United Nations
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UNEP/WG.170/7
20 May 1987

Original: ENGLISH

MEDITERRANEAN ACTION PLAN

Meeting of the National Focal Points for
Priority Actions Programme (PAP)

Split, 24-26 June 1987

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# DEFINITION OF ECOLOGICAL CRITERIA FOR THE RATIONAL DEVELOPMENT OF AQUACULTURE IN MEDITERRANEAN COASTAL AREAS

(A Project Proposal)

In co-operation with:

F A O

Priority Actions Programme
Regional Activity Centre
April, 1987

# DEFINITION OF ECOLOGICAL CRITERIA FOR THE RATIONAL DEVELOPMENT OF AQUACULTURE IN MEDITERRANEAN COASTAL AREAS

11 May 1987

# DEFINITION OF ECOLOGICAL CRITERIA FOR THE RATIONAL DEVELOPMENT OF AQUACULTURE IN MEDITERRANEAN COASTAL AREAS

A Project Proposal

## 1. INTRODUCTION

The potentialities of the Mediterranean coastal environments for the development of aquaculture have only recently been fully recognized. With this recognition, almost all the countries have implemented or are in the process of planning substantial aquaculture activities.

This process should be seen in the broader context of the "littoralization" which is affecting the entire area. Aquaculture, in fact, is but one of many productive activities that are exploiting more and more fully the natural resources of the coastal environments. Unfortunately, the development of aquaculture, especially in its more modern forms, has so far been seen primarily as a biotechnical problem, even though the objectives are generally spelled out in socio-economic terms. Potential interactions with other productive activities, particularly where those are mediated by environmental effects, have been little considered.

The programme proposed herein is designed to help the governments of the Mediterranean to plan and carry out appropriate actions to ensure that environmental and broad socio-economic considerations are adequately considered along with more strictly economic and bio-technical issues, in the course of promoting aquaculture.

### 1.1 Aquaculture in the Mediterranean

Although fish and shellfish have been cultured in marine waters in the region for five or six centuries, it has only been recently that intensive, more fully controlled forms of aquaculture have been attempted, and then mostly in the northwestern part. The region has had close links technologically and economically with Europe. It has, however, particular geographic and hydrobiological characteristics which dictate particular forms of aquaculture, especially in marine waters.

At least for the near future, only sites well protected from storm wave action are practical for culture purposes. This limits appropriate sites to three types: lagoons, estuaries, and sheltered coastal zones.

1.1.1 Ecological factors

The open waters of the Mediterranean are relatively low in nutrients. Nevertheless, many of the lagoonal or estuarine areas receive nutrients from land-based sources. Hence those sites suitably protected for aquaculture purpose are often also those of higher nutrient concentrations. For the same reasons, however, they may also be more subject to various types of pollutants.

The temperature is also favourable, varying from about 5°C in winter to 27°C in summer, but the northern and western parts are generally colder than the southern and eastern parts. Salinity is usually high (between 36-38 g/l).

1.1.2 Historical and economic factors

Marine aquaculture development started in Italy, in the delta of the Po River, and in Egypt, in the Nile Delta, many centuries ago through the progressive improvement of lagoon fisheries for mullet, sea-bass, sea bream and eels that migrate into coastal lagoons in spring and back to the sea in the autumn. The natural productivity of the lagoons provided excellent conditions for growth, and the techniques employed consisted primarily of improvements in the channelization of water and in the traps used to catch the fish as they returned to the sea.

During the last 15 to 20 years a new type of aquaculture has developed in the region, similar to intensive animal breeding and husbandry. To date, such "intensive" aquaculture has only proved economically interesting for relatively high priced species, owing to the high input costs and greater risks associated with disease or unusual climatic conditions. Reproduction in artificial conditions has proved particularly difficult for marine fishes. Nevertheless, there is considerable promise for such cultures in the near future. At present, there are also intermediate forms of management and culture of good quality fish and shellfish products which are suitable for protected marine waters.

1.1.3 Demand

The Mediterranean countries enjoy relatively good economic conditions, with a GNP/inhabitant/year of over $500. The food and protein consumption per capita is also high with the exception of Morocco and Egypt. Thus the demand for seafood is selective, and the common coastal fish suitable for culture enjoy high prices. While only about 8 percent of the total Mediterranean production of fish and shellfish is derived from aquaculture, their value approaches 20 percent of the total.

While there should not be major marketing problems for these species, at least until the expected increase of 20 to 30 000 tons is reached over the next 10-15 years, a number of the countries with significant potential do not yet have the market experience and facilities needed to tap the best markets.

### 1.1.4 Types of production systems

Valliculture. The gradual improvement of simple methods of managing the lagoon fisheries of the northern Adriatic led to what is called vallicultura, a system of management in which water and salinity levels are controlled, small fish or "fry" are collected and stocked in special embanked areas (valli arginate). Fish are selected and harvested in complex weirs, while undersized fish are held back to pass the winter in deep trenches to be released back to the "valli" to grow another summer. Still being improved, this is at present the main type of commercial production of finfish.

Pond culture. Culture of marine fish in ponds is a recent development, but is being put into practice on a large scale in Israel, Italy, Egypt, France, and Spain. Production is usually "semi-intensive", that is, using earthen ponds provided with sea water at ambient temperature and salinity, and stocked with wild or artificially produced fry or larger fish. Supplementary feed is usually provided, but for some species, natural food produced within the pond by fertilization is the main source.

Cage culture. Floating cages or fenced enclosures are being used on a semi-commercial basis, especially for sea bass and sea bream, in France, Yugoslavia, and Israel, and on an experimental basis in Cyprus and Tunisia. The cages are used for growout of either wild-caught or hatchery produced fry. Feed is provided, either as minced fish, or various types of pellets.

Closed systems. Highly sophisticated closed or partly closed systems employing various types of tanks provided with high quality water at optimal temperature and salinity are being employed in France and Italy with increasing success for the intensive culture of seabass and seabream, and in Italy, also for eels.

Mollusc culture. Oysters and mussels are grown on a commercial scale in several countries, especially in Italy, France, and Spain. Owing to the small tidal amplitude, suspension from fixed structures is usually used, but floats or rafts are also sometimes employed. Clams are being produced on a small scale where the substrate and currents are suitable. They are cultured on-bottom.

Others. Several other forms of aquaculture, either combining some of the above techniques with the use of waste waters or heated effluents, or combining several species together for improved utilization of food and space, are under development in the region.

### 1.1.5 Current production

The total production from aquaculture in the Mediterranean in 1985 is estimated at about 95 000 metric tons. Of this, about 80 000 was oysters and mussels. The balance were fish produced in managed lagoons, including valliculture. The intensive or semi-intensive production of marine fish, though expanding, is still only a few hundred tons.

## 1.2 Aquaculture and the Environment

As evident from the foregoing discussion, most aquaculture is at present being carried out in ways which are to a considerable degree dependent on the resources of the site itself, i.e. water, nutrients, and even feed. Thus the selected site must provide these resources in the appropriate amounts and quality for the kind of culture to be practised. The maintenance of these initially suitable ecological conditions is, in itself, a limit for the development of aquaculture, as no undue stress should be caused on the environment and on other activities at or near the site.

### 1.2.1 Interactions with other activities

Fisheries. In the minds of the public and the majority of political and administrative leaders aquaculture and fisheries are closely connected. Not infrequently this creates confusion in policy and decision-making. While there is considerable interaction between the two, particularly where they are both practised in the same or contiguous areas, they differ markedly in the spatial scales at which they operate, and in the number and kinds of parameters which the producer (operator or manager) attempts to modify or control to orient production to a particular product or products. Accordingly, there are often marked distinctions between fishermen and fish farmers and the respective social institutions with which they associate. Conflicts may arise over use of territory, use of the biogical and/or human resources, use of financial resources, and marketing of their products. The latter is of particular importance to aquaculturists as, in the initial stages of culture, availability and hence price of the product is determined by the economics of fishing rather than of its production through culture.

While these competitive interactions are important, it is important to note that they are mostly limited. This may partly occur through differention in the marketplace with respect to time or place of delivery; and with respect to size, uniformity or quality of product. Sound management of lagoons or other coastal areas of the Mediterranean should generally promote parallel development of fisheries and culture, possibly even through the various forms of integration which are possible and feasible.

Agriculture. Few forms of aquaculture are likely to compete with agriculture in the land market, especially those that require saline water. Where agriculture can be practiced on the same land, its actual use will generally be determined by the relative profit of water vs land farming, a factor which has been shown to undergo considerable change over relatively short periods of time. More usually, aquaculture will be sited on low valued land (saline or waterlogged), or, for saltwater species, close to the sea.

Indeed for salt water cultures, a good supply of freshwater as well as of saltwater will be required.

Agricultural by-products can often be utilized in aquaculture. But, at the same time, various feed ingredients, fertilizers or other inputs needed for agriculture, are used also for fish.

Tourism. Adverse interactions between aquaculture and tourism are generally only to be expected with cages or pens, where these are sited in protected bays or similar scenic sites or sites with high value for water sports. More often, however, it will be the less attractive lagoonal or marshy sites that will be selected for aquaculture. Conversely, the impact of tourism may affect water quality adversely and create nuisance problems for the fish farmer. Nevertheless, tourism may supply an important market for aquatic products. Careful planning and zoning is thus a necessity for rational development of aquaculture.

Urbanization. In contrast to the other interactions discussed, there is little possibility for aquaculture in heavily urbanized areas, except perhaps, as explained above, where and when an "industrial" level, fully controlled and very intensive production system is economically justifiable.

1.2.2 Potential impacts of aquaculture

Construction. Site development and construction are not likely to produce serious adverse impacts on surrounding land or water areas, except where large, semi-intensive or intensive farms are constructed with considerable concrete work. Even then the scale of impact is small, and can be further limited by care in the design and techniques employed for construction.

Biological Impact. A very important potential impact of aquaculture is the problem of inadvertent introduction of diseases of fish or shellfish as a result of importation of stocks from other regions. The near destruction of the European flat oyster stocks by two successive disease outbreaks in the 70's and the severe effects of crayfish plague in Northern Europe and more recently in Turkey are dramatic examples, but similar problems also affect the culture of salmon and trout. The introduction of new species for aquaculture purposes may also inadvertently result in serious problems. The impacts of such introductions are very difficult to predict.

The discharge of toxic materials to water from aquaculture is more readily controlled, once the existence of the substance is demonstrated and its source identified. To date, few such problems have arisen. The adverse environmental affects of antifouling agents used for salmon cages is, however, one demonstrated case.

<u>Effluents and water quality</u>. More serious problems are likely to arise as a result of waste discharge from intensive aquaculture operations in ponds, raceways, and cages. Effluents with high concentrations of nutrients and high BOD are common, unless they are pretreated before discharge. The amounts that can be discharged without adverse effects depend very much on the site. If the receiving water body is an important recreational or tourism area, very stringent control will generally be required. Otherwise, the most important factor may be the depression of dissolved oxygen in the water body and consequent adverse effects on fisheries. Where pens or cages are used for culture, excessive discharge becomes self-limiting.

<u>It is clear from the above that monitoring and controlling the quality of the environment is perhaps the most important problem for aquaculture. Insofar as the amount of expansion of aquaculture which can be permitted at a given site or in a given area is strongly dependent on the maintenance of adequate water quality, accurate prediction of "carrying capacity" is an essential base for planning rational development in the sector. This is the essential rationale for the study proposed.</u>

## 2. PROJECT DESCRIPTION

### 2.1 <u>Background</u>

Aquaculture is one of the priority fields of the Priority Actions Programme (PAP). In the framework of the PAP workplan for the 1986-1987 biennium (UNEP/WG.129.5) the formulation of a joint project of PAP and the FAO/UNDP Mediterranean Regional Aquaculture Project (MEDRAP) was envisaged which would be concerned with the environmental aspects of aquaculture management. This came about as a result of cooperation between PAP and MEDRAP experts in the 1984-87 period, during which the need to define and test an effective procedure for the proper management of aquaculture in lagoon and coastal ecosystems was thoroughly investigated.

The aims of this preparatory phase were, among others, to identify and select the relevant environmental scenarios and productive systems in a number of sites, to assess the level of information available for each site and to evaluate the local means and facilities which could be put at disposal of the project.

The information obtained during the Preparatory Phase (1986-1987), made possible a realistic evaluation of the needs and the constraints of both scientific and technical nature for the implementation of the project. This led to the formulation of the present proposal.

## 2.2 Project Objectives

While there are no doubts that an operative procedure capable of producing sensible evaluations and forecasts, under different environmental and productive scenarios, would represent a precious tool both for coastal zone planners and entrepeneurs, such a procedure does not exist at present.

It is in fact clear from the analysis of the studies that have been carried out in this field that only qualitative suggestions were possible within the descriptive and scientifically informal approaches that have been adopted.

This is due to conceptual, technical and economic constraints, some of which are specific to the field of aquaculture, especially in terms of equipment and manpower costs and time necessary for a more scientifically "sound" environmental analysis.

The long-term objectives of the project are therefore:

- to establish a conceptual and operational procedure of site evaluation and monitoring for the development and the protection of aquaculture in Mediterranean coastal environments, with special reference to lagoons;

- to define a realistic and consistent set-up of operations necessary to calibrate and validate the procedure as a whole and its individual components.

It is, however, essential that the procedure to be developed is in line with the specific problems and needs of aquaculture, of general applicability, simple and cheap in terms of field efforts, and capable of providing accurate estimates and predictions.

The immediate objectives (pilot phase) are:

- to obtain an evaluation of previous data;

- to obtain supplementary data;

- to prepare and run a preliminary model;

- to prepare an Operational Handbook;

- to provide preliminary indications for aquaculture development and protection;

- to provide preliminary training of local staff in field operations.

To achieve these objectives, it is necessary to frame different production systems and their development in various environmental scenarios, to define the scenarios by means of efficient descriptors and to choose a sampling design for each descriptor according to its specific space and time scales. Also, a set of numerical techniques has to be defined that can treat the information obtained so as to produce the desired quantitative assessments and forecasts, as well as to assess the relative significance of the selected descriptors. Furthermore, the most appropriate numerical simulation models of the ecological events that are most relevant for aquaculture production systems have to be selected and validated.

### 2.3 Expected Outputs

When such a procedure is constructed and validated, the following outputs illustrate the results expected as far as aquaculture is concerned:

- guidelines for the selection of sites suitable for aquaculture developments;

- guidelines to assess the compatibility of already existing or planned aquaculture activities with the development of other forms of natural resources exploitation (e.g. a prediction of cumulative effects of organic enrichment from aquaculture and urban wastes);

- guidelines for the selection, within a given ecosystem, of the zones that are best suited for the various production systems (e.g. the prediction of the best combination of water movement types for the installation of fishculture cages);

- guidelines for the definition of how far a given type of production can be developed without overriding the carrying capacity of an ecosystem (e.g. the prediction of achievable shellfish culture density vs the phytoplankton productivity);

- guidelines for the definition of the amount of exploitable resources (e.g. the accurate estimate of the biomass of prey for the commercially valuable species in semi-intensive cultures, such as enclosures);

- guidelines for the definition of the extent to which available resources can be developed by intervention (e.g. the prediction of the yield obtainable by fertilizing semi-intensive fish cultures).

These guidelines and their associated models will be designed to be readily used by decision-makers and aquaculture professionals without a specific training. As is implicit in simulation, they can be used to perform computer experiments utilizing various types of scenarios and productive systems, prior to the real implementation of any aquaculture development.

## 2.4 Feasibility Evaluation

The available information on the selected sites afforded sufficient material to assess the needs and constrains for the development of the project.

The following favorable pre-requisites were identified:

- ongoing programmes related to the PAP-MEDRAP project exist in practically every country of the region. These are often connected and/or motivated by ongoing or foreseen national acquaculture development plans;
- local means seem available everywhere although to different extents;
- motivation and a cooperation attitude was good everywhere;
- interest was strong in participating in an international programme with possible academic outputs on individual basis.

The following constraints were identified:

- although there are published or readily available unpublished reports, some components or individual descriptors of the eco-systems have not been included in these studies;
- the levels of detail of the available data are uneven in both time and space; in general resolution or detail is rather poor;
- data are often only qualitative, even in recent studies;
- data for some groups of descriptors are not available in all sites;
- facilities for laboratory and field work are unevenly distributed;
- expertise and manpower are unevenly distributed; educational level of the staff is uneven, depending on the functions performed by local institutions.

From the above, the following was considered essential:

- The collection of further data in a consistent manner, selecting those descriptors that render valuable information and do not pose technical and quality control problems in sampling or measuring, and optimizing the ratio of information to effort by appropriate sampling designs.
- Standardization and intercalibration of sampling and measurement techniques, as well as a quality control procedure: this implies the necessity of equalizing instrumentation and laboratory/field

facilities among participating institutions to a minimum common standard adapted to the scientific workplan.

- Assistance and guidance to local staff not only by the necessary documentation but, also, by improving and/or promoting motivations and willingness through both financial and direct scientific support, including advanced training and related activities that can broaden individual knowledge and contacts.

## 2.5 Organization of the Project

In the light of the above considerations, the project has been organized in the following integrated parts:

i. Pilot Programme to integrate previous data and to collect supplementary data, to prepare pre-models, and to start the operational calibration of the project, with particular reférence to sampling design and related technical problems.

ii. Core Programme, to perform those basic research activities that are feasible at all sites; to implement Seminars and Advanced Training Missions.

iii. Parallel National Activities (so-called 'Satellite Programmes') to be performed in individual Institutions, depending on both their specific interests and experience/ facilities; the Satellite Programmes will include complementary parts of the project that can be developed independently but consistently to the project itself; specific local problems may be taken into account.

iv. Training Component. The project will have a strong training component consisting of seminars, training missions and the preparation of a methodological manual and an Operation Handbook.

### 2.5.1 The Pilot Programme

The Pilot Programme will be carried out mostly by the Coordinating Group. It will be performed "una tantum" at the onset of the project, on all the previously selected sites. It will cover sampling and measurements of sediment descriptors, water levels and water flows. Furthermore, it will include sampling and measurements of all the descriptors listed in the Core Programme, except items a and b (see technical annex) for which no direct investigation is considered.

The Pilot Programme will establish:

a. the grid for spatial analyses to used in the Core Programme for the benthos;

b. the time variability (high frequency) of physical and chemical descriptors of the water column, thus establishing the optimum sampling frequency to be adopted in the Core Programme;

c. the bathymetry of the basin if the available one is older than 50 years (or if bathymetry is not available at all);

d. the location and permanent marking of sampling sites to be adopted in the Core Programme.

The Pilot Programme also includes the preparation and running of the hydrodynamic model for each site, the results of which will form the basis for the definition of the space grid for pelagic sampling to be adopted in the Core Programme.

In addition, a methodological manual will be provided as an output of the Pilot Programme. This manual will provide 'how-to-do' assistance in all the practical steps of the procedure, including standard cards for data logging during the Core Programme.

2.5.2 The Core Programme

The Core Programme is designed to validate numerical models (see annex) on the basis of a minimum number of descriptors which are easily obtained or measured. Some descriptors (e.g. incident radiation) can be calculated from known physical laws or used as variable forcing functions (e.g. nutrients). By consequence, these descriptors are not included in the list that follows.

The expected result is a validated and calibrated model which will permit simulations by varying the level of the forcing functions and/or border conditions. For example, the model would predict the increase of BOD under a set of cages in a lagoon under different conditions of water exchanges with the sea.

The Core Programme will concern the following descriptors:

- Meteorological descriptors (25 year time series), like air temperature, relative humidity, sky cover, rainfall and wind. Data can be obtained locally or from the nearest Meteorological Office. Raw data are sufficient if no statistic analyses are available.

- Continental hydrography descriptors, such as watershed, soil data, main water inflow and runoff sources. Data can be otained locally or should be available at different Regional or National Authorities.

- Geomorphological descriptors, like lagoon-bathymetry and length, width and depth of outlets.

- Physical descriptors, like water temperature and water transparency.

- Chemical descriptors, like salinity and oxygen content.

- Biological descriptors, like biomass of plankton, benthos and nekton.

The operational sampling design for the Core Programme will partly depend on the results obtained in the the Pilot Programme. It should be considered that sampling, data analysis and modelling are performed interactively (eventually with blocks deriving from the Satellite Programmes). For this reason, flexible sampling designs are proposed. The general strategy aims at obtaining the best coverage of the system. It can be briefly described as follows:

- meso-scale space grid for sediment and benthos sampling: the system will be divided into squares the size and number of which will depend on the size of the system; two sampling points will be included in each square; only one of the two samples will be studied while the remaining one will be part of a "reserve" to be used, if necessary, based on a "map of errors" generated by space distribution analyses;

- micro-scale space grid for benthos sampling: the grid will have the fixed size of 100 x 100 m and will contain a number of squares in which two samplings will take place with the same criteria as described above. The location of the micro-scale grid will depend on the results of the analysis of meso-scale spatial patterns;

- space scale for pelagic sampling: in general, space resolution will be kept rather low (4-5 sampling points);

- sampling time scale: basic frequency for time series generation of pelagos descriptors is 1/4 of a tidal cycle; sampling will be carried out in seasonal "batches" of 3 consecutive days (6 tidal cycles) centered on seasonal average meteorological conditions; sampling frequency for benthos will be once a year; fish fry migration studies will be performed once a month, with observations along two consecutive days.

2.5.3 Satellite Programmes

The goal of the Satellite Programmes is to develop particular aspects of an aquatic ecosystem dynamics.

The choice depends on the specific problems posed by the unique aspects of different sites and of the different environmental scenarios with respect to the respective aquaculture activities and/or plans.

It will be up to local institutions to select a subject which best suits both the site problems and laboratory facilities/ expertise that can be devoted to these special studies. The only condition required will be consistency with the sampling and modelling strategies adopted in the Project (see annex).

At this stage, one can only list examples of research which might be undertaken in the Satellite Programmes. These activities will be agreed upon with the staff of local Institutions after the completion of the Pilot Programme. Possible items are:

- Time variability in nutrients and primary producer biomass concentration (high frequency, e.g. weekly);
- Nutrient uptake experiments in micro- and macrophytes;
- Oxygen production and respiration by in situ experiments;
- Primary production experiments;
- Spatial distribution of size spectrum in selected benthic species;
- Gut content analysis in fish of commercial interest (by age and by time);
- Feeding and excretion rate experiments on selected species (e.g. Cerastoderma, Sparus aurata);
- Fish stock assessment by different experimental strategies (e.g. capture-recapture, etc.);
- Utilization of waste feeds from cage culture by "wild" stocks.

2.5.4 Training Component

Four Project Seminars, spread over the whole duration of the Project, will provide opportunity for discussion and planning among the Coordinating Group and the Local Units (see 2.6 below). They are designed as "Plenary Assemblies" of the Project, at the beginning and at the end of particular phases, where an active flow of ideas and experiences, as well as problem-solving can be obtained. Seminars also represent the occasion for personal contacts and it is expected they will promote self-identification in the Project of all its participants.

Two Advanced Training Missions are offered to Local Units. ATMs are meant to improve the knowledge of already experienced staff Members of LU in particular fields concerning the Project. Special reference is made to methodology in model building and managing, electronic data processing (EDP) and related topics.

An Operation Handbook will be an operative output of the whole Project. It will provide reminders to the users in the application of the procedure under different environmental scenarios and with different production models. The handbook will condense the experience obtained in the Project in terms of problem solutions, data base and case-history reports. It will also include a user-friendly soft-ware running under most of IBM PC compatibles, designed to carry out Numerical Analysis and Simulations.

## 2.6 The Operative Structure

The Operative Structure consists of:

- A Coordinating Group, which will be a sort of 'task team' carrying out most of the work foreseen in the Pilot Programme, with some assistance of the Local Units (see below). The members of the CG will therefore not constitute a permanent unit with an established office during the whole duration of the Project but meet whenever needed in order to direct the activities.

In particular, the role of the CG is

- to carry out the Pilot Programme;
- to perform quality controls;
- to plan and to assist in Seminars and Workshops;
- to perform data processing and modelling;
- to prepare reports.

The members of the CG will be assited by consultants during the Pilot Programme phase as needed. The CG will have at its disposal its own instrumentation in order to assure the uniformity of the collected data and computer facilities for data processing.

- Local Units composed of up to seven staff members (juniors and students included) and a local Coordinator from relevant National Institutions. The role of LU is to carry out, in cooperation with the CG, the activities planned for the Core Programme and (eventually) for the Satellite Programmes, to cooperate with the CG and participants in the Pilot Programme, to provide laboratory facilities, field work facilities, instruments and whatever necessary to execute the project.

## 2.7 Timing

Activities of the Project are scheduled as follows (times are computed from the operative clearance):

- Step 1: Pilot Programme. Seven field missions, one at each site, are included. Data analysis, pre-models, preparation of reports, methodological manual and Data Log. Duration: 10 months

- Step 2: Core Programme Phase 1. Data collection and analysis, pre-validation of models, training, Parallel National Activities (Satellite Programmes). 2 Seminars, 2 quality control-assistance missions, 2 advanced training missions, 1 meeting of CG are included. Duration: 12 months

- Step 3: Core Programme Phase 2. Data collection and analysis, validation of models, application, training, Parallel National Activities (Satellite Programmes). 2 Seminars, 2 quality control-assistance missions and 2 advanced training missions are included. Preparation of final reports and of an Operation Handbook. 1 CG meeting is included. Duration: 18 months

Total duration from clearance: 40 months

2.8 Expected Achievements

The major practical achievements expected from the project will include a validated analytical tool for site evaluation and impact assessment with regard to the specific needs of aquaculture under different ecological and development scenarios. Hence, planning of production activities will become easier and more efficient. In particular, the project will provide a tool to manage and increase biological production of economic interest without imposing undue stress on the environment. A deeper insight into the so-far available information will also be gained and additional valuable information on the ecological state of the investigated sites will be made available.

This set of achievements will be transferrable at both national decision-maker and professional levels, thus improving rational planning of aquaculture in the framework of other production activities using the same environmental resources.

Another important expected achievement is the promotion of advanced education and specialized training enabling improvement of national capabilities for aquaculture development and protection through an efficient site selection and monitoring.

Finally, the role of the Project in promoting cooperation, communication and exchange of both scientific knowledge and practical experience in the field of applied ecology and aquaculture among Mediterranean countries, should be underlined.

2.9 Financing

The tentative budget has been calculated on the basis of the following criteria:

- provide the Coordinating Group with equipment and date processing facilities to meet the necessities of both the Pilot Programme and Core Programme;

- provide each Local Unit with a contribution to bring its equipment to the level required for the Core Programme;

- provide each Local Unit with a contribution to the costs of field work and expendable materials.

No financial support is initially foreseen for the Satellite Programmes. However, it is definitely considered that those Local Units that are able to execute the Core Programme by their own means (equipment, manpower, etc.) as required in this proposal may allocate the financial support to the development of one (or more) Satellite Programme(s).

This flexibility is designed to compensate for the fact that some Local Units have a level of equipment that already meets the requirements of the Core Programme, as well as expertise enabling the successful implementation of Satellite Programmes. It is expected that this will allow the improvement of the overall output level of the Project.

## I. Pilot Programme

### A. Coordinating Group

| | | |
|---|---|---|
| 1. | Equipment | 96 000 |
| 2. | Missions | 45 800 |
| 3. | Consultants (6 m/m) | 29 400 |
| 4. | Electronic Data Processing (EDP) | 18 000 |
| 5. | Reports | 7 000 |
| 6. | Meetings | 7 200 |
| Sub-total | | 203 400 |

### B. Local Units

| | | |
|---|---|---|
| 1. | Equipment | 140 000 |
| Grand Total | | 343 400 |

## II. Core Programme Phase 1

### A. Coordinating Group

| | | |
|---|---|---|
| 1. | Missions | 56 000 |
| 2. | Electronic Data Processing (EDP) | 36 000 |
| 3. | Reports | 14 000 |
| Sub-total | | 106 000 |

### B. Local Units

| | | |
|---|---|---|
| 1. | Contribution to field work | 51 000 |
| 2 | Expendable material | 6 900 |
| 3. | Seminars | 93 000 |
| 4. | Advanced Training Missions | 23 100 |
| Sub-total | | 174 000 |
| Grand Total | | 280 000 |

## III. Core Programme Phase 2

| | | |
|---|---|---|
| **A. Coordinating Group** | | |
| 1. | Missions | 56 000 |
| 2. | Electronic Data Processing (EDP) | 36 000 |
| 3. | Reports | 14 000 |
| Sub-total | | 106 000 |
| **B. Local Units** | | |
| 1. | Contribution to field work | 51 000 |
| 2. | Expendable material | 6 900 |
| 3. | Seminars | 93 000 |
| 4. | Advanced Training Missions | 23 100 |
| Sub-total | | 174 000 |
| Grand Total | | 280 000 |
| PROJECT TOTAL COST | | 903 400 |

Technical Annex

# 1. METHODOLOGY

## 1.1 Elaboration of the Procedure

The procedure results from a "methodological amalgamation" based on the convergent and integrated application of different approaches and techniques (or their adaptations) to the study of aquatic ecosystems. The procedure is scientifically formal in that it makes reference to inductive and deductive methods both in the planning of information collection and in the data analysis. For these reasons, although it does not disregard inputs from purely descriptive and analogic "readings", the procedure aims at the construction and testing of numerical models. Models are of both statistical and mechanistic nature and are used interactively. Their major role is to produce at least sensible assessments and forecasts.

Due to the nature of the specific problems concerning aquaculture, the evaluation of conceptual, technical and mathematical constraints is done in the light of economical constraints, in terms of costs, time and manpower. The parametrization of the above items is expected to lead to an optimized operational scheme.

The procedure consists of the following steps:

Step A: construction of the mechanistic model. It implies (1) identification of the system of interest, (2) definition of the objectives of the model, (3) definitions of conceptual, physical and temporal boundaries, (4) identification of sub-systems, (5) identification of internal and external forcing functions, (6) selection of state variables (descriptors), (7) creation of the conceptual model, (8) collection and evaluation of available information, (9) specification of functional relationships, (10) translation into mathematics, (11) translation into a computer programme, (12) test for sensitivity and select coefficients, (13) simulations, (14) compare with reality often based on sub-step 8.

Step B: based on the results of the model, establish a sampling design which should afford: (1) a validation scheme for the model as a whole by comparisons, (2) data for synthetic descriptions and factorizations, (3) a scheme for the statistical testing of some of the relevant hypotheses done in the previous step (e.g. correlations, causal paths, zonal patterns and anisotropies), (4) construction of statistical models in both space and time, (5) interpretation of facts. The sampling design does not necessarily imply a unique set of variables and is not restricted to passive observation. Some manipulative experiments are, in fact, recommended if not necessary. Finally, some of the variables are of interest only in a synchronic context: their spatial configurations may be used for indirect validations by analogy or correspondence. A list of variables to be measured during the Pilot and the Core Programmes as well as information on sampling and measurement techniques as given in the Appendix.

Step C: feed back onto the conceptual model and its mathematical formulation. At this time, the mechanistic model has a stochastic component.

Step D: iterations through Step A and B up to the point the results match with observed data.

Step E: applications

It is worth noting that in many modelling exercises, Step B is either simplified or lacking. In this case, sub-step 14 may represent nothing else than a fitting exercise.

In both Steps A and B the selection of descriptors is crucial as from this point on, the system will coincide with the list of its descriptors. There is no prescribed way of choosing these descripors, besides the consistency with formulated hypotheses and the consideration of a number of constraints. These are of technical as well as of mathematical nature in the sense that they must be readily measurable and their number manageable with limited computing facilities. Natural constraints, depending on the properties of the variables, should be carefully considered.

The above described procedure has never been applied as such. Its main advantage seems to consist in the interaction between mechanistic and statistic modelling as it should solve problems connnected to the fact that mechanistic models often lack data for validation and statistic models need large and expensive sampling efforts. In our case, the mechanistic model "guides" the sampling design for the statistical model, the results of which will serve for validation.

## 1.2 Modelling Mediterranean Lagoons

The term "modelling" is used here in its broadest sense of rational simplification and abstraction of the real world.

Ordination or cluster models have been used in several instances and mainly regarded zonal patterns of both abiotic and biotic characteristics. Most of them have suffered from inadequate sampling designs. Model time series are more rare and some also address the stability of spatial configurations. A few examples exist of path analysis (linear) and its predictive application. There have also ben several exercises in modelling population dynamics of some species of economic interest.

Mechanistic models and simulations are very rare. Some of them deal with the Lagoon of Venice and Rhone Delta lagoons. There are a couple of applications in Sardinian lagoons. Several modelling exercises are now developing in a variety of sites (France, Italy, Tunisia). In general, the physical sub-system is the one which has attracted the major efforts. Simulations of bi-dimensional velocity fields as basis for the study of advective transport phenomena are the most interesting applications. Numerical approximations of Navier-Stokes equations were used and solved by either finite difference or finite element method. These models are inspired to Leendertse's solution which is particularly suited for shallow waters and proved to be rather satisfactory in both estuaries and closed bays.

Ecological (trophic) models have been also used. Solutions are 0-dimensional (the space component is not considered) and therefore numerical solutions deal with ordinary differential equations. There are a few applications (e.g. the Lagoon of Venice) the formulation of which is largely inspired to the classic Kremer & Nixon's Narragansett Bay model. Simulations of primary and secondary production in the pelagic compartment seem to offer the most interesting perspectives.

### 1.3 Modelling Approach Proposed for the Project

The formulation of mechanistic model is derived from:

- Leedertse approximation for the hydrodynamic and for the dispersion model. A finite difference solution and the related NSMODEL program, written in BASIC for a MS-DOS environment (PC-level hardware), is available for the hydrodynamic subsystem. A finite element solution is being developed which seems better adapted to manage the complex geometries of coastal lagoons. This will form the basis for a 2-dimensional dispersion and trophic model (at least for pelagic primary and secondary production). At present, the model also computes water exchanges at the opend boundary (e.g. lagoon-sea boundary). There are several applications to coastal lagoons and bays. Validation is mostly indirect (by analogy).

- Kremer & Nixon 0-dimensional ecological model, including a stochastic component for the forcing functions at the water-air boudary (meteorological events are defined at random within the 25-year statistical limits of the region). At present, spatial elements are identified on the basis of the results of hydrodynamic model (persistent isokinetic fields and circulation patterns). The coupling with pelagic production to selected benthic elements (e.g. Molluscs) is being developed. Computer programmes are available under the same conditions as NSMODEL. This model will be later merged with NSMODEL in order to obtain two-dimensional biological reactors. Validation of physical exchanges has been performed.

- Evapo-transpiration model to simulate surface hydrography in the watershed.

As for the statistical models, several methods are available depending of the scopes, hypotheses and type of variables. A major role is taken by space configuration analysis especially of conservative or semi-conservative characteristics of the system. A variety of techniques are available for stochastic interpolative mapping (Kriging), regionalization by free and constrained clustering, fuzzy partitions, anisotropy and clump detections, clump size evaluation, coherence evaluation of physical and ecological spaces, etc. for both uni- and multi-dimensional data sets. Several algorithms are available for the study of "resemblance" matrices, such as Multi-dimensional Scaling, Coordinate Analysis, Factor Analysis, Component Analysis, Correspondence Analysis (both simple and multiple), etc., which perform "ordinations" in two-way data sets.

Another important class of statistical models is represented by Causal Analysis. Canonical Correlations, Procuste's Analysis and Mantel's statistics are considered (and computer programmes available) for multiple data sets. Path-analysis is another relevant approach to detect direct and indirect causation models and derive linear (multi-regressive type) predictive equations.

Time series can be analysed (and models constructed) by a series of innovative techniques such as chronological clustering, auto-distance analysis, contingency periodograms, Markovian chains and related methods. More conventional methods (e.g. Spectrum Analysis, ARMA and ARIMA models, etc.) are available depending on the quality and the amount of data.

Finally, population models, growth statistics, biometric evaluation methods, and, more generally, the classic tools of parametric statistics have their own typical application in modelling exercises, whenever hypothesis testing is feasible.

A library of computer programmes developed for IBM compatible PC is available for the project. This library ensures an interactive use of the available techniques; a part of the library can be used for didactic purposes.

Appendix

A. DATA TO BE COLLECTED DURING THE PILOT PROGRAMME

1. Sediment granulometry distribution (Wentworth or Doeglass classes), with special reference to clay smaller fractions (< 18f)

2. Sediment CaCO3 content

3. Sediment TOM content

4. Water level (in selected places)

5. Water velocity (at the oulets)

B. DATA TO BE COLLECTED DURING THE CORE PROGRAMME

a. Meteorological descriptors (25 year time series). Data can be obtained locally or from the nearest Meteorological Office. Raw data are sufficient if no statistic analyses are available. Measurements of descriptors a.1, a.3 and a.5 (direction and speed) will be made in each sampling operation. Other data (e.g. incident radiation, evaporation, etc,) necessary to the model implementation, will be calculated on the basis of known relationships with the measured descriptors.

a.1 Air temperature
a.2 Relative humidity
a.3 Sky cover
a.4 Rainfall
a.5 Wind direction frequency, speed and duration

b. Continental hydrography descriptors. Data can be otained locally or should be available at different Regional or National Authorities.

b.1 Watershed (surface)
b.2 Soil permeability (average)
b.3 Type of soils
b.4 Main inflows (max and min flows)
b.5 Main runoff sources (max and min flows, type: industrial, domestic, equivalents, etc.)

c. Geomorphological descriptors. Detailed maps (1: 5-10.000) are needed.

c.1 Bathymetry
c.2 Length, width and depth of outlets

d. Physical descriptors.

d.1 Water temperature
d.2 Water transparency

e. Chemical descriptors.

e.1 Salinity
e.2 02 saturation (%)

f. Biological descriptors.

f.1 Phytoplankton biomass (as cell number of Diatoms, Dinoflagellates, Gymnodiniaceae, Small Flagellates, Chlorophytes)

f.2 Zooplankton Biomass (as number of Copepods, Cladocerans, Other Taxa)

f.3 Macrozoobenthos Biomass (as wet weight of Anellids, Molluscs, Crustaceans, Others)

f.4 Macrophytobenthos Biomass (as cover and wet weight)

f.5 Nekton biomass, including fry, of Sparids, Mugilids, Serranids, Eels

f.6 Nekton populations size structure

C. SAMPLING AND MEASUREMENT TECHNIQUES FOR THE CORE PROGRAMME

Methods and equipment to be used are as follows:

- Air temperature: mercury thermometer

- Sky cover: direct estimation

- Wind speed and direction: hand anemometer

- Salinity: refractometer

- Dissolved oxygen: polarographic electrode

- Temperature: mercury thermometer

- Transparency: Secchi disk

- Phytoplankton: Niskins bottles, Lugol fixation and Utermohl counting techniques; cell volume-based biomass estimates

- Zooplankton: bongo net, sample splitting and counting; biomass estimates according to Shmeleva's conversion formulae

- Benthos: Petersen grab, sieving onto 1mm mesh, weighing on technical balance
- Nekton (fry): visual catches with Italian fish fry net; samples with purse seins
- Nekton (sub-adults and adults): fisheries catches, measurements as usual.