.49	36.04	22.63	0.15
Mte6	16.74	19.83	22.65	26.86	0.09	25.83	24.94	31.89	0.12	18.63	23.90	26.18	31.46	28.52	18.86	0.09
Mte7	15.48	18.69	22.04	26.01	0.08	28.06	26.95	33.31	0.11	15.28	21.46	24.23	30.78	31.57	20.92	0.12
Pnl1	15.43	20.36	26.97	37.72	0.17	21.36	24.68	32.60	0.14	13.94	20.41	21.72	29.75	37.68	28.79	0.16
Pnl2	18.53	23.55	29.64	38.86	0.13	21.58	22.67	30.83	0.15	13.94	20.41	21.72	29.75	37.68	28.79	0.16
Pnl3	10.93	13.88	16.55	25.89	0.22	22.03	21.92	33.67	0.21	13.77	21.46	22.28	29.06	32.04	24.34	0.13
Pnl4	20.70	26.45	32.53	39.69	0.10	26.27	24.94	35.09	0.17	14.94	20.06	23.11	28.03	33.45	25.37	0.10
Pnl5	18.01	22.79	28.31	33.44	0.08	26.27	28.46	32.60	0.07	14.11	20.41	22.84	27.35	31.57	23.66	0.09
Pnl6	16.94	21.40	27.04	32.99	0.10	27.17	26.19	35.80	0.16	13.77	20.41	22.28	27.35	33.45	25.71	0.10
Pyo1	16.65	20.18	24.67	31.08	0.11	24.71	25.44	31.54	0.11	16.79	24.25	26.46	33.18	39.56	27.42	0.11
Pyo2	20.58	25.30	30.39	37.99	0.11	24.71	25.44	31.54	0.11	16.79	24.25	26.46	33.18	39.56	27.42	0.11
Pyo3	17.94	21.08	24.71	29.33	0.09	23.82	23.18	28.69	0.11	15.11	22.50	24.23	30.43	36.74	26.05	0.11
Pyo4	20.27	24.48	29.21	36.35	0.11	24.71	25.44	31.54	0.11	16.79	24.25	26.46	33.18	39.56	27.42	0.11

Table A3.10 (cont.). Reflectance and NDVI of the points sampled with CropScan, on Quickbird and Landsat of 2007.

	QUICKBIRD					ASTER				LANDSAT						
	Band 1	**Band 2**	**Band 3**	**Band 4**	**NDVI**	**Band 2**	**Band 3**	**Band 4**	**NDVI**	**Band 1**	**Band 2**	**Band 3**	**Band 4**	**Band 5**	**Band 6**	**NDVI**
Pyo5	21.12	26.02	31.02	38.29	0.10	24.71	25.44	31.54	0.11	16.79	24.25	26.46	33.18	39.56	27.42	0.11
Sal1	14.34	17.56	21.87	30.07	0.16	25.83	27.96	37.22	0.14	16.12	22.16	26.46	34.89	40.03	32.56	0.14
Sal2	15.65	18.38	22.31	27.04	0.10	21.81	22.17	30.83	0.16	14.78	20.76	23.39	30.43	33.22	24.68	0.13
Sal3	15.42	18.19	22.58	27.53	0.10	21.81	22.17	30.83	0.16	14.78	20.76	23.39	30.43	33.22	24.68	0.13
Sal4	18.49	21.89	27.05	32.67	0.09	24.26	24.94	31.18	0.11	14.11	20.76	24.23	32.83	33.92	26.39	0.15
Sal5	20.22	23.92	29.31	35.28	0.09	26.94	30.72	41.49	0.15	15.61	22.16	25.34	32.83	30.87	21.94	0.13
Sal6	19.41	22.63	26.97	30.62	0.06	26.27	27.96	35.09	0.11	15.61	22.16	25.34	32.83	30.87	21.94	0.13
Sal7	24.65	29.03	35.13	39.08	0.05	26.27	27.96	35.09	0.11	18.63	24.25	26.46	31.81	21.95	16.81	0.09
Sal8	23.50	27.68	32.76	36.07	0.05	26.27	27.96	35.09	0.11	18.63	24.25	26.46	31.81	21.95	16.81	0.09
Sal9	19.11	22.04	25.70	29.60	0.07	25.60	26.70	34.74	0.13	16.79	23.55	26.46	34.55	34.86	26.05	0.13
Sal10	17.92	21.39	26.89	33.66	0.11	32.30	30.98	37.94	0.10	14.94	21.81	25.34	33.86	41.44	31.87	0.14
Sal11	18.06	21.51	26.04	32.51	0.11	23.82	26.19	35.09	0.15	16.28	23.20	25.90	34.55	36.74	28.45	0.14
Sal12	17.36	20.75	24.78	31.70	0.12	23.82	26.19	35.09	0.15	14.78	19.72	22.28	30.78	25.47	17.84	0.16
Sal13	19.08	22.12	26.50	31.52	0.09	24.71	25.44	34.38	0.15	14.78	19.72	22.28	30.78	25.47	17.84	0.16
Sal14	18.90	21.75	26.05	30.39	0.08	24.71	25.44	34.38	0.15	14.78	19.72	22.28	30.78	25.47	17.84	0.16
Sal15	15.37	18.76	22.84	34.42	0.20	30.29	28.46	37.22	0.13	15.28	20.76	25.06	34.21	38.85	30.16	0.15
Sal16	16.55	19.86	24.98	32.77	0.13	24.04	23.68	35.09	0.19	15.28	20.76	25.06	34.21	38.85	30.16	0.15
Sal17	16.37	19.75	24.88	32.41	0.13	24.04	23.68	35.09	0.19	15.28	20.76	25.06	34.21	38.85	30.16	0.15
Sal18	15.21	17.99	22.22	30.79	0.16	25.16	26.19	33.31	0.12	14.27	19.72	23.39	30.09	28.52	19.20	0.13
Sal19	8.23	10.28	11.54	28.15	0.42	16.00	15.88	30.47	0.31	16.95	20.41	22.56	30.43	25.47	18.18	0.15
Sal20	9.78	12.41	14.70	30.04	0.34	18.68	19.40	31.89	0.24	16.95	20.41	22.56	30.43	25.47	18.18	0.15
Sal21	8.66	11.26	12.74	32.41	0.44	25.16	28.46	32.25	0.06	14.27	20.06	21.72	29.40	21.95	14.75	0.15
Sal22	12.84	15.44	18.17	31.54	0.27	25.16	28.46	32.25	0.06	13.77	19.72	19.77	28.72	23.59	13.73	0.18
Sal23	17.54	20.64	23.66	30.20	0.12	22.70	24.18	31.54	0.13	13.77	19.72	19.77	28.72	23.59	13.73	0.18
Sal24	11.00	12.97	15.66	25.89	0.25	22.70	24.18	31.54	0.13	13.77	19.72	19.77	28.72	23.59	13.73	0.18
Sal25	10.62	12.87	15.56	27.46	0.28	22.70	24.18	31.54	0.13	13.77	19.72	19.77	28.72	23.59	13.73	0.18

Table A3.10 (cont.). Reflectance and NDVI of the points sampled with CropScan, on Quickbird and Landsat of 2007.

	QUICKBIRD					ASTER				LANDSAT						
	Band 1	**Band 2**	**Band 3**	**Band 4**	**NDVI**	**Band 2**	**Band 3**	**Band 4**	**NDVI**	**Band 1**	**Band 2**	**Band 3**	**Band 4**	**Band 5**	**Band 6**	**NDVI**
Sal26	8.25	10.09	11.48	26.46	0.39	15.10	17.89	30.47	0.26	14.27	20.06	21.72	29.40	21.95	14.75	0.15
Sal27	20.28	23.87	28.52	37.21	0.13	25.16	24.18	33.31	0.16	13.94	20.06	22.00	27.35	30.40	19.55	0.11
Sal28	15.54	18.84	23.97	32.38	0.15	22.03	23.43	32.96	0.17	15.78	21.81	23.39	29.40	39.56	28.79	0.11
Sal29	17.48	21.04	26.49	34.00	0.12	19.57	21.16	30.47	0.18	13.94	18.67	20.61	28.72	36.74	27.42	0.16
Sal30	18.51	22.02	26.58	31.29	0.08	34.09	31.73	41.13	0.13	14.44	23.55	23.11	27.35	21.01	16.81	0.08
Sal31	18.28	21.37	25.35	31.37	0.11	26.72	24.43	33.31	0.15	14.44	20.41	21.72	29.06	28.29	20.57	0.14
Sal32	12.22	14.70	17.57	31.04	0.28	20.24	24.18	35.09	0.18	14.11	22.50	21.16	29.06	16.31	13.73	0.16
Sal33	12.99	15.24	18.08	28.28	0.22	19.13	17.64	28.69	0.24	13.77	19.72	18.94	31.81	21.95	16.81	0.25
Sal34	17.83	21.45	25.42	34.43	0.15	18.90	15.88	27.27	0.26	13.27	16.58	17.54	30.09	24.30	18.52	0.26
cmr1	*	*	*	*	*	21.81	23.68	29.40	0.11	13.77	19.02	21.16	27.69	37.44	30.16	0.13
cmr2	*	*	*	*	*	21.36	22.92	30.11	0.14	15.11	22.16	23.95	29.40	35.33	28.11	0.10
cmr3	*	*	*	*	*	22.03	23.68	30.83	0.13	14.11	19.02	20.61	27.00	35.33	28.11	0.13
cmr4	*	*	*	*	*	20.69	21.92	28.34	0.13	19.13	25.99	26.46	31.81	36.27	29.48	0.09

Table A3.11. Reflectance and NDVI of the points sampled with CROPSACN on Quickbird and Landsat of 2008.

	QUICKBIRD					LANDSAT						
	Band 1	Band 2	Band 3	Band 4	NDVI	Band 1	Band 2	Band 3	Band 4	Band 5	Band 6	NDVI
agu1	11.24	14.16	18.90	25.02	0.14	11.65	15.07	17.23	31.87	41.96	30.55	0.10
agu2	11.71	14.71	17.95	25.32	0.17	8.77	13.30	14.40	23.53	26.51	20.49	0.18
agu3	10.39	12.99	16.05	22.64	0.17	8.77	13.30	14.40	23.53	26.51	20.49	0.18
agu4	10.39	13.16	17.00	24.16	0.17	8.77	13.30	14.40	23.53	26.51	20.49	0.18
agu5	9.97	12.31	15.33	21.17	0.16	11.99	16.84	17.51	23.53	30.55	21.19	0.20
agu6	10.45	12.75	15.10	19.24	0.12	12.50	17.54	18.36	23.53	30.31	22.57	0.16
agu7	10.08	12.31	14.67	18.84	0.12	13.01	18.60	18.64	24.58	31.50	22.57	0.16
agu8	9.81	11.65	13.81	17.52	0.12	14.03	20.37	20.90	26.66	34.35	23.61	0.16
agu9	9.29	11.52	13.43	16.50	0.10	13.69	18.96	20.05	25.97	32.69	23.27	0.16
agu10	8.60	10.18	11.77	15.03	0.12	12.50	18.25	19.77	25.62	30.55	21.19	0.16
agu11	11.50	14.26	17.00	22.23	0.13	10.80	14.72	16.38	22.49	28.88	22.57	0.10
agu12	8.86	10.76	13.29	16.81	0.12	9.62	14.01	15.25	22.49	32.21	24.65	0.15
agu13	9.02	11.55	14.43	20.76	0.18	14.03	19.66	21.74	30.83	37.44	29.16	0.17
agu14	9.87	12.41	16.00	22.89	0.18	13.69	20.02	22.59	38.13	42.20	29.51	0.23
agu15	8.50	10.24	13.00	20.10	0.21	13.69	20.02	22.59	38.13	42.20	29.51	0.18
lpl1	8.13	10.04	12.67	17.21	0.15	10.97	14.36	17.23	25.62	29.12	17.37	0.23
lpl2	10.76	13.54	17.38	22.03	0.12	10.80	14.01	16.66	24.92	29.36	17.72	0.14
lpl3	10.39	12.92	16.29	20.86	0.12	10.80	14.01	16.66	24.92	29.36	17.72	0.25
lpl4	6.75	8.35	9.67	14.22	0.19	10.80	16.48	18.92	24.92	23.42	17.72	0.21
lpl5	8.65	10.90	13.38	18.13	0.15	11.14	12.95	12.99	25.97	25.08	16.68	0.15
lpl6	6.91	8.11	9.62	15.44	0.23	8.94	11.89	12.43	22.84	27.70	15.64	0.28
lpl7	7.60	8.56	10.43	15.44	0.19	8.09	10.48	11.02	19.36	23.18	17.02	0.25
lpl8	10.87	14.02	17.43	22.28	0.12	11.48	18.60	18.92	26.31	28.41	18.41	0.06
lpl9	10.87	13.92	17.43	21.77	0.11	11.48	18.60	18.92	26.31	28.41	18.41	0.06
lpl11	10.45	13.03	16.38	20.46	0.11	11.82	15.78	17.79	24.92	28.41	19.45	0.10
lpl12	9.08	10.90	13.86	18.13	0.13	12.16	17.90	20.33	25.62	31.26	21.88	0.12

Table A3.11 (cont.). Reflectance and NDVI of the points sampled with CropScan on Quickbird and Landsat of 2008.

	QUICKBIRD					LANDSAT						
	Band 1	**Band 2**	**Band 3**	**Band 4**	**NDVI**	**Band 1**	**Band 2**	**Band 3**	**Band 4**	**Band 5**	**Band 6**	**NDVI**
lpl13	10.82	12.65	15.95	20.30	0.12	12.16	17.90	20.33	25.62	31.26	21.88	0.11
lpl14	12.03	14.95	19.24	25.93	0.15	13.01	18.96	21.74	31.18	35.54	26.73	0.16
lpl15	11.45	14.37	18.05	25.37	0.17	13.01	18.96	21.74	31.18	35.54	26.73	0.16
lpl16	12.40	15.47	21.04	27.40	0.13	13.01	18.96	21.74	31.18	35.54	26.73	0.16
pto1	9.76	12.58	15.86	21.67	0.15	15.55	19.66	24.57	36.74	36.25	29.85	0.19
pto2	10.87	13.75	17.00	23.19	0.15	15.55	19.66	24.57	36.74	36.25	29.85	0.19
pto3	8.97	11.93	14.14	19.44	0.16	11.48	17.90	18.64	25.97	35.30	26.73	0.12
pto4	14.14	18.22	22.76	29.63	0.13	14.20	22.49	23.72	29.44	36.73	30.20	0.14
pto5	13.03	16.77	21.42	27.86	0.13	16.57	25.32	27.67	35.00	40.53	31.24	0.14
pto6	13.56	17.32	22.28	28.67	0.13	15.72	21.78	24.85	33.96	41.72	29.85	0.14
pto7	15.88	20.24	25.33	32.01	0.12	15.72	21.78	24.85	33.96	41.72	29.85	0.13
pto8	11.71	14.64	18.38	23.29	0.12	15.55	22.14	24.85	33.26	42.20	30.55	0.17
pto9	10.92	13.92	16.81	23.90	0.17	15.04	20.72	23.72	32.92	39.11	28.47	0.12
pto10	11.87	14.33	16.90	22.59	0.14	13.86	18.60	20.33	29.09	33.40	25.00	0.18
pto11	11.29	13.51	16.48	21.52	0.13	13.35	18.60	20.33	26.31	30.55	20.49	0.14
pto12	11.29	14.13	16.90	20.71	0.10	13.01	18.25	19.20	24.92	28.17	18.06	0.10
pto13	10.55	12.86	16.67	21.93	0.14	13.18	18.96	20.05	27.70	33.40	23.27	0.16
grm1	*	*	*	*	*	14.37	21.78	26.82	34.31	46.72	40.60	0.15
grm2	*	*	*	*	*	13.69	17.90	24.00	31.18	46.95	39.91	0.20
grm3	*	*	*	*	*	11.99	19.31	20.05	29.44	40.30	31.94	0.15
grm4	*	*	*	*	*	11.99	19.31	20.05	29.44	40.30	31.94	0.18
grm5	*	*	*	*	*	13.18	17.19	22.59	30.14	39.11	30.55	0.22
grm6	*	*	*	*	*	8.43	14.01	14.40	21.45	30.07	22.57	0.22
grm7	*	*	*	*	*	8.43	14.01	14.40	21.45	30.07	22.57	0.25
grm8	*	*	*	*	*	8.43	14.01	14.40	21.45	30.07	22.57	0.26
grm9	*	*	*	*	*	8.60	12.95	14.69	22.14	31.02	22.92	0.27

Table A3.11 (cont.). Reflectance and NDVI of the points sampled with CropScan on Quickbird and Landsat of 2008.

	QUICKBIRD					LANDSAT						
	Band 1	**Band 2**	**Band 3**	**Band 4**	**NDVI**	**Band 1**	**Band 2**	**Band 3**	**Band 4**	**Band 5**	**Band 6**	**NDVI**
aa1	*	*	*	*	*	10.80	17.19	20.33	33.26	35.78	25.35	0.25
aa2	*	*	*	*	*	12.67	20.37	22.87	30.83	39.11	29.51	0.15
aa3	*	*	*	*	*	13.69	18.25	21.46	29.09	39.11	26.73	0.16
aa4	*	*	*	*	*	11.82	20.02	19.20	27.01	30.31	20.49	0.10
aa5	*	*	*	*	*	11.82	20.02	19.20	27.01	30.31	20.49	0.09
aa6	*	*	*	*	*	12.33	18.25	20.90	27.70	30.07	20.84	0.11
aa7	*	*	*	*	*	16.57	23.55	27.11	36.39	39.35	27.77	0.16
aa8	*	*	*	*	*	16.57	23.55	27.11	36.39	39.35	27.77	0.13
aa9	*	*	*	*	*	14.37	22.84	24.28	31.87	40.06	31.59	0.12
aa10	*	*	*	*	*	15.55	21.78	24.85	32.57	38.39	27.43	0.17
aa11	*	*	*	*	*	15.55	21.78	24.85	32.57	38.39	27.43	0.14
aa12	*	*	*	*	*	15.55	21.78	24.85	32.57	38.39	27.43	0.14
aa13	*	*	*	*	*	15.21	21.43	25.41	31.53	42.91	33.32	0.14
aa14	*	*	*	*	*	15.21	21.43	25.41	31.53	42.91	33.32	0.11
aa15	*	*	*	*	*	15.21	23.55	26.54	34.65	42.20	37.48	0.14
aa16	*	*	*	*	*	13.52	16.48	20.05	27.36	33.88	26.39	0.14
aa17	*	*	*	*	*	13.52	16.48	20.05	27.36	33.88	26.39	0.11
aa18	*	*	*	*	*	14.03	19.66	22.59	30.48	36.02	25.69	0.14
aa19	*	*	*	*	*	9.11	12.95	15.25	23.53	27.46	20.49	0.12
aa20	*	*	*	*	*	14.53	20.37	23.44	29.79	36.25	27.43	0.28
aa21	*	*	*	*	*	15.21	21.43	25.41	31.53	42.91	33.32	0.23
2lpl1	7.23	9.08	11.15	16.45	0.19	12.84	20.02	23.44	30.83	31.02	21.88	0.21
2lpl2	10.13	12.55	15.43	19.70	0.12	10.80	16.48	18.92	24.92	23.42	17.72	0.23
2lpl3	10.92	13.41	17.38	22.53	0.13	10.80	14.01	16.66	24.92	29.36	17.72	0.17
2lpl4	8.81	11.10	13.62	18.73	0.16	9.11	12.95	14.69	21.10	21.75	15.29	0.18
2lpl5	9.87	12.61	17.00	23.24	0.16	11.14	12.95	12.99	25.97	25.08	16.68	0.15

Table A3.11 (cont.). Reflectance and NDVI of the points sampled with CropScan on Quickbird and Landsat of 2008.

	QUICKBIRD					LANDSAT						
	Band 1	Band 2	Band 3	Band 4	NDVI	Band 1	Band 2	Band 3	Band 4	Band 5	Band 6	NDVI
2lpl6	6.60	7.98	9.34	14.33	0.21	7.24	10.12	11.02	18.32	21.28	15.64	0.21
2lpl7	10.97	13.51	17.38	21.57	0.11	9.45	13.66	14.12	20.75	24.84	17.02	0.17
2lpl8	10.71	13.30	17.05	21.52	0.12	10.80	16.13	16.94	22.84	27.70	19.10	0.06
2lpl9	10.66	13.34	16.90	21.72	0.12	11.48	18.60	18.92	26.31	28.41	18.41	0.07
2lpl10	10.29	12.89	16.10	20.00	0.11	10.97	15.78	17.79	21.80	27.70	18.76	0.08
2lpl11	10.92	13.54	17.05	21.42	0.11	11.82	16.48	17.79	23.53	29.84	21.19	0.09
2lpl12	11.08	13.89	17.38	21.83	0.11	11.82	16.48	17.79	23.53	29.84	21.19	0.10
2lpl13	10.76	13.51	17.00	21.57	0.12	12.16	17.90	20.33	25.62	31.26	21.88	0.11
2lpl14	11.29	14.13	17.71	22.53	0.12	12.16	17.90	20.33	25.62	31.26	21.88	0.11
Mte1	*	*	*	*	*	13.86	20.37	25.13	35.35	41.72	31.59	0.14
Mte2	*	*	*	*	*	13.86	20.37	25.13	35.35	41.72	31.59	0.13
Mte3	*	*	*	*	*	14.37	25.67	25.13	33.26	38.16	27.43	0.15
Mte4	*	*	*	*	*	18.95	26.38	31.06	40.21	43.15	31.24	0.17
Mte5	*	*	*	*	*	17.25	23.55	26.82	35.35	35.30	24.65	0.14
Mte6	*	*	*	*	*	15.21	18.60	21.18	28.40	24.37	14.94	0.12
Mte7	*	*	*	*	*	15.04	21.43	24.00	30.83	30.07	19.10	0.11
Pnl1	*	*	*	*	*	14.03	16.84	35.01	41.26	43.62	32.28	0.14
Pnl2	*	*	*	*	*	14.03	16.84	35.01	41.26	43.62	32.28	0.15
Pnl3	*	*	*	*	*	9.28	16.13	23.15	30.14	32.69	24.65	0.21
Pnl4	*	*	*	*	*	12.67	19.66	18.64	26.31	31.74	24.31	0.17
Pnl5	*	*	*	*	*	13.69	20.02	19.77	25.27	32.93	25.69	0.07
Pnl6	*	*	*	*	*	11.31	17.19	23.72	31.18	33.40	26.04	0.16
Pyo1	12.40	15.50	18.86	24.66	0.13	10.63	16.13	17.51	23.53	29.60	23.61	0.11
Pyo2	12.40	15.50	18.86	24.66	0.13	11.48	17.19	19.77	24.92	29.60	25.00	0.11
Pyo3	10.45	13.20	15.76	20.66	0.13	11.48	17.54	19.20	27.01	33.16	22.57	0.11
Pyo4	17.15	22.10	27.56	33.48	0.10	11.31	16.13	17.79	22.49	27.70	19.80	0.11
Pyo5	15.56	19.45	23.76	31.55	0.14	16.40	23.55	26.54	33.96	39.35	29.16	0.11

Table A3.11 (cont.). Reflectance and NDVI of the points sampled with CropScan on Quickbird and Landsat of 2008.

	QUICKBIRD					LANDSAT						
	Band 1	Band 2	Band 3	Band 4	NDVI	Band 1	Band 2	Band 3	Band 4	Band 5	Band 6	NDVI
Sal1	7.97	10.59	13.10	21.17	0.24	14.70	20.72	23.72	30.14	39.58	34.02	0.14
Sal2	8.97	11.55	14.34	20.76	0.18	14.37	20.37	22.03	29.09	38.87	32.98	0.16
Sal3	9.97	12.03	15.86	20.81	0.13	14.37	20.37	22.03	29.09	38.87	32.98	0.16
Sal4	11.92	15.47	20.47	25.83	0.12	16.06	21.78	24.85	30.83	39.82	34.02	0.11
Sal5	10.71	13.41	17.76	25.17	0.17	15.72	21.78	24.00	31.87	37.68	21.88	0.15
Sal6	12.14	15.54	20.19	25.98	0.13	16.91	23.55	26.54	33.96	31.02	28.12	0.11
Sal7	12.61	16.29	21.38	23.55	0.05	15.04	21.08	22.59	29.44	23.65	17.72	0.11
Sal8	10.66	13.96	18.28	17.01	-0.04	15.04	21.08	22.59	29.44	23.65	17.72	0.11
Sal9	11.03	14.02	18.81	24.46	0.13	16.91	24.26	26.54	33.96	36.97	30.55	0.13
Sal10	9.97	13.54	17.33	24.11	0.16	15.89	22.14	25.13	32.22	42.44	35.40	0.10
Sal11	10.61	14.47	19.19	25.63	0.14	16.91	24.26	26.54	33.96	36.97	30.55	0.15
Sal12	8.55	11.52	14.43	25.78	0.28	14.03	20.37	23.44	30.83	34.59	27.08	0.15
Sal13	10.34	13.34	18.33	25.27	0.16	14.03	20.37	23.44	30.83	34.59	27.08	0.15
Sal14	9.13	11.27	14.19	23.24	0.24	14.03	20.37	23.44	30.83	34.59	27.08	0.15
Sal15	7.39	9.69	11.53	21.88	0.31	15.38	23.20	26.26	32.22	40.30	32.98	0.13
Sal16	8.07	10.21	12.81	20.86	0.24	15.38	23.20	26.26	32.22	40.30	32.98	0.19
Sal17	8.07	10.21	12.81	20.86	0.24	15.38	23.20	26.26	32.22	40.30	32.98	0.19
Sal18	10.24	12.72	16.86	24.00	0.17	15.21	22.14	27.11	32.57	28.88	30.55	0.12
Sal19	6.86	8.77	9.96	22.13	0.38	13.69	20.02	23.15	29.09	28.88	19.45	0.31
Sal20	7.49	9.49	10.77	22.84	0.36	13.69	20.02	23.15	29.09	28.88	19.45	0.24
Sal21	6.70	8.53	9.43	20.05	0.36	9.95	15.42	18.64	27.36	23.65	14.25	0.06
Sal22	10.82	14.47	18.24	22.94	0.11	9.95	15.42	18.64	27.36	23.65	14.25	0.06
Sal23	12.98	15.91	20.47	25.47	0.11	9.95	15.42	18.64	27.36	23.65	14.25	0.13
Sal24	11.61	14.81	19.14	25.07	0.13	9.95	15.42	18.64	27.36	23.65	14.25	0.13
Sal25	10.87	13.61	17.48	23.95	0.16	9.95	15.42	18.64	27.36	23.65	14.25	0.13
Sal26	6.28	8.11	8.91	22.48	0.43	13.18	22.84	28.52	31.87	26.98	18.41	0.26
Sal27	10.61	13.16	16.67	23.60	0.17	15.04	17.19	15.82	28.40	23.65	14.25	0.16

Table A3.11 (cont.). Reflectance and NDVI of the points sampled with CropScan on Quickbird and Landsat of 2008.

	QUICKBIRD					LANDSAT						
	Band 1	**Band 2**	**Band 3**	**Band 4**	**NDVI**	**Band 1**	**Band 2**	**Band 3**	**Band 4**	**Band 5**	**Band 6**	**NDVI**
Sal28	9.55	12.44	15.62	24.31	0.22	15.04	21.08	22.31	28.05	25.08	16.68	0.17
Sal29	9.02	11.62	14.67	22.23	0.20	13.69	18.96	21.46	30.48	38.87	30.20	0.18
Sal30	10.45	13.71	17.76	21.06	0.09	12.16	20.02	20.90	27.01	22.94	18.06	0.13
Sal31	9.39	12.37	14.72	19.19	0.13	14.20	19.31	20.05	29.44	26.98	20.49	0.15
Sal32	6.44	8.04	8.91	13.67	0.21	13.01	18.60	19.20	31.53	17.00	13.21	0.18
Sal33	6.49	8.49	9.58	17.72	0.30	15.72	24.26	27.39	36.74	36.73	31.59	0.24
Sal34	7.55	10.04	12.05	20.76	0.27	15.72	22.14	24.85	37.78	30.31	24.31	0.26
cmr1	*	*	*	*	*	10.63	16.13	17.51	23.53	29.60	23.61	0.11
cmr2	*	*	*	*	*	11.48	17.19	19.77	24.92	29.60	25.00	0.14
cmr3	*	*	*	*	*	11.48	17.54	19.20	27.01	33.16	22.57	0.13
cmr4	*	*	*	*	*	11.31	16.13	17.79	22.49	27.70	19.80	0.13