INCO : International Scientific Cooperation Projects (1998-2002)

Contract number : ICA3-CT-2002-10012

FINAL REPORT

Start date: 1 July 2002 **Duration: 36 months**

Title : Sustainability of Mediterranean coastal lagoon ecosystems under semi-arid climate

Project homepage : http://www.colasu.com

Keywords : Mediterranean coastal lagoons, anthropogenic impact on ecosystems

COLASU

Contract number : ICA3-CT-2002-10012

FINAL REPORT

1st July 2002 – 30th June 2005

Contract number : **ICA3-CT-2002-10012**

TITLE : Sustainability of Mediterranean coastal lagoon ecosystems under semi-arid climate

SCIENTIFIC COORDINATOR

IRMCo
Cavalier Buildings
21-22-23 Victory Street
Senglea CSP06
Malta

Ms. Anna Spiteri
E-M : irmco@keyworld.net
TEL : 356 21891340
FAX : 356 21676152

ADMINISTRATIVE AND FINANCIAL COORDINATOR

CNRS
EOST, CGS
1, rue Blessig
67084 Strasbourg Cédex
France

Dr. J. Duplay
E-M : jduplay@illite.u-strasbg.fr
TEL : 33 3 90 24 04 24
FAX : 33 3 88 36 72 35

CONTRACTORS

Faculty of Sciences
Département des Sciences de la Terre
BP 1014 RP Rabat
Morocco

Prof. Naima Hamoumi
E-M : hamoumi@fsr.ac.ma
TEL : 212 61 07 50 39
FAX : 212 37 77 19 57

Faculté des Sciences de Tunis
Département de Géologie
Campus Universitaire
2092 Manar Tunis
Tunisia

Prof. Fadila Gueddari
E-M : : fadila.gueddari@eudoramail.com
TEL : 216 71 87 26 00 p. 300
FAX : 216 71 885 408

University of Sevilla
Faculty of Chemistry
Dept. of Mineralogy
C/San Fernando n°4
41004 Sevilla
Spain

Prof. Emilio Galan
E-M : egalan@us.es
TEL : 34 95 448 81 01
FAX : 34 95 448 81 24

Instituto Tecnologico e Nuclear (ITN)
Estrada Nacional 10,
2686-953 Sacavém,
Portugal

Dr. Isabel Prudencio
E-M : :iprudencio@itn.pt
TEL : 351 21 994 6223
FAX : 351 21 994 14 55

University of Human Science (FSHST)
94 Avenue du 9 Avril 1938 Tunis,
Tunisia

Prof. Ali Toumi
E-M : alitoumi2003@yahoo.fr
TEL : 216 71 75 75 14
FAX : 216 71 76 84 51

Sustainability of Mediterranean coastal lagoon ecosystems under semi-arid climate

Abstract

The three year COLASU project launched on July 1st 2002, succeeded in carrying out a thorough study on two lagoons in North Africa. The **Nador lagoon** in Morocco, the second largest lagoon of northern Africa, and **El Meleh**, a small coastal lagoon located near the town of Slimene in Tunisia.

The first step of the research was focused on understanding the present state of the lagoons by conducting **major sampling campaigns** to collect data on soils, sediments and water which led to maps showing the present pollution distribution in the lagoons. The project built **a database of regional maps**, using Geographic Information Systems, as a spatial analytical tool, to contribute towards the analysis and interpretation of the human impact on the lagoon environment **at the catchment scale.**

To gain further insight into the direct effect of human activities on the lagoon, the water treatment stations of Nador and Slimene, and the Marost aquaculture concern in Nador lagoon were chosen for the application of the **Life Cycle Assessment** (LCA).

This tool is used to assess the **environmental impact** of a system from the production of raw materials to the disposal of the final waste products (ISO 14040). Further research into the possible linking of the two decision-making tools, i.e. coupling the LCA with GIS, led to a new **innovative approach**, whereby the system under investigation is not an industrial process but an ecosystem. This novel approach was tested by assessing the impact factors on the eutrophication potential in both lagoons.

The relevant **stakeholders and endusers** were involved throughout every step of the project by informative letters and seminars, and at the end of three years are being given **a series of practical recommendations for sustainable lagoon management**.

Specific recommendations in the form of **technical cards** have been drawn up with regard to wastewater treatment and aquaculture. Broader **'good practice'** recommendations, aimed at stakeholders concerned with the overall management of coastal zones, include a description of the **harmful effects of heavy metals on human health**.

Anna Spiteri
Scientific Coordinator
IRMCo Ltd

July 2005

Summary of Final Report

Launched on July 1st 2002, the COLASU research project focused on the study of Nador lagoon in Morocco, the second largest lagoon complex of northern Africa, and on El Meleh, a small coastal lagoon located near the town of Slimene in Tunisia. The 3-year Workplan was organized in five workpackages: WP1 Study Areas, WP2 Data Collection, WP3 Ecosystem Functioning, WP4 Global Diagnosis and WP5 Lagoon Management.

Within the overall objective to assess and forecast the possible future morphodynamic and geochemical evolution scenario of both lagoon ecosystems and to furnish tools to help decision makers, the following specific objectives were envisaged:

- WP1 aimed at bringing together available scientific literature data and present socio-economic data, the characterization of the geomorphological past and present state and the geological background.
- WP2 concerned the collection of present state data, i.e. sampling of soils, sediments and water, analysing the samples using physical, chemical and biochemical approaches in order to produce maps showing the pollution distribution in water and sediments.
- WP3 aimed at the interpretation of the above data with the objective to provide a description of the morphodynamic scenario; to assess the anthropogenic impacts according to the present pollution levels; and to forecast the future natural and/or human-induced changes of the two lagoons.
- WP4 targeted the appraisal of the environmental impacts of two pre-selected types of anthropogenic activities and the sustainability of the lagoons.
- WP5 aimed at a concise review of all the information provided by the previous workpackages to produce guidelines for the decision-makers.

It should be noted that the originally foreseen objectives in terms of coordination among the partners in the Colasu Consortium, were extended with the aim to establish an active dialogue and collaboration with the stakeholders and end-users throughout the lifetime of the project.

The bibliographic synthesis achieved in WP1 brings together a clear overview of the different fields of expertise brought together by the various partners in the Colasu Consortium. Most worthwhile, this provided a **detailed insight into the existing knowledge on both lagoons** from a climate, geological, geomorphological, hydrogeological, legislative and socio-economic point of view. Purposely designed, **standard scientific matrices** were used to document existing information and, in particular, existing maps for both lagoons.

Sampling campaigns of different types of samples (water, sediment, soil) constituted a very important component of this project, as these provided essential information to establish possible evolution scenarios. Following on the experienced gained in the first, Summer 2002 campaign, considerable attention was given to the formulation of a **sampling protocol**, which among other, provided **standardized criteria** to document the sample collection during fieldwork for both lagoons and to report on the various analyses, performed at the different partner laboratories, as needed for the compilation of a **database of analytical results** in WP2.

Sediment, soil and parent rock samples for each of the campaigns were analyzed by different methods according to the established protocol. The main methodological approaches included:

- chemical composition of selected elements for sediments, soils and parent rock samples (INAA and ICP-OES),
- mineralogical composition of selected soils and sediments samples (X-ray diffraction of bulk sample and < 2 μm fraction),
- micropaleontology, organics, mobility, bioavailability and Fe speciation (Mössbauer spectroscopy) in selected sediments samples.

For water samples the analyses comprised (including in situ measurements):

Water column; pH in situ; Temperature (ºC); Eh; Salinity (‰); Conductivity (mohs); Dissolved O_2 (mg/l); Suspended matter (mg/l); Nutrients (PO_4, P_organic, P Total, NO_3, NO_2, NH^+_4, N_Kjeld, N_organic and N_total); Anions (Cl^-, SO_4^-, HCO_3^-); Cations (Na^+, K^+, Ca^{++}, Mg^{++}); in specific water samples Cu, Zn, Cd, Pb, As, Ba, Co, Cr, Mn, Ni and Fe were determined.

As an immediate result of a very extensive second campaign during Winter 2003, **more samples were collected for analysis than was envisaged for the entire project duration**. A preliminary evaluation and interpretation of this campaign was used to plan a much smaller but more targeted Summer 2003 Campaign for both lagoons. All sediment and soil samples collected during the first three sampling campaigns were analysed for 27 different elements (major and trace elements).

In the final, fourth campaign, conducted in May 2004, water samples were collected in a few, precise locations for trace element analyses, while for El Meleh, also a core drilling of sediments was achieved.

A geochemical interpretation based on the normalization of trace and major elements was used to produce a **present state water contamination map** in both lagoons. The approach is based on the determination of Enrichment Factors in order to obtain a global scenario, by taking into account natural variability and identifying anomalous trace elements.

The starting point for WP3 consisted in the drawing up of an inventory of factors affecting a) morphological changes and b) the mobility of pollutants, on the basis of a literature review.

Factors of particular relevance to the case studies were illustrated by means of several GIS derived layers for both lagoons: stratigraphic age, drainage network and landuse maps for both lagoons, a geomorphology map based on aerial photo interpretation for El Meleh and a slope map derived from a digital elevation model for Nador. As an immediate consequence, a **substantial increase of the database of regional maps** became available for both study areas. In parallel to this, the analytical database of results compiled in WP2 enabled the production of maps showing the distribution of major and trace elements in both lagoons.

Two groups of benthic organisms, ostracoda and foraminifera, were selected as tracers of the environmental conditions in the coastal lagoons, and the following aspects were accomplished: a) the taxonomic identification of the species present in

the different areas of both lagoons; b) an approximation to the analysis of the ecological assemblages, with the estimation of densities, diversities and the additional/secondary species; and c) the delineation of the areas occupied by the main assemblages.

The **delineation of the main ecosystem assemblages** in both lagoons, was then combined with the interpretation of the analytical results on water, sediments and soils. Based on the spatial variations of water parameters, sediment and soil properties and microfauna, a **morphodynamic scenario for both lagoons** emerged.

The delineation of zones with common characteristics in terms of pollution levels within each of the lagoons, was then evaluated in relation to the anthropogenic activities found within their catchment.

For Nador lagoon this resulted in the delineation of five zones. Among the major findings it emerged that the confined Beni Enzar-Atalayoum zone (NW part of lagoon) is characterized by a very high heavy metal pollution in the bottom sediments and the almost disappearance of the bottom microfauna, and is most likely caused by the absence of environmental controls on the tailing pond of Atalayoum the old iron mine. In the zone below, adjacent to the city of Nador, it was observed that the water treatment station makes use of extensive maturation ponds for the drying of excess sludge. This is considered as being the most likely cause of a slight increase in the heavy metal contents (mainly As, Cd, Cu, Mn, Pb and Zn) because it produces a permanent flow of heavy metals to the lagoon.

For El Meleh lagoon the integrated assessment resulted in no less than seven zones. In terms of pollution, the Slimene water treatment plant produces an important impact in the southwestern confined area of the lagoon, with the presence of polyhaline, nearly oligohaline waters with the highest nutrient concentrations of the lagoon. In this special area, the clayey-silty sediments present the highest concentrations in Cr and Cu of the lagoon, whereas Cd is more abundant at the point of discharge of the treated effluent into the lagoon. The presence of surface fresh waters and high brackish ostracods in the bottom indicate a partial water stratification in the very shallow waters. This situation is frequent in estuarine mouths, indicating that the treatment plant's effluent operates as a river in this limited space.

A the comparison of the previous results with two old bathymetrical maps of Nador and two historical earlier photographs of El Meleh, allowed to outline some **future trends in the evolution of both lagoons**. This revealed that in the case of Nador, it is essential to maintain the connection with the Mediterranean Sea through the sandy barrier. An interruption of the marine inputs will cause drastic changes in the lagoon ecosystem, an increasing filling, the immersion of numerous coastal areas and the acceleration of the natural evolution from the present lagoon to a broad sebkha. The trend in El Meleh suggests a continued, gradual isolation of the very shallow zones with permanent water from tidal fluxes and their conversion into salt marshes. While this process could be delayed if the inlet to the lagoon was enlarged, this type of alteration should be made subject of an evaluation of the ecological consequences. The progressive desiccation of El Meleh lagoon and the creation of a sebkha should always remain duly considered as the natural end of this geological process.

WP4 concerned the application of the **Life Cycle Assessment** (LCA), a standard tool to assess the environmental impact of a system from the production of raw materials to the disposal of the final waste products (ISO 14040). Three case studies were selected for the application of the LCA: the waste water treatment stations of Slimene and Nador, and Marost aquaculture in Nador lagoon.

Nador treatment plant treats the waste water of Nador city. Originally managed by the municipality, responsibility for its operation today lies with RADEEN, a semi-public entity. The treatment process is based on activated sludge. The analyses of treated water discharged into the lagoon is sub-contracted with INRH (National Institute of Halieutic Research), which warns RADEEN in the event standards are exceeded.

Slimene treatment plant treats both domestic and industrial wastewater and is managed by ONAS (Office National d' Assainissement). Unable to cope with the ever-increasing quantities of waste water it receives, both the treated and excess waste water are discharged in the El Meleh lagoon. To remedy this situation, a second treatment plant, based on the same, biological treatment, process was already under construction when the Colasu research started.

The Morrocan Company of Fishculture and Shellfishculture (MAROST) is a private fishery concern specializing in the cultivation of a wide range of fish and shellfish, including sea bass, sea bream, eel and oysters. As an export-oriented company, the company is strongly dependent on delivering products of the highest quality to its predominantly overseas customers, hence the priority concern the company gives to the preservation of the Nador lagoon ecosystem.

First, PhD students from Morocco and Tunisia together with 2 MSc students in Environmental Sciences received training in LCA and then progressed with the collection of data, which ended with a targeted water sampling campaign.

Each of the four logical steps that are found in the **classical LCA approach were achieved for the three case studies**: (1) goal and scope definition, (2) inventory analysis, (3) impact assessment, and (4) interpretation. This result could not have been achieved without the active support and assistance of RADEEN, ONAS and MAROST, who welcomed the Colasu researchers.

However, it became exceedingly clear that the main focus of attention within the overall scope of the Colasu research project does not lie with an industrial process or product, but rather with the respective lagoon ecosystems. With the knowledge that – overall - the heavy metal concentrations in lagoon water and sediments proved less substantial than envisaged prior to the start of the Colasu research project, it was opted to study a different type of environmental impact: the **aquatic eutrophication potential (AEP)**.

In this novel approach to the LCA, the Redfield Ratio was used to quantify the AEP in terms of nitrogen and phosphorous compounds. Interpretation of the findings indicated that for Nador lagoon, the prevalence of organic matter and nutrients in waste waters, the insufficient means of water treatment and the hydrodynamic functioning of the lagoon are likely to generate critical phases of eutrophication. For

El Meleh, the highest eutrophication potential was observed at the point where the treated waste water is released into the lagoon.

In conformity with the original objectives, WP5 was used to bring together a summary of the outputs of all previous workpackages, starting from an outline description of the harmful effects of individual heavy metals on human health; and good practice for the identification of heavy metals in water, sediments and soils.

The description of the case studies is aimed at demonstrating the use of two distinct tools that were used in Colasu for the purpose of lagoon management: the Geographic Information System (GIS) and the Life Cycle Assessment (LCA). The former documents the substantial increase that was achieved in terms of regional maps, i.e. at the lagoon catchment scale, as required for the integrated environmental assessment and the approach to the future evolution of both lagoons.

A review of the application of the LCA at the site specific scale, i.e. for the Nador and Slimene water treatment plants as well as for the Marost fishery, is followed by a presentation of the **Colasu research into the possible coupling of LCA with GIS**. It is considered most worthwhile that the research into a possible coupling or linkage between the "site specific" and the "catchment scale", **was at the basis of the development of a new approach to the LCA**, in which it is recognized that the system under investigation is not an industrial process but an ecosystem.

The strength of the novel approach to the LCA, lies with its capacity to determine on which inputs (impacts) efforts should be concentrated to protect and conserve the fragile, lagoon environment. However, more in-depth research is needed, for example to arrive at the temporal boundaries of the system under investigation, i.e. the residence time of pollutants.

Finally, in terms of lagoon management, the "site specific" scale provides guidelines, drawn up in the format of technical cards, aimed particularly to assist the authorities concerned with the management of aquaculture and wastewater treatment, while the recommendations for the sustainable management of the lagoons at the "catchment scale" are likely to be of interest to a larger group of stakeholders concerned with the management of coastal zones.

In addition to two Moroccan and Tunisian PhD, two MSc on Colasu, the AUF (Agence Universitaire de la Francophonie) has awarded a PhD bursary to study the impact of heavy metals and pesticides on El Meleh lagoon. This thesis will employ the LCA, adapted in Colasu to study an ecosystem rather than an industrial process, and will continue to monitor the pollution transfer within the lagoon until 2007, i.e. up to two years after the end of the Colasu project.

Consolidated Scientific Report

Introduction

The overall Colasu Workplan distinguishes between six Workpackages, each of which has been the object of Annual Progress and/or a Final Report as shown in the Table 1 below. For easier cross-referencing, the present report reviews the objectives, activities, and the results achieved according to this division in six Workpackages.

Workpackages	**Report type**	**Submitted with**
WP1 Study Areas	**Final** Report: Deliverables	Year 1 Report
WP2 Data Collection	**Annual Progress** Report: Tasks **Final** Report: Deliverables	Year 1&2 Reports **Final Report Annex 2**
WP3 Ecosystem Functioning	**Annual Progress** Report: Tasks **Final** Report: Deliverables	Year 1&2 Reports **Final Report Annex 3**
WP4 Global Diagnosis	**Annual Progress** Report: Tasks **Final** Report: Deliverables	Year 1&2 Reports **Final Report Annex 4**
WP5 Lagoon Management	**Final** Report: Deliverables	**Final Report Annex 5**
WP6 Coordination	**Minutes of Meetings** - organized during Year 3	Year 1&2 Reports **Final Report Annex 1**
	Publications - issued during Year 3	Year 2 Report **Final Report Annex 6**

Table 1 Structure of Annexes to Final Report

A recapitulation of the Meetings held during the course of project is presented in the Management Report, which also includes a synthesis of the tasks performed and their outcome with respect to the interaction between the Consortium and the Stakeholders and End-users relevant to the Colasu project.

Objectives

Within the overall objective to assess and forecast the possible future morphodynamic and geochemical evolution scenario of the Nador and El Meleh lagoon ecosystems and to furnish tools to help decision makers, the following objectives have been envisaged:

- WP1 is aimed at bringing together available scientific literature data and present socio-economic data, the characterization of the geomorphological past and present state and the geological background
- WP2 concerns the collection of present state data, i.e. sampling of soils, sediments and water, analysing the samples using physical, chemical and biochemical approaches in order to produce maps showing the pollution distribution in water and sediments
- WP3 is aimed at the interpretation of the above data with the objective to provide a description of the morphodynamic scenario; to assess the anthropogenic impacts according to the present pollution levels and the evolutionary trends in the last

decades; and to forecast the future natural and/or human-induced changes of the two lagoons.
- WP4 targets an appraisal of the environmental impacts of two pre-selected types of anthropogenic activities and the sustainability of the lagoons
- WP5 reviews all the information provided by the previous workpackages with the purpose to produce guidelines for decision-makers.

It should be noted that the originally foreseen objectives in terms of coordination among the partners in the Colasu Consortium (WP6) were extended with the aim to establish an active dialogue and collaboration with the stakeholders and end-users throughout the lifetime of the project.

Activities

Table 2 below provides a schematic review of the tasks achieved for each of the Workpackages as well as each partner's involvement towards their completion. While the column 'Tasks' are reproduced from the Technical Annex, the column 'Workplan' shows the reference to the task numbers as adopted at the coordination meetings.

	Task leader	Tasks	Workplan	Completed	Task performed by
Work Package 1 Leader P4	P4	Bibliographic synthesis	Task 1.1 (f)	All relevant domains, 65 pages	Input by all partners, compiled by **P1**
	Added Task	Inventory of Base Maps	Task 1.1 a	Nador 3 sheets El Meleh 1 sheet	Format by **P2** Filled by **P3**, **P4**
	P3, **P4**	Geological map	Task 1.2	Nador, El-Meleh 1 map each with table	Supplied by **P3**, **P4**, digitized by **P2**
	Added Task	Inventory Matrix on Geology	Task 1.2 a	Nador 1 sheet El Meleh 1 sheet	Filled by **P3**, Filled by **P4**, Harmonized by **P2**
	P4, **P3**	Geomorphology map	See Task 3.3	El Meleh (See WP3 report)	
		Geomorphology study	Task 1.3	Nador 13 pages	Drawn up by **P3**
	P4, **P3**	Hydrogeological study	Task 1.4	Nador 10 pages; El Meleh 8 pages	Drawn up by **P3**, Drawn up by **P4**
	P2	Legislative framework comparative analysis	Task 1.5	Morocco, Tunisia 14 pages	Drawn up by **P2**, confirmed by **P3**, **P4** respectively
	P1 (P12)	Inventory of anthropogenic pollution activities	Task 1.6	Introductory text 4 pages Harmonized Inventory	Drawn up by **P12**, with input from **P2** & confirmed by **P3**, **P4-P10**
	P1 (P12)	Socio-economic context study	Task 1.7	Nador 10 pages; El Meleh 6 pages, Translated Report 8 pages	Drawn up by **P3**, **P10** , translated and harmonized by **P12**

	Task leader	Tasks	Workplan	Completed	Task performed by
Work Package 2 Leader P6	P4, P3	Sampling of soils, sediments and water	**Sampling Campaigns** **I** Summer 02 **II** Winter 03 **III** Summer03 **IV** May 04 a) Transects, Location b) Collection of samples c) Laboratory analysis d) Prelim. evaluation and inter-pretation	**Final Report** of 31 pages, covering: - review of four sampling campaigns - Methods used for sampling analysis - Geochemical database - Contribution to geochemical interpretation: present state water contamination map	Drawn up by P6 with inputs from P1, P3, P4 & P5
	P4, P3	Analyses of water			Database compiled by P6, transferred into GIS by P2
	P5	Mineralogical and geochemical analyses of soils and sediments			- preliminary interpretation and evaluation of Winter 03 by P5
	P3	Ostracoda and foraminifera study	Interpretation of these data transferred to WP3 tasks	Analytical results in Year 2 Report	Supplied by P5
	P3	Sedimentological analyses			Supplied by P4
	P2	Satellite image interpretation	Transferred to WP3		Purchase of images by P1
	Task leader	**Tasks**	**Workplan**	**Completed**	**Task performed by**
W P 3 Leaders P3 & P5	P3	Present morphodynamic scenario	Interpretation of analytical results collected in WP2 Tasks T3.1 to T3.6 - Factors - Sedimento-logical study - Geomorpho-logical study - Hydrological study - Geomorpho-logical and Geochemical evolution scenarios	**Final Report** of 32 pages, covering: - General features - Interpretation of analytical results pertaining to water, sediments and soils, ostracoda and formanifera, leading to - ecological zonation, - integrated environmental scenario and approach to future evolution of both lagoons **Note:** maps with distribution of trace elements in both lagoons submitted with Year 2 Report	Drawn up by P5 with inputs of specific studies on water analyses (P3 and P4), mineralogy (P1), chemical analyses of sediments and soils, and micro-paleontology (P5), geomorphology map from aerial photo interpre-tation (P2), anthropogenic activities (P1-P12 and P4-P10) and GIS layers: geology, digital elevation model, drainage network, landuse (P2)
	P5	Present bioavailability and toxicity			
	P3, P5	Contamination/ morphodynamics assessment			

	Task leader	Tasks	Workplan	Completed	Task performed by
WP 4 Leader P1 (P12)	**P12**	Life Cycle Inventory	Tasks T4.1 to T4.8 - Training on LCA - LCA data requirements - Data collection for LCA Inventory - Location map & attribute data on AA - LCA on selected activities	**Final Report** of 66 Pages, covering: - LCA applied to three case studies a) Nador water treatment plant b) MAROST fishery c) Slimene water treatment plant - **new approach to LCA**: applied to lagoon ecosystem **Notes** - Training material - industries in El Meleh study area	Report drawn up by **P12** **Notes** - Parallel inputs by **P12** and **P2** on coupling between LCA with GIS taken up in WP5 - Training notes by **P12** & - AA Inventory and report by P4 **(P10)** presented in Year 2 Report
	P12	Life Cycle Impact Assessment			
	Task leader	**Tasks**	**Workplan**	**Completed**	**Task performed by**
WP 5 Leader P2	**P2**	Elaboration of decision making tool	Tasks T5.1 to T5.4 - Good practice in sampling & analyses - Presentation of decision-making tools - Database of maps (GIS) - Technical cards (LCA) **Note**: active engagement of non-funded partners	**Final Report** of 65 Pages, covering: - Heavy metals in the environment - Review of Case Study findings at 1) catchment scale (GIS based) 2) site specific scale (LCA) - Coupling of LCA with GIS - Summary of recommendations at site specific and catchment scale	Report drawn up by **P2** with inputs from **P6** (good practice on data collection), **P5** (WP3 outputs), and **P12** (WP4 outputs). **Note**: outputs based on active discussions and collaboration with RADEEN, ONAS and Marost fishery, and assistance from ANPE
	P2	Elaboration of technical cards			
	P2	Elaboration of guidelines			
	P7, P8	Impact measurement, feedback test			

Table 2 Schematic review of Tasks and Partner's inputs

Results achieved

WP1 Study areas

The study areas are Nador lagoon in Morocco, the second largest lagoon of northern Africa (115 km^2), and El Meleh, a small coastal lagoon (200 Ha) located near the town of Slimene in Tunisia.

The bibliographic synthesis achieved in WP1 brings together a clear overview of the different fields of expertise brought together by the various partners in the Colasu Consortium. All deliverables in WP1 taken together provide a **detailed insight into the existing knowledge on both lagoons** from a climate, geological, geomorphological, hydrogeological, legislative and socio-economic point of view.

The design and use of a standard scientific matrix to document existing information and particularly to document the available maps for both lagoons provided another important result.

Through the **direct consultation with various stakeholders** in Tunisia, it was decided to consider a much larger catchment area (and hence additional topography and geology maps) for El Meleh while maps at a much more detailed scale were acquired and digitised for Nador lagoon.

WP2 – Data Collection

Sampling campaigns of different types of samples (water, sediment, soil) constituted a very important component of this project, as these provided essential information to establish possible evolution scenarios. Considerable attention was therefore given to the formulation of a **sampling protocol**, which among other, provided **standardized criteria** to document the sample collection during fieldwork for both lagoons and to report on the various analyses, performed at the different partner laboratories, as needed for the compilation of a **database of analytical results**.

Sediment, soil and parent rock samples for each of the campaigns were analyzed by different methods according to the established protocol. The main methodological approaches included:

- chemical composition of selected elements for sediments, soils and parent rock samples (INAA and ICP-OES),
- mineralogical composition of selected soils and sediments samples (X-ray diffraction of bulk sample and < 2 µm fraction),
- micropaleontology, organics, mobility, bioavailability and Fe speciation (Mössbauer spectroscopy) in selected sediments samples.

For water samples the analyses comprised (including in situ measurements):

Water column; pH in situ; Temperature (°C); Eh; Salinity (‰); Conductivity (mohs); Dissolved O_2 (mg/l); Suspended matter (mg/l); Nutrients (PO_4, P_organic, P Total, NO_3, NO_2, NH^+_4, N_Kjeld, N_organic and N_total); Anions (Cl^-, SO_4^-, HCO_3^-); Cations (Na^+, K^+, Ca^{++}, Mg^{++}); in specific water samples Cu, Zn, Cd, Pb, As, Ba, Co, Cr, Mn, Ni and Fe were determined.

During the first year of the project **more samples were collected for analysis than was envisaged for the entire project duration**. All sediment and soil samples collected during the first three sampling campaigns (see Table 4) were analysed for 27 different elements (major and trace elements).

Nador Sampling Campaigns			El Meleh Sampling Campaigns		
Summer 02	Winter 03	Summer 03	Summer 02	Winter 03	Summer 03
25	107	19	18	41	8

Table 4 Number of sediment and soil samples analysed for trace elements

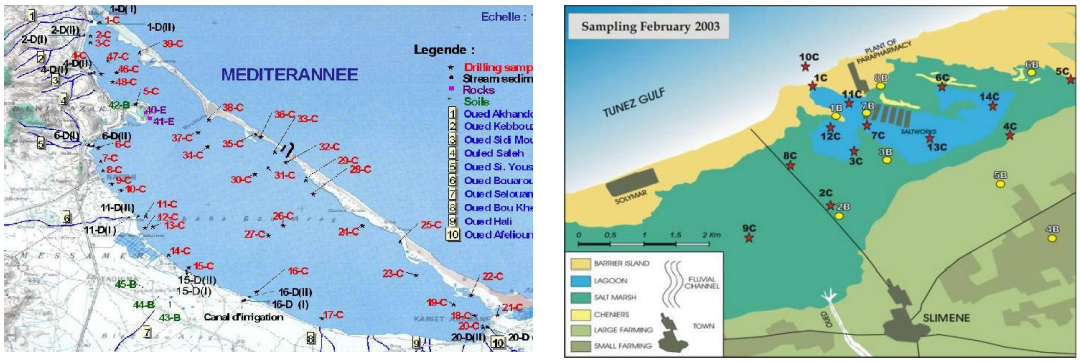

Fig. 1 Winter 2003 Sampling location of sediments and soils in Nador and El Meleh

The preliminary evaluation and interpretation of the Winter 03 Campaign (see Fig. 1) was used to plan a much smaller but more targeted Summer 03 Campaign for both lagoons. Considering the trace elements absolute contents in the lagoon sediments of the Winter 2003 campaigns for both lagoons, it was decided that no Winter 2004 campaign was necessary for chemical analysis of soils and sediments, in accordance with the sampling protocol established during Year 1.

With regard to the final, fourth campaign, conducted in May 2004, it was decided to collect only selected samples in precise locations. Thus, for El Meleh, a few water samples were collected, as well as a core drilling of sediments for specific analysis. For Nador only some water samples were collected.

A geochemical interpretation based on the normalization of trace and major elements was used to produce a **present state water contamination map** in both lagoons. The approach is based on the determination of Enrichment Factors in order to obtain a global scenario, by taking into account natural variability and identifying anomalous trace elements.

WP3 – Ecosystem Functioning

The starting point for this Workpackage consisted in the drawing up of an inventory of factors affecting a) morphological changes and b) the mobility of pollutants, on the basis of a literature review.

Factors of particular relevance to the case studies were illustrated by means of several GIS derived layers for both lagoons: stratigraphic age, drainage network and landuse maps for both lagoons, a geomorphology map based on aerial photo interpretation for El Meleh and a slope map derived from a digital elevation model for Nador. As an immediate consequence, a **substantial increase of the database of regional maps** became available for both case studies. In parallel to this, the analytical database of results compiled in WP2 enabled the production of maps showing the distribution of major and trace elements in both lagoons.

Two groups of benthic organisms, ostracoda and foraminifera, were selected as tracers of the environmental conditions in the coastal lagoons, and the following aspects were accomplished: a) the taxonomic identification of the species present in the different areas of both lagoons; b) an approximation to the analysis of the ecological assemblages, with the estimation of densities, diversities and the additional/secondary species; and c) the delineation of the areas occupied by the main assemblages.

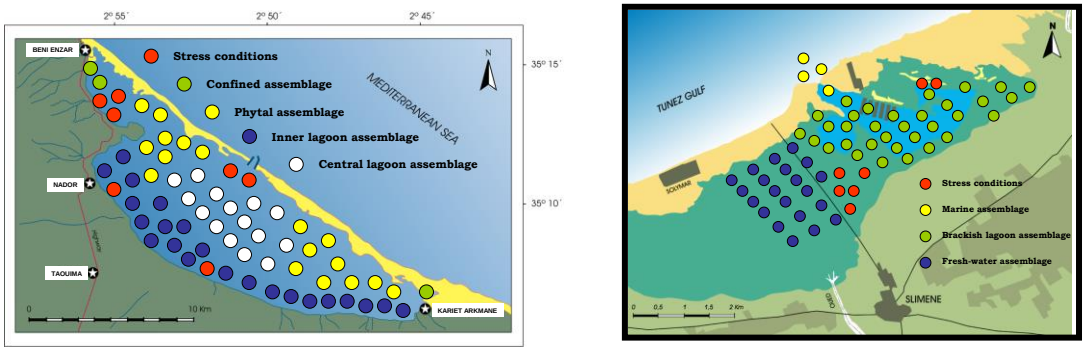

Fig 2 Ecological zonation of Nador and El Meleh lagoon

The **delineation of the main ecosystem assemblages** in both lagoons (see Fig 1), was then combined with the interpretation of the analytical results on water, sediments and soils. Based on the spatial variations of water parameters, sediment and soil properties and microfauna, a **morphodynamic scenario for both lagoons** emerged.

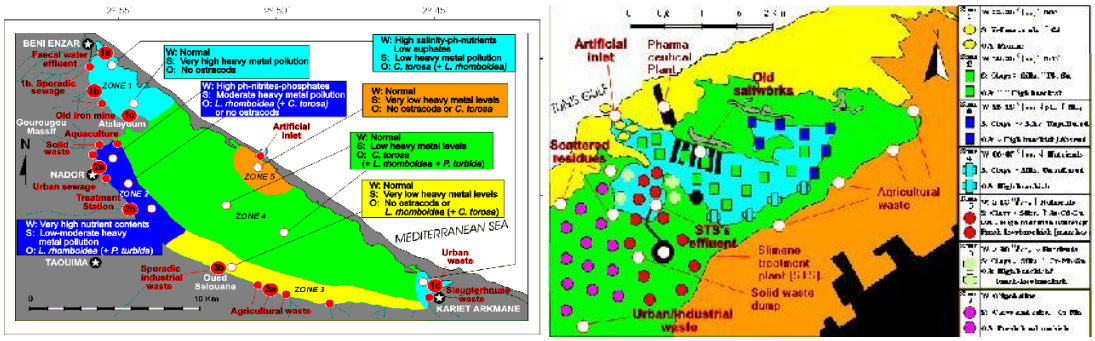

Fig. 3 Integrated Environmental Assessment of Nador and El Meleh lagoon
W: Water, S: Sediment, O (OA): Ostracod assemblage

The delineation of zones with common characteristics in terms of pollution levels within each of the lagoons, as shown in Fig. 3, was then evaluated in relation to the anthropogenic activities found within the catchment of the lagoons. Some of the major findings are presented here.

In Nador lagoon, the upper left of the five zones that emerged is characterized by a very high heavy metal pollution in the bottom sediments and the almost disappearance of the bottom microfauna, most likely caused by the absence of environmental controls on the tailing pond of the Atalayoum old iron mine. The zone shown in blue is host to the Nador treatment station which makes use of maturation ponds for the drying of sludge. This is considered as being the cause of a slight increase in the heavy metal contents (mainly As, Cd, Cu, Mn, Pb and Zn) because it produces a permanent flow of heavy metals to the lagoon.

For El Meleh lagoon the integrated assessment resulted in no less than seven zones. In terms of pollution, the zone marked in red shows the highest levels. This confirms that the Slimene water treatment plant produces an important impact in the southwestern confined area of the lagoon, with the presence of polyhaline, nearly oligohaline waters with the highest nutrient concentrations of the lagoon. In this special area, the clayey-silty sediments present the highest concentrations in Cr and Cu of the lagoon, whereas Cd is more abundant near the STS´s effluent. The presence of surface fresh waters and high brackish ostracods in the bottom indicate a partial water stratification in the very shallow waters. This situation is frequent in estuarine mouths, indicating that the treatment plant's effluent operates as a river in this limited space.

Finally, the comparison of the previous results with two old bathymetrical maps of Nador and two historical earlier photographs of El Meleh, allowed to outline some **future trends in the evolution of both lagoons**. This revealed that in the case of Nador, it is essential to maintain the connection with the Mediterranean Sea through the sandy barrier. An interruption of the marine inputs will cause drastic changes in the lagoon ecosystem, an increasing filling, the emersion of numerous coastal areas and the acceleration of the natural evolution from the present lagoon to a broad sebkha. The trend in El Meleh suggests a continued, gradual isolation of the very shallow zones with permanent water from tidal fluxes and their conversion into salt marshes. While this process could be delayed if the inlet to the lagoon was enlarged, this type of alteration should be made subject of an evaluation of the ecological consequences. The progressive desiccation of El Meleh lagoon and the creation of a sebkha should always remain duly considered as the natural end of this geological process.

WP4 – Global Diagnosis

This fourth Workpackage is concerned with the application of the **Life Cycle Assessment** (LCA), a standard tool to assess the environmental impact of a system from the production of raw materials to the disposal of the final waste products (ISO 14040). Three case studies were selected for the application of the LCA: the waste water treatment stations of Nador and Slimene, and Marost aquaculture in Nador lagoon.

Nador treatment plant treats the waste water of Nador city. Originally managed by the municipality, responsibility for its operation today lies with RADEEN, a semi-public entity. The treatment process is based on activated sludge. The analyses of treated water discharged into the lagoon is sub-contracted with INRH (National

Institute of Halieutic Research), which warns RADEEN in the event standards are exceeded

Slimene treatment plant treats both domestic and industrial waste water and is managed by ONAS (Office National d' Assainissement). Unable to cope with the ever-increasing quantities of waste water it receives, both the treated and excess waste water are discharged in the El Meleh lagoon. To remedy this situation, a second treatment plant, based on the same biological treatment process was already under construction when the Colasu research started.

The Moroccan Company of Fishculture and Shellfishculture (MAROST) is a private fishery concern specializing in the cultivation of a wide range of fish and shellfish, including sea bass, sea bream, eel and oysters. As an export-oriented company, the company is strongly dependent on delivering products of the highest quality to its predominantly overseas customers, hence the priority concern the company gives to the preservation of the Nador lagoon ecosystem.

First, PhD students from Morocco and Tunisia together with 2 MSc students in Environmental Sciences received training in LCA and then progressed with the collection of data, which ended with a targeted water sampling campaign.

Each of the four logical steps that are found in the **classical LCA approach were achieved for the three case studies**: (1) goal and scope definition, (2) inventory analysis, (3) impact assessment, and (4) interpretation. This result could not have been achieved without the active support and assistance of RADEEN, ONAS and MAROST, who welcomed the Colasu researchers.

However, it became exceedingly clear that the main focus of attention within the overall scope of the Colasu research project does not lie with an industrial process or product, but rather with the respective lagoon ecosystems. A schematic presentation of this **novel application of the LCA approach to an ecosystem** is shown in Fig. 4.

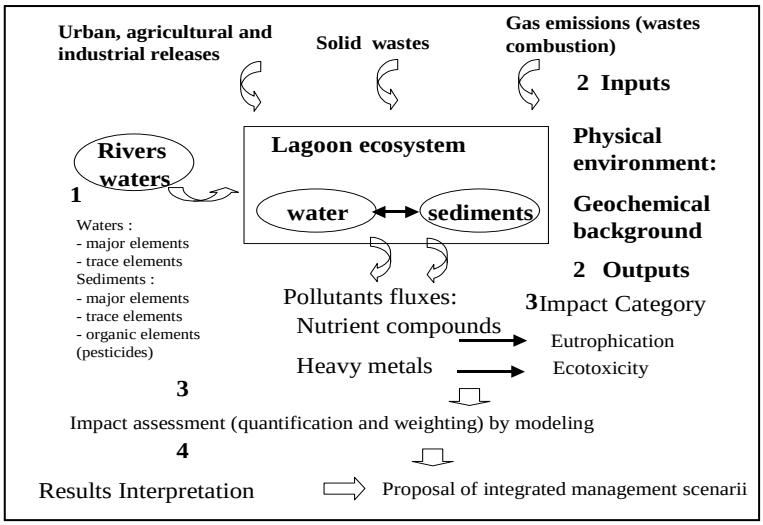

Fig. 4 LCA methodology applied to an ecosystem: a novel approach

With the knowledge that heavy metal concentrations in lagoon water and sediments proved less substantial than envisaged prior to the start of the Colasu research project, it was opted to study a different type of environmental impact: the **aquatic eutrophication potential (AEP)**.

Using the Redfield Ratio to quantify the AEP in terms of nitrogen and phosphorous compounds indicated that for Nador lagoon, the prevalence of organic matter and nutrients in waste waters, the insufficient means of water treatment and the hydrodynamic functioning of the lagoon are likely to generate critical phases of eutrophication. For El Meleh, the highest eutrophication potential was observed at the point where the treated waste water is released into the lagoon.

WP5 Lagoon Management

In conformity with the original objectives, this final workpackage was used to bring together a summary of the outputs of all previous workpackages, starting from an outline description of the harmful effects of individual heavy metals on human health; and good practice for the identification of heavy metals in water, sediments and soils.

The description of the case studies is aimed at demonstrating the use of two distinct tools that were used in Colasu for the purpose of lagoon management: Geographic Information System (GIS) and Life Cycle Assessment (LCA). The former documents the substantial increase that was achieved in terms of regional maps, i.e. at the lagoon catchment scale, as required for the integrated environmental assessment and the approach to the future evolution of both lagoons.

A summary review of the application of the LCA at the site specific scale, i.e. for the Nador and Slimene water treatment plants as well as for the Marost fishery, is followed by a presentation on the **possible coupling of LCA with GIS**. It is considered most worthwhile that the research into a possible coupling or linkage between the "site specific" and the "catchment scale", was **at the basis of the development of a new approach to the LCA**, in which it is recognized that the system under investigation is not an industrial process but an ecosystem.

The strength of the novel approach to the LCA, lies with its capacity to determine on which inputs (impacts) efforts should be concentrated to protect and conserve the fragile, lagoon environment. However, more in-depth research is needed, for example to arrive at the temporal boundaries of the system under investigation, i.e. the residence time of pollutants.

Finally, in terms of lagoon management, the "site specific" scale provides guidelines, drawn up in the format of technical cards, aimed particularly to assist the authorities concerned with the management of aquaculture and wastewater treatment, while the recommendations for the sustainable management of the lagoons at the "catchment scale" are likely to be of interest to a larger group of stakeholders concerned with the management of coastal zones.

Selected Publications on Colasu

RUIZ F., ABAD M., BODERGAT A.M., CARBONEL P., RODRÝ´GUEZ-LA´ZARO J., YASUHARA M. - Marine and brackish-water ostracods as sentinels of anthropogenic impacts. ***Earth-Science Reviews 2005. Accepted for publication 4 May 2005, pp.23***

PRUDÊNCIO M. I., GONZALEZ M. I., DIAS M. I., GALAN E., RUIZ F., DUPLAY J., GUEDDARI F., AHMED R. - ***Geochemistry, mineralogy and micropaleontology of sediments from El Meleh lagoon, Tunisia.*** Goldschmidt Conference Abstracts 2005, Environmental Geochemistry / Mineralogy**.** ***Geochimica et Cosmochimica Acta, Volume 69, Issue 10, Supplement 1, Page 817 (15 May 2005)***

HADJ AMOR R., QUARANTA G., GUEDDARI DARRAGI F. and CLAUER N - ***Life Cycle Impact Assessment (LCA): Preliminary evaluation of the Aquatic Eutrophication Potential of the coastal lagoon of Slimane (Tunisia).*** (Poster) **–** SETAC EUROP 15th Annual Meeting, ***Lille, 22-26 May 2005***

DE KETELAERE D. and SPITERI A. – ***Utilising GIS to meet the expectations of the local community.*** Poster 1 El Meleh, Tunisia & Poster 2 Nador, Morocco. 11th EC-GI&GIS Workshop – ESDI:Setting the Framework, ***Alghero, Sardinia, 29 June - 1 July 2005, Abstracts Page 163***

QUARANTA G., BLOUNDI K. and DUPLAY J **-** ***LCA: A tool for integrated Mediterranean coastal zone management. Part 1 Conceptual Basis.*** Ocean and Coastal Management, Journal published by Elsevier, submitted May 2005

QUARANTA G., BLOUNDI K. and DUPLAY J - ***LCA: A tool for integrated Mediterranean coastal zone management. Part II The Case study of Nador lagoon – Morocco***. Ocean and Coastal Management, Journal published by Elsevier, submitted May 2005

RUIZ F., ABAD M., GALÁN E., GONZÁLEZ I., ÁGUILA E., OLIAS M., GÓMEZ ARIZA J.L. **–** ***The present environmental scenario of El Melah Lagoon (NE Tunissia): Evolution from a past open lagoon to a future Sabkha.*** Journal of African Earth Sciences. Submitted 7 January 2005.

RUIZ F., ABAD M., OLIAS M., GALÁN E., GONZÁLEZ I., ÁGUILA E., HAMOUMI N., BOUMAGGARD E.H., BOUAMTERHANE I. **–** ***The present environmental scenario of the Nador Lagoon (Morocco).*** Marine Pollution Bulletin. Submitted 14 February 2005.