GEF

UNDP/GEF PROJECT ENTITLED "REDUCING ENVIRONMENTAL STRESS IN THE YELLOW SEA LARGE MARINE ECOSYSTEM"

UNDP/GEF/YS/RWG-F.3/8
Date: 26 September 2006
English only

Third Meeting of the Regional Working Group for the Fisheries Component
Weihai, China, 25-28 October 2006

Carrying Capacity and Assimilative Capacity: An overview for a preliminary approach in YSLME coastal waters and preliminary recommendations for a practical approach

- Working document -

Aquaculture, in common with all other food production practices, is facing challenges for sustainable development. Most aqua-farmers, like their terrestrial counterparts, are continuously pursuing ways and means of improving their production practices, to make them more efficient and cost-effective. Awareness of potential environmental problems has increased significantly. Efforts are under way to further improve human capacity, resource use and environmental management in aquaculture.

The potentially adverse impacts of aquaculture are widely documented in the literature. Current issues of alleged concerns include nutrients and organic enrichment and lack of sustainability. For some time it has been suggested that such impacts could be minimised or negated by the adoption of appropriate environmental safeguards including regulatory, control and monitoring procedures. In addition, the aquaculture industry has a vital interest in a clean environment and therefore, in the context of integrated coastal zone management (ICZM), there is a definite need to safeguard the marine environment. The competitive use of coastal resources has highlighted the importance of satisfactory control measures to protect the natural environment and to safeguard the developing aquaculture industry.

The aquaculture industries have been largely expanded over past decades, and subsequently, attention has been given to the environmental impacts of such activities. It is not possible to generalise and distinguish between the actual and potential impacts of aquaculture given that a multitude of approaches are in place. However, in general, the potential impacts of aquaculture are wide-ranging, from aesthetic aspects to direct pollution problems. Marine aquaculture operations and the associated infrastructure can, for example, impact on scenic rural areas. Fish production generates considerable amounts of effluent (e.g. nutrients, waste feed and faeces, together with associated by-products such as medication and pesticides) that can have undesirable impacts on the environment. There may also be unwanted effects on wild populations, such as genetic disturbance, and disease transfer by escapees or ingestion of contaminated waste, and effects on the wider ecosystem.

The literature review for the so called "carrying capacity for fisheries" has some direct links to "stock assessment" approaches. Stock assessment involves using mathematical and statistical models to examine the retrospective development of the stock and to make quantitative predictions to address the following fisheries management questions: What is the current state of the stock? What has happened to the stock in the past? What will happen to the stock in the future under alternative management choices? To answer those questions a summary of the most recent stock assessments done by specialised institutes/organisations together with fisheries management issues available at any given country will help to determine the Total Allowable Catch (TAC). These TACs will help decision makers to determine the quotas to be given to the fisheries sector.

Therefore, considering the concepts available for "marine fish stock assessment" and the practical use of its results to manage fisheries in a given area, it is considered necessary that the concept of "carrying capacity" and "assimilative capacity" should be applied, within the context of the YSLME Project, mainly to aquaculture activities.

From the preceding review, it is clear that there is no universally applicable approach to the determination of the carrying capacity or assimilative capacity of coastal water bodies for cultured species. Growth rates are limited by the available food supply and by the physiological capability of the cultured aquatic organisms to take advantage of the available food. Another main concern for environmental issues arise from the discharge of particulate waste matter, the increased rate of recycling of dissolved nutrients, disturbance of wildlife, introduction of new species etc. To be useful, possible approaches to the estimation of carrying or assimilative capacity need to be subject to quantification and to lead to quantitative expression of the capacity.

The overview (attached) concentrated on the marine environment mainly because the scope of the YSLME centered on potential for problems in coastal waters. YSLME may convene the next RWG-Fisheries and submit the preliminary approach on carrying capacity matters. The group of experts may in future seek additional expert assistance as deemed necessary. The goal of the overview is to provide with the suggested necessary issues that need to be addressed when a carrying capacity study is considered to be developed. The main objectives of this preliminary approach are:

1. To outline the need of a detailed review of the approaches used in the YSLME region or elsewhere to establish the carrying or holding/carrying capacity of coastal waters for fish and shellfish farming;
2. To identify those approaches which can be adapted to YSLME-region waters;
3. To identify possible combinations of modelling and field indicators of carrying capacity with emphasis on their appropriateness for YSLME environmental conditions and concerns.

Likewise, the recommendations (attached) mainly focus in the need to scope a carrying or assimilative capacity study and to conduct a demonstration site in order to get the "target standards" or "preliminary guidelines" that the YSLME member countries may wish to discuss and, eventually, endorse.

After reviewing the working documents, participants may consider to comment on this particular approach as an activity for year 2007 looking forward to the TDA and eventually the Strategic Action Programme.

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- working document -

UNDP/GEF Yellow Sea Project
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1 INTRODUCTION

Aquaculture, in common with all other food production practices, is facing challenges for sustainable development. Most aqua-farmers, like their terrestrial counterparts, are continuously pursuing ways and means of improving their production practices, to make them more efficient and cost-effective. Awareness of potential environmental problems has increased significantly. Efforts are under way to further improve human capacity, resource use and environmental management in aquaculture.

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2 BACKGROUND

During the Second Meeting of the Regional Working Group -Fisheries[1] the PMO invited members to review and revise the workplan for the RWG-F, for submission and approval at the 2nd PSC meeting. Annex V of the RWG-F report included the DATA INFORMATION TABLE that considered the major problems addressing fisheries issues: [2] i) Decline in many commercially important fishery species; ii) Lack of knowledge of carrying capacity; iii) Unsustainable mariculture; iv) Environmentally destructive aquaculture practices; and, v) Socio-economic data required.

During the First Meeting of the Regional Scientific and Technical Panel of the YSLME[3], the RWG-F agreed "….*on the use of some methods to assess carrying capacity with which the Group was satisfied….*" The RWG-F also agreed that "….*the focus of carrying capacity assessment will be on fisheries resources, namely the highest possible fish biomass in the Yellow Sea from surveys, with the output from Ecosystem Component's primary and secondary production assessment serving as input for the estimation of carrying capacity in the Fisheries Component….".* The RWG-F reported that it would pursue the goal in two ways: 1) population dynamics approach; and, 2) lower trophic productivity – higher trophic level model (possibly ECOPATH) approach.

The Second Project Steering Committee meeting[4] approved, among others, the TORs for the RWG-F. Within the agreements, the **major responsibilities** of the REGIONAL THEMATIC WORKING GROUP FISHERIES considered:

a. Provide guidance to develop common methodology for **regional stock assessment** strategy and region-wide monitoring; perform initial joint stock assessment; elaborate an effective mechanism for regional stock assessment.
b. Provide guidance to perform re-iterative series of regional analyses of carrying capacity, and provide recommendations for regional carrying capacity determination.
c. Develop joint applied research programmes for **sustainable mariculture**. Pilot demonstration project(s) in mariculture to assist the participating countries in implementing sustainable mariculture techniques that are suitable for the Yellow Sea region.
d. Coordinate joint efforts in developing and demonstrating technical methods for diagnosis, prevention and control of **disease in mariculture**. Develop a regional communication network about diseases to reduce transboundary implications.
e. Facilitate preparation and endorsement of regional agreement for sustainable **use of fisheries resources**.

3 GOAL AND OBJECTIVES

The goal of this concept working-paper is to provide with the necessary issues that need to be addressed when a carrying capacity study is considered to be developed.

The main objectives of this preliminary approach are:

1. To outline the need of a detailed review of the approaches used in the YSLME region or elsewhere to establish the carrying or holding/carrying capacity of coastal waters for fish and shellfish farming;
2. To identify those approaches which can be adapted to YSLME-region waters;
3. To identify possible combinations of modelling and field indicators of carrying capacity with emphasis on their appropriateness for YSLME environmental conditions and concerns.

[1] 2nd Meeting of the Regional Working Group-Fisheries. Busan, ROK, 17-20 November 2005.

[2] During this RWG-F meeting the members AGREED ON DATA FORMATS (Annex III of the report) and AGREED ON THE LIST OF SPECIES (Annex IV of the report).

[3] 1st Meeting of the Regional Scientific and Technical Panel. Dalian, China, 4 - 6 July 2005.

[4] The Second Project Steering Committee meeting for the UNDP/GEF Yellow Sea Project was held in Kunming, China from 19 to 20 December 2005.

4 OVERVIEW

4.1 Marine fish stock assessment

4.1.1 General issues

A "**stock**" is a population of a species living in a defined geographical area with similar biological parameters (e.g. growth, size at maturity, fecundity etc.) and a shared mortality rate. A thorough understanding of the fisheries biology of any species is needed to define these biological parameters. **Stock assessment** involves using mathematical and statistical models to examine the retrospective development of the stock and to make quantitative predictions to address the following fisheries management questions:

1. What is the current state of the stock?
2. What has happened to the stock in the past?
3. What will happen to the stock in the future under alternative management choices?

A summary of the most recent stock assessments done by specialized institutes/organizations together with fisheries management issues available at any given country will determine the Total Allowable Catch (**TAC**). These TACs will help decision makers to determine the quotas to be given to the fisheries sector.

4.1.2 Methods

There is a wide variety of recognized assessment models and statistical methods to assess the stocks of fish around the world. These methods can be classified by groups:

GROUP	METHODS
Simple Holistic Methods	Including production models, swept area estimates, acoustic biomass estimates, egg production methods, direct counts, mark recapture experiments, life tables etc.
Complex Analytical Methods	Such as traditional VPA (Virtual Population Analysis), XSA (extended Survivor Analysis), statistical catch at age methods, ICA (Integrated Catch at age Analysis) and Separable VPAs, complex depletion models etc.

4.1.3 Data Requirements

Data from a large number of sources are required to make robust assessments of fish stocks. It is also essential to have these data over as long a time period as is possible. Samples should be taken throughout a given shoreline and deep into the sea as specified by the methodology requirements. Sampling programmes provide information on the age structure of fished stock. Surveys provide important fisheries-independent data on structure, catch-per-unit-effort (**CPUE**), distribution, recruitment and biology of fished stocks. Data from surveys are very important in the stock assessment process. Equally important are data on landings and CPUE from the commercial fleet.

4.1.4 Participation of Fishing Industry

It is fundamental to involve the fishing industry throughout the stock assessment process. As fishermen spend more time at sea than any scientist, their knowledge is unique and essential to a precise understanding of fish stock distribution and behavior. The industry may co-operate with the institution conducting the study by providing access to samples - both in the ports and at sea on surveys and observer trips. Input from the fishing industry improves scientific understanding of fleet behavior. It identifies the limitations of, and possible biases in, assessment input data.

As fisheries develop it is essential to involve the industry in the stock assessment process. These assessments may identify sustainable fisheries development opportunities. Regular assessment can also provide early warning of over-fishing and help prevent overcapitalisation of the industry.

In fully and over-exploited fisheries, stock assessment will help managers and industry by defining the risk associated with various management choices. Computer-based simulations can quantify the long-term gains from rebuilding stocks as well as the short-term costs (in yield reduction) required to rebuild.

Stock assessment can be of greatest benefit to the fishing industry through cooperative management regimes (e.g. Pelagic Management Committees). Whatever the management objectives for a stock (e.g. maximum sustainable yield, maximum economic yield, maximum employment etc.), stock assessments will be required to quantify the risks and uncertainties around management choices in what is a dynamic ecosystem. Finally, a key element in the stock assessment process is the communication of results to industry.

4.2 Carrying Capacity

4.2.1 Review of available definitions

In areas where there are multiple potential contamination sources within the same body of water, the possibility for synergistic effects should be considered through modeling. In this context it is important to consider how different environments may be affected in different ways by multiple operations and therefore the monitoring programme will have to assess the potential assimilative capacity of the system and any outcomes should be incorporated when designing future monitoring programmes.

Table 1. Concepts widely used in aquaculture management (GESAMP 1986; Rosenthal et al. 1988)

TERM	DEFINITION
Carrying capacity	(of a defined area) refers to the potential maximum **production** of a species or population that can be maintained within that area in relation to the available food and environmental resources.
Holding capacity	The potential maximum production which is limited by a non-trophic resource.
Assimilative capacity	The **ability of an area to maintain** a “healthy” environment and “accommodate” wastes.
Production capacity	The maximum tonnage level that can be attained without producing a negative impact on the environment and on the farmed stock.
Environmental capacity	Refers to the ability of the environment to accommodate a particular activity or rate of activity without an unacceptable impact.

4.2.2 Carrying Capacity and Assimilative Capacity

It is often understood that “carrying capacity” means the ability of the environment to accommodate aquaculture, and in the context of this project is concerned with marine environmental factors. Therefore, it excludes other environmental consequences of the development of fish farming in remote areas, for example infrastructure development (roads, housing, schools etc).

The definition of “assimilative capacity” as cited above extends beyond ‘carrying capacity, to encompass the biological and chemical parameters that may be measured by scientific investigation. The processes which would be included within the term “assimilative capacity” are those associated with the fate of waste (eg. faeces) produced by the shellfish, and the ecological effects on the wider ecosystem which might be brought about by the greatly increased pressure of the farmed species on phytoplankton.

The terms “carrying capacity” and “assimilative capacity” will therefore both be used as appropriate in this working document.

An important distinction should be made between the assimilative capacity of an aquaculture site eg. shellfish farm site, and the assimilative capacity of a body of water (eg. a estuary, bay).

- The assimilative capacity of an **aquaculture site** will be dependent on the impact of that single site on the environment. In practice, particularly where there is more than one farm site in a body of water, this means the impact of the shellfish farm on the immediately surrounding environment, within which there can be a degree of confidence that any effects can be related directly to the farm under consideration. A good example is the footprint of organically-enriched sediment commonly found immediately below and around shellfish lines in areas where water movements are rather weak.
- The **assimilative capacity** of an estuary or other body of water must seek to integrate the effects of all the shellfish farms that are present in that body of water, taking into accounts other activities, eg nutrient-rich discharges from agriculture, or domestic sewage inputs. Effects will be considered to be the consequences of the presence of all the shellfish farms in the body of water. They would be assessed on a wider scale than just the immediate surroundings of individual farms, although the summation of localized impacts and consideration of their consequences for the whole water body would be a component of many approaches.

These broader-scale assessments of carrying and assimilative capacity are the main targets of this document, although, in addressing this target, consideration will need to be given to the capacity of individual aquaculture sites eg. shellfish farm sites. Amenity and aesthetic factors are outside the scope of this analysis.

4.2.3 Current approaches for estimation of assimilative or carrying capacity

4.2.3.1 Assimilative or carrying capacity in a regulatory framework

There is a need to identify any formal procedure within the regulatory framework in China and South Korea for the estimation of the assimilative or carrying capacity of marine areas with respect to aquaculture activities. However, the concept of nutrition planning framework is intuitively logical and clear, and knowledge of such a constraint, through modelling, would form an effective and appropriate tool for guiding the future development of the sector. The regulation of the scale and location of aquaculture farms that lead to the granting of a license should be reviewed. It might be possible to introduce assessments of carrying and assimilative capacity into this process, thereby providing a more substantial scientific basis for decisions on the appropriate scale and location of shellfish farms.

The YSLME member countries may consider undertaking a large review of the approaches available to estimate the carrying capacity of coastal waters for aquaculture practices, as part of the consideration of an over-arching aquaculture strategy at a national level.

4.2.3.2 Research activity in the fields of assimilative and carrying capacity

The carrying capacity of coastal ecosystems for cultivated organisms has been defined as the maximum standing stock that can be supported by that ecosystem for a given time, while enabling maximum annual production of individuals without a reduction in market size. The issue is the number of individual cultured organisms that any given ‘biomass’ is divided between. If the standing stock expands beyond the optimum, the inevitable result is a decline in size of individuals, e.g. carrying capacity for bivalves depends on the availability of space (substrate), and, more critically, food. In coastal waters, space is rarely the limiting factor for cultivated shellfish, as it is normal practice to introduce artificial substrate, in the form of suspension equipment such as ropes, bags, cages etc to increase the density of the cultivated species.[5]

[5] Most of the approaches found in the literature reviewed are referred to shellfish (crustaceans and bivalves). Since YSLME mariculture reports mainly shellfish and seaweeds it was deemed necessary to focus on these main commodities.

Table 2. Models of the carrying capacity of coastal ecosystems: required information

Requirement	Description
First	Primary production of the system, the scale of the established natural population and introduced population(s) and also on the exchange of materials with adjacent ecosystems.
Second	Parameterization of the ecophysiology and the bioenergetics of the cultivated species, ie, the feeding behavior of the naturally occurring and cultivated species and the efficiency with which they can convert absorbed organic matter into growth. Models need to take account of the ways in which the above processes vary with factors such as water temperature, and the quantity and quality of the suspended matter
Third	The third requirement for application by both growers and planners is a model of the variation in stock performance in response to a range of factors related to choice of site and husbandry of the stock, including size of animal. This can be combined with models of the age/size composition of the stock to derive estimates of the timing and quantity of harvestable product.

4.2.3.3 Models of primary production, hydrography and the supply of food to mollusks

In open coastal waters, the food supply available to filter feeding bivalves is derived from the annual primary production in the water column. There is a need of comprehensive data on the annual cycle of primary production, and hence of total primary production in targeted areas eg. YSLME region.

Likewise, it would be possible to estimate the biomass of filter feeding shellfish that could be produced annually. However, this is clearly not all available for cultivated shellfish, as there is extensive competition for this primary production from natural filter-feeding organisms, including natural shellfish populations and zooplankton.

In certain coastal environments, the food supply available to natural and cultivated populations of filter feeding bivalves is the sum of the primary production in the water column of that coastal environment and the articulate organic matter brought in by tidal and other circulation from adjacent coastal waters, minus the particulate organic matter lost to coastal waters on the ebb tide. The interactions between production processes in the open waters and other coastal environments, and the supply and loss of phytoplankton biomass are complex.

As for coastal waters, there will be similar competition between cultivated shellfish and other filter feeders, such as zooplankton. The “box model” methodology of Smith and Hollibaugh was applied to calculate the horizontal mixing and advection exchanges between lake basins by means of salt balance. Then the model was used to compute the net fluxes of plankton at monthly intervals over the year. Modelling of this type provides the basis for models that can be used to address the availability of food to filter feeding organisms in sea enclosed areas.[6]

4.2.3.4 Models of bivalve mollusk physiology and feeding/growth bioenergetics

There is a need to consider a review of the state of knowledge on suspension feeding behavior of mollusks. A particularly important outcome from this kind of review may describe general relationships between the feeding behaviors of several important commercial bivalve species. Thus, it is expected that very soon, there will be available models for each main species cultured within the YSLME region. These tools will definitely help to optimize sustainable culture practices.

[6] Cited in Rosenthal, 1988 (pls. see references)

4.2.3.5 Models to predict growth rates under varying stocking levels, densities, etc.

The combination of the approaches described above give opportunities to estimate the maximum biomass of filter-feeding shellfish that could be produced in coastal water bodies, through a combination of modelling of the available food and modelling of the uptake of that food by the shellfish. This modelling can be undertaken on the scale of an enclosed water body, or any defined area of more open coastal water.

However, the question as to whether the theoretical carrying capacity (and production) can be attained brings in more detailed questions relating to the characteristics of individual shellfish growing sites, and the husbandry strategies that might be applied. This in turn is of great importance to the economic success of any shellfish farming operation. But development of such models will be essential to support a credible, coherent and sustainable planning regime, and to assist progress towards an optimization of shellfish cultivation developments.

4.3 Modelling

4.3.1 Background

There has been much debate over the nature, scale and significance of the environmental effects of fisheries and aquaculture activities. Conventional cage design does not permit treatment of wastes before their discharge to the sea. Cage fish farming as practiced commonly relies on natural dilution and degradation to assimilate its wastes. The capacity of the environment to assimilate waste is limited by the hydrodynamic characteristics of the recipient water bodies.

From the general perspective of minimizing the risk of pollution, or the particular perspective of ensuring compliance with any available “Environmental Quality Standards”, the YSLME PMO have therefore recognized the importance to propose it’s members the need for better predictive tools to match scales of development to the assimilative capacity of the environment.[7]

4.3.2 Allowable Zone of Effects-AZE or “Buffer Zone”

In common with the approach taken with all other effluent discharges, the YSLME PMO suggests the Regional Scientific and Technical Panel (RSTP) to acknowledge the need for a mixing zone around aquaculture farms where pollutants are at first diluted. This could be known as an allowable zone of effects (AZE) and is defined as:

> *“The area (or volume) of sea-bed or receiving water body in which YSLME members will allow some figures exceeding the relevant environmental quality standard that might be available for the YSLME region or some non-permanent damage to the environment”.*

This concept may become fundamental to the system of environmental management within the YSLME region. It follows that any modelling approach used in regulating effluent discharges must allow appropriate boundaries to be set defining where the YSLME experts expect the EQS to be achieved, taking account of natural processes of dispersion and degradation of the various types of wastes.

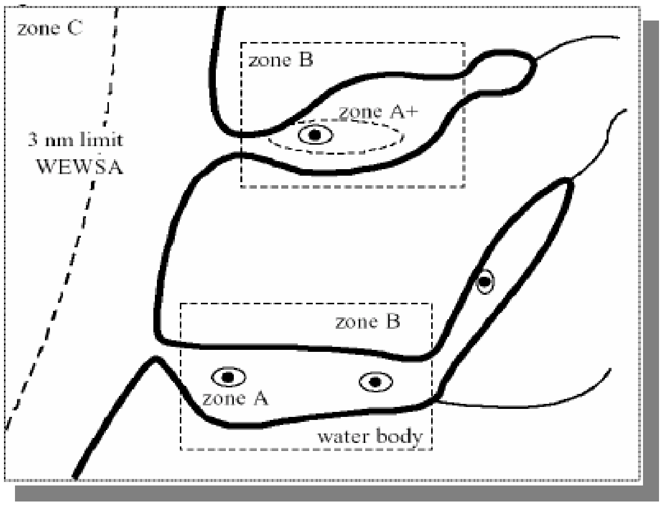
4.3.3 Equilibrium Concentration Enhancement Modelling (ECE Modelling)

Guidelines of Aquaculture Activities in YSLME member countries should be developed. A modelling technique developed within that context may represent a significant first step in the strategic assessment of assimilative capacity. A precautionary approach to further development may also be considered, using a predictive model to highlight areas where the natural capacity to assimilate additional nutrient load and particulate organic matter adequately may be most at risk. The modelling could assume that increases in natural concentrations of nutrients and the impact of organic matter may be estimated by comparison of such inputs to available tidally-driven dilution in the recipient waters, as **equilibrium concentration enhancements** (ECE).

[7] Napier University (UK) is a good start point if more info on modelling is required.

4.3.4 CSTT Modelling

Nutrient impacts arising from sewage discharges in marine waters should be modelled by using the Comprehensive Studies Task Team approach (CSTT, 1993). It uses a **series of nested boxes around a discharge**. The size of each box is determined by the local dispersion and by the time-scales of critical biochemical processes in relation to the residence time (RT) of nutrients within the box. The inner box (zone A) has a short RT of a few minutes or hours, certainly less than a tidal cycle; the zone B box has a RT of a few days, corresponding to the period required for growth of primary producer species in response to nutrients; the outer box (zone C) has a RT of weeks to months, corresponding to the time needed to mineralize organic particulate material. Zones B and, to a lesser extent, zone C are where the group's main work is concentrated.



4.3.5 Combined ECE/CSTT modelling

There might be chance to consider combining the ECE and CSTT approaches. Because the modelling required to assess assimilative capacity in relation to fish farming focuses on multiple rather than single inputs, an inner box (zone A) is believed to be unnecessary. Biogeochemical transformations occurring – by definition - in the outer box (zone C) happen in an area beyond that considered in the current ECE formulation and would, if incorporated, require a more sophisticated tool.

The volume of water in current ECE modelling is determined by the size and tidal range of the targeted area in which the discharges occur. To extend the ECE method to handle open water areas, we advocate the use of CSTT style boxes at the box B scale.

Thus, the research need is to establish a box size suitable for use in enclosed and open waters. The horizontal size depends on tidal excursion and dispersion: both of these are site-specific and might be quantified from extant data, although it may be desirable to simplify dispersion with a set of standard values. The vertical size may be determined by details of the site-specific stratification. Sensitivity testing is essential to establish suitable ranges and the necessary degree of accuracy.

4.3.6 Assimilative capacity modelling issues

The assimilative capacity approach considers the maintenance of a healthy environment in relation to its ability to deal with inputs of waste wherever they arise. Although it is important to take into account waste such as sewage discharges and diffuse inputs from agriculture and forestry, the important cage fish farming waste components are nutrients, particulates and associated potential biochemical oxygen demand (BOD) resulting from the metabolism of fish food, and residues of sea-lice treatment chemicals. The YSLME PMO may consider to discuss on the inclusion of escapees and chemicals e.g. sea lice treatments amongst the issues for consideration. It might be considered the adoption of a "zero emission" target for sea lice and escapes in further.

Literature review indicates that fish farming on its own is unlikely to create significant impacts at the zone B and C scales. However, should a combination of sources result in an excess of nutrients, particularly at a zone B scale, there is potential for eutrophication with the added risk of algal blooms, changes in food webs, decreases in water transparency, or increases in biomass – all contributing to BOD.

Significant increases in deposition of organic solids may lead to local covering of the sea bed near fish farms. In some circumstances the resultant increases in BOD may change the fauna and deoxygenate the sediment over a wider area (zone A) and may in a few circumstances increase the risk of de-oxygenation of deep water on a zone B scale; especially where there is a restricted tidal flux or geomorphologic characteristics that restrict water circulation and allow build-up of organic sediment.

In zone A, treatment chemicals may have temporary toxic effects on resident benthos or toxic effects on transitory plankton. As the use of these compounds is episodic, the risk of chronic toxic effects on plankton on a zone B and C scale is considered to be negligible.

4.3.7 The environmental state variable (or vector) model concept

"State" may mean a category, such as trophic state, or the position of a point in a multi-dimensional space defined by a set of state variables each characteristic of the ecosystem. Models can represent some or all of these variables by dynamic equations.

State variables for assimilative capacity models include:

- Concentrations of drivers such as nutrients;
- Environmental factors such as temperature; and,
- **E**nvironmental **Q**uality **V**ariables (EQVs) defined by the regulators, such as dissolved oxygen concentrations.

Some variables may belong to several categories.

To estimate assimilative capacity with such models, appropriate environmental quality standards (EQSs) corresponding to each EQV must be available. They may be established by standard methods taking account of sensitive environmental processes. For example, the EQS for oxygen concentration might be set to the minimum needed for passage of fish. Simulations may reveal the range of inputs that in most conditions keeps each EQV within its corresponding EQS. The maximum particular input satisfying this condition is then the upper limit of the assimilative capacity for that substance. Management of inputs from various water users below this maximum may in turn ensure that the assimilative capacity is not exceeded. This capacity may well vary according to the particular waste and, if so, allowable waste inputs must be governed by whichever is the lowest estimated value.

4.3.8 Summary of Models

Table 3. Models, Concepts and Scales

Model & key components	Regulatory concept	Scale (CSTT zone)
Benthic impact: AZE determined by models such as the particle-tracking model DEPOMOD	AZE (Allowable Zone of Effect) and related relaxed standards for seabed	A
Local dilution/dispersion: Simple dispersion models (for example models used to predict dispersion of sea lice bath treatments)	short-term* EQS for water-column	A+
Equilibrium Concentration Enhancement: ECE = box exchange physics + budget (of nutrients and medicines)	long-term* EQS	B
Environmental State Vector: ESV = ECE + biogeochemistry + (e.g. nutrient to chlorophyll conversion) for a set of environmental quality variables (e.g. chlorophyll, oxygen, transparency)	long-term* EQS and basin scale assimilative capacity	B
Ecosystem model: = ESV + ecology + (several types of organism at several trophic levels), with implicit or explicit detailed physics	long-term* EQS and assimilative capacity on regional scale	(B),C
Harmful Algal Blooms model = ecosystem model + model for population dynamics of harmful species		(B), C

4.4 Assessment of research requirements

4.4.1 Limit to nutrients and seabed impacts according to a set of Preliminary Guidelines

The Preliminary Guidelines depend on predictive models to estimate the environmental sensitivity of water bodies to given inputs. They lead to coastal waters designation as Category 1 (most sensitive), 2, or 3 (least sensitive). Because of physical characteristics, some waters are unclassified but are also unlikely to be considered environmentally sensitive. Models used in this categorization are being refined at FRS.

To develop an iterative regulatory tool, the process would be reversed so as to determine the maximum permissible input, and hence the additional biomass that could be accommodated, without breaching the criteria that would result in a Category 1 classification.

4.4.2 Improvements to ECE Modelling

Improvements to the current ECE approach are needed, both to the water modelling and to the prescription of all nutrient inputs and their variability.

4.4.2.1 Water Modelling

ECE modelling assumes water in a sea enclosed areas to be mixed fully within internal waters and exchanged fully with coastal waters on each tide. However, these assumptions may merely approximate reality. There is a general need to improve modelling of physical processes, simplifying and parameterising them for inclusion in biological and biochemical impact models at scales relevant to determining assimilative capacity. For example, temperature and salinity surveys in combination with ratios such as silt depth or the ratio of sill depth to maximum basin depth may give insight and quantify internal mixing. With a better understanding of internal mixing and the degree and extent to which variables such as freshwater input, tidal and wind regimes most affect stratification, mixing and exchange with coastal waters, it is believed that a partial mixing factor may then be included.

4.4.2.2 Nutrient Inputs

Two improvements would be beneficial:

1. More detail of variation in feed inputs through the year would estimate better the nutrients available for algal growth and improve the categorizing of waters;
2. More comprehensive modelling would account for other sources of nutrients.

The current ECE method considers natural inputs but not anthropogenic inputs such as land runoff and its variability with land use, other trade and sewage effluents, or atmospheric inputs. The method should distinguish areas of different background nutrient levels. Thus, seems desirable to incorporate other nutrient sources from runoff data used in the assessment.

4.4.2.3 Environmental State Variable (or Vector) Models

ECE models are simple exchange models with budgeted inputs but no biogeochemical transformations of the nutrients. To improve ECE models, Environmental State Vector models add water quality variables and deal with such transformations.

A simple example is the CSTT eutrophication model (CSTT, 1993) that uses an equation to describe transformation of ECE nutrient to chlorophyll – and compares the maximum with a chlorophyll EQS. An ideal ESV model contains equations for all environmental quality variables relevant to a particular reality. Relevant variables might be concentrations of dissolved available inorganic nitrogen, dissolved inorganic phosphate, chlorophyll, dissolved oxygen, water transparency, or the ratio of diatoms to flagellates.

Such models would predict assimilative capacity on a basin (zone B) scale for inputs of nutrients and BOD. Research is needed to: 1. Identify the key variables; 2. Propose EQS; and, 3. Develop and validate the models.

Ideally, the models should be simple and transparent, requiring few local observations, so as to act as rapid screening tools for industry and regulators.

Validation of the models under a variety of meteorological conditions needs measurements. These may be collected as a time-series over a number of years at a small range of sites representing the variety of aquaculture sites, and including type-specific reference sites as identified for certain purposes at which conditions are almost pristine. Offshore sites, in which zone B may be defined by residence time, should be included. Such time-series tests would also inform EQS assessments. They may include *in-situ* monitoring devices, with basic measurements and preserved samples collected by willing volunteers for example, fish farm operators routinely working in the area.

Once developed, ESV models may estimate assimilative capacity by scenario analysis: seasonal cycles are simulated for a variety of weather, nutrient and organic inputs, and those scenarios that keep all ESVs within the defined EQS are consequently identified. To develop such models will sometimes require new work on key parameter values (e.g. the yield of chlorophyll to be expected from a limiting nutrient).

4.4.2.4 Ecosystem Models

Literature review shows that Ecosystem Models are more complicated, containing more parameters than the ESV class of biogeochemical models, and must be supplied with the values of more initial or boundary values for each state variable. Intrinsically, they contain expressions that seek to simulate ecological processes, such as allowing for competitive interactions between populations at each trophic level. This in turn generates simulated ecosystem behavior, such as variations in population abundance that need critical interpretation by appropriate specialists.

Such models might be applied on scales of basins or zone B but the costs may only rarely be justified. Ecosystem models are most useful and relevant in dealing with zone C and far-field issues, including the provision of boundary conditions for zone B models, assessments of assimilative capacity on regional scales, and in relation to integrated coastal zone management. Because physical heterogeneity is inherent in larger scales, ecosystem models must be linked computationally and explicitly to spatially resolving physical models. A final desirable development of ecosystem models is to include in them sub-models for the population dynamics of harmful algae.

4.4.3 Limiting organic matter input to the seabed on the scale of zone B via bottom water oxygen levels and ecological impact upon seabed communities

Fish farms represent only one source of organic matter in coastal waters. Others are phytoplankton, bacteria, seaweeds and sea grasses, natural and anthropogenic inputs from rivers, and point discharges. As this organic matter decays it consumes oxygen, with the potential to dangerously or to promote anoxia in sediments and near-bottom waters.

Soft muddy sediments – those with high proportions of silt and clay - are naturally anoxic a few centimeters below their surface. This regime is useful as an environment for denitrification. What should be avoided is widespread anoxia at the sediment surface, because it kills almost all multicellular benthic animals and thus seriously impairs ecosystem function. The particle-tracking model DEPOMOD predicts the footprint of sinking organic matter below fish farm cages and thus the zone A area at risk of de-oxygenation may be estimated. The present regulatory process allows for a small area (AZE) to be partly degraded, from the viewpoint that small areas recover once cages are moved. Such recovery happens because the planktonic larvae of many macrobenthic animals are dispersed widely by water movements and so decolonize previously degraded areas.

This leads to an important benthic zone B assimilative capacity issue: what proportion of the bed of a sea enclosed areas may be partly degraded without posing long-term harm? Research is required to address this issue. However, some of the related questions are fundamental to community ecology and are unlikely to be solved either quickly or cheaply. It is believed that a review of spatial and temporal variability on the zone B scale would be useful and that it may, in due course, point to the minimum anthropogenic degradation detectable against the background both of natural variability and of other widespread anthropogenic influence in coastal waters, for example, the disturbance of the coastal seabed by demersal fishing gear.

If the fish farming industry were to shift cages to regions of high dispersion, the impact within the AZE (within zone A) would diminish but organic material may spread further a field into zone B. Other zone B problems would remain, needing to be considered in the suite of methods used to assess development proposals. A boxed approach might be used to budget inputs and losses of organic matter. A reasonably simple extension to a 2- or 3- layer model may account for bottom water oxygen consumption. Such a component should be included in research commissioned for the development of ESV models.

For the long term, an account of possible synergies between an ecosystem approach and the hydrographic effects of climate would be useful.

4.4.4 Limiting biomass via consent limits for chemicals e.g. sea lice treatments

Limitation of biomass by a methodology based on consenting limits for treatment chemicals would probably involve unreliable or contentious assumptions about the numbers of treatments needed at a site. However, a simple limiting factor criterion might be that a fish farm should have the capability to treat all the maximum biomass with at least one of the available medicines.

In the past, there has been concern about a possible risk of overlapping effects from the coincident release of medicines from several sites. The risk depends critically on the fate and behavior of the various compounds. In view of its water solubility characteristics, Azamethiphos was thought to pose the most significant risk but, as other compounds have become available, complete reliance on Azamethiphos for spring strategic treatments has declined. The fate and behavior of in-feed treatments may be predicted by the particle-tracking model DEPOMOD.

The industry has indicated a wish to produce at fewer but larger sites in order to cut unit costs. Therefore, it will be advisable to focus on the relative risks and benefits of the use and discharge of active ingredients at a single site rather than numerous smaller amounts at several sites in a given area.

4.4.5 Limiting development for conservation reasons

Relevant authorities considering aquaculture developments within or close to sites identified as Marine Protected Areas or the like must assess whether the development will have adverse effect on the integrity of the site in terms of the identified conservation objectives. The conservation concerns may arise on a broad scale such as Marine Reserves or on scales as small as reefs, otter habitats or localized sea grass beds.

4.5 Carrying Capacity and impact of aquaculture on the environment in Chinese bays

4.5.1 General issues

The literature review shows an EU project entitled *Carrying capacity and impact of aquaculture on the environment in Chinese bays*, funded by the International Cooperation with Developing Countries (INCO-DC) program. [8]

The general objective of this project was to model and define the carrying capacity for sustainable development of aquaculture in Chinese semi-enclosed bays - e.g. the maximum number or biomass of cultivated species which can be cultivated in a zone without decrease of the yield and environmental deleterious effects, taking into account constraints due to cultivation practices.

This project is documented at http://www.ecowin.org/china/ and was carried out under a 36 month contract, from November 1st 1998 to October 31st 2001, by a consortium of research institutes from the European Union, China and Canada, coordinated by Dr. Cedric Bacher from IFREMER. A summary of the final report for this activity is available as Annex 1 of this working document or at this link: http://www.ecowin.org/china/catalogue/cat980291.pdf

4.5.2 Objectives

The project focused on three specific objectives:

- To improve scientific knowledge on the interactions between aquaculture and environment in coastal areas, including the interactions between different types of aquaculture or exploitation of natural resources, with an emphasis on polyculture.
- To establish models that predicts the carrying capacity for aquaculture and its resulting impacts according to different types of aquaculture in different environments.
- To provide scientific information and recommendations that facilitates sustainable aquaculture management.

4.5.3 The partnership

The partnership which carried out this work included three European and four Chinese laboratories, and Dalhousie University in Canada, which was sub-contracted to IFREMER[9]. The partner institutes are shown in the table, together with the name and contact of the lead scientist from each. [10]

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[8] Details of this experience in China could be found at: http://www.ecowin.org/china/

[9] French Research Institute for Exploitation of the Sea. Pls. check this link for further details: http://www.ifremer.fr/francais/index.php

[10] Details can be reviewed at: http://www.ecowin.org/china/partners.htm

Institution	Expert
CREMA - IFREMER - FRANCE	Cedric Bacher
Plymouth Marine Laboratory - U.K.	Tony Hawkins
IMAR - Portugal	Joao Gomes Ferreira
First Institute of Oceanography -China	Zhu Mingyuan
Yellow Sea Fisheries Research Institute - China	Tang Qisheng
Second Institute of Oceanography -China	Ning Xiuren
Shandong Mariculture Institute - China	Mou Shaodun
Dalhousie University - Canada	Jon Grant

The consortium carried out fieldwork, laboratory and in situ experiments and numerical modelling on two bays where shellfish aquaculture plays an important role in the local economy. Jiaozhou Bay is a 400km2 bay adjacent to Qingdao (pop. 6 million), a very busy port in Northern China, and Sanggou Bay is a smaller system (140km2) further to the north, dedicated almost exclusively to polyculture of shellfish and seaweeds.

IFREMER coordinated the project as a whole, and the First Institute of Oceanography of China was responsible for coordinating the work carried out by the Chinese partners. The project management was carried out by a steering committee which was composed of the lead scientists from the different teams.

4.5.4 Methodologies

The project studied and modeled aquaculture in two bays; Jiaozhou and Sanggou, both in Shandong Province, in Northern China.[11]

A metadata base was first constructed that synthesized existing data from historical records, statistics for mariculture production, available databases and spatial information both on cultivated species and hydrobiological characteristics.

From May 1999 to April 2000, data required for calibrating and ground-truthing our models were obtained through additional field work in the natural environment (in situ spatial and temporal variability in natural environmental variables, measured monthly at seven stations in each bay), including studies of the cultivated species (stock assessment, population dynamics, growth), as well as interactions between those species and the environment (ecophysiology experiments). Findings define the effects of temperature, nitrogen availability and light intensity on growth of the main cultured macroalgae, *Laminaria japonica*.

In addition, for the main species of cultured shellfish, the “Chinese scallop” *Chlamys farreri*, the “Manila clam” *Ruditapes philippinarum* and the “Pacific oyster” *Crassostrea gigas*, the project developed separated dynamic models that could replicate responsive adjustments in feeding, metabolism and growth across full natural ranges of temperature, food availability and food composition.

Models defining ecophysiological responses in each main cultured species were coupled with hydrodynamic and biogeochemical elements in common geographic grids, allowing analyses of key processes in a range of simulations at different spatial and temporal scales, according to different modeling objectives.

At the local farm scale, towards a practical tool that can be used locally by marine farmers to predict the effects of culture density upon shellfish growth at different sites, the project developed a depletion model which couples our models of shellfish ecophysiology with a one-dimensional horizontal transport formulation.

[11] More details about methodologies used are available at this link: http://www.ecowin.org/china/methods.htm

At wider bay scales, two complementary strategies were employed to assess environmental carrying capacities for culture, taking into account interactions between each cultivated species, as well as between those species and their environments. Firstly, a 2D coupled physical-biogeochemical model was developed for Sanggou Bay, based on a bathymetric grid of 1120 cells affording a spatial resolution of 500 m, to simulate short term responses (e.g. one year) to changes in cultivation practice.

Secondly, a box model was developed using a quasi one-dimensional approach without spatial variability to assess effects of culture practice on production in the longer term. Both of these bay scale models accounted for primary production, bivalve and kelp ecophysiology and growth, exchange with the ocean, mineralization of detritus, particle sedimentation and re-suspension, species densities, and times of seeding and harvesting.

By these means, integrated assessments were undertaken to consider how different scenarios of multi-species culture may affect ecosystem functioning and sustainable capacities for exploitation. The scenarios were recommended by local fisheries managers, and the outputs considered collectively in associated workshops, as significant contributions in the development of local fisheries practice.

4.5.5 Results

Elements of the models used by the project defining shellfish responses were cutting edge, with novel approaches that they expect and could be applied widely. In particular, for the first time in such models, the project resolved significant adjustments in the relative processing of living chlorophyll-rich phytoplankton organics, non-phytoplankton organics and the remaining inorganic matter during both differential retention on the gill and selective pre-ingestive rejection within pseudofaeces.[12]

The project also included a facility to simulate the energy content of non-phytoplankton organics. This is significant, for that energy content was very much more variable than for phytoplankton organics, and which represented less than 20% of all suspended particulate organic matter.

Such resolution of the relative processing of different particle types allows simulation of how the rates, organic compositions and energy contents of filtered, ingested and deposited matter change in response to wide differences in seawater temperature, seston availability and seston composition.

Dependent relations predicted rates of energy absorption, energy expenditure and excretion. By these means, the models used were more adaptable that past models of shellfish physiology, replicating dynamic adjustments in feeding and metabolism across full ranges of relevant natural variability, and successfully simulating growth from larvae or seed to harvestable size under different temporal and spatial scenarios of culture.

This was an important advance compared with simpler models that do not simulate responsive adjustments, for only by modeling the complex set of feedbacks, both positive and negative, whereby suspension feeding shellfish interact with ecosystem processes, can one realistically hope to assess environmental capacities for culture.

Measurements and simulations of the effects of culture on hydrodynamics indicated that disregard for physical barriers associated with culture will result in a serious overestimation of the particle renewal term and thus an overestimation of carrying capacity. Coupling our models of bivalve ecophysiology and one-dimensional hydrodynamics, the resulting depletion model for use by farm managers demonstrated how shellfish density has an increasingly negative effect on growth in regions with higher water residence times or lower depths, and which may be used to establish optimal densities for aquaculture at different locations throughout the bay.

The coupled bay-scale models were used to simulate various culture scenarios, each scenario representing a whole cultivation cycle, whilst depicting differences in time of seeding and/or harvesting, according to recent changes in aquaculture practice, including different spatial distributions and/or densities of the main cultivated species. Findings establish how coupled models of this kind are increasingly able to simulate the general behavior of key ecosystem

[12] More details on the results of this project can be found at: http://www.ecowin.org/china/results.htm

variables, both in space and time, at least within the context of this relatively simple marine system, dominated by a few species.

Main innovative findings within the content of community ecology generally include how very sensitive total production can be to changes in the composition, densities and/or distributions of dominant cultured species, where changes in local density may have effects at the bay scale.

Collective findings from different simulations using both our 2D and box models at bay-scale suggested that Sanggou Bay is already being exploited close to the environmental carrying capacity for scallop production, albeit with some potential for increased oyster production. This reflects inter-specific competition for food, with a competitive advantage for oysters compared with scallops, despite being cultivated in different areas of the bay.

Given apparent limitations on harvest yield for scallops, a hypothetical scenario was requested by local managers to assess whether scallop production might be increased without changing bivalve loads, in which the total quantity of scallops and oysters remained the same as present, but when the scallops are distributed over the area currently given over for cultivation of both scallops and kelp, thereby creating areas of combined kelp and scallop culture, in which average scallop density is reduced. Predictions under this suggested alternative management strategy suggest that harvest yields that oyster yield would be maintained, yet scallop production increased by more than three fold. This represents an increase of nearly 50% in the total combined yield of shellfish in comparison with current aquaculture scenario. The change is consistent with past observations whereby similar combinations of scallop and kelp culture have proven successful elsewhere, and which was later understood it was being trialed in Sanggou Bay.

The project's approach was considered generic in the sense that modelling tools and concepts can be applied to other sites and cultivated species. Tools and concepts were widely discussed and disseminated within the consortium. Databases, Geographic Information Systems and models remain available for use by others as indicated in the project's Technology Implementation Plan.

4.5.6 Workshops and Training programmes

Training sessions and workshops took place throughout the project, both in China and Europe. This included training in i) **ecophysiology experiments**, ii) **ecosystem and ecophysiology modelling**; and, iii) **database management**. [13]

4.5.6.1 Workshop No. 1

The kick-off workshop took place in Qingdao, China, from November 30th to December 4th 1998. At this workshop, the project was presented to the decision-making community of Shandong Province, general presentations were made by the participants, and the project workplan was reviewed by the team. The key issues were: i) Presentation of the different partners and task allocations; ii) Review of the project agenda and workplan; and, iii) Definition of coordination and sub-groups for main tasks.

4.5.6.2 Training No. 1

This was followed by cooperative model training and experimental activities in the Spring of 1999, which took place both in Qingdao and in Rongsheng city, Shandong province.

[13] The project team as a whole felt that the achievements of the work made an important contribution to aquaculture resource management in China, showing how a state of the art modelling toolset could be employed for management both at local and generic scales. The lessons learnt by European researchers on the Chinese approach to polyculture, traditionally applied for thousands of years, were no less important. Some of these concepts are only now starting to gain favor in Europe and the U.S. The end of the project additionally revealed how far the integration of Chinese and European scientists had progressed throughout the three years of cooperation, across age, subject and cultural boundaries. Source of info: http://www.ecowin.org/china/workshops.htm

4.5.6.3 Workshop No. 2

The second annual workshop took place in Oporto, Portugal, from 8-11 November 1999. Reviews of work carried out were presented by participants, including database, GIS, modelling, fieldwork and experimental activities. Details were presented regarding training in China, and proposed courses in the year 2000 on data management and ecological modelling.

4.5.6.4 Training No. 2

In Qingdao, a modelling training workshop was held from 14-20 May 2000, which focused on capacity building for database use and modelling, both at the physiology and ecosystem scale.

4.5.6.5 Training No. 3

An intensive training course was held from 11th to14th October 2000, at La Rochelle, France, on ecological modelling using the EcoWin2000 platform. The course, attended by about 10 scientists, was divided into three blocks: The first day for introductory aspects, 1.5 days for using the model and the remaining period for object-oriented programming for ecological modelling. During this period, the database framework which was used to store field and experimental data for Jiaozhou Bay and Sanggou Bay was also explored.

4.5.6.6 Workshop No. 3

Following the course, **the third annual workshop** was held at La Rochelle, from the 16-18th October, 2000. The first day was used to present results, the second day for detailed planning of activities for the third project year, and the last day was reserved for the steering committee meeting and workshop conclusions. An interim project meeting was scheduled for Spring 2001 in Qingdao, to allow timely preparation of reports and final project actions.

4.5.6.7 Workshop No. 4

The Spring meeting took place from May 31st to June 1st 2001, and allowed final decisions to be taken regarding integration of models, scheduling for production of the various work-package and partner final reports, and distribution of complete datasets and database software. This meeting was followed by a field trip to coastal areas in Zhejiang province, which were examined for a potential continuation of this work, and visits to SIO and Ningbo University.

4.5.6.8 Workshop No. 5

The final project workshop took place in Qingdao, from 6th to 9th November 2001. The key objectives were:

- Presentation of the project outcomes to a wide audience of Chinese decision-makers, scientists and aquaculture managers
- Review of the final detailed results for the different activities, and analysis of complementary methodologies
- Conclusions, overview of the project and detailed planning of result exploitation and dissemination activities, of which this website is an example.

4.5.7 Publications

The results and conclusions of this project lead to the development of several concept papers, some of the titles can be revised at: http://www.ecowin.org/china/publications.htm or at Annex 2 of this working document.

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http://www.ecowin.org/china/catalogue/cat980291.pdf

http://www.imar.pt/

http://www.phys.ocean.dal.ca/

Carrying capacity and impact of aquaculture on the environment in Chinese bays

Project number: IC18980291 5^{TH} Framework Programme

Duration: 1/11/1998 to 31/10/2001 (36 months)

Coordinator:Dr. Cedric Bacher, IFREMER CREMA, France

Context and objectives

Aquaculture in Asia has a long history of combining different species in polyculture. This embraces principles of ecological engineering within integrated farming systems, to achieve more sustainable solutions through the recycling of wastes from culture cages, culture ponds and sewage outfalls into high-value protein crops that may be removed for human consumption. In China alone, the annual output from aquaculture is more than 20 million tons, which is 30% higher than the wild catch, and represents more than 60% of total global aquaculture.

The general objective of this project was to model and define the carrying capacity for sustainable development of aquaculture in Chinese semi-enclosed bays - e.g. the maximum number or biomass of cultivated species which can be cultivated in a zone without decrease of the yield and deleterious environmental effects, taking into account constraints due to cultivation practices.

Specific objectives included:

1. To improve scientific knowledge on the interactions between aquaculture and environment in coastal areas, including the interactions between different types of aquaculture or exploitation of natural resources, with an emphasis on polyculture.
2. To establish models to predict the carrying capacity for aquaculture and its impacts resulting from different types of aquaculture in different environments.
3. To provide scientific information and recommendations that facilitate sustainable aquaculture management.

Activities

Aquaculture was studied and modelled in two bays; Jiaozhou and Sanggou, both in Shandong Province. A metadatabase was first constructed which synthesised existing data from historical records, statistics for mariculture production, available databases and spatial information both on cultivated species and hydrobiological characteristics. Data required to calibrate and ground truth the models was obtained through additional field work that involved *in situ* spatial and temporal variability in natural environmental variables, measured monthly at seven stations in each bay. Measures included stock assessment, growth rates and population dynamics of the cultivated species, as well as ecophysiological measures of interactions between those species and the environment.

Findings defined the effects of temperature, nitrogen availability and light intensity on growth of the main cultured macroalgae, the kelp *Laminaria japonica*. In addition, for each main species of cultured shellfish, which included the Chinese scallop *Chlamys farreri*, the Manila clam *Ruditapes philippinarum* and the Pacific oyster *Crassostrea gigas*, we developed separate dynamic models to replicate responsive adjustments in feeding, metabolism and growth across full natural ranges of temperature, food availability and food composition.

Models defining ecophysiological responses in each main cultured species were coupled with hydrodynamic and biogeochemical elements in common geographic grids, allowing analyses of key processes in a range of simulations at different spatial and temporal scales, according to different modelling objectives.

At the local farm scale, towards a practical tool which could be used locally by marine farmers to predict the effects of culture density upon shellfish growth at different sites, a depletion model was developed that combines each model of shellfish ecophysiology with a one-dimensional horizontal transport formulation.

At wider bay scales, two complementary strategies were employed to assess environmental carrying capacities for culture, taking into account interactions between each cultivated species, as well as between those species and their environments. Firstly, a two-dimensional coupled physical-biogeochemical model was developed for Sanggou Bay, based on a bathymetric grid of 1120 cells affording a spatial resolution of 500 m, to simulate short term responses (e.g. one year) to changes in cultivation practice. Secondly, a box model was developed using a quasi one-dimensional approach without spatial variability to assess effects of culture practice on production in the longer term. Both of these bay scale models accounted for the same processes: primary production, bivalve and kelp ecophysiology and growth, exchange with the ocean, mineralisation of detritus, particle sedimentation and resuspension, species densities, and times of seeding and harvesting.

Integrated assessments were undertaken using these tools to consider how different scenarios of multi-species culture may affect ecosystem functioning and sustainable capacities for exploitation. The scenarios considered were recommended by local fisheries managers, and the outputs considered collectively in associated workshops, as significant contributions in the development of local fisheries practice.

Training sessions and workshops took place throughout the project, both in China and Europe. This included training in database management, ecophysiology experiments, ecophysiology and ecosystem modelling.

Results and outcomes

Elements of the models defining shellfish responses are cutting edge. In particular, for the first time in such models, significant adjustments were resolved in the relative processing of living chlorophyll-rich phytoplankton organics, non-phytoplankton organics and the remaining inorganic matter during both differential retention on the gill and selective pre-ingestive rejection within pseudofaeces. A facility to simulate the energy content of non-phytoplankton organics was included. This was significant, for that energy content was very much more variable than for phytoplankton organics, and which represented less than 20% of all suspended particulate organic matter. Such resolution of the relative processing of different particle types allowed simulation of how the rates, organic compositions and energy contents of filtered, ingested and deposited matter change in response to wide differences in seawater temperature, seston availability and seston composition. Dependent relations predict rates of energy absorption, energy expenditure and excretion. By these means, resulting models were more adaptable that past models of shellfish physiology, replicating dynamic adjustments in feeding and metabolism across full ranges of relevant natural variability, and successfully simulating growth from larvae or seed to harvestable size under different temporal and spatial scenarios of culture.

Measurements and simulations of the effects of culture on hydrodynamics indicated that disregard for physical barriers associated with culture would result in a serious overestimation of the particle renewal term and thus an overestimation of carrying capacity. Coupling the models of bivalve ecophysiology and one-dimensional hydrodynamics, the resulting depletion model for use by farm managers demonstrated how shellfish density had an increasingly negative effect on growth in regions with higher water residence times or lower depths, and which could be used to establish optimal densities for aquaculture at different locations throughout the bay.

The coupled bay-scale models were used to simulate various culture scenarios, each scenario representing a whole cultivation cycle, whilst depicting differences in time of seeding and/or harvesting, according to recent changes in aquaculture practice, including different spatial distributions and/or densities of the main cultivated species. Findings established how coupled models of this kind were increasingly able to simulate the general behaviour of key ecosystem variables, both in space and time, at least within the context of this relatively simple marine system, dominated by a few species.

Main innovative findings within the content of community ecology generally included how very sensitive total production could be to changes in the composition, densities and/or distributions of dominant cultured species, where changes in local density may have effects at the bay scale.

Collective findings from different simulations using both the 2D and box models at bay-scale suggest that Sanggou Bay was already being exploited close to the environmental carrying capacity for scallop production, albeit with some potential for increased oyster production. This reflected inter-specific competition for food, with a competitive advantage for oysters compared with scallops, despite being cultivated in different areas of the bay. Given apparent limitations on harvest yield for scallops, a hypothetical analysis was requested by local managers to assess whether scallop production might be increased without changing bivalve loads, in which the total quantity of scallops and oysters remained the same as present, but when the scallops are distributed over the area currently given over for cultivation of both scallops and kelp, thereby creating areas of combined kelp and scallop culture, in which average scallop density is reduced. Predictions under this alternative management scenario suggested that harvest yields that oyster yield would be maintained, yet scallop production increased by more than three fold. This represented an increase of nearly 50% in the total combined yield of shellfish in comparison with current aquaculture scenario. The change was consistent with past observations whereby similar combinations of scallop and kelp culture had been proven successful elsewhere, and which we now understand is being trialled in Sanggou Bay.

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ANNEX 2

Carrying capacity and impact of aquaculture on the environment in Chinese bays[14]

INCO-DC contract Nº ERBIC4CT 98-0291[15]

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UNDP/GEF PROJECT ENTITLED "REDUCING ENVIRONMENTAL STRESS IN THE

YELLOW SEA LARGE MARINE ECOSYSTEM"

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Carrying Capacity and Assimilative Capacity:
- Recommendations for a practical approach -
- working document -

UNDP/GEF Yellow Sea Project
Ansan, KOREA

- 2006 -

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1 EXECUTIVE SUMMARY

Aquaculture, in common with all other food production practices, is facing challenges for sustainable development. Most aqua-farmers, like their terrestrial counterparts, are continuously pursuing ways and means of improving their production practices, to make them more efficient and cost-effective. Awareness of potential environmental problems has increased significantly. Efforts are under way to further improve human capacity, resource use and environmental management in aquaculture.

The potentially adverse impacts of aquaculture are widely documented in the literature. Current issues of alleged concern include organic enrichment and lack of sustainability. For some time it has been suggested that such impacts could be minimized or negated by the adoption of appropriate environmental safeguards including regulatory, control and monitoring procedures. In addition, the aquaculture industry has a vital interest in a clean environment and therefore, in the context of integrated coastal zone management (ICZM), there is a definite need to safeguard the marine environment. The competitive use of coastal resources has highlighted the importance of satisfactory control measures to protect the natural environment and to safeguard the developing aquaculture industry.

The aquaculture industries have seen large expansion over past decades, and subsequently, attention has been given to the environmental effects of such activities. It is not possible to generalize and distinguish between the actual and potential impacts of aquaculture given that a multitude of approaches is in place. However, in general, the potential impacts of aquaculture are wide-ranging, from aesthetic aspects to direct pollution problems. Marine aquaculture operations and the associated infrastructure can, for example, impact on scenic rural areas. Fish production generates considerable amounts of effluent (e.g. nutrients, waste feed and faeces, together with associated by-products such as medication and pesticides) that can have undesirable impacts on the environment. There may also be unwanted effects on wild populations, such as genetic disturbance, and disease transfer by escapees or ingestion of contaminated waste, and effects on the wider ecosystem.

The literature review for the so called "carrying capacity for fisheries" has some direct links to "stock assessment" approaches. **Stock assessment** involves using mathematical and statistical models to examine the retrospective development of the stock and to make quantitative predictions to address the following fisheries management questions: *What is the current state of the stock? What has happened to the stock in the past? What will happen to the stock in the future under alternative management choices?* To answer those questions a summary of the most recent stock assessments done by specialized institutes/organizations together with fisheries management issues available at any given country will determine the Total Allowable Catch (**TAC**). These TACs will help decision makers to determine the quotas to be given to the fisheries sector.

Therefore, considering the concepts available for "marine fish stock assessment" and the practical use of its results to manage fisheries in a given area, it is considered necessary that the concept of "carrying capacity" and "assimilative capacity" should be applied, within the context of the YSLME Project, mainly to aquaculture activities.

From the preceding review, it is clear that there is no universally applicable approach to the determination of the carrying capacity or assimilative capacity of coastal water bodies for cultured species. Growth rates are limited by the available food supply and by the physiological capability of the cultured aquatic organisms to take advantage of the available food. Another main concern for environmental issues arise from the discharge of particulate waste matter, the increased rate of recycling of dissolved nutrients, disturbance of wildlife, introduction of new species etc. To be useful, possible approaches to the estimation of carrying or assimilative capacity need to be subject to quantification and to lead to quantitative expression of the capacity.

This working document recommends the need to scope a carrying or assimilative capacity study and to conduct a demonstration site in order to get the "target standards" or "preliminary guidelines" that the YSLME member countries may wish to discuss and, eventually, endorse.

2 GOAL AND OBJECTIVES

2.1 Goal

The goal of this working-paper is to provide with a preliminary approach addressing issues towards the development of a carrying capacity procedure for a given area.

2.2 Objectives

The main objectives of this preliminary approach are:

1. To outline the requirements for a carrying capacity study for a given area e.g. bays
2. To identify possible combinations of modelling and field indicators of carrying capacity with emphasis on their appropriateness for YSLME environmental conditions and concerns.
3. To outline and prioritize field and laboratory investigations of the application of indicators of carrying capacity to YSLME coastal waters

3 RATIONALE

The literature review has shown that carrying capacity is a concept widely used for cultured species and leaves "stock assessment" approaches for fisheries management purposes. Therefore, this working document mainly focuses the carrying capacity and assimilative capacity approaches over mariculture issues in the YSLME region.

Likewise, the analysis of aquaculture data for the YSLME region shows that the YSLME member countries have most of its mariculture production represented by **seaweeds and shellfish** (crustaceans and mollusks included). For instance, statistics available at YSLME PMO for 1994-2004 show that:

- Chinese YS mariculture is represented mainly by shellfish and seaweeds which both major groups comprising up to 90% of the total Chinese YS mariculture production. Seaweeds represent a solid 10-20% of the total Chinese YS mariculture production throughout the given period. However, shellfish production comprises the largest cultured species representing 70-80% of total Chinese YS mariculture for the same period of time having as major commodities shrimps and bivalves such as oysters, clams and mussels.

- Korean YS mariculture is represented mainly by seaweeds and shellfish which both major groups comprising up to 95% of the total Korean YS mariculture production. Shellfish represent a solid 15-25% of the total Korean YS mariculture production throughout the given period. However, seaweed production comprises the largest cultured species representing 70-80% of total Korean YS mariculture for the same period of time having as major commodities *Porhyra spp*[1], *Laminaria japonica*[2], *Undaria pinnatifida*[3], *Hihija fusiforme and Enteromorpha spp.*

Thus, it is considered that a special attention should be given to these particular commodities when deciding the carrying capacity or assimilative capacity approach to be applied.

Within this context, seems to be appropriate: i) to analyze the possibility to review of approaches used in the YSLME and elsewhere to establish the carrying or holding/carrying capacity of coastal waters for fish and shellfish farming; ii) to identify those approaches which can be adapted to the YSLME waters; iii) to identify possible combinations of modelling and field indicators of carrying capacity with emphasis on their appropriateness for YSLME environmental conditions and concerns; and, iv) to outline and prioritize field and laboratory investigations of the application of indicators of carrying capacity to YSLME coastal waters. This approach could fit into a **Scoping Study** for Research into the aquaculture carrying capacity of YSLME region.

There is also a current need to establish scientific guidelines for **Best Environmental Practice** for the Regulation and Monitoring of Marine Aquaculture throughout the YSLME region. This can complement any carrying capacity or assimilative capacity approach through a comprehensive literature review and a brief comparison of the regulations and monitoring programmes associated with marine aquaculture in the region. This can become in further a regional target for the region.

Seems to be that the YSLME member countries have extensive data on long term monitoring of water and sediment quality, and hydrography, collected through specialized institutions. Thus, it will be possible and somehow necessary to conduct a study in which their aims may consider: i) to produce a carrying capacity model for specific **demonstration site(s)** eg. a bay; and, ii) to assess the environmental sustainability of current aquaculture activities in the demo site.

1 *Porphyra spp*. commonly know as "nori", is the most widely consumed seaweed in the world. It's commonly found in Asian food.

2 *Laminaria* products are used for industrial purposes, for medical purposes, for human consumption and as livestock fodder. The chief products extracted from *Laminaria* during industrial processing are: iodine, algin and mannitol. Mannitol is used as an anti-depressive medicine in Asian countries. *Laminaria* is increasingly being used for human consumption, especially in China and Japan where seaweeds are processed into a wide variety of food items. Laminaria is used in China as a livestock fodder for chickens and cattle.

3 *Undaria pinnatifida,* best known by its Japanese name, *wakame*

4 ANALYSIS

The following section presents a series of possible approaches to estimate carrying capacity towards a quantitative expression of the capacity.

4.1 Current approaches to estimation of assimilative or carrying capacity

4.1.1 Assimilative or Carrying Capacity in a Regulatory Framework

There is a need to identify any formal procedure within the regulatory framework in China and South Korea for the estimation of the assimilative or carrying capacity of marine areas with respect to aquaculture activities. However, the concept of nutrition planning framework is intuitively logical and clear, and knowledge of such a constraint, through modelling, would form an effective and appropriate tool for guiding the future development of the sector. The regulation of the scale and location of aquaculture farms that lead to the granting of a license should be reviewed. It might be possible to introduce assessments of carrying and assimilative capacity into this process, thereby providing a more substantial scientific basis for decisions on the appropriate scale and location of shellfish farms.

The YSLME member countries may consider undertaking a large review of the approaches available to estimate the carrying capacity of coastal waters for aquaculture practices, as part of the consideration of an over-arching aquaculture strategy at a national level.

4.1.2 Research activity in the fields of assimilative and carrying capacity

The carrying capacity of coastal ecosystems for cultivated organisms has been defined as the maximum standing stock that can be supported by that ecosystem for a given time, while enabling maximum annual production of individuals without a reduction in market size. The issue is the number of individual cultured organisms that any given 'biomass' is divided between. If the standing stock expands beyond the optimum, the inevitable result is a decline in size of individuals, e.g. carrying capacity for bivalves depends on the availability of space (substrate), and, more critically, food. In coastal waters, space is rarely the limiting factor for cultivated shellfish, as it is normal practice to introduce artificial substrate, in the form of suspension equipment such as ropes, bags, cages etc to increase the density of the cultivated species.

Models of the carrying capacity of coastal ecosystems therefore require information on the primary production of the system, the scale of the established natural population and introduced population(s) and also on the exchange of materials with adjacent ecosystems.

The second requirement for models of carrying capacity is for parameterization of the ecophysiology and the bioenergetics of the cultivated species, e.g. the feeding behavior of the naturally occurring and cultivated species and the efficiency with which they can convert absorbed organic matter into growth. Models need to take account of the ways in which the above processes vary with factors such as water temperature, and the quantity and quality of the suspended matter.

The third requirement for application by both growers and planners is a model of the variation in stock performance in response to a range of factors related to choice of site and husbandry of the stock, including size of animal. This can be combined with models of the age/size composition of the stock to derive estimates of the timing and quantity of harvestable product.

- Models of primary production, hydrography, and the supply of food;
- Models of bivalve mollusk physiology and feeding/growth bioenergetics;
- Models to predict growth rates under varying stocking levels, densities, etc.

4.2 Possible alternative approaches to the estimation of carrying and assimilative capacities

4.2.1 Carrying Capacity[4]

4.2.1.1 Modelling of available food supply

The shellfish currently of primary interest to the cultivation industry are mollusks.[5] They gain their nutrition by filtering phytoplankton and other particles from the surrounding water column. They are dependent upon natural processes of primary production and water currents to bring food particles to them.

A range of mathematical models have been published which seek to balance the supply of food particles with the filtration efficiency and predicted growth rates of farmed shellfish.[6] The models differ greatly in complexity, and normally operate on a whole-basin scale (e.g. a bay). The supply of food particles is normally considered to be a combination of estimates of the exchange delivery of food particles by water movements (e.g. tidal currents) plus the primary production that takes place within the water body.

The growth characteristics of some shellfish, particularly mussels and oysters, have been well-parameterized. The filtration rates and ingestion efficiencies under different conditions of temperature, particulate matter loading in the water, etc can be modelled to derive estimates of the net energy available to the shellfish for growth. The combination of food supply estimates and growth characteristics can be converted into a predicted aggregate biomass production rate.

Nevertheless, a review should be carried out of the potential of the various available models applicable to YSLME estuaries and open coastal areas. From this review, a set of appropriate models for specific locations could be selected and applied to areas of interest, by entrepreneurs, planners and regulators.

4.2.1.2 Environmental requirements

Shellfish farming differs from fish farming in that the different shellfish species are cultivated in different ways, often in different environmental settings. The main methods of cultivation in YSLME for the main species of interest are shown below:

Species	Cultivation Techniques
Mussel	On ropes suspended from surface long-lines On ropes suspended from rafts On the sea bed, usually in inter-tidal or shallow sub-tidal areas
Oyster	On trestles in inter-tidal areas In lantern nets suspended from rafts or long-lines In trays, stacked on the seabed On ropes, suspended from loglines
King scallop	In lantern nets suspended from rafts or long-lines On the sea bed (sub-tidal sandy areas) Suspended from ropes

[4] Most of the approaches found in the literature reviewed are referred to shellfish (crustaceans and bivalves). Since YSLME mariculture reports mainly shellfish and seaweeds (over 90% of mariculture production) it was deemed necessary to focus the analysis and recommendations on these main commodities.
[5] In the case of YSLME mariculture the major groups are oysters, clams and mussels.
[6] Please see item: MODELLING of the concept paper.

Shellfish farmers can therefore utilize both inter-tidal and sub-tidal areas, above, on or in the sediment. The range of types of environment that can be utilized by shellfish growers is much wider than that usable by fish farmers. However, the availability of these environments will limit the potential areas that could be used for shellfish farming. It is proposed that a review should be carried out, the elements of which would be to:

- Define the environmental requirements for different forms of shellfish cultivation
- Determine the distribution of these environments in coastal waters
- Assess the current activities in these areas and their consequential availability for shellfish farming

The results of such a review would contribute added value to the 'carrying capacity' review.

4.2.1.3 Limitations on availability of sea areas for conservation reasons

There is a need to review the current legislation available related to Special Areas of Conservation (SACs), Marine Protected Areas (MPAs) or any other similar to those. In each case, the reasons for the designations could give reasons for the rising to particular sensitivities that need to be taken into account in proposals for shellfish farm developments. In some cases, the sensitivities may be such as to argue strongly against aquacultural development.

In addition to these rather broad designated areas, there are a large number of other sensitivities, such as the presence of sea grass beds for instance. It is clear that conservation interests can present constraints to development, most probably through reduction in the sea areas available for development. A full definition of the scale of these constraints should be determined. Such constraints will have some effect on the opportunities to find suitable sites for shellfish farming in coastal waters.

4.2.1.4 Limitations on availability due to undeveloped sites

A possible scenario where the system for leasing of sites for fish or shellfish farming allows site leases to be obtained by potential operators, but then held in an undeveloped (or very slightly developed) condition for a number of years should be reviewed. Concern has been expressed that a proportion of these leases could be obtained and retained as a mechanism of limiting further development (fish of shellfish cultivation) in the areas concerned. Such practices would appear to restrict both the scope for potential new enterprises, and also the efficient utilization of the coastal waters.

The degree to which undeveloped leases might be retained should be assessed. A project could be undertaken to review the state of exploitation of leases. The objective would be to identify unexploited leases that may act as constraints on the development of the shellfish cultivation industry, with a view to revoking these leases and opening the areas to alternative utilization.

4.2.1.5 Limitations on availability of sea areas for reasons of pollution

There is a need to review the current YSLME member countries legislation on monitoring of its coastal waters. Two main outputs could be obtained:

a. YSLME Directive on the Quality of Shellfish Growing Waters

This suggested Directive concerns the quality of shellfish waters in areas designated by the Member States as needing protection or improvement in order to contribute to the high quality of shellfish products directly edible by man. Guidelines and imperative values for contaminants in shellfish flesh and shellfish waters could be considered in the Directive. YSLME member countries may consider establishing programmes for reducing pollution to ensure that designated waters comply with the defined standards.

b. YSLME Shellfish Hygiene Guidelines

Guidelines should be put into consideration of the YSLME member countries and should address the concern of the quality of waters where shellfish are grown for commercial harvesting and highly consider health conditions for producing and placing on the market of live bivalve mollusks (e.g. oysters, mussels, scallops). The competent authority of the YSLME member country may consider establishing the location and fixing the boundaries of production areas. On the basis of bacteriological criteria, the authority must list and classify these production areas according to the degree of contamination by faecal indicator bacteria present in samples of mollusk flesh. Additionally, shellfish waters are monitored for potentially toxic plankton, and shellfish are monitored for biotoxins.

Table 1. Proposed classification criteria for shellfish waters

Category	Criteria	Meaning of Classification
A	Less than NNN *E. coli* per 100g flesh; or less than NNN faecal coliforms per 100 g flesh	May go direct for human consumption if end product standards are met
B	Less than NNN *E. coli* per 100 g flesh (in 90% of samples) or less than NNN faecal coliforms per 100 g flesh (in 90% of samples)	Must be depurated, heat treated or relayed to meet Category A requirements
C	Less than NNNN faecal coliforms per 100g flesh	Must be under observation. There is a need of additional processes to meet Category A or B
D	Above NNNN faecal coliforms per 100 g flesh	Unsuitable for production

It is proposed that a review should be carried out of the results of monitoring under the above two proposed Guidelines with a view to identifying those areas which are less suitable for bivalve mollusk production. These two Guidelines will place important constraints on the availability of waters for shellfish cultivation and the ability to harvest mollusks on a consistent basis. Some international regulations available at main targeted markets for aquaculture products of YSLME should be reviewed.

4.2.1.6 Technological constraints

Some of the techniques widely used for growing shellfish are relatively simple, well-adapted to conditions where they are used. For example, oyster cultivation on trestles[7] is limited to sheltered intertidal areas, and it is difficult to see how such as system could be developed to work reliably on open coastal sites.

On the other hand, other cultivation systems have potential for development. Rafts have evolved into technically complex working platforms, showing little in common with their predecessors. In an analogous manner to that in which improvements in design of fish farm rafts and cages have allowed fish to be grown in more exposed locations, much potential remains for improved designs of shellfish rafts.

Similarly, many long-line systems used in mussel cultivation have been relatively small, and often make use of a low degree of mechanization. In addition, the utilization of submerged long-lines and submersible rafts might further increase unit capacity, exploit primary production ‘hot spots’, and reduce some areas of potential conflict with other users of the coastal zone. An important issue for the development of some aspects of shellfish cultivation is therefore the technology of equipment construction and operation.

7 A set of sloping supports holding a horizontal structure.

An assessment could be undertaken to bring together equipment specifications and capabilities, sea bed topography, weather/wave records and primary productivity models to map open coastal areas. The output could be a pragmatic based assessment of the current feasibility of using these areas for aquaculture purposes.

4.2.2 Assimilative Capacity

The following section presents a series of possible approaches to estimate assimilative capacity towards a quantitative expression of the capacity.[8]

4.2.2.1 Impact on sea bed communities

The feeding activity of mollusk shellfish gives rise to the excretion of particulate matter in the form of faeces and pseudo-faeces. This material can accumulate on the sea bed in some circumstances and can modify benthic conditions and the benthic fauna. The localized impact of particulate organic waste from fish farms has been widely recognized, and can be approached through modelling procedures. The pressure on the sea bed communities at fish farms can be viewed as acute, in that large changes in the structure of these communities can occur below and immediately around fish farms. In these areas, the character of the sea bed and the associated animals can be strongly altered.

4.2.2.2 Impact on sea enclosed areas benthic communities

As a continuation of this approach, it would be necessary to take a wider, water-body scale view of the significance of impact on the sea bed. As outlined above, the localized impact of waste from shellfish farming sites on sea bed communities is recognized, and can be approached through modelling procedures.

It is generally accepted that a small area of altered sediment within a sea enclosed areas has little, if any, significant impact on the structure and function of the ecosystem in the wider area. However, if a significant area of the surface of a sea enclosed area was utilized for shellfish cultivation, such that a large proportion of the underlying sea bed was affected by particulate waste, analogous to over-intensive finfish farming, then the situation would intuitively be non-sustainable. One would expect that the sea enclosed areas ecosystem might no longer function in the same way. The point at which the enclosed area benthic ecosystem in some way no longer “functions as a sea enclosed area” could provide a limit to the assimilative capacity.

This would probably be a long-term research activity, involving the application of theoretical biology and field validation programmes.

4.2.2.3 Monitoring of productivity

The most commonly-reported consequence of exceeding the carrying capacity of a body of water for farmed shellfish is that the growth rate of the farmed stock declines. This reflects the depletion of the available food supply and the consequential reduction in the energy available to the shellfish for growth. Monitoring of the rate of growth could therefore provide a very direct indication of whether attempts to increase production through increasing stocking had led to the carrying capacity being exceeded.

At present, information on stock and growth rates is not collated centrally. The natural availability of food, and the natural temperature cycles (and other factors that can affect growth rates) vary from place to place. Therefore, simple comparisons of growth rates between areas are unlikely to provide information that can be reliably interpreted.

[8] This is just a general overview of WHAT is required to conduct an Assimilative Capacity Approach. This is the reason WHY it is important to hire the specialist to do an extensive review on the Carrying Capacity approaches suitable to be implemented in the YSLME and to implement a DEMONSTRATION SITE.

4.3 Summary of possible approaches

Table 2. Summary of approaches towards the CARRYING CAPACITY and ASSIMILATIVE CAPACITY studies of coastal waters for specific aquaculture practices e.g. shellfish farming

Item	Approach	Summary Comment
CARRYING CAPACITY	Modelling of available food supply/conversion efficiencies	Achievable. Would give quantified results. Applicable to sea enclosed areas and open coastal areas
	Environmental requirements	Achievable. Would give useful maps of suitable areas. Could be adapted to apply to open coastal areas.
	Limitations on availability of sea areas for conservation reasons	Achievable. Should indicate which areas have what level of constraint on development. Could be applied to both sea enclosed areas and coastal sites. Necessary support for other approaches.
	Limitations on availability due to undeveloped sites.	
	Limitations on availability of sea areas for reasons of pollution	Achievable. Uses internationally recognized Assessment criteria. Could be applied to both sea enclosed areas and coastal sites. Necessary support for other approaches.
	Technological constraints	Achievable. Should provide coherent assessment of the potential commercial use of coastal sites. Analytical techniques exist.
ASSIMILATIVE CAPACITY	Impact on sea bed communities	Achievable at individual site level. Should enable prediction of benthic impacts.
	Impact on sea enclosed benthic communities	At water-body scale, this is a novel research area. Not clear whether would be successful. Initially probably only applicable to estuaries
	Monitoring of productivity	Probably achievable. Would rely on info probably already collected by farmers. Might require several years of data before reliable interpretations might be attempted.

5 CONCLUSION

The literature review for the so called “carrying capacity for fisheries” has some direct links to “stock assessment” approaches. **Stock assessment** involves using mathematical and statistical models to examine the retrospective development of the stock and to make quantitative predictions to address the following fisheries management questions: *What is the current state of the stock? What has happened to the stock in the past? What will happen to the stock in the future under alternative management choices?* To answer those questions a summary of the most recent stock assessments done by specialized institutes/organizations together with fisheries management issues available at any given country will determine the Total Allowable Catch (**TAC**). These TACs will help decision makers to determine the quotas to be given to the fisheries sector.

Therefore, considering the concepts available for “marine fish stock assessment” and the practical use of its results to manage fisheries in a given area, it is considered necessary that the concept of “carrying capacity” and “assimilative capacity” should be applied, within the context of the YSLME Project, mainly to aquaculture activities.

From the preceding review, it is clear that there is no universally applicable approach to the determination of the carrying capacity or assimilative capacity of coastal water bodies for cultured species. Growth rates are limited by the available food supply and by the physiological capability of the cultured aquatic organisms to take advantage of the available food. Another main concern for environmental issues arise from the discharge of particulate waste matter, the increased rate of recycling of dissolved nutrients, disturbance of wildlife, introduction of new species etc. To be useful, possible approaches to the estimation of carrying or assimilative capacity need to be subject to quantification and to lead to quantitative expression of the capacity.

6 RECOMMENDATION

CARRYING CAPACITY and ASSIMILATIVE CAPACITY approaches of coastal waters for specific aquaculture practices in the YSLME region might be considered.

6.1 Step 1. Scoping study

After the literature review It is considered suitable to make a starting point in order to get a carrying capacity approach for the YSLME region. Thus, the YSLME project may consider the development of **Scooping study for research into the aquaculture (fish and shellfish) carrying capacity of YSLME coastal waters.** The outlines for this preliminary approach are given in Annex 2.

The person responsible of this task should bring to the project many years of experience of fish and shellfish farming research, industry development and research, together with comprehensive contacts, nationally and internationally, with aquaculture industries, regulators and research groups. They have the spread of skills and experience necessary to address the broad issues and research requirements involved in the derivation of robust approaches to holding capacity of coastal waters for farmed fish, and carrying capacity for shellfish.

The carrying capacity of coastal waters for aquaculture practices is dependent on a range of environmental factors, including the available food supply, the potential environmental impacts of the process, and other interactions with uses of coastal waters, for example, as recipients of storm water and sewage effluents. The carrying capacity of any system will fluctuate in line with natural variability within the marine ecosystem. The holding capacity for fish farms will also be dependent on environmental factors.

6.2 Step 2. Review of Regulation and Monitoring of Aquaculture

Once the Scooping Study is done, it is considered suitable to develop a "**Review of the regulation and monitoring of aquaculture in YSLME region**" that should put emphasis on environment and consumer protection. The outlines for this preliminary approach are given in Annex 3.

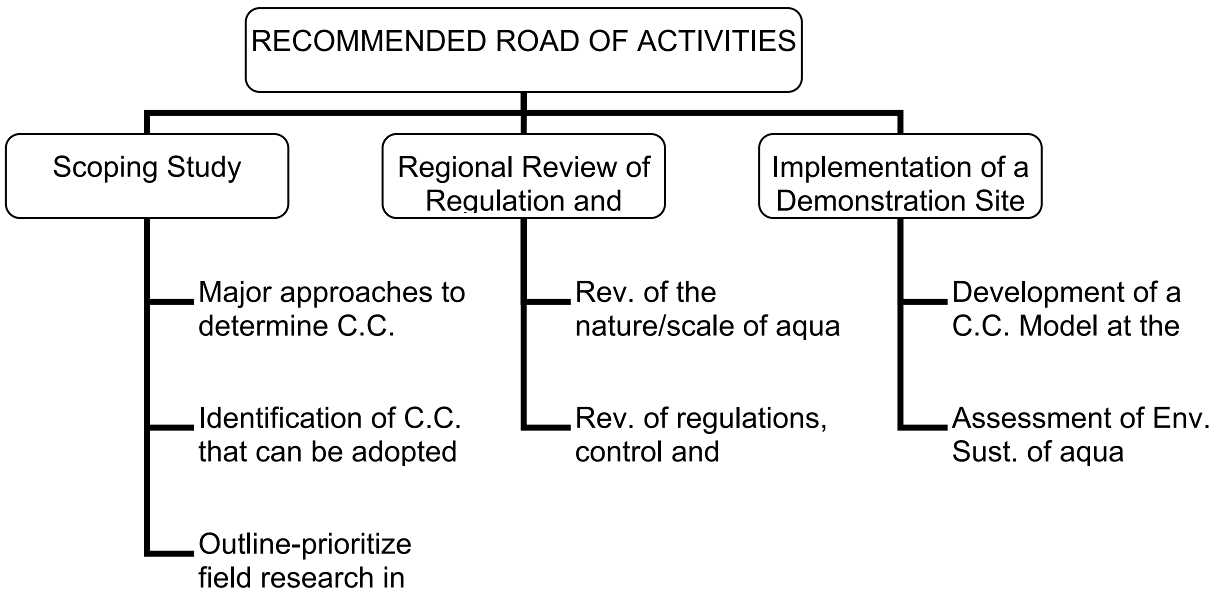
The evaluation and review of the nature and scale of marine aquaculture production and of the current practices relating to regulation, control and monitoring of marine aquaculture could be achieved through a process of literature review and consultation and networking with experts, regulatory authorities and the marine aquaculture industry in YSLME member countries. Reports of current practices as a result of this process should be reviewed by all partners for analysis and determination of a scientific basis for an applicable BEP (Best Environment Practice). Determination of Scientific Guidelines for Best Environmental Practice could be achieved through a process of consultation and discussion.

Therefore, an extensive literature review on this particular topic may, among others, summarize some major issues in a sort of logical framework approach that could allow YSLME PMO to analyze possible REGIONAL TARGETS e.g. regional guidelines, national action plans, etc.

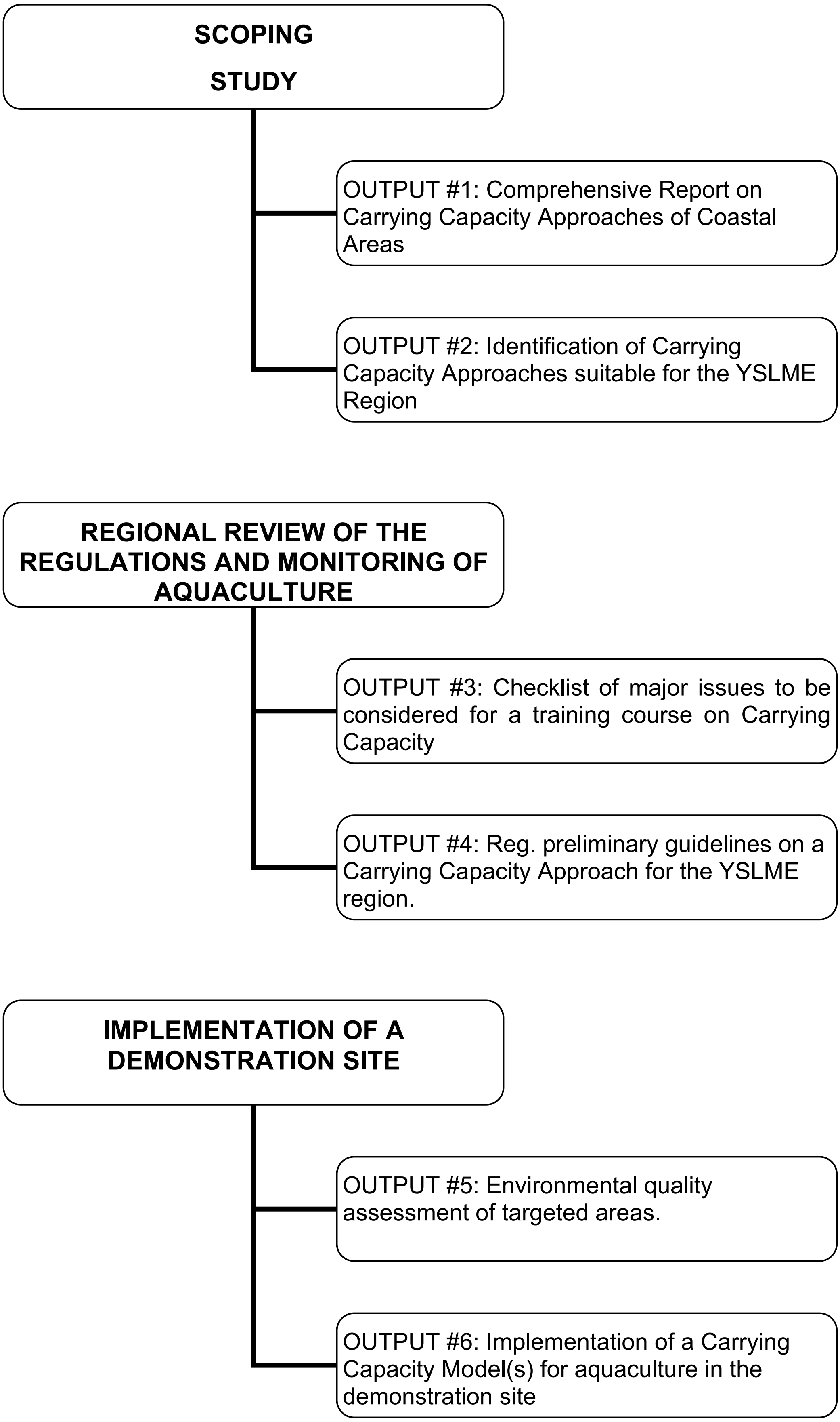
Potential Direct Impacts	Potential Consequences	Management Actions
Organic enrichment	Impact on wildlife/habitats	▪ National and Regional guidelines
Nutrient enrichment	Trigger of toxic blooms	▪ Maximum cultured biomass
Chemicals release	Demise of wild stocks	▪ Maximum feed limit
		▪ Restricted use of chemicals
Spread of diseases		▪ Management guidelines (codes of practice)
Escapes	"Genetic dilution"	▪ Improvement of cage designs
	Demise of wild stocks	▪ Management guidelines
Interaction with other costal activities	Visual impacts and conflicts eg. tourism, sport fishing, maritime transport, etc.	▪ National and regional guidelines ▪ Coastal Management plans

6.3 Step 3. Implementation of a Demonstration Site

Finally, there is a need to consider the possibility to identify and implement a demo site(s) in the YSLME region in order to undertake a carrying Capacity or an Assimilative Capacity approach. The set up for this activity will demand all the theoretical considerations from previous steps. This activity can complement the desired REGIONAL TARGETS e.g. standards, maximum yield per given area, etc. Further details on this particular approach could be reviewed in ANNEX 4.



7 EXPECTED OUTPUTS



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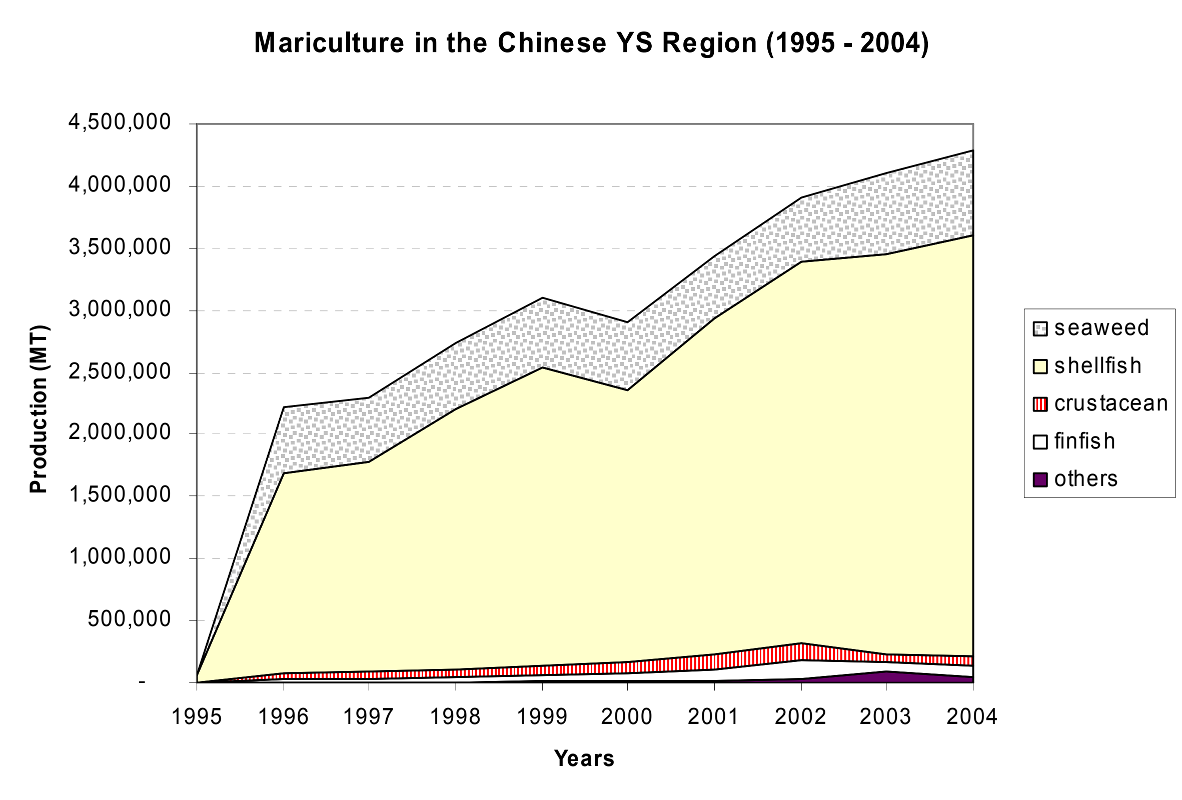
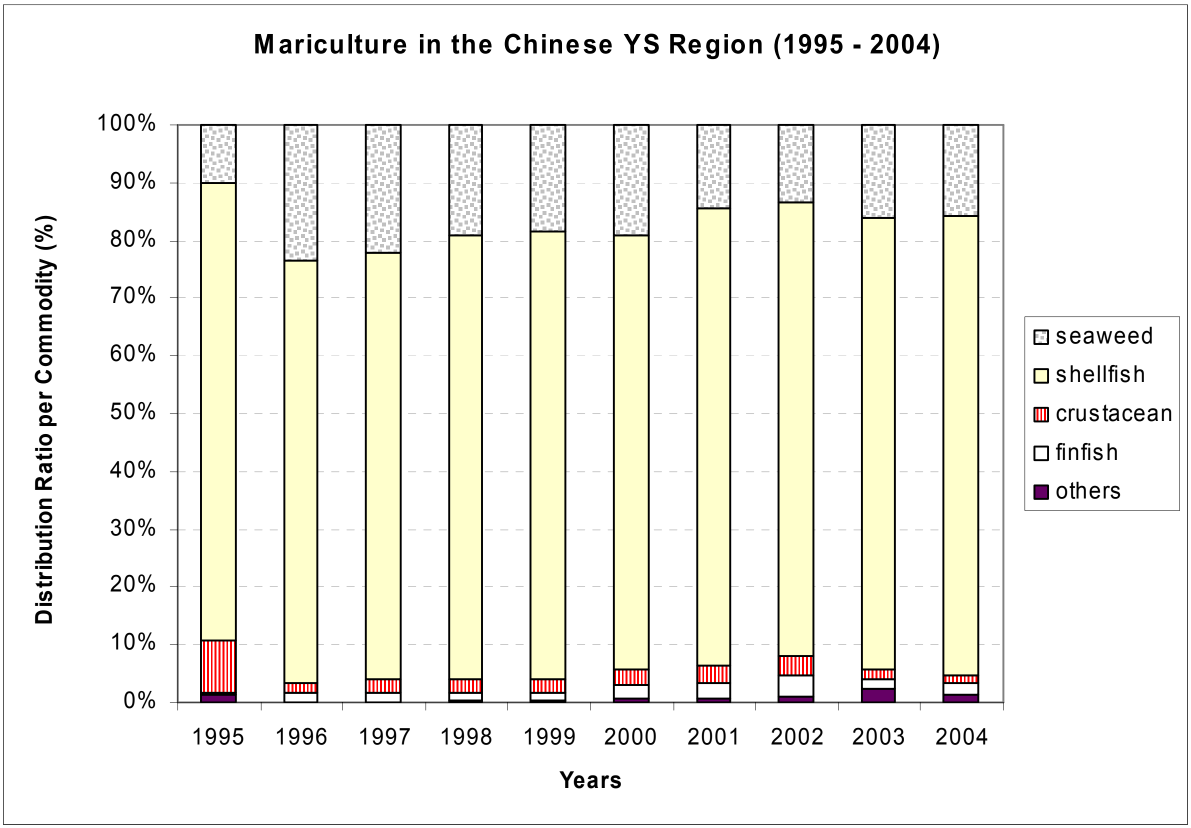
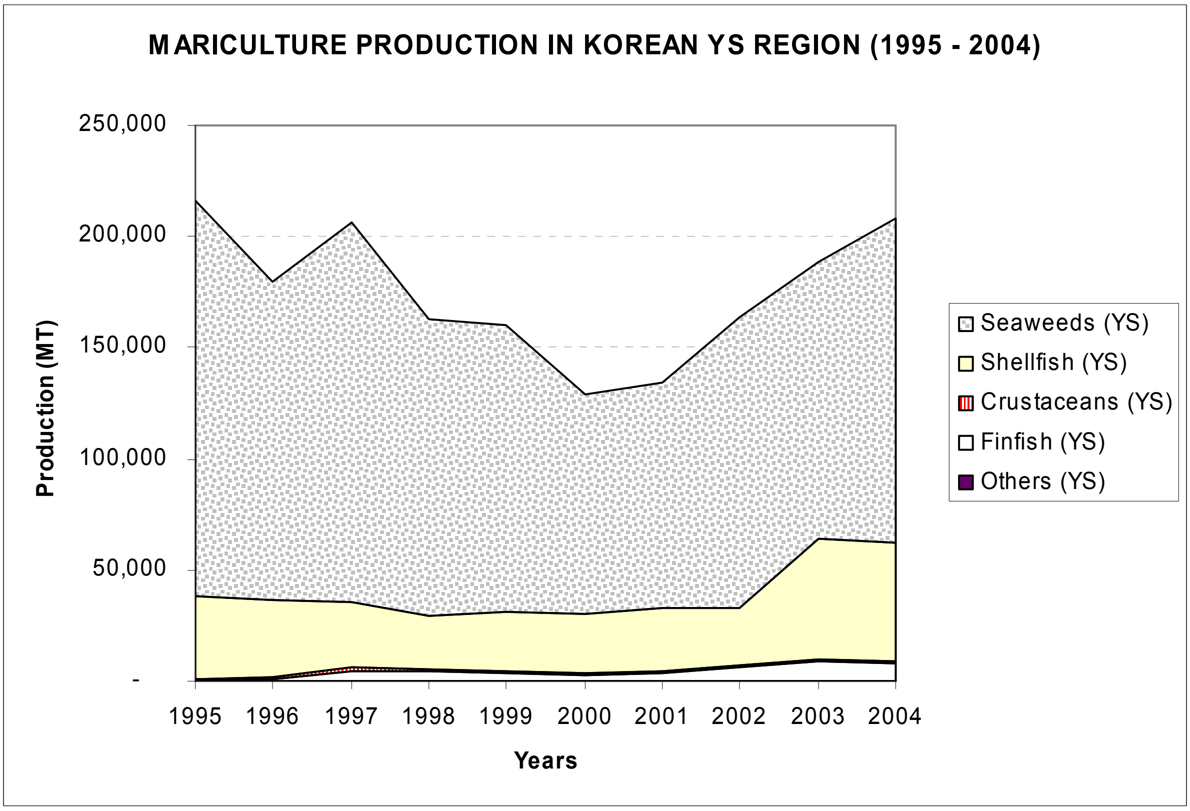
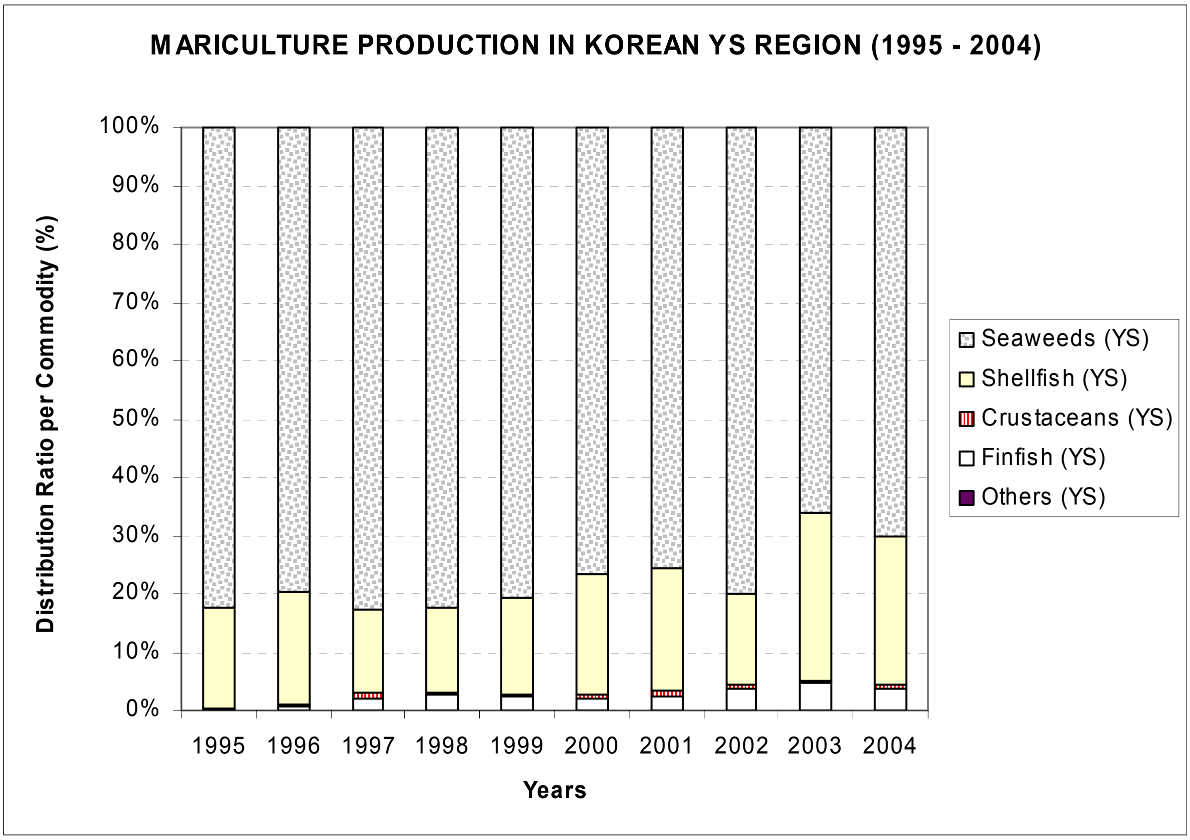
ANNEX 1


Mariculture in the Chinese YS Region (1995 - 2004)
4,500,000
4,000,000
3,500,000
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
-
Production (MT)
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
Years
seaweed
shellfish
crustacean
finfish
others


Mariculture in the Chinese YS Region (1995 - 2004)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Distribution Ratio per Commodity (%)
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
Years
seaweed
shellfish
crustacean
finfish
others


MARICULTURE PRODUCTION IN KOREAN YS REGION (1995 - 2004)
250,000
200,000
150,000
100,000
50,000
-
Production (MT)
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004
Years
Seaweeds (YS)
Shellfish (YS)
Crustaceans (YS)
Finfish (YS)
Others (YS)


MARICULTURE PRODUCTION IN KOREAN YS REGION (1995 - 2004)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Distribution Ratio per Commodity (%)
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004
Years
Seaweeds (YS)
Shellfish (YS)
Crustaceans (YS)
Finfish (YS)
Others (YS)

ANNEX 2

Scoping study for research into the aquaculture (fish and shellfish) carrying capacity of YSLME coastal waters

Proposed objectives

- To prepare a review of approaches used in the YSLME and elsewhere to establish the carrying or holding/carrying capacity of coastal waters for fish and shellfish farming
- To identify those approaches which can be adapted to the YSLME waters.
- To identify possible combinations of modelling and field indicators of carrying capacity with emphasis on their appropriateness for YSLME environmental conditions and concerns.
- To outline and prioritize field and laboratory investigations of the application of indicators of carrying capacity to YSLME coastal waters

Suggested methodology

The consultant should bring to the project many years of experience of fish and shellfish farming research, industry development and research, together with comprehensive contacts, nationally and internationally, with aquaculture industries, regulators and research groups. They have the spread of skills and experience necessary to address the broad issues and research requirements involved in the derivation of robust approaches to holding capacity of coastal waters for farmed fish, and carrying capacity for shellfish.

The carrying capacity of coastal waters for aquaculture practices is dependent on a range of environmental factors, including the available food supply, the potential environmental impacts of the process, and other interactions with uses of coastal waters, for example, as recipients of storm water and sewage effluents. The carrying capacity of any system will fluctuate in line with natural variability within the marine ecosystem. The holding capacity for fish farms will also be dependent on environmental factors.

Item	Description
Objective 1	A literature review of literature on carrying/holding capacity of coastal waters for aquaculture will be carried out using appropriate on-line databases. National and international contacts available will be useful for gathering information on current and past approaches to the definition of carrying capacities of coastal waters for cultivated fish and shellfish. It will be important to include a wide range of environmental factors, together with industry structural (eg any new species), fish health, aesthetic, socio-economic issues where they have environmental implications. Current and past research, focused on the management and husbandry strategies associated with the shellfish industry in particular, will be assessed. In addition, the interaction of shellfish farming with the environment and other species (e.g. wading birds and ducks, if any) should be assessed. The conflicts between aquaculture and other coastal zone users will also be identified, including inter-species factors (mainly relating to disease control in fish).
Objective 2	The results of the above survey will be critically evaluated in relation to the YSLME situation, taking account of relevant reports available in the region. A sub-set of approaches identified that might be applicable in YSLME.

Objective 3	The sub-set identified above will be further refined and assessed, taking into account possible cross-disciplinary approaches and current state of knowledge and research opportunities to provide a prioritized list of approaches most likely to deliver the research necessary to develop a suitable policy.
Objective 4	The consensus of scientific and industrial stakeholders available within the YSLME region (not yet defined) should be accessed through a series of Workshops (technical, by invitation only, involving relevant stakeholders) to develop outlines of research tasks, testing and validation procedures to be applied to the most promising approaches.

Innovation

The innovative aspects of this project arise from this being a unique opportunity to undertake an international review of approaches to carrying capacity for coastal waters to sustain fish and shellfish farming. The combination of scientific, regulatory and industrial experience will provide an effective system for the assessment of the potential for the application of different approaches to the YSLME region, and will lead to informed prioritization of future research and other work.

ANNEX 3

Review of the regulations and monitoring of aquaculture in YSLME region, with emphasis on environment and consumer protection

ANNEX 4

DEMONSTRATION SITE WITHIN THE YSLME REGION
- Proposed implementation process -

1. PROPOSED OBJETIVES

- To produce a carrying capacity model for a Demonstration Site
- To assess the environmental sustainability of aquaculture activities in the demo site.

2. SUGGESTED METHODOLOGY

2.1. Overview of the YSLME demonstration site

2.1.1. Description of aquaculture activities

- Fish culture
- Shellfish and mollusks culture

2.1.2. Description of other aquatic resources

- Housing and sewage
- Land-based pollution activities
- Description of socio-economic issues

2.2. Description of the physical environment

2.2.1. Hydrographic characteristics and water flow of targeted areas

Hydrographic data has should be collected for the fish cage sites within the targeted area. Measurement might be made using direct self-recording meters which employ an impeller for which the revolutions per time are counted and current speed measured. The current meters swivel freely on the moorings in the direction of the current and this is recorded using an “on-board” flux-gate compass. Measurement could be made over an averaging period of 1 minute every 20 minutes during the deployment period (e.g. 15 days). To allow for variable tidal flow with depth, currents shall be measured near the surface (approx. 3 m from lowest tide during deployment) and 3 m from the seabed. Wind data can be recorded using a weather station. This is not used directly in calculation of water movement but its impact on flow is advisable to be observed. These data can be used later for modelling the dispersion of particulate wastes. Data might be rejected from these models if the wind strength was too strong.

The distribution of the sea cage sites throughout the targeted area will ensure that main characteristics were obtained for each of the distinct basins or areas. This will enable the characterization of the water flow in each area. To do this scatter plots should be created, which are a function of direction and current speed and residual current flow. Descriptions and conclusions could therefore be made for each area, within the context of the bay as a whole.

2.2.2. Flushing times and exchange rates for targeted areas

Based on the hydrographic characteristics described above, the different areas within the targeted area should be considered separately in terms of flushing and exchange rates. These measures can be used to calculate the retention of dissolved nutrients, dissolved oxygen turnover and particulate food availability within the coastal areas, thus allowing modifying factors such as replenishment of food and dissolved oxygen to be taken into account. The more localized dispersal of particulate material from fish cages could be modelled using hydrographic characteristics and production data.

2.3. Environmental quality description

2.3.1. Water quality

These includes the measurement of both physical (e.g. temperature) and chemical (dissolved oxygen (D.O.), pH, salinity, nitrite, nitrate, ammonia, dissolved reactive phosphorus (DRP) and chlorophyll 'a') parameters at various locations in the targeted area. Water quality should be assessed annually at 8 to 12 sites, at the same time each year, thus allowing comparisons to be made between survey results from different years.

The temperature, D.O., salinity and pH of a water body, and fluctuations in these parameters, are important in determining the types of organisms that can exist. Dissolved oxygen concentrations are known to fluctuate with temperature, weather conditions and biochemical / biological demand (due to respiration of aquatic organisms), meaning that D.O. could become low in warm waters with a high density of organisms (e.g. near to fish cages or mussel lines, or near to sediments where bacterial loads are high) during the summer months.

Nitrogen and phosphorus are important requirements for phytoplankton growth in the marine environment and are largely responsible for its control. Levels of these nutrients vary with depth, but they are generally lower in the surface layer where plankton productivity is high. Higher values in surface waters are often recorded in shallow, coastal areas where there is some disturbance of the seabed, or where convection currents and up-welling bring deeper waters to the surface. Inputs from land run-off and rivers may also increase nutrient levels in coastal area.

2.3.2. Sediment Quality: Chemistry and Macrofauna

Physical and chemical analyses. Several physical and chemical analyses can be used to determine the quality of sediments, including redox potential, particle size and organic fraction (measured as a function of % carbon and nitrogen). The redox potential of sediment is a quantitative measure of oxygen demand. This is influenced by the rate of oxygen diffusion between the water column and sediment (a function of pore size and oxygen concentration in the overlying water) and rate of oxygen consumption by inorganic and organic processes in the sediment (e.g. chemical reactions and microbial activity). High inputs of organic matter from waste products to a system can severely reduce oxygen concentrations. Reduced oxygen availability can disturb benthic in faunal communities, while creating favorable conditions for anaerobic sulphur-oxidising bacteria. These organisms reduce sulphur to hydrogen sulphide that is released as a gas (a process termed out-gassing) and can be potentially damaging to fish.

Organic inputs to sediments can be measured directly by calculating their carbon content. Generally a carbon content of less than 5% indicates little or no organic enrichment, while values of 5-15% suggest a certain amount of enrichment. Values greater than 15% only generally occur in areas of serious organic loading. However, these values do not account for shell matter, containing calcium carbonate, that occurs naturally in sediments. This can increase percentage carbon values. It is therefore important to make observations of the physical characteristics of sediments to compare with the results of chemical analyses. Sediment nitrogen is often used as a more accurate indicator of sediment enrichment, due to the fact that this is mostly derived from external inputs, such as cage wastes. Perhaps a more reliable indicator of nutrient inputs to sediment is a measure of organic nitrogen content. Nitrogen levels reflect the nutrient status of sediments and unlike carbon, are not influenced by the presence of shell matter.

Biological analysis. Changes in organic input to an area can lead to variations in chemical, physical and biological sediment characteristics, which in turn have direct or indirect impacts on benthic fauna. Fluctuations in organic load are considered to be among the principal factors influencing changes in benthic faunal communities. In marine sediments, polychaetes form the dominant fauna and can be used as indicators of change. Opportunistic species e.g. *Capitella sp.* and *Malacoceros fuliginosus* are known indicators of organic pollution and tend to dominate communities in organically enriched, oxygen depleted sediments. In areas where highly anoxic conditions exist, benthic fauna is often absent or severely reduced, and sediments are characterized by a high abundance of sulphur reducing bacteria.

The extent of organic enrichment in the marine environment can therefore be assessed using changes in benthic invertebrate community composition. This can also be tied in with physical parameters of the sediment, such as particle size, in order to gain a more complete understanding of any differences in community structure that arise between areas.

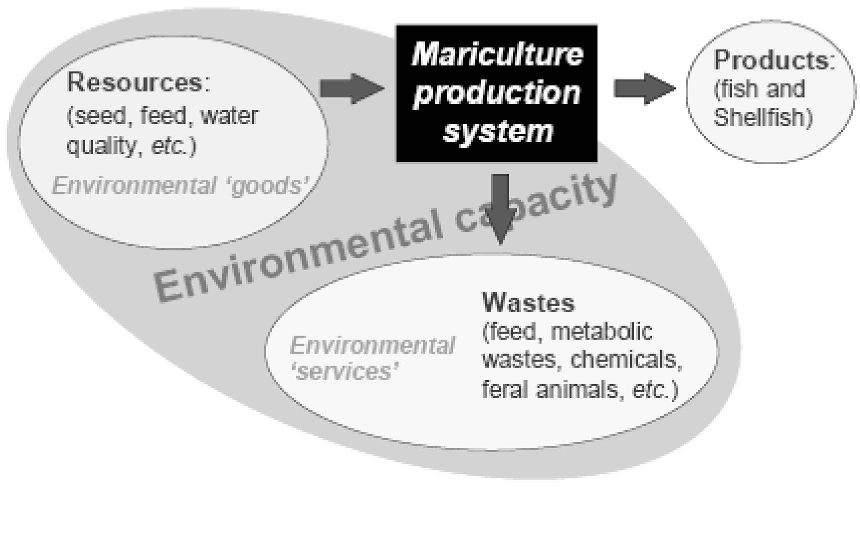
2.4. Aquaculture capacity models

The capacity of a system to sustain a function may be calculated in a variety of ways and is dependent on many factors, and as such can be an inexact measure. However, despite its limitations an estimate of capacity can be used as a tool for management of resources, providing it is applied carefully and with expert knowledge.

2.4.1. Concepts of carrying capacity within the marine environment

The term environmental capacity used here defines the amount of aquaculture production that can be sustained by an environment, within certain defined criteria. Irrespective of environment or method of aquaculture, all capacity models must consider the following:

- What determines the productivity of the environment
- What the farmed organisms consume/produce in terms of food/wastes
- How the environment responds to waste loadings
- How much change is permissible



2.4.2. Models of the distribution of particulate waste material from fish cages

The loading area of sediment around a fish cage is an important factor in determining the impacts of waste accumulation, and is dependent on the quantity of waste released, water depth, current velocity and direction, and the settling rate of waste particles. Where wastes are readily dispersed and low levels of loading occur over a wide area, or where inputs do not exceed the carrying capacity of the sediment, adverse effects will be slight. In some cases, low levels of extra nutrients provide additional food for sediment in fauna, leading to increased abundance and diversity. On the other hand, if high loading occurs in a small area then impacts are likely to be higher, but less widespread.

2.4.3. Estimation of aquaculture capacity of targeted areas within the YSLME region

- **Capacity for shellfish culture** (food availability)
- **Capacity for fish culture** (Oxygen availability)

3. EXPECTED OUTPUTS

- Environmental quality assessment of targeted areas
- Carrying Capacity Model(s) for aquaculture in the demonstration site