6th WADI International Meeting

27 to 30 of June 2007 · Coimbra · Portugal

Programme
List of participants
Abstracts

6th WADI International Meeting - WORKING PROGRAMME

	27 june	28 june	29 june	30 june
9h00	Marques, João Carlos - WELCOMES Scapini, Felicita – Opening words Bou Salah, Fatiha - Framework for the integration of gender dimension in WADI Project. Cassar, Louis & Conrad, Elisabeth – Assessing coastal landscapes within WADI study sites: a report on progress. Pastor-Lopez, Antonio & Perez-Lahiguera, Jose Antonio - Water-flow related landscape features relevant for biodiversity. Assessing comparability among WADI sites.	Maury, René G. & Cantarino, Carlos M. – Patrimoine culturel de l'eau: une recherche de terrain positive pour sauver un patrimoine en danger (El Hondo, Vega del Rio Segura, Espagne). **– LAKE MARYUIT, Egypt –** Abdrabo, Mohamed – Baseline environmental conditions in Lake Maryuit. Abdrabo, Mohamed – Socioeconomic conditions in Lake Maryuit vicinity. Serrano, Laura; Serrano, O. & Mateo, Miguel Ángel – Lake Maryuit: preliminary environmental assessment.	**Visit to the Mondego estuary**	**GENERAL BRAINSTORMING:** **"Were are we? Were do we want to go"** Scapini, Felicita – The project WADI: where are we? Introduction to a brain storming.
10h30 – 11h00	C O F F E E B R E A K			C O F F E E B R E A K
	– EL HONDO, Spain – Pastor-Lopez, Antonio & Perez-Lahiguera, Jose Antonio - Natural and Man-made sources of Environmental Heterogeneity affecting quantitative ecosystem description for different water-use scenarios in El Hondo and related agroecosystems. Cantarino, Carlos M.; Candela, Jose & Pastor, Antonio – An overview of the socio-ecological research done until now in El Hondo site, and some reflections on the importance of social relevance for attaining WADI objectives. **- Oued Tahaddart Lagoon / Oued Gharifa, Marocco -** Bayed, Abdellatif – Tentative d'application de la Directive Eau de l'UE dans les eaux de transition de l'Oued Gharifa. Bazairi, Hocein – Etat de la biodiversité et de la qualité du milieu estuarien du Tahaddart. Quinba, Abdeljebbar – Evaluation des valeurs écologiques des systèmes aquatiques par l'analyse des oiseaux d'eau du bas Tahaddart.	**– Oued Laou, Marocco –** - Fanini, Lucia; Gecchele, Lisa; Gambineri, Simone & Scapini, Felicita - Sandhopper orientation at Oued Laou and Oued Ghirfa mouth - Hypotheses under test and preliminary results. Bennas Nard – Rôle des femmes et des hommes dans l'utilisation et la gestion des ressources naturelles dans le Bassin Versant de Oued Laou : résultats préliminaires. Stitou el Messari, Jamal – Water resources and an assessment of the vulnerability to contamination of the Oued Laou aquifer. Hmimsa, Younés – Etude comparative de l'Agrobiodiversité dans les 2 sites marocains. **– Low plain of Oued Medjerda / Lagoon of Ghar El Melh, Tunisia –** Ben Saad, Sémia – La vegetation naturelle des berges de la lagune de Ghar el Meleh. Oueslati, Ameur – Un état d'avancement dans l'étude du site tunisien. (text)	**Visit to the Mondego estuary**	**GENERAL BRAINSTORMING *(cont)*** **"Deliverables and dissemination on the project"**
13h00 – 14h30	L U N C H B R E A K		PICNIC	L U N C H B R E A K
14h30	**– GROSSETO PLAIN, Italy –** Chelazzi, Lorenzo; Colombini, Isabella; Fallaci, M & Gagnarli, E.– Spatial and temporal variation of macrofauna diversity in relation to the salinisation of the water table in the Maremma Regional Park. Zanchi, Camillo & Cecchi, Stefano – Soil salinization in the Grosseto plain: the agricultural scenary Rossano, Claudia - Preliminary studies on arthropodofauna biodiversity in Italy (Maremma) related to salt accumulation in cultivated fields and not cultivated areas.	Charfi, Faouzia – Données biologiques sur le site tunisien. **BRAINSTORMING: Lake Maryuit, Oued Laou Basin, low plain Oued Medjerd, lagoon of Ghar El Melh** "Work done, perspectives and integration"	**Visit to the Mondego estuary**	**GENERAL BRAINSTORMING *(cont)***
16h00 – 16h30	C O F F E E B R E A K			C O F F E E B R E A K
16h30	**BRAINSTORMING: El Hondo, Oued Tahaddart Lagoon/ Oued Gharifa & Grosseto plain** "Work done, perspectives and integration"	**– MONDEGO ESTUARY, Portugal –** Pinto, Rute; Neto, João; Patrício, Joana & Marques, João Carlos – Mapping ecosystem services: An insight to choice and valuation. The Mondego estuary case-study. Pinto, Rute; Neto, João; Patrício, Joana, Salas, Fuen & Marques, João Carlos – Productivity effects on water quality, and vice-versa, in the Mondego estuary – An integrated ecosystem services approach. **BRAINSTORMING: Mondego estuary** "Work done, perspectives and integration" " Ecosystem services – implementation challenges"		**Small tour in Coimbra** *(only if this period is not necessary for discussion)*
18h00	D E S E R V E D R E S T			D E S E R V E D R E S T

LIST OF PARTICIPANTS

6th WADI International Meeting

27 to 30 of June 2007 – Coimbra – Portugal

EGYPT – CEDARE
Mohamed A. Abdrabo

ITALY – ISE
Lorenzo Chelazzi
Isabella Colombini

ITALY – Univ. Florence
Felicita Scapini
Claudia Rossano
Lucia Fanini
Stefano Cecchi

ITALY – Univ. Naples
René G. Maury

MALTA – IEI, Univ. Malta
Louis Cassar
Elisabeth Conrad

MOROCCO – Univ. Mohammed V
Abdellatif Bayed
Hocein Bazairi

MOROCCO – Univ. Abdelmalek Essaâdi
Mohammed Ater
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PORTUGAL – IMAR
João Carlos Marques
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TUNISIA – Univ. El Manar
Faouzia Charfi

TUNISIA – APAL
Fadhel Baccar

ABSTRACTS

Intégration de la dimension genre dans le Project WADI

Bou-Salah, F.
Expert on Gender and Rural Development

La question de la participation des hommes et des femmes à la gestion durable de la ressource en eau est clairement mentionnée dans le document du projet WADI, ce qui a donné lieu à un travail d'intégration de la dimension genre dans les activités.

Une telle approche est relativement nouvelle dans le domaine des sciences et technologies, car relevant à priori des sciences humaines. La prise en compte de l'élément humain en général, et de la dimension genre en particulier dans la plupart des actions initiées dans le domaine du développement durable constitue aujourd'hui une priorité aux niveaux international et national. Sans entrer dans des détails du concept, on peut dire que dans le cas de WADI, il s'agit, d'une démarche ou d'une approche qui prend en compte les rôles, besoins, priorités et potentialités des populations : hommes et femmes dans la gestion durable des ressources en eau. De telles informations contribueront notamment, à donner une plus grande visibilité au travail effectué par les femmes dans ce domaine. Elles seront intégrées dans l'Analyse Socio-économique et environnementale du projet WADI en vue de l'atteinte des objectifs.

Intégrer la dimension genre dans le projet WADI c'est :

Prendre en compte les rôles des femmes et des hommes lorsque cela est approprié;

Donner plus de chance aux propositions qui seront formulées par le projet d'être adaptées au contexte socio-culturel des populations qui vivent sur les sites;

S'assurer que la dimension genre apparaît dans l'analyse socio-économique et environnementale de WADI.

L'intégration de la dimension genre dans la mise en œuvre du projet WADI se présente sous deux aspects :

- Le premier concerne l'intégration transversale dans toute l'analyse socio-économique du projet WADI : la base de la mise en œuvre de l'approche genre est la collecte/analyse de données desagrégées par sexe
- Le second aspect est relatif à l'étude détaillée sur « la participation des femmes et des hommes à la gestion des ressources naturelles » travers une recherche rapprochée : la question de l'eau ne sera pas être traitée d'une manière isolée, car liée à d'autres éléments y compris les autres ressources naturelles.

L'étude détaillée a été initiée par l'équipe de WADI de l'Université de Tétouan, au Maroc, et menée sur le site de Oued Laou.

Pour la mise en œuvre de la démarche, une note d'orientation méthodologique été élaborée sur la base des objectifs de WADI, ainsi que des observations réalisées lors des visites de terrain et des réunions /discussions qui ont eu lieu sur les sites. La note méthodologique mentionne les phases de réalisation des activités à mener dans le cadre de l'étude, y compris le processus à suivre pour la conduite de l'enquête participative en vue de la collecte et l'analyse des données.

La méthode s'inspire en grande partie de celles développées par les institutions internationales en matière d'analyse de genre, et également des expériences de mise en œuvre de cette approche dans les pays de la région. La finalité de l'analyse socio-économique selon le genre étant l'identification des écarts d'accès et de contrôle des ressources et des bénéfices entre catégories de population, notamment les hommes et les femmes, en vue de leur réduction pour parvenir a un développement durable, efficace et paritaire.

Lake Maryut: preliminary environmental assessment

Serrano, L., Serrano, O. & Mateo, M.A.
CEAB – CSIC | Spain

Low land stagnant water masses are very complex ecosystems with a high biological richness and abundant natural resources. Too often, this kind of environments are suffering from strong anthropogenic disturbances that lead them to a state of almost irreversible degradation. Lake Maryut, located at the south of Alexandria (Egypt), is one of these ecosystems that, despite of its beauty and natural resources (such as fisheries and aquaculture), is receiving an uncontrolled amount of untreated waste waters from agricultural, urban, and industrial drains. The ecological status of the lake was assessed by establishing 40 stations, most of them over the main basin of the lake. Abundant measurements and observations were taken in the water column (temperature, depth, pH, oxygen content, conductivity, nutrients, heavy metals content), in the sediments (carbonate content, organic matter content), and of the lush fringing vegetation (composition, density, cover, abundance and biomass). It is a brackish (5.03 mS mean) hypertrophic lake (2.04 mg/l of $PO_4$2+ mean values) with high levels of water anoxia (in some areas down to 0.8% oxygen; 0.05 mgO_2/l) and organic and inorganic pollutants (eg., 3.31 mg/l of Pb2+, mean value; 13.29 mg/l NH_4+mean value) in almost all stations. These conditions determine a fairly homogeneous vegetation composition all over the lake, dominated by pollution-tolerant species such as *Phragmites australis* (43% mean total plant cover) and *Eicchornia crassipes* (21% mean total plant cover). An increasing pollution and eutrophication gradient was observed from the south to the north of the main basin, consequence of the waste water inputs occurring in the north-east. Based on the data collected and processed so far, we have crudely confirmed the prevalence of the, since long, well known poor ecological status of the lake. Most of the physical and biological indicators studied yielded values that largely exceed those standard values established by different Institutions as minimal requirements for a safe water (e.g., lead is present in concentrations up to 2000 times those admitted by the EPA, even in tap 'drinkable waters'). We recommend that investments in the health of the lake should be now devoted to remediation actions. Any useful further research should be focussed on the monitoring of the effectiveness of those remediation actions. These should include i) stopping the dumping of untreated waste waters, ii) bio-depuration programmes using the standing bio-accumulator vegetation, and iii) the systematic removal of excess of vegetation and anoxic sediments all over the lake.

Spatial and temporal variation of macrofauna diversity in relation to the salinisation of the water table in the Maremma Regional Park.

Chelazzi, L., Colombini, I., Fallaci, M. & Gagnarli E.
ISE – Institute of Ecosystems Study of Florence | Italy

Within the Wadi Project INCO-CT-2005-015226 a study was conducted at the Maremma Regional Park to assess how changes occur over space and time in the biotic components of the beach ecosystem in relation to salt water intrusion. Changes in biodiversity and biomass of sample plots are analysed both quantitatively and qualitatively, according to their height from the water table and to their distance from the sea taking into account vegetation type, water quality and seasonality. To this aim during spring-summer months 2006, the study site was selected, beach profiles were assessed, wells were drilled to reach the water table and a preliminary assessment of the vegetation was carried out. The work was conducted by the Italian and Maltese team of the Wadi Project. Monthly surveys, starting in October 2006, were carried out by the Italian team. Two transects perpendicular to the shoreline were set from the shoreline to the retrodune to assess species diversity, richness and abundance.

To assess water levels along transects and the chemical characteristics of the water table for each well direct measures of temperature, salinity (conductivity), pH and depth were measured. Soil samples were also taken using cores. In the laboratory sand samples were analysed to determine grain size, moisture, pH, salinity (conductivity) and organic matter with standard methods. To determine total rainfall during each month a permanent rainfall station was placed on the dune close to the transects. Furthermore, beach features (slope, width and orientation) were assessed along transects.

During the field trips of July 2006 and April 2007 the vegetation along the two transects was determined quantitatively within quadrates of 1 x 1 m. Every metre frequency and species number was recorded in the three metres to the right and three to the left from the reference pegs of the transect. Abundance for each plant species was calculated in three beach fasciae (0-50 m, 51-100 m, 101-150 m). To assess the vegetation quantitatively along transects quadrates (50 x 50 cm) of vegetation were sampled every 5 m. All material in the sample was collected and weighed. Sampling for plant biomass was conducted seasonally (four months). Successively in the laboratory each sample was oven dried at 70° and then weighed again. Wet vs dry weights were used to determine water content of plants. Vegetation biomass was also calculated.

The results indicate that the lowest level of the water table was reached in January. Water temperatures of wells reflected the decreasing seasonal temperatures with slightly lower values in the retrodunal areas. Salinity and pH of the water table decreased from the sea to the base of the dune. In all sampled months trends of soil moisture were similar with lower values in dunal areas and higher ones in the retrodune where soil was muddy. Soil conductivity showed higher concentrations of salt towards sea and in retrodunal depression. The pH of the soil presented variations according to the salinity of the substrate with more base values towards sea and in correspondence to the depression of the retrodune. Rainfall was highest in December reaching 147 mm of rain. In October a total 8711 macroinvertebrates were collected of which 5143 were amphipods, 2260 were isopods and 540 were coleopterans. Species richness increased landwards. α diversity calculated on the captured macrofauna varied in space but not in time (seasonally). Plant biomass was highest at 60m 95m and 125m in transect A and at 75 m 100 m 115m in transect B. The endemic plant *Limonium etruscum* was significantly correlated with substrate salinity and was highly abundant in the retrodunal areas.

Soil salinization in the Grosseto Plain: the agricultural scenery

Zanchi, C. & Cecchi, S.
University of Florence | Italy

In the Grosseto Plain the prevailing environmental feature is the “agro-ecosystem”: the total cultivated area (about 29.000 hectares) is the 60% of the total surface of 48.000 hectares. According to ISTAT, the Italian Institute for Statistics, on these 29.000 hectares the agricultural activity is carried out by more than 2.000 enterprises, and the workers employed directly in agriculture are almost 10.000. The percentage of workers employed in agriculture in the Province of Grosseto (11.3%) is almost three times the Regional and National datum that is around the 4%. In addition, in the Grosseto Plain the agricultural production of forages supports an important activity of cuttle breeding, and in the Grosseto Plain agriculture allows another important and widespread economical activity, that is Agritourism. These data show the economical and social importance of agriculture for the Grosseto Plain, an agriculture that involves the economy and the life of a lot of people. And this is the scenery, the agricultural context where the soil salinization happens.

In the Grosseto Plain the problems due to soil salinization are well known. The causes of this soil degradation process have been identified in the use of saline water for irrigation and the raise of salts from ground water to the surface of the soil by capillary action. Because of the overexploitation of water resources for human needs, the natural condition of balance between fresh and saline groundwater has been broken, with the intrusion of salt water from the sea into the ground water table that is the main source of water for irrigation. So the intrusion of sea-water into the fresh ground table induces the salinization of the water that becomes the means of salinization of the soils irrigated with that saline ground water. And considering that this process happens in an agro-ecosystem (the Grosseto Plain) where the most important and widespread crops are cultivated during the spring-summer season and need of irrigation, that the water deficit during the irrigation season is about 450 mm, and that the 85% of the irrigation water is drawn from wells, we can understand the importance, the impact of such severe, rapid and widespread soil degradation process on the economical and environmental context of the Grosseto Plain.

In the Grosseto Plain the salinity of irrigation water caused in the last decade a reduction of 15% of the irrigated land and a change of agricultural crops: the remunerative but saline-sensitive crops such as strawberry and carrot have been replaced with tomato which is less remunerative but more salt-tolerant. Moreover in some areas of the Grosseto Plain, because of this soil degradation process, the “agricultural desertification” has been induced or it is going on: the soil salt content has reached a level no more compatible with agriculture.

The agronomic limitations due to salinity are the resultant of the interactions between water and soil resources and can be managed mainly through the correct execution of the irrigation and drainage techniques. To avoid salt accumulation, the salt has to be removed by percolation of water (irrigation water and/or rainfall) inducing the leaching of salts of the root zone. As a consequence in an irrigation system the calculation of water requirement must take into account not only the water consumption of the irrigated crops, but also the quantity of water necessary to displace the salts from the root zone. This quantity is known as the Leaching Requirement. From the knowledge of the salinity of the irrigation water and of crop water requirements, it is possible to predict the accumulation of salts in the root zone and to compute the amount of additional water (other than irrigation and rainfall) necessary to keep the salt content in the soil sufficiently low for maintain as high a production level as feasible. In essence, the Leaching Requirement approach utilizes a combination of applied irrigation water and precipitation for the leaching process.

In the context of the WADI Project for the Grosseto Plain, the DISAT is carrying out the route of study and research that involves soil investigations and agro-climatic elaborations.

According to the “Soil map of the Grosseto area” (University of Amsterdam, 1986), for each type of soil samples have been taken for laboratory analyses to determine the chemical (reaction pH, electrical conductivity) physical (bulk density, texture, permeability) and hydropedological (field capacity, wilting point, available water) characteristics of soils related to salinity and salinization. The results of these investigations are useful to elaborate the “map of the potential salinization risk of the soils” in the Grosseto Plain.

Analysing a 50-years long period of climatological data for the Grosseto Plain, the climatic conditions of the study area have been investigated for evaluating the leaching effect of rainfall.

For the most important irrigated crops of the study area (maize, vegetables, soybean, lucerne, tomato, melon, water melon, peach-tree), crop water requirements are estimated from climatological data according to the FAO methodology, and as a consequence the quantity of water to be applied for irrigation has been assessed.

For each type of soil and for each crop, the amount of additional water (Leaching Requirement) necessary to keep the salt content in the soil sufficiently low for normal plant growth is computed.

The results of the research will be organized in a framework (temporarily called “Salinity Tool”) of simple and immediate use for farmers, and represent a support for policy makers too, because facilitate the planning of measures to protect and conserve the soil and water. Knowing the crop, the type of soil and the salinity (electrical conductivity) of irrigation water, the “Salinity Tool” provides the yield expected, the crop water requirement, the leaching requirement and directs the irrigation management.

Preliminary studies on arthropodofauna biodiversity in Italy (Maremma) related to salt accumulation in cultivated fields and not cultivated areas

Rossano C., Gambineri S., Gecchele L. and Scapini F.
University of Florence | Italy

The salinization of the ground water due to water draw from the ground water table and the intrusion of salty water from the sea through the Ombrone river mouth to some kilometres upstream probably are the origin of the soil salinization in the Ombrone river basin.

In the Maremma Regional Park (Grosseto, Italy) a strip of biologically cultivated land of the Alberese Farm situated along the Ombrone left bank, was investigated for invertebrate biodiversity, along the apparent increasing salt gradient from East to West.

10 locations belonging to 4 types of vegetation were chosen: *trifolium* and wheat cultivations, abandoned land and not cultivated soil on river banks. In each location we installed 2 crosses of 5 traps each for macro-invertebrates collection and collected 2 soil cubes of 10x10x10 cm for Berlese extraction of micro-arthropods (Parisi 2005). For each soil sample salinity pH and soil texture will be determined. The data are still under analysis and depending on the results some adjustment of the protocol in a further September-October field sampling will be done.

The aim of this preliminary work on cultivated soil in the Maremma Regional Park is to define a protocol to establish the presence of any relationship between invertebrate fauna and a salt gradient on cultivated land, and eventually to identify salt bioindicators among micro and macro-invertebrates. Within the aim of WADI project this research could be useful as further assessment of salty water problem in the Ombrone river basin.

Patrimoine culturel de l'eau: une recherche de terrain positive pour sauver un patrimoine en danger (El Hondo, Vega del Río Segura, Espagne)

MAURY, R. G.[1] & CANTARINO, C. M.[2]
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[2]University of Alicante | Spain

La communication illustre une riche et passionnante et recherche de terrain effectuée dans les régions d'Alicante, Elche et Murcia, particulièrement dans la basse vallée du fleuve Segura et dans la zone du Parc El Hondo en 2006 (meeting WADI, Crevillent-Alicante, février 2006; initiative "Sistemas de regadío históricos y valores ambientales", Elx, novembre 2006), très opportune:
- par l'actualité, en général, du thème "la sauvegarde du patrimoine hydraulique – l'archéologie hydraulique", dans une époque, actuelle ou récente, de reconversion des systèmes hydrauliques traditionnels vers des formes plus modernes d'exploitation, dans un contexte de forte transformation du territoire (urbanisation, industrialisation), notamment l'agressive spéculation immobilière et touristique, destructrice du paysage et de l'agriculture, des écosystèmes et des communautés rurales des côtes méditerranéennes (en Espagne et autres pays du nord, sud et est de la Méditerranée);
- par la pertinence et le contexte particulièrement intéressant: grande région du Levante espagnol, comme d'autres, à longue tradition hydraulique agricole (systèmes hydrauliques et d'irrigation d'origine romaine ou arabe, cultures irriguées anciennes et modernes ou particulières (la chufa/xufa a Valencia), et plus particulièrement dans la basse vallée Vega du Segura (entre Alicante. et Elx, Orirheula et Murcia) et la dépression de El Hondo (parc naturel et cultures agricoles);
- par la situation particulière de la célébration du centenaire de la "Nuevos Riegos El Progresso", société agricole d'irrigation ou association de propriétaires (Elx, 1906-2006), toujours en activité et en cours de modernisation, et l'opportunité d'en récupérer son patrimoine historique.
La longue recherche de terrain, pluridisciplinaire, avait pour objectif:
- visiter et relever les anciennes infrastructures hydrauliques (barrages, canaux; stations de pompages et leurs machines hydrauliques, etc.) de "Riegos El Progreso", ainsi que d'autres sites, grands ou petits, connus ou inconnus, comme les grandes norias d'Alcántara (Murcia), Benijófar (restaurée en 2006), des systèmes d'irrigation, de puits et aqueducs, de moulins et fontaines, etc.;
- rencontrer et sensibiliser un vaste public (dirigeants et "regantes" (paysans irrigants), enseignants et autres acteurs politiques et culturels, les medias) sur l'importance de la sauvegarde d'un tel patrimoine hydraulique agricole et non, dans le monde méditerranéen et non, conforté par quelques rares initiatives (musées de l'eau à Murcia et près d'Alcoy) et le soutien de quelques autorités politiques et culturelles, medias, enseignants, etc. –
En conclusion, une opération d'études et de recherche extrèmement positive, comme collaboration internationale dans le cadre de la recherche internationale WADI, et surtout pour ses résultats concrets (ex: sauvetage in extremis di patrimoine de "Riegos El Progreso"), outre la meilleure connaissance du patrimoine hydraulique et culturel trop peu valorisé - dans un pays comme l'Espagne, déjà assez sensibile à l'*archeología hidráulica* - pouvant être un modèle à d'autres initiatives similaires dans le cadre du programme WADI, ou ailleurs.

Tentative d'application de la Directive Eau de l'UE dans les eaux de transition de l'Oued Gharifa : Evaluation de la qualité écologique

Tentative of application of the water framework directive of the EU in the transitional water of Oued Gharifa: Ecological Status assessment

Chaouti, P. A. & Bayed, A.
Unité de Recherche OCEMAR | Marocco

Résumé

L'état de la qualité écologique (EcoQ) de l'Oued Ghrifa a été approché en utilisant des indices pris en compte par la Directive Européenne Cadre sur l'Eau (BI, AMBI, BENTIX, BOPA, indice trophique ITI). L'analyse se base sur 14 stations échantillonnées le long de cet estuaire entre l'été 2006 et le printemps 2007. L'évolution saisonnière de la composition et la structure de la macrofaune et de l'état de la qualité écologique a été également effectuée en y intégrant d'autres descripteurs biologiques (richesse spécifique, abondance, indices de diversité et d'équitabilité). Il apparaît que la macrofaune est essentiellement dominée par les espèces sensibles et tolérantes. Bien que l'évaluation du EcoQ soit effectuée à l'aide d'indices différents, les tendances de ses différents états restent comparables. Les valeurs obtenues permettent de qualifier le EcoQ de l'estuaire de l'Oued Ghrifa de modéré à bon. La saisonnalité ne paraît pas avoir un effet évident sur le EcoQ.

Abstract

Using recent indices developed, in part, for use under the European Water Framework Directive, the ecological quality (EcoQ) status of the Oued Ghrifa, was determined on seasonal scale. Fourteen stations sampled along the estuary over four seasons (summer 2006 to spring 2007) were analyzed. The seasonal evolution of the structure and composition of the macrofauna and that of the ecological quality status was considered using biotic indices together with other biological descriptors (e.g., Margalef index as species richness, total abundance, and Shannon-Wiener index as diversity and Pielou's index as evenness). The macrofauna was dominated by the sensitive and tolerant species. Though the values calculated with the various indices were different, the trends of the specific ecological quality were almost similar. The values produced by the five indices used in the study allowed attribution of a moderate to good EcoQ status to Oued Ghrifa estuary. The seasonality didn't have any evident effect on the EcoQ status.

Etat de la biodiversité et de la qualité du milieu estuarien du Tahaddart

Bazairi, H.[1] & Bayed, A.[2]
[1] Université Hassan II Aïn Chock | Marocco
[2] Université Mohammed V | Marocco

Dans le cadre du projet WADI, l'étude de la macrofaune benthique de l'estuaire de Tahaddart se propose de répondre aux objectifs prévus par le workpackage 1 *(description qualitative du système)*, le workpackage 2 *(description quantitative du système)* et le workpackage 3 *(évaluation des impacts sur les différents compartiments)*.

Les recherches menées sur ce compartiment biologique concernent la zone intertidale estuarienne essentiellement. Elles sont basées sur une approche spatiale (31 stations échantillonnées en juin 2006), d'une part, et temporelle (17 stations prélevées en juin 2006, septembre 2006, décembre 2006, mars 2007 et juin 2007), d'autre part.

Sur le plan qualitatif, une cinquantaine d'espèces ont été recensées. Elles sont dominées par les Crustacés, Annélides Polychètes et mollusques et se rapportent pour la plupart à la faune laguno-estuarienne de la côte atlantique marocaine. Parmi ces espèces cinq d'entre elles sont fortement exploitées par les riverains en tant qu'appât pour la pêche.

L'analyse quantitative de la faune benthique et l'utilisation de méthodes d'ordination multivariée a permis d'établir un zonage de l'estuaire et de déterminer, d'une part, les espèces les plus contributives dans la zonation observée, et d'identifier, d'autre part, les paramètres de structuration des communautés benthiques notamment la présence d'herbiers de phanérogames marines.

La bio-évaluation des structures benthiques de l'estuaire de Tahaddart a été approchée par l'utilisation de la méthode des groupes écologiques et indices biotiques, notamment le M-AMBI. Les résultats obtenus plaideraient en faveur d'une bonne santé des communautés benthiques de l'estuaire. Une comparaison avec les résultats d'autres recherches menées dans le cadre du projet WADI permettrait de mieux cerner la qualité de l'environnement de l'estuaire de Tahaddart.

Evaluation des valeurs écologiques des systèmes aquatiques par l'analyse des oiseaux d'eau du Bas Tahaddart

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L'avifaune aquatique du complexe de zones humides du Bas Tahaddart avait fait l'objet d'un suivi régulier durant les années 1970 (Pineau & Giraud-Audine 1974, 1975, 1976, 1977 & 1979). Depuis, seule la composante hivernante de ce peuplement continue à être suivie dans le cadre des dénombrements hivernaux internationaux coordonnés à l'échelle nationale par le Centre d'Etude des Migrations d'Oiseaux (CEMO) de l'Institut Scientifique de Rabat (Dakki *et al*. 1995 et 2002…). Les recherches sur les espèces reproductrices sont limitées aux travaux réalisés durant cette dernière décennie sur l'unique population aficaine de Grande Outarde *Otis tarda* (Hellmich *et al*. 1999 ; Alonso *et al*. 2000 et 2004 ; Hellmich et Idaghdour 2002).

Nous avons, par conséquent, privilégié la thématique de la nidification des oiseaux d'eau du Bas Tahaddart dans les recherches que nous menons dans le cadre du projet WADI afin d'actualiser nos connaissances sur les oiseaux reproducteurs, surtout que le site a connu de nombreux aménagements, routiers en particulier, qui ont dû affecter l'hydrologie des habitats. En effet, plus que les populations hivernantes ou migratrices, les contingents de reproducteurs sont très sensibles aux modifications hydrologiques de leurs lieux de nidification.

Les prospections de terrain réalisées au cours des années 2006 et 2007 ont été donc concentrées sur les périodes de nidification des oiseaux (avril à juillet) ; cependant, nous avions également prévu quelques autres missions afin de couvrir les périodes de migration dans le but d'actualiser également l'inventaire global du peuplement d'oiseaux d'eau du Bas Tahaddart et de préciser le statut phénologique de ceux-ci. Alors que nous avions pu disposer des résultats des dénombrements hivernaux réalisés par des observateurs partenaires du CEMO.

Lors de chacune de nos prospections de terrain, toutes les espèces d'oiseaux aquatiques vues ou entendues ont été relevées et leurs effectifs (ou au moins des indices de leur abondance) notés. Durant la période de nidification, nous avons procédé au relevé de tout indice de reproduction (formation de couples, cantonnement et comportements d'alerte, parades, accouplements, présence de nids et de poussins).

L'inventaire des oiseaux d'eau du Bas Tahaddart compte 65 espèces dont une vingtaine de nicheurs, qui, pour la plupart, sont cités dans la site comme éléments reproducteurs pour la première fois : Grèbe castagneux *Tachybaptus ruficollis*, Héron pourpré *Ardea purpurea*, Aigrette garzette *Egretta garzetta*, Outarde canepetière *Tetrax tetrax*, Talève sultane *Porphyrio porphyrio* et Foulque macroule *Fulica atra*. La nidification de plusieurs autres espèces a été prouvée alors qu'elle n'était que suspectée auparavant ; c'est notamment le cas de la Gallinule poule d'eau *Gallinula chloropus*, de l'Echasse blanche *Himantopus himantopus* et de l'Avocette *Recurvirostra avosetta*. Par ailleurs, une importante colonie reproductrice de Glaréole à collier *Glareola pratincola*, oiseau nicheur déjà connu dans le site, a été découverte.

Parmi les oiseaux fréquentant le site du Bas Tahaddart, 16 espèces présentent une valeur patrimoniale en tant qu'espèces menacées ou rares à l'échelle mondiale ou nationale ; les plus intéressantes d'entre-elles sont incontestablement le Héron pourpré *Ardea purpurea*, le Fuligule nyroca *Aythya nyroca*, la Talève sultane

Porphyrio porphyrio, la Grue cendrée *Grus grus*, les Outardes barbue *Otis tarda* et canepetière *Tetrax tetrax*, le Goéland d'Audouin *Larus audouinii* et le Hibou du Cap *Asio capensis*.

En période d'hivernage, le site du Bas Tahaddart héberge 4400 hivernants (moyenne calculée sur 25 années) ; ce chiffre varie de 700 à plus de 10500 individus. L'évolution globale de l'effectif des hivernants a montré que les valeurs les plus élevées ont été obtenues entre 1993 et 2002 ; le même schéma d'évolution a été obtenu pour les principaux groupes d'oiseaux présents dans le Bas Tahaddart : les Anatidés, les Limicoles et les Ardéidés. Les causes précises de cette évolution doivent probablement être cherchées dans les variations de la capacité d'accueil du site en relation avec les changements dans les caractéristiques hydrologiques liées aux différents aménagements routiers que la région a connus ces dernières décennies. Cette hypothèse reste toutefois à vérifier.

En nous basant sur toutes les données concernant les oiseaux d'eau du Bas Tahaddart, aussi bien celles relatives à l'hivernage (de 1983 à 2007) que celles recueillies durant ces deux dernières années sur les populations nicheuses, nous avons tenté une ré-évaluation ornithologique du site grâce aux critères de la Convention de Ramsar sachant qu'une première évaluation par cette méthode a été réalisée à l'occasion du projet d'inscriptions de nouvelles zones humides marocaines sur le liste de cette Convention entre 2003 et 2005 (Projet WWF International – HCEFLCD – GREPOM).

Il s'est avéré que le site du Bas Tahaddart vérifie quatre critères de la Convention de Ramsar :

Critère 2 : Il héberge des espèces menacées, vulnérables ou rares à l'échelle nationale et/ou mondiale : Héron pourpré *Ardea purpurea*, Spatule blanche *Platalea leucorodia*, Grue cendrée *Grus grus*, Fuligule nyroca *Aythya nyroca*, Grande Outarde *Otis tarda*, Outarde canepetière *Tetrax tetrax*, Talève sultane *Porphyrio porphyrio*, Glaréole à collier *Glareola pratincola*, Goéland d'Audouin *Larus audouinii*, Sterne caspienne *Sterna caspia*, Sterne royale *Sterna maxima*, Sterne naine *Sternula albifrons*, Hibou du Cap *Asio capensis*.

Critère 3 : Il abrite des populations d'oiseaux importantes pour le maintien de la diversité biologique au niveau de la région nord-ouest africaine : Héron pourpré *Ardea purpurea*, Grande Outarde *Otis tarda*, Outarde canepetière *Tetrax tetrax*, Avocette élégante *Recurvirostra avosetta*, Glaréole à collier *Glareola pratincola*, Sterne naine *Sternula albifrons*, Hibou du Cap *Asio capensis*. En effet, le Bas Tahaddart est l'une des rares zones humides au niveau du Nord-Ouest de l'Afrique qui restent encore favorables à ces espèces.

Critère 4 : Il accueille des espèces d'oiseaux à un stade critique de leur cycle de vie. C'est, en effet, une zone d'escale migratoire importante pour de nombreux oiseaux européens à l'aller comme au retour. C'est aussi un site de nidification important pour des espèces menacées, rares ou vulnérables : Héron pourpré *Ardea purpurea*, Grande Outarde *Otis tarda*, Outarde canepetière *Tetrax tetrax*, Avocette élégante *Recurvirostra avosetta*, Glaréole à collier *Glareola pratincola*, Sterne naine *Sternula albifrons*, Hibou du Cap *Asio capensis*.

Critère 6 : Il abrite régulièrement plus de 1% des individus de plusieurs populations régionales d'oiseaux : Grande Outarde *Otis tarda*, Outarde canepetière *Tetrax tetrax*, Glaréole à collier *Glareola pratincola*, et de manière irrégulière celles de la Grue cendrée *Grus grus* et du Gravelot à collier interrompu *Charadrius alexandrinus*.

En conclusion, Les résultats recueillis dans le cadre du projet WADI ont permis d'actualiser nos connaissances sur l'avifaune aquatique du Bas Tahaddart, surtout en ce qui concerne les populations nicheuses. Nous avons pu, effet, recenser les populations nicheuses actuelles dans le site ; nous avons également pu proposer des estimations de la taille de la plupart de ces contingents. Ceci nous a permis d'identifier les principales valeurs ornithologiques que présentent les zones humides de ce complexe du Bas Tahaddart.

Sandhopper orientation at Oued Laou and Oued Ghrifa mouh –Hypotheses under test and preliminary results.

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Orientation experiments on sandhopper populations were carried out at two different sites, both of them characterised by the presence of a river mouth. Assuming that sandhoppers orientation is fitted to the local context and to the temporal variation, the main objective of this study was to identify different behavioural responses with respect to stability/instability condition of the beach ecosystem. We listed the possible sources of instability, both natural and anthropogenic, acting on the two sites and the differences in orientation (in terms of precision, orientation mechanisms and expression of behavioural diversity) will be therefore analysed as response to those environmental differences.

The summer season was identified as “critical season” with respect to variables such as dryness and tourism impact on the beach, so the experiments are planned to be carried out before and after the summer season. Preliminary results (on the first replicate only) highlighted a behavioural diversity due to sensitiveness to immediate parameters, such as meteorological conditions and sun position in the sky (azimuth). That stressed the need of replicates to achieve the identification of general trends of environmental status by means of sandhopper orientation as indicator.

Rôle des femmes et des hommes dans l'utilisation et la gestion des ressources naturelles dans le Bassin Versant de Oued Laou : Résultats préliminaires.

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La dimension genre a été prévue parmi les objectifs du projet Wadi. Dans ce sens, une étude concernant cette approche a été entamée dans le Bassin Versant de Oued Laou. Il s'agit de collecter et d'analyser au niveau du terrain la situation, les problèmes et attentes des populations, leurs potentialités, leur participation et leurs réactions aux actions de développement entreprises en leur direction dans le domaine de la gestion de l'eau et des ressources naturelles qui lui sont liées.

Le choix de populations s'est basé sur leur répartition géographique couvrant une bonne partie du bassin versant, le type d'activité (pêche, agriculture, pâturage, artisanat etc.) et la facilité d'accès. Neuf populations dont 3 urbaines et 6 rurales, considérées comme représentatives du Bassin Versant de Oued Laou ont été retenues. L'échantillon étudié se compose de 50 familles dont 30 rurales et 20 urbaines.

Un questionnaire préliminaire répondant aux objectifs du projet Wadi a été établi. Durant une phase exploratoire, il a été testé auprès de deux populations l'une urbaine et l'autre rurale. Cette phase nous a permis de l'ajuster aux besoins et nécessités de la région.

Le questionnaire définitif comporte l'information sur la situation de la famille (statut, accès aux services, accès aux ressources), la répartition des rôles et activités entre les femmes et les hommes, les potentialités, les contraintes rencontrées dans la gestion et l'utilisation des ressources naturelles, les besoins et priorités des femmes et enfin des propositions de solutions pour améliorer la situation.

Water resources and an assessment of the vulnerability to contamination of the Oued Laou aquifer

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L'aquifère de l'Oued Laou, étendu sur une superficie de 18 km^2, se localise dans la Wilaya de Tétouan, dans la partie septentrionale du Maroc. L'accroissement rapide de la demande en eau lié à l'évolution démographique et aux nécessités d'un développement économique, social et touristique de cette région a conduit à une mobilisation croissante des eaux aussi bien superficielles que souterraines. Toutefois, ces ressources en eaux sont devenues plus vulnérables à la pollution et l'acuité du problème de la dégradation de la qualité des eaux s'accroît à terme en raison de l'augmentation des rejets polluants dans les milieux récepteurs sans traitement préalable.

Afin d'obtenir une efficacité meilleure lors de la mise en place des mesures susceptibles de préserver la qualité naturelle des ressources en eaux souterraines, ce travail s'est proposé d'établir des cartes de vulnérabilité à la pollution et de risque de pollution. Ces cartes sont définies comme étant un outil d'orientation et d'aide à la décision pour l'aménagement du territoire. Ce travail s'inscrit, donc, dans le cadre des efforts déployés visant à préserver l'eau non seulement sur le plan quantitatif mais aussi qualitatif.

Du faite de la grande variabilité spatio-temporelle des conditions climatiques, on a tenté de cartographier la vulnérabilité à la pollution selon trois années pluviométriques distinctes. Les méthodes utilisées, DRASTIC et GOD, ont montré une dissimilitude dans les résultats obtenus. Ainsi, la carte de vulnérabilité selon la méthode DRASTIC pour l'année humide a été choisie comme carte de référence. Cette carte montre, en fait, que la majorité de la superficie de la plaine est marquée par une forte vulnérabilité alors que les zones à vulnérabilité modérée et faible se localisent principalement au centre aval de la plaine.

En outre, l'établissement de la carte de risque de pollution consiste à superposer la carte de vulnérabilité avec la carte de foyers de pollution. Ainsi, la carte résultante montre que les zones où le risque de pollution est fort se situent dans des terrains caractérisés par l'existence de la voirie et des rejets domestiques, industrielles et de services.

Les résultats ressortant ont été comparés avec les périmètres de protection des champs captants d'Amendis. Cette comparaison indique que les principales zones à risque fort sont repérées au sein du périmètre rapproché des champs captants; d'où la nécessité d'une intervention à court terme pour remédier les inquiétudes actuelles et pour protéger les eaux de la nappe contre tout risque futur de détérioration.

Mots clés : Ressources en eaux, vulnérabilité, risque, pollution, DRASTIC, GOD, aquifère, Oued Laou, Maroc.

Données biologiques sur le site tunisien.

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Information on the numbers of individuals in a population represents some of the most basic data that are needed to conserve populations. Over the past decades, many waterbird populations have undergone rapid changes in number as well as changes in distribution in response to the creation of refuges, management of populations, the creation of man-made wetlands and climate change. These continuing changes make it necessary to update population estimates on a regular basis. To this point of view, surveys of wintering waterbirds were carried out in wetlands belonging to WADI site. A total of 25375 individuals and 44 species were detected belonging to 8 orders and 16 families which were in general occurring in flocks. Charadriiformes are the most abundant taxonomical group with 14097 individuals (55.55 % of the total) as well as the most diverse with 23 species (52.27% of the total). The most abundant species accounted for more than 92.01 % of the total abundance were *Phoenicopterus ruber* (33.89%), *Calidris alpina* (24.71%), *Vanellus vanellus* (12.24%), *Calidris minuta* (9.88%), *Tadorna tadorna* (5.91%), *Larus ridibundus* (3.09%), *Tringa totanus* (1.24%), *Anas clypeata* (1.04%). Furthermore, only Sebkhat Ariana site satisfied three selection criteria of the Ramsar Convention (Ramsar 2005: criteria 2, 5 and 6) confirming its international importance in waterbird population conservations. Indeed, the carrying capacity of this site is higher than 2000 individuals, one threatened species is presents on the site (*Oxyura leucocephala*) and two species constitute more than 1% of the original population (*Tadorna tadorna* and *Phoenicopterus ruber*). These results indicate the high ornithological value of this wetland in winter period. However, the continuing changes on the WADI wetland structures mainly cause a general perturbation of the considered winterquarter and its avifauna. Thus, it's essential to use appropriate management strategies to enhance the value of this area for the waterbird species, which was very sensitive to habitat productivity changes.

The terrestrial isopodofauna is studied in the the WADI site, particularly in Ennahli Park. Samplings in this park were carried out in different seasons. Some species were common in Tunisia and a new species of *Armadillidium* was identified.

The benthic macrofauna and macroflora of the eastern coast of the Ghar El Melh lagoon were studied and a checklist was established. Furthermore, some species considered as good bioindictors were sampled monthly for a more detailed study; *Cymodocea nodosa*, *Pinna nobilis* and *Caprellids* were selected. Spatial and temporal distributions of these species show a seasonal fluctuations and variation related to the distance from the sea and to the impact of the anthropogenic action.

Locomoteur activity rhythm was monitored for specimens of *Talitrus saltator* under several experimental conditions (Light-Dark cycles (LD) and continuous darkness (DD)). Animals were collected from Sidi Ali El Mekki, Kalaat Landalous and Oued Medjerda beaches. Preliminary results showed differences and similarities between studied populations. The highest mortality percentage was observed at Kalaat Landalous. The ecological significance of the observed rhythms will be discussed in relation to the ecosystem dynamic.

Mapping ecosystem services: An insight to choice and valuation. The Mondego estuary case-study.

Pinto, R., Patrício, J., Neto, J. & Marques, J. C.
IMAR – Institute of Marine Research | Portugal

The ecosystem services and goods approach allows the quantification and assessment of the several biological, chemical and physical processes occurring in a system, as well as the determination of its evolution and trends. The services and goods obtained are the basis for human welfare, since natural ecosystems provide food, materials, fuels and water that are primary necessities for human life, in addition to several indirect benefits, such as leisure spaces or recreation activities, which increase the individual quality of life. Most of the goods produced by the ecosystems can pass through the society markets, and so have a price ascription; nevertheless, most of the services provided cannot be measured and, consequently, neither be attributed a value to it. To ensure the desired provision of ecosystem goods and services by the ecosystems it will require an understanding of the complex interactions among ecosystem assets, processes and functions. The first step is to guarantee a complete inventory of the possible ecosystem services and goods provided in addition to dissect it according to the main drivers and pressures that determine their condition. The aim of this work is to go over the main ecosystem services and goods definitions, to make an inventory of the main assets obtained, to identify the main interrelations among them, and look upon the methodologies currently available to quantifying and evaluate these products. The ultimate goal is to exemplify the ecosystem approach functioning and application upon the systems under study.

Productivity effects on water quality, and vice-versa, in the Mondego estuary – An integrated ecosystem services approach.

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The Mondego estuary has been widely studied throughout the last two decades, with most of the research being focused on the response of biological communities to different types of environmental stress, namely eutrophication, and to impacts that the anthropogenic activities supported by it may cause on the system. The human modification of ecosystems is having a major impact on ecosystem services at a global level. There is an environmental limit of ecosystem degradation or loss beyond which ecosystem service supply will not be sufficient to provide the required benefits. With this work, we analysed this system from an ecosystem services and goods point of view, describing its present state and establishing scenarios regarding the foreseeable evolution of different ecosystem services, respectively food production, water quality, recreation and biodiversity. This approach allowed us to check the interactions between each one of the ecosystem services and to establish that water quality is currently the service that influences the most all the rest. Specifically, water quality contributes to a complex system of services and goods, being the benefits obtained very distinct:
a) as the result of economic activities,
b) benefits that have indirect links with economic activities and,
c) benefits that do not result from economic activities.

A special attention was given to the food production and water quality services once their intrinsic nature influence and determines the status and provision capacity of each other. As a conclusion, it appears clear that appropriate water management procedures will have a positive influence upon all ecosystem services.

WHERE ARE WE?

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The context of WADI is complex and the project is ambitious in its aims, but the strategy we adopted is apparently feasible, with the contribution of all. At the mid-term of the project WADI we shall examine the outcomes and eventually update the objectives.

In the first period (year 2006) we completed for each study site:

1) a stakeholder analysis;
2) a qualitative system description.

Has this been achieved at all sites?

We are well aware of the difficulty to give an holistic description of a site. However this is the objective of the project. As a strategy, a specific issue should be focused, and the factors and interactions influencing it analysed, considering the changes and evolution of the dynamic system under study.

The results are in the first report to the EC, annexes and deliverables. We have been asked to disseminate the results, which are potentially exploitable by the stakeholders, including the scientific community, the managers and local people. The latter stakeholders are a major target of the dissemination of results from projects financed by the European Commission. Efforts should be done to reach this target: Science & Society Communication.

In the second semester of the project (months 7 to 19) , phase two was started at all sites aiming at a quantitative system description.

Do we have clear strategies on how to achieve this objective?

According to the contract, during the second period of project WADI we shall provide the following deliverables on month 19 (July 2007, soon after the mid-term meeting) :

1) Socioeconomic questionnaires
2) Sampling protocols
3) Data bases for each study site
4) Quantitative system description of each study site.

These deliverables will mark the end of phase two of the project and the start of phase three – Assessment of the impacts on different compartments (months 18-25).

Which strategies have been adopted at each site to achieve the objective of phase three?

Can we agree on some of these strategies to achieve a Mediterranean integration?

With the information shared at the mid-term meeting, we will be able to discuss positive and negative aspects of the work in a brain-storming that will be held at the end of the meeting along with the following questions:

1) *logistic issues;*
2) *issues of communication with stakeholders;*
3) *collaboration with partners;*
4) *integration between disciplines;*
5) *……other…….*

As a matter of example, I'll illustrate a management and communication issue at the Italian site: the Maremma Regional Park, where a scientifically fruitful work together took place during the MEDCORE project. The participants produced valuable scientific papers, presented at the MEDCORE final conference, and published in

the Proceedings at the end of 2006, and a divulgation book on the park in Italian: A guide to know and understand the park and the surrounding territory, now under press. Despite our efforts of communicating the ecological uniqueness of the sandy littoral facing the park, a project of nourishment has been made by the park managers, which implies the taking of sand from the ecologically richest sector, the Collelungo beach, to nourish the eroded sector of the beach, near the car parking. A strange project inside a natural park! This action will likely destroy beautiful natural dunes with their vegetation, including an endemic plant, *Limonium etruscum*, and some protected insects. Now, the park managers do not want to hear our criticisms on the project of beach nourishment, and have delayed the publication of the book as much as possible, when we asked their collaboration. Now, that the book is being printed by a private publisher with a partial financial support of the project WADI, they are denying the permission to sell the book in the park book shop. I do not know yet how this story will end, but I feel that we have a duty of communication of the scientific results and of criticising potentially negative actions when necessary.

Annex I

Sixth International Meeting
Coimbra (Portugal), 27 to 30 of June 2007

Un état d'avancement dans la connaissance du site tunisien

-contribution géographique et géomorphologique-

Oueslati A. et Laroui W.

La réunion de Tunis, tenue en décembre 2006 avec la participation de différents stakeholders, a été l'occasion pour mieux s'informer sur les questions relatives à l'eau et de connaître celles d'intérêt ou préoccupantes dans la région. Les questions au niveau desquelles l'approche géographique et géomorphologique peut apporter une contribution utile sont variées ; les plus importantes s'articulent autour des chapitres suivants :

1-l'érosion des terres sur les versants ;
2-les risques d'inondation dans les topographies basses ;
3-l'utilisation de l'eau : aujourd'hui et son évolution, à travers les temps historiques (perception, usages, techniques, méthodes, …) ;
4-le déplacement du rivage et ses conséquences (érosion marine, menaces sur les aménagements côtiers, altération des écosystèmes par la salinisation des sols ou des aquifères, dégradation de la végétation,…) ;
5-les cultures du type *Ramli* pratiquées sur le cordon littoral ou dans des parcelles gagnées, par un système de «poldérisation», aux dépens de la lagune et des marécages qui la bordent.

En fait, il ne nous a pas été possible d'aborder toutes ces questions au même niveau. Dans cette première étape du projet, l'effort a été concentré sur le point 5. Les cultures pratiquant la technique *Ramli* qui ont occupé une place importante tant au niveau des séances de présentation en salle que sur le terrain lors de la réunion de Tunis, nous paraissent en effet, mériter une attention particulière. Outre leur intérêt dans le secteur agricole de la région, elles sont le fruit d'une histoire importante à travers laquelle ont été forgées des formes d'adaptation aux contraintes et de valorisation des atouts du site. Le résultat est un terroir original, peut être

unique en son genre en Méditerranée, et qui revêt, de ce fait, outre son importance pour l'économie de la région, une valeur patrimoniale.
Précisons enfin, que nous nous sommes intéressé surtout à la partie orientale du système lagunaire, notamment celle située autour de la lagune de Sidi Ali El Mekki, qui renferme la plus grande concentration et la plus grande variété de parcelles de culture *Ramli*.

Deux principaux types de travaux ont été effectués :

***-un travail de prospection** sur le terrain et dans la bibliographie avec comme objectif principal la caractérisation et la compréhension du milieu dans lequel évoluent les espaces exploités par la culture *Ramli* ainsi qu'une identification des principaux facteurs et processus en action. Dans cette étape, l'accent a été mis, surtout lors des visites du terrain, sur les données naturelles. Nous avons volontairement reporté le contact avec la population et les différents stakeholders. Ce contact occupera une place importante dans des phases ultérieure, avec une place privilégiée aux enquêtes socio-économiques.
De fait, cette première étape, qui a plutôt valeur de diagnostic, est, à notre avis, indispensable. Elle doit permettre de mieux préparer aux contacts précités. L'observation et l'effort de compréhension de ce qui se passe sur le terrain susciteront des questionnements qui peuvent aider lors de l'étape de discussion avec les stakeholders ainsi que dans le choix des questions à inscrire sur les fiches des enquêtes socio-économiques et dans la définition des méthodes à suivre pour l'exécution de ces enquêtes.

***-une exploitation de la documentation** rassemblée ; la priorité a été donnée au traitement des documents cartographiques, photo-graphiques et d'imagerie. Le but est de réaliser une cartographie diachronique des espaces exploités par la culture *Ramli* et de suivre leur évolution dans le temps, tant au niveau de leurs superficies qu'au niveau de leur forme et de leur répartition spatiale. Ceci doit révéler des situations qui appellent des explications à chercher dans le fonctionnement du milieu naturel (par l'observation du terrain) ou dans les pratiques humaines (par les contacts et l'enquête socio-économique).

I-La terre du terroir *Ramli*

Très écrasées et, en apparence, très homogènes, les terres exploitées par la technique *Ramli* sont en fait assez variées. Des différences sensibles existent tant au niveau de leur localisation et genèse que dans leur dynamique et la nature de leur matériel. Il a été possible de distinguer quatre principaux types de situations (fig.1):

1-une situation à *Edhrea*[1] ;

[1] *Edhrea* signifie en arabe le bras

2-une situation dans le cordon littoral actuel ;
3-une situation dans les îlots dispersés dans la lagune ;
4-une situation sur la berge nord de la lagune dans la continuité du pied du versant de Jbel Ennadhour

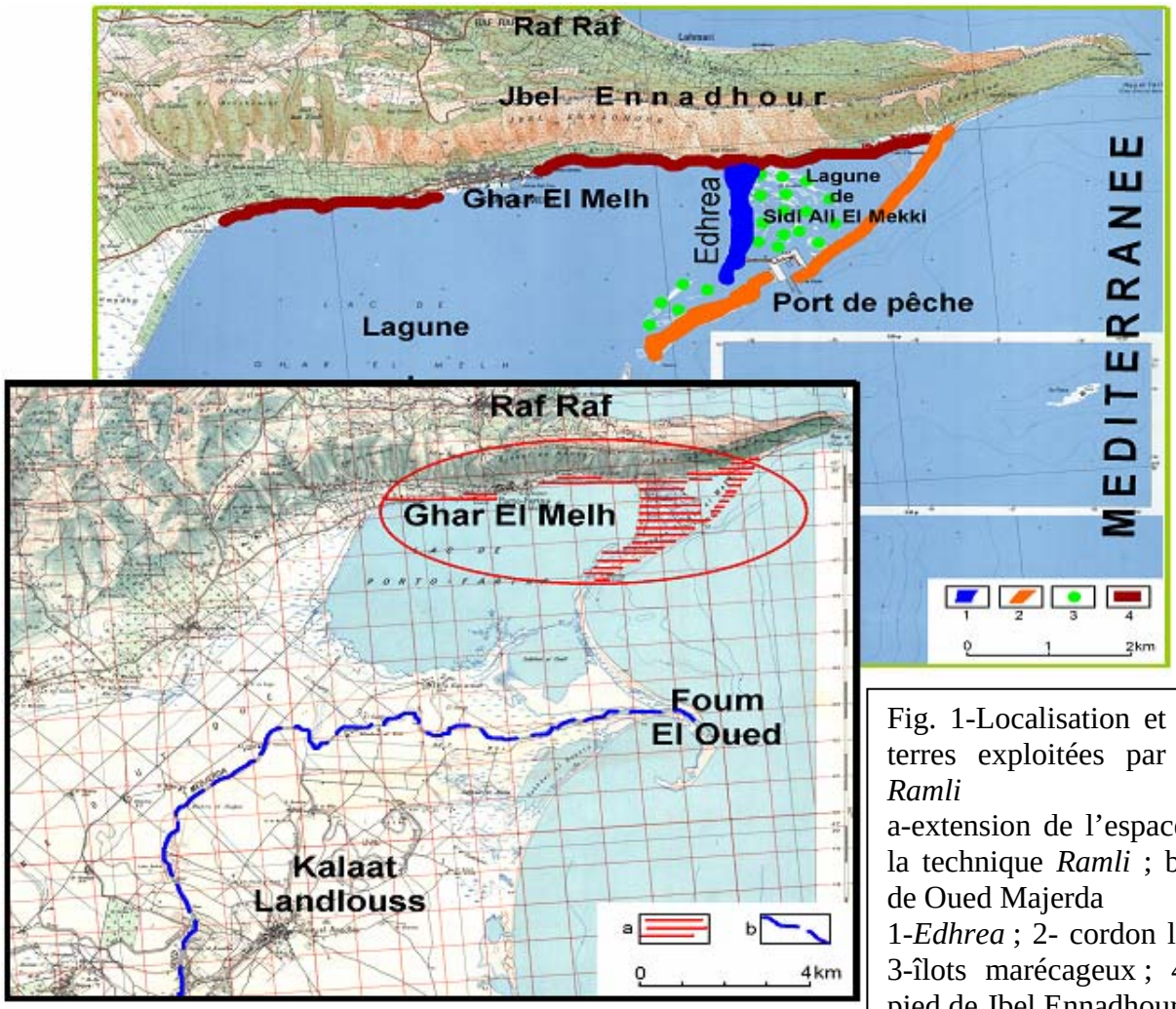


Fig. 1-Localisation et typologie des terres exploitées par la technique *Ramli*
a-extension de l'espace exploité par la technique *Ramli* ; b-ancien cours de Oued Majerda
1-*Edhrea* ; 2- cordon littoral actuel ; 3-îlots marécageux ; 4-berge nord-pied de Jbel Ennadhour

-Edhrea

C'est une langue de terre qui s'étire depuis le pied de Jbel Ennadhour, selon une orientation N-S, séparant la lagune de Ghar El Melah de son annexe la lagune de Sidi Ali El Mekki. Il s'agit, très vraisemblablement, d'une ancienne flèche littorale qui marquait la position de la ligne de rivage de la mer à un moment où la lagune de Sidi Ali El Mekki ne s'était pas encore individualisée. Son sol originel est essentiellement sableux, mais un changement latéral se fait en direction de sa racine sous l'influence des apports du ruissellement qui opère sur le versant qui la domine.

-Le cordon littoral actuel

Sableux et orienté NE-SW, il s'étend depuis le pied de Jbel Ennadhour jusqu'à l'ancienne embouchure de Oued Majerda. Mais seule sa partie

située au Nord-Est de l'ancien *Boughaz*, jadis équipé par une bordigue et aujourd'hui ensablé et abandonné (fig. 2), est concernée par les cultures *Ramli*.
Malgré sa largeur qui dépasse localement 200m et son épaisseur parfois supérieure à 1,5m, ce cordon n'est pas infranchissable pour les vagues. Jusqu'à la veille de 1974, année de création du nouveau port de pêche, la communication mer-lagune se faisait surtout par l'intermédiaire de l'ancien *Boughaz*. Au cours des dernières années, une nouvelle passe (nouveau *Boughaz*) est apparue immédiatement au Sud du port suite à l'érosion d'une partie du cordon littoral. Plus au Nord, les eaux marines peuvent, à l'occasion des tempêtes, rejoindre la lagune de Sidi Ali El Mekki par l'intermédiaire d'une série de brèches.

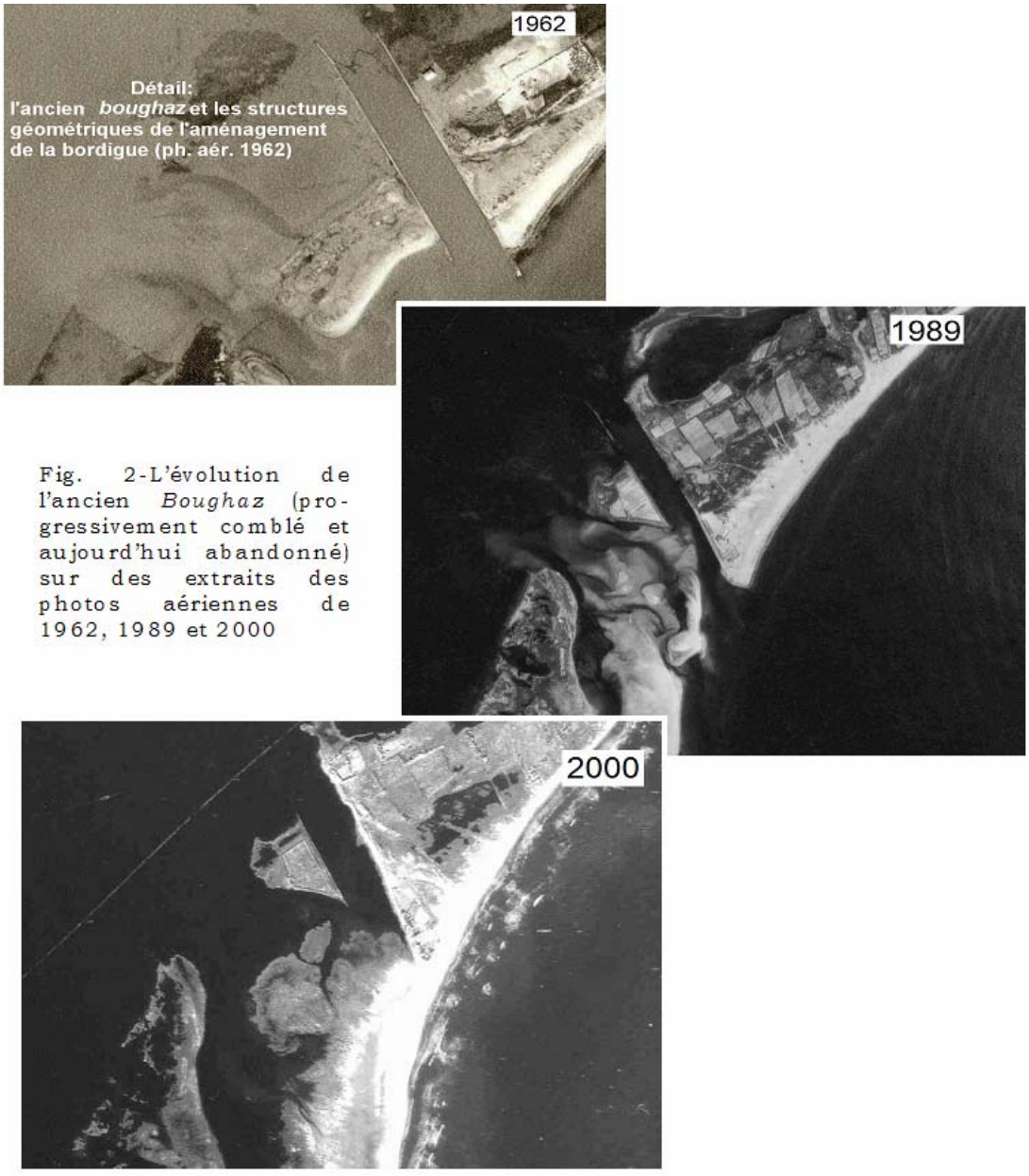


Fig. 2-L'évolution de l'ancien *Boughaz* (progressivement comblé et aujourd'hui abandonné) sur des extraits des photos aériennes de 1962, 1989 et 2000

-Les îlots (*G'tayas*)
Ils occupent une grande place dans la partie occidentale de la lagune de Sidi Ali El Mekki. Ailleurs, on les trouve surtout dans le prolongement

méridional d'*Edhrea* où elles sont très proches du cordon littoral actuel. Ces îlots, qui correspondent en fait aux vraies *G'tayas*[2], sont constitués essentiellement d'un matériel vaseux à vaso-sableux. Ceux qui ne sont pas encore gagnés par les cultures correspondent à des taches de marécages occupés par une végétation halophile parfois très dense. Ils se distinguent aussi par l'extrême faiblesse de leur topographie ; leur surface se situe très souvent à moins d'une trentaine de centimètres d'altitude et peut être entièrement envahie par les eaux à l'occasion des tempêtes.

-Sur la berge nord, au pied du relief

Les cultures sont le plus souvent pratiquées dans des parcelles aménagées, parfois sous la forme de casiers étagés, aux dépens du front d'anciennes accumulations alluviales ou de remblais artificiels aux dépens du plan d'eau ou renforçant de telles accumulations. Ces dernières correspondent souvent au front de cônes de déjection formés au débouché des torrents qui découpent le revers de Jbel Ennadhour. Quoi qu'il en soit, dans ces sites les parcelles cultivées se distinguent, de celles aménagées à la faveur des îlots ou du cordon littoral, par leur sol généralement plus grossier et moins sableux puisqu'il provient surtout du versant. Il faut préciser aussi que seules les parcelles les plus proches du rivage de la lagune sont concernées par la technique *Ramli*.

II- Un environnement d'interactions

En parlant des potagers, les paysans, mais les ingénieurs aussi, du moins ceux que nous avons pu contacter ou écouter comme à l'occasion de la réunion de Tunis organisée en décembre 2006, évoquent deux points essentiels : l'importance du travail humain d'une part, surtout par l'apport de la terre nécessaire à la création et à l'extension des parcelles de culture et le rôle du mouvement vertical de la nappe phréatique qui se fait en rapport avec la marée et qui permet d'irriguer, par le bas, les cultures pratiquées.

Ces éléments sont très importants. Ils sont à la base de la technique *Ramli* et à l'origine de l'originalité et de l'intérêt du site. Mais ils dépendent de bien d'autres facteurs et ne sont pas les seuls qui méritent d'être considérés dans une réflexion qui vise à aboutir à des recommandations permettant une meilleure valorisation de ce terroir et surtout sa durabilité.

Nos premières prospections, axées principalement sur les données naturelles du milieu, permettent déjà de dire que ce terroir occupe une position de rencontre par excellence. Il est sous l'influence de plusieurs facteurs et processus qu'il faut bien connaître surtout qu'ils agissent dans un espace peu étendu et qu'ils montrent parfois des interactions très serrées. Ceci est

[2] -*G'tayas* (s'écrit aussi *Gtaiea, Guetaiea* et *Guetayas*) est le pluriel de *Gataya*, toponyme local, mais qu'on retrouve aussi dans différents secteurs côtiers de la Tunisie orientale. Il signifie morceau de terre isolé, ressemblant à un îlot, dans un terrain plat, très bas et souvent envahi par les eaux continentales et/ou marines (sebkha, marais, …).

d'autant plus vrai que certaines modifications dans leurs caractéristiques ou dans les échanges qui les lient peuvent être, ainsi qu'on peut le comprendre par exemple de certaines caractéristiques de l'évolution dont on donnera quelques illustrations, lourdes de conséquences.

La figure 3 tente de représenter les plus influents de ces facteurs et processus. Il les classe dans deux ensembles principaux. Le premier regroupe les facteurs qu'on peut qualifier de facteurs de base et qu'on essayera de caractériser dans ce premier rapport. Dans le deuxième ensemble on trouve les facteurs et processus qu'on peut qualifier d'ajoutées. Ils sont essentiellement d'ordre anthropique (aménagements sur le rivage ou sur les pentes, types de cultures, techniques utilisées, contraintes sociales ou foncières, …) ou relèvent des modifications préconisées, pour l'avenir, au niveau de certains constituants de l'environnement naturel comme l'élévation du niveau marin. Les flèches sont utilisées pour révéler les principales interactions

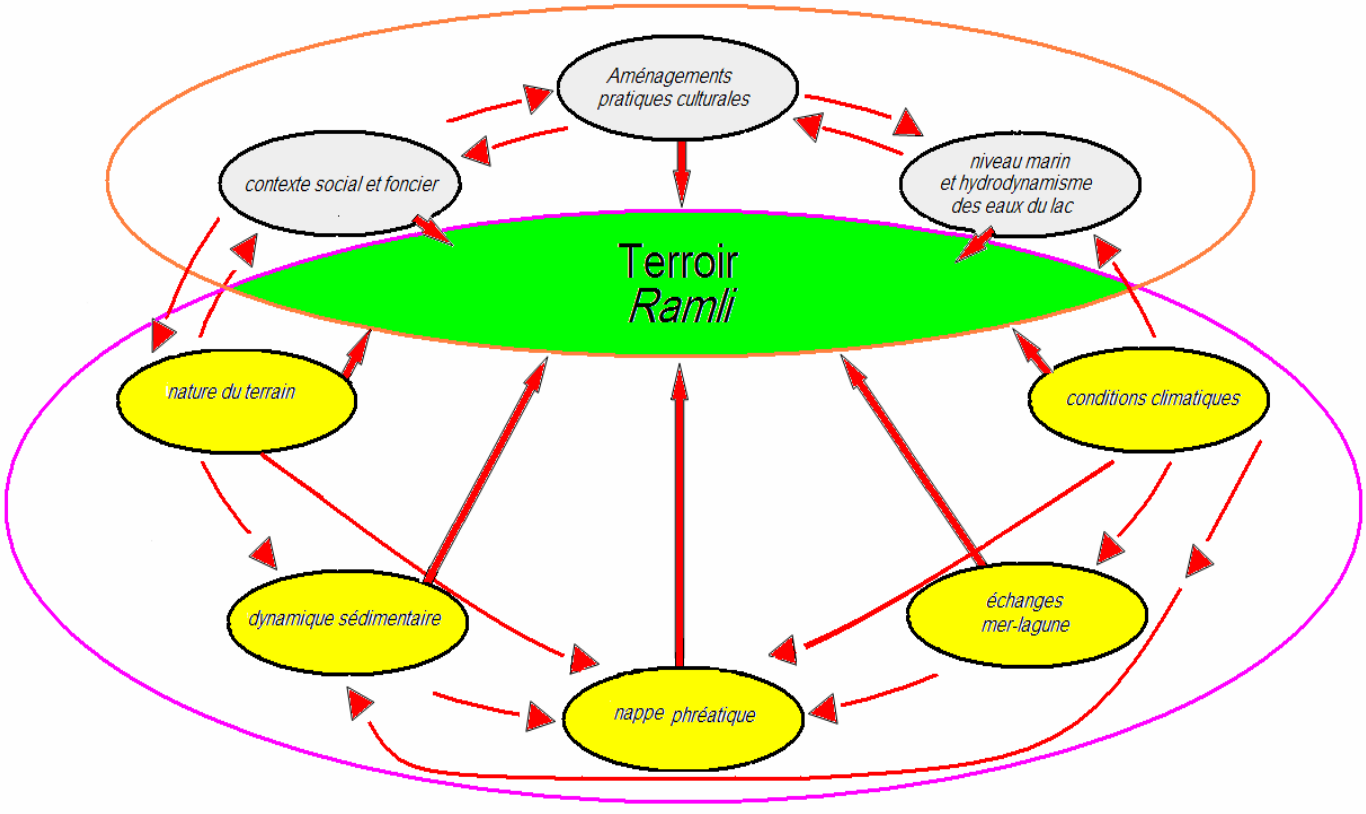


Fig. 3-Les facteurs en action dans le terroir *Ramli* :
influences et interactions

-Les facteurs naturels de base :

Au nombre de cinq, ces facteurs sont qualifiés ainsi parce qu'ils ont un rôle essentiel dans la formation et l'évolution des espaces exploités par la technique *Ramli*. D'un autre côté, ils occupent une place fondamentale dans la définition des aptitudes de ces espaces à la mise en valeur et dans les choix culturaux. Enfin, leur présence est indispensable à la pérennité de l'ensemble du système et leur dynamique occupe une place importante

dans son équilibre. En fait, les interactions qui les caractérisent ou qu'ils ont avec les autres facteurs sont variables.

-Les conditions climatiques ont des liens avec tous les autres facteurs en action. Outre leur importance dans le choix des cultures et les rendements, elles influencent la dynamique des paysages. Leur rôle est également essentiel dans l'évolution, l'alimentation et la régulation de la nappe phréatique exploitée dans les potagers. Une succession d'années sèches par exemple, peut être fatale pour ces derniers. Leur importance apparaît aussi à travers leur influence sur l'état de la mer et la dynamique d'échanges entre cette dernière et la lagune. Elle se dégage également de la dynamique des eaux courantes et de celle responsable de la mobilité des sédiments tant du côté continental que du côté maritime. Or, de telles dynamiques peuvent être, on en verra des illustrations, décisives pour le maintien, l'extension ou même la formation et la disparition des espaces exploités dans la culture *Ramli*.

-La nature du terrain intervient également à différents niveaux et a des liens avec, ou influence, la plupart des autres facteurs. Elle est importance d'abord dans ce sens où c'est elle, suite à l'agencement du relief et l'étroitesse de la bande littorale qui en résulte, qui a poussé les habitants à s'ingénier pour valoriser au maximum le peu de terrain utile sur le plan agricole, à maximiser l'exploitation de tout terrain peu accidenté et à inventer la technique *Ramli*. L'aménagement de parcelles de terres aux dépens de la lagune et des marécages qui la bordent n'est elle pas une forme d'adaptation aux contraintes du site et une réponse au manque de terres cultivables.
C'est aussi, des caractéristiques du cadre topographique et géologique que dépendent, dans une large mesure, la nature et la disponibilité du matériel utilisé pour remblayer les berges de la lagune et partant, les caractéristiques des sols artificiels. Ces mêmes données influencent la dynamique des eaux de surface qui, on le verra, joue un rôle parfois essentiel dans les apports détritiques qui constituent le corps de bien des parcelles de terres cultivées. Leur rôle est important aussi au niveau de la nappe phréatique. Les sources et puits qu'on rencontre ici et là au voisinage des berges de la lagune doivent leur formation à l'existence d'une nappe favorisée par la nature du substratum géologique (grès sur marnes pliocènes) et la couverture quaternaire (cône alluviaux et dunes).
En fait, l'effet de la nature du terrain apparaît à toutes les échelles. D'ailleurs, la réussite de la technique *Ramli* exige une attention au niveau de la topographie de détail et de la distribution du matériel travaillé. Dans le secteur d'*Edhrea* par exemple, l'épaisseur du sol artificiel varie en fonction de la position par rapport au plan d'eau et au pied du Jbel. Dans le cordon littoral actuel, le profil transversal ainsi que la morphologie de la dune bordière, son volume et sa positon par rapport au rivage de la mer et de la lagune semblent revêtir une grande importance. Nous avons constaté par exemple, que la surface du sol des potagers se trouve souvent à un

niveau topographique supérieur à celui dans les *G'tayas*. Il est d'autant plus haut que le cordon est étendu et que sa dune est épaisse et continue ; sans doute parce qu'on est dans une situation plus favorable à l'emmagasinage des eaux et plus exposée aux effets des variations de l'état de la mer.

-L'échange d'eau entre la mer et la lagune est l'une des conditions les plus importantes pour le bon fonctionnement du système *Ramli*. Ceci est particulièrement vrai dans la lagune de Sidi Ali El Mekki à cause de son extension limitée, de sa faible profondeur mais aussi parce qu'elle est plus facilement isolable de la mer. Or, c'est au contact de ce plan d'eau qu'on trouve la plus grande concentration de potagers. L'importance d'un tel échange se dégage par exemple, de la dure épreuve vécue par les cultures, au début des années 1990, suite à une réduction brusque de l'entrée des eaux marines dans la lagune. Ceci avait d'ailleurs imposé des aménagements au niveau de la route qui mène au port en vue d'agrandir la communication avec la lagune de Ghar El Melh.

-La dynamique sédimentaire est commandée par la nature du relief ainsi que par les éléments du climat et l'hydrologie marine et continentale. Elle est d'une grande importance pour la formation, l'évolution et l'équilibre des terres exploitées par le système *Ramli*.
C'est ce qu'on peut comprendre par exemple, de l'examen des potagers situés au droit des oueds qui découpent les pentes de Jbel Ennadhour. Dans bien des cas, ils sont aménagés à la faveur de la frange aval de cônes alluviaux formée par les matériaux les plus récents et qui continue à être alimentée en sédiments à l'occasion de certains écoulements. Mais c'est sans doute au niveau du cordon littoral et de la partie orientale de la berge nord de la lagune de Sidi Ali El Mekki qu'on trouve les illustrations les plus éloquentes.
Dans le cordon littoral, l'épaisseur et le profil transversal du cordon ainsi que la place qu'y occupent les constructions éoliennes, œuvre de l'action conjuguée des vagues et du vent, sont également importants. Le paysage des potagers (niveau du sol, type de cultures, …) ainsi que le volume de l'eau douce emmagasinée dans le sol et le niveau de la nappe en dépendent étroitement. Le transit sédimentaire joue un rôle fondamental et son dérèglement peut être lourd de conséquences. Ce qui s'est produit par exemple, à la suite de l'implantation du nouveau port de pêche est plein d'enseignements. En s'opposant à la libre circulation, par ses jetées, ce port a entraîné une érosion rapide du cordon littoral et de nombreuses parcelles de culture du côté sud-ouest. Du côté nord-est, une évolution opposée s'est produite. Le cordon littoral s'est développé favorisant la multiplication et l'extension des parcelles de culture dans un espace qui était jusque là très peu recherché pour les potagers !
De son côté, la partie orientale de la berge nord de la lagune de Sidi Ali El Mekki est le lieu d'une dynamique sédimentaire assez particulière. Une partie des terres à la faveur desquelles ont été aménagés les potagers

résultent d'une action simultanée du vent et des eaux courantes. Ces dernières font parvenir jusqu'au rivage les matériaux qu'elles arrachent aux pentes mais aussi le sable poussé par le vent depuis les dunes du versant nord (versant de Raf Raf) et qui arrive parfois à franchir la crête de Jbel Ennadhour.

Les interventions qui ont eu un impact sur la mobilité sédimentaire se trouvent également sur les pentes. Certains travaux ont parfois conduit à un dérèglement au niveau de l'alimentation sédimentaire du rivage de la mer et des berges de la lagune (fig. 4 et 5). C'est le cas notamment des travaux de reboisement qui ont sensiblement réduit les apports sableux, poussés par le vent puis le ruissellement, depuis les dunes du versant de Raf Raf. Or, de tels apports ont longtemps contribué au développement du cordon littoral et des terrains qui le bordent du côté interne et à la faveur desquels a été aménagée une partie des parcelles exploitées selon la technique *Ramli*. Cette réduction de l'alimentation sédimentaire a été accentuée au cours des dernières années par la multiplication des résidences secondaires. Celles-ci constituent un obstacle sur le chemin des sables qui continuent à dévaler le versant sud de Jbel Ennadhour mais sont en même temps menacées d'ensablement.

Certes, les travaux menés sur les pentes ont leurs justificatifs. Certains ont parfois eu des effets positifs, surtout en matière lutter contre l'érosion hydrique et éolienne ou en matière d'enrichissement du cortège floristique et au niveau paysager. Mais rien n'indique que la composante impact sur les parcelles de culture qui bordent la lagune ou qui ont été aménagées aux dépens du cordon littoral ait été considérée. C'est toute l'importance de l'approche par laquelle on intervient et la nécessité de considérer au maximum les différents composants du système.

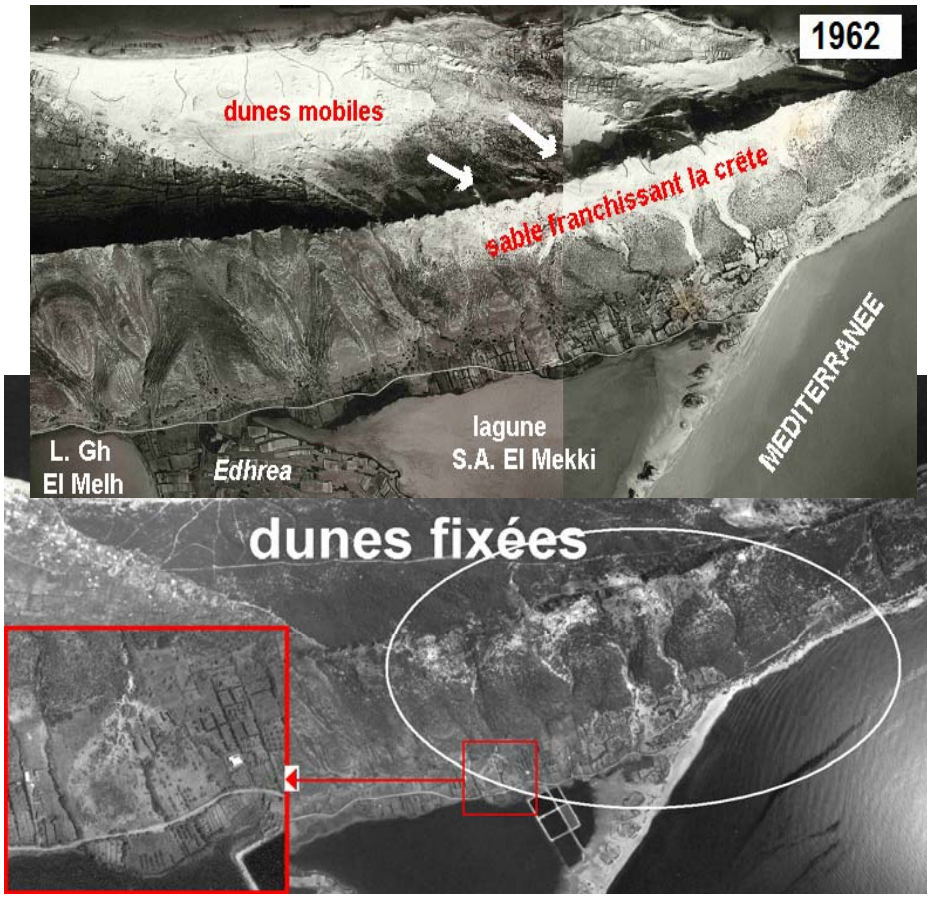


Fig. 4 et 5-Extraits des photos aérien-

nes de 1962 et de 1989. Sur le premier, antérieur aux travaux de fixation des dunes, on reconnaît l'importance des volumes sableux qui franchissent la crête pour être dirigés vers la racine du cordon littoral et la partie orientale de la berge nord de la lagune. Noter aussi l'importance des parcelles de culture au droit des langues de sable.
Sur le deuxième extrait, les dunes sont déjà largement végétalisées et la circulation du sable à travers la crête sensiblement réduite.
Dans l'encadré, on reconnaît un cône de déjection dont le front s'avance au détriment de la lagune ; c'est aux dépens de lui que s'est faite l'extension des parcelles *Ramli*. En fait, la formation de ce cône est en partie favorisée par le sable poussé depuis la crête.

-La nappe phréatique est une pièce clé dans le système *Ramli*. Mais elle constitue aussi l'élément le plus influençable par les autres facteurs. Son comportement et son équilibre dépendent de la nature des terrains qui bordent les parcelles de culture ainsi que des données hydrologiques et des échanges mer-lagune. Ils dépendent aussi des conditions climatiques, notamment la pluviométrie, du comportement de l'aquifère du piémont de Jbel Ennadhour et des caractéristiques (épaisseur, perméabilité, …) du sol mis en culture.

III- Une quantification des espaces exploités par la technique *Ramli* et de leur évolution

Ce ne sont là que des résultats préliminaires issus du travail, en cours, d'exploitation de cartes marines et topographiques, de photographies aériennes et d'images satellitaires de différentes dates (*cf.* tableau). La période couverte s'étend sur une soixantaine d'années et sur plus d'un siècle si on considère la carte marine la plus ancienne datant de 1887. L'objectif était d'avoir une idée sur la superficie des terres exploitées par la technique *Ramli* et surtout de dégager son évolution à travers le temps. Ceci doit aider à dégager les tendances que cet espace a pu connaître et, en même temps, à mieux préparer les questions nécessaires à la compréhension d'une telle évolution, dans l'optique d'une enquête socio professionnelle.

Ces documents ont été soumis à différents traitements utilisant des logiciels adaptés dont le détail est donné dans le tableau suivant :

Documents	Nom, date et échelle	Type de traitement
Cartes topographiques	*Carte marine du Cap Farina au Cap Carthage au 1/61750. et datée de 1887. *Carte topographique de Porto Farina au 1/50000 (type 1922). *Carte topographique de Ghar El Melh NE au 1/25000 (levée en 1974 et complétée en 1980).	*Correction géométrique par le logiciel de traitement d'image ENVI.

Photographies aériennes	* Mission 1948 (1/20000). * Mission 1962 (1/25000). * Mission 1974 (1/25000). * Mission 1989 (1/20000).	*Correction géométrique par le logiciel de traitement d'image ENVI. *Ces photos sont, par la suite, traitées par un logiciel de SIG, il s'agit d'ARC VIEW. Deux grandes étapes : -Une étape de numérisations des parcelles *Ramli*. -Une étape de superposition, en vue d'une cartographie de l'évolution.
Images satellitaires	*Image Spot : 1988 et 1989. *Image Spot de 2002. *Image Google du 26/10/2006.	Le même traitement que pour les photographies aériennes.

Les documents exploités et les types de traitements

Exprimées par des graphiques suivants, les superficies ont connu une tendance générale à la hausse puisqu'elles sont passées de 81,2ha en 1948 à 112,5ha[3] en 2006. La courbe générale montre toutefois un certain fléchissement entre 1962 et 1989 (fig. 6). Ceci pourrait s'expliquer, au moins en partie et surtout pour la période 1974-1989, par l'érosion du cordon littoral qui a suivi la construction du nouveau port de pêche.

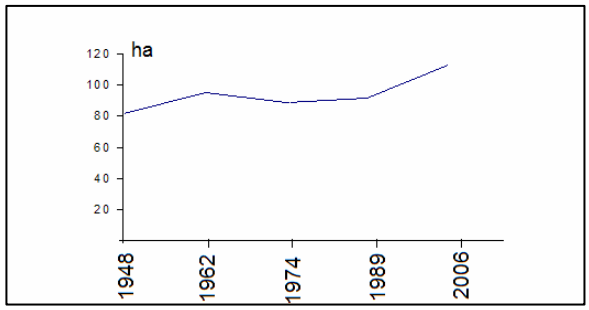


Fig. 6-Evolution de la superficie totale des parcelles

En fait, cette courbe générale cache des différences, parfois très importantes, entre les différents compartiments de l'espace exploité par la culture *Ramli*. L'analyse de ces derniers séparément, révèle mieux les tendances. C'est ainsi que :

-dans le secteur d'*Edhrea : à part une légère diminution en 1974, qu'on ne peut pas expliquer par la création du port, puisque ce dernier n'apparaît pas encore sur les photos de 1974, la tendance a été à la hausse (fig. 7). De 1948 jusqu'à nos jours, quelque 5,6ha[4] ont été gagnés.

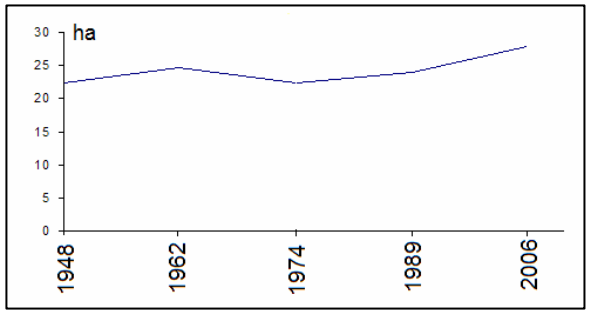


Fig. 7-Evolution de la superficie des parcelles dans le secteur d'*Edhrea*

[3] -valeur inférieure à celle (200ha) avancée par les représentants du Ministère de l'Agriculture à l'occasion de la réunion de Tunis (déc. 2006) parce que nous n'avons pas considéré tous les terrains exploités par la technique *Ramli*. Nous nous sommes limité au secteur situé autour de la lagune de Sidi Ali El Mekki et le cordon littoral.

[4] -Valeurs qui peuvent paraître faibles. En fait, elles sont d'une grande importance lorsqu'on sait que la superficie des propriétés se mesure souvent à l'are ou au nombre de kilos de pommes de terre qu'on peut y semer.

***-dans les îlots** (*G'tayas*), l'augmentation la plus nette a été enregistrée à partir de 1974 permettant un gain de 7,4ha (fig.8). Là aussi, on est dans un espace situé à l'écart du port et les éléments d'explication doivent être cherchés ailleurs.

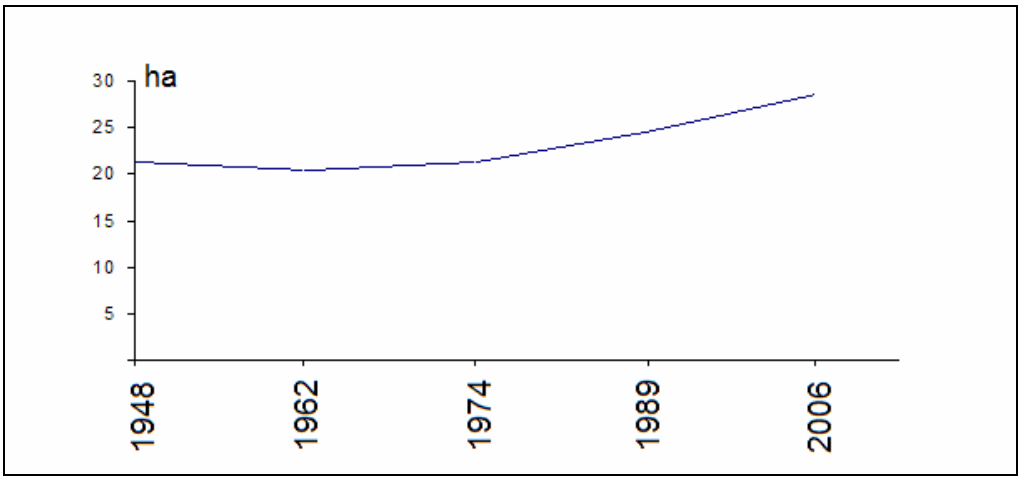


Fig. 8-Evolution de la superficie des parcelles dans le secteur des îlots

***-dans la berge nord de la lagune**, ont été gagnés quelque 7 à 8ha depuis 1948. Mais l'évolution a été plus irrégulière que dans les secteurs précédents, avec, deux pointes en 1989 et surtout en 1962 (fig. 9) qu'il faudrait essayer d'expliquer par des enquêtes directes.

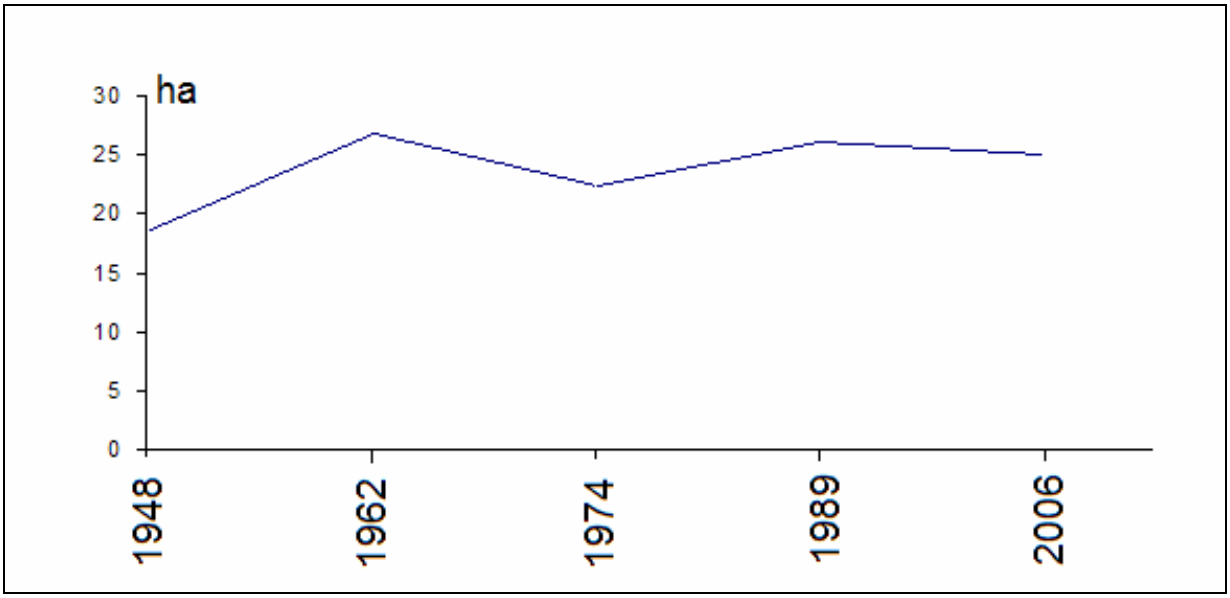


Fig. 9-Evolution de la superficie des parcelles dans la berge nord de la lagune de Sidi Ali El Mekki

***-dans le cordon littoral** a été enregistrée l'évolution la plus importante. En considérant l'ensemble de ce cordon, la tendance générale a été vers la diminution des superficies qui sont passées de 19.2ha en 1948 à 31.3ha aujourd'hui. Mais une augmentation a été enregistrée après la création du port.

En fait, les choses deviennent plus claires lorsqu'on examine, indépendamment, les secteurs situés de part et d'autre du port (fig. 10 et 11). Du

côté sud-ouest, les superficies n'ont cessé de reculer. La diminution la plus importante a été enregistrée après 1974, date de création du port, et surtout après 1989. Le recul a été de l'ordre de 94%. Du côté nord-est, une évolution opposée s'est produite ; les superficies ont augmenté de presque 43%.

Une telle évolution s'explique par les modifications enregistrées au niveau du cordon littoral lui-même qui a connu, suite au dérèglement du transit littoral par les structures du port et les épis créés plus tard, une extension importante au Nord-Est et une érosion au Sud Ouest. Mais d'autres éléments d'explication doivent être cherchés dans le comportement de la population. Car, avant 1974 c'est la partie du cordon située au Sud Ouest du site du port qui était la plus recherchée pour les cultures *Ramli*. En 1962 par exemple, la partie nord-est du cordon était presque sans parcelles de culture *Ramli* (fig. 12 et 13). Des réponses à ce changement dans la perception du terrain et son occupation doivent être cherchées par des enquêtes auprès des propriétaires et de certains autres stakeholders.

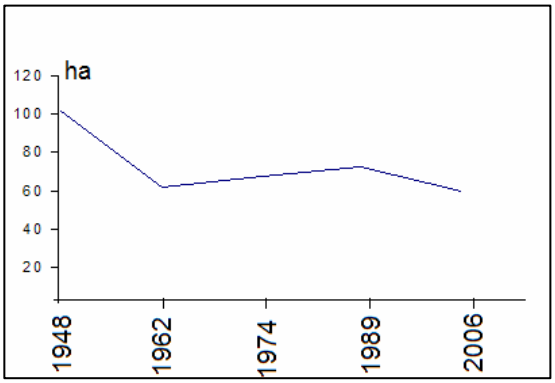
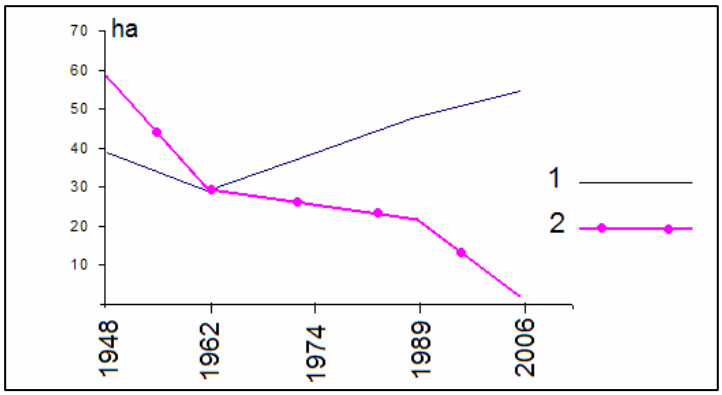


Fig. 10-Evolution des superficies totales des parcelles *Ramli* dans le cordon littoral

Fig. 11-Evolution de la superficie des parcelles selon la position par rapport au site du port

1-au Nord-Est du port ; 2-au Sud-Ouest du port



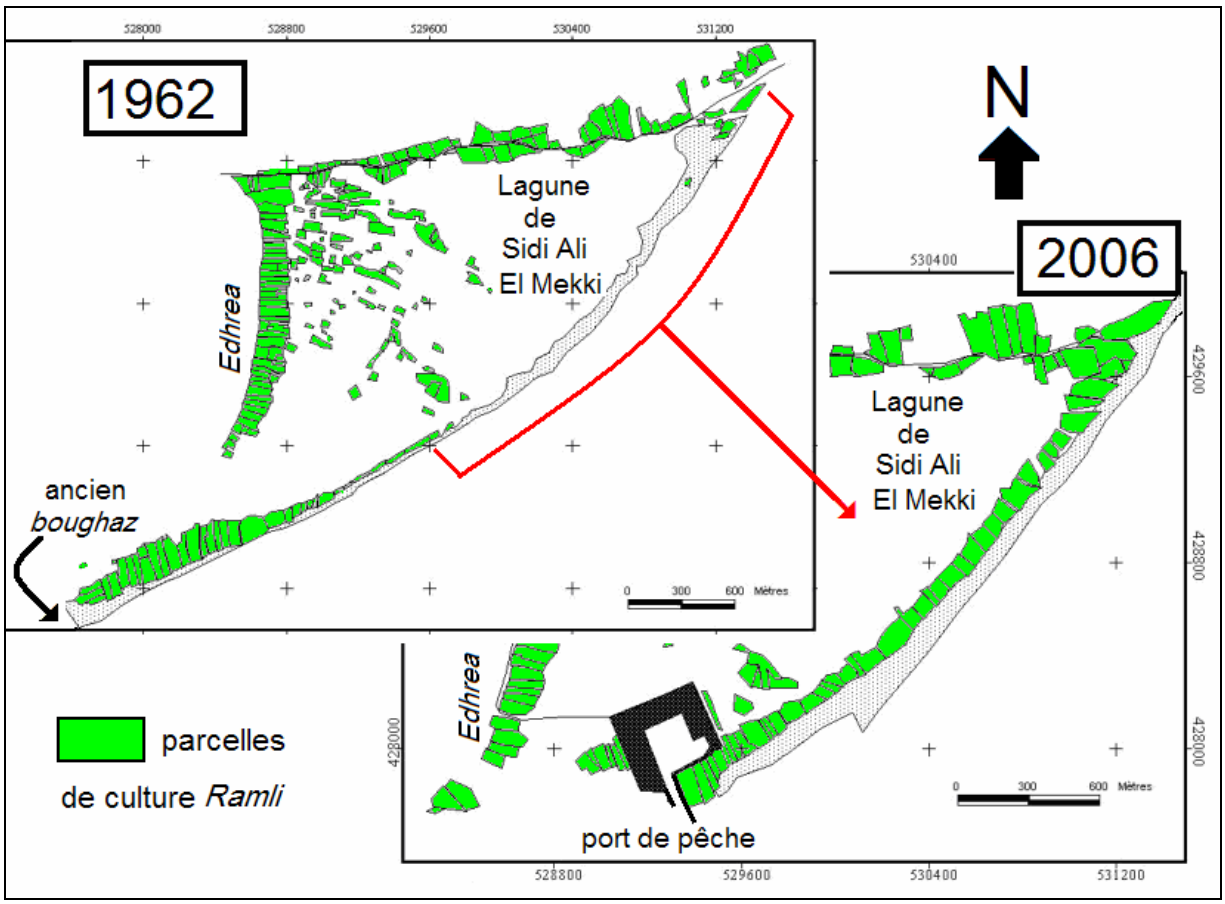


Fig. 12-L'extension des parcelles de culture *Ramli*

dans la partie nord-est du cordon littoral. Avant la création du port, les parcelles étaient concentrées dans la partie sud-ouest. Après la construction du port, la partie nord-est qui était presque désertée a accueilli un grand nombre de parcelles. Des réponses sont à chercher, par des enquêtes directes, quant au statut foncier, les propriétaires, le DPM, …

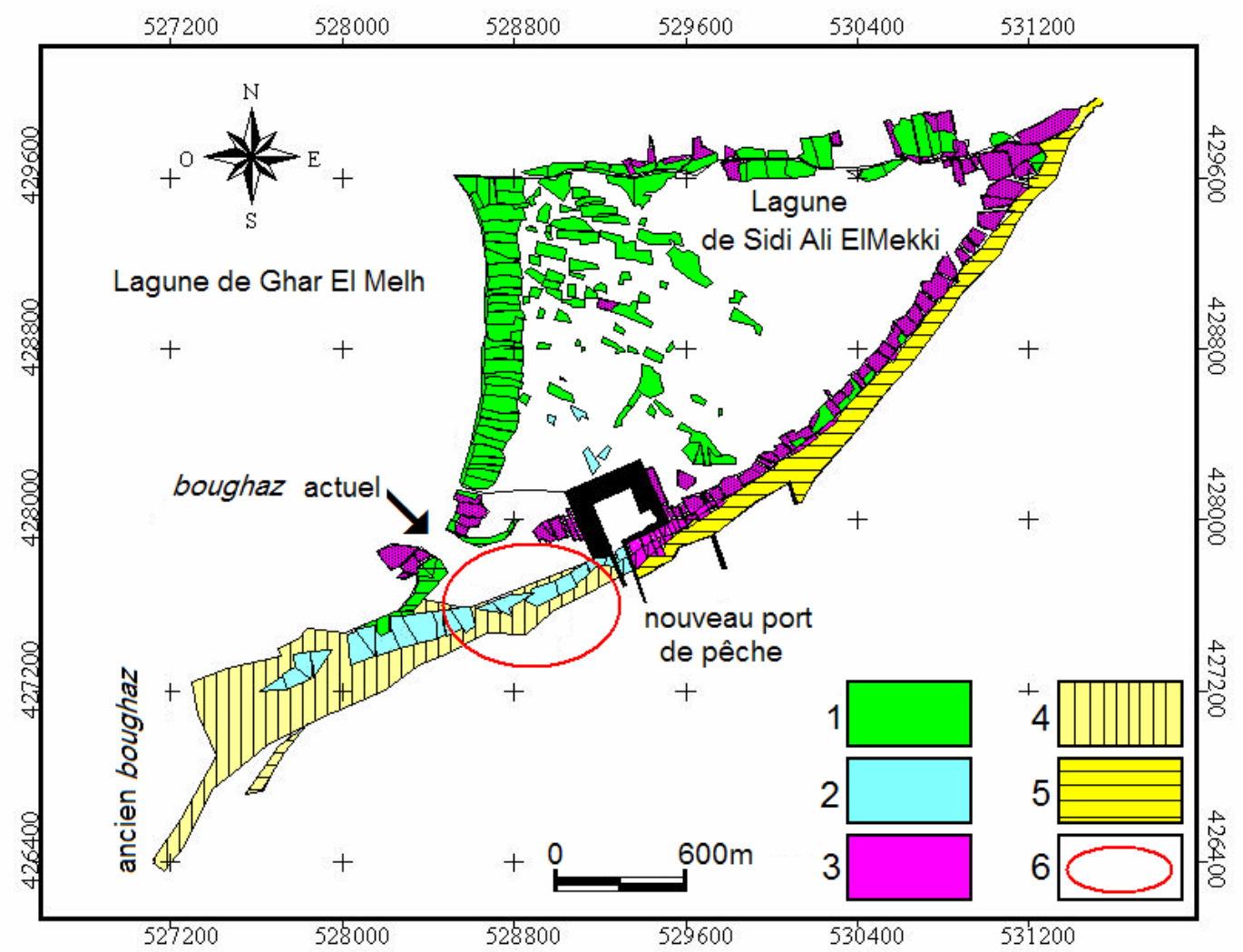


Fig. 13-Evolution des espaces exploitées par la technique *Ramli* au cours des quarante cinq dernières années (1962-2006) 1-parcelles existantes en 1962 et aujourd'hui ; 2-existantes en 1962 et disparues aujourd'hui ; 3-parcelles actuelles inexistantes en 1962 ; 4-cordon littoral en démaigrissement ; 5-cordon littoral en engraissement ; 6-partie du cordon littoral totalement érodée.

IV-Préparer une importante enquête socio-économique

En fait, le travail réalisé jusqu'ici s'inscrit plus dans une tentative de diagnostic de la situation, par l'observation directe du terrain et l'exploitation de la documentation disponible, sans contacts avec les intervenants dans le système. C'est, à notre avis, une étape indispensable et qui doit mieux préparer aux contacts avec les différents stakeholders. Elle permet, tout au long de l'effort d'observation et d'essai de compréhension de ce qui se passe sur le terrain, par l'effort du chercheur isolé, l'émersion de questionnements qui aideront à mieux se préparer pour comprendre les attentes et les interventions des intéressés, à mieux meubler les questionnaires dans une perspective d'enquêtes socio-économiques et à mieux proposer pour l'avenir.
Il se dégage déjà et assez clairement que :

***-**Le terroir *Ramli* est né dans un environnement marqué par l'intervention de plusieurs facteurs et de processus qui agissent, parfois, dans des interactions serrées compte tenu de l'exiguïté du terrain ; le tout constitue un système complexe, déjà au niveau naturel. Toute modification dans les caractéristiques de ces facteurs et processus pourrait générer des problèmes dans le fonctionnement et l'équilibre du terroir. La complexité de la situation sera sans doute mieux révélée lorsqu'on abordera le côté humain.

Quoi qu'il en soit ce terroir est aujourd'hui l'un des constituants d'un tel système. Mais c'est un constituant qui subit et qui est de ce fait d'une grande sensibilité. Les interventions, pour l'exploitation ou même celles qui visent la protection et la valorisation, doivent partir d'une connaissance approfondie de ses exigences ainsi que de celles des différents facteurs en action. Son équilibre et sa durabilité dépendent de la qualité d'une telle connaissance.

Cette sensibilité s'est révélée à différentes reprises. Nos premières investigations de terrain indiquent que des aménagements ont été parfois réalisés sans, apparemment, considération du jeu d'interactions et des exigences précités ou qui n'ont considéré que les données nécessaires à la réussite de l'intervention entreprise. Si bien que, même des travaux qui, théoriquement, sont considérées comme d'un grand intérêt environnemental ou économique ont conduit à différents dérèglements et parfois à des situations menaçantes, voire même catastrophiques, dans certains cas, notamment pour les espaces exploités par la technique *Ramli*.

***-**certains éléments naturels ne sont pas encore suffisamment bien connus et caractérisés et appellent davantage de réflexion. Nous pensons par exemple, à la nappe phréatique et aux mécanismes qui la régissent. Nous pensons aussi à la sensibilité du système *Ramli* aux éventuelles modifications hydrodynamiques dans la lagune (suite par exemple, à des variations au niveau des échanges avec la mer) ou à une éventuelle variation dans le niveau marin.

***-**bien des questions sont à expliquer par des facteurs humains et qu'une (ou des) enquête (s) socio-économique (s) s'imposent.

En fait, nous pensons qu'il faut deux types de questionnaires, l'un orienté aux paysans qui travaillent dans les parcelles *Ramli* ou qui en sont propriétaires et l'autre orienté aux responsables locaux ou régionaux et surtout aux structures menant des actions auprès des paysans ou qui agissent dans le domaine de l'environnement et du patrimoine comme le CRDA, les ONG, …

Aussi, nous proposons, qu'à la lumière de ce qui précède, les questionnaires soient structurés autour d'une dizaine de rubriques principales formées, chacune, de questions ayant pour objectifs de mieux connaître ou d'avoir des éclairages significatifs sur :

***-**les caractéristiques démographiques et sociales de la population directement impliquée dans le système *Ramli*,

***-**la culture *Ramli* telle qu'elle est pratiquée aujourd'hui: techniques utilisées, exigences au niveau du type et de la qualité du terrain, types de cultures et critères de leur définition, fertilisants, comportement par rapport à la nappe d'eau douce, différences en fonction des secteurs (îlots, cordon littoral, …), …
***-**l'extension et la répartition spatiale des parcelles de culture : conditions, préférences pour la localisation, évolution dans le temps, explication de certaines modifications (superficies, sites, types de cultures, …) comme dans le cordon littoral, … ;
***-**la structure foncière et le statut juridique des terres exploitées par la technique *Ramli* et position par rapport à la loi (D.P.M, D.P.H., …),
***-**l'importance économique du terroir *Ramli* aux niveaux familial, local et régional (emploi, production, rendements, revenus, place dans le revenu familial, …),
***-**la sensibilité de la technique *Ramli* aux aléas naturels et à l'évolution sociale et démographique: accidents survenus dans le passé (au moins les plus mémorables : séries d'années sèches, tempêtes marines,…), évolution du niveau de vie de la population, impacts de l'évolution des autres secteurs économiques (pêche, tourisme,…), scolarisation, émigration, main d'œuvre, …
***-**les principaux problèmes et contraintes rencontrés par les paysans,
***-**la perception, par les paysans et les autres stakeholders, des effets des aménagements déjà existants et la position par rapport aux aménagements en cours ou programmés,
***-**la perception, par les paysans et les autres stakeholders, du milieu naturel dans ses rapports avec les cultures pratiquées : aujourd'hui et par rapport aux risques de l'avenir,
***-**la perception, par les paysans et les autres stakeholders, de la valeur patrimoniale du système *Ramli*, (histoire, caractère unique, valeur de terroir,…),
***-**l'attachement à la terre et au terroir et le sentiment quant à l'avenir de ce dernier: les recommandations pour l'actuel et les actions à envisager pour l'avenir.

6th WADI International Meeting

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The Mondego estuary case-study.

THE MONDEGO ESTUARY: ENVIRONMENTAL QUALITY, MANAGEMENT, AND EVOLUTIVE SCENARIOS.

1. GENERAL INTRODUCTION

The Mondego begins in the "Estrela" range of mountains and extends along 227 Km, draining a hydrological basin of approximately 6670 Km^2, the largest one entirely comprised in Portuguese territory (Figure 1).

The main tributaries of the Mondego are the rivers Dão, Ançã and Foja, in the right margin, and the rivers Alva, Ceira, Cernache, Ega, Arunca, and Pranto, in the left margin, the Pranto River converging with the Mondego already in the estuarine area. The Mondego valley is considerably deep upstream from Coimbra, but spreads downstream from this town to form a vast alluvial plain, the Lower Mondego Region, which consists of 15 000 hectares of good agricultural land.

The Mondego river basin plays an important role regarding the activities and day-by-day life of more than half a million people. Nevertheless, in the early sixties, the basin was still sub-utilised. From 1962, the "Direcção Geral de Recursos e Aproveitamentos Hidráulicos", as it was called at that time, prepared a hydro-agricultural plan aiming to improve the use of the basin water resources. The main objectives were to control the river flow, regarding the water and sediments, provide water to populations, industries, and agriculture, and produce electric power.

As a whole, this plan was only partially accomplished, but we shall not utter here any opinion concerning the plan it self or its execution. Nevertheless, floods control was made possible through river regularisation and by the construction of several dams ("Aguieira", "Raiva" and "Açude de Coimbra", in the Mondego, and "Fronhas", in the Alva river), which had doubtless a considerable environmental impact, namely in the Mondego hydrological regimen.

The Lower Mondego river valley, at the present, consists essentially of agricultural land where the main production is rice (60% of the valley). Other significant productions are corn and beans (18.1% of the area). Non-cultivated areas, such as swamps, are usually located in the perimeter of the valley and exhibit a flourishing fauna and flora. Drainage channels, which are widespread across the whole valley, also constitute a biological reservoir.

The drainage from all this area obviously contributes with an important discharge of nutrients and several chemical compounds into the Mondego estuary, located in the western coast of Portugal. Besides, the estuary it self constitutes an important system to support human activities, correspond to a considerable concentration of people and goods. Actually, the estuary is the location of a mercantile harbour, "Figueira da Foz", which has considerable regional importance, namely regarding the export of wood pulp for paper production. Urban waste waters are still let out into the Mondego with deficient treatment, and besides the harbour facilities, the estuary supports industrial activities, salt-works, and

aquaculture farms. Additionally, the city of “Figueira da Foz” constitutes an important centre for tourism activities, which implies a seasonal increase of the human pressure on the system.

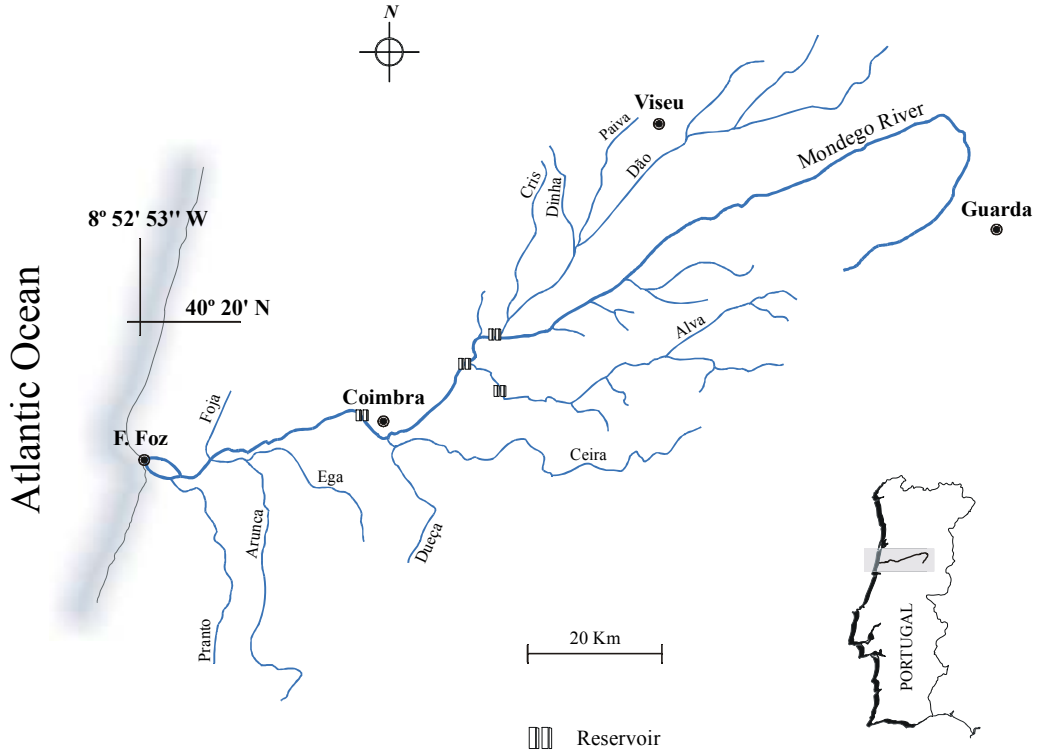

Figure 1: The Mondego river hydrological basin.

2. ESTUARY HYDROGRAPHICAL AND ECOLOGICAL CONDITIONS

The Mondego estuary is located in a warm temperate region with a basic Mediterranean temperate climate. It consists of two arms, North and South (Figure 2) separated by an island. The two arms become separated in the estuarine upstream area, at about 7 Km from the sea, and join again near the mouth. These two arms of the estuary present very different hydrographic characteristics. The North arm is deeper (5 to 10 m during high tide, tidal range about 2 to 3 m), while the South arm (2 to 4 m deep, during high tide) was, until a year ago (May 2006), almost silted up in the upstream areas, which caused the freshwater of the river to flow essentially by the North arm. The water circulation in the South arm was then mostly due to tides and to the relatively small fresh water input of a tributary, the Pranto River, which is artificially controlled by a sluice, located at 3 km from the confluence with the South arm of the estuary. In addition, due to differences in depth, the penetration of the tide is faster in the North arm, causing daily changes in salinity to be much stronger, whereas daily temperature changes are higher in the South arm.

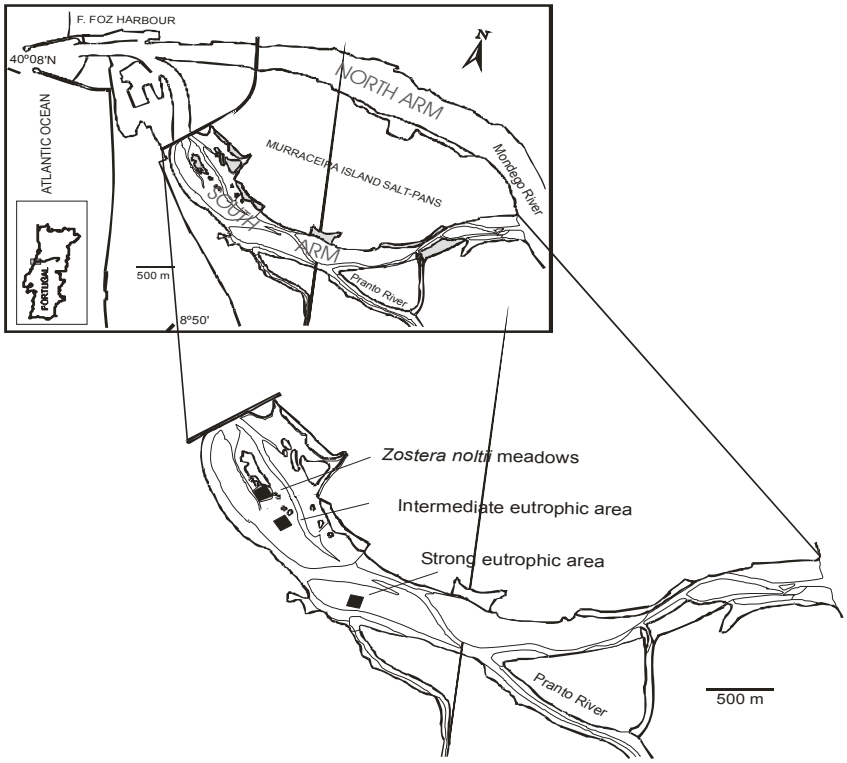

Figure 2: The Mondego consists of two arms, North and South separated by an island. The water circulation in the South arm has been up to recently mostly due to tides and to the relatively small fresh water input of a tributary, the Pranto River, which is artificially controlled by a sluice, located at 3 km from the confluence with the South arm of the estuary. Seasonal intertidal macroalgae blooms (mainly of *Ulva* spp.) used to be reported in the South arm of the estuary since the early 1990s, and three areas were defined along the eutrophication gradient: a) Non eutrophic (*Zostera noltii* meadows); b) Intermediate eutrophic (roots of *Zostera* still present, moderate *Ulva* blooms; c) Strongly eutrophic (total absence of *Zostera* and strong *Ulva* blooms).

Eutrophication is increasing in most estuaries all over the world, probably as a result of excessive nutrient release into coastal waters, and the Mondego estuary is no exception. Up to recently, seasonal intertidal macroalgae blooms (mainly of *Ulva* spp.) have been reported in the South arm of the estuary for several years. As a pattern, although there is a clear inter-annual variation as a function of hydrological conditions, *Ulva spp*. biomass used to increase from early winter (February/March) up to July, when an algae crash usually occurred. A second but much less important algae biomass peak could normally be observed in September followed by a decrease up to the winter.

The *Zostera noltii* beds, which represent the richest habitat with regard to productivity and biodiversity, have been drastically reduced in the south arm of the Mondego estuary since the early 1990s, presumably as a function of competition with *Ulva*, resulting from the different strategies of macroalgae and macrophytes to uptake nutrients. Such shift in the benthic primary producers due to eutrophication affected the structure and functioning of the communities, including the species composition, and through time such modifications tended to determine a selected new trophic structure (Figures 3, and 4).

The ongoing process as been studied in detail since the early 1990s, and a large amount of information is available in the literature.

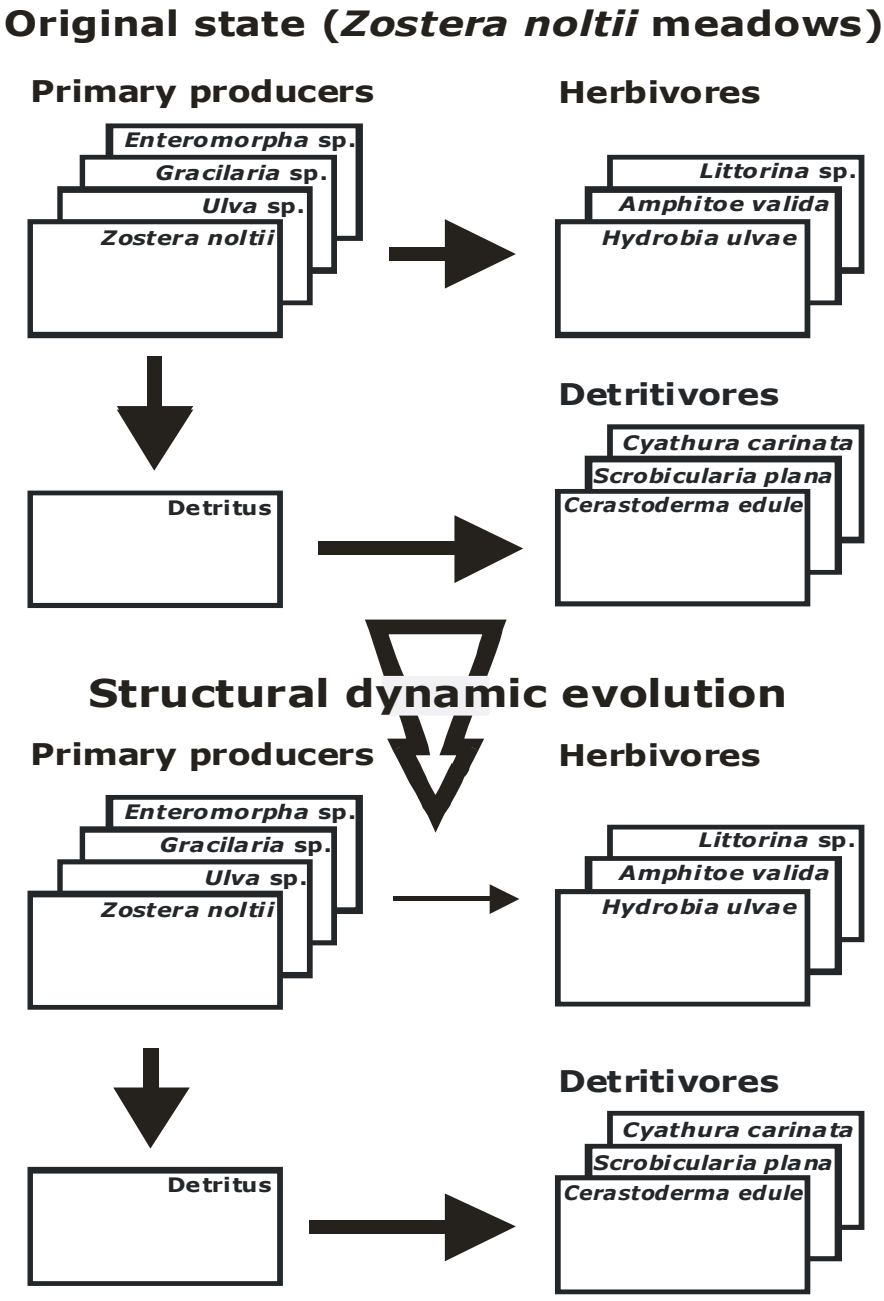

Figure 3: Structural changes in the trophic network in the South arm of the Mondego estuary as a function of the shift in primary producers induced by eutrophication. A – Situation at the *Zostera noltii* beds, at the non eutrophied area, assumed to represent the original state of the system; B – Situation at the most eutrophic area, where macroalgae blooms take place, assumed to represent the new state of the system. Boxes represent species or species aggregations according to their function in the trophic network. White boxes represent the dominant species in each situation, and dark boxes represent species poorly represented. Arrows represent matter fluxes. The width of the arrows reflects the relative importance of the path.

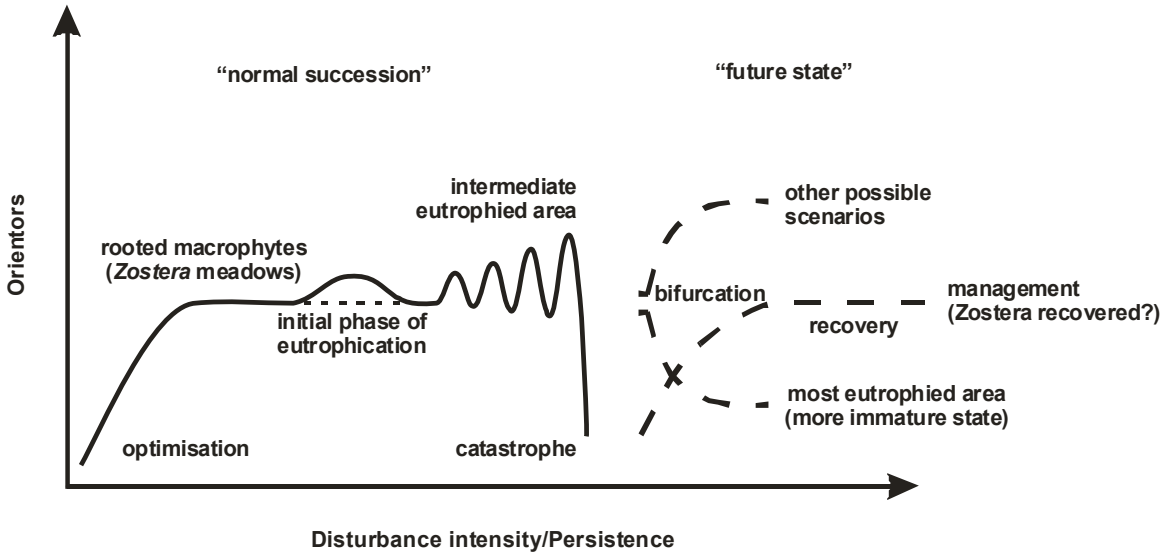

Figure 4: Orientors (e.g. many of the ecological indicators referred in the literature) development during stress. Possible interpretation of changes ongoing in the Mondego estuary in the framework of ecological theory.

3. MANAGEMENT AND EVOLUTIVE SCENARIOS

The application of a comprehensive scientific approach to the Mondego estuary ecosystem made possible a good understanding of its characteristics and functioning. Such knowledge allowed proposing a set of management steps aiming at reducing the anthropogenic effects on the system, which changed the previous prevailing conditions, and at establishing plans to restore its environmental quality. As so, an assessment of the environmental quality was conducted in order to evaluate the impacts of the re-connection between the two estuarine arms, being the study divided in: before the interruption, during the interruption and after the experimental opening.

Such study on the Mondego estuary environmental quality has been carried out over a period of more than two decades, covering the system's most important quality elements: water quality, hydraulics and sediments dynamics, plankton communities (phyto, zoo, and ichtyoplankton), the term evolution of the benthic communities (both intertidal and subtidal), and finally the changes in macrophytes' beds (*Zostera noltii*) and green macroalgae distribution as a function of morphological alterations observed in the estuary over the years.

3.1. WATER QUALITY

Regarding water quality, it was found that the temperature, salinity and dissolved oxygen did not exhibit significant interannual changes over the study period, showing, normal seasonal variation for the intertidal and subtidal areas.

The nitrite and nitrate measured in intertidal water samples showed no differences between the "during the interruption" and "after the experimental opening" periods. The ammonia-nitrogen exhibited behaviour quite distinct from the other compounds, decreasing considerably "after the experimental opening" and no longer exhibiting seasonal fluctuations as marked as those observed for the "during the

interruption" period. In the subtidal zone, nitrite values remained similar throughout the study period, and the nitrate level generally increased "after the experimental opening". The ammonia concentration was always higher in the more inland parts of the system, showing that its source was upstream and that the Pranto is probably one of the gateways for the entry of this compound into the south arm. The winter values were always higher because of the stronger flow of the river and is course along the Lower Mondego Valley.

In the intertidal zones of the south arm, phosphorus tended to increase in the period "after the experimental opening". In the subtidal zone, the highest values were found "during the interruption".

In the intertidal zone, the levels of organic material in the sediment (MO) were always higher in the banks of *Zostera noltii*, throughout the study period (before the interruption, during the interruption and after the experimental opening). For the subtidal area, the parts of the system further inland had the highest MO content. The findings indicate the "during works" period as having the highest MO values.

According to the classification criteria defined by the EEA for the nitrogen compounds (NO_2 + NO_3), using the most comprehensive time series (subtidal, bottom water, spring), it was found that there was a worsening of the water quality "during the interruption" and a recovery "after the experimental opening". For phosphate, the results of the EEA classification indicate that there is no clear seasonal pattern and that the zones further inland (Pranto and USA) have lower classifications. In the "during the interruption" period, all zones exhibited extremely high values of this nutrient in all seasons, leading to a classification of Bad. These data suggest that, in this year, the work that brought about the interruption of the connection between the two channels led to considerable worsening of the state of water quality in the study area.

3. 2. EVOLUTION OF THE MACROPHYTE AND GREEN MACROALGAL COVER

Analysis of the photographic records taken over time shows the evolution of the works carried out on the estuary, along with the dynamic of the plant cover in the south arm. It was thus found that, for the "after the interruption" period, the opening at the head of the south arm was over 40 m wide (in 1958 and 1977), and that values for the *Zostera noltii* cover were in the region of 15 ha (in 1986). In the "during the interruption" period, which culminated in the complete closure of communication between the two arms of the river, there were high productions of green macroalgae (415 g m^{-2} in 1993), at the same time as the macrophyte cover decreased (0.02 ha in 1997). From 1997, when a channel was opened in the rock-fill of the left bank of the north arm, the macroalgae biomass fell (4.8-12.6 g m^{-2}) and the *Z. noltii* cover began to recover the area it had lost earlier. In 2004, the banks of *Z. noltii* occupied an area of about 3.3 ha (Figure 5).

Analysis of the photographic records taken over time shows the evolution of the works carried out on the estuary, along with the dynamic of the plant cover in the south arm. Figure 5 shows that "after the

interruption" the channel at the entrance of the south arm is over 40 m wide (in 1958 and 1977), and that values for the *Zostera noltii* cover were in the region of 15 ha (in 1986). "During the interruption" there was high production of green macroalgae (415 g m^{-2} in 1993), at the same time as the macrophyte cover decreased (1.6 ha in 1993). When a channel was opened in the rock-fill of the left bank of the north arm, in 1997, to re-establish the link between the arms, the macroalgae biomass fell (3.47 g m^{-2} in 1996) and the *Zostera noltii* cover reached its lowest value (0.02 ha in 1997). The green macroalgae never again reached biomass levels like those recorded in the "during the interruption" period, and the *Zostera noltii* began to recover the area it had previously lost. In 2004, the banks of *Z. noltii* occupied an area of about 3.3 ha.

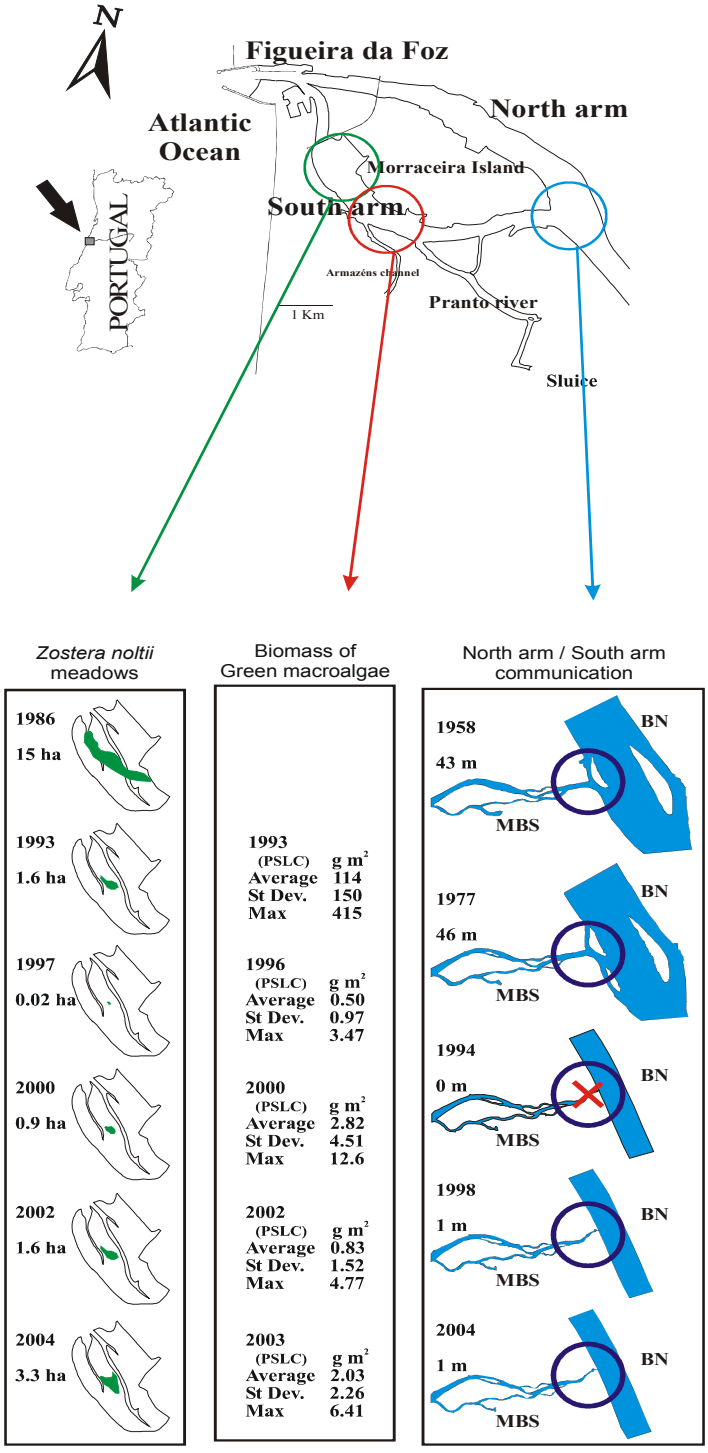

Figure 5. Fluctuation over time of plant cover area (*Zostera noltii*), green macroalgae biomass and width of connection channel between the two arms of the estuary.

It is known that increased turbidity and nutrients is prejudicial to plants with roots (*Zostera noltii*), which, as they are fixed, cannot adapt to sudden changes in their conditions (e.g. intensity of light). However, these conditions do favour the growth of green macroalgae which, being more opportunistic, manage to develop and occupy considerable portions of the existing space. Furthermore, it was found that the green macroalgae competed for the same intertidal space occupied by *Zostera*, over lying them and preventing the macrophytes from carrying out their photosynthesis functions efficiently, increasing their mortality.

With the experimental opening, even though it was only small (compared with the initial 40 m), water could then enter through the top of the south arm, which led to a reduction in the system's residence time. This change, plus the other experimental management measures put into place in the middle of 1998 (i.e. reducing the discharge of water through the Pranto floodgate) affected the production of macroalgae and allowed the *Z. noltii* cover to begin to recover (Figure 5) (Neto, 2004). Information that has recently become available about the area occupied by the *Zostera noltii* macrophyte in the south arm of the estuary has shown that it has increased since the last records from 2004, from around 3.3 ha to cover 4.8 ha in 2006.

In the “during the interruption" period there was an initial increase in turbidity and in the nutrient concentrations available for the primary producers, and, finally, an increase in the residence time in the south arm (due to the reduced flow upstream). These were the factors favouring the appearance of opportunistic green macroalgal blooms and the gradual elimination of the macrophytes (adapting more slowly to the environmental changes). There was also direct competition between the green macroalgae for the same intertidal space occupied by *Zostera*. The overlaying of the macrophytes by the green algae made it impossible for them to efficiently carry out their function of photosynthesis, increasing mortality in the *Zostera* banks.

With the experimental opening, water could then enter through the top of the south arm, which led to a reduction in the system's residence time. This change, plus the other experimental management measures put into place in 1997/1998 (i.e. reducing the discharge of water through the Pranto sluice) affected the production of macroalgae and allowed the *Z. noltii* cover to begin to recover (Neto, 2004).

3.3. ECOLOGICAL QUALITY BASED ON BENTHIC MACROINVERTEBRATES

As was anticipated, the *Zostera noltii* meadows had significantly higher values for total abundance, biomass, number of species and Margalef index than the eutrophic area, indicating better ecological conditions than in the eutrophic area. The values for the Shannon-Wiener index were significantly higher in the eutrophic area thanks to the undisputed dominance of the gastropod *Hydrobia ulvae* in the *Zostera noltii* community (it accounts for practically 90% of the total density).

In both the sampling zones the results of the ANOSIM analysis show significant differences (p<0.1%) between the three time periods. In spite of the recovery, it was noted that the communities have still not achieved a structure similar to that “before the interruption”.

No such marked difference was found over the time period in the subtidal region. Analysing the total abundance of individuals in the subtidal area of the estuary, in general the communities in the south arm zones (Downstream South Arm, Upstream South Arm) and Pranto exhibited higher densities than those in the north arm (Mouth and North Arm). The Upstream South Arm zone was usually the one to show the greater abundance, as opposed to the North Arm zone, which almost always exhibited lower densities, during the study period. The zone that exhibited the greatest number of species was the Mouth, whereas the furthest inland zone of the south arm of the estuary (Pranto) was the poorest, with the lowest average number of species over the study period. It is likely that the factors determining the ordering of the subtidal macrobenthonic community samples are parameters for determining spatial differences (e.g. salinity and sediment granulometry), and not temporal differences. Bearing in mind that the available subtidal data do not exhibit a very frequent sampling, and do not always coincide with the interventions in the estuary, it is hard, with this data series, to monitor some of the temporal effects of the interventions on the subtidal communities.

In spite of this, the WFD methodology for assessing the ecological quality on the basis of benthic macroinvertebrates, when applied to this data series for the Mondego subtidal zone, detects improvements in the system between the periods before and after intervention in the estuary (Table 1). In 1990 and 1992, before the experimental mitigation measures and when there were evident signs of eutrophication in the south arm, the results indicate a worse status for these communities. The data from 2003, on the other hand, after the interventions, show an improvement in the quality status to the Good category.

Table 1. Evolution of the ecological status in the Mondego estuary from 19990 to 2006, according to the WFD classification, in the five study zones (Orange:Poor, Yellow: Moderate, Green: Good).

	Zones	1990	1992	1998	2000	2002	2003	2004	2005	2006
WINTER	M	M	P				P	G	G	G
	NA	P	M				P	G	G	G
	DSA	M	G				M	G	G	G
	USA	M	G				M	M	G	G
	P	M	P				G	G	G	G

	Zones	1990	1992	1998	2000	2002	2003	2004	2005	2006
SPRING	M	M	M	G	G	G	M	G	G	
	NA	G	M	G	M	G	M	G	G	
	DSA	G	G	P	G	M	M	M	G	
	USA	M	G	M	G	G	G	G	G	
	P	G	M	M	M	G	M	M	G	

3.4. IMPLEMENTATION OF ENVIRONMENTAL QUALITY PROGRAMME OF GOALS - EUTROPHICATION (ECOQOS-EUTRO-OSPAR)

Although various gaps have been detected, the analysis of the parameters considered in the OSPAR COMPP does reveal some trends and allow relevant conclusions to be drawn in support of the decision taken about what management strategy to follow for the Mondego estuary.

Under the application of the OSPAR COMPP, in 2002, the Mondego estuary has been classified as a potential problem area (PPA) (INAG/MARETEC, 2002; Marques *et al*., 2004).

In this study, for the 2003 to 2005 period, the classification first obtained was of a non-problem area (NPA), since the system showed improvement. But despite the improvement in the environmental quality of the system due to the experimental mitigation measures implemented in 1997, it was decided to make a final classification of ***potential problem area*** since the measures taken were insufficient to solve the eutrophication that affected the south arm of the system (particularly in relation to Category I - Degree of nutrient enrichment). It should be noted that the partial re-establishment of the communication between the two arms upstream and the diversion of the freshwater discharge from the River Pranto led to a reduction in the eutrophication symptoms. However, the discharge from the River Pranto was only diverted to the north arm (through another sluice, further upstream). So these measures have not helped to reduce the oxidised forms of nitrogen and phosphate, and so the input of nutrients into the system remains high.

The OSPAR COMPP, however, permits a global assessment, considering nutrients, chlorophyll *a* concentrations, phytoplankton-indicating species, macrophytes, degree of oxygen deficiency, changes and kills in zoobenthos, etc., thus contributing to an integrated assessment of the system's condition. Regarding the Mondego estuary, the improvement in the ecological status of the benthic macroinvertebrate biological element, the non-competition of macroalgal blooms after the experimental opening of the communication (1997) and the recovery of the *Zostera noltii* banks, all symptoms of improved environmental quality, are a good indicator and serve to support the intervention undertaken in the spring of 2006 (May) - the generous re-establishment of communication between the two arms.

3.5. MATHEMATICAL SIMULATION OF SCENARIOS

The information analysed shows that the ecological conditions of the south arm deteriorated when the connection between the two channels was blocked (Figures 6 and 7).

Figure 6: Detail of the communication between the two arms of the estuary at the upstream area in 1994.

Figure 7: Detail of the communication between the two arms of the estuary at the upstream area in 1994.

They recovered slightly with the reopening undertaken in 1997/98. Analysis of existing data reinforced by the results of mathematical modelling simulations, suggest the actual residence time for the water in the south arm (between 48 and 50 hours) is not enough to maintain good drainage conditions around the Murraceira island. This is shown in Figures 8 and 9, resulting from the assessment of the various scenarios for drainage around the Murraceira island, where the velocity fields are simulated for rising tide and falling tide conditions, with and without the connection between the two arms upstream of the island (Marques *et al*., 2005).

The available knowledge on the system (empirical data, theoretical interpretation, hydrodynamic and ecological models) allowed concluding that environmental quality deterioration in the South arm of the estuary was clearly related with the increase of water residence time (48 to 50 hours since the

interruption of the communication), which became incompatible to an efficient water renewal. Consequently, the re-establishment of the communication between the two arms could drive to an improvement of the system ecological quality, since the South arm would allow the circulation of a much larger volume of water, decreasing the residence time and increasing the transport capacity. This notion was reinforced through the evaluation of a number of scenarios regarding water circulation in the South arm, simulating high and low tide situations, with and without communication between the two arms of the estuary (Figures 8 and 9).

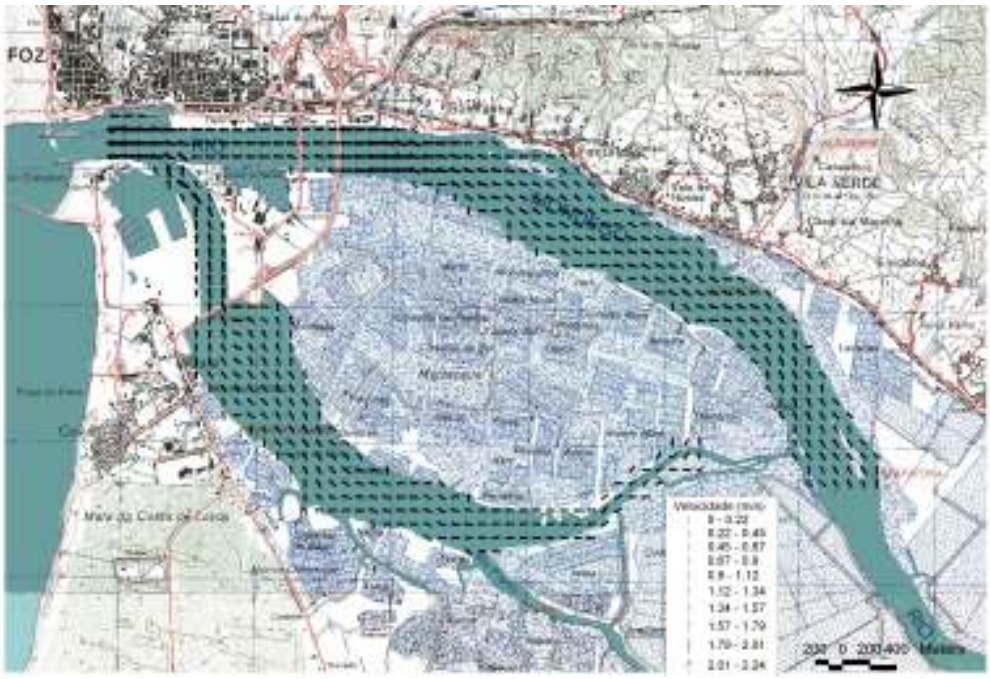

Figure 8: Water circulation: Field velocities in both arms of the Mondego estuary without connection between them in the upstream area. The tidal outflow after entering in the tide three periods domain is simulated.

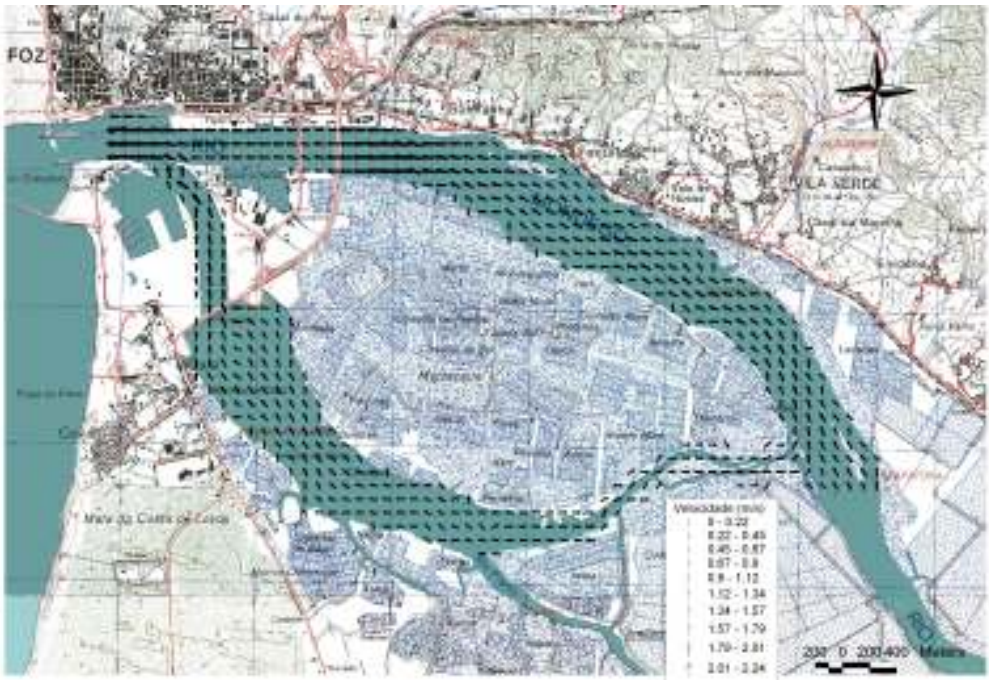

Figure 9: Water circulation: Field velocities in both arms of the Mondego estuary with re-establishing of the communication between them in the upstream area. The tidal outflow after entering in the tide three periods domain is considered.

Following the scientific advice, the re-establishment of the communication between the two arms of the estuary was decided at the Portuguese government level, and carried out in the spring of 2006 (concluded the 6 of May 2006). The new state of the system is presently under assessment.

With the generous widening of the connection between the two main channels, the south arm no longer exhibited “bag” type behaviour, and allowed the circulation of a considerable volume of water between the two subsystems, reducing the residence time and increasing the transport capacity in the water column in this sector of the estuary (Figure 8 and 9). In brief, analysis of the results of the simulations performed clearly suggests that the ecological condition could improve considerably if the connection were widened.

3. 6. CONCLUSIONS - SUPPORT FOR DECISION TAKING

The eutrophication of coastal waters, characterised mainly by an increase in nutrients, is currently recognised as one of the main problems felt at global level (Diaz & Rosenberg, 1995, Norkko & Bonsdorff, 1996a, b, Raffaelli *et al.*, 1998). One of the chief symptoms of eutrophication in these areas is the replacement of plants with roots (i.e. *Zostera* sp.) and slow-growing macroalgae (i.e. *Fucus* spp,) with quick-growing opportunistic marcroalgae (i.e. *Ulva* sp.) and phytoplankton (reviewed in Schramm & Nienhuis, 1996, Valiela *et al.*, 1997). The loss of these meadows also leads to changes in the associated biological communities (Dolbeth *et al.*, 2003, Cardoso *et al.*, 2004) and to considerable changes in the functions, services and materials that these rooted plants provide to their surroundings (Jonge *et al.*, 2000, Duarte 2000, 2002, Jackson *et al.*, 2001). This phenomenon has been observed in the Mondego estuary, where the *Zostera noltii* almost became extinct. As described earlier, the area occupied by these banks of macrophytes was in excess of 15 ha in the mid 1980s, and fell to 0.02 ha by 1997 (Cardoso *et al.*, 2004, Neto, 2004), imposing an urgent need here, as in many other sites, to put in place environmental recovery measures.

It is well known that the disturbances which these coastal areas like the Mondego estuary suffer are very much anthropogenic in origin. They are due to the development of urban agglomerations and human activities that are usually associated with bodies of water and water courses. These procedures lead to excessive increases in nutrients and changes in the flow regimes of water courses, giving rise to countless ecological problems.

On the whole, initiatives that contemplate only reducing the entry of nutrients into the systems are less successful and inadequate, on their own, to ensure the satisfactory recovery of these degraded areas, especially the macrophyte banks (Cardoso *et al.*, 2004). It is extremely important to consider all the other aspects, too, including hydrodynamism, the physical protection of the meadows and the possibility of transplanting plants from areas where they are thriving.

Bearing all these aspects in mind, the ecological quality of the Mondego estuary was characterised over time, assessing the water quality, macrophyte cover in the south arm and ecological quality based on the intertidal and subtidal benthic macroinvertebrates. Supported by historic knowledge of the area and by data from mathematical simulations, suggestions were proposed to implement management measures that would help to eliminate the eutrophication symptoms (green macroalgal blooms) seen in the south arm of the Mondego estuary. These measures indicated that widening the communication between the two arms of the river and reducing the discharges of nutrients coming directly to the south arm were the most urgent.

As may be understood from the preceding explanation, three basic time periods were considered in the analysis: “before the interruption”, “during the interruption” and “after the experimental opening”. The first period would supply information on the initial status of the system (or when the degree of disturbance was less-well documented), the second would indicate the impact of the interventions, and the third would have important pointers for the likely effectiveness of the planned measures in terms of improving the environmental quality of the south arm (opening the communication between the arms).

After analysing all the data, it was found that in the “during the interruption” period there was an overall worsening of all the factors studied (i.e. water quality, plant cover, benthic macroinvertebrates), and a general improvement in the physical-chemical parameters that characterise the ecological state of the estuary, “after the experimental opening”. But is should be stressed that the concentration of some nutrients remained high in the “after the experimental opening” period. This fact is related to the upstream sitting of the origin of the nutrients, and to the fact that they are released gradually (basically the phosphorus) from the sediment. This is why the classification in terms of water quality did not noticeably improve.

The morphological alterations have led to hydrodynamic changes in the estuary, and these in turn, together with the ready supply of nutrients from the water for agricultural, urban and industrial use (with little subsequent treatment), have encouraged the appearance of eutrophication symptoms in some parts of the system, and the gradual replacement of the primary producers occurred, with all the consequences already described.. In these circumstances, an intervention plan was drawn up, with the aim of putting right the problems experienced in the system. After the minor experimental intervention in 1997/1998, the plant cover made a clear recovery and the community of benthic macroinvertebrates is steadily approaching the estuarine community as it was in the 1980s, in structural terms. A positive evolution of the ecological status (macrophytes and plant cover) was observed. In addition, with the aid of mathematical simulations, it was found that widening the communication between the two arms would lead to a faster current in the south arm, which would help to cut the residence time of the water and increase the load capacity for the water mass. The benefit would be better transport power for the south arm, enabling larger amounts of dissolved or suspended materials to be exported, and so prevent their build-up within the system. It was therefore deemed appropriate to intervene in the system by re-

establishing the communication between the two main channels. And so the reopening of the connection between the two arms of the Mondego went ahead. The work was carried out in May 2006, by INAG.

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The Mondego estuary under the
Ecosystem Services and Goods approach.

The Mondego estuary from the Ecosystem Services and Goods point of view

Abstract

The Mondego estuary has been widely studied throughout the last two decades, with most of the research being focused on the response of biological communities to different types of environmental stress, namely eutrophication. With this work, we analysed this system from an ecosystem services and goods point of view, describing its present state and establishing scenarios regarding the foreseeable evolution of three different ecosystem services, respectively food production, water quality and recreation, and its association to biodiversity assets. This approach allowed us to check the interactions between each one of the ecosystem services and to establish that water quality is currently the service that influences the most all the rest. As a conclusion, it appears clear that appropriate water management procedures will have a positive influence upon all ecosystem services.

1. Introduction

The benefits that humans can acquire from natural systems (ecosystem services and goods) may be measured and evaluated through an estimation of the ecosystem functions (that can be defined as the processes and properties of the system). Ecosystem services are the conditions and processes through which natural ecosystems sustain and fulfil human life (Daily, 1997) (e.g. recreation activities, natural depuration capacity of a system). Ecosystems goods can be described as the products that can be obtained from natural systems for human use (DeGroot *et al.*, 2002) (e.g. food production or raw materials). The services and goods provided by natural ecosystems form the basis of human welfare, so the evaluation of these ecosystem features must be done based on integrative approaches, since it comprises both human interests and biophysical processes.

There are many categories defined for ecosystem services and goods, depending on the criteria used. According to the SA work group (2005) ecosystem services can be grouped into six categories broadly based on both their ecological and economic function:

(a) Purification and detoxification: filtration, purification and detoxification of air, water and soils;

(b) Cycling processes: nutrient cycling, nitrogen fixation, carbon sequestration, soil formation;

(c) Regulation and stabilisation: pest and disease control, mitigation of storms and floods, erosion control, regulation of rainfall and water supply;

(d) Habitat provision: refuge for animals and plants, storehouse for genetic material;

(e) Regeneration and production: production of biomass providing raw materials and food, pollination and seed dispersal; and

(f) Information/life-fulfilling: aesthetic, recreational, cultural and spiritual role, education and research.

Moreover following the Millennium Ecosystem Assessment (2003), the consequences of ecosystem changes for human well-being and options for responding to those changes have been highlighted. As so, four categories were defined, considering goods and services as 'services':

(a) Provisioning (*Products obtained from ecosystems*): food, fresh water, fuel wood, fiber;

(b) Regulating (*Benefits obtained from regulation of ecosystem processes*): climate regulation, disease regulation, water regulation, water purification, pollination;

(c) Cultural (*Nonmaterial benefits obtained from ecosystems*): spiritual & religious, recreation & ecotourism, aesthetic, inspirational, sense of place, cultural heritage;

(d) Supporting (*Services necessary for the production of other ecosystem services*): soil formation, nutrient cycling, and primary production.

Nevertheless, independently of the chosen approach, the ultimate goal of this kind of analyses is the same: to evaluate and assess the stability of ecosystems in accordance to their natural capacity to sustain human activities. According to Armsworth & Roughgarden (2003) the dynamical stability of ecosystems and populations rules their responsiveness to variable environmental conditions and determines with what reliability these natural resources provide life-sustaining services to society.

Estuaries are considered among the most productive and valuable natural systems around the world [for instance Costanza *et al.* (1997) roughly estimated the average economic value of 17 estuaries of different regions at 22,832 \$ ha $^{-1}$ yr $^{-1}$], acting namely as nurseries and refuges for many fish, bird, molluscs and crustaceans species. In terms of coastal zones' environmental quality and management, estuarine processes are crucial from the ecological and economic points of view, namely in ensuring fisheries' sustainability. Estuaries are expected to support a variety of human activities, ranging from commercial and recreational fisheries to marine transportation to discharge of chemical and thermal wastes. One measure of coastal condition is the assessment and evaluation of an estuary to maintain these human uses. As the demand for certain services increases, human actions often rely on the modification of ecosystems, in order to increase their provisioning capacity. This anthropogenic transformation of ecosystems often enhances the production of some services at the expense of others (Jackson *et al.*, 2001). The Mondego River Basin was selected for assessment, with emphasis on the estuarine part of the system.

The major environmental pressures affecting the Mondego estuary are related to agriculture activities, due to the use of fertilizers which caused clear eutrophication symptoms in the ecosystem. Consequently, many studies have been worked out in this ecosystem, namely in the last decade, to understand the ongoing processes and to evaluate the biological effects produced by nutrients increase in the water column (e.g. Marques *et al.*, 1993a; 1993b; 1997; 2003; Flindt *et al.*, 1997; Lopes *et al.*, 2000; Pardal *et al.*, 2000; Martins *et al.*, 2001; Cardoso *et al.*, 2002).

Under the scope of the ecosystem services and goods approach, the condition and trends of ecosystem services, like water quality, food production, biodiversity, and recreation have been taken into account.

The importance of this new point of view is related to the interdependence existing among the different ecosystem services. An analysis of the evolution of each one of them will serve to determine management response actions, as well as the measures that should be implemented when ecosystem services condition is low or shows tendency to decrease. The quality of ecosystem valuations is only as good as the estimates of the changes in ecosystem condition generated by the ecological assessment (Suter II, 1995). This statement reveals the importance and extent of the inventory and of the determination of conditions and trends, among ecosystem services and goods, that compose the initial phase of our assessment. According to Meyerson et al. (2005) it is the ability to report trends in the quantity of ecosystem services/goods that is critical to knowing whether or not these natural resources are being used in a sustainable way.

The ecosystem services and goods approach can be useful, allowing the integration of ecological and economic perspectives, enabling scientists and decision makers to link different parts' interests (stakeholders approach), land use development, and ecological systems conservation in a more feasible and balanced way.

2. Methods

2.1 Description of the study area

The Mondego estuary, on the western coast of Portugal, is the location of a mercantile harbour (Figueira da Foz). Besides the harbour facilities, the estuary supports industrial activities, salt-works, and aquaculture farms (Figure 1).

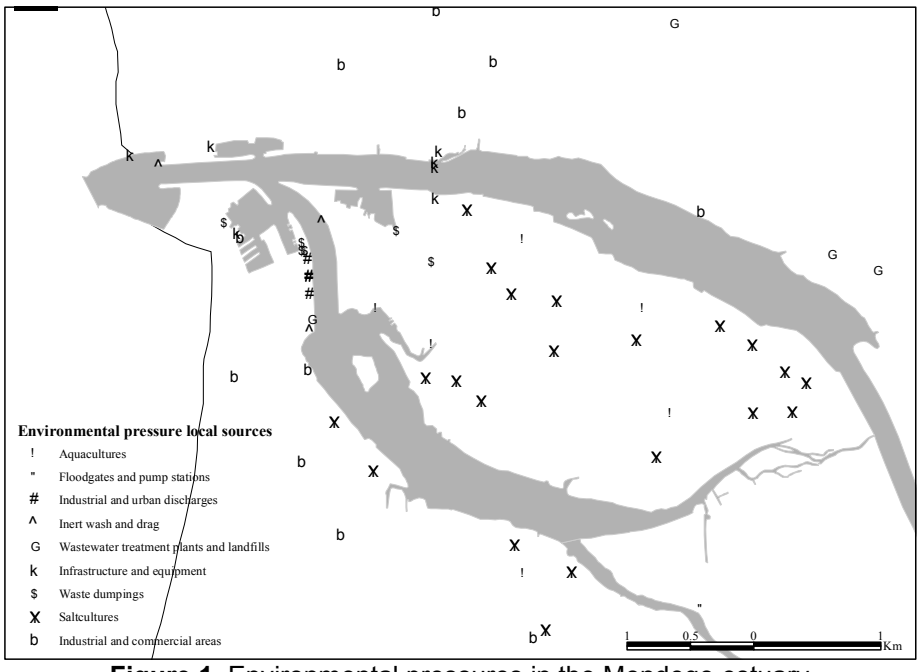

Figure 1. Environmental pressures in the Mondego estuary

The estuary consists of two arms, north and south, which become separated by an island (Morraceira Island) in the estuarine upstream area, at about 7 Km from the sea, joining again near the mouth.

The two arms exhibit very different hydrographical characteristics. The North arm is deeper (5 to 10 m during high tide, tidal range about 2 to 3 m), while the South arm is shallower (2 to 4 m deep, during high tide) and was almost silted up in the upstream areas, which caused the freshwater of the river to flow essentially through the North arm. As so, the water circulation in the South arm was mostly due to tides and to the freshwater input of a tributary, the Pranto River, which is artificially controlled by a sluice, located at 3 km from the confluence with the south arm of the estuary. In addition, due to differences in depth, the penetration of the tide is faster in the north arm, causing daily changes in salinity to be much stronger, whereas daily temperature changes are higher in the south arm (Marques *et al.*, 1993a; 2003).

Moreover, the entire estuary is under permanent anthropogenic pressures and several impacts determine its maintenance and development as a system (Marques et al., 2003; Dolbeth et al., 2003; Cardoso et al., 2004). From 1998 onwards several experimental mitigation measures have been applied attempting to reduce the eutrophication symptoms in the South arm (e.g. reduction of *Zostera noltii* beds). Among the interventions to restore the system environmental quality includes:

- the re-establishment of the communication between the north and south channels by an opening with a cross-section of 1 square meter. This experimental opening showed a subtle decrease in the water residence time in this subsystem; and,
- the diversion of the draining waters from agricultural fields from the sluice opening in the Pranto River into a channel discharging into the North arm of the estuary (this arm presents a higher water flow and a lower water residence time than the South arm and consequently the effects of extra nutrient supply will cause less impact).

With the experimental opening, water could then enter through the top of the South arm, which led to a reduction in the water residence time. This change, plus the reduction of water discharges through the Pranto sluice affected the production of green macroalgae and allowed the partial recovery of *Zostera noltii* meadows. However, these measures have not helped to reduce the oxidised forms of nitrogen and phosphate, and so the input of nutrients into the system remains high.

2.2 Data sources

A data set was chosen to estimate biodiversity and water quality in the Mondego estuary. It was provided by a monitoring programme on the subtidal soft bottom communities, which characterized the whole system with regard to the species composition and abundance and to the physicochemical parameters of water and sediments. Samples have being carried out in 1990, 1992, 1998 and 2000, in spring, along the two arms of the estuary (Figure 2).

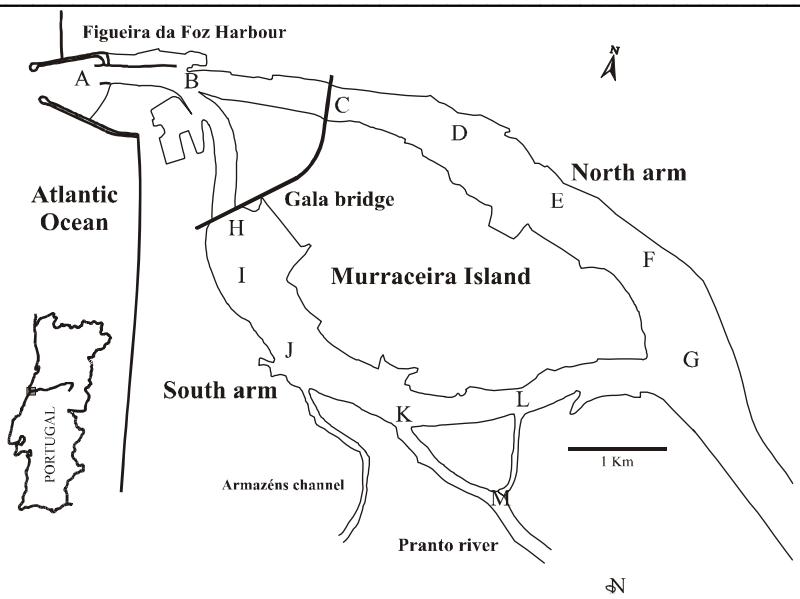

Figure 2. The Mondego estuary. Location of the subtidal sampling stations used to estimate the biodiversity assets and the water quality service.

The Shannon-Wiener (Shannon & Wiener, 1963) and Margalef (Margalef, 1968) indices were applied to estimate biological diversity. Regarding the rest of ecosystem services, the main sources of information have been INE (Instituto Nacional de Estatística), IPIMAR (Instituto de Investigação das Pescas e do Mar) for the food production service, and the DRAOT (Direcção Geral do Ambiente e Ordenamento do Território do Centro) for recreation services.

Data related to food production services mainly consist of identification and amount (Tons per year) of fish species captured in the estuary from 1994 to 2001. Besides that, data on the salt extraction were obtained in terms of number salt factories and quantity of salt produced (Tons) produced from 1994 to 2001. Fish farming activities were also taken into account, as it is one of the food producing activities in the estuary, although data obtained concern only the years 1994 and 2003.

Regarding recreation services, data available consists only of qualitative estimates on the importance of that service on the Mondego Estuary.

2.3 Data treatment

When the type of data consisted of a complete long-term series, trend lines were built using the method of the least squares, reflecting the development to be expected over time. In the case of incomplete temporal data series a simple method was used, dividing data in the last year by the data of the first year of the period considered. Despite being simple, this method is well straightforward to detect trends when the quality of the data does not allow us a more sophisticated analysis.

Furthermore, the fact that data corresponding to water quality and biodiversity services were obtained at a fixed set of sampling stations allowed us to apply analysis of variance (One-way-ANOVA) to detect possible significant inter annual differences.

3. Results. Ecosystem services present condition

3.1 Water quality

Results obtained from the analysis of physicochemical parameters throughout a decade (1990-2000) in the two arms of the estuary show that the concentration of nutrients in the water column significantly increased (p<0.001) (Table 1).

Table 1. Application of a One-way ANOVA test considering the nutrient concentrations obtained in 1990 and 2000 (p<0.05).

		NO_3^{2-}		
	n	Mean	*F*	*p*
1990	13	0.008	29.40	1.25 E-05
2000	14	0.045		
		NO_2^{2-}		
	n	Mean	*F*	*p*
1990	13	0.058	11.92	0.001
2000	14	0.170		
		PO_4^{2-}		
	n	Mean	*F*	*p*
1990	13	0.016	22.73	6.79 E-05
2000	14	0.034		

Such increment gives rise to classifying the system as under low eutrophication in 1990, following the criteria for the assessment of water quality proposed by Briker *et al.* (2003) (see Table 2), whereas in 2000 the system turns to be considered as medium eutrophied.

Table 2. Criteria for assessment of nutrients' levels in transitional water (*in* Bricker *et al.*, 2003).

Quality status	**Nitrogen (mg/l)** (maximum dissolved surface conc.)	**Phosphorus (mg/l)** (maximum dissolved surface conc.)
High eutrophication	**≥**1	≥0.1
Medium eutrophication	**≥**0.1 - <1	**≥**0.01 - <0.1
Low eutrophication	**≥**0 and <0.1	**≥**0 and <0.01

In the study period, symptoms of eutrophication were in fact evident in the South arm of the estuary, appearing to be related with water circulation problems, and not only with nutrients loading. The most visible feature of this environmental stress was the occurrence of seasonal green macroalgae blooms (mainly of *Ulva* spp.), which have been reported in the South arm for several years (Marques *et al.*, 1993a; 1993b; 1997; 2003; Flindt *et al.*, 1997).

3.2 Food Production

The main food products produced in the estuary are those from the fishing and fish farming industries.

Fishing in the estuary and its surroundings is mainly focused on species as *Petromyzon marinus*, *Alosa alosa*, and *Alosa fallax.* The capture of such species has a considerable socioeconomic impact as the price per Kg is very high. Out of those, it is *Alosa alosa* the most captured species, reaching 93% of the total caught in 1994 and 87% in 1997. Nevertheless, the trend lines show a fall in the captures of this species against an increment for the other two, although in both cases, differences are not significant (Figures 3 A, B and C).

Besides, with a seasonal character, species such as *Sepia officinalis*, *Platichthys flesus*, *Solea vulgaris*, *D. labrax*, *Mugil cephalus*, *Chelon labrosus*, *Liza urta* and *Carcinus maenas* are also captured. Mollusc species as *Cerastoderma edule*, *Venerupis decussata* or *Scrobicularia plana* are mainly collected in the South arm of the estuary. Moreover, captures of mussels (*Mytilus edulis*) near the mouth of the estuary have significant commercial value, namely during the summer tourism season.

The evolution of the amount of tons fished of all the species from 1994 to 2001 slightly tends to fall but not significantly (Figure 3 D), which allows considering it as remaining steady.

Salt production is another activity still present in the Mondego estuary, although high costs resulting of the traditional way of extraction, together with the great offer of product in better conditions from other areas of the country and abroad, have lead to its progressive decline (Figure 3E) due to the production units abandon.

Since the eighties some of the inactive saline industries have been reoriented into fish farming factories, mainly of intensive production, where local species like *Sparus aurata* and *Dicentrarchus labrax*, are grown.

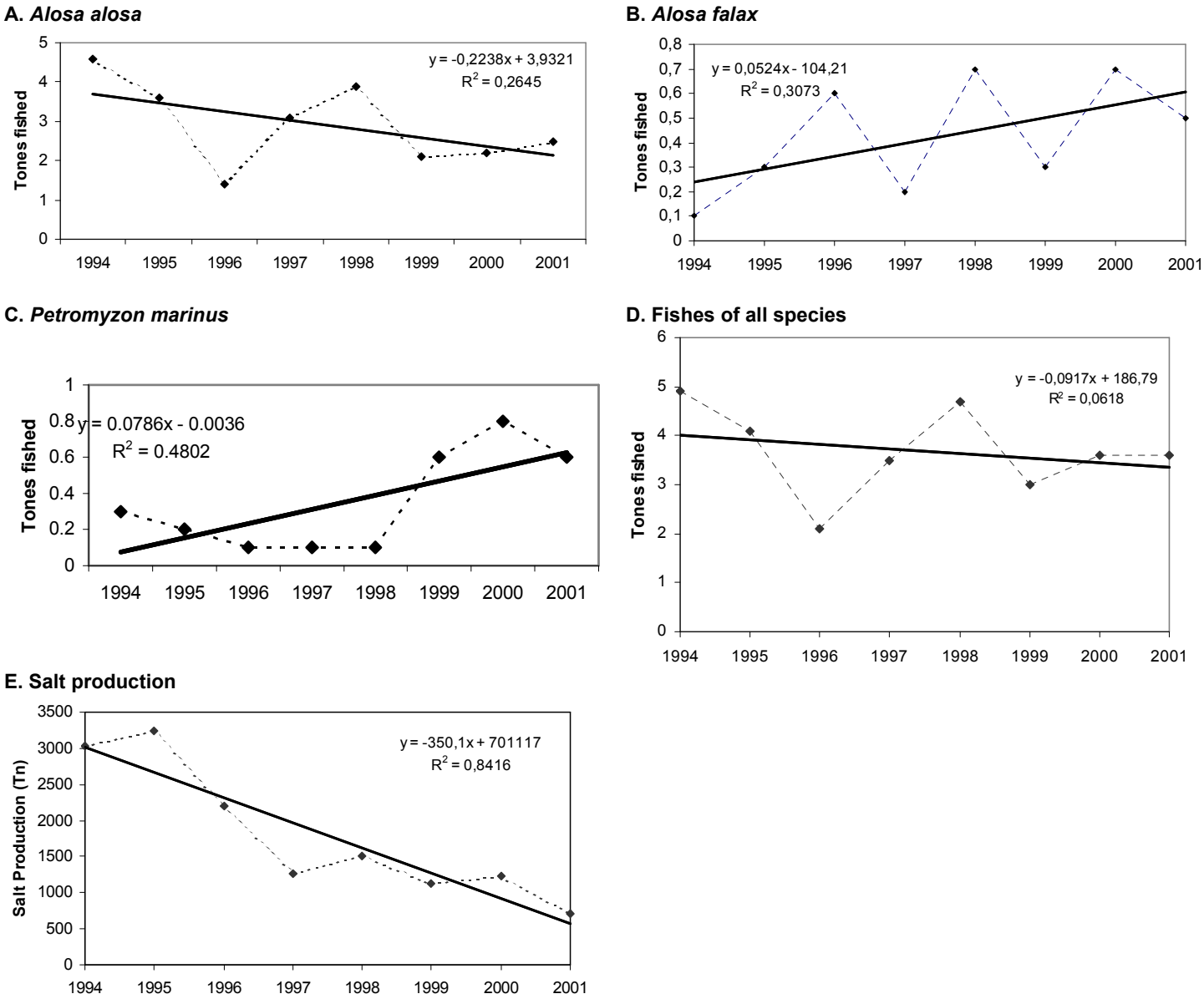

Figure 3. Trend line showing evolution of the amount of tons fished of A. *Alosa alosa,* B. *Alosa falax,* C. *Petromyzon marinus,* D. All species and E. Salt production in Mondego estuary.

Despite the fact that the area devoted to fish farming has been increasing in the estuary, the same has not occurred with regard to production. In fact, the total production in 2003 was 200 tons per year, while ten years before each company devoted to such activity produced approximately 120 tons per year. The drop in the fish farming production appears to be mainly related to water quality, since presently it is only possible to cultivate 1 kg per m^3, compared to the 2-3 Kg per m^3 obtained in the past. The nutrients enrichment of the system and the subsequent eutrophication effect, leading to a fall in the oxygen dissolved in the water column, might have been affecting the survival of the organisms.

3.3 Recreation

Despite the lack of quantitative data on recreational activities in the estuary, it is reasonable to assume that its location near the city of Figueira da Foz, where seasonal tourism constitutes one of the major income sources, causes the estuary to be influenced and to influence such activity.

An example of that is the fact that the Figueira da Foz City Hall funded the development of a comprehensive management plan for the Morraceira Island, which includes tourism and leisure activities. One of the main objectives of this plan involves the exploitation of natural and cultural resources of the Island, favouring eco-tourism, related to the development of environmental education activities, which lead us to believe that in the coming years the recreational activity in the estuary will be increased.

3.4 Biodiversity

In 1990 samples carried out on the Mondego estuary subtidal communities, which provided an average 10297 macroinvertebrates per m^2 belonging to 31 species. Polychaetes were the dominant phylum (87.56 %), while 7.9% were molluscs, 8.9 % crustaceans and 3% of all taxa belonged to minor phyla. This proportion of the different groups stands approximately the same in 2000, but with a lower number of individuals (8018 per m^2), and a higher number of species (48).

As a general basis, the dominance of certain species, such as *Alkmaria romajnii*, *Cyathura carinata*, *Nereis diversicolor* and *Scrobicularia plana* was clearly stated in the estuary.

Biological diversity of subtidal communities measured by Shannon-Wiener diversity index, are in a range from 1 to 3 bits/ind, with most of the sampling stations exhibiting low values near to 1 (Table 3). Similarly, values of the Margalef index show low figures (Table 4), which in rare occasions (like in station I in 1990) go beyond 3.

Table 3. Values of the Shannon-Wiener index estimated at the sampling stations in the Mondego estuary (campaigns from 1990 to 2000).

	Shannon-Wiener			
Stations	**1990**	**1992**	**1998**	**2000**
A			2.64	0.90
B	1.55	1.73	2.45	3.44
C	1.50	0.96	1.36	2.40
D	1.84	2.44	2.77	1.84
E	1.55	0	2.14	0.65
F	2.94	1.75	2.61	1.37
G	1.20	0.54	0.87	2.03
H	2.55	2.94	0	2.55
I	3.11	2.41	1.43	2.92
J	1.22	2.73	2.03	2.51
K	0.71	1.88	1.91	1.46
L	1.61	1.44	1.66	2.39
M	1.93	2.34	1.32	1.68
N	2.30	0.34	0.63	1.38

Table 4. Values of the Margalef index estimated at the sampling stations in the Mondego estuary (campaigns from 1990 to 2000).

	Margalef			
Stations	**1990**	**1992**	**1998**	**2000**
A			2.32	1.44
B	0.91	1.25	1.08	4.01
C	0.76	0.71	0.89	1.52
D	0.94	1.37	1.99	0.89
E	0.99	0	1.26	0.27
F	1.94	0.73	1.55	0.66
G	0.79	0.36	0.60	1.23
H	1.46	2.01	0	1.73
I	3.14	1.46	0.94	1.99
J	2.10	1.91	1.07	1.34
K	1.17	1.32	1.25	1.02
L	1.57	0.71	0.81	1.43
M	1.24	1.17	0.98	1.14
N	1.37	0.38	0.72	0.79

The analysis of the Shannon-Wiener and Margalef indices (Figure 4) allowed some pattern observations of the ecological condition of the macrobenthic communities on the Mondego estuary. During the study period significant changes occurred. The system was divided in South and North arms due to the different hydromorphological differences between the two sub-systems. It is possible to observe that the North arm presents a strong biodiversity decline in 1992 and after it shows some recoveries (Figure 4A). This situation may have been caused by the regularization actions made on this system. The South arm presents also a significant biodiversity decline, reaching its peak in 1998; nevertheless this reduction was provoked by the eutrophication symptoms felt in this sub-system. Once that the mitigation measures to recover the system diversity began the system started to improve its condition.

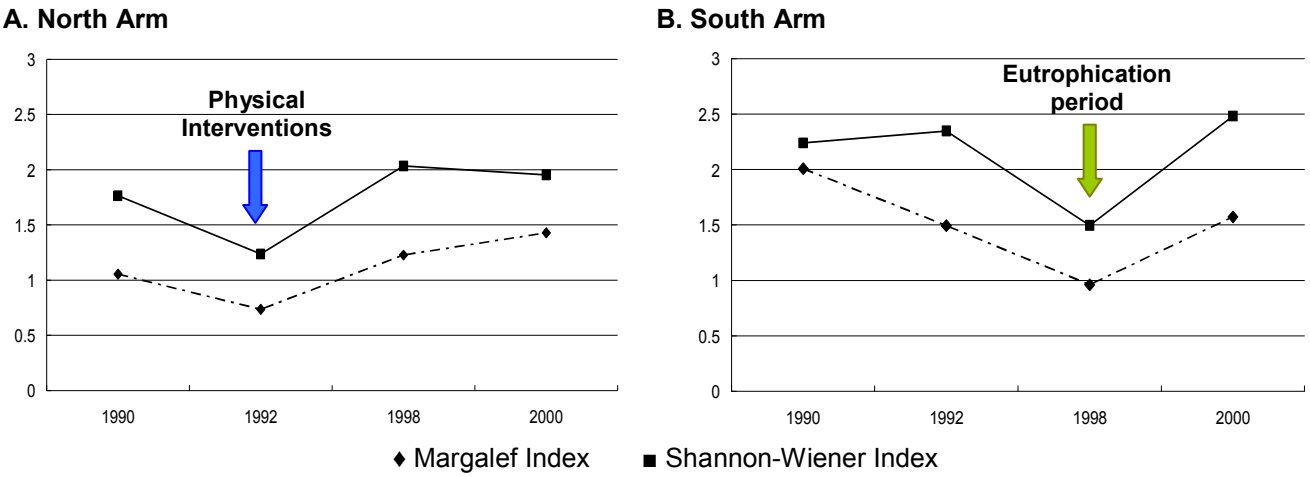

Figure 4. Margalef and Shannon-Wiener indices behaviour along our study period, in the sub-systems: A. North arm, and B. South arm in the Mondego estuary.

Such values might indicate, according to the European Water Framework Directive (WFD), a poor to moderate ecological status, following the classification developed by Molvaer et al. (1997) for the Shannon index and by Bellan-Santini (1980) and Ros et al. (1990) for the Margalef index.

On the other hand, with regard to the intertidal communities, several studies showed during this study period that the *Zostera noltii* beds, which represent the richest habitat with regard to productivity and biodiversity (Marques et al., 1993b; 1997), have been drastically reduced in the South arm of the Mondego estuary, most likely as a function of competition with *Ulva* sp., resulting from the different strategies of macroalgae and macrophytes to uptake nutrients, and also from the shading effects of macroalgae on macrophytes (Hardy *et al.*, 1993; Hartog, 1994). In fact, in the beginning of the 1980s, the *Zostera noltii* beds covered a large fraction of the intertidal area, extending to the upstream section of the South arm, along the Morraceira Island, while by the end of the 1990s this species distribution was restricted to its downstream section. To try to solve this situation some mitigation measures were implemented, and after 1998 the *Zostera* beds started to recover.

4. Discussion and conclusions

In general, human activities cause a series of environmental damages and stress, which may alter natural processes in ecosystems.

The most important problems in aquatic environments have to do with the input of nutrients (eutrophication), erosion, and the input of swept away materials from the land (increase of water turbidity), the sewage drain and the alteration of water quality, microbiological pollution, changes in the original structure of the communities and input of aloctone species, pollution in general, habitat destruction and loss of diversity (Marcos & Pérez-Ruzafa, 2003).

On top of the environmental problems, social, cultural and economical ones are overlapped, finding then those activities are never isolated or take place in the environment through cause effect linear relations, otherwise they interact, meet and compete for area, summing effects up and producing there a complex net of interrelations which make even more difficult to analyze the situation.

A typical example of the interaction of different activities can be seen in the Mondego estuary, and such interaction is one of the factors that influence on the condition of ecosystem services.

The trends of each ecosystem service considered in the present work may be assessed based on the available data (Figure 5), as well as the interrelation between the status and tendencies of those services (Figure 6).

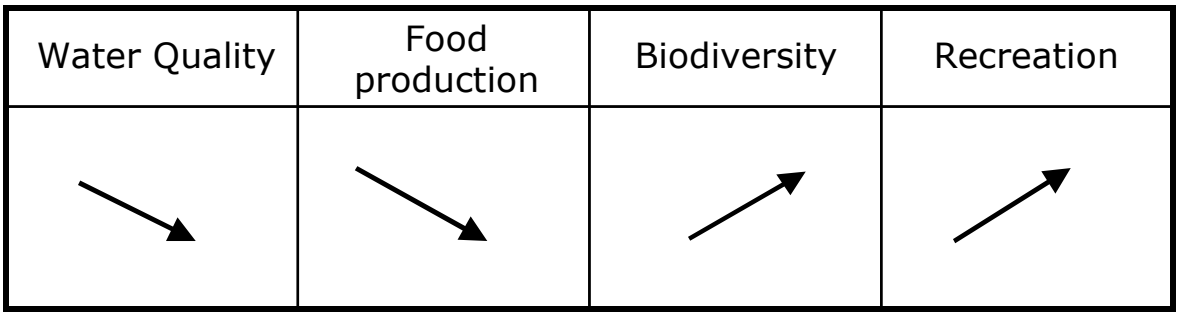

Figure 5. Trends of each one of the services (water quality, food production and recreation), as well as of biodiversity assets, on the basis of our results in Mondego estuary.

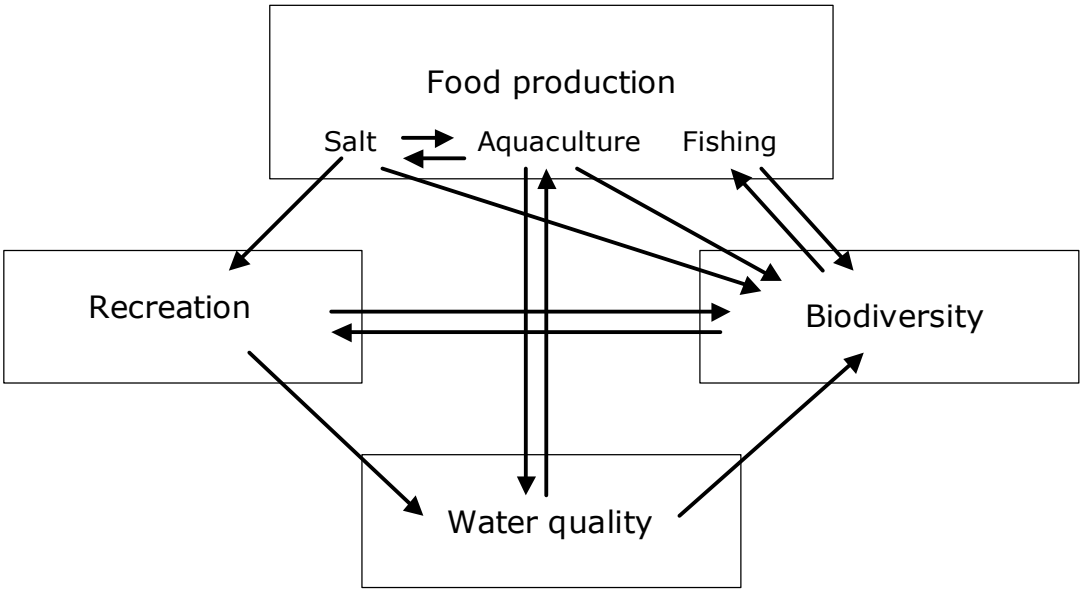

Figure 6. Interrelations between the different services in Mondego estuary.

In general, the increasing concentration of nutrients in the water column due to the waste of both agriculture and aquiculture activities produces not only a worsening in water quality, but influences also the aquiculture production itself.

On top of that, the worsening in water quality tends to affect the diversity of the aquatic communities. At present, with regard to the subtidal communities, diversity appears to be improving its status, after the mitigation measures and management procedures undertaken. A lower biological diversity in benthic communities, that serve as food for many fish species, might then, eventually, originate a decrease in the fishing production.

Besides, regarding the food production service, if we focus on the salt extraction activity, it is reasonable to consider that a decrease in the area occupied by salt will not only mean an obvious drop in local salt production, but also an inconvenience to many bird species (and consequently to biodiversity), as salt pans constitute an important area for waders foraging and breeding, acting as a complementary habitat of salt-marshes during high-water periods.

In general, we are lead to think that any measure undertaken to improve any of the ecosystem services in isolation will directly or indirectly have repercussions on the other ones.

Possibly, at the moment, the water quality service is the one that requires a higher attention as it influences in a great extent on the evolution of the others. Agricultural activities are the main cause of the observed eutrophication symptoms in the Mondego estuary, but on the other hand this activity is fundamental in the economy of the whole area of the Low Mondego River Valley. In order to try to solve this problem, a deviation of the agriculture waters was performed. Nevertheless, measures that might be undertaken must account for this socioeconomic reality.

It obviously advisable to improve agricultural practices in order to regulate and decrease the use of fertilizers, as very often they are used in excess for fear of not obtaining optimal harvest of the agricultural products.

This approach will contribute to make compatible in a suitable way the development of the whole ecosystem, and should be carried out in the near future to reach a balance between the numerous interests and opportunities that overlap in an area such as the Mondego estuary. Therefore, basic research efforts, continuous compilation of data and information, as well as a multidisciplinary approach must be seen as the way to achieve that objective satisfactorily (Marcos & Pérez-Ruzafa, 1994).

5. Future Directions

Although the conditions and trends assessment for the four main ecosystem services and goods in this particular case-study have been done, a further insightful research have to be achieved. It is necessary to adjust the observed results according to new techniques refined for the system (e.g. P-BAT – Portuguese Benthic Assessment Tool – for the ecosystem quality determination), as well as to deepen the verified interrelations among services and goods.

In a posterior phase, a valuation of these services will be conducted according to the latest valuation techniques and methods available, in order to provide a comprehensive framework of the complex functioning and interrelations of this system. In a first step it will be conducted a valuation of the ecosystem services that can be directly linked to economic activity (e.g. food production, recreation services, industrial services). In a posterior phase it will be encouraged the non-market services valuation study.

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