Southampton Oceanography Centre

Report

# Ocean Harvest 97

A workshop on new concepts to increase the sustainabl
development of marine biological resources



Natural Environment Research Council

University of Southampton

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A workshop on new concepts to increase the sustainable development of marine biological resources

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# Summary

The primary production of the world's oceans is comparable to that of land, but its contribution to human food supplies is only a small fraction of the total, at present. The principal reason for this is that most food from the sea is harvested at a higher trophic level (carnivores) than on land (plants and herbivores), at an overall trophic conversion efficiency of only about 1% compared to that of about 30% achievable on land. In addition, the most productive oceanic systems (upwelling areas and continental shelves) occupy only a small fraction of the total area, of which the major part is a much less productive deep open ocean system.

It is therefore possible that there is some potential for increasing the supply of food from the sea, by exploiting existing resources more effectively, and less wastefully, by the development of aquaculture, by greater harvesting at lower trophic levels (especially plants), by improved utilisation of available nutrients, by artificially enhancing the productivity of the less productive areas, or by some combination of these. This could make a useful contribution to increasing future world supplies of food, especially of protein, although it could not solve the problems to be expected if global population were to double, as some forecasts predict.

However before such enhancement of marine supplies of food can be seriously considered, a number of problems need to be overcome. Firstly, the structure and dynamics of marine ecosystems are understood only at a rather general level. Our understanding of detailed mechanisms is limited, and at present not adequate for reliable predictions of the consequences of human intervention, either by attempts to enhance basic productivity, or to modify the composition of marine food webs by selective exploitation. Further work, building on our understanding of relatively simple systems from small-scale experimentation, and extending this to larger and more complex systems, is required. Secondly, the technology for enhancement at an economic cost is not available at present, particularly because of the very large spatial scales and remote locations which might be involved. Finally, the scientific, social, economic, aesthetic and ethical issues which would be involved in large-scale intervention have not been thoroughly examined, nor are the procedures for so doing yet properly established.

The present requirements are therefore for

- carefully designed and controlled experiments covering an appropriate hierarchy of scales, to assist our understanding of marine and coastal ecosystems, especially by testing our ability to model and predict their behaviour, and to evaluate the theories and models developed from smaller-scale studies

- progressive development of appropriate technology on an experimental scale

- greater efforts to analyse and understand existing information, especially that derived from the "natural experiments" caused by natural perturbations of marine systems

- a major effort to bring together and analyse the positive and negative features of human intervention in marine systems, including scientific, technical, social, economic, aesthetic and ethical considerations. This applies in principle to existing activities (such as fishing and aquaculture) as well as future activities, whether they are experimental or operational. It should include consideration of the benefits achievable by restoration of degraded habitats, reduction and recycling of wastes, and removal of excessive nutrients, for example

- development and application of techniques for improved decision analysis involving risk and uncertainty, when there are multiple (and possibly conflicting) objectives, in order to facilitate improved dialogue between scientists and policy-makers

- continued long-term support for basic and strategic research on the structure, function, dynamics and modelling of both off-shore and coastal marine ecosystems, and their linkage to their physical environment.

It would be feasible for many of these requirements to be addressed as part of a biologically orientated Grand Challenge programme of marine research, and existing proposals (ECOPS, 1994) for such a programme should be reviewed and revised, to incorporate the experimental approaches to marine ecology envisaged in this report.

## Introduction and Background

The ocean is an important protein source for mankind and will become increasingly important as it becomes more and more difficult for agriculture to meet the nutritional demands of a growing world population. Harvest levels of most of the wild fish species currently exploited appear to be at, or over, maximum acceptable levels for sustainable fisheries. Thus, a number of different activities with the aim of increasing the potentially harvestable biomass from the ocean have been initiated or are being contemplated. Examples here include exploitation of currently non-harvested organisms, stock enhancement (sea ranching), establishment of new habitats (i.e., artificial reefs), aquaculture, food web manipulation, artificial upwelling and selective nutrient enrichment. Knowledge about the feasibility of these initiatives and how they may impact the environment and interact with other resource users is still a matter of debate.

It seems clear that, in the next century, a specific management strategy with respect to exploitation of the ocean will be required and that this management strategy must be based on sound scientific knowledge concerning the ecosystem implications of various activities. The European scientific community should actively address these issues by proposing an effective research programme for the next decade which, in addition to suggesting and testing new ways of harvesting the ocean on a sustainable basis, should quantify the ecosystem interactions that these different activities elicit. The knowledge arising out of this research should provide a test of our capacity to understand, model and predict the functioning of marine ecosystems. The scientific community should be prepared to provide the necessary scientific background to evaluate the initiatives and interest of European industry regarding the use of marine biological resources and to ensure that industrial initiatives are not in conflict with the concept of sustainable use and management of ecological systems.

The goal of the workshop was to examine our present knowledge, and identify strategic research needed to predict the ecosystem consequences of various initiatives to increase the potential harvest from the sea. The results of the workshop will be considered by the European Union Commission for implementation under the Fifth Framework Programme.

The workshop was organised at the Southampton Oceanography Centre as a 3 day meeting from Wednesday, 11 June to Friday, 13 June and was chaired by Professor John Shepherd, Director of the Southampton Oceanography Centre.

The workshop was supported financially by the European Union, DG XII - MAST, and the industrial company, Norsk Hydro. The workshop was supported scientifically by the European Marine and Polar Science (EMaPS) board of the European Science Foundation. The International Council for the Exploitation of the Sea (ICES) are observing the result of the workshop.

The editorial board included members of the organising committee, the working group chairpersons and appointed rapporteurs.

The workshop had alternating plenary sessions, parallel working group sessions for drafting recommendations and plenary sessions for reporting and discussing results from the working groups.

Participants were allocated to one of the following working groups (WG):

WG1 - Productivity regulation and ecosystem variability: Ecosystem manipulation.
WG2 - Productivity regulation and ecosystem variability: Ecosystem exploitation.
WG3 - Harvest enhancement by creation of artificial ecosystems.
WG4 - Optimum use of resources: Interaction between users and society.

## WG 1: Productivity regulation and ecosystem variability: Ecosystem manipulation.

Chairperson: Prof. Victor Smetacek
Rapporteur: Dr. Martin Angel

The working group addressed the research needed to address the possibilities of harvest enhancement by ecosystem manipulation and the ability to predict the consequences of such initiatives. This working group took a bottom up view of ecosystems, concentrating on lower tropic levels. Examples included nutrient enrichment and food web manipulation. What are the possibilities and their constraints?

Key themes:
a) The functioning of foodwebs and the role of nutrients, channelling productivity.
b) Artificial upwelling, ocean fertilisation, nutrient recycling.
c) Improving predictive capabilities with respect to ecosystem responses
d) The need for experimental design and ecosystem/field experiments to assist predictive modelling.

## WG 2: Productivity regulation and ecosystem variability: Ecosystem exploitation.

Chairperson: Prof. John Shepherd
Rapporteur: Dr. Niels Daan

The working group addressed research needs concerning possibilities for harvest enhancement by ecosystem exploitation and the ability to predict the consequences of changed activity with respect to harvesting biological resources. The working group considered top down influences on ecosystems and concentrated on higher trophic levels and the output of the ecosystems. What are the possibilities and their consequences?

Key themes
a) Fisheries, sea ranching and exploitation of currently non harvested resources.
b) Predator removal, Changed competition.
c) Modifying marine populations: selective stocking and harvesting
d) Possibilities for reduction of natural variability in recruitment.
e) Natural variability as a source of uncertainty in decision making

## WG 3: Harvest enhancement by creation of artificial ecosystems.

Chairperson: Prof. Harald Rosenthal
Rapporteur: Prof. Patric Sorgeloos

This working group concentrated on heavily modified and artificial systems, such as aquaculture, coastal modification, artificial reefs, sea-ranching and species restocking. The working group addressed research needs concerning the ability to develop and predict the outcome of such modifications and their environmental interaction. What information do we need to achieve an optimum sustainable mix of various harvesting initiatives?

Key themes:
a) Alternative concepts for the use of the oceans for biological production
b) Habitat improvements: Artificial reefs, artificial upwelling, habitat and substrate modifications, recovery measures.
c) Interaction between and integration of different biological production systems
d) Modifying marine populations: selective stocking and harvesting

## WG 4: Optimum use of resources: Interaction between users and society.

Chairperson: Prof. Ulf Lie
Rapporteur: Prof. John Gray

The working group addressed research needs concerning the ability to develop an optimum management strategy for various harvest enhancement initiatives, interactions between different initiatives and with the environment. The group discussed research needs concerning the ability to integrate the needs for biological production with the needs for conservation of natural environments. What information do we need to develop a management programme with multiple strategies for harvesting the ocean? What legal, ethical and social questions must be answered in order to optimise the use of the ocean and its resources? How can we ensure proper transformation of knowledge from scientists to end users?

Key themes:
a) Preserving ecosystem integrity; risk assessment of various uses.
b) Integrated/cross sectional coastal zone management.
c) Interaction with other resource users, identifying the potential conflicts, indicators for sustainability.
d) Environmental economics.
e) Licensing and legal aspects of resource use, international implications, regulative harmonisation.
f) Making science applicable and building bridges between science and end users.

# 1. Working Group 1: Productivity regulation and ecosystem variability: Ecosystem manipulation.

## 1.1 Introduction

The working group was asked to address research needs concerning the possibilities for harvest enhancement by ecosystem manipulation and our abilities to predict the consequences of such initiatives. The topic of the working group could be viewed as the bottom-up influences of the ecosystem that are concentrated in the lower trophic levels. Examples we were asked to consider were nutrient enrichment and food web manipulation. What are the possibilities and their constraints?

The key themes set were:

- The functioning of foodwebs and the role of nutrients, channelling productivity.
- Artificial upwelling, ocean fertilisation, nutrient re-cycling.
- Improving the predictive capabilities with respect to ecosystem responses.
- The need for experimental design and ecosystem/field experiments to assist predictive modelling.

## 1.2 Abstracts of Working Group 1 prepared papers

### 1.2.1 Abstract of paper entitled, *Productivity enhancement in the Japanese Government program* by Professor Shinji Morimura, Japan International Food and Aquaculture Society.

It is generally known that organic materials that sink to the bottom of the sea are decomposed by bacteria into useful nutrients for the propagation of phytoplankton. Below the phytosphere (photic zone) in the deep sea, utilisation of these nutrients by phytoplankton cannot be active because of the lack of light.

If we can draw up the bottom water which is rich in nutrients into the surface layers, we can expect phytoplankton growth to be stimulated and as a consequence an exploitable food chain will be developed. A major experiment to create artificial upwelling from the nutrient-rich deep-water up into the phytosphere has been conducted for the last decade as a project developed by Marino Forum 21 in Japan. After conducting some tank tests, a series of concrete structures designed to guide upwelling flows were constructed in the Sea of Uwa off Ehime Prefecture, Shikoku in three stages in 1987, 1992 and 1994. Observations are continuing on the effects of the artificial upwelling induced.

The observations show that in the immediate vicinity of the structures, dissolved nitrogen concentrations increased by a factor of 2.6, the abundance of phytoplankton cells by a factor of 7.5 to 25, and zooplankton abundance by a factor of 2.3 to 2.6. Airborne remote sensing shows the presence of patches of cold water and elevated concentrations of surface chlorophyll. Fishermen have reported that fish catches have increased near the structures. Thus, the experiment is considered to be a success.

In the decades following the Second World War, Japanese fishing fleets went far and wide to catch large quantities of fish, giving the impression to the rest of the World that Japan might be overexploiting fish stocks. However, at the same time Japan has been investing heavily in seeking ways of improving the harvest of fish, without, as yet, seeing the fruits of these efforts. It may be to early to be too confident about the results of this experiment in creating artificial upwelling, but it has boosted Japan's ability eventually to contribute substantially to the enhancement of fish resources world-wide.

We believe that Japan will in due course contribute substantially to reducing the problem of food shortages in the World through the spirit of the Maricult project. We will present the results of our recent activities aimed at enhancing Japan's fish resources, including our artificial upwelling system and experiments in the fertilisation of the sea.

### 1.2.2 Abstract of paper entitled, *Open ocean ecosystem manipulation 1: The experience of Ironex* by Professor Andrew Watson, University of East Anglia.

Two unenclosed iron enrichment experiments were carried out in the equatorial Pacific between 1993 and 1995. These were the first mesoscale ecosystem manipulation experiments to be conducted in the open sea. The experiments were successful in that they showed that it is possible to fertilise certain regions of the ocean, enhancing their productivity and substantially altering the species composition of their pelagic ecosystems. However, the outcomes of the two very similar experiments were far from being identical. The experiments demonstrated that the biological development occurring in an enriched body of water depends critically, and in a way that is poorly understood, on its previous history and subsequent fate.

If other HNLC (High Nitrate Low Chlorophyll) regions of the ocean are limited in the way the Equatorial Pacific has been shown to be, it would be comparatively easy to enhance the productivity of large regions by the addition of iron. This might one day, be of commercial interest in enhancing the fisheries potential of these regions.

### 1.2.3 Abstract of paper entitled, *Open ocean ecosystem manipulation 2: The biological responses in Ironex 1 and* 2 by Professor Richard T. Barber, Duke University, North Carolina

The design of the Ironex 1 and 2 transient iron enrichment experiments and their dramatically different biogeochemical consequences have been described by Andrew Watson. This abstract focuses on describing the differing biological responses in the two open ocean experiments.

The bulk chemical conditions at the start of the two experiments were remarkably similar in terms of macronutrient concentrations, initial chlorophyll concentrations and physical water column conditions. Ironex 1 was located at 5°S 90°W immediately south of the Galapagos Islands. John Martin had initially decided to locate the experiment at 5°S 95°W, a region that historically is relatively free of surface features. However, at the request (or demand) of the NASA aircraft team that was providing remote sensing of physical and chemical properties, the site was moved eastwards better to accommodate the range of the aircraft flying from the mainland of Ecuador. The relocation of the site 550km eastwards moved Ironex 1 into a more active frontal region, and such a surface front was an important part of the physical setting during the experiment. The Ironex 1 patch of SF6 tagged water drifted northwards in a series of slow circular loops. The Ironex 2 patch was located at 3.5°S 104°W moved rapidly Southwest under the influence of the South Equatorial Current and the equatorial divergence.

In both Ironex 1 and 2 the initial response to the iron enrichment was rapid; all the major phytoplankton taxa dramatically increased their photosynthetic performance in the first 24 hours. Initially diatoms were rare at both sites, so the observed rapid increases in quantum yield and photochemical conversion efficiency were responses of the ambient picoplankton. In Ironex 1 the largest changes in both rates and biomass occurred on day 1 and subsequently the increases were small. The biological response to the 4nm iron enrichment in Ironex 1 was a dramatic increase in regenerated productivity and micrograzing. With this iron enrichment, the "balanced" or steady-state system did not shift to a bloom condition, but it did shift to a new steady state with approximately doubled rates and biomass.

The response in Ironex 2 was almost identical on days 1 and 2, with increased rates and biomass in all taxa. However, in Ironex 2 diatoms >18μm in size continued to increase exponentially for 5 days with a net specific growth (or accumulation) rate of about 1.0/d for the five days. Diatom chlorophyll concentrations went from 0.01 to 2.70 $mg/m^3$. The sudden bloom of large diatoms was present by the end of day 2. The second and third doses of iron did not initiate the bloom, but they certainly sustained it. As Professor Watson indicated the dense accumulation of new organic matter dramatically reduced $\Sigma CO_2$ and $pCO_2$ in the patches as Martin had predicted.

In the subsequent discussion it was pointed out that the iron fertilisation had led to increases in desirable products (e.g. increased standing crops of crustacean zooplankton). Fertilisation with "traditional" nutrients such as N and P has seldom lead to the enhancement of similarly "desirable" secondary productions. Can we compare the effects of changing different nutrient loads on the dynamics of different marine ecosystems such as in the shelf regions of the North Sea and the N. Pacific? The results from the limited numbers of experiments conducted so far, show that the interactions are complex with different factors being important in the different systems, so no generalisations can yet be drawn.

## 1.3 Summary of issues discussed

### 1.3.1 Possibilities (intended effects)

Potentially marine harvests can be enhanced in four ways:
1) by enhancing productivity,
2) by increasing the flow of primary production reaching the desired harvestable stock,
3) by seeking new resources,
4) by improving present methods of exploiting stocks.

#### 1.3.1.1 The enhancement of productivity

It has be demonstrated that productivity can be increased by direct fertilisation with nutrients, micronutrients or organic enrichments (human and agricultural wastes). Increased production can also be a by-product of other activities such as OTEC (Ocean Thermal Energy Conversion) in which cold nutrient rich water is pumped up from depths of around 1000m and heat exchangers are used to generate energy. The plume of water can then be discharged into the photic zone and as artificial upwelling. However, we noted that the economic assessment of such processes seldom take into account the overall benefits in terms of "by-products" or other the environmental benefits.

In stratified coastal waters artificial upwelling has been achieved either by direct pumping, or by soft engineering structures (construction of baffles, berms and mounds) to create artificial upwelling in suitable stratified regimes where tidal currents are suitable (see 1.2.1 the abstract by Professor Morimura).

It has been suggested by mathematical modelling that artificial upwelling could be induced in Norwegian fjords by the injection of fresh river water down a pipe into subthermocline depths at a rate of $10m^3/s$. For every litre of freshwater injected, 20 litres of subthermocline nutrient-rich water could be mixed up into the photic zone. The model shows that chlorophyll enhancement is detected as much as 60km along the fjord. The system has considerable potential as an experimental approach to researching the importance of timing nutrient enhancements and would lend itself to replication. This has the advantage that the process does not involve the addition of any substance or materials into the ecosystem that would not otherwise enter the system. It also has considerable potential for controlled experimentation.

The main limitation of this approach to enhancement is the apparent low efficiency (<1%) of nutrient utilisation by the exploited stocks in this system. Hence direct fertilisation in this case may not be cost effective. In addition, possible down-stream impacts need to be considered. Fertilisation and artificial upwelling may only enhance the exploited stocks locally at the expense of production elsewhere and so may not result in any "global" increase in productivity. Furthermore there is no guarantee that the enhanced productivity will stimulate desirable forms of secondary production.

Natural experiments will continue to be a rich source of insight into the functioning of ecosystems, despite lacking the controls that are incorporated into properly designed scientific experiments. For example, it is known that the development of toxic blooms can be brought to a halt by breaking up the stratification of the water column.

#### 1.3.1.2 Enhancement of harvestable stocks

Theoretically this can be achieved by improving the efficiency of the flow of productivity into commercial stocks. Approaches might include:
1) reducing the length of the food chain,
2) reductions in the populations of direct competitors,
3) reductions in predation pressure by culling predators,
4) increasing the competitiveness of the commercial stock by control of diseases and predators, and
5) by direct stock enhancement.

Food-chain manipulation will be difficult in open ecosystems and are most practical in controlled conditions of mariculture. Since they involve direct manipulation of biodiversity by suppressing some species and encouraging the dominance of others, they are likely to incur opposition. Food-chain manipulation would also be a slave of hydrography and the vagaries of weather, and so on the basis of present knowledge and ability to forecast hydrographic conditions, the outcomes would be unpredictable, and would probably be contested on the basis of the precautionary principle.

One approach, involving minimal intervention, might be to improve recruitment by increasing larval fish survival during critical life-history stages when natural mortality is high. For instance, the creation of artificial upwelling such that it enhances productivity in the nursery feeding grounds just at the critical time when the juvenile fish start to feed, and at a time when normally there are minimum concentrations of food available, may be critical for larval survival.

Another more controversial approach is the release of sterile hybrids which have faster growth rates and more efficient energy conversion. This approach has already been used for intensive culture of *Tilapia*. It may be a more cost-effective method, and carry less environmental risk, in the better controlled conditions of enclosures. The release of sterile hybrids into the environment while not altering the genetic diversity of the natural populations may change the competitive balance and may reduce marketability, if the public are resistant to consuming genetically engineered fish.

#### 1.3.1.3 New resources

Apart from re-stocking with local species, which has, in some areas, been successful in increasing catches, the introduction of exotic species into open conditions is fraught with difficulties and dangers. However, there are opportunities to improve harvests by switching to new target stocks lower down the food chain. This effectively increases the efficiency of the utilisation of productivity by shortening the food-chain. However, new food processing technology may be needed if the product is to be marketable.

Suggestions made during the discussion included:

a) the use of rafts in the open ocean to grow lepadomorph barnacles which have remarkably high growth rates; goose barnacles have been observed to mature and to release larvae within ten days of settlement.
b) the exploitation of seamounts, especially those which are presently insufficiently productive to be commercially exploited and also which lack endemic fauna (e.g. many of the sea-mounts in the North-east Atlantic). Direct organic fertilisation or artificial upwelling might prove to be effective in creating a local fishery around seamounts by increasing productivity and so attracting commercial species. Such developments might be feasible on seamounts within the EEZ's of individual coastal states but would require some re-negotiation of UNCLOS if located in the global commons.
c) the culture of algae on rafts whether for food or biomass energy.

### 1.3.1.4 Improving present methods of exploiting stocks

The improvement of present methods of fishing and management could result in an almost instantaneous increase in harvest. The utilisation of discards would result in an immediate increase in protein production of about 20%. More flexible approach to fishery management, tuned more to the natural cycles rather than to human socio-economic cycles, would greatly improve sustainability, but would be hard to implement in the present political environment. Another improvement would be the establishment of extensive no-take marine reserves. Modelling suggests that if a single block of 35% of the area of the North Sea was freed from all fishing pressures, the catches from the remaining 65% would be increased substantially and sustainably above the present levels.

If better protection were afforded to some breeding stocks, recruitment would be improved, although in many commercial stocks there is little evidence for recruitment being linked to the size of the breeding stock. However, the exploitation of breeding shoals of the deep-living Orange Roughy has succeeded in destroying the commercial viability of the stocks around New Zealand in less than a decade. Subsequent commercial exploitation of other deep-living species has built up without the collection of any baseline data and in the absence of any attempts to develop rational science-based management.

### 1.3.1.5 The contribution of science

The working group expressed its strong belief that marine scientists have a strong ethical responsibility to provide Society with the best basis on which to formulate environmental policies. Marine science has a major contribution to make in solving the problems of sustainability being created by human population growth and the uneven distribution of global wealth and resources. Marine science must continue to develop and explore, both intellectually and experimentally, new concepts aimed at improving harvests, and must also seek to highlight the consequences of new and continuing, well-established policies.

Scientists must become far more aware of the beliefs, aspirations, sensitivities and priorities of other components of the community. However, the discipline of the precautionary principle has to be applied to old, as well as new, approaches to environmental management and utilisation. The scientific method is a crucial tool for optimising policies in managing global resources, and scientists must play a greater role in interpreting the implications of scientific outputs and in highlighting the uncertainties. Scientists are trained to be objective and critical in their thinking, hence the potential value of their contribution to the political process of policy-making is greater than that provided by special-interest groups. Even so, individual scientists are no less subject to being influenced by self-interest and pre-conditioning. However, it is manifestly untrue to say that the opinions of scientists should be valued less than of other pressure groups more traditionally involved in the political process. Equally the pursuit of scientific goals must not be limited solely to the creation of wealth.

### 1.3.2 Constraints (Unintended effects)

The constraints fall into four main categories:
1) a lack of basic understanding and baseline information,
2) process limitations,
3) social limitations,
4) practical constraints.

#### 1.3.2.1 Lack of basic understanding and baseline information

The factors controlling the structure of biological communities and how production flows through food-chains are still poorly understood. This limits our ability to model and predict to conditions in which physical processes are the dominant factors. Even under these conditions non-linear responses can generate chaotic responses which at present limits predictability. For example, the mismatch of the time characteristics of primary and secondary producers can lead to unexpected responses. Another major difficulty is that adequate baseline information is seldom collected prior to any experimental or industrial intervention in the marine (or any other) environment.

#### 1.3.2.2 Process limitations

The non-linearity of interactions and responses in biological processes poses unsolved problems in the prediction and management of natural resources. For example, fertilisation may equally well stimulate undesirable species of phytoplankton to bloom, such as *Phaeocystis* and toxic red-tide species, as well as desirable species which will stimulate useful increases in secondary production. The scale at which experiments will need to be carried out, so that the outcome can be confidentially extrapolated to the scales needed for commercial activity, must be larger than the small-scale experiments that have been conducted up until now.

In the open environment dilution and dispersion will limit our ability to control fully the system. Any experiment will be a slave to the hydrography and the vagaries of the weather. Our ability to model the effects of physical forcing in this respect is crucial.

Any attempt to increase production and to optimise the useful yields (including predator, disease and parasite controls) will have an impact on biodiversity, and hence might be considered deleterious. Any increases in bulk loading on natural systems may lead to deleterious effects such as the development of anoxic sediments and/or water beneath intensive shellfish cultures. However, some of these impacts can be avoided. For example, if a toxic bloom begins to develop, disruption of the stratification of the water column would bring the bloom to a halt.

There are many biological patterns that are consistent and predictable. For example, biogeographical patterns, which are predominantly forced by planetary processes, are stable. The overall system responses to nutrient enhancement are qualitatively well-described and predictable. It is in the detailed dynamics and in the prediction of precise population responses that the biological non-linearities result in seemingly chaotic and unpredictable responses. Thus we emphasise the need for improving our understanding and ability to model multispecies population interactions and dynamics.

#### 1.3.2.3 Social limitations

There are limited economic resources for science and so most science is targeted at achieving tightly defined goals. The history of science shows that the critical developments are often the product of curiosity-driven research and often in a discipline that is unexpected. One possible answer to this dilemma is to continue, or even increase, the fraction of funding going into fundamental and strategic research which has no obvious immediate economic pay-back but is nevertheless aimed at meeting the long-term needs of society.

There will be conflicts with other interests and operations. For example, attempts to expand ocean harvest will be dependent on clean seas. Many deleterious impacts in coastal waters are a result of land-use in the coastal hinterland. Coral reefs and other coastal ecosystems are put at risk by increased turbidity of inshore waters resulting from forest clearance, intensive agriculture, sewage discharges and industrial activities including the extraction of hydrocarbons.

Another social limitation is that either existing law and conventions may ban, or the prevailing public opinion may not accept, the implications of experimental findings. Scientists must cease being so remote from social and political processes and must be much more active in participating in public and political processes particularly in public education. For example, there is considerable confusion about biodiversity. Any experiment or commercial venture will have an impact on "biodiversity" at some scale in time and space. So in the absence of any criteria whereby the extent of any impacts can be assessed and the limits agreed, the precautionary principle will constantly be evoked to stop the R&D.

There are several critical concepts in the public realm that are ambiguously applied. Biodiversity, defined as the variability of biological systems, can be applied at all spatial scales and organisational levels. Most frequently it is used as measure of the number of species present (in a sample, community, ecosystem or region), but it can also be used to describe the evenness and/or degree of dominance of individual species within a community, and to describe the genetic heterogeneity within a population. Consequently, describing impacts can be contradictory. For example, fertilisation experiments in open ocean consistently result in a local increase in the numbers of species occurring (i.e. an increase in biodiversity), but there is a reduction in evenness as a few species become dominant within the communities (i.e. a decrease in biodiversity)

Science has to overcome the belief held in some areas of Society that all scientists live in a world of their own, and are only interested in furthering their own research interests rather than in trying to serve the long-term needs of Society. There will often be strong resistance to in situ experiments and commercial developments, and scientists will have to play an active role in winning public approval for experimental approaches.

### 1.3.3 Interactions with other users

The introduction of exotic species or genetic stock, whether purposeful (for re-stocking or the introduction of new harvestable species) or inadvertent (e.g. introduction of diseases and parasites when restocking, or of propagules of exotic species in ballast water) must be minimised.

There are major incompatibilities between the short-term needs to make profits, to protect employment, and not to erode traditional liberties and rights, and the long-term needs to ensure that environmental resources and qualities are maintained in the face of growing pressure from the burgeoning human population. Resolution of these socio-economic problems can be helped by scientific research. Malthus was right in that resources of the Planet are finite and the full consequences have only averted by human ingenuity, especially in the fields of science and technology. However, there is little optimism that time can continue to be bought in this way as human population approaches 10 billion in the next century.

### 1.3.4 Research needs

The research required varies according to the system to be understood and the conceptual objectives. There will be sharp contrasts in the scales, requirements and operational limitations of experiments conducted in near-shore and off-shore environments. Off-shore, the dominant factors are often physical and may be more accessible to modelling, but the scale of experiments has to be larger with greater logistic problems and less control over the experimental conditions. Inshore ecosystems tend to be finer-scaled, so results tend to be less widely applicable. Interaction with other users and environmental controls tend to inhibit experimental design and operations more. However, it is in near-shore and coastal waters where commercial operations are most likely to be developed.

The research needed will fall into three broad categories:
1) research improving basic scientific understanding,
2) research at the pre-industrial stage provide a demonstration of concept, and
3) research at the socio-economic interface needed to underpin management (discussed in Working Group 4).

Proper scientific methodology needs to be adopted, with adequate replication and controls to ensure that the effects observed can be unambiguously attributed to the correct cause, and the uncertainties defined and taken into account when drawing up the conclusions. The temporal and spatial scales of the experiments must be appropriate. Impact assessments must be conducted before the experiments are initiated and re-evaluated post-experimentally. This will require adequate baseline observations to be carried out so any local and regional changes induced can be described and quantified. The resilience of the systems needs to be monitored, i.e. the rate at which it recovers to a state comparable to control sites. This approach will be essential if public opinion is to be reassured.

There will need to be "down-stream" research involved in these evaluations. For example, local increases in harvest resulting from artificial upwelling by be at the expense of harvest further downstream. The side effects of artificial upwelling resulting from the de-gassing of carbon dioxide from the cool water brought to the surface may more than off-set any benefits in harvest. In near-shore waters there may be considerable impacts on neighbouring soft-sediment and rocky-shore communities.

#### 1.3.4.1 Basic research

Aspects identified as needing particular attention are:

a) Better understanding of the conditions that lead to the development of toxic blooms.

b) Most of the present models of biological dynamics are extremely sensitive to the zooplankton parameters chosen, and so measurement of higher trophic level responses will be particularly important.

c) There is a lack of understanding of the factors which determine the dynamics of the species composition following perturbations (including fertilisation). Components of the system respond more rapidly than others; for example, the microbial loop responds most rapidly to upwelling events, but even so the whole pelagic system switches into a new functional mode within the first day or so of such an event.

d) The mode and timing of enrichment may be critical in determining the dynamics of the response. Iron fertilisation appears to favour diatom growth. Recruitment of commercial fish species may be increased if food availability is increased at critical developmental stages.

There are logistic limitations that can be alleviated with new technology. Specific suggestions include:

a) The development of remotely piloted airborne vehicles (such as small autonomous aircraft developed by armies to locate targets for artillery) to fly sensors around a survey area. Experimental plumes could then be tracked by remote-sensing under conditions of complete cloud cover; the traditional approach to the mapping of bodies of enriched water has been standard hydrographic stations, instrumented buoys and in some cases towed undulators.

b) The use of autonomous underwater vehicles (AUV) would allow detailed mapping to be conducted while the other research vessel is making other observations.

Fine-resolution dynamic models have be used to predict the patterns of movement and dispersal of eddies in real-time so that they can be targeted with much greater precision. We foresee that although the costs of well-designed experiments will be high, the main limitation will be a lack of suitably trained personnel. Thus we see a need to concentrate European research efforts into such experiments which can be overcome by collaboration at the European scale.

**1.3.4.2 Pre-industrial experiments.**

Proof of concept will require experiments that are scaled adequately for the outcome to be extrapolated to full-scale operation. Prior to the experiment it must be certain within a reasonable measure of doubt that the experiment will cause no permanent changes to the manipulated environment (for instance the extinction of any species).

Risk management will require movement towards modular production systems which will allow some measure of control. Such systems must be included into the experimental design, while at the same time bridging the gap between small-scale and large-scale system dynamics.

Temporal studies and modelling exercises already provide some means of estimating the bulk carrying capacity for sustainable operations, but these require further development.

# 2. Working Group 2: Productivity regulation and ecosystem variability: Ecosystem exploitation

## 2.1 Introduction

The working group addressed issues concerning harvest enhancement by ecosystem management in relation to our ability to predict the consequences of harvesting activities on different resources. The working group addressed top-down influences on the ecosystem with the emphasis on the higher tropic levels and system output.

The key themes identified were:

- Fisheries, sea ranching and exploitation of currently non-harvested resources.
- Predator removal, changed competition.
- The reduction of natural variability in recruitment.
- Natural variability as a source of uncertainty in decision making.

## 2.2 Abstracts of Working Group 2 prepared papers

### 2.2.1 Abstract of paper entitled, *Productivity regulation and ecosystem variability, ecosystem exploitation: modelling results* by Professor Villy Christensen, ICLARM.

**Introduction**

Global synthesis of the present state of marine fisheries, trade, and fish stocks are almost exclusively prepared by FAO, (e.g., FAO 1996). These synthesis are well known in the fisheries world, and will not be a topic in this brief overview. I will instead focus on the state of exploited marine *ecosystems*, paying special interest to what can be extracted from trophic modelling that may be of interest for the prospects of increasing or sustaining global harvest levels.

It needs hardly be mentioned that in general the world's fish stocks are overexploited, and that the prospects for developing new fisheries are dwindling. Hence, we have to get the best out of the limited resources at our disposal.

**The present state of ecosystem exploitation**

**Primary production required**

As a measure of the state of exploitation of the world's aquatic ecosystems Pauly and Christensen (1995) estimated how much primary production was required to sustain the global fisheries in 1988-1991. As basis for the calculations FAO catch statistics were split into six major aquatic resource ecosystem types, and aggregated into 39 major species groups for which information on trophic status was extracted from information in 48 published trophic models of ecosystems. The results showed that globally some 8% of the aquatic primary production was appropriated by fisheries, and that there was considerable variation between resource system types: for open ocean fisheries only 2% was required, while upwelling, shelves and freshwater systems required of the order of 25-35% of the total primary production. When we add to this that a subsequent study (Trites et al *in press*) found that the marine mammals in the Pacific required an additional 20-25% of the primary production it may be concluded (or at least assumed) that the primary production is about totally utilised. We can only expect to use say, one third of the total primary production – for terrestrial systems (which in general are more fully exploitable and exploited) the global average is thus that 35-45% of the primary production is appropriated by humans, directly or indirectly.

## The modelling basis

The studies discussed above are based on information extracted from published trophic ecosystem models prepared using the Ecopath approach and software (freely available through v.christensen@cgnet.com). Such models are designed to describe the trophic fluxes and state variables in ecosystems, and are constructed as follows: 1. Define an ecosystem; 2. Aggregate its components into a manageable number of compartments; 3. Enter available information on biomasses, consumption and production rates and diet compositions; and 4. Construct the model based on the diagnostic and tools built into the system.

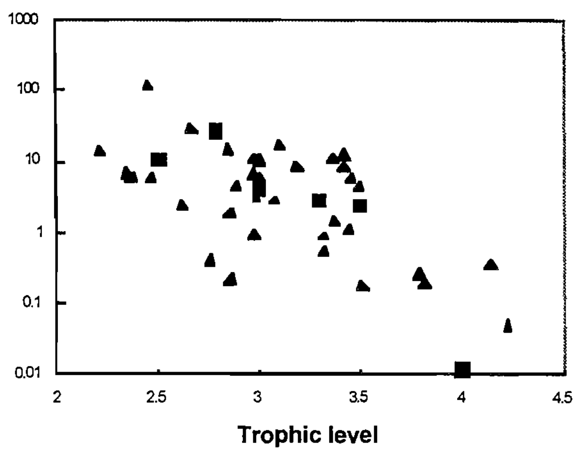


**Figure 1.** Average catch of finfish vs. average trophic level of the catch based on 36 ecosystem models (triangles, Christensen 1996a). The six squared symbols represents averages by system type, with increasing trophic level: coastal, upwellings, freshwater, tropical shelves, non-tropical shelves, and oceanic systems.

Once a model has been constructed the basic information required to evaluate the trophic structure of the ecosystem is available in a well-structured form incorporating our best knowledge of the trophic interactions in the ecosystem – especially for the upper trophic levels where human interest is the strongest. By their very nature such models encourage comparisons within and between ecosystems. The following will exemplify this.

## Avenues for increased, sustainable exploitation

## Fishing down the food web

If, as discussed above, stocks in general are fully exploited, we cannot expect to get increased catches by simply increasing the effort. Can we instead increase the harvest by changing the exploitation pattern? At present the global fisheries are to quite an extent based on fishing large, piscivorous fish – by weight one third are piscivorous (Christensen 1996a). In addition there is a negative correlation between catch rates and the trophic level of the catch, see Figure 1. It is therefore a relevant question if increased gain can be obtained by "fishing down the food web", i.e. by initially targeting the predators and subsequently fishing (an increasing amount of) the prey. Indeed, if trophic transfer efficiencies are around 10% by trophic level as studies indicate (Christensen and Pauly 1993, Pauly and Christensen 1995) there may be considerable gain anticipated.

The present state of exploitation varies between systems, and we may gain an idea of how far the "fishing down the food web" can be taken in practice by examining a number of test cases. For this purpose I have compared 33 published trophic models of exploited ecosystems, including African lakes, coastal/shelf systems and upwelling ecosystems (Figure 2).

**Table 1.** Catches of finfish in 1991 by resource system types, and very tentative estimates of the global estimates of predation loss of finfish. Oceanic systems are not included. Units are million tonnes · year$^{-1}$. From Christensen (1996a).

| Resource system type | Catch of finfish | Finfish eaten by other finfish |
|---|---|---|
| Upwelling | 17 | 50 |
| Tropical shelves | 16 | 48 |
| Non-tropical shelves | 28 | 56 |
| Coastal | 8 | 30 |
| Freshwater | 8 | 30 |
| Total | 77 | 214 |

The general conclusion to be drawn from Figure 2 is that even in the most heavily exploited coastal/shelf systems, fish predation on fish amounts to more than the catch – the only real exception is an extremely, intensively fished Lingayen Gulf (Philippines), where the catches are dominated by immature fish; a not very desirable situation. Hence, believing that the catches can amount to more than half of the predation is probably neither possible nor desirable. A very tentative estimate of the global finfish predation on finfish is presented in Table 1.

Where the preliminary studies above pointed toward *status quo* we might question if it would be possible to increase harvest by intelligently "fishing down the food web" as opposed to the blind, market-driven approach applied hitherto. Addressing such questions in my opinion holds far more scientific challenge and perspective than the massive, yet rather futile efforts allocated over the past decades to improve our stock assessment methodologies so as to be better able to 'count fish'.

Valuable experience related to this has been gained from various sources, not the least in connection with the work around development and implementation of the multispecies virtual population analysis, MSVPA, in the North Sea (Pope 1991, Christensen 1996b). I will briefly present some of the findings and perspectives in the following.

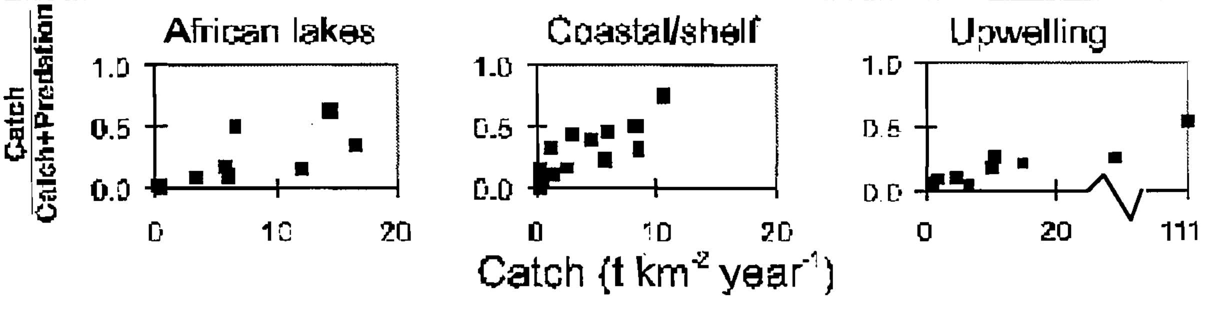


**Figure 2.** Finfish exploitation-predation rate index as a function of total catch of finfish in three resource system types. Based on trophic models (based on Christensen 1996a).

## Predator removal

Humans generally dislike competitors, not the least if they are taking what we want for ourselves. On this background it is no wonder that an initial reaction to a fishery crisis may be to eliminate the competitors, which in this case primarily will be such top-predators as marine mammals, birds, and piscivorous fish, (the 'whale strategy' of Pauly 1979). In Antarctica the reduction of whale populations has thus led to, or contributed to, an exploitation of krill at a level of 300 000 tonnes · year$^{-1}$.

For African lakes several scientists have over the years speculated whether harvests could be increased by removing the predators. Even if exploitation levels may have increased the results are, however, far from conclusive, and my overall conclusion is that predator removal in general is a problematic avenue which may have unwanted side-effects, not discussed here but see Christensen (1996a). As expressed by Larkin (1979): "Do not expect long-term benefits to the prey from predator control."

## Prey exploitation

Another simple step on the "fishing down the food web" ladder is to target the prey populations directly. This may lead to considerable catches of often low-valued species. Economical considerations may be used to consider the degree to which such a situation is desirable. Other considerations are, however, also called for.

An anticipated result of the 'whale strategy' discussed above is that environmental groups will protest – the same holds for the 'Lilliput strategy' (*sensu* Pauly 1979) discussed here. Prey exploitation will impact the top predators in a system, and, as the Greenpeace action against industrial sandeel fishing on "Wee Bankie" off the Scottish coast in the spring of 1996 showed, there are strong opinions on prey exploitation.

From a scientific point of view the Greenpeace action was interesting as it showed that in spite of the North Sea being the area where species interaction is best studied of anywhere it was not possible to give convincing scientific arguments about the impact of the industrial fishing. We need to be able to address such questions.

As a related example, the study of Trites et al. (*in press*) is interesting. They calculated for the seven FAO statistical areas constituting the Pacific Ocean how much primary production that was required to sustain the catches, and the marine mammal populations. Their results indicate that there is an inverse relationship. In the regions where the catches appropriate most of the primary production the marine mammals take less – or less is left to the marine mammals, the poorer competitor in this example of what may be "food web competition".

## Predator/prey coexistence

Coexistence is a scientifically more challenging approach than elimination, and it is in the long run the only sustainable option – environmental concerns will gain increased importance, fisheries may not. The, by now, well established procedure for managing predator/prey coexistence is MSVPA as introduced above. In the North Sea the forerunner of the MSVPA, the North Sea model of Andersen and Ursin (1977) was initially used to give guidelines for how the catches could be doubled. The MSVPA has not been used for anything similar, mainly because such considerations needs to involve economical and sociological factors, and neither of the models do.

A new tool for studies of predator/prey coexistence, and the impact of different harvest strategies has recently emerged in the form of a truly generic, dynamic simulation model, Ecosim, developed to be part of the Ecopath system (Walters et al. 1997).

## Rebuilding stocks: marine protected areas

A final form for management potentially leading toward increased harvest should be discussed: rebuilding stocks through closing areas for fishing or at least for destructive fishing. The idea is not new, it has been part of many traditional management schemes, and it has been part of fisheries science at least since Beverton and Holt.

Due to its importance in relation to biodiversity conservation marine protected areas (MPAs) have gained renewed interest in recent years, but also other factors speaks for their inclusion in modern fisheries science.

As a major example work has been underway with MPAs in the Philippines for decades, see, e.g., Russ and Alcala (1994). The studies indicate that the benefits for society from establishing MPAs outweighs the costs involved in establishing and protecting them. It appears that MPAs can enhance fishing yields in adjacent areas, can reduce the risk of fishery collapses by preserving spawning stocks, and can increase the reproductive potential of stocks if properly designed.

A related angle was used by Christensen and Pauly (*MS*), and Pauly and Christensen (1996) to simulate how fish stocks may once have been. Once, before humans started exploiting the marine environment there must have been much higher populations of especially top-predators, and hence, also of the intermediate predators on which they relied. If we could re-establish such ecosystems, and if we were to manage them sustainably, how much more could we extract from them? The initial analysis indicate that the ecosystems studied may be able to accommodate 3 to 4 times as high fish biomasses before reaching ecosystem carrying capacity, and indeed give reason to the serious consideration of the possibility of managing with "increased capital in the bank" instead of the present impoverished situation.

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### 2.2.2 Abstract of paper entitled, *Testing the feasibility and potential benefits of open ocean macroalgal farming* by Professor Arne Jensen, Institute of Biotechnology, Norway

Twenty-five years of government and industry tests in the US have demonstrated that seaweed can be grown on open-ocean rafts with a potential major contribution to greenhouse control and protein supplies. The biggest question is whether sales of the resulting fuels, food, pharmaceutical and chemical products can cover the farm costs. The key to a successful program is a high seaweed yield. This requires a productive plant, a conducive ocean site, and effective nutrient management.

The best candidates for macroalgal farming so far are two red algae rich in proteins and polysaccharides - *Gracilaria* and *Cappaphycus*, respectively - with strong growth performance in coastal settings. The best open-ocean locality appears to be the eastern end of the Pacific Equatorial Belt with a surface-current/undercurrent interphase that provides good nutrition, with ideal water temperature, and with low storm incidence. The crucial next step is to determine the productivity of these plants at this site under various nutrient regimes. A test for this purpose will require that a research vessel remains on station for four weeks - deploying rafts in various nutrient conditions and determining the seaweed yield, chemical composition and weather conditions.

The test is estimated to cost US $ 400,000. The World Bank is seriously considering the funding of all or most of the estimated cost and has in this connection requested a projection of the net cost per ton for sequestering or recycling atmospheric carbon in a full farm program. Working out the economic projection will take time and means that the first possible date for the full test will be July 1988.

It is highly desirable, however, to have tentative indication of the on-site seaweed yield and overall program feasibility in time for discussion at the UN Global Conference in Japan this September. Plans for a small-scale test this July for this purpose have therefore been worked out and the financing is being explored.

### 2.3 Summary of issues discussed

The results of the Static Mass Balance Models presented, provoked a prolonged discussion on

1) the usefulness of ecosystem modelling studies,
2) the sensitivity to small changes in the structure and/or parameter values, and
3) the reliability of conclusions based on these models.

Difficulties lie on in the fact that, at present, equally plausible models give widely different but equally plausible results. There is no consensus of opinion as to which the best models are.

Two particular problems were identified in relation to the models based on equilibrium situations. Firstly, equilibrium conditions appear to be the exception rather than the rule. There are continuous changes at all time and space scales and models that do not take into account the dynamics of the system may actually have little predictability.

Another shortcoming of existing models appears to be that many species cannot be uniquely assigned to a particular trophic level but actually may evolve through 3 different levels during their life. The interpretation of productivity in relation to length of the food chain is thus problematic.

Although the view was expressed that scientists should be humble regarding their abilities to predict the likely effects of multispecies/ecosystem management, the existing models are not completely useless. A lot depends on the type of questions one seeks to answer. Whereas it is impossible to predict the effect of a particular management measure, especially if this extends over more than one trophic level, it is quite possible to give guidance as to management measures which are unlikely to result in unintended effects.

There was a general consensus that although many fisheries are overexploited and are managed badly, there is limited scope for increasing ocean harvest significantly by top-down management measures. Reduction in fishing effort may result in a 10% increase in yield. There is also a potential in turning at least part of the discarded catch into profitable yield by changing exploitation patterns. However, the resulting figures would clearly not lead to significant increases of the contribution of fish to the world food demand. Also, the present state of knowledge would not allow for a reliable evaluation of the effect the removal of particular predator or prey stocks might have on the harvest potential of other species.

Other potential management methods, such as good stewardship of good yearclasses, were discussed briefly, but in general their value is extremely limited. Although they may help to rebuild a depleted stock, they have no particular bearing on enhancement of yields.

An interesting description was given of the Barents Sea, where a good year class of herring appears to cause capelin stocks to collapse, simply because the capelin larvae spawning offshore to the colder waters of the eastern Barents Sea encounter the herring schools on their migration, which reduce capelin numbers substantially. If the herring schools could be diverted away from critical areas by seismic waves, co-occurance of capelin and herring stocks might be achieved, which would not only enhance the potential yield in the fishery but also the natural productivity of the system. No other fishery resource develops in the eastern Barents Sea if capelin recruitment fails.

The more immediate task of ecosystem management is to define acceptable levels of impact, taking into account the precautionary approach. Given the uncertainty about the functioning of the marine ecosystem, the precautionary approach clearly sets strict limits to experiments assessing different harvesting levels. Potentially useful ideas to "weed" jellyfish as predators of fish larvae, or to poison the microbial loop thus enhancing primary production further up the food chain, are likely to remain untestable in practice.

It was stressed that fish products to a large extent represent a luxury rather than a staple food for nourishing the world population. This suggests that other issues are at stake as well, and that it is in many cases more important to raise the value of a catch rather than the actual yield. It is particularly in terms of "value" that fisheries management could have its greatest effect.

The keynote on the feasibility of open-ocean macroalgal farming was to some extent displaced, because it is related more to the topic of harvest enhancement through artificial ecosystems of Working Group 3. Nevertheless, a lively discussion developed. Although the costs of open ocean farming are formidable compared to farming in the coastal zone, interference with other users might be less prohibitive for any large scale development. Offshore oceanic rafts might be a possibility, although an area of up-welling of nutrients is obviously a prerequisite. Another advantage of the open ocean might be that there are likely to be few unintended side effects because, as described below, it is a virtually "sterile" environment. Storm events would only result in sinking of lost material below the photic zone, where the plants would die. Also, the eggs would be taken before the algae would reproduce and settlement of new plants would be out of the question anyway.

It was questioned whether further development of models should be a research priority because the predictability of major disturbances is very low. However, there was consensus that ecosystem models are valuable in bringing together data, ideas and knowledge of particular systems. Beyond that, good models are useful in describing possible ways in which a system could respond to perturbations. Opinions were mixed, however, with regard to the ability of even the best models available to predict which future outcomes or configurations were most (or even more) likely. Fundamental research on the processes and functions of marine ecosystems remain on the list of priorities to improve the understanding of ocean harvest.

Following on from these thoughts the notion of "reversibility" of ecosystems was discussed. There was agreement that impacted systems are not reversible, in the narrow sense that they can be managed back along a specific pathway it has been following, to regain a particular earlier state. "Natural" experiments, like reduction on fishing during the two World Wars, have demonstrated that with reduced fishing intensity, the abundance of most species increases considerably although the relative species composition is different to what it had been before. Also, it is well known that it may take a very long time before a depleted stock may start to rebuild. Reversibility is not an easily measurable parameter.

There is a clear need for identifying ecosystem level properties which are sensitive to perturbations, such as fishing, and properties (if any) which may be conserved. In particular, size spectra and diversity spectra were mentioned as providing useful parameters.

One possibility to improve our understanding of the effect of perturbation on ecosystems would be to make a better use of "natural experiments". These have been events in the part, which must be considered as significant perturbation. Examples are:

– the Arctic-Norwegian spring spawning of herring has dumped in recent years 3 million tonnes of egg and milt in a small area off the Norwegian costs. What effect has this on the local food structure?

– the post spawning mortality of capelin may amount up to 1 million tonnes in some years. Again this is an enormous organic input locally, but it is known how this taken up in the food chain.

– The moratorium on northern cod has caused a large reduction in discards, the effect of which might be studied on dependent seabird populations.

Although such studies would clearly contribute to our understanding of ecosystem processes, interpretation should acknowledge the lack of controls and replicates in such "natural" experiments.

# 3. Working Group 3: Harvest enhancement by creation of artificial ecosystems

## 3.1 Introduction

This working group concentrated on the potential to enhance aquatic harvests in purposefully modified and artificially created systems, such as artificial reefs and artificial upwelling systems, through species restocking, application of polyculture systems, and waste recycling through specific management measures

## 3.2 Abstracts of Working Group 3 prepared papers

### 3.2.1 Abstract of paper entitled, *Enhancing the marine harvest using artificial reefs* by Dr. Antony Jensen, Southampton Oceanography Centre

Practical examples of harvest enhancement from artificial reefs can be found from a variety of reefs throughout the world. Oil rigs placed as reefs enhance the sport fishing yield in the USA, and purposed designed and built reefs in Japan's coastal waters have succeeded in increasing the seafood harvest as the catch from the distant water fleet declined. In Europe, bivalve (mussel) harvests from artificial reefs in the Adriatic Sea have exceeded costs of reef deployment in a few years and commercial fish yield around reefs is higher than at local control sites.

Artificial reefs appear to have the potential for inclusion in future plans to facilitate fish capture; to create "no fishing" areas; to ranch animals that require rocky habitat, such as lobsters; to provide habitat for animals beneficial to net cage fish culture, such as wrasse and to provide physical structures upon which aquaculture equipment can be set, e.g. mussel ropes or just to provide a barrier from unwanted intrusion by other water users such as trawlers.

The challenge is to suit the reef type and design to the task required, something that requires further research effort by the scientific community in collaboration with fisheries and aquaculture interests to increase understanding of the habitat requirements of target species or groups.

Artificial reef research is still establishing the ecological basis for reef operation. Fish attraction is an established fact, as is increased fishery yield, but as yet definitive works on reef productivity have not been published. The practical problems of determining fish biomass production are large, especially where fish are not long term residents around a structure. Intuitively, if fish gain advantage from being close to a reef, for example shelter from predators, currents or feeding opportunities, then growth rate my be greater for fish close to a reef that those in control "natural" areas. Whether a reef related increase in growth rate or survival rate can be translated into increased fecundity (and in time, adult fish) is almost impossible to determine in field experiments, but if fish are "fitter" and/or survive in greater numbers then it is likely this will be reflected in fecundity. Planktonic larval survival will be outside the sphere of influence of an artificial reef.

Fish attraction is often seen as pre-disposing fish to over-exploitation, concentrating the biomass and in turn concentrating the predators (human and marine). Fishing mortality has the potential to be the greatest influence on a reef community, but can be controlled by the physical size and design of the artificial reef area or by legal restrictions on activities within the reef area. It is also realistic to place structures within legal reserves or create "no fishing" areas where reefs act primarily to prevent fishing, so that populations can be given respite from fishing mortality.

Research into the implications of fish attraction to artificial reefs is required, definitive research into biomass production is important and results are likely to be species specific. The displacement of fish from that area around an artificial reef is also an interesting topic. Are predators also concentrated? Do other individuals move into the areas where fish numbers have theoretically been reduced by the attractiveness of an artificial reef? If the latter is true a possible increase in fish numbers could result from reef deployment.

Artificial reefs provide habitat for benthic species and may have an important role to play in the ranching or management of wild populations of commercial species that are obligatory hard substratum dwellers. Octopus populations have been increased by deploying artificial habitat in Japan, with no detectable reduction in the population in the neighbouring natural rocky habitat. Lobsters are also a group that may benefit from artificial habitat deployment, either to create a new "lobster reef" or to augment habitat to provide shelter sizes that are lacking.

The extension of this into a purpose designed habitat for ranching seems possible. More research into habitat requirement is needed to specify the size and arrangement of shelters, but hatchery techniques for Homarid lobsters are well established and with some work to reduce cost per animal could produce juvenile Homarid lobsters for placement on natural or artificial reefs. Legal provision to grant harvesting rights to individuals or companies will facilitate ranching activity, possibly leading, in the case of the clawed lobsters (*Hommarus* spp.) to the placement of specifically designed artificial reefs stocked with hatchery reared juveniles.

That more research in to habitat requirements and benefits to animals living on, in or close to reefs is not in doubt. The European Artificial Reef Research Network (EARRN) is currently summarising European advances in artificial reef technology and preparing recommendations for future direction of research activity.

### 3.2.2 Abstract of paper entitled, *Sustainable aquaculture, theoretical vision of commercial reality?* by Dr. Torjan Bodvin, Marine Productions A/S, Norway

Sustainable development is the new "in" word in international industrial development. It is meant to be a description of how we in the future will have to organise the use of the resources on our planet to make Tellus a place for the human race in the years to come. In a practical approach towards a biological production, this means that we have to look at how efficiently we use our limited resources of, for example, protein, carbohydrates and fat, to create food for human consumption within the limits of ecological balance.

In aquaculture these kinds of thoughts have been used to establish different kinds of ideal models. But the construction of the models has been carried out mostly by researchers with a very strong theoretical knowledge and with very little practical experience of production processes, technological limitations and commercial demands. Systems have been created that in theory seem to give excellent results, but which in practice are impossible to carry out on a commercial scale. The systems have not been adopted by the industry.

In Asia, the principle of sustainable aquaculture has been the basis for most production systems. In freshwater, integrated systems involving aquaculture, agriculture and waste-handling from human activity have been developed over centuries. The production of fish (or other products) has been balanced with the agricultural production and the population size. But with an increased demand for more "efficient" production and an increased economical output, one has during the last decades introduced artificial feed for fish into the systems. In sea water, combinations of seaweed and mussel production have also been used.

Marine aquaculture in Europe has seen the development of many different production processes, each process specialised to producing a single species with an increased demand for efficiency and volume. As production has increased, this has led to increasing environmental problems. The way to solve this has mainly been to move the production out into the open sea where, so far, there have been no problems. But still large amounts of nutritional and organic input have been introduced into the sea as wastes and not looked upon as resources for a new production.

Nutritional and organic wastes from, for example, salmon production have so far been looked upon as negative factors, both by the fish farmer and by Governments. The main focus has been "end-of-pipe" solutions to reduce the outgoing waste which create increasing production costs for the farmer and a disposal problem for Governments. There would be an advantage if these wastes were used to boost production rather than being lost to the system, particularly as with increased competition in salmon farming, the feeding conversion factor in the industry has been dropping dramatically during the last 10 years. Set out below is a classic example showing that as long as one can link an environmental improvement to an increased commercial output, the industry is able to incorporate this improvement very rapidly.

In 1990, fish farmers in Flekkefjord on the south coast of Norway, established a floating, closed fish farm for salmon to avoid problems with toxic algae. The farm had also a "trap" system to collect spilled feed and faeces. Later, in 1992, a group of scientists from the south coast of Norway and from NTNU in Trondheim, presented a concept of integrated production of salmon, mussels and seaweed in a floating, closed farm. In addition to the problems associated with nutritional and organic wastes, the concept included relating both problems to the use of chemicals in production processes and to the design and construction of the farm. It was also a separate project on aesthetic problems linked to location and architecture of the farm. This idea was further developed during the next years, and in 1994 a company called Marine Production AS was established to realise these ideas in a full, commercial scale farm. The first farm, Oksefjorden Havbruksanlegg, was established in 1996, and is now in full production.

In our activity on Oksefjorden Havbruksanlegg, we have combined a production of salmon (600 t/y) and mussels (400 t/y). The salmon is produced in floating, closed bags while the mussels are hanging down from the steel cage surrounding the bags. By doing this, we can use people, investments and equipment linked to both production processes and thereby reduce the production costs for both products. In addition, we have 2 more mussel farms in the same area which means that in 2 to 3 years we will remove more nutritional and organic wastes from the area by harvesting the mussels than goes out at present from the outlet from the salmon farm. We also collect all particles larger than 0.2 mm from the outlet of the salmon farm with an "end-of-pipe" technology. By linking this to a feed controlling system we appear to be able to reduce the feed conversion factor by 5 - 10%. The cost of the system is about £8,000 to 10,000 per year , but the reduction in feed consumption reduces the production costs by £15,000 to £30,000 per year.

To be able to implement the different aspects of sustainable aquaculture into a commercial production, there has to be a very close relationship between research institutions and farming industry. In this way, one can develop new production processes that have the necessary balance between theoretical approaches and commercial potential.

Some of the main problems in this kind of development are official regulations and laws. A development which integrates production between different kinds of species will, in many countries, be in conflict with for example veterinary regulations. To avoid these kind of problems, it would probably be wise to include the different governmental institutions very early in decision processes.

## 3.3 Summary of issues discussed (possibilities and constraints)

### 3.3.1. Artificial Reefs

The empirical nature of many artificial reef experiments performed so far have, with a few exceptions, not provided scientific proof that artificial reefs do enhance productivity, rather than simply attracting fish and facilitating their fishing; i.e. the statistical power of an experiment to detect a predicted increase in density around an artificial reef is quite large; the corresponding predicted decrease elsewhere (if reefs "attract" but do not "enhance") is likely to be small; statistical power to detect such a decrease is therefore small.

Careful experimentation about the potential use of artificial reefs should also consider possible risks for physical damage to coastline ecosystems, over-fishing, reducing artisanal fisheries resources, species competition and diseases through the introduction of foreign organisms. Artificial reefs, however, can assist as an exclusion method to deter trawl fishing and thereby supporting artisanal fisheries.

It is particularly worthwhile to study the potential of artificial reefs in highly eutrophic habitats because the provision of additional substrates enhances the productivity of harvestable biomass, e.g. bivalves.

Interdisciplinary research should furthermore tackle questions related to the durability of the reef structures, biological succession on the reefs, the socio-economics and possible interactions with other resource users.

More attention should be paid to the protection and restoration of natural reefs and other degraded coastal ecosystems, e.g. abandoned shrimp ponds, prior to promoting the concept of artificial reefs as a means of habitat replacement/improvement.

### 3.3.2 Enhanced productivity through recycling of phosphates and nitrates

Based on successful applications of waste recycling in aquaculture systems in China, Italy, Germany, etc. one could theoretically propose effective solutions to reduce the eutrophic status of the larger nearshore water bodies, e.g. North Sea. Such solutions, for example seaweed cultivation, mussel farming, etc., might not prove relevant from a commercial point of view in some European waters. Also, the possible consequences on the ecosystem should be assessed, e.g. accumulation of organic matter may have a major impact on the viability and stability of the ecosystem. Furthermore, a major constraint might be the possible accumulation of contaminants.

Nonetheless such innovative concepts for nutrient recycling should be actively pursued, realising that this is an area which will require an integrated approach, not only at the systems level, but also at political and regulatory levels. Possible options are to increase primary production in restricted areas, select culture systems with shortened food chains, whilst developing those in confined systems.

In view of the immense input of nutrients to coastal ecosystems from the terrestrial environment, measures should be propagated to optimise nutrient use in terrestrial farming and to develop waste treatment and/or deposition on land.

### 3.3.3. Sustainability and the Farming Industry

The industry realises that sustainable use of resources in modern aquaculture (such as salmon cage farming) requires biotechnological solutions that are embedded in multiple resource use whilst being practised in a compatible manner to other salmon farming activities. Yet there has been little integration with other farming activities operating at different trophic levels, such as mussel and seaweed culture. An attempt to overcome this shortcoming was presented in which a new culture system design was tested.

New approaches need close cooperation between scientists and farmers. However, scientists and farmers set their priorities differently; while at the same time regulatory authorities, which are not part of the development, often respond with contradictory policies despite their intent to promote environmental friendly husbandry techniques.

It must be recognised that new approaches will require a much longer lead time before reaching the stage of commercial application. The past experience in modern aquaculture system development demonstrates this fact very clearly. In the context of developing new methods for enhanced productivity in the sea, this observation will certainly apply. Industry, the scientific community and public funding agencies should be fully aware of the needs of long-term strategic research and development from bench to pilot-scale and finally full-scale production systems.

### 3.3.4 Sustainability and Marine Resource Production

The sustainable production and subsequent optimisation of marine resources form a major challenge for science, the private sector and government. There is growing awareness among these parties that optimisation of marine resource production can only be promoted if three basic issues are addressed, namely:

1.) Eduction of stresses on coastal and marine ecosystems originally caused by the adverse effects of poorly planned and managed development. Unless these stresses are reduced, opportunities for utilising existing marine resources will be foreclosed and the development of enhanced marine resource production will be made more costly and technically difficult.

2.) Improved allocation of resources to improve the efficiency of their use and to avoid further adverse impacts on coastal and marine ecosystems.

3.) Promote improved cooperation among scientists and the private sector to encourage the identification of opportunities for developing appropriate technologies to achieve enhanced and sustainable marine resource production.

The successful resolution of these factors will require a broader scientific and resource management framework than is currently being utilised.

### 3.3.5. Stock Enhancement through Restocking

In salt water, there is a long history of attempts to enhance stocks of commercially valuable fish and shellfish species. In most cases, the outcomes were difficult to assess in terms of actual additions to the population as opposed to displacement of "natural" members of the population.

The following were brought to the notice of the meeting:

The first example in the Sea of Azov/Black Sea area was of the deliberate introduction of the mullet haarder (*Mugil so-iuy*) from the Far East between the late 1960s and 1980. The release of juveniles was accompanied by controlled rearing of juveniles. The species has become established in the wild, and breeds successfully. In 1995, the catch amounted to 100 tonnes, and therefore the costs of stocking could be recovered from one year's landings. The authors were encouraged that the haarder could replace depleted stocks of local species. It is highly adaptable, and is considered likely to spread to other parts of the Black Sea, and into the Mediterranean Sea.

The second example was of the enhancement of striped mullet (*Mugil cepahalus*) stocks in Hawaii. The programme is being conducted in a step-wise fashion, with the aim of determining the range of conditions most conducive to good survival and growth of the released juveniles. Information has been obtained on the most appropriate location for release (stream mouths), season of release, and matching the size distribution of released animals to the size structure of the wild populations. Studies in nursery habitat indicate that the released animals do not displace wild stocks, and therefore make a positive contribution to the total stock of juveniles. The impact on adult catches has yet to be determined.

Experiments in the UK and Norway have shown that it is technically feasible to rear *Homarus gammarus* in a hatchery and release juveniles into the wild. Monitoring of tagged animal recaptures in the UK shows that the released lobsters survive to reach minimum landing size in 4 - 5 years, may reproduce, and are taken by the fishery. Socio-economic considerations suggest that this is a valid "public good" exercise, and the financial returns are not immediate, but reduction in hatchery costs may push the economics to a more commercial state.

There may be scope for localised, effective, restocking or stock enhancement programmes using relatively sessile organisms of high value in areas where some protection (biological, physical and legal) can be given to the organisms in the sea. Examples include areas allocated to the bottom cultivation of scallops, the construction and stocking of artificial reefs with lobsters, and the stock enhancement of abalone. There also may be opportunities for innovative programs concerning the introduction of hatchery reared juvenile fish into over-exploited reef environments.

In general, for future enhancement programmes to be have increased potential for success, more information is required on the details of habitat requirement at the various life stages concerned, the carrying capacity of areas considered for enhancement, the interactions of wild and hatchery-reared animals, and the possible genetic differences between local and introduced animals.

### 3.3.6. Artificial Upwelling

Securing decent living conditions for today's human population in a sustainable way requires increased use of the marine environment. Promising possibilities appear to involve expansion of existing and creation of new upwelling areas offshore and open ocean macroalgal farming and cultures of organisms low in the food chain (e.g. mussels and other filter-feeders) in coastal waters.

A plan for macroalgal farming is presented in Section 2.2.2.

The crucial next step is to determine the productivity of these plants at this site under various nutrient regimes and to project the net cost per tonne for sequestering or recycling atmospheric carbon in a full farm programme. As shown in China and Japan, macroalgal farms are efficient in converting polluting nutrients in coastal areas to biomass. Questions were raised, asking if sufficient environmental studies have been performed to elucidate environmental consequences before starting large scale experiments or production programmes, and if there are reasons to believe that predators (herbivores) might interfere.

### 3.3.7 Genetically Modified Organisms (GMOs)

Regarding the genetic engineering of marine organisms to be used in aquaculture, we are sceptical about the application of the techniques at the present state of development.

There are considerable concerns that escaped GMOs could alter the genetic structure of the wild population, and also interact with members of other species in the ecosystem.

There are great difficulties in the prediction of the likely impact of escapees on local populations or communities. Some attempts are being made to develop risk assessment and management procedures. Some strategies have been suggested for minimising the hazards, for example using closed culture techniques, or sterilised stock. Sterile triploid salmon and trout have been available for some time, and while trout are used in cultivation, triploid salmon have not proved popular with commercial growers. There is need for research on marker sequences that will enable the identification of GMOs, on the possibilities of constructing closed systems for field testing of GMO, and on the behaviour, fitness and other aspects of the possible interactions between escaped GMO fish/shellfish and wild populations.

We want, however, to emphasise that traditional breeding programs for terrestrial plants and animals, which have shaped our modern aquaculture, should be extensively applied to the marine organisms we want to culture. The economy and performance of algal farming and marine aquaculture will be decided by the success of such breeding programmes.

## 3.4 Summary and Suggestions

- Artificial reef deployment appears to have potential applications in finfish fishery management and in ranching of invertebrate species. Gaps in knowledge include a thorough understanding of habitat requirements for target species, whether fish productivity is achieved and what impacts on fish population distribution reefs really do have. The need for materials assessment and socio-economic appraisal was also raised.

- It was stressed that when considering the restoration of damaged ecosystems it was more appropriate to address the damage directly than deploy reefs to create new habitats.

- Waste recycling and reduction initiatives on land were considered important in reducing excess nutrient loading in coastal waters. Marine initiatives were considered possible but likely to need political will and regulatory support.

- Reduction of environmental stress on the coastal area is vital if sustainable resources are to be developed. For this to happen there is a need for closer cooperation between the different sciences and between the scientific community and the private sector.

- Stock enhancement was shown to be variable in its success, but two examples (finfish and lobster) were shown to have promise. One area of concern addressed was the difficult, but necessary, task of determining if surviving hatchery-reared stock were truly additions to the stock or merely displacing wild individuals.

- A major hope of significant increase in ocean productivity was thought to be the growing of algae on rafts situated in ocean upwelling zones. Concerns were expressed that any such programme must fully evaluate the environmental consequences of such activities.

- The use and inevitable consequent accidental release of Genetically Modified Organisms (GMOs) in aquaculture programmes was considered unacceptable. Selective breeding was thought to be a much safer way of improving the performance of cultured species.

- There is a need for a strategic vision for research to evaluate current constraints on the successful promotion of improved marine resource production in different regions of the world. This should be related to an analysis of the forms of applied research and resources management which may be appropriate to assisting nations in achieving enhanced sustainable and optimal use of potential marine resource production.

# 4. Working Group 4: Optimum use of resources: Interaction between users and society

## 4.1 Abstract of Working Group 4 prepared paper

### 4.1.1 Abstract of paper entitled, *Exploitation of Marine Resources and Environmental Conservation* by Dr. Sidney Holt

It is now generally acknowledged that sea fisheries based on wild stocks are in a global crisis. This crisis is a consequence of excessive fishing. A crisis of 'over fishing' was well-known at the regional level, in the North Atlantic and North Pacific particularly, since before the Second World War. It has extended to global proportion in the post-war years, especially since the 1970's, and from, originally bottom-living (demersal) species to the once extremely abundant pelagic (surface and mid-water) species. The root causes of this, together, are the evolution of a global market for frozen and otherwise processed products - especially fish meal - and technical advances permitting fishing operations especially in deeper and mid-water, with ever-increasing efficiency. The proximate causes of the continuing worsening of the situation are the explicit and hidden subsidies from many governments that distort the fishing economy, and the failure by the industry or the relevant authorities to apply rigorous restraintive measures.

So, does commercial sea fishing have a future, and, in particular a sustainable future? I think it does, *in principle*, though it will never provide substantial nourishment to a growing human population. Whether it does, *in practice*, depends upon vigorous action by those in the industry and in government to halt the continuing growth in 'fishing effort' and 'fishing power' and to bring those down - in some situations drastically - in many areas. Whether this will be *politically* possible remains to be seen; it will almost inevitably involve some sacrifice of short-term profits in exchange for longer-term benefits in catch and, probably, profits.

Several of the recent failures in fisheries management for sustainability are evidently the result of managers not following the reasonably cautious advice of their scientific advisers, or not having scientific advisers - at least, not competent ones - and not having invested in adequate research. But, also, there are instances where the scientific advice has been insufficiently 'conservative' and would have led to failures even if it *had* been taken. Occasionally, scientists have been unwilling to make recommendations that they feared would be too easily rejected by managers and by the industry. But there has been a methodological problem, too: most commonly this has consisted in using methods for calculating 'allowable catches' that did not take due account of the fact that recruitment into a fish stock ultimately depends on the size of the parent generation, even though that relationship is far from linear.

Recently much concern has been expressed about the consequences for fisheries of deterioration of environmental quality - through pollution of various kinds and destruction of coastal breeding habitats. There is no doubt that the viability of many marine living resources is at risk from such activities as the destruction of mangroves, blasting of coral reefs, and so on. And some vulnerable resources, such as marine turtles, dolphins and other especially slowly reproducing species, are at risk as incidental catches in fishing operations for other species. I do not wish to appear careless about such threats, or to the possible deleterious effects of atmospheric/sea changes, such as stratospheric ozone depletion and greenhouse warning. However, it must be said that our ability to predict effectively and to evaluate the consequences of living resources of such processes remains very weak.

We do *know* that excessive fishing undesirably depletes fisheries resources, and also that depleted resources are more vulnerable to environmental changes than stocks restored to or maintained at close to their pristine levels. Hence we need management policies that seek to maintain populations of fish at relatively high levels, so that they play their normal roles in the ecosystems of which they are parts. And we need scientific procedures to guarantee that errors resulting from weakness of current knowledge and inherent uncertainties. The need for such procedures was fully recognised in the document Agenda 21 that emerged by consensus from the UN Conference on Environment and Development (UNCED) in Rio di Janeiro in June 1992. It is embedded in the concept of the *precautionary principle* and, more loosely, a *precautionary approach.*

At the scientific field I think one of the most important developments in this respect in recent years has taken place in the International Whaling Commission (IWC) through the work of a group of independent scientists in its Scientific Committee, and especially Drs William de la Mare and Justin Cooke. This work resulted in the formulation of an algorithm for a Revised Management Procedure (RMP) which has been adopted by the IWC itself but not yet implemented - awaiting agreement on water-tight international control and inspection arrangements which, together with the RMP, will comprise the Commission's *Revised Management System* (RMS).

The essence of the RMS is that it is conservative - I would say parsimonious - in order to avoid over-exploitation through ignorance. It seeks to maintain stocks at levels not so very far below their pristine levels (and to restore depleted ones reasonably rapidly); it seeks sustainable yields but not unknown maximum sustainable yields (MSY). A minimum of detailed biological information is required for its application, but it does call for estimates of the numbers or biomass of the stock, observed at regular intervals and by means that are independent of the fishing operations. The approach is through computer simulation of the fishing-resource system, and the management algorithm is inter-active. The approach to management now agreed is more akin to systems engineering than to traditional 'biology'.

The IWC approach is now being taken towards regulation of such diverse fisheries as those for bluefin tuna and Antarctic krill. The ICS scientists had a special opportunity provided by the commercial moratorium on all commercial whaling adopted in 1982 and implemented in 1986, so they no longer had to put all their effort each year into calculating and agreeing on annual allowable catches. In other situations they may not be so fortunate.

**Sidney Holt: Additions to abstract**

1. Constanza et al's recent Nature paper (May 1997) shows that the value of services provided by marine systems greatly outweighs the value of fish and shellfish catch.

2. Research periods are nearly always too short to track natural changes in marine systems. But usually management systems are too short also.

3. Newer techniques available include modelling in a management context e.g. whale management which takes into account the whole system, including human behaviour and the tendency to cheat, and other factors not previously considered.

4. Multi-species models were not considered since they were found to be too sensitive to errors. The new models include alternative algorithms which were evaluated and then used to simulate various management scenarios. Thus these are plausible but simple models (which are not maximum sustainable yield models) and which incorporate environmental change.

5. Environmental change is incorporated as deterioration over periods of up to 50 years or large reductions in primary production over short time intervals.

6. The new models are in keeping with the precautionary principle since they take into account uncertainties.

## 4.2 Summary of Issues Discussed

For regional global fisheries the working group find the most likely improvement to be gained from reductions of the post harvest losses. This requires research into both managerial and technological improvements with the aim of obtaining sustainable harvesting. It is recognised that physics control the system and limit our ability to control biology.

The group conclude that intensive aquaculture cannot solve the global food problem, but could, when properly executed, contribute to better food security and improvement of the quality of life. They consider the only real potential for increased production in the coastal area to be within mussel and macroalgae farming.

Management decisions are too often made on a poor scientific basis, and are not properly followed by adequate monitoring of the effects of the decisions. There is a need for research into improved monitoring techniques utilising new statistical and sampling design, further need for strategic research on socio-economic models which take into account the variability of the marine system, as well as management models that conserve the function and processes of the systems for biological production. The group also find a need for research into the validation of the service functions of marine ecosystems and into the acceptable risk levels of management decisions.

Research into or definition of what should be considered as the "pristine state" is needed. The group do however consider that there is no "normal" level of ecosystem and functioning, and that it therefore is impossible to return to a pristine state, at least not as a stable situation equal to the time before manipulation. Neither does the group think that natural variations in stocks and biomass can be manipulated to steady states.

Recognising a series of possible user conflicts a research priority is to strengthen the cross disciplinary research, e.g., biological science and environmental economics, and on the multicriteria decision making process.

### 4.2.1. Optimum management strategy for various harvest enhancement initiatives and their interactions with the environment.

1. Post harvest losses are probably the greatest sources of loss of protein globally. In the sea this includes by-catches and discards. The solution to this problem requires research, both managerial and technological, with the aim of obtaining stable harvesting.

2. Over the past decade it has become clear that the new paradigm for marine production is that physics controls biology directly, which is not so on land and is thus a major difference between the two systems. (A good example, shown at this meeting, is how production is controlled in the Benguela upwelling region, S. Africa). Since the natural physical processes limits are usually of large scale our ability to control the system is likely to be limited.

It was the consensus of the group that there is perhaps too much focus on the detail of how biological systems function, where the real advances will be made by taking coarser approaches, proxies, for the biological detail, (e.g. sea level as used in the Benguela upwelling region).

Too often management decisions are not followed up by properly controlled data collection to test whether the objectives have been achieved. In the area of modelling in a management context new types of modelling (see above) have an important role to play.

Episodic events are known to be highly important for many coastal processes yet the present monitoring systems are inadequate to give the data coverage. Thus EUROGOOS is highly important since it's data collection system is planned at the appropriate temporal and spatial scales for modelling coastal processes. Measurement of biological parameters is a key part of this system.

The Constanza et al. (1997) valuation of marine ecosystem services, (Nature **387**, 253-260), is a useful start but misses a number of key processes e.g. contaminant treatment in coastal areas. There is a clear need for research on these and other related issues. Furthermore, there is a need for strategic research on socio-economic models which take account of the variability of the marine system. In this context one needs to know what are the real costs and risks of variability in natural systems.

3. The old idea of maximum sustainable yield nearly always leads to depletions and negative impacts on the system. Recent evidence suggests that the best strategy for management is to harvest at a stock level close to the pristine level. This will achieve long-term stability which is of high economic value. However, this will take time and needs development of management strategies that adopt a precautionary approach.

4. Users need to be incorporated in management practices and fiscal measures are needed. Whilst these are well developed in some limited areas of marine management practices (e.g. ICES) these need to be applied in other geographical areas.

5. Probably the only real potential for increased production in the coastal area is of mussel and macroalgal culture. But extensive culture will lead to conflicts with other users of the coast, in particular recreation and tourism and these need careful consideration.

### 4.2.2. How to integrate needs for biological production with the needs for environmental conservation.

There is a need for new management models that conserve the functions and processes of the system that in turn generate models of the biological production of target species. In coastal areas increased harvesting often conflicts with the needs to conserve the basic unit of production the habitat and landscape (variety of habitats). Sustainable usage of habitats is the best option but is rarely practised. Integrated coastal management is the appropriate tool (see later).

### 4.2.3 What legal, ethical and social questions must be answered in order to optimise the use of the ocean and its resources.

Too often exploitation of marine resources has not been sustainable. There are countless examples of over-exploitation of marine resources and this is an ever-increasing problem. An example is the development of prawn fisheries in tropical coastal areas at the expense of mangrove forests which provide the basis for coastal fisheries, including the larval prawn stocks.

The Working Group considered that to claim that mariculture can solve the global food problem is not true and verges on the unethical. Mariculture can be expected to provide only a small percentage of future food resources.

On the legal side UNCLOS is in need of revision since many of the ideas were developed some 20 years ago.

Coastal aquaculture has led to large problems especially in developing countries and there is a need for consideration of effects on system services which are presently totally ignored when making assessments of the viability of projects. Again the approach pioneered by Constanza et al. is a start but much more research is needed.

### 4.2.4 Preserving ecosystem integrity

There is a fundamental misunderstanding that ecosystems are static over time and that there is a "normal" level of ecosystem structure and functioning. There are natural variations in production, stocks and biomass that cannot be manipulated by human interventions to steady state levels. Therefore, it is extremely difficult to define what is the normal or pristine state. The best example of large scale natural variability, which is impossible to manipulate, are the El Niño Southern Oscillation events (ENSO) which affect the whole of the southern hemisphere.

Wild stocks of exploited species need to be managed with care since most are clearly over-exploited. Yet defining the level of sustainable exploitation for given stocks is difficult. Whilst it is claimed that one needs to define the pristine state for stock sizes of commercial species this is not a realistic scientific or management goal, given the known variability of ecosytems. New management tools (e.g. the new whaling models) offer better ways of achieving sustainable stock sizes.

It is physical alteration of ecosystems that is the most damaging. This may be due to climate induced physical effects or due to man's direct intervention in the coastal area. Once a marine ecosystem is destroyed it is impossible to get full restoration back to the original condition. Thus restoration ecology has a different goal than restoration to the pristine level. Today there is often more effort (and funds) devoted to restoration than conservation of the pristine condition. More research effort needs to be devoted to conservation. A key issue is whether, once the structure of the system has been restored, the functions also have been restored?

The problem of management of fish stocks is not primarily a natural science issue but needs a socio-economic approach. Aquaculture, by definition, has strong human intervention and maintenance of ecosystem integrity is not a goal.

### 4.2.5 Risk assessment

Great progress has been made in the application of risk assessment techniques to stock size management, but there are needs to further explore aspects of acceptable risk levels and to test the effectiveness of management decisions. This is particularly important in relation to the precautionary principle.

Another key aspect for future research is concerned with risk assessment and monitoring of the state of the marine environment. Monitoring programmes are rarely based on testing of type II statistical errors. For example in the North Sea reductions in toxic wastes and nutrients of approximately 50% have been made yet the present monitoring programmes are unable to tell what changes have occurred as a result. This is due to the poor design of the monitoring programme. There is a strong need to better utilise new statistical and sampling design techniques across a wide range of monitoring programmes.

### 4.2.6 Integrated coastal management

Too often, even in Europe, there is no coastal policy developed and the political system does not enable cross-sectoral management across different authorities.

The primary goals of integrated coastal management are often to utilise, in a sustainable manner, the biological resources of the coastal area and to optimise multiple use of the coast. Yet the goals and needs will vary greatly from region to region.

One of the primary roles for science is to identify potential conflicts and to develop alternative solutions. Good examples of known conflicts are tourism and use of biological resources, aquaculture and capture fisheries, port development and nutrient and metal fluxes, coastal protection and the value of wetlands. Another key aspect is the testing of management strategies.

The research priority is to strength the opportunities for research across disciplines, e.g. ecological/environmental economics and cross disciplinary work within biological sciences. Research is also needed on the decision-making (multi-criteria) processes themselves.

## 4.3 Conclusions and Suggestions

1. In relation to reducing by-catches of fishing, research is required into both managerial and technological improvements with the aim of obtaining stable harvesting.

2. Rather than studying the details of the biological system it is felt that real advances can be made by use of proxies which may be easier to measure and to incorporate in models (a good example is the use of sea level changes as a proxy for production in the Benguela upwelling area).

3. There is a need to test management decisions thoroughly. Too often management decisions are not followed up by data collection which allow tests of whether or not the objectives have been met.

4. EUROGOOS with it's data collection system is highly important since data will be collected at appropriate spatial and temporal scales for modelling of coastal processes. Measurement of biological variables is a key part of the system.

5. There is a need for strategic research on socio-economic models which take account of the variability of marine systems.

6. New types of management models that conserve the functions and processes of the system and in turn generate biological production data for target species have a wide potential for application.

7. The balance of research between restoration ecology and conservation of pristine habitats should be heavily weighted to conserving pristine habitats. It is important to note that the goal for restoration ecology is not full restoration to pristine conditions.

8. Risk assessment techniques, whilst fairly well developed, need to consider acceptable risk levels and how they can be used to test management decisions. A major failing of present monitoring programmes is that they do not take account of recent statistical developments such as new sampling designs and power analyses. It is strongly recommended that these new methods are applied across a wide range of monitoring programmes.

9. In relation to integrated coastal management a research priority is to strength the opportunities for research across disciplines, e.g. ecological/environmental economics and cross disciplinary work within biological sciences.

# 5. Abstracts of Plenary Keynote Talks

## 5.1 Opening Address: *Expectations to the Workshop* by Dr. Jean Boissonnas, DGXII - Marine Science and Technology, MAST

Questions relating to the marine environment and the exploitation of its resources have been tackled already in research programmes funded by the European Union, i.e. in FP IV (Framework Programme IV, 1994 - 1998), specific research programmes FAIR, MAST and Environment and Climate (ENV2C):

Topics covered by existing projects in Fisheries and Aquaculture (FAIR) are:
- the impact of environmental variation and of pollution on fisheries and aquaculture,
- the impact of fisheries and aquaculture on the ecosystem,
- the improvement of fishing gear, aquaculture techniques and fisheries management,
- there is some research on the improve of the biology of fishes for better results in aquaculture production.

No research on ecosystem management in view of stabilising the environment has been carried out so far.

Topics covered by existing projects in MAST and ENV2C relate mainly to two areas, namely Coastal Zone Ecosystem Research and Marine Biotechnology. They are:

- in coastal zone ecosystem research: carbon and nutrient cycling, pelagic productivity and human impact by pollution,
- in biotechnology: identification of new substances from marine invertebrates and micro-organisms.

Little research has been carried out on:
- direct effects of human intervention and socio-economic effects (although the calls covered these topics as well)
- the development of culturing techniques for marine invertebrates and micro-organisms of biotechnological interest to avoid over-exploitation of species by harvesting natural populations.

Questions which need to be addressed in the next decade in respect to marine biological resources are:
How can it be done?
What would be the consequences for the ecosystem?
What would be the associated social and economic consequences?
Is ecosystem variability predictable?
How can we avoid detrimental environmental and societal effects?

To answer these questions more knowledge is needed on:
- the functioning principles of ecosystems;
- the natural variability of ecosystems;
- the predictability of ecosystem variation;
- the inter-dependence of ecosystem conservation and socio-economic factors.

Research should aim at these questions while focusing on the need to preserve ecosystems as living environments for mankind. The research topics must thus be developed in the spirit of the existing national and international regulations on environmental protection.

It is clear, furthermore, that there is an urgent need to manage biological resources better in order to maintain, and possibly increase, the yield from the sea.

These aspects are reflected in the European Commission's proposal for the Fifth EU Framework Programme (FPV) on RTD Activities which includes four activities:

*First Activity:*
consists of 3 specific RTD Programmes (Specific Programme - SP):
SPI: Unlocking the resources of the living world and the ecosystem
SPII: Creating a user friendly information society
SPIII: Promoting competitive and sustainable growth.
*Second Activity:*
Confirming the international role of community research
*Third Activity*
Innovation and participation of SMEs
*Fourth Activity*
Improving human potential

Specific Programme I structure (Living resources and ecosystems):

| | |
|---|---|
| Key action 1: | Health and Food |
| Key action 2: | Control of viral and other infectious diseases |
| Key action 3: | The cell factory |
| Key action 4: | Management and quality of water |
| Key action 5: | Environment and health |
| Key action 6: | Integrated development of rural and coastal areas |

Support to:
- global change research
- research and development of generic technologies
- research infrastructures.

The goal of this workshop is, thus, to discuss new concepts for the management of marine biological resources and their utilisation by man, with a view to combine ecosystem conservation with resource utilisation. Recommendations from this workshop will be taken into consideration when formulating the specific research goals of the activities in FP V.

## 5.2 Abstract of a Keynote Talk entitled, *Food for an increasing population* by Professor Kåre Ringlund, Norwegian Agricultural University

### Introduction

The British economist Thomas Robert Malthus warned in 1797 that a global famine would occur unless measures were taken to reduce population growth. Since then both the World's population and food production have multiplied many times. Food production per capita has remained approximately the same. During the last 200 years, large areas of land have been developed for agricultural production, and during the last century the genetic resources of our main food-producing plants have been improved substantially and diversified. However, today there are more hungry people than ever before, despite food surpluses being a major problem in some regions.

An important question is whether, or for how long, increases in the agricultural food production will continue. There are also growing concerns about the sustainability of our present food production systems. The balance between population growth and food production is indeed as fragile today as it was when Malthus predicted a global famine.

As background for the main topic of this symposium I will give an overview of FAO's present statistics on population development, on food consumption and food composition, and on terrestrial food production as exemplified by cereal production.

### Population

There are presently about 5700 million human inhabitants on this planet. The population increases by between 85 and 90 million per year, which is 235 000 per day and almost 10 000 per hour. Future prognoses are made on the basis of estimates of when different countries will reach replacement level fertility and on life expectancy. Demographers agree that a reasonable estimate for the year 2050 is a total population of 9 - 10 milliards.

More and more people live in urban areas. The ratio of rural to urban population has decreased from 1.9 to 1.2 over the last 30 years. Fewer and fewer people are involved in food production or live near food-producing areas. Food availability, therefore, depends not only on food production but also increasingly on resources for transportation and distribution.

### Food consumption

The average global menu consists of 85% plant products and 15% animal products. About 1% is of marine origin. Over the last 30 years there has been a 10% increase in the average calorie intake per person per day. Populations in industrialised countries consume more than 20% above the mean, and with substantially more animal products, than the populations in developing countries. Some areas in developing countries are in a constant famine situation. More than 800 million people are undernourished, and additional millions are malnourished. Aspects of nutritional, sensoric and technological quality are also important in the evaluation of the future human diet.

### Plant production

Plant production, the conversion of solar energy to organic molecules, is based on the process of photosynthesis. The agricultural biomass production per unit area has been increased through improved tillage, use of fertiliser, irrigation, weed- and pest control. The mechanisation of agriculture has influenced production by positive and negative effects on tillage, by more intensive exploitation of the growing seasons, by improvements in harvest and storage technology etc.

Important gains in the food production have been achieved through genetic improvement of our food crops. Many crops have been changed to yield more of the total biomass as a harvestable product, or to give more desirable products for human consumption. Examples are more grain and less straw in cereals, more potatoes, more fruits and berries, and changes in the fatty acid composition of rape seed.

About 50% of the energy and 40% of the protein in the human diet is provided by cereals as a primary food source. In addition, cereals are a major component of the feed for domestic animals.

Cereal production has almost doubled since 1960. Over the past 15 years there has been a slight decline in the production area, leaving the productivity per unit area as the only factor for increased production. Wheat production statistics provided by CIMMYT (The International Maize and Wheat Research Centre) shows that the production increases were 2.5 to 3.0% from 1950 to 1985. For the last decade the production increase was only 0.9%.

The world average cereal yield is only 2.6 tons per hectare, whereas farmers in some areas harvest 8 to 12 tons. The differences in yield are mainly due to the availability of water, but there are still possibilities for global yield increases through genetic and technological improvements.

Only 50% of the cereal production is typical food grains, wheat and rice, but an important portion of the coarse grains, maize, sorghum, barley, oats, millet etc. are also consumed directly by humans.

An indicator for food security on the global level is the amount of grain in storage. A stock of 15% of consumption has been regarded as a critical minimum. This is based on the stocks during the «oil crisis» in 1973 when world wheat prices tripled. Over the last two years the stocks have been below the 1973-level with only slight influences on world prices.

**Animal production**

Some animals, in particular poultry and pigs, feed on plant products that can be used directly as human food. Conversion of cereals to meat is a costly process, and the cereal requirement for a diet based on 25% meat is about 4 times that of a pure plant diet. However, the ruminants feed on plant products that cannot be used for direct human consumption. Meat and milk products from these animals supplement the human "plant" diet without competing for the same basic photosynthetic product.

Increased animal production has been brought about through genetic improvement of the animals in their efficiency to convert plant products to meat, milk, eggs etc., and through improved production technology.

**Conclusions**

The world population will grow to 9-10 milliards within the next 50 years. This increase will require an additional cereal production of 1 200 million tons per year, and an equal increase in other food products to maintain the present diet.

The conference on Food Security arranged by FAO in November last year, agreed to reduce the number of undernourished people by 50% during the next 20 years. By 2050 hunger should be eradicated, which means an additional requirement for 300-400 million tons of cereals per year. The change towards a more "meaty" diet as societies become more affluent, requires further increases in basic plant production. A realistic target is a doubling of the food production over the next 50 years. Since there are limited prospects for increased production area, the increase must be based on an annual increased production efficiency of 2%. This is twice the level of the present yield increase of wheat.

A growing population also demands more land for housing, roads and recreational areas. Most urban areas are expanding on the best agricultural land. All alternatives to the present food production must be exploited, and in this context the expansion of marine food production potentials is very appropriate.

# *Food for a Growing Population*

by

Kåre Ringlund

Agricultural University of Norway

# *Outline*

- Human population, changes and projections
- Food consumption and food composition
- Terrestrial production exemplified by cereal production
- Conclusions

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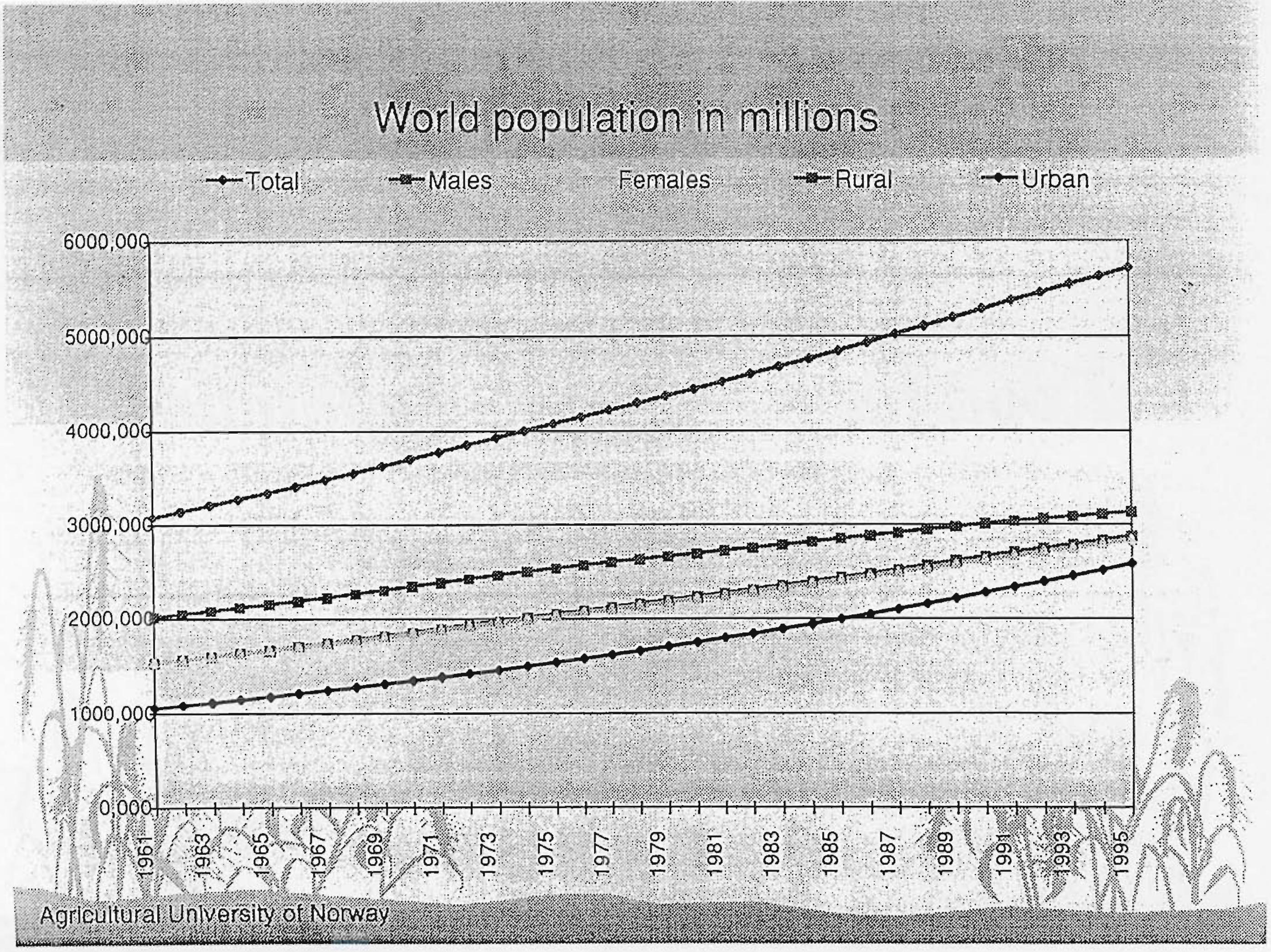
World population in millions
Total
Males
Females
Rural
Urban
6000,000
5000,000
4000,000
3000,000
2000,000
1000,000
0,000
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
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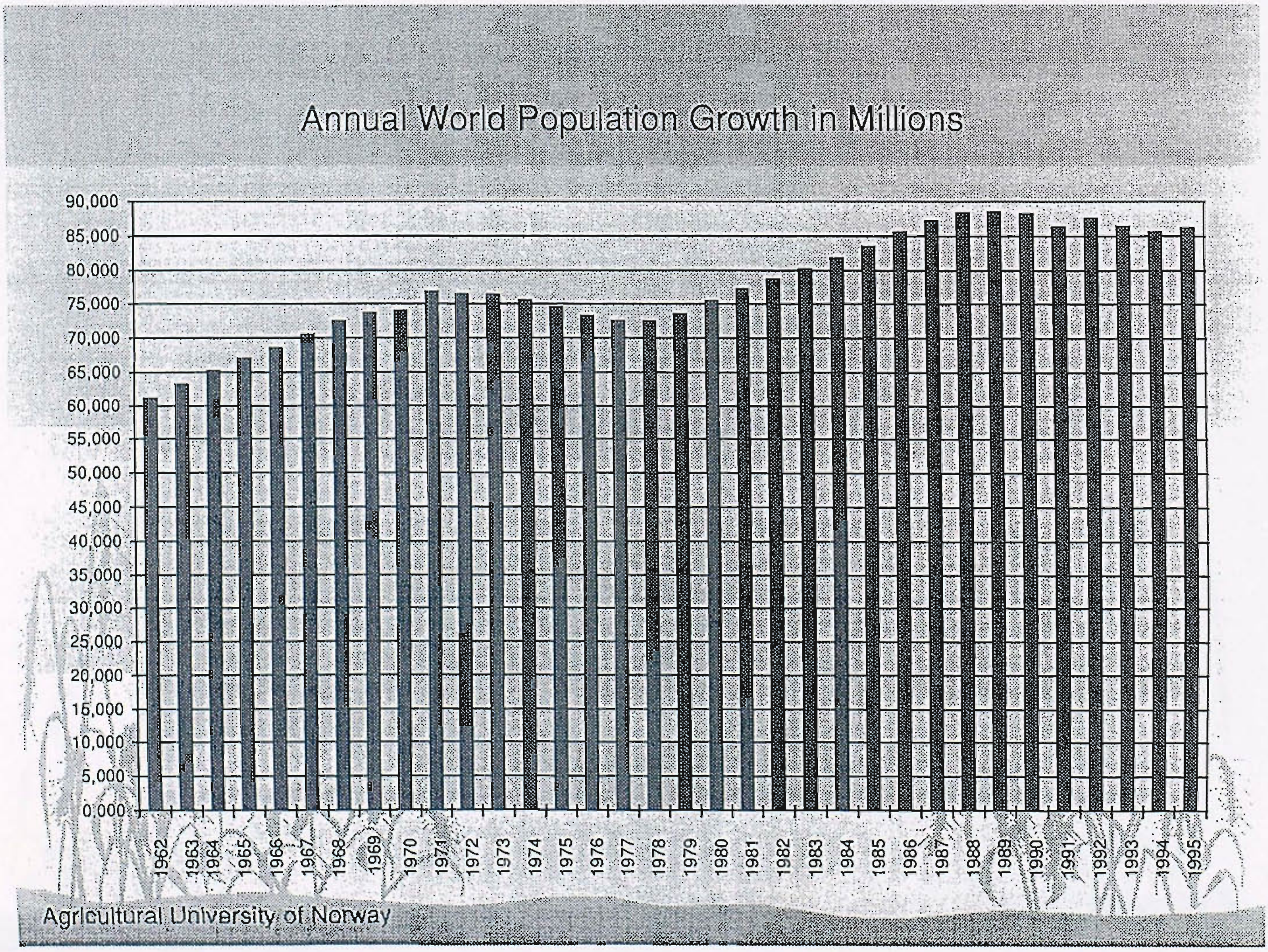
Annual World Population Growth in Millions
90,000
85,000
80,000
75,000
70,000
65,000
60,000
55,000
50,000
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0,000
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
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1977
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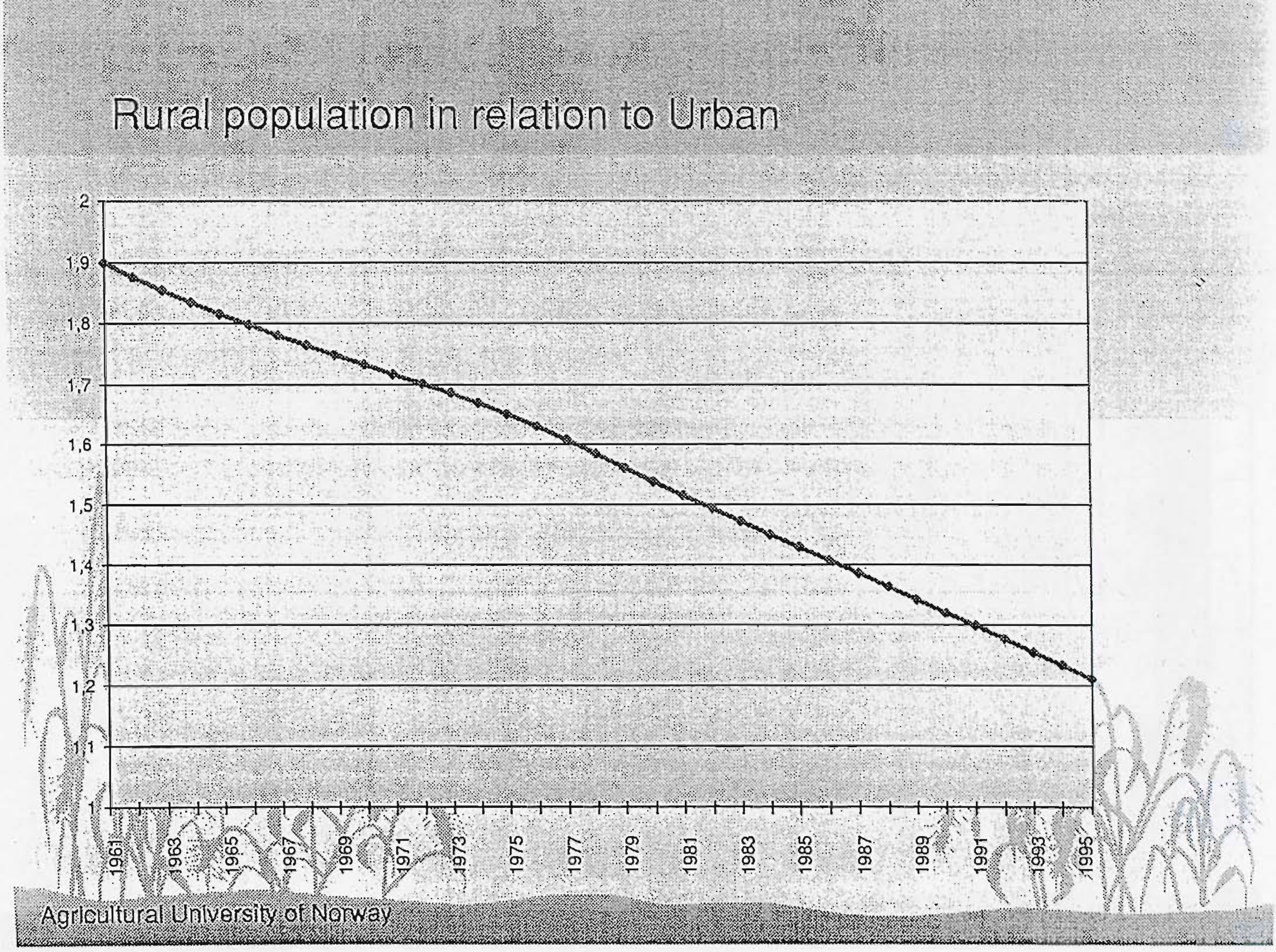
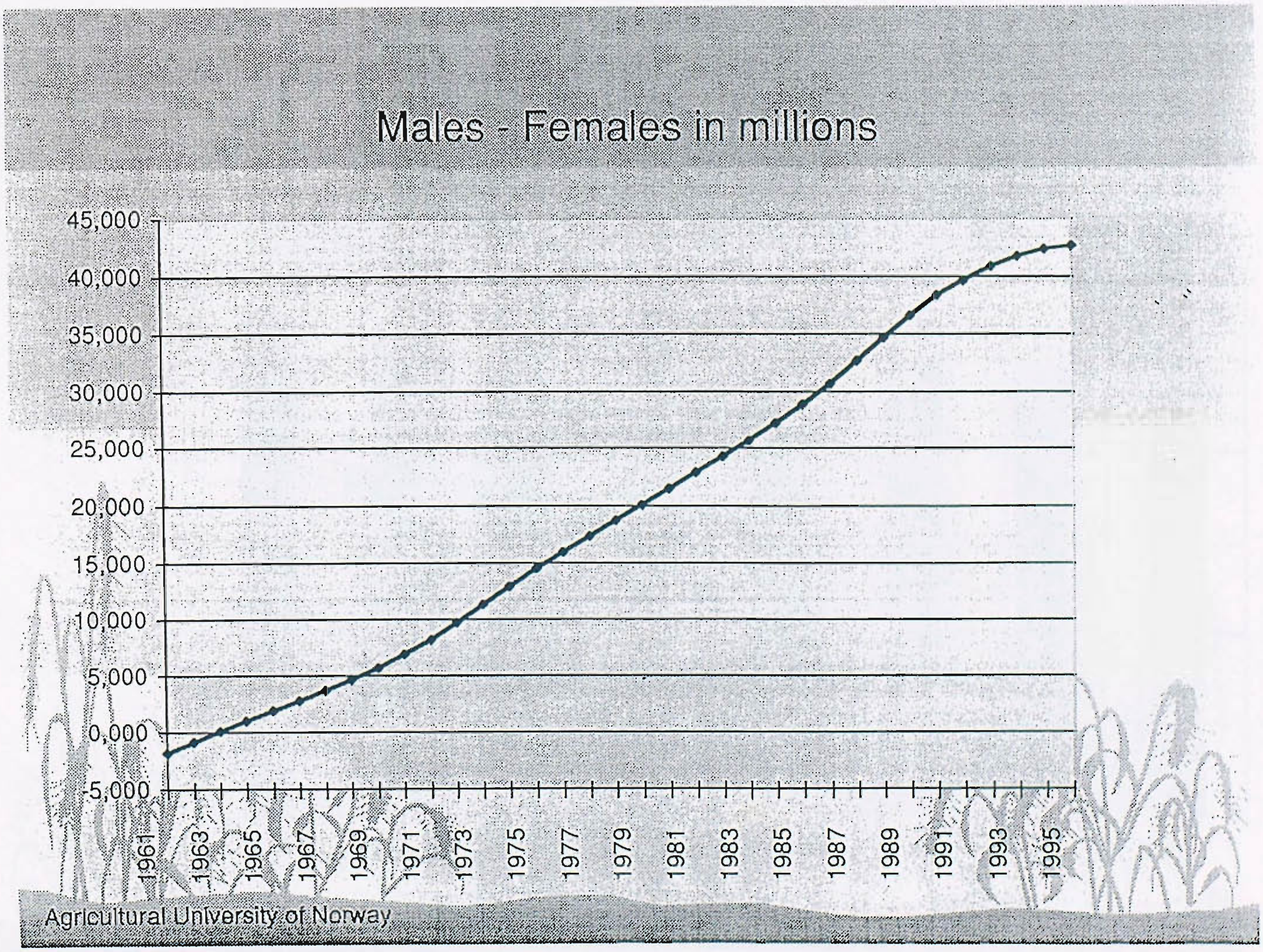
1995
Agricultural University of Norway



Rural population in relation to Urban
2
1,9
1,8
1,7
1,6
1,5
1,4
1,3
1,2
1,1
1
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
Agricultural University of Norway

Males - Females in millions
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0,000
-5,000
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
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# *Food and food composition*

- Calorie requirement
- Protein
- Protein composition
- Fat and fatty acid composition
- Minerals and vitamins

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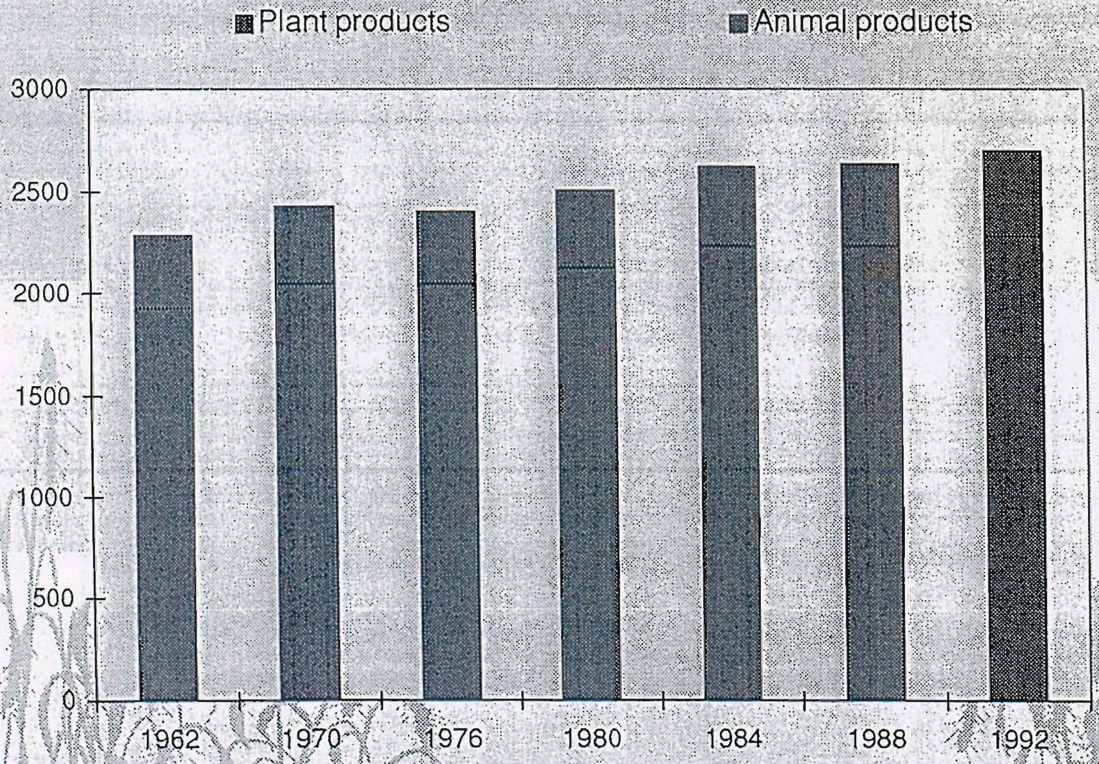
## Calorie intake per person per day

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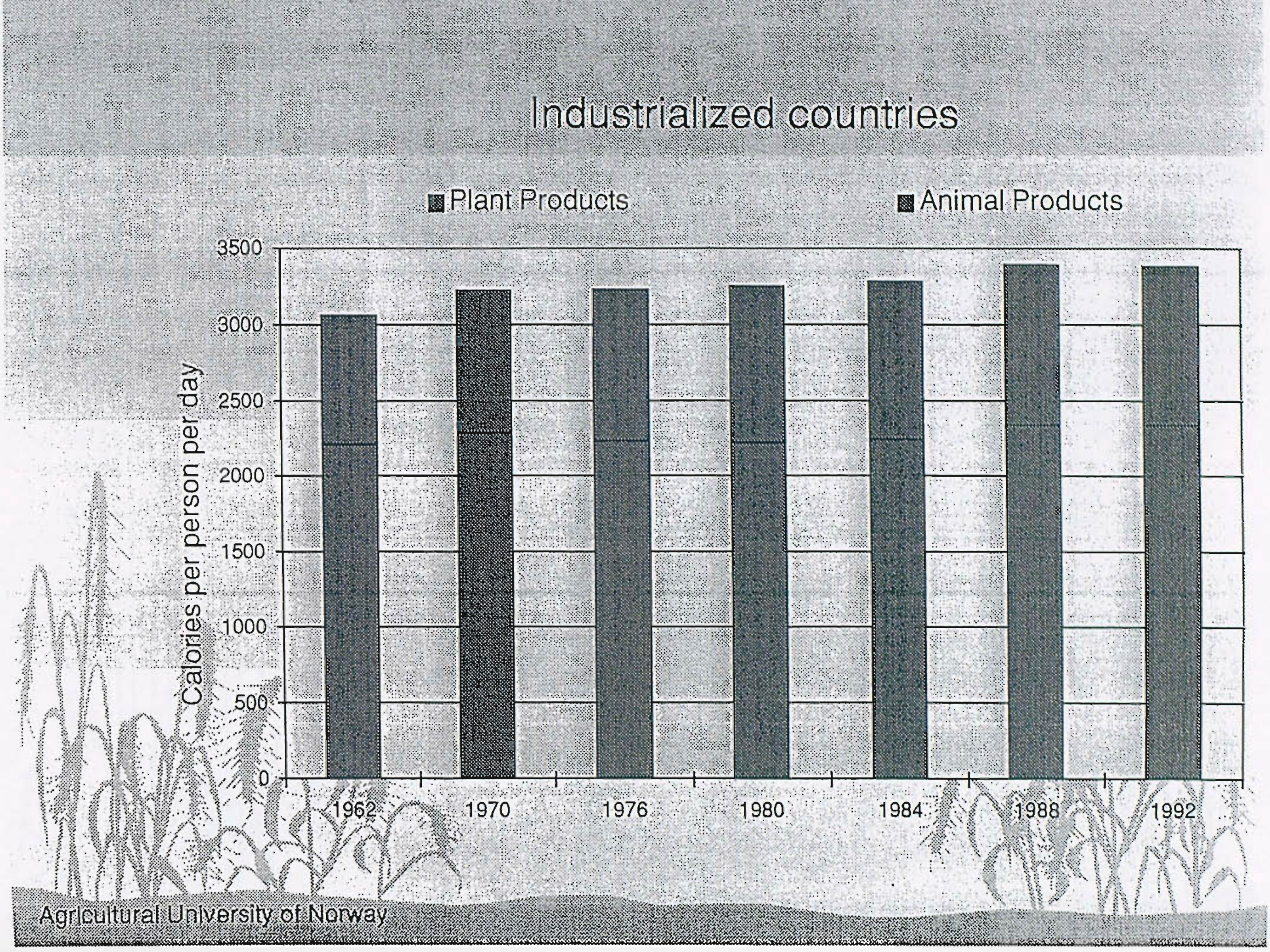
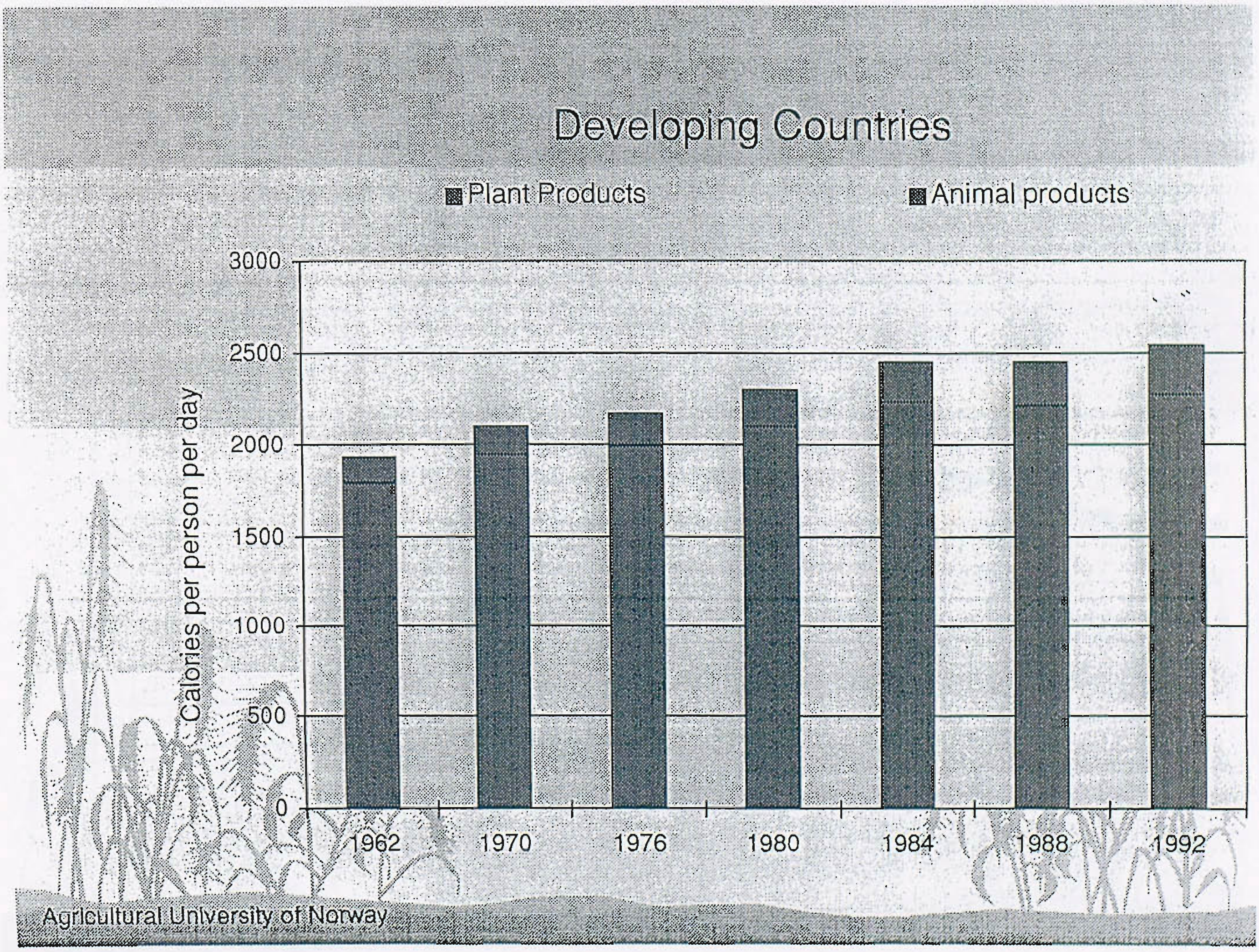


Industrialized countries
Plant Products
Animal Products
Calories per person per day
3500
3000
2500
2000
1500
1000
500
0
1962
1970
1976
1980
1984
1988
1992
Agricultural University of Norway

Developing Countries
Plant Products
Animal products
Calories per person per day
3000
2500
2000
1500
1000
500
0
1962
1970
1976
1980
1984
1988
1992
Agricultural University of Norway

# *Plant production*

- Production area
- Water
- Fertiliser
- Genetic improvements
- Pesticides
- Mechanization
- Importance of cereals

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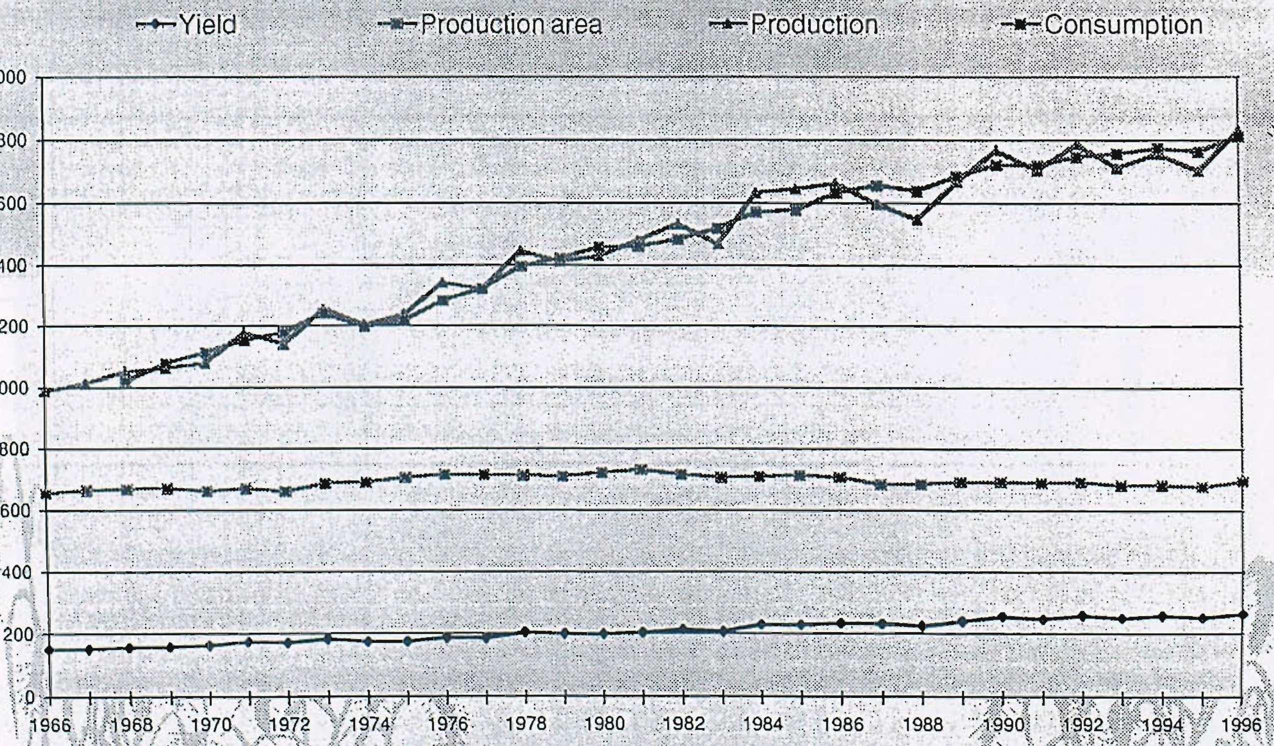
## Cereal production and consumption

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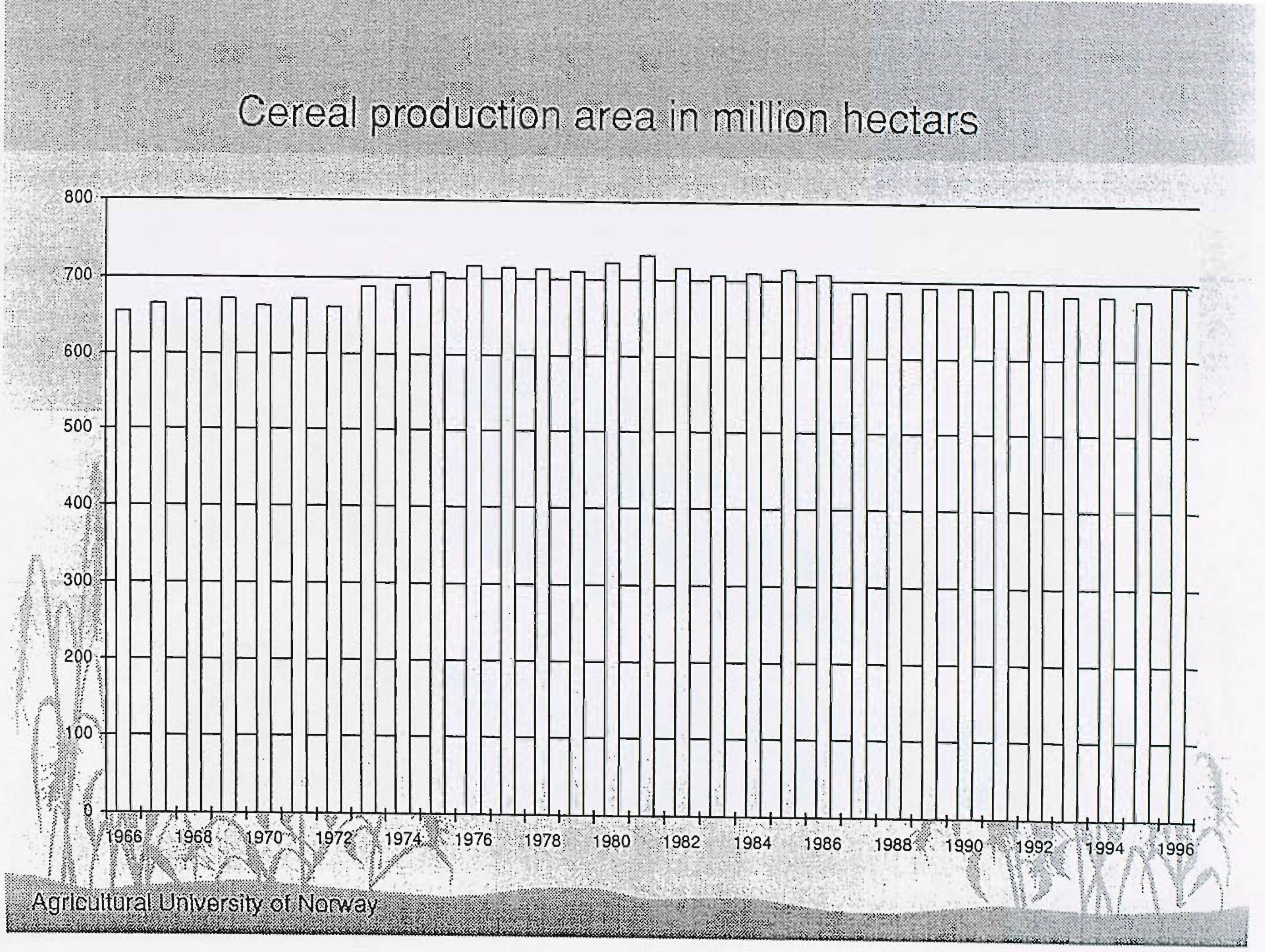
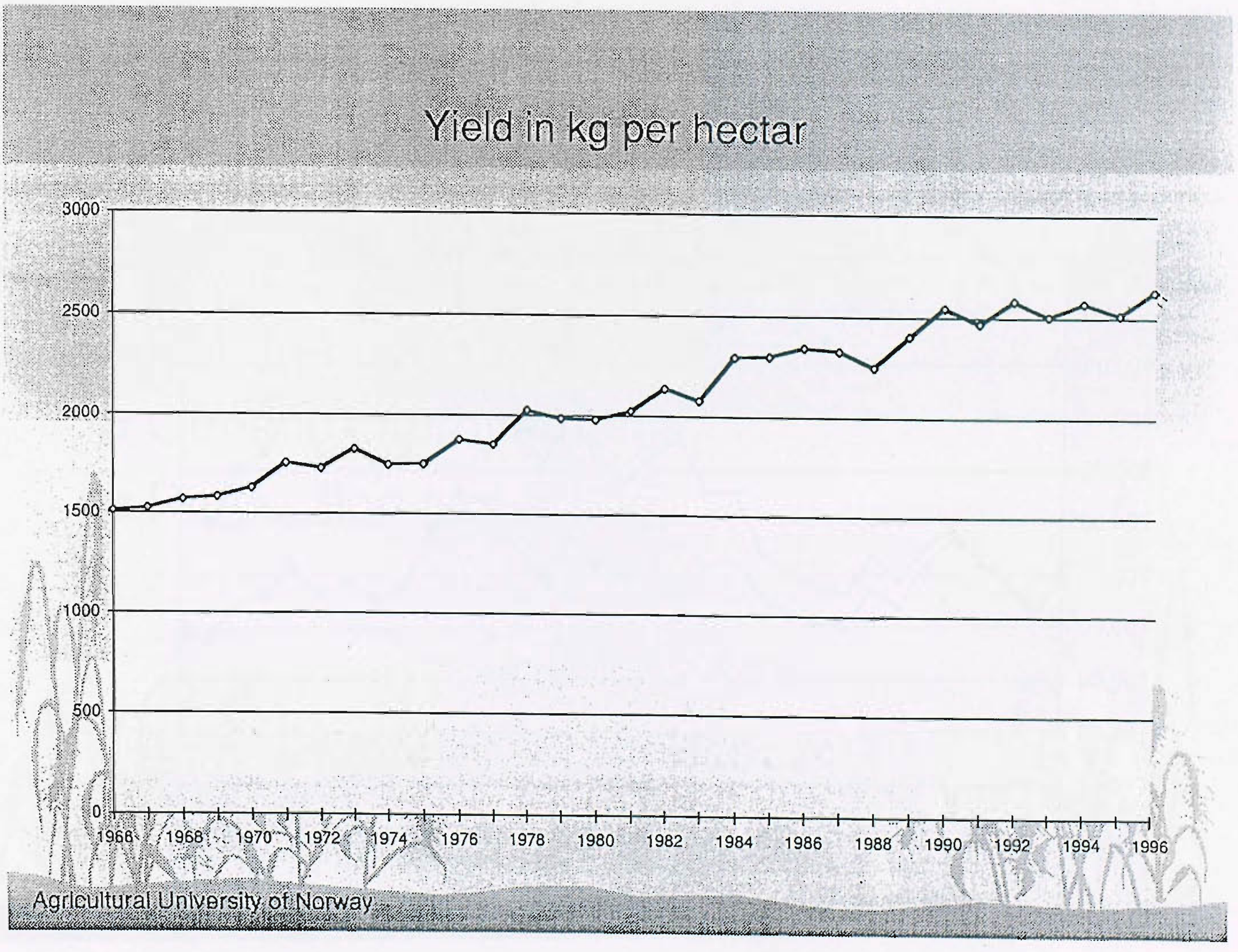
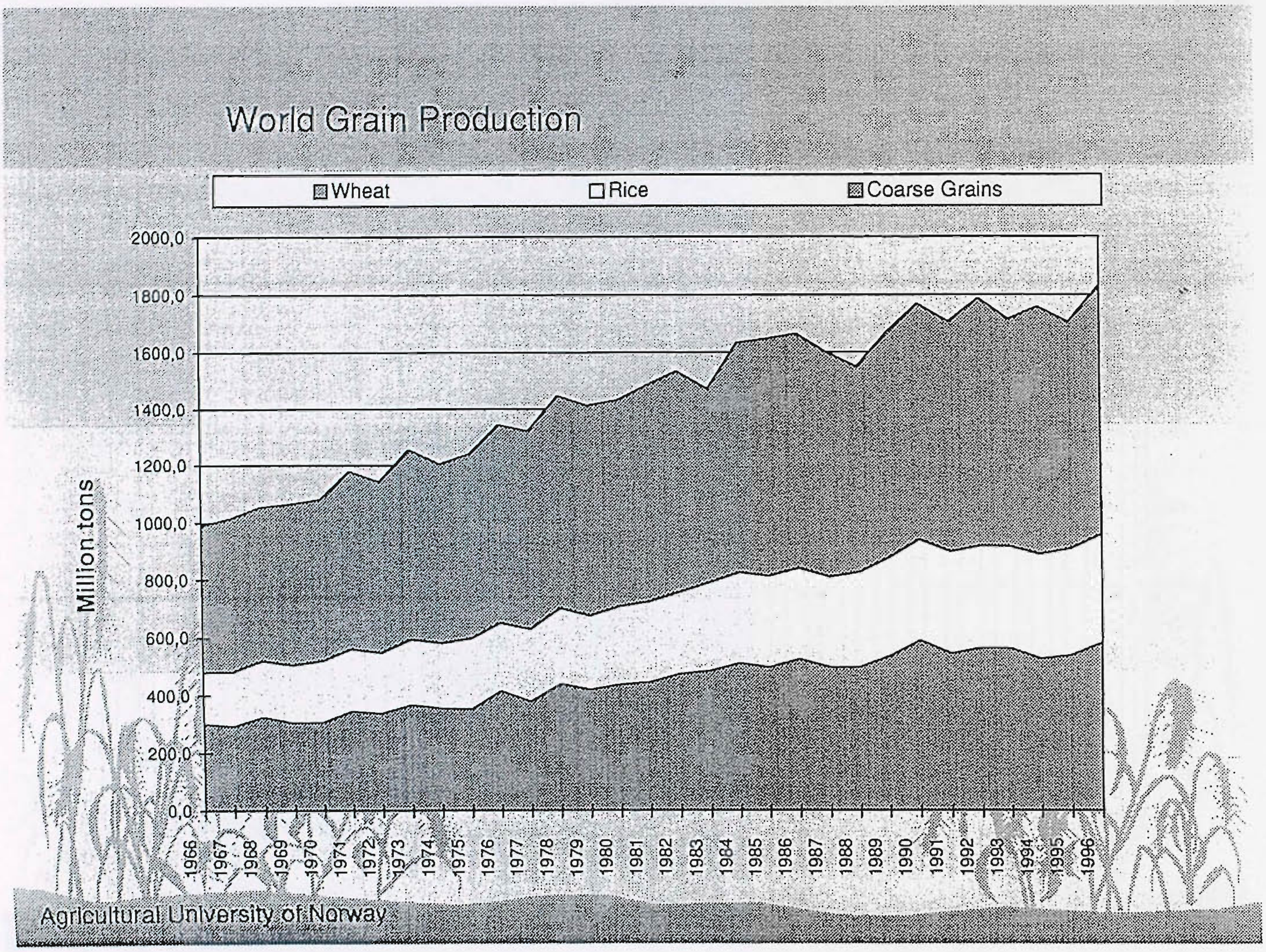
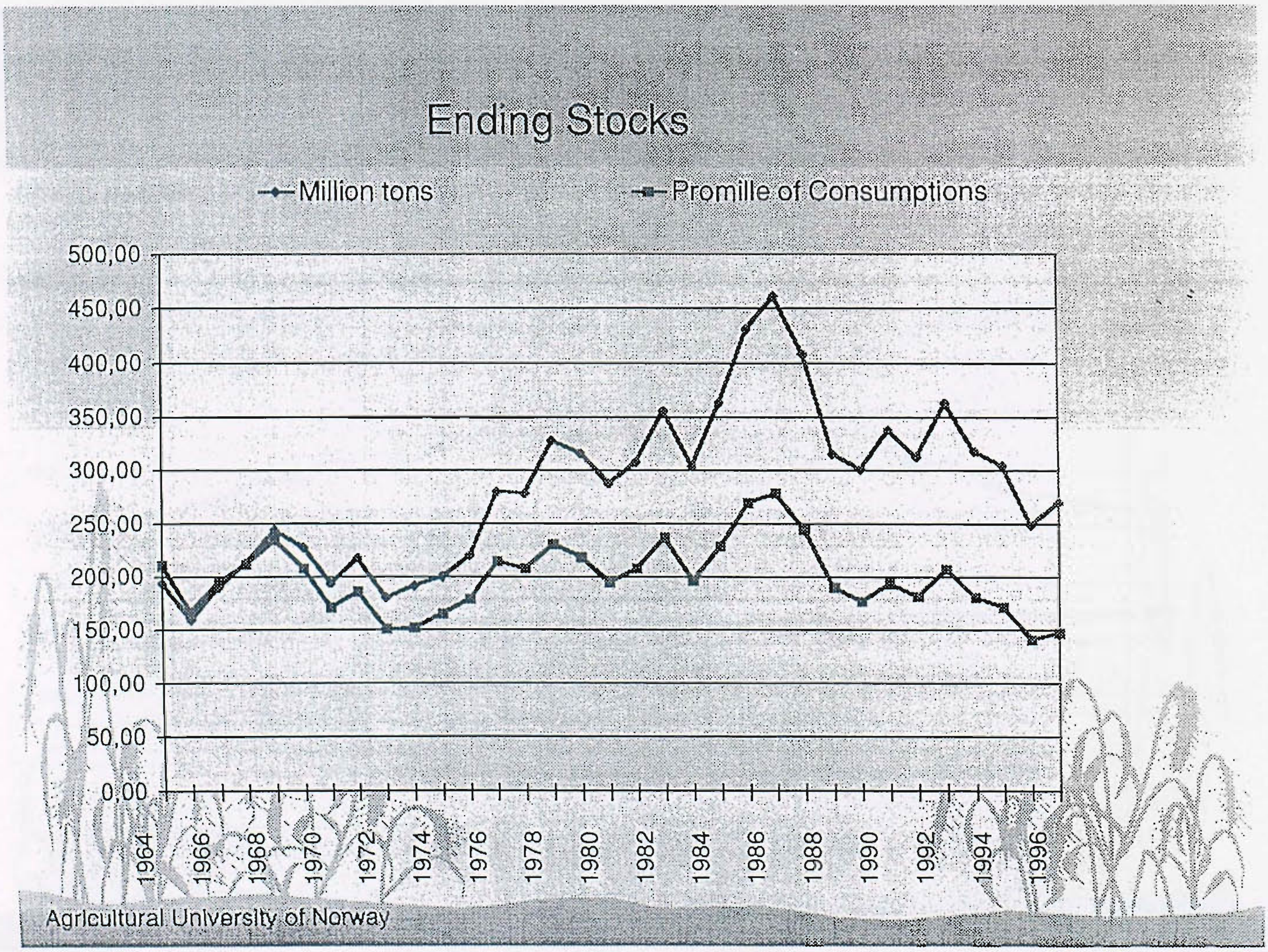


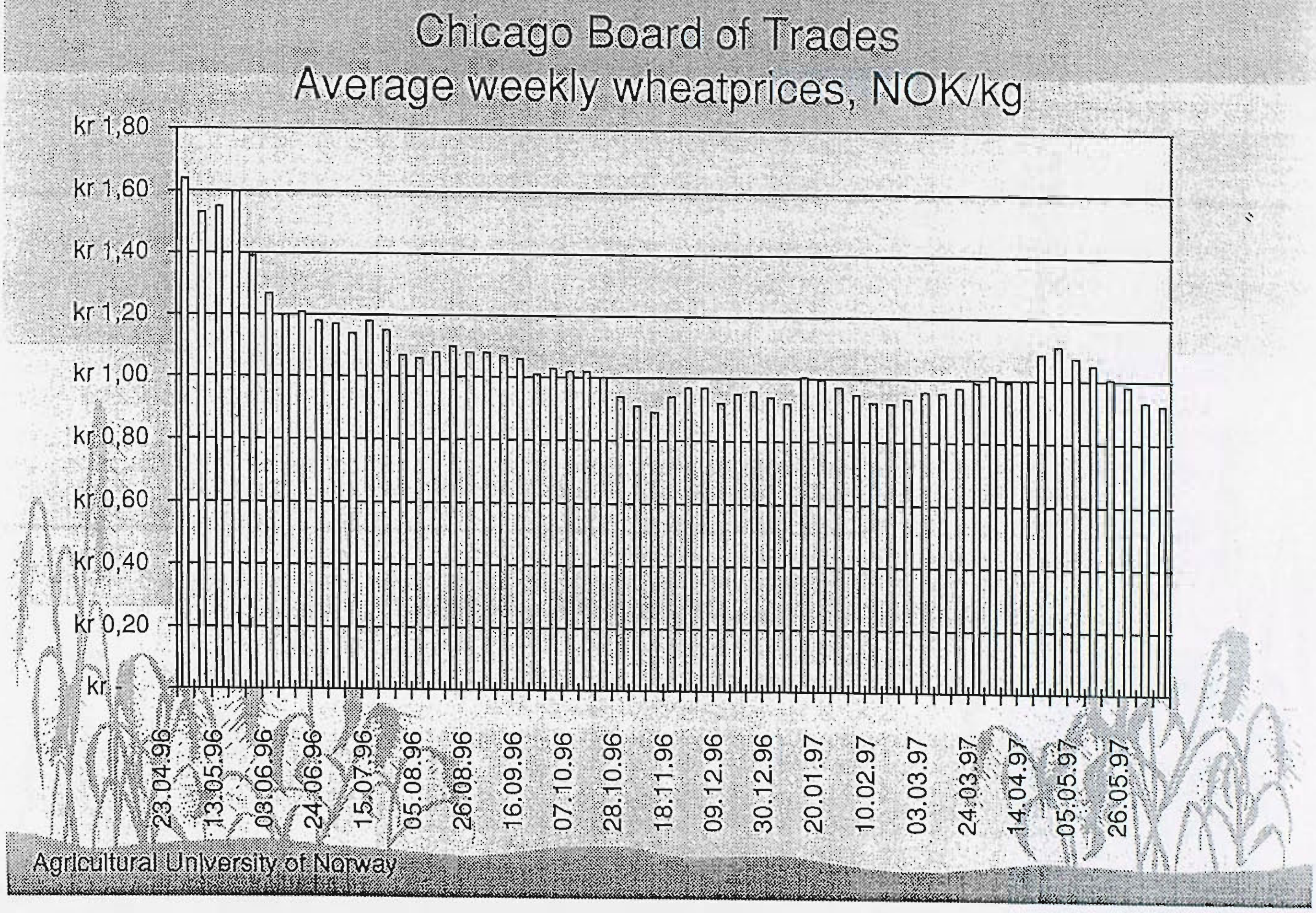
Cereal production area in million hectars
800
700
600
500
400
300
200
100
0
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
Agricultural University of Norway

Yield in kg per hectar
3000
2500
2000
1500
1000
500
0
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
Agricultural University of Norway


World Grain Production
Wheat
Rice
Coarse Grains
Million tons
2000,0
1800,0
1600,0
1400,0
1200,0
1000,0
800,0
600,0
400,0
200,0
0,0
1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996
Agricultural University of Norway


Ending Stocks
Million tons
Promille of Consumptions
500,00
450,00
400,00
350,00
300,00
250,00
200,00
150,00
100,00
50,00
0,00
1964 1966 1968 1970 1972 1974 1976 1978 1980 1982 1984 1986 1988 1990 1992 1994 1996
Agricultural University of Norway




# *Animal production*

- Competitors for human food
- Ruffage converters, ruminants
- Genetic improvements
- Production technology

Agricultural University of Norway

# Conclusions

- The world population will grow to 9 - 10 milliards within the next 50 years
- 10 - 15 per cent of the population is undernurished
- Increased terrestrial food production depends on yield increases alone
- It is very appropriate to explore marine food production capasities

## 5.3 Abstract of a Keynote Talk entitled, *Opportunities for increasing biological production* by Professor Yngvar Olsen, University of Trondheim

A surprisingly low fraction of human food originates from the ocean although the biological production is of same magnitude as in the terrestrial biosphere. Agriculture, developed through a 9000 year tradition, explains this difference. The human marine tradition is to harvest wild stocks, and more recently, as the harvesting technology has improved, also to manage these stocks. Aquaculture is developing, but only countries in Asia have historical traditions in this field. We have apparently reached the maximum level of global wild catches. With the questions of future global supply of food in mind, it is, according to my opinion, the obligation of science to question if the sustainable marine production and harvest can be increased in an environmentally acceptable way; the potential consequences of future food shortage and malnutrition are simply too threatening. Successful production of single-cell protein, genetic engineering in agriculture, reclamation of new agricultural land in Africa and South America, new ways of saving water supply for agriculture, or ultimately, reduced growth rate of the human population, are among the alternative or complementary approaches.

There are presently more questions than answers regarding the possibility of increasing the production of sea food from the ocean, but the challenge has at least two strategic blocks:

- Efficient fishery management and optimal harvesting of natural stocks.
- Development of diverse and comprehensive activities in extensive mariculture.

Both types of efforts have the ultimate primary need for more fundamental information of the marine system, which I will emphasise as the main challenge now. A more holistic approach in fishery management, including a global management strategy, will probably be the most rapid mean to enhance natural catches. These questions are already on the political agenda, and will not be treated specifically.

Extensive mariculture, defined as partly-controlled production using sunlight as source of energy (i.e. no addition of feed), has a short history in the western world. Such cultivation may involve diverse measures, ranging from, for example, traditional mussel production to the more sophisticated manipulation of entire natural marine communities. The efforts in Europe should concentrate on developing the present activity in extensive mariculture.

Extensive mariculture which is economically feasible must most likely be based on some degree of control with both species and nutrient supply, but nature demonstrates that food web structure is more important for animal production than the supply rate of nutrients. Our current practise of nutrient management is obviously not sustainable, and a general strategy that could be adopted in mariculture may be to utilise suitable anthropogenic sources of nutrients. This will help to bring nutrient resources under control and back into the biological cycle resulting in better water quality in the coastal zone.

It is important to emphasise that food production will necessarily require a clean environment free of toxins. A main immediate challenge in Europe is therefore a major change in attitude regarding the way we use the coastal zone as recipient for toxic substances. A change in practice will affect all sectors of the community, and it cannot be implemented unless all sectors have the common understanding of the future potential of the sea in food production.

# Workshop - Ocean Harvest 97

New concepts to increase the sustainable use of marine biological resources

Can we increase the harvest?

What are the opportunities and the constraints?

# *Opportunities for increasing biological production*

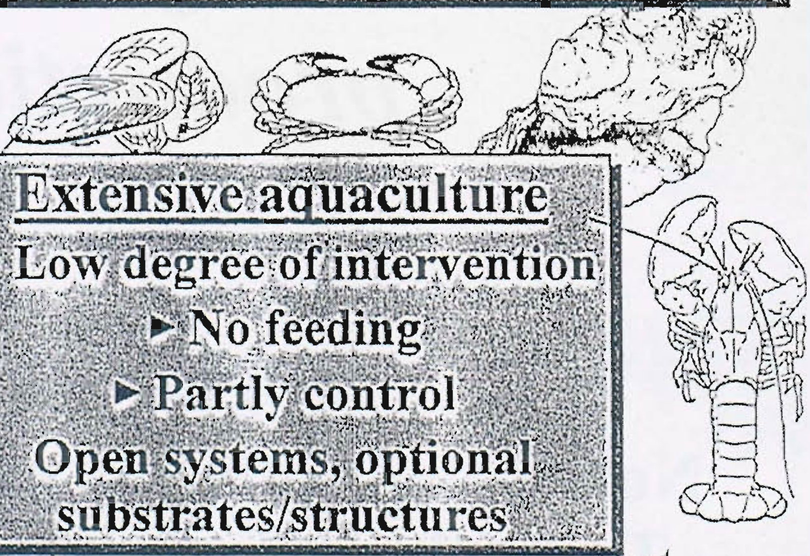
Yngvar Olsen

Norwegian University of Science and Technology, Trondhjem Biological Station, Bynesveien 46, N-7018 Trondheim, Norway

# MARINE BIOLOGICAL RESOURCES - VISION 2050

- ✓ We will produce and harvest far more food and raw material from the ocean in the future
- ✓ The environmental impact of further developments in mariculture will be lower than that of developments in land based production

## EXTENSIVE AQUACULTURE - FOR FILLING THE GAP BETWEEN FISHERIES AND TRADITIONAL INTENSIVE AQUACULTURE



**Classical aquaculture**

- Strong intervention
- Food addition
- High degree of production control

Cages, ponds, land based farms

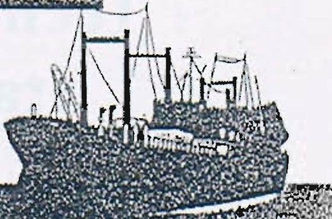
**Extensive aquaculture**

- Low degree of intervention
- No feeding
- Partly control

Open systems, optional substrates/structures

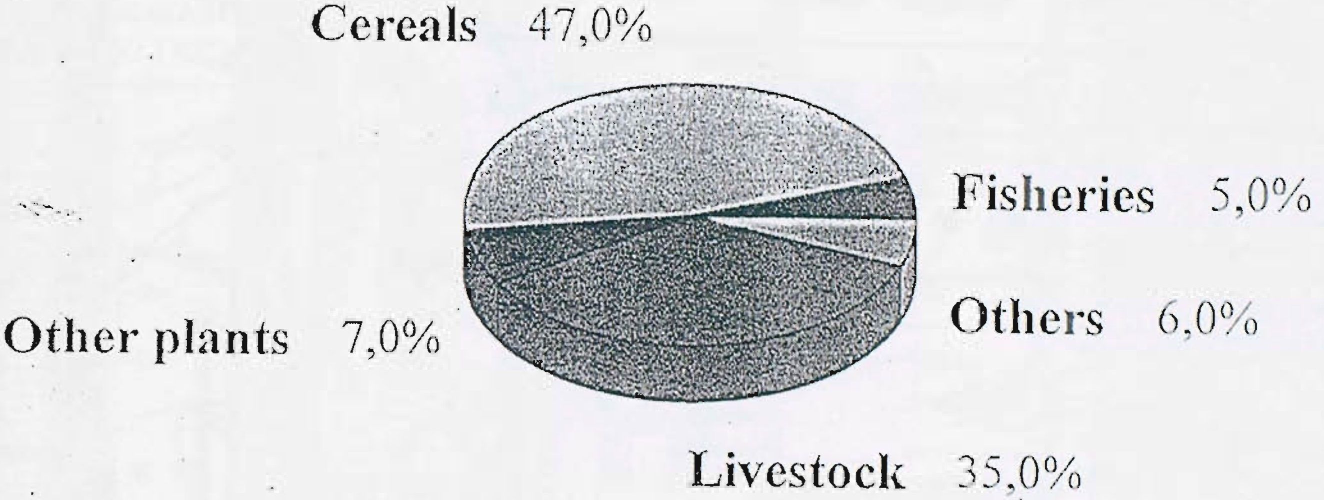
- Marine feed
- Technology

- Nutrients
- Sun energy



Fisheries

## HUMAN PROTEIN CONSUMPTION
(FAO statistics, 1991)

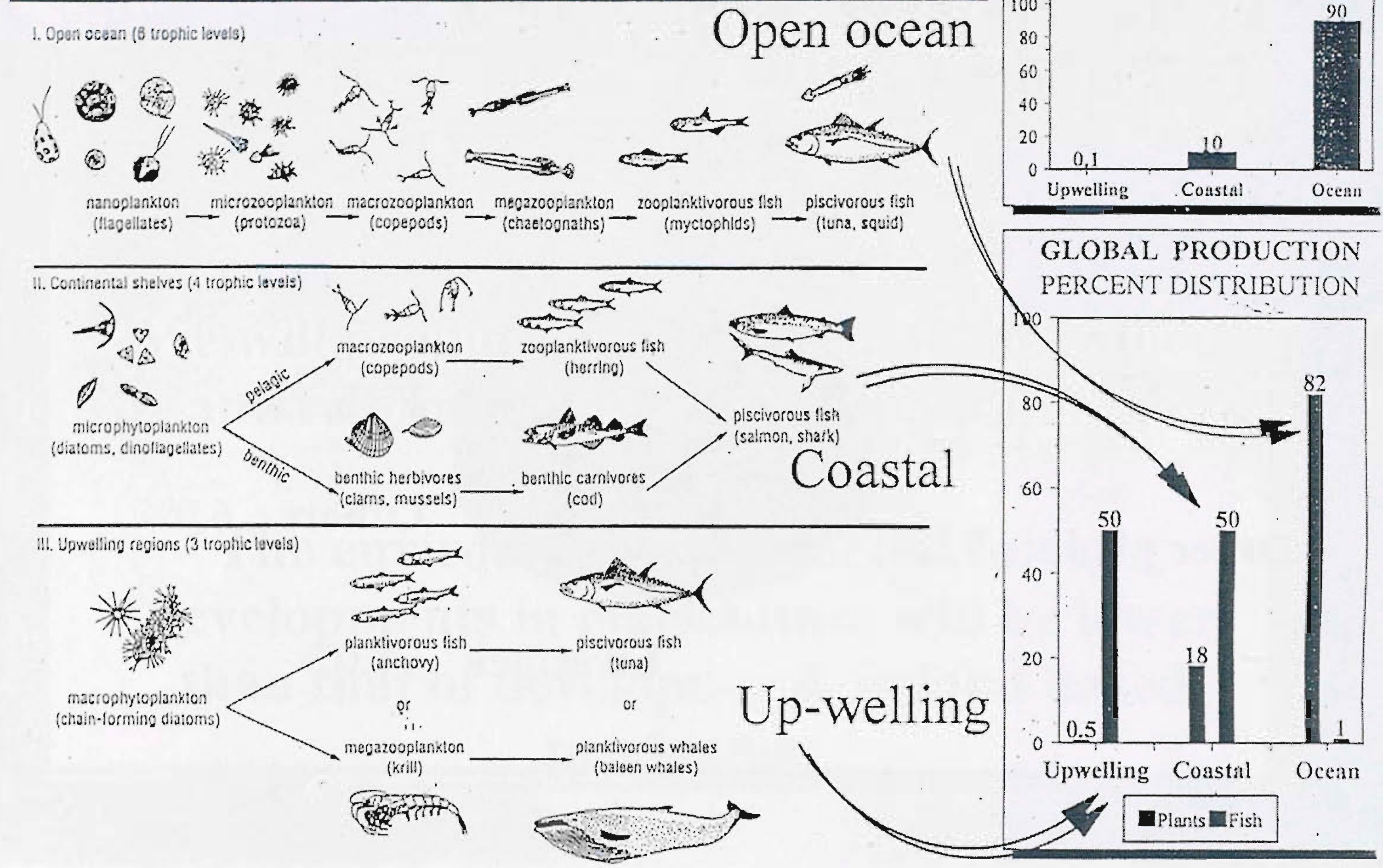


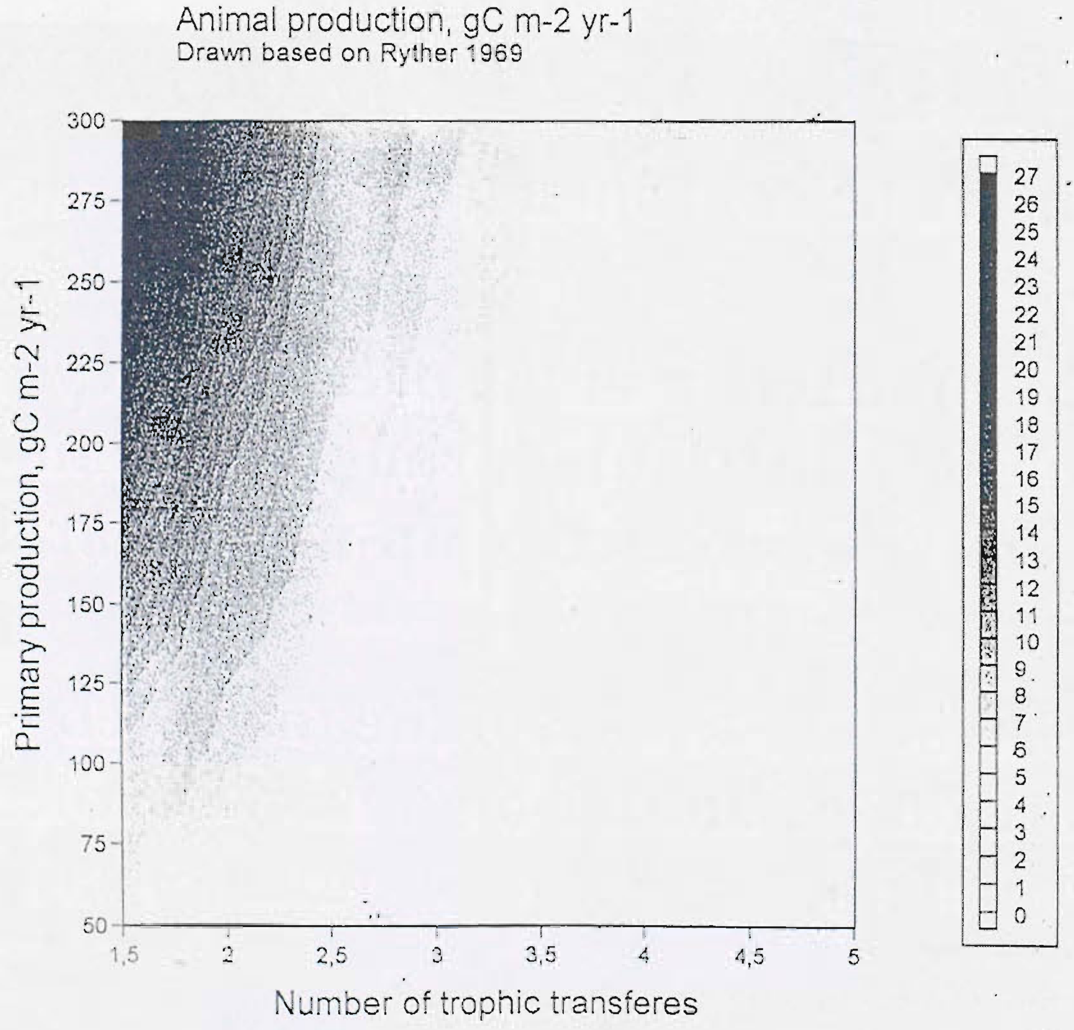

## *GLOBAL MARINE PRODUCTION -*

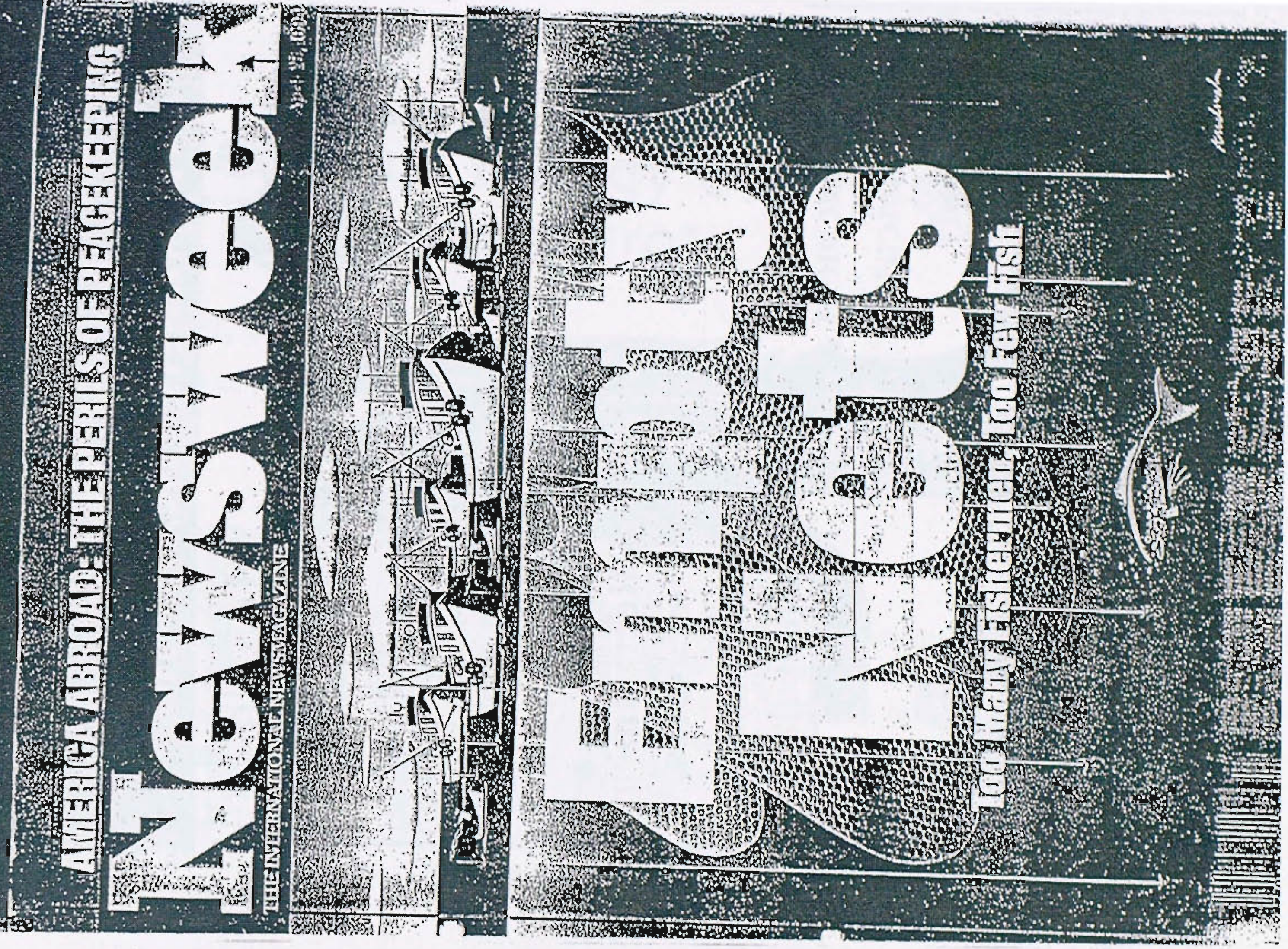
## What can we learn from natures laboratory?

- ✓ The production in the ocean is very unevenly distributed; ranging ocean "desserts" to productive up-welling areas
- ✓ The structure/length of the food web is more important for high harvestable production than the rate of nutrient supply

# Food web structure and production





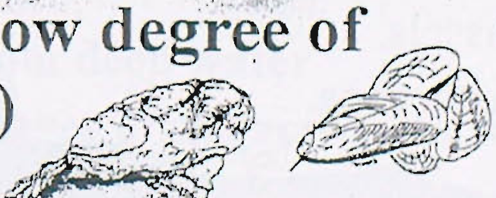

## *METHODS TO ENHANCE PRODUCTION AND HARVESTING OF SEAFOOD*

**Ecosystem based management of fish stocks**

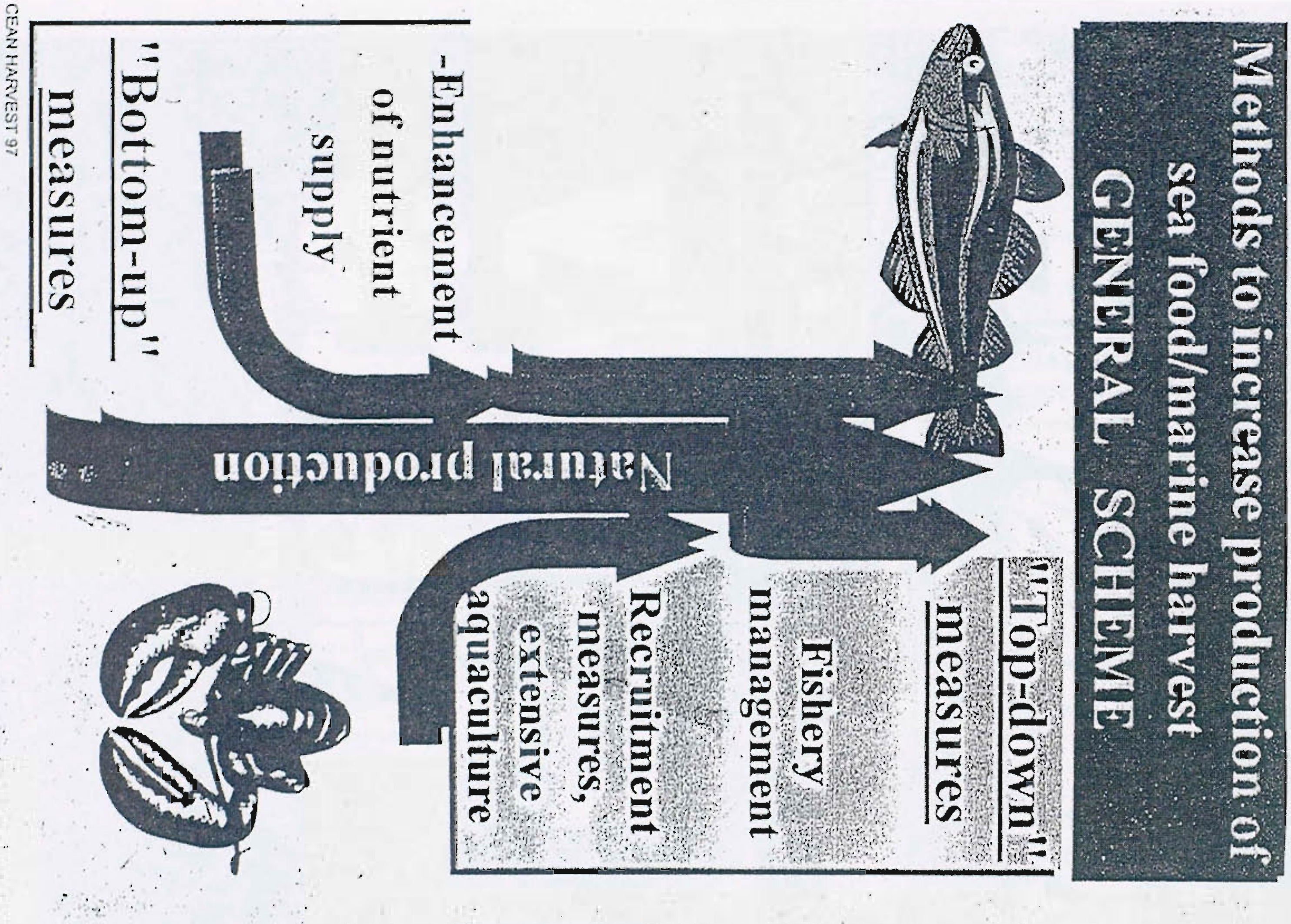
- ✓ Avoid overfishing of important stocks
- ✓ Sustainable production at optimum level
- ✓ National priority

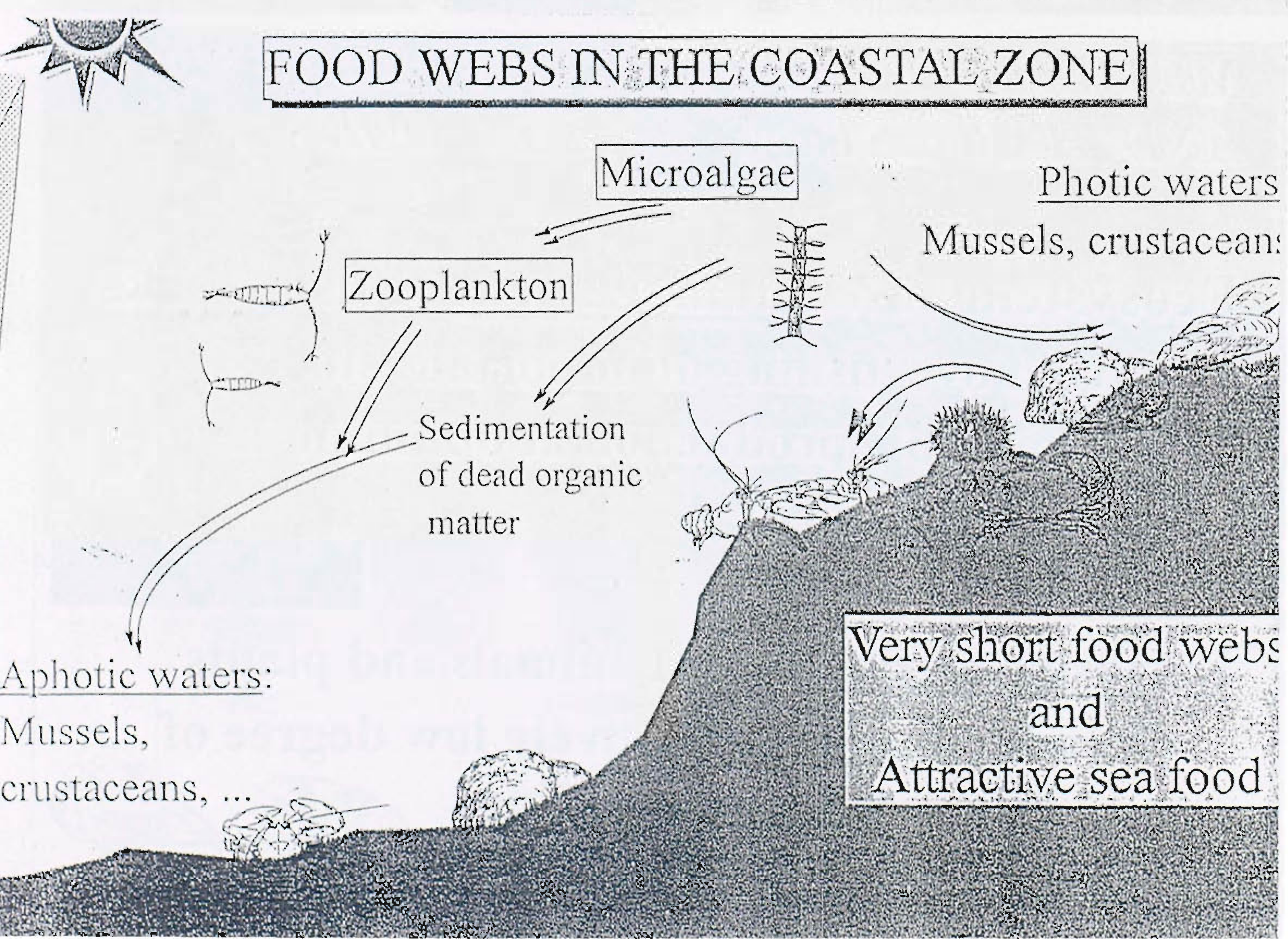
**Extensive mariculture of animals and plants**

- ✓ Production with relatively low degree of intervention (no feeding)



CEAN HARVEST 97



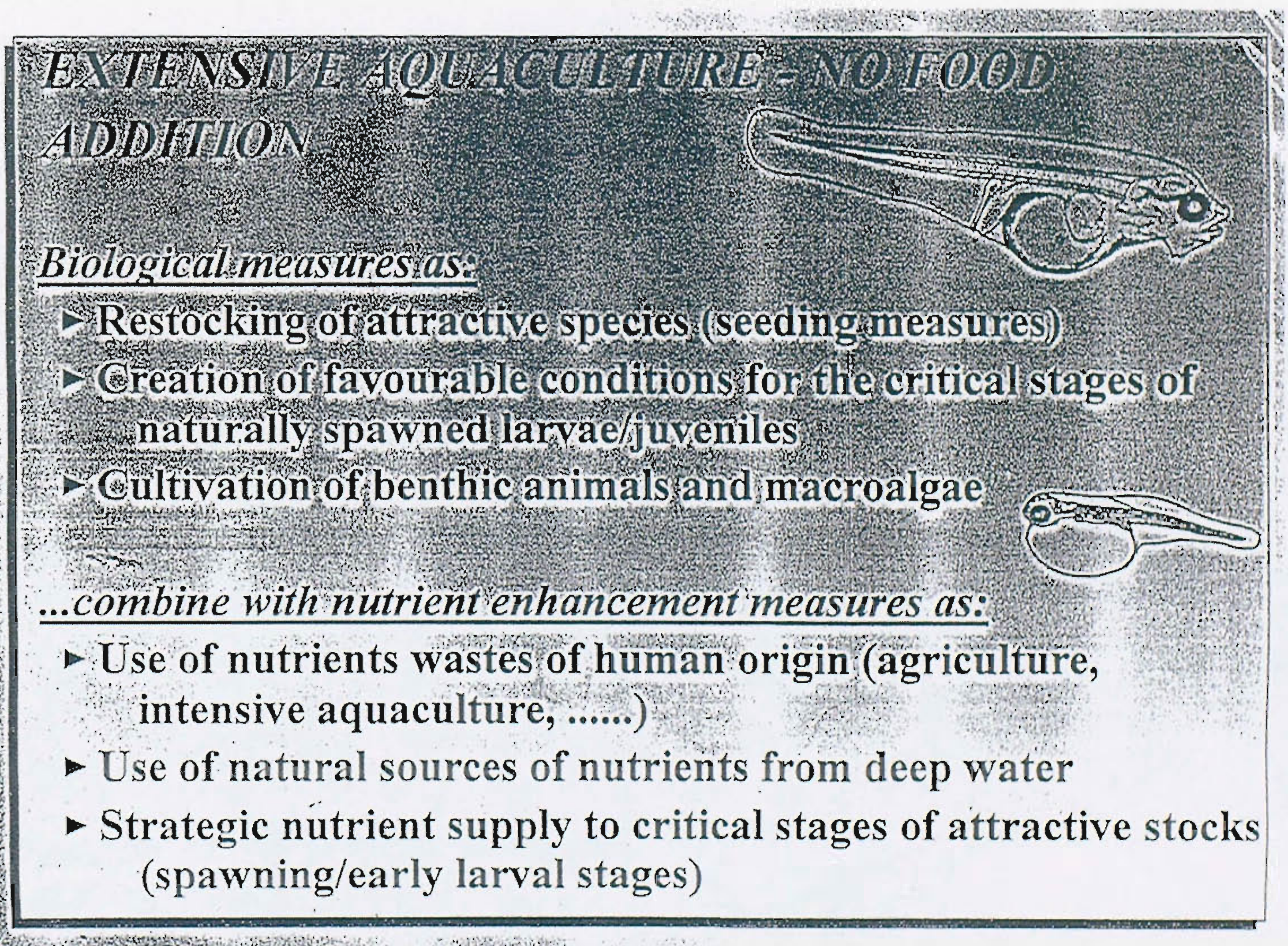
# Ocean Thermal Energy Conversion (OTEC) and OTEC Aquaculture*

*Arlo W. Fast, Ph.D.*

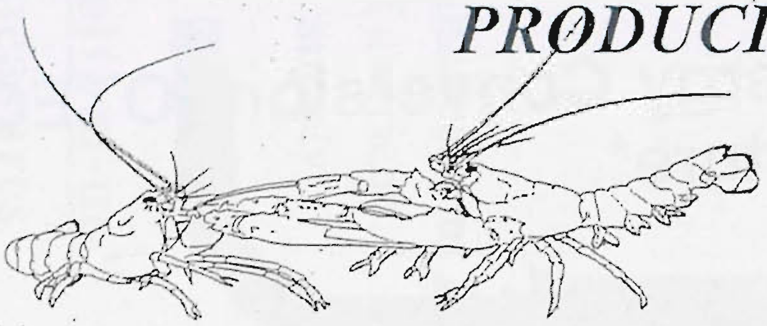
Hawaii Institute of Marine Biology, University of Hawaii at Manoa, P.O. Box 1346, Kaneohe, I
96744

*Hawaii Institute of Marine Biology Contribution No. 856.

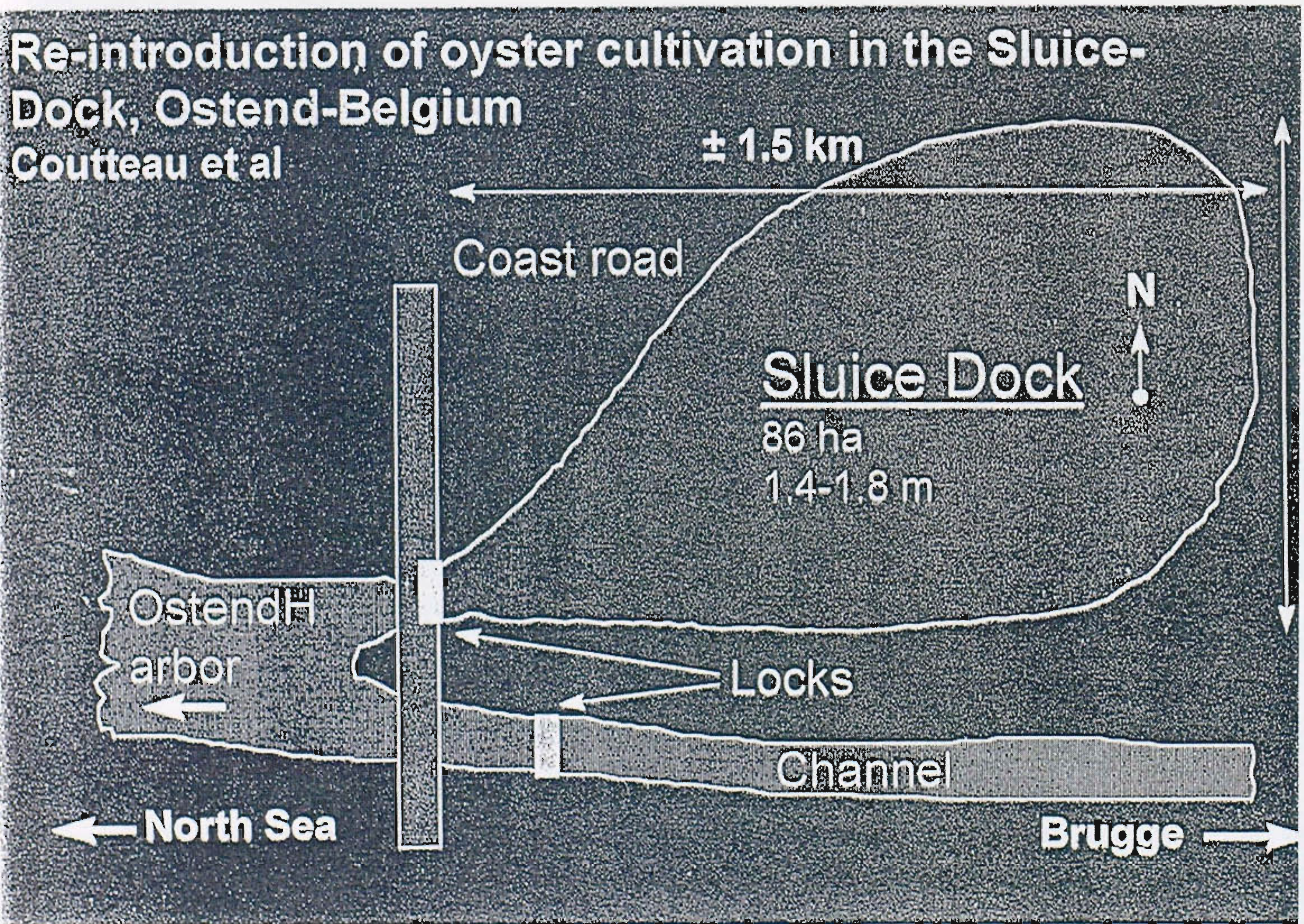
ABSTRACT: Ocean thermal energy conversion (OTEC) is a process whereby mechanical an ergy is produced based on temperature differences between the surface and deep waters of the systems are of three types: closed-cycle where two surface-type heat exchangers are used to e culating working fluid, such as ammonia or freon; open-cycle where the warm water itself becom fluid through flash evaporation without recirculation; or hybrid-cycle systems where a closed-c combined with an open-cycle system for the co-production of fresh water. The OTEC princ described in 1881 by the French physicist D'Arsonval, and was later demonstrated by his st during the 1930s in Cuba. Considerable interest developed in OTEC during the 1970s and ear lowing the energy crisis of 1973 ...



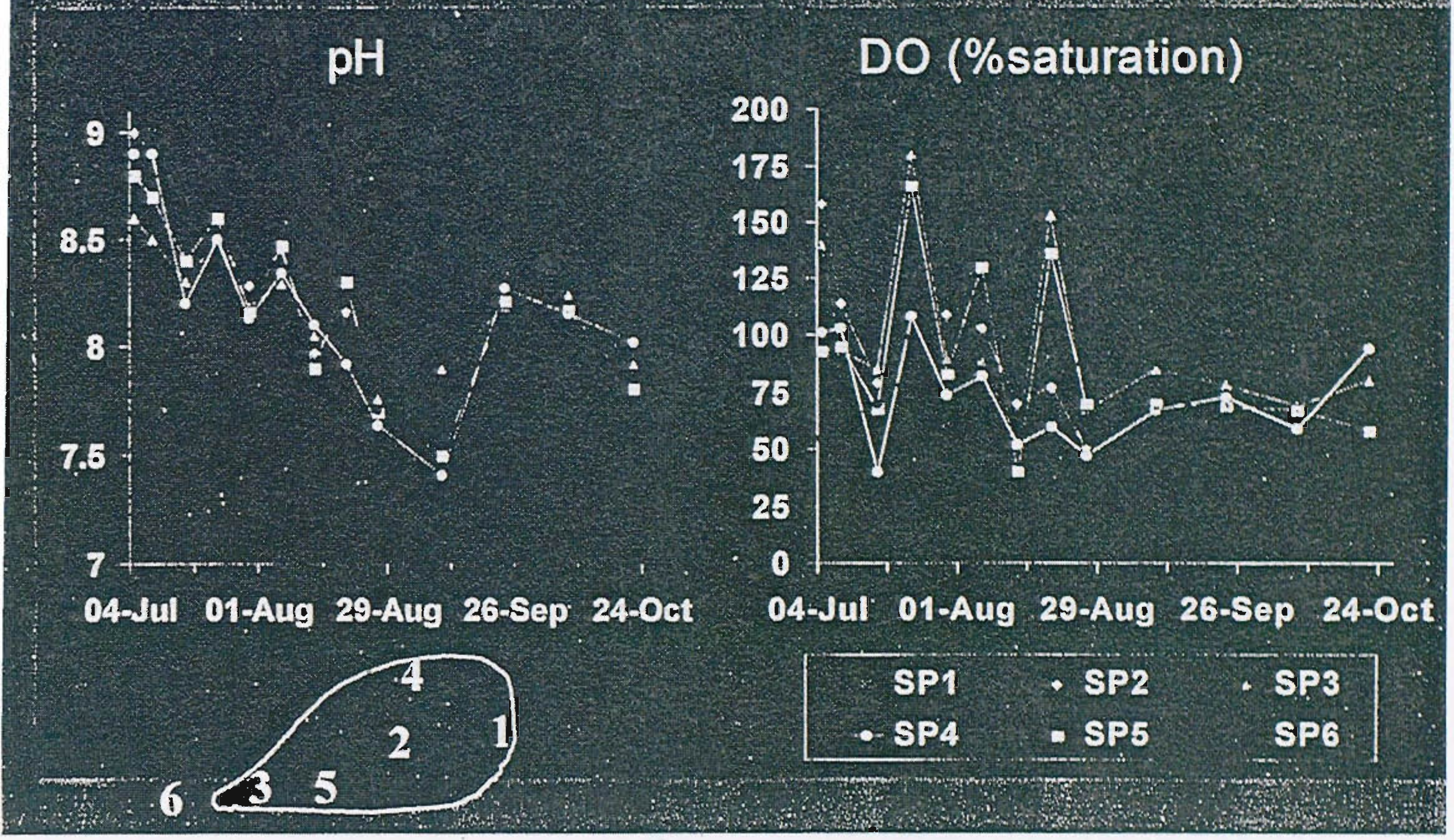
## *CRITICAL FACTORS FOR PRODUCING MORE FOOD IN THE SEA*



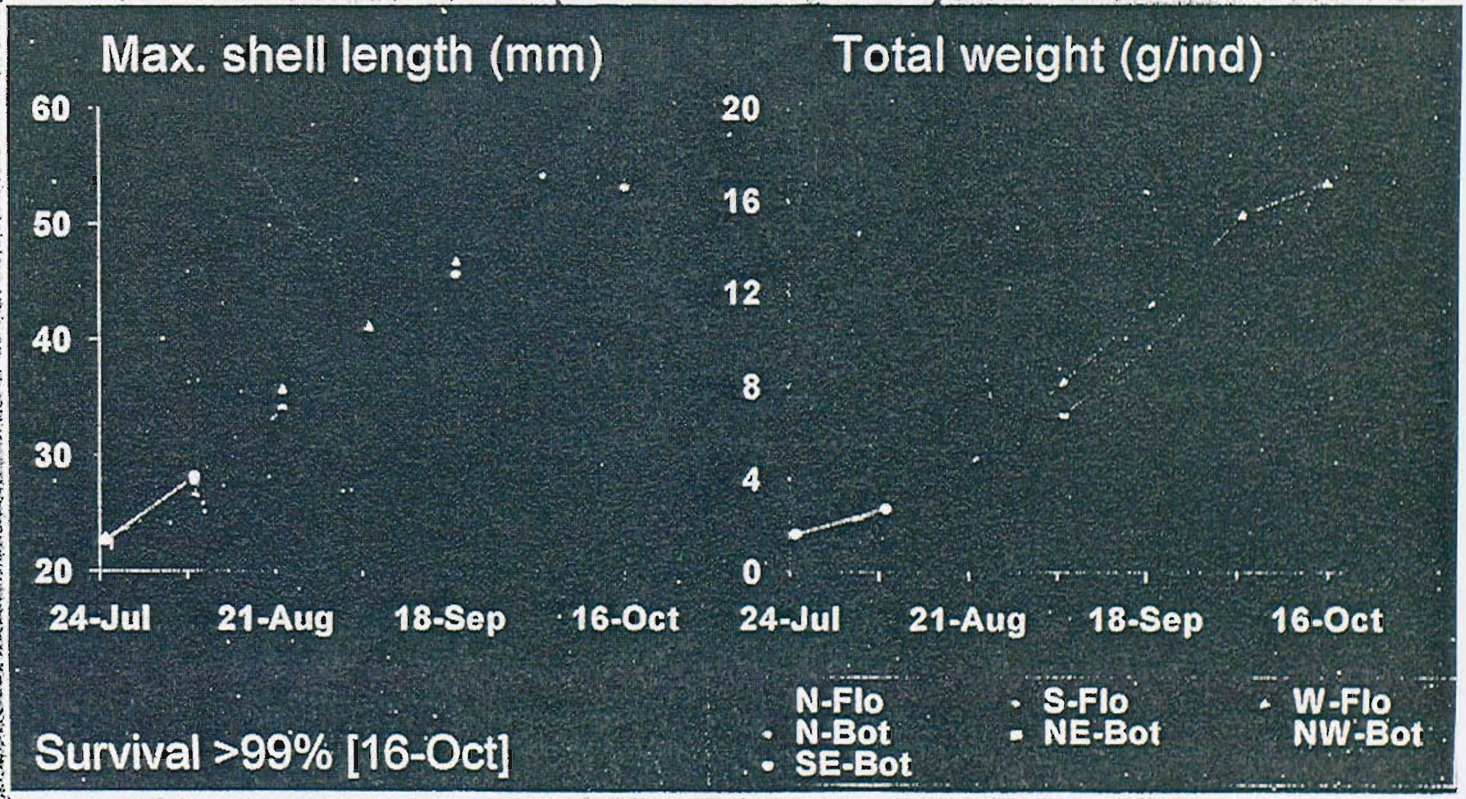
- ✓ Adequate basic knowledge of the marine ecosystem
- ✓ Environmentally and economically feasible methods and production technology
- ✓ A clean and unpolluted coastal/marine environment and a sustainable management practise of human discharges



# pH and dissolved oxygen




# Oyster (*C. gigas*) growth & survival aug-oct '96 (Coutteau et al)



## A MAJOR QUESTION:

**WHAT IS NEEDED TO KEEP THE COASTAL ZONE AND THE MARINE ENVIRONMENT CLEAN ?**

- Heavy metals and toxic compounds are still accumulating
- Nutrients are mixed with toxic compounds
- Air borne transport of organic pollutants

**WILL PEOPLE EAT SEAFOOD PRODUCED IN THE COASTAL ZONE OR SEA IF WE CONTINUE TO USE THE MARINE SYSTEM AS RECIPIENT FOR HUMAN WASTES AS WE DO ?**

## WHAT NOW ? Conclusions

- Improve fundamental knowledge of the marine ecosystem - long time perspective
- Improve fishery management
- Explore possibilities in extensive aquaculture
  - benthic animals, coastal zone
  - anthropogenic nutrients, close cycles!
- Emission of toxic substances, reconsider practise.
- Involve all sectors; public, private and science.

## 5.4 Abstract of a Keynote Talk entitled, *Limits to predicting the consequences of managing marine ecosystems* by Professor Tony Underwood, University of Sydney

Manipulations of marine habitats and populations are widespread, particularly in coastal waters, because of the existing rates of harvesting, major use of coastal ecosystems for disposal of wastes and large-scale alterations and destruction of habitats themselves. All attempts to manage such systems, for sustained use, for enhancement of exploitation or for repair or rehabilitation are therefore made against a background of exploitation or over-exploitation.

The present levels of human activity in marine systems have, however, allowed some understanding of limits and constraints. The degree to which coastal receiving waters can continue to assimilate wastes, the nature of interactive build-up of contaminants via bio-accumulation and methodologies to detect and quantify pollutants and environmental disturbances have been well-developed and are part of on-going research. The outcomes of previous and current research have, however, not been so successful for describing, understanding and predicting the consequences of human intrusions in so far as they affect ecological structures, interactions and processes.

There are several fundamental reasons why ecological science has not yet produced models that can successfully describe marine systems or from which accurate predictions can be made. Nowhere has this been clearer than in the fields of management of fisheries and predictions of consequences of environmental impacts - precisely the areas relevant to consideration of enhanced marine harvesting.

There are two types of major constraints on our capacity to predict the potential outcomes of increased harvesting or alterations of habitats or processes in attempts to "farm" the sea more successfully. First is contemporary ignorance about ecological processes and systems - i.e. ignorance that could be dispelled by increased research, particularly at the relevant scales. For example, for many marine organisms (from bacteria to vertebrates), we have limited knowledge of life-histories, biological interactions and the relevant temporal or spatial scales in which to make predictions.

Understanding the genetic structure of marine populations is in its infancy, although modern biotechnologies could be applied to solve some current problems. At present, however, we do not know the size and genetic connectedness of marine metapopulations (i.e. stocks), we do not know the extent to which outbreeding, genetic drift, founder effects, etc., influence sustainability of many localised populations (e.g. in estuaries).

Biological interactions in marine habitats are numerous, widespread, varied, complex and important. One of the successes of modern experimental ecology has been the elucidation of the nature of interactions among species, particularly in response to disturbances. Thus, the roles of pre-emptive competition, behaviour of propagules, predation, provision of habitat by one species for another, are clear for some assemblages in some habitats.

Predicting changes in these habitats has, however, not become particularly more precise. Part of the reason is "fundamental" because of uncertainty in recruitment (see below). Much, however, is because of historical lacks of resources and commitment to experimental studies at the necessary and appropriate spatial and temporal scales. Thus, knowing there are, say, ten possible pathways and/or five possible end-points for development of ecological structures in a patch of habitat that is being recolonized is a long way from being able to predict which pathways and end-points will be relevant at any place or time.

Much of the empirical ecological work has been done at very small spatial scales and with limited regional or geographical representation of study-sites or species. Most of it has been done with very restricted time-scales - the typical postgraduate study (the majority of new research) and the typical longevity of grant-cycles (the basis of the vast majority of all published research) are about 3 - 4 years. Such stop-start research projects do not build larger scale or longer-term comprehension of ecological processes with time-scales of decades and spatial scales of hundreds of kilometres.

This type of uncertainty leading to lack of predictive capacity could, however, be resolved. Two major changes are necessary in the way relevant ecological work is done. First, marine ecologists must lobby for funding of longer-term studies about processes. Responses of assemblages to environmental perturbations, be they natural (severe storms, major diseases), anthropogenic (introductions of exotic species, clearings of habitats for so-called "reclamation") or of uncertain origin (e.g. outbreaks of urchins in kelp-beds or starfish on coral reefs) are often quite long-term. Well-conceived research programmes identifying the need for a long time-course deserve and should get support from the scientific community for the necessary longer-term funding. There must, however, be sensible, explicit and strongly evaluated schedules for external assessment of progress, to prevent abuse of funding. It would be too easy to argue that funding should continue over a long period simply because it was originally agreed that this was originally desirable.

The second change is to recognise the need for (and therefore to plan) larger-scale studies of processes of recruitment, sizes of populations, connectedness of metapopulations, interactions between species, regionality of biological diversity, etc. Apart from larger-scale studies being appropriate in their own right as the only means relevant to investigate large-scale processes, they are also the tool to evaluate methodologies for integrating results from small-scale studies. Scaling up to larger areas or widespread problems is not just a process of multiplying or summing small-scale studies. Numerous issues must be addressed about how to combine studies from different areas and different starting conditions.

The second form of ignorance is more fundamental and not likely to be dispelled. As mentioned above, many marine populations naturally fluctuate in abundances from place to place and time to time. One primary reason for this is a consequence of planktonic stages of the life-cycle, subject to very large rates of mortality due primarily to predation (it is widely believed although hard evidence is not often available). Given even only slight variations in intensity of predation, availability of food for planktotrophic species and rates of development (e.g. due to variations in temperature), very large variations will occur in proportional survival to the end of the planktonic phase. Consequently, in many habitats, we will always have great uncertainty about outcomes of anthropogenic intrusions and activities.

Further, many large-scale ecological processes are, at least partially, driven by physical factors lumpable into the generic term "weather". Predictability of weather is not yet (if it ever will be) very certain. On-sets of large-scale phenomena (El Niños, pulses of warm water into more northern cooler seas), meso-scale phenomena (cyclones, large floods) and smaller-scale vagaries of weather can only be predicted with very large confidence intervals. It is not surprising that predicting their ecological consequences should be intrinsically uncertain.

Finally, complex interactive sets of species have numerous potential end-points in terms of structure of assemblages, organisation of food-webs and rates of transfer of energy through trophic levels. Although increased research will inevitably reduce ignorance about these (as discussed above) it may not (and is unlikely to) increase predictive capacity to be adequate for the large-scale alterations necessary to increase harvesting. There are too many pathways and too much dependency on initial conditions in terms of relative abundances of interacting species to hope that guess-work can be turned into a triumph of correct predictions.

Where does this lead for future contributions by marine ecologists? First and of great importance, we need a collective effort to make clear the uncertainty of our contributions to decision-making. Dealing with uncertainty requires (at least) three things:

(i) there is no need to be defensive about (or to give up because of) large fundamental unpredictability. Policy-makers, environmental and resource managers are used (or resigned) to dealing with very great uncertainty in weather-forecasting and anticipation of trends in economic indicators. They have no reason to require more certainty from marine scientists, given the fundamental reasons why we cannot dispel ignorance. So, we need greater public awareness of why systems are uncertain.

(ii) despite their appeal, deterministic models and theories about marine processes are not going to help until contemporary ignorance has been dispelled. So far, the history of ecology suggests this will take a long time and pressing needs for better management of marine harvesting and environmental care cannot and will not wait for the answers.

(iii) we need to present our findings in less dogmatic terms. Provide firm statements about scenarios we do understand; provide strong answers where current knowledge allows it. In contrast, where there is (and must be) uncertainty, make that clear. We must provide confidence intervals or other probabilistic measures of uncertainty. We must couple these with clear messages about the potential consequences and risks brought about by uncertainty.

Second and most importantly we need to move more cautiously and to advocate incremental changes, not massive commitments towards predicted outcomes from fuzzy current thinking. This requires precaution and care for untoward outcomes of actions. Above all, however, it requires widespread concerted action to fit managerial decisions and responses to policy-making into a more explicit experimental programme. Decisions to alter fishing pressures, to change patterns of use of discarded fish, to reclaim coastal land, to dredge or not dredge harbours, to add to or subtract from amounts of nutrients released into coastal waters are all manipulations of environments. With very few exceptions (which presumably could not be justified at all, by anyone), such decisions are based on the premise that someone understands (or has been forced to accept a model for) the underlying ecological, biological and social processes. Changes to fisheries, scales of aquaculture or magnitude of nutrients in receiving waters are made because it has been predicted that certain consequences will now happen. These statements are scientific hypotheses. What is needed is much greater attention to the form, origin and nature of the underlying theories. The precise nature of the predictions, any alternatives to them and their magnitudes and time-courses should be explicit. The assumptions made and possible alternative predictions should be clear. Then, wherever possible, the decision-making and its outcomes can be properly evaluated for what they are - an ecological experiment.

The relevant experimental designs may be flawed (inadequate replication and lack of critical controls will be common). Substantial progress has, however, been made by marine ecologists about how to design properly interpretable experiments and what are the consequences for interpretation when components are missing or compromised. Regardless of the problems, dispelling myths, reducing ignorance and learning from past mistakes are the trademarks of successful scientific contributions to human welfare. Reducing (where possible) and dealing with (where necessary) uncertainty and thereby increasing precision and value of predictive capacity depend on wise use of scientific, empirical and experimental procedures.

Removal of some of the current limits to predictive capacity of marine scientists is going to be brought about by what we do best (and by what defines us) - the application of normative marine scientific procedures and rigour.

## 5.5 Abstract of a Keynote Talk entitled, *The precautionary principle in marine environmental policy - a constraint to ecosystem manipulation* by Dr. Stephan Lutter, World Wide Fund for Nature (WWF)

By signing the 1992 OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic, 15 riparian countries and the EU adopted "the precautionary principle by virtue of which preventive measures are to be taken when there are reasonable grounds for concern that substances or energy introduced, directly or indirectly, into the marine environment may bring about hazards to human health, harm living resources and marine ecosystems, damage amenities or interfere with other legitimate uses of the sea, even when there is no conclusive evidence of a casual relationship between the inputs and effects" (article 2; para 2 a).

Building on this principle and/or its precursors and spurred by concerns about "adverse effects of eutrophication" such as "algal growth, changes in the biological community structure and biodiversity including the occurrence of harmful algae, oxygen depletion and mass mortality of benthic organisms and fish", a number of commitments have been adopted by the North Sea Conference (NSC) and/or OSPAR Contracting Parties all of which aim at minimising nutrient inputs into the marine ecosystem: e.g. §§ 30-40 4th NSC Declaration (Esbjerg 1995); PARCOM Recommendations 88/2, 89/4, 92/7; OSPAE Strategy and Objective with regard to Eutrophication to be approved by the 1997 OSPAR Ministerial Conference.

Furthermore, it has been confirmed by the North Sea Interministerial Meeting on the Integration of Fisheries and Environmental Issues (IMM, Bergen, March 1997) that, inter alia, environmental objectives need to be integrated into fisheries policy, the precautionary approach applies to the management of living marine resources and any adverse effects of stock enhancement and sea ranching should be minimised. Moreover, the establishment of Annex V to the OSPAR Convention regarding the protection of species and habitats in the maritime area will result in protective or precautionary measures related to specific areas or sites.

In conclusion, it can be stated that the primary guiding objective in marine environmental policy is to protect natural systems and return those that have been damaged to their natural state or as close as possible. To rectify one environmental problem, over-fishing induced reductions in fish stocks, by pushing the ecosystem even further away from its natural state e.g. by artificial nutrient supply and manipulation of the food web, runs contrary to the precautionary principle.

Work by the scientific community, and in particular interdisciplinary frameworks such as MARICULT, which aims to clarify "the possibilities and the constraints for increasing sustainable production and harvest of food and raw materials from the oceans" must be conducted within the framework of the principles and commitments described above. Therefore, it was pointed out to the 18th OSPAR Annual Meeting (Oslo 1996) by a WWF intervention that artificial fertilisation of coastal or offshore waters, manipulation of currents, imitation of upwelling conditions as well as field projects to test the feasibility of such options are supposed to breach the provisions of the relevant Conventions. In a joint letter to DG XII, 4 European umbrella E-NGOs and 4 national E-NGOs strongly supported this view. The delegation of the European Union at OSPAR responded that "considerations for future funding" (of MARICULT) "would also take into account existing international measures and agreements to reduce nutrient inputs, which have been adopted, inter alia, within OSPAR".

## 5.6 Abstract of a Keynote Talk entitled, *Productivity regulation in the Benguela Ecosystem* by Professor John Field, Marine Biology Research Institute, University of Cape Town

The multi-institutional, interdisciplinary Benguela Ecology Programme has focused on understanding the biogeochemical processes which lead to fish production in one of the four main eastern boundary current upwelling systems of the world. North - South differences in the large-scale physical forcing of the system shed some light on its functioning. The Benguela System can be divided into three subsystems, each with two main upwelling cells. Upwelling appears to occur in two stages: in stage one, water upwells onto the shelf from over the slope at three topographically defined "gateways", and is enriched in nutrients as it moves polewards over the shelf before stage two, when it is wind-lifted into the photic zone at one of the main upwelling cells. It then drifts equatorwards near the surface and is stripped of nutrients by phytoplankton blooms.

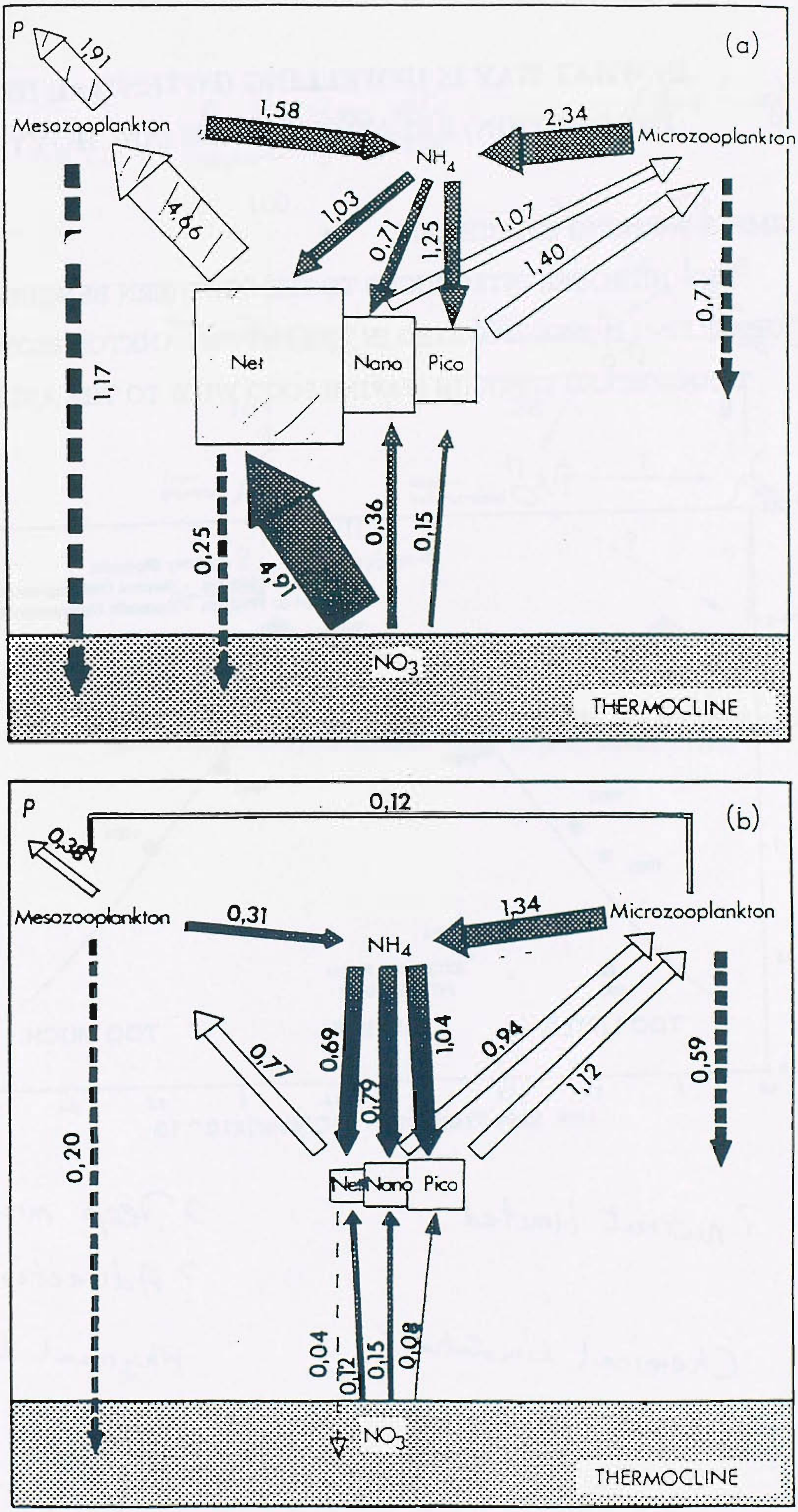
**Phytoplankton Biomass and Variability:** The phytoplankton biomass is estimated to be about 2.5 million tons in the northern half of the system and some 1.2 million tons in the southern half. Diatoms bloom some 4 - 8 days after an upwelling event commences, and studies have shown that small diatoms (such as Chaetoceros sp.) provide good food for copepods, resulting in rapid egg production 3 - 4 days after upwelling, in immediate response to diatom production. Netphytoplankton (>20µm) take up more nitrate than smaller phytoplankton cells, leading to a biomass increase after upwelling, and a five-fold increase in the flows of carbon to mesozooplankton compared to the periods between pulses of upwelling when the microbial loop sustains the mesozooplankton-fish foodweb at a low level. The microbial loop is slightly stimulated by upwelling (Figure 1). The pulsed upwelling of the Southern Benguela subsystem results in a mismatch between the time scales of the microbial foodweb (1 - 2 days), diatom blooms (4 - 8 days), mesozooplankton (12 - 30 days), and anchovy (1 year).

**System Productivity:** Estimates from satellite remote sensing of Sea Surface Temperature (SST) plus regression of SST in the 10 - 17 C range of upwelled water, with nitrate integrated to 30m depth, give estimates of "potential new production" for each upwelling event (Waldron et al in press). The sizes and number of upwelling events per year were estimated using sea level change (after filtering out tides and atmospheric pressure) as a proxy for large-scale wind forcing. The best regression to predict potential new production per event, was obtained with sea level rise, as the upwelling system relaxes after offshore wind stress. Annual estimates of new production for each year were thus obtained for the decade of 1980 - 1990. When acoustic and other estimates of annual anchovy (Engraulis japonicus, which has a 1-year life cycle) biomass are plotted against either the "annual potential production" or cumulative annual sea level rise, a Gaussian curve, or optimal environmental window, is obtained (Figure 2). This is interpreted as suggesting that too little upwelling results in nutrient limitation, on the left side of the dome, whereas too much upwelling results in physical disturbance of the system, either through advection of young anchovy stages out of the system, or deep mixing limits phytoplankton growth. Thus in the Southern Benguela subsystem, pulsed upwelling results in mismatches between phytoplankton, zooplankton and fish. This is inefficient in carbon transfer through the food web, which alternates between a short diatom-zooplankton-anchovy foodweb for a few days after upwelling, and the long microbial loop foodweb.

The Central Benguela subsystem has strong perennial upwelling and accounts for a good deal of the potential production of the whole system. The cool water and deep mixing appear to act as a barrier separating the northern and southern stocks of small pelagic fish. The Northern Benguela subsystem has gentler and relatively continuous upwelling which results in sustained diatom blooms and high phytoplankton biomasses. Here it appears that there is a better match between phytoplankton, zooplankton and fish in a short food web. This subsystem is periodically disrupted by intrusions of warm, nutrient-poor water from the north (Benguela Niños) and by intrusions of oligoxic water along the shelf on similar time scales.

Thus differences in the large-scale physical forcing of the system result in major differences in the resulting food webs and in fish recruitment. Management of fish stocks in regions of such large scale physical forcing needs to be done in harmony with the physical forces acting on the system.

Fig.




Days 4-8 after upwelling event

> 8 days after upwelling event

Probyn (1992)

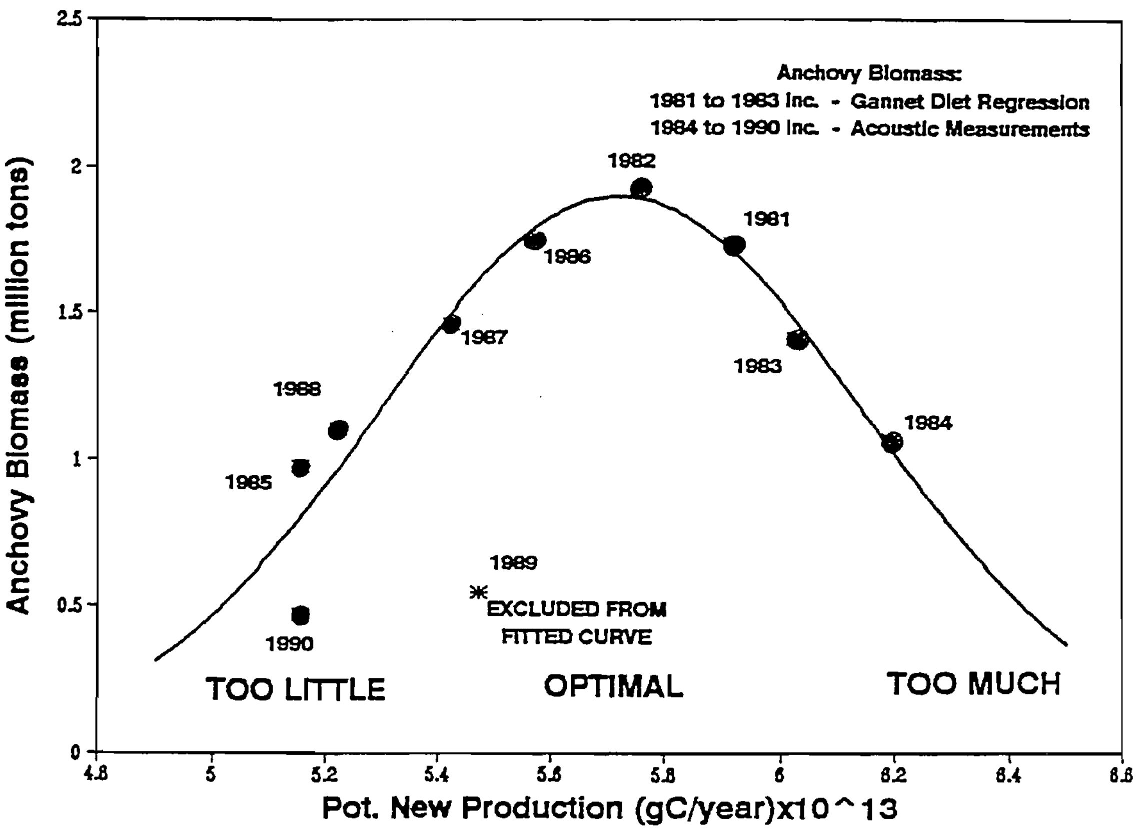
11a
29

F[ig] 2.

# IN WHAT WAY IS UPWELLING (POTENTIAL NEW PRODUCTION) RELATED TO FISH (ANCHOVY)?

SIMPLE WORKING HYPOTHESIS:

NEW NITROGEN INTRODUCED TO THE SOUTHERN BENGUELA BY UPWELLING IS INCORPORATED IN THE PHYTOPLANKTON BIOMASS AND TRANSFERRED THROUGH MARINE FOOD WEBS TO THE ANCHOVY.




? nutrient limited

? Deep mixing
? Advection

Chemical Limitation?

Physical Limitati[on]

Fig 3.

(Fig. 10).

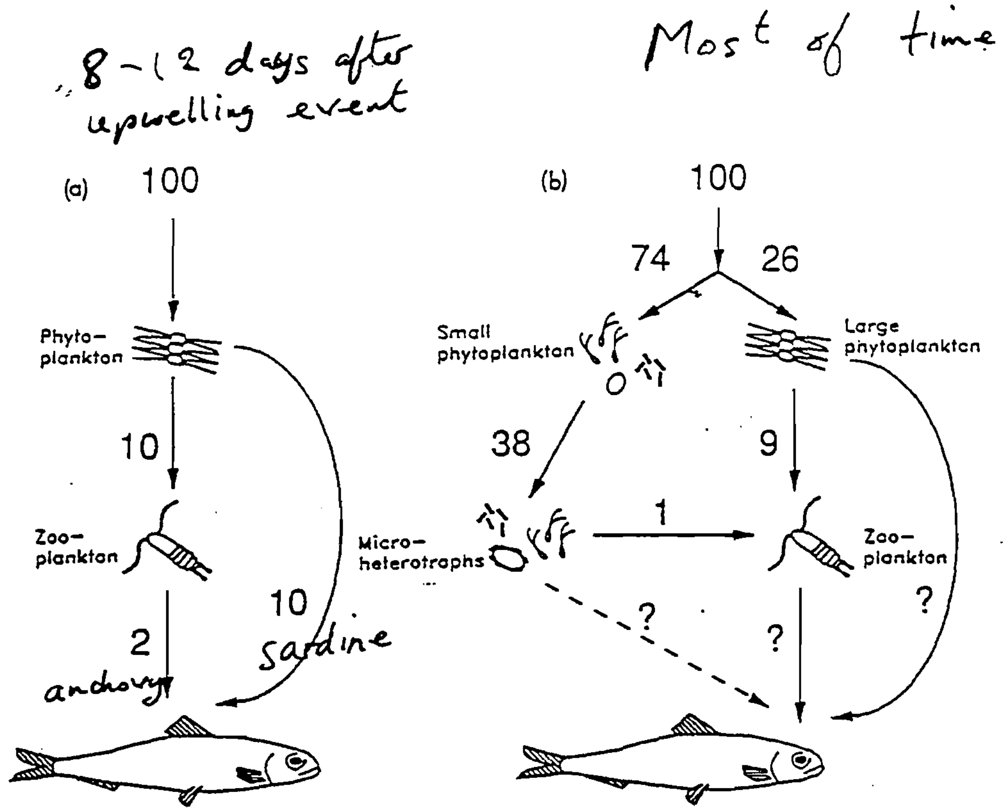



Fig. 10 Southern Benguela upwelling food web models (a) Ryther's (1969) model and (b) a revised model incorporating the microbial food web (after Moloney 1992)

5.7 **Abstract of Keynote Talk entitled, *Optimal use of marine resources in the context of sustainability* by Peter R. Burbridge, Centre for Coastal Management University of Newcastle**


**Abstract**

The optimal and sustainable use of renewable marine resources will be influenced by three fundamental issues, namely:

1. maintenance of the functional integrity of coastal and marine ecosystems which help to sustain marine living resources;

2. resolution of non-sustainable management practices adversely affecting the production and use of renewable marine resources;

3. economically efficient and socially equitable allocation of resources among competing uses;

The paper examines each of these interdependent issues and argues that their resolution will require the creative integration of scientific information with resource management principles. A case is made for treating integrated coastal management as a powerful tool capable of helping to achieve optimal and sustainable use of marine resources. A case is also made for multiple use management of coastal ecosystems to optimise the use of the flows of marine resources they help to sustain.


**i) Introduction**

The concept of sustainable utilisation of marine resources refers primarily to the use of the flows of resources within an appropriate time frame. Fossil fuels, such as oil and gas, mined from the seabed could form a renewable resource if humans live to great ages and consume these fuels at a rate whereby geological processes can replenish stocks. However, sustainable use of marine resources will necessarily apply only to resources which can be renewed by natural biological and chemical processes within modest time-scales such as the lifetime of the peoples who exploit those resources.

We should therefore differentiate between **stocks** of resources, such as deposits of oil and gas or stocks of fish, and the rates at which such stocks can be regenerated by nature relative to man's dependence on those resources. This gives us a measure of the **flows** of resources which can be harvested at a sustainable level within a known time frame. Within these definitions we can incorporate tangible resources including various plants, such as seaweeds, animals such as fish, and materials such as coral sands. Each has a rate or renewal which we must understand before we attempt to determine a level of sustainable harvest. For example, a coral reef may take between 10 and 60 years to replace a cubic meter of sand excavated to build up a beach while a particular fish stock may take only months to regenerate if harvested at a low rate.

We should also include in our definition of marine resources environmental services such as oceanic-atmospheric gas exchange which helps to regulate our global climate or protection of coastal land uses provided through coral reefs acting as a buffer to oceanic wave energy. These environmental services are not normally consumed. Nor are they directly utilised by human activities. However, loss of services and functions may not always become apparent, for example loss of $CO_2$ absorption. Where such services are reduced through poorly planned and managed development, such as coral mining, their value in sustaining human welfare is soon recognised.

Few if any of these resources will continue to exist if we do not prevent adverse impacts on the natural ecosystems which generate those resources. This raises a fundamental issue- can we hope to achieve sustainable use of marine resources just by managing the rate at which they are harvested? The author would argue that we must broaden our concept of sustainable marine resource development to include the ecological processes which maintain the health and productivity of the ecosystems that sustain the stocks and flows of coastal and marine resources we seek to utilise.

The management of complex marine ecosystems may not be feasible and this should be discussed at the Ocean Harvest Meeting. However, it is feasible to maintain the functional integrity of coastal and marine ecosystems by managing human activities in order to reduce adverse direct and indirect effects. This requires a more holistic concept of marine resource management where the management of resources is linked to the management of a wide range of human activities and their impacts on environmental processes that maintain the health and productivity coastal and marine ecosystems. This raises a second fundamental issue- does the scientific knowledge exist to enable us to fully comprehend the environmental processes liking coastal and marine ecosystems, how marine and coastal systems function, how they may be mutually supporting, what forms or resources they generate and what forms and levels of resource use they can sustain. Without such basic information it will be very difficult to manage sustainable resources production or to optimise their subsequent use.

### ii) The Role of Coastal Ecosystems in Sustaining Marine Resources Production

When we examine the renewable resource production of the marine environment it is clear that it is the shallow coastal seas and nearshore marine environments which support the greater proportion of current forms of renewable as well as non-renewable resources production. For example, world-wide, only 5% of all marine capture fisheries harvests are from deep marine waters, with 95% being derived from coastal waters (FAO, 1992). While harvests are not necessarily an accurate reflection of actual marine resource production, they do reflect the general geographic foci and levels of exploitation.

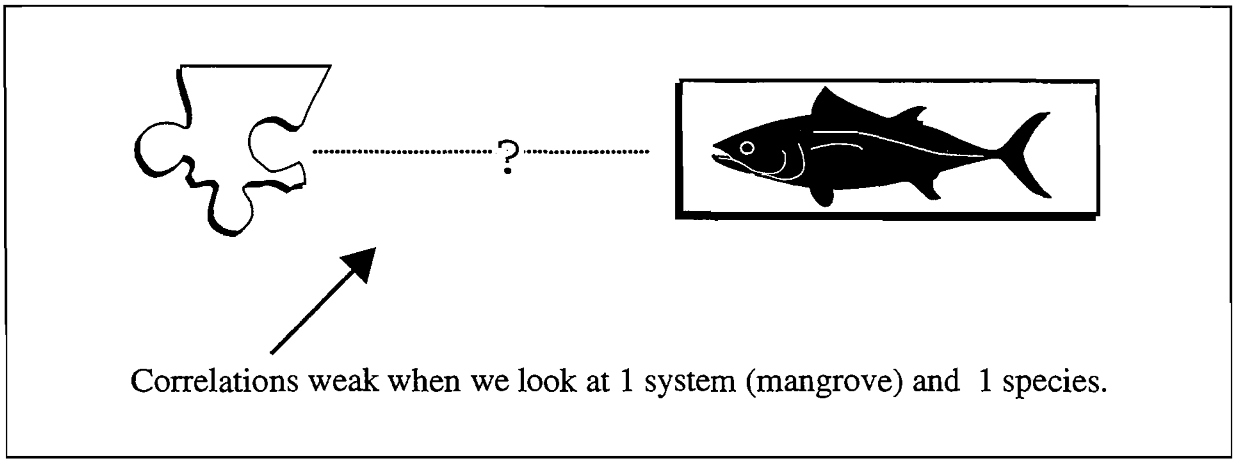
The concept of Large Marine Ecosystems (LMEs) has been developed to monitor conditions and assess natural resources features of the marine environment. For example Bakun (1995) attempts to relate coastal upwellings and other large-scale physical processes, such as monsoon influenced currents, with the overall poor productivity of fisheries in the West Indian Ocean. The LME framework is a useful tool for integrating different forms of scientific information, including productivity, fish stocks and fisheries, pollution and ecosystem health, socio-economic conditions and governance. However, there is a long way to go before we have the basic information on marine ecosystem functions and health, including issues such as resilience, stability, productivity, and biodiversity, which are critical to determining potential optimal resources yields.

There also remain large gaps in our scientific understanding of the linkages between terrestrial, coastal, and marine ecosystems. While the LME concept can be extended to incorporate coastal areas and ecosystems, emphasis has often been placed on specific forcing functions such as the effect of land based sources of pollution on marine systems. This narrow focus can obscure other critical relationships which we need to comprehend before guidelines for resources management can be formulated which would help to promote sustainable development as set out in Agenda 21 Chapter 17 where priority is given to the development of integrated coastal management as a major tool in securing improved protection of the marine environment.

In a recent paper presented to the Working Group on Coastal Management of ICES a case was made for adopting a more holistic approach to the evaluation of the role of coastal systems in sustaining marine biological resource production where the functional linkages among ecosystems are used to identify groups of linked systems so that their combined contribution in generating and supporting marine resource production can be assessed (Burbridge et al, 1995). These groups of linked coastal and marine ecosystems could form the basis for defining management units appropriate to the development of new management frameworks for sustainable marine resources production and optimisation of their use.

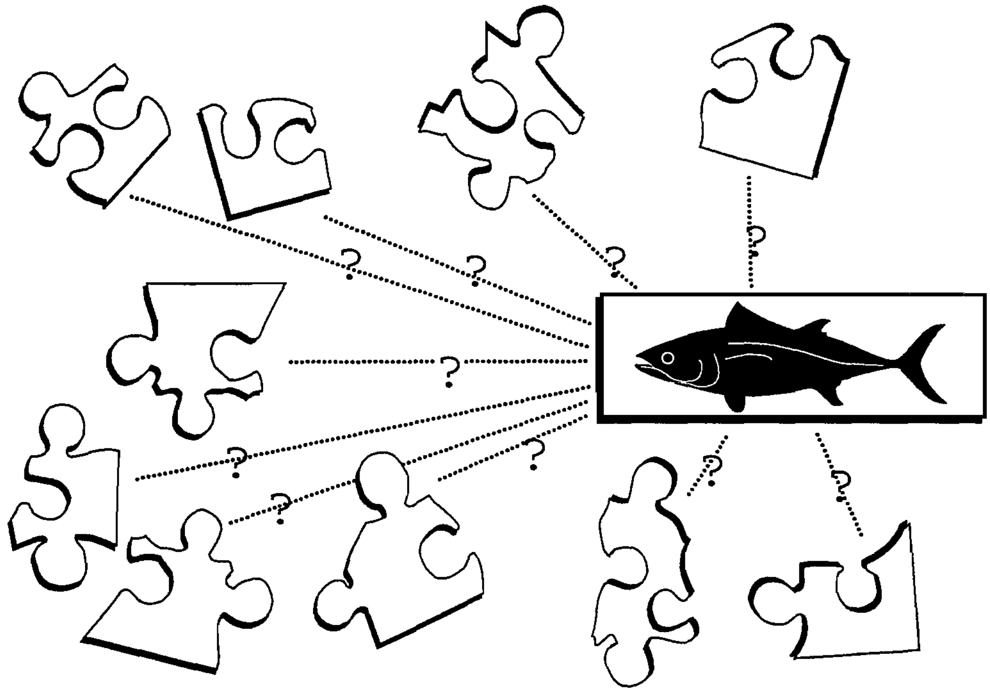
Burbridge et al (1995) argue that a broader scientific framework is required to comprehend the linkages among specific coastal and marine ecosystems and renewable marine resources production (**see Figures 1, 2 and 3**). In **Figure 1** the question is posed what is the role of a coastal ecosystem, such as a mangrove, in supporting fish stocks. This approach is questioned because we are looking at only one part of a more complex mosaic of inter-related coastal ecosystems.

**Fig. 1**




If we ask the same question about each ecosystem in isolation from the others (see **Figure 2**), we will continue to get poor statistical corrrelations because we are not taking into account the combined and mutually supporting attributes of the mosaic of interlinked coastal systems and their combined contribution to the production of renewable marine resources.

**Fig. 2**



Many systems directly or indirectly help to sustain fish stocks but we need to look at how these systems work together to form a strong base of support.

**Fig. 3**

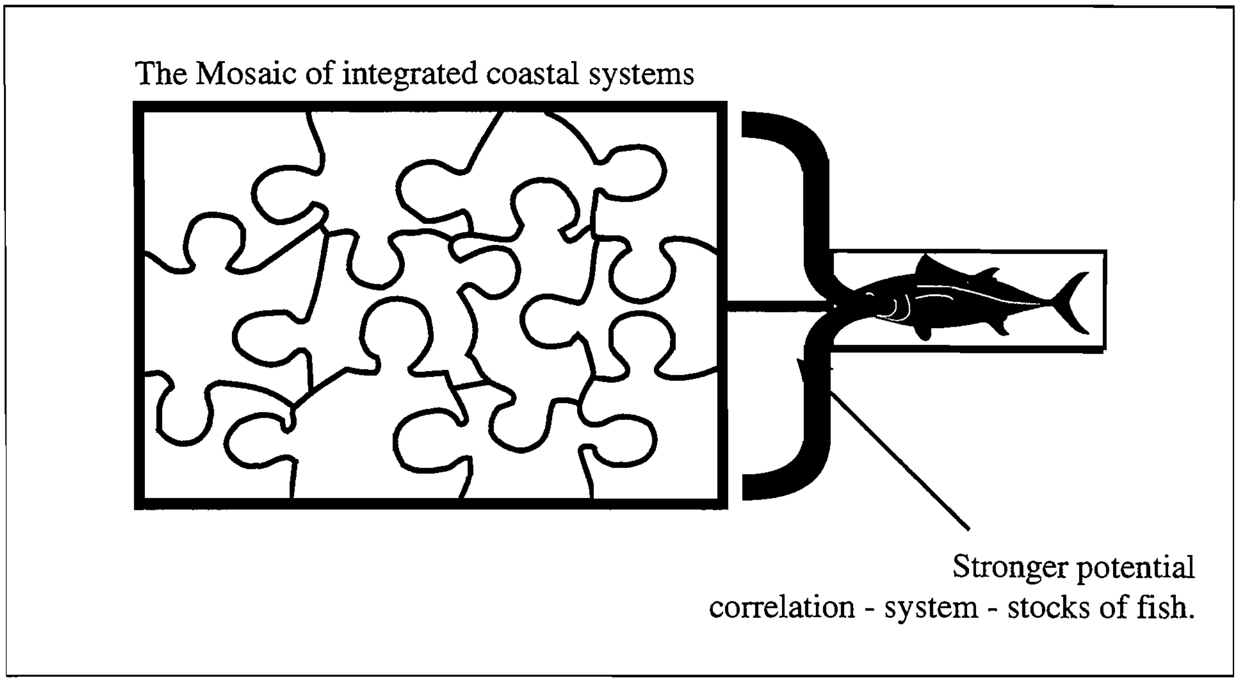



**Figure 3** suggests that we will gain a much clearer understanding of the role of a coastal ecosystems in supporting marine fish stocks and other renewable biological resources if we adopt a more holistic approach which incorporates the linkages among ecosystems such as mangrove, seagrass beds, coral reefs, tidal creeks, and mudflats.

Although there is a vast literature on mangroves, seagrass beds and coral reefs, very little information exists on interactions among them. It is instructive that the most widely quoted reference on interactions among these ecosystems is still Ogden and Gladfelter (1983) which stemmed from a UNESCO workshop in 1982. The report essentially concluded that little was known of the interactions; this remains equally true today. An understanding of how coastal ecosystems function and interact with each other, and with adjacent terrestrial and offshore areas is of primary importance as a basis on which to make rational management decisions (Birkeland and Grosenbaugh, 1985). Without understanding how the environmental processes that sustain fisheries and other marine biological resources are integrated, it is difficult to propose integrated planning and management strategies. This means that research of an integrated nature is essential if the linkages between components of the marine biological resources support system are to be understood.

### iii) Functional Analysis : A Tool for Understanding the Linkages Between Coastal Ecosystems and the Sustainable Production of Marine Biological Resources

When we look closely at coastal ecosystems we discover that they perform a series of important functions that help to sustain fish stocks and other marine biological resources. Examples include spawning and nursery areas, nutrient exchange and water quality control. These, and other functions that support a wide range of activities, have been reviewed by a number of authors (Gosselink and Turner, 1978; Burbridge, 1984; Mitsch and Gosselink, 1986; Hollis and Maltby, 1987, Maltby, 1991). Some of the most important functions are summarised below:

**Production:** Primary and secondary production is a key function that sustains the populations of plants and animals in wetlands and in associated coastal and marine ecosystems (Maltby, 1991).

**Storage:** Wetlands act as a permanent sink for materials such as sediments and organic carbon, and store other materials, such as water, on a temporary basis. The value of these storage functions is increasingly recognised as an important feature of hydrological functions of watersheds such as flood control, geomorphological processes such as control of coastal erosion, accumulation of organic carbon (Maltby, 1991; Immirizi et al., 1992), and the maintenance of genetic resources (James, 1991).

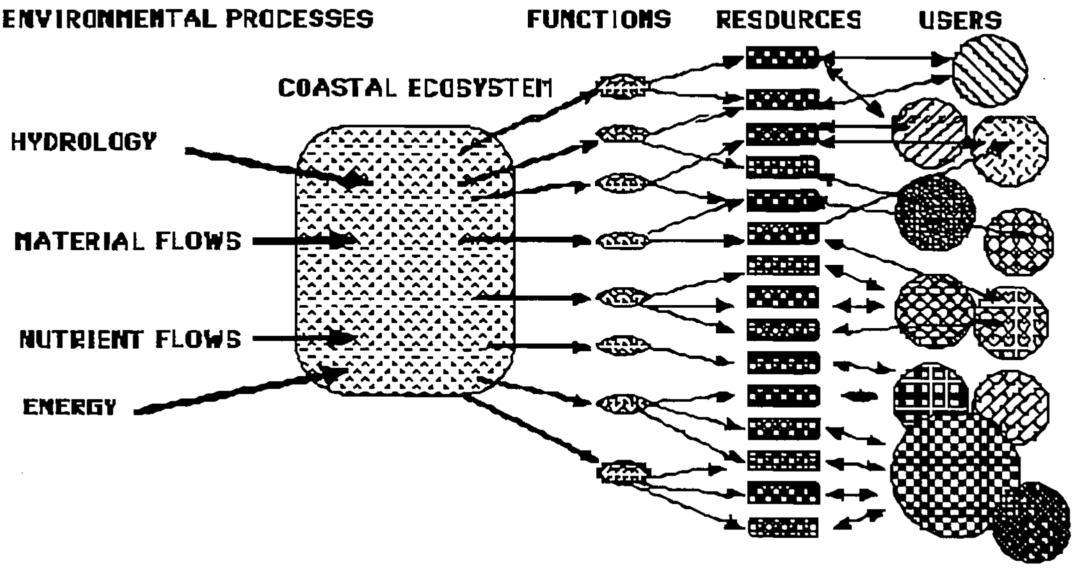
**Filtration and Cleansing:** The biogeochemical dynamics of wetlands also play a major role in filtering and cleansing water, for example the removal of toxic material from the water column (Richardson, 1985). These functions are considered of great potential economic value in providing tertiary treatment of sewage and reducing pollution from agricultural wastes (Maltby, 1991).

**Pathways or Linkages Among Ecosystems:** The movement of water, nutrients and organic materials between wetlands and other ecosystems is essential to the maintenance of food chains, migration routes, other pathways, and environmental linkages that support the productivity and health of marine ecosystems and renewable resources.

**Buffer:** Coastal wetlands provide a number of buffer functions that help to protect life, property and the economy of local communities and nations. Wetlands help to regulate the rates of surface water flow and groundwater recharge. This reduces flood water peaks and regulates base water flows in rivers. Coastal wetlands serve as a buffer to coastal storm surges and winds (Hamilton and Snedaker, 1984). When these wetlands are destroyed, the risk to human life and the economic welfare of coastal communities increases dramatically. In effect, poor planning and management can turn a natural event such as a coastal storm into a human disaster (Wijkman and Timberlake, 1984).

The essential starting point for optimising the production of marine biological resources which depend on coastal ecosystems is the assessment of the functions of those ecosystems and how they support marine ecosystems. **Figure 4** illustrates a coastal ecosystem, the environmental processes that are essential to the continued health and productivity of that system, the different functions it produces, the resources generated by those functions and the different human activities that make use of those resources.

Figure 4 : A Coastal Ecosystem




Points that should be noted from **Figure 4** are:

- the essential role played by physical, chemical and biological processes in creating and then maintaining the functional integrity, and dynamic character of the coastal ecosystem;
- the direct link between environmental functions and the generation of renewable resources;
- the use of one form of resource by more than one type of human activity;
- exploitation of a specific resource by one or more users can have an adverse effect on other users and other resources;
- competition for access to resources can lead to over-exploitation;
- some form of control over resource use may be required to achieve optimum uses of available resources within limits that can be sustained by the ecosystem;
- management must be extended to include the maintenance of the health and productivity of the system if resource flows and optimal use are to be realised.

Based on these points it can be argued that we need to broaden our concept of management to extend well beyond the control of human activities which seek to exploit the resources generated by a coastal or marine system to include the maintenance of the functional integrity of that system. Like a factory, you cannot expect the system to continue to produce products unless you pay attention to the amount and quality of inputs required to maintain the productivity and functional integrity of the system.

This highlights one of the basic problems we face in promoting sustainable development and optimal use of marine resources, namely that economic planning and management systems are designed to manage human activities which is not the same as sustaining the flows of renewable resources through maintenance of the functional integrity of natural systems. For example, we have created ministries of Fisheries, Agriculture, Forestry, Tourism, Industry, Transport and Public Works. All of which represent different economic sectors or specialised public services. Where competition exists for the use of resources amongst sectors, we tend to look for the highest returns from alternative uses of a particular resource rather than the optimum return from a mix of uses of resources from a system. As a result we find extensive areas of mangrove, coral reef, mudflats, peat swamp forests and other coastal systems converted to single purpose activities such as shrimp ponds or agriculture. Such conversions alienate all other potential users of the system. In the case of a mangrove, their conversion to shrimp ponds can reduce opportunities for 70 or more other resource uses. This brings us to another major issue- the resolution of non-sustainable management practices affecting the production and use of renewable marine resources.

**iv) Resolution of Non-sustainable Management Practices Adversely Affecting the Production and Use of Renewable Marine Resources**

**iv.i) Management of Development Activities and Potential Impacts on Coastal and Marine Ecosystems**

**Figure 5** presents a matrix of some of the adverse impacts different forms of human development can have on coastal and marine ecosystems:

**Figure 5 Development Activities that can Adversely Affect Tropical Coastal and Marine Ecosystems**

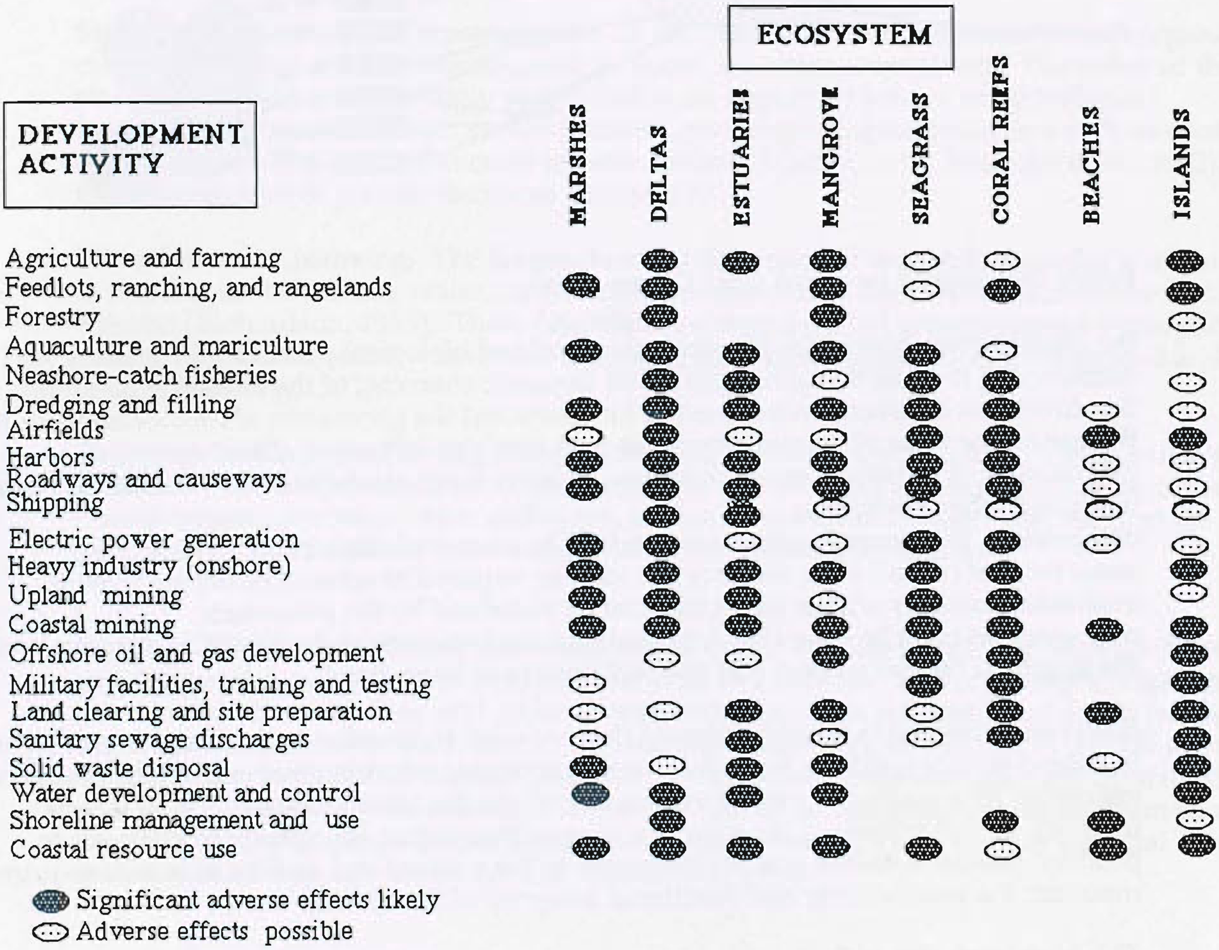



**Figure 5** demonstrates four very important points. The first is that any single form of human activity can have a significant impact on more than one coastal or marine ecosystem. Secondly, each of these ecosystems can be adversely affected by more than one form of human activity. Thirdly, the cumulative impact on any one system from even minor impacts from different forms of development can have a major influence on that system and other systems to which it may be linked to. This brings us to the fourth point, and that is we must give greater attention to reducing the adverse environmental effects on the entire coastal ecosystem if we are to promote the functional integrity of related marine ecosystems which form the basis for sustaining marine resource production.

Damage to any coastal system can have an adverse influence on other systems and upon human activities based on those systems. This is illustrated in the following figure where the inter-dependent coastal ecosystems are represented as stone blocks forming the arch of a bridge in **Figure 6** below:

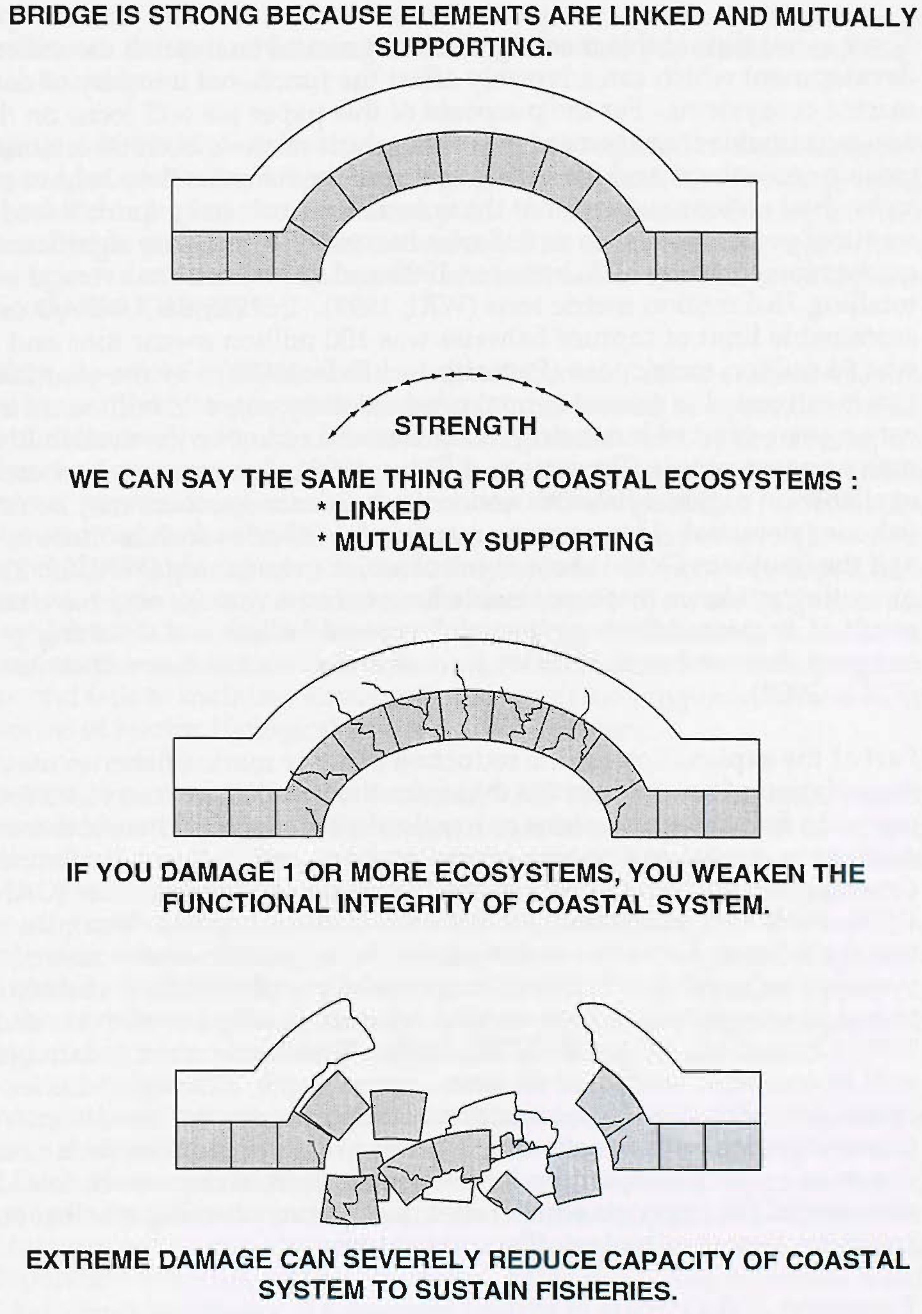



**Figure 6** demonstrates two important points. The first is that marine resources production depends on maintaining the health and productivity of a series of interrelated coastal and marine ecosystems. Secondly, damage to one or more of these systems can adversely affect specific resource management systems, for example aquaculture production can be reduced

due to flooding when a mangrove is removed and there is little protection against coastal; storm surges. The combined effect is that there will be a weakening of the productive capacity of the coastal and marine resource system and the remaining natural resource production will be placed under increased pressure due to the loss of production from the managed systems such as aquaculture.

### iv.ii) Non-Sustainable Development of Fisheries as an Example of the Need for an Ecosystems Management Framework

There is not time at this meeting to catalogue and analyse all the different forms of development which can adversely affect the functional integrity of coastal and related marine ecosystems. For the purposes of this paper we will focus on the need to address non-sustainable management practices which relate to both the management of coastal and marine ecosystems and the management of the fisheries they help to sustain. Projections by individual nations suggest that the volume and value of exports based on marine biological resource production, such as fisheries harvests will increase significantly. World wide fish catches increased by 30 % between 1980 and 1990 with the average annual marine harvest totalling 78.6 million metric tons (WRI, 1993). In 1985 the UNFAO estimated that the sustainable limit of capture fisheries was 100 million metric tons and in 1988 the total catch was 94 million metric tons (Pernetta and Elder, 1993). By the year 2000 demand for marine fish is estimated to exceed annual production by some 20 million metric tons with the consequent effect of increasing real prices and reducing the availability of marine protein to many poorer people (Pernetta and Elder, 1993). In some cases where accurate data is available on regional fisheries and inshore fish stocks, there may be untapped capture fisheries potential. However, many regional fisheries such as those in the Northwest Pacific and the Southern Ocean show signs of major over fishing (WRI, 1993). There is also mounting evidence that sustainable limits of some stocks may have been exceeded as a result of increased fishing effort and increased efficiency of fishing gear. FAO data suggests that catches in 19 fishing zones are above the limits of estimated sustainable yield (FAO, 1992).

Part of the explanation for the reduction of some marine fisheries may lie with the degradation of coastal habitats that form the breeding, nursery and feeding grounds for many fin fish and crustaceans currently exploited. World-wide there is a sad catalogue of damage to coastal and marine ecosystems as a result of poorly planned and managed development, including overexploitation of renewable resources (CAMPNET, 1989; WRI, 1993). Although scientifically it is very hard to accurately determine the total impact on marine fisheries harvests resulting from the large scale destruction of coastal ecosystems, it is widely believed that stocks of commercially exploited fin and shellfish are declining due to loss of mangrove, damage to coral reefs, and pollution of rivers and estuaries (AWB, 1992; Chou et al., 1991; CIMTPSP, 1988). The effects of such damage affect the social as well as economic welfare of societies. For example, although fisheries development is of critical importance to food security and employment, there has been a decline in the number of persons employed in artisanal fisheries in many countries such as the Philippines. This is due to increasing competition for inshore stock from more mechanised and capital intensive commercial fishing boats which raises questions concerning whether such development is equitable as well as biologically sustainable.

Expansion of the culture of marine organisms is sometimes promoted as a means of meeting increased demands for protein as well as providing employment for fishermen. Aquaculture in coastal areas takes many forms, including the culture of: crustaceans, molluscs, fin fish, and plants. The total world production of coastal aquaculture in 1990 was 7.5 million metric tons and was valued at US$ 13.2 billion, this is expected to rise to about 10 million metric tons by the year 2000 (FAO, 1992). It is by no means certain that the expansion of aquaculture in coastal and nearshore marine waters will actually increase the overall production of marine protein. There is some evidence to suggest that it may only make up for the potential production lost due to degradation of coastal ecosystems and pollution of the marine environment.

Aquaculture relies heavily on natural land and water resources for its very existence. Aquaculture also performs best in areas where there is a very high quality environment. This can often mean a search for new locations isolated from other forms of development that compete for resources or which reduce environmental quality. This can result in aquaculture being located in some of the most remote and disadvantaged regions with limited opportunities for alternative forms of development. However, where there are other competing interests for coastal space, it is not surprising that there have been instances of conflict and it is most likely that the number of conflicts will increase in the future. For instance, aquaculture has been accused of visual, organic, chemical and genetic pollution in addition to disease and parasite transfer to the native fish populations and the cause of navigational hazards.

On the positive side the high environmental standards required to make aquaculture sustainable and profitable can help discourage pollution from less environmentally-friendly industries and technologies. An important point to stress here is that aquaculture projects that have resulted in pollution, almost exclusively due to poor management, have ultimately ended in their own demise and unnecessary environmental impacts on other activities (ICES Working Groups on CZM, 1995).

Unfortunately, the rapid expansion of traditional forms of small-scale brackish water aquaculture in many developing nations and the introduction of aquaculture into formerly undeveloped areas in developed nations has not been matched by the development of policies, plans and management strategies to guide aquaculture and protect other users of coastal zones or marine ecosystems and resources. Where guidance has been developed, this has followed rather than led the development process and often fails to incorporate good science and valuable experience from other regions. In more developed nations where aquaculture is a relatively new form of coastal activity, farmers are subject to controls and standards which are administered by a complex array of institutions far in advance of those applied to other activities. This both hinders the legitimate development of aquaculture and fails to maintain environmental conditions required to sustain aquaculture and other forms of marine biological resources development.

Although agencies such as the World Bank and FAO are addressing basic institutional and technical issues concerning the establishment of coastal management in developing nations, no international organisation has yet developed pro-active approaches, or practical guidelines for the integration of aquaculture as a legitimate development activity into coastal planning and management activities in both developing and developed nations. Where integration is being attempted, it is based upon local or regional planning within individual nations (ICES Working Groups on CZM, 1995). As a result, opportunities for promoting the sustainable growth and diversification of coastal aquaculture are not being fully realised and options for future development are being foreclosed.

There is an urgent need to actively promote pro-active approaches for planning and managing aquaculture as an integral part of coastal zone management plans and investment strategies. Such plans and management strategies must be based upon sound scientific management principles for the protection of environmental processes which maintain the functional integrity of coastal ecosystems and sustain aquaculture and other renewable resource dependent activities. Basic objectives of this pro-active approach would be to :

- Promote the integration of aquaculture into sustainable resources management strategies;

- Analyse, document, and disseminate information on trends in coastal resources development and utilisation;

- Increase awareness of the importance of coastal resource management policies and identifying management capabilities;

- Suggest solutions to coastal resources use conflicts;

- Promote institutional arrangements that foster integrated multi-sectorial planning of coastal and related marine resource utilisation.

> (Based on recommendations of the ICES Working Group on Environmental Interactions with Aquaculture 1995, 1996.)

The potentially adverse effects of new aquaculture development can be minimised through good planning and management. To be fully successful, such plans and management arrangements must recognise that aquaculture should have equal rights of access to and use of natural resources and to a good quality environment. It is suggested that Integrated Coastal Zone Management can provide a beneficial framework for the development of aquaculture where due care and attention is given to the maintenance of the functional integrity of coastal ecosystems that sustain aquaculture and other natural resources dependent activities. It is also suggested that multiple use management of coastal ecosystems will provide a better basis for integrating aquaculture with other activities which have a common dependence on the functions and resources provided by one or more coastal ecosystems.

### iv.iii) Rehabilitation of Degraded Coastal and Marine Areas and Ecosystems

Where the development of coastal and marine activities has not been well planned and managed, extensive areas have often proved unproductive and have been abandoned or are lying idle. This undermines the potential for coastal zones to help sustain marine resource development. We cannot afford to allow the very extensive areas of degraded and unproductive coastal and marine systems to remain idle if we are to meet the development needs of coastal communities as well as national development objectives such as food security, and international obligations such as the conservation of biodiversity.

This raises a question of whether it would be better to rehabilitate these areas and restore the original ecosystem, or to find a means of modifying the remaining ecosystem to allow it to be more productive and capable of sustaining an alternative use. There are good arguments for both alternatives. On one hand, the rehabilitation of the original ecosystem such as a mangrove may help to rejuvenate coastal capture fisheries stocks and the income of fishermen, improve bio-diversity, reduce salinization of soils and groundwater which adversely affect agriculture and domestic water supplies, and support eco-tourism. However, it must be realised that rehabilitation will cost money, will take considerable time and may not be welcomed by local people who may see little benefit to them.

On the other hand, developing more productive use of unsuccessful development sites could allow the original developers to achieve a reasonable return on their investment, could provide opportunities to diversify and expand local employment and could reduce pressures for further conversion or coastal and marine ecosystems. For example, mixed aquaculture systems may help improve the food security of rural communities and reduce organic pollution loads from other forms of development, including more intensive aquaculture. One example might be the change from non-profitable intensive or semi-intensive shrimp culture to a less intensive polyculture system or an integrated aquaculture, agriculture, forestry system.

One innovation which is worth citing here is the development of polyceate worm culture in abandoned fish/shrimp ponds and salinized agricultural fields. This is being pioneered by Dr Peter Olive from the University of Newcastle and offers an opportunity to

- bring such lands into productive use;
- diversify the economic base;
- provide an alternative food stock for hatcheries and for pond culture systems;
- reduce the demand for trash fish which could also help maintain capture fisheries.

### v) Multiple-use of Coastal and Marine Systems as a Means of Optimising the Use of Renewable Marine Resources

The need for more integrated approaches to fisheries development and other forms of marine resources management was raised at the ICES meetings in 1994 in a paper by Burbridge (1994) which explored innovative approaches for planning for and managing the wise and sustainable use of renewable coastal resources. A major thesis presented in that paper was that planning and management systems need to be reoriented towards the maintenance of the functional integrity of coastal ecosystems which help to sustain marine biological resources. A case was also presented for multiple use management of the flows of renewable resources to promote the optimisation of economic and social benefits from coastal zone development which can also be applied to marine activities.

The concept of multiple-use can be applied to the management of coastal and marine ecosystems and the development of different marine resources. For example, mangroves can be managed to allow controlled timber production while maintaining nutrient flows to support fisheries development and to maintain coastal erosion control services of benefit to navigation. However, multiple-use planning and management in coastal and marine areas will be more complex than for upland watersheds. This is because the coastal zones of the world are ecologically, economically and socially far more complex than most watersheds. Substantial investment will be required to strengthen human resources and institutional arrangements to allow multiple-use management concepts, principles and techniques to be integrated into the thinking and actions of the myriad of agencies and resources uses with interests in promoting wise and sustainable coastal and marine resource development. This investment would be cost-effective because the sum of the benefits that could be realised from multiple use of resources sustained by coastal and marine systems would, in most cases, be superior to the maximisation of the production of one specific resource.

Multiple-use management provides the foundation for the optimisation of the use of the flows of resources generated by coastal and nearshore marine systems. However, optimisation may require management of the systems to allow some improvement in the production of selected resources. The choice of preferred resources will depend on a number of variables, including: social preference, ecological feasibility, avoidance of foreclosure of future options, equitable access to and use of resources and improved efficiency in the use of resources to allow demand and supply to be balanced with a "safe" margin for error.

### vi) The challenge of Optimising the Economic and Social Benefits Derived from Maintaining the Flow of Goods and Services Supplied by Coastal and Marine Ecosystems

By paying increased attention to both the ecology and the actual use of coastal and marine environments we have gained a clearer perception of the wide range of economic activities they support and the critically important environmental services they provide. Where the economic and environmental goods and services have been documented, the information serves as a means of illustrating their value to people responsible for allocation and use of different coastal systems. It also serves to illustrate the common dependence of different economic sectors on the same coastal ecosystems.

Although such evaluations help illustrate the significance of the environmental systems, a basic problem which remains is that the multiple functions they provide and many of the corresponding goods and services are often not understood by central government officials responsible for the formulation of development policies, investment and the allocation of coastal resources systems. These officials do, however, recognise the economic activities which seek to maximise the returns from specific resources through single purpose activities. Unfortunately, the establishment of strong government agencies to promote sectoral development activities reinforces single purpose approaches to the allocation and use of coastal and marine areas. Single purpose, zonation-based planning is the most common approach to coastal zone management in most developing countries.

A fundamental problem this creates is that agencies formed to provide leadership in one economic sector are put in charge of resource systems which may be equally important to other sectors of the economy. The classic example is the allocation of the responsibility for mangroves to departments of forestry. In comparison to upland forests, the sustainable extraction of timber and secondary forest products from mangrove is difficult and provides relatively modest revenues to forestry departments. The limited revenues earned provide little incentive or cash to manage mangrove forests well and virtually no incentive to manage them in a manner which will sustain other mangrove dependent uses such as fisheries.

Reliance on sectoral approaches creates a series of problems which make it difficult to make full use of coastal resources systems, namely:

1. a narrow range of economic activities dominate assessments of the potential use of coastal land and water resources by the sectoral agencies concerned;

2. development and investment plans are generally based upon exclusive, single purpose development;

3. inter and intra-sectoral conflicts arise which detract from the effectiveness of development initiatives and investment, and

4. it is difficult to persuade sectoral agencies that multiple-use concepts are a logical alternative for fulfilling competing development objectives.

In effect, the sectoral agencies believe they are acting in the best interests of a nation and give priority to the efficient pursuit of their development remits at the cost of other activities.

In developing nations there is growing awareness of the problems associated with sectoral approaches to the management of coastal and marine environments held in the public domain. However, breaking away from sectoral control has proven difficult and attempts to establish special agencies at the national level and working parties at the international level have not overcome practical management problems.

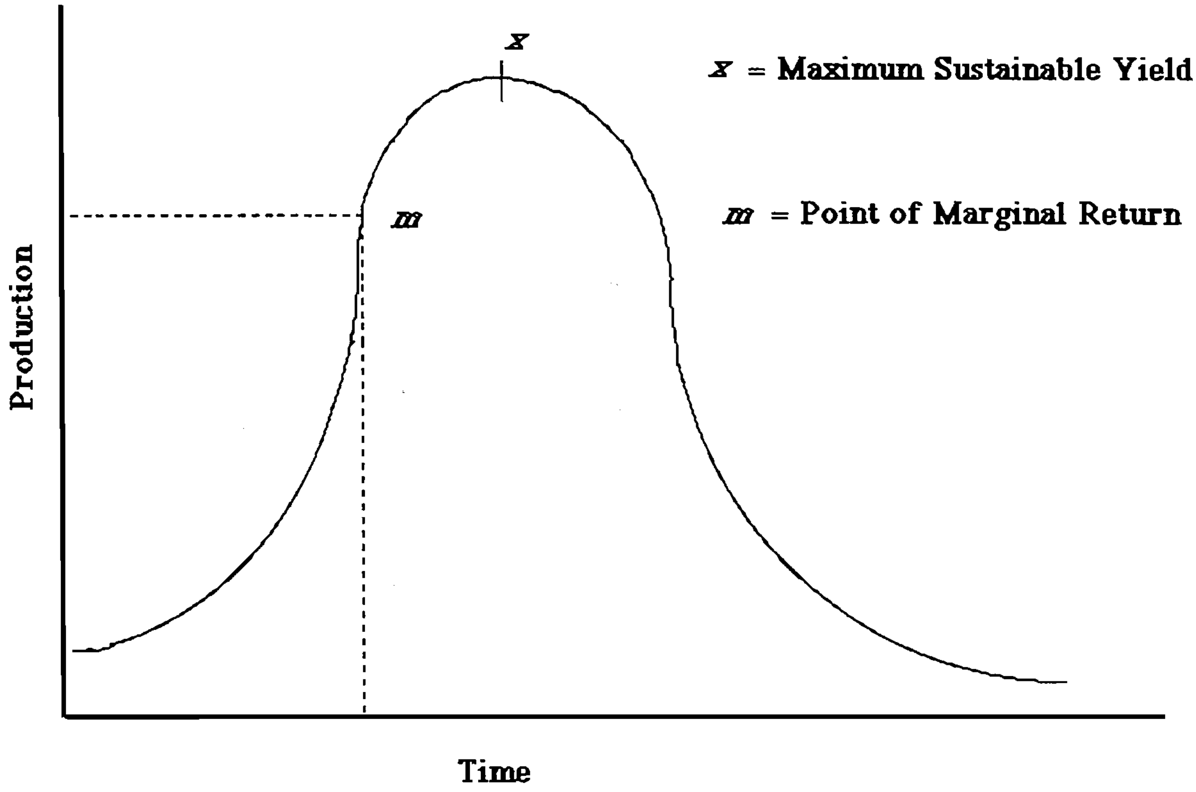
### vi.i) A Model to Help Demonstrate the Benefits of Optimising the use of Marine Resources

There is a strong need for a model for scientists to use in illustrating the benefits that can be derived from multiple use of resources generated by coastal and marine ecosystems and to facilitate the use of this information by planners and managers in strengthening the planning and management of economic activities. **Figure 4** illustrates a variety of different economic activities can be sustained by the different resources generated by one coastal or marine ecosystem. There may be competition among different users for the same resource and there will be corresponding economic links among the different users. For example, there may be a finite supply of mangrove poles to make fish traps. If one user exploits the resource heavily there will be less poles for other users.

In theory there is a point of maximum sustainable yield (MSY) for each renewable resource produced by an ecosystem beyond which production declines (**See Figure 7**). MSY of one resource cannot be viewed in isolation from the MSY of other resources from the same ecosystem. Maximum exploitation of one resource can have a negative influence on other resources. For example, if a mangrove is clear cut to maximise the extraction of timber there can be a reduction in leaf litter production which enters the estuarine food web. This can reduce secondary production of organisms which form the catch of local fishermen.

There are decreasing financial returns per unit effort expended for the extraction of the maximum sustainable yield of a renewable natural resource, such as mangrove timber, by individuals competing for that resource. This means that there is a point on a curve of production (point "m" in **Figure 7**) beyond which there are decreasing returns per unit effort/investment.

**Figure 7 Single Sector Perspective on the Use of a Marine Resource**




The same logic can be applied to the production of a series of resources generated by a coastal ecosystem where the exploitation of one resource will have a corresponding effect on the production of other resources and on potential users of those resources. If it is considered economically and socially desirable to maintain production of the mix of resources, then a level of exploitation of individual resources will have to be found which will minimise adverse effects on the production of other resources. This level of exploitation can be termed the Optimal level of Sustainable Yield or OSY. This is illustrated in **Figure 8**. It is interesting to note that the total area under the production curve at OSY for a specific resource may not be a great deal less than that for the point "m" at which increasingly marginal returns on investment or effort are realised.

**Figure 8 Illustration of Optimal Sustainable Yield Of a Marine Resource**

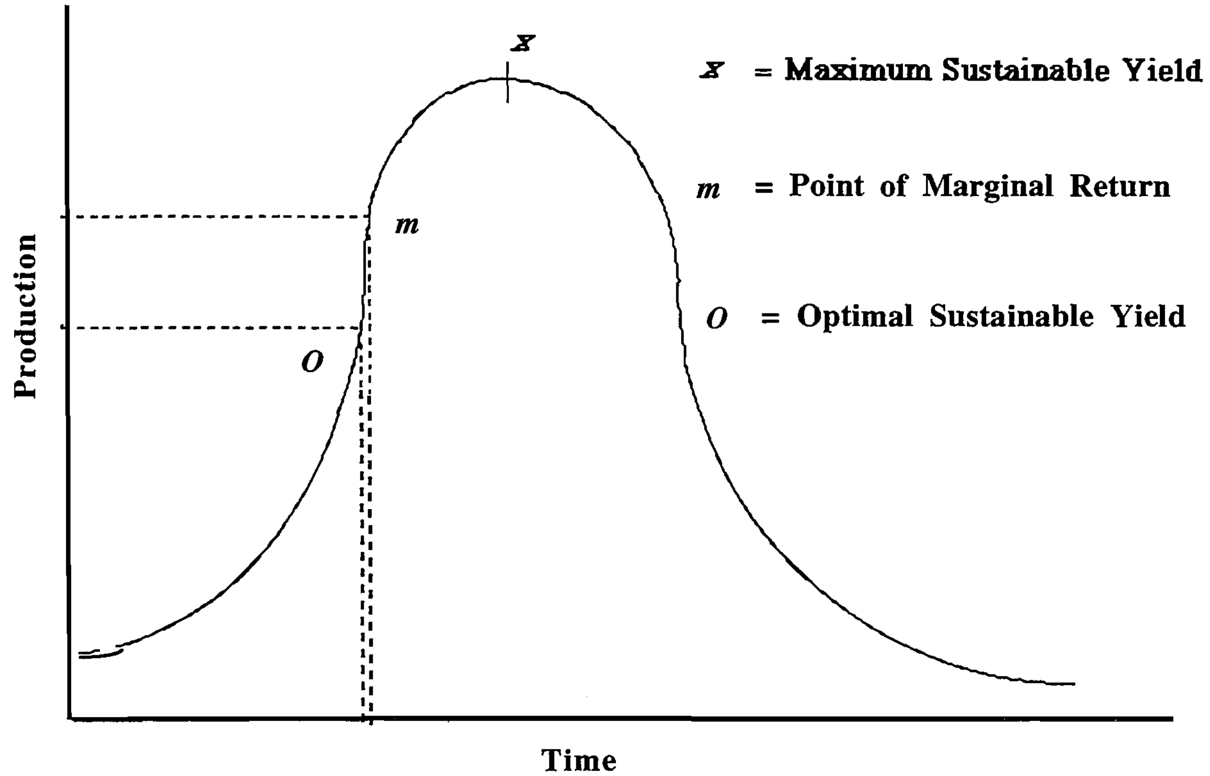
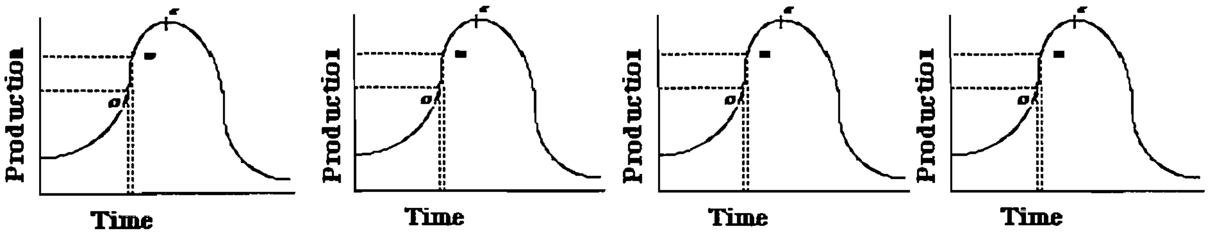



**Figure 9** illustrates a series of uses of different resources generated by a coastal or marine ecosystem where Optimum Sustainable Yields are maintained. Note that the **SUM** of the benefits is equal to the sum of the individual levels of OSY for all direct uses of resources. To this can be added a multiplier resulting from secondary economic activities sustained by the direct resource uses.

**Figure 9 Optimal Sustainable Yield from Integrated Use of Marine Resources**




*O* $\quad$ $O^1$ $\quad$ $O^2$ $\quad$ $O^3$

**Total Benefit = Sum** $O + O^1 + O^2 + O^3 + \ldots\ldots O^n$

To actually achieve the total benefits illustrated in Figure 9 will require a very good information base on the maximum sustainable yield of individual resources and how different forms and levels of exploitation of those resources will affect the health and productivity of the entire ecosystem. It will also require good information on social preferences for different resources, including the sustained availability of environmental goods and services which may not be extracted or consumed. This is a very complex challenge indeed and reinforces the idea that we need to find better ways of integrating environmental, social and economic information to help us develop the skills required to manage complex coastal systems in a sophisticated manner.

**vii) Conclusions**

For the foreseeable future most coastal nations will remain heavily dependent upon marine resources to meet the needs of expanding populations and the need to expand and diversify their economies. However, there is mounting evidence of damage to the functional integrity of coastal and related marine ecosystems, declining availability of marine resources and the loss of future development options for optimising the use of marine resources. Most of these issues have come about as a result of:

1. incomplete scientific understanding of how marine resources production is linked to the functions of coastal and related marine ecosystems;

2. a serious underestimation of the value of coastal and marine ecosystems and the resources, including services, they generate;

3. sectoral policies, management strategies and plans which focus upon individual forms of marine resource development in isolation from one another;

4. adoption of resource allocation and management practices which focus upon managing harvesting pressures and largely ignore the need to maintain the health and productivity of ecosystems which sustain those resources;

5. adoption of management units which artificially separate marine and coastal systems and ignore the environmental linkages that influence their health and productivity.

It will be very difficult, if not impossible, to achieve optimal use of marine resources without dealing with these issues which lead to degradation of the functional integrity of coastal and marine ecosystems and weaken their ability to generate the resources that sustain human development needs. We need to develop a broader concept of management- one that is based on:

- The ecology of the natural systems which sustain the creation of marine resources;
- The management of the environmental impacts that a wide array of human activities can impose on the functional integrity of those natural systems;
- The adoption of marine resources management units based on the environmental linkages among coastal and marine ecosystems. Such units could provide an appropriate framework for integrating the scientific research required to develop our understanding of functional linkages shared by coastal and marine ecosystems;
- The use of these units as a more rational basis for developing integrated systems based management policies and management practices which would support measures to sustain marine resource production and use;
- The adoption of multiple use management concepts as a more rational basis for developing more integrated policies and resources management strategies; and
- The development of more sophisticated economic techniques for defining optimal levels of resource use for specific activities which share a common dependence on marine resources generated by associated coastal and marine ecosystems.

There will still remain the challenge of developing economically efficient and socially equitable allocation of resources among competing users. This will require further advances in economics to develop tools to help us bridge concepts of environmentally sustainable resource production with economically efficient and socially equitable forms of resource use that can be adjusted as the needs and aspirations of societies evolve. This reinforces the need for better scientific information, the need to integrate both information and its interpretation among disciplines in order to strengthen the process of formulating and implementing policies, investment strategies and development plans for sustainable and optimal marine resource utilisation.

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# Optimal Use : Fundamental Considerations

- How the resources we wish to exploit are created - Renewable versus Non-renewable resources
- Maintenance of the functional integrity of the systems that create marine biological resources
- Harvesting the Flows of resources from coastal and marine ecosystems
- Resolution of non-sustainable management practices affecting the production and utilisation of those resources
- Economically efficient and equitable allocation of resources among competing uses

# Sustainable Production and Utilisation of Marine Resources

- The concept of sustainable utilisation of marine resources refers primarily to the use of the **flows** of resources created by marine ecosystems within an appropriate time frame.
- We should therefore differentiate between **stocks** of resources, such as deposits of oil and gas or stocks of fish, and the rates at which such stocks can be regenerated by nature relative to man's dependence on those resources. This gives us a measure of the **flows** of resources which can be harvested at a sustainable level within a known time frame.

# Sustainable Production and Utilisation of Marine Resources

- Our definition of marine resources should include **environmental services**
- Few if any of these resources will continue to exist if we do not prevent adverse impacts on the natural ecosystems which generate those resources. This raises a fundamental issue-
- Can we hope to achieve sustainable use of marine resources just by managing the rate at which they are harvested ? **NO**

# A Broader Scientific and Management Framework is Required

- We need to broaden the scientific framework for sustainable marine resource development to include the ecological processes which maintain the health and productivity of the ecosystems that sustain the stocks and flows of coastal and marine resources we seek to utilise.

# Improved Scientific Knowledge Is Required

- Does the scientific knowledge exist to enable us to fully comprehend the environmental processes linking coastal and marine ecosystems, how marine and coastal systems function, how they may be mutually supporting, what forms or resources they generate and what forms and levels of resource use they can sustain ????.
- Without such basic information it will be very difficult to manage sustainable resources production or to optimise their subsequent use.

# Broadening Scientific Framework for Marine Resources Management

- Functional Analysis of coastal and marine ecosystems
- Understanding the Linkages among coastal and marine ecosystems

## Functional Analysis of Coastal and Marine Ecosystems

## Functions of Mangrove Ecosystems

- Primary Production
- Secondary Production
- Storage
- Filtration and Cleansing
- Pathways of Linkages among ecosystems
- Buffer

## Broadening the Management Framework for Sustainable Marine Resources Development

- Understanding the Impact of human activities on the health and productivity of coastal and marine ecosystems
- Managing Impacts as a means of maintaining the carrying capacity of coastal and marine ecosystems
- Resolving Non-sustainable management practices that adversely affect the production and use of renewable marine resources
- Rehabilitation of degraded ecosystems

## Integrating Concepts For Optimising Marine Resources Development

- Multiple-use of coastal and marine systems as a means of optimising the use of renewable marine resources
- Demonstrating the benefits of optimising resource production and utilisation

## Conclusions

- A broader foundation for marine resource management is needed- one that is based on:
- The ecology of the natural systems which sustain the creation of marine resources;
- The management of the environmental impacts that a wide array of human activities can impose on the functional integrity of those natural systems;
- The adoption of marine resources management units based on the environmental linkages among coastal and marine ecosystems.

# Conclusions continued

- Use of these units as a more rational basis for developing integrated systems based management policies and management practices which would support measures to sustain marine resource production and use;
- Adoption of multiple use management concepts as a more rational basis for developing integrated policies and resources management strategies; and
- Development of more sophisticated economic techniques for defining optimal levels of resource use for specific activities which share a common dependence on marine resources generated by associated coastal and marine ecosystems.

## 5.8 Abstract of a Keynote Talk entitled, *The role of industry in enhancing the harvest of the ocean* by Espen Hoell, Norsk Hydro - Research Centre Porsgrunn

### Background

First of all it is natural to ask; what is the reason for industrial involvement in sustainable harvest of marine biological resources? Until recently, industry has been concerned about making most profit out of natural resources, often at the cost of the environment. Extensive fisheries, beyond limits of sustainable harvest, is one example and during the last decade, aquaculture has offered business opportunities, not always without influence on the environment.

However significant changes have occurred in the strategic thinking of many industrial enterprises the last decade, with the implementation of management systems for such concerns as environmental reporting, discharge elimination, environmental performance indicators, environmental management principles etc. Although difficult to put into operation, many industries have adopted the concept of sustainable development into their thinking, in the meaning; we cannot operate today in a manner that damages the environment so that we cannot continue the same processes in future generations.

For Norsk Hydro the matter could be simplified to: "We have made our business on the global demands for food during the last 100 years, and we will continue to do so for the next 100 years." It is obvious that global food production cannot be based on a polluted and degraded environment. A key question is therefore; *How can the demands of the rapidly growing population be met without further environmental degradation, hopefully even with improved environmental quality at a global scale?*

The company's environmental principles state that the basis for its policy and decision making will be:

- care for the environment and the well-being of future generations
- a strong sense of responsibility for people and the environment
- product designs to have minimum adverse effect on the environment throughout their entire life cycle
- promotion of the correct and appropriate use of our products to minimise pollution and risks
- encouraging the re-use and recycling of our products
- knowledge expansion through research and development, to ensure that our solutions are appropriate for the environment in the long term
- management responsibility for integrating the company's environmental principles into long term objectives and strategies.

Norsk Hydro has several activities related to the utilisation of living marine resources. We are a significant salmon and alginate producer at world scale. We produce omega-3 fatty acids, chitosan and other marine biochemicals for several purposes and our fish feed production is important for the European salmon industry. Last, but not least, our agricultural division are engaged in food production world-wide.

### Pointing at needs to increase the marine harvest

Although FAO are optimistic about the possibilities of agriculture sustaining the nutritional requirements of a doubling in World population, there are many reasons to consider new possibilities:

- Significantly, more land area for cultivation is needed.
- Problems connected to freshwater supply, irrigation and groundwater table.
- Even higher productivity of agricultural land is needed, using modern technology and at the same time reducing losses and environmental impact of agriculture

- Changing the human diet towards more grain and vegetables and less meat consumption per capita.

Some, such as the World Watch Institute even consider the global food production today as having reached the limit of carrying capacity. Most experts however, seem to think that reality will be somewhat in between these extremes. This is also the case for Norsk Hydro. Therefore there is an urgent need to initiate large scale research into new possibilities. *The utilisation of the ocean for food production purposes, not only by hunting the resources, but also by cultivating some of these systems, stand out as one of few options available for the future,* especially because of the availability of water and sunlight over vast areas.

Both FAO and World Watch seem to agree that fisheries today are at or above the limit of sustainable harvest, about 80 mill tons annually. There is little doubt that world fisheries at the moment are under great stress, with 2/3 of the worlds fish stocks being fished at or beyond their level of maximum productivity. Just increasing the harvest therefore seems unlikely, although there may be a potential for better utilisation of the discards and bycatch than today, and it is believed that an additional 20 mill tons could be harvested if the stocks where allowed to recover to healthy conditions. Besides strictly regulating and downsizing the fishing fleet, *the only way to increase the harvest is to investigate new methods of increasing the productivity of the fish stocks.*

Aquaculture is one of the few bright spots, rapidly growing, and now accounting for nearly 16% of the fish harvest, but also here availability of fish protein for feed production is a limiting factor. *Finding new sources for protein-rich marine feed is another demanding task.*

Also degradation of coastal ecosystems has affected spawning seriously, probably depleting many fish stocks. *There is a strong need to find ways for the remediation of these areas,* e.g. by substrate improvements, artificial constructions, restoring the nutrient balance and composition of coastal waters and recycling of nutrients. The latter are causing environmental problems, but could be potential resources if they were utilised better in aquaculture production.

In addition to fisheries regulation, the only way to secure sustainable development and use of marine living resources is to *initiate targeted, fundamental ecological research with long perspectives, including learning from the mistakes made by agriculture and human exploitation of the marine environment.* Yet, to trigger the interest of European industry, *the research must also have applied aspects,* opening for utilisation of commercial possibilities along the way. It should *involve experimental aspects,* demonstrating commercial opportunities. *The research must involve the concentration of a large number of scientists over a significant period of time.* This is truly a great challenge.

**Observing variable efficiency and asking questions**

As scientists in industry we look for, and observe, a great variation in the efficiency of food production of various production systems in the world. A noteworthy difference exists between marine and terrestrial productivity. Although the oceans are twice the area of the land, the primary production of the two systems are of the same magnitude. In addition, our utilisation of terrestrial primary productivity for human protein is at least 20 times greater than that of the ocean. The reason probably, at least partially, is that terrestrial productivity has been developed in agriculture for centuries or even millennia, while marine harvest still is at the hunter-gatherer stage. This indicates a large potential for marine living resources; is *it possible to cultivate parts of the marine systems and resources?*

Looking at ocean areas we find great differences in efficiency. It seems that about 80% of the marine primary production takes place in the open ocean (90 % of the World covered by the sea), yet sustaining only 0.2% of the fisheries. Likewise the upwelling areas, covering 0.1% of the seas, sustain 50% of the fisheries based on 0.5% of the primary production of the ocean. Coastal systems lie between these two extremes. Upwelling areas seem to be characterised by the semi-continuous supply of nutrient-rich deep water, in balanced composition, stimulating short and efficient food chains, while the open oceans are characterised by long food chains and microbial loops. In Europe the upwelling off Galicia is a good example of such a rich system. Mostly they seem to function well without environmental problems. These differences indicate potentials for expansion and creation of similar functioning systems. *Can we learn to simulate the dynamics, function and efficiency of upwelling systems? Could it be possible to increase the fisheries by 50% with a doubling of the upwelling area?*

The spring bloom situation of temperate shelf systems is another example of efficient productivity, in this case over a shorter period of time. Well-mixed, nutrient-rich waters at the offset of the spring bloom set up an intensive primary production, efficiently channelled through zooplankton to species higher up in the food web. The new production of these systems is able to remove most of the nutrients from the upper waters. This productivity forms the basis for rich fisheries, such as on the Norwegian shelf. In summer, however, the system is characterised by lower efficiency mostly with regenerated production of the microbial loop. *Would it be possible to prolong the spring bloom situation and channel more productivity into the harvestable species?*

Northern waters, such as the Barents Sea, also exhibit amazingly high productivity in spite of the short periods with sufficient light for primary production. According to the ProMare programme this is due to the regular passage of polar "atmospheric" low's, passing every fortnight, setting up a situation with alternating stratified upper water and mixing with deeper nutrient-rich water, the pulsed supply to the system being a key factor to high productivity and efficient transformation to higher levels of the food chain. *Could one set up similar pulsing systems other places, and achieve a similar productivity?*

In systems dominated by spring blooms a typical feature seems to be intensive spawning timed almost perfectly to the onset of the spring bloom. Good year-classes seem to occur when there is a close match between spawning and the spring bloom, while in years with a mismatch between spawning and spring bloom timing poor year-classes are produced. *Is it possible to produce more good year-classes by improving the match/mismatch situation?* Spawning seems to represent a significant transport of nutrients and organic matter from the open ocean to shelf and inshore waters, because only a minor part of the spawning products develop successfully to surviving fish larvae. The faeces produced by high density spawning stocks and their decomposed spawning products must represent a significant natural fertilisation of the very same waters in which the eggs will develop. *Could it be that the present reduction of spawning stocks has depleted this natural mechanism, thus reducing the possibility for a close match between spawning and spring bloom intensity?*

The above are some examples, among many, that indicate potentials for a significant increase in the marine productivity, *demanding a significant targeted research effort which could prove very important for future generations.*

**Initiating research**

Being a world-wide international company with high economical and environmental ambitions it is natural for us to initiate research into areas recognised as having a major importance for the development of the company. Research with a long-term perspective has been initiated by Norsk Hydro with a view of a good financial return for the company in the long-term. Developing knowledge is the fundament for all our activities, and it is recognised by the company that new knowledge provides new business opportunities.

For these reasons we have initiated the Norwegian research programme MARICULT running from 1996 through to 2000, and we have taken the initiative to support this workshop. Critics of MARICULT believe it is a nasty attempt to make profit by destroying the marine environment; the reality is that MARICULT is a serious initiative to investigate possibilities for sustainable harvest enhancement and understanding marine productivity. However, as we realise that the topic of sustainable development of marine living resources is of importance across Europe, as well as for our business opportunities, we wish to see a larger *targeted research activity* organised within the Fifth Framework Programme (FPV) where good science dominates over politics, on the matters addressed by the workshop. We are sure that such research also will benefit several other European industries. However, it should be pointed out that the interest of European industry in marine research has been low so far, probably because there has been a lack of opportunity-oriented goals and experimental activity on former Framework Programmes. *To improve on this we recommend that research expertise from major food and marine-related European industries is included in the programme planning and proposal evaluation stages of Framework 5 (FPV).*

**Closing loops**

Being the leading supplier of nutrients to agriculture in Europe, Norsk Hydro are fully aware of the negative environmental effects related to excess consumption of these products in intensive agriculture, especially because a large proportion of agricultural production is channelled through intensive husbandry resulting in excess manure in relation to available dispersal area. The company has for a decade adopted product responsibility by involvement in programmes to reduce the excess consumption of fertilisers, and to improve the utilisation of these resources in agriculture. In recent years we have been involved also in developing good agricultural practices, precision farming, soil quality testing, and balanced fertiliser composition.

Our environmental principles also include product recycling. For nutrients that are widely distributed and occur in several different streams this is extremely difficult, however, and need to be integrated across many of the Society's activities. We are now considering various options for nutrient recycling, and realise that these must include the marine system also. Nutrients tend to end up in the sea and cause environmental problems due to concentrated discharges, poor elemental balance, and interaction with other effluents, such as organic matter, environmental toxins and heavy metals. In cases where clean-up operations are not sufficient, the task will involve redistributing nutrients, restoring natural balance, and using biological production for bioremediation and harvesting purposes. *Research is needed to improve the knowledge on how nutrients structure the functioning of food webs, what the systems carrying capacities are and how nutrients could be channelled from eutrophication problems to harvestable resources.* This certainly is not a research task for industry alone.

One interesting option could be to grow different types of seaweed in polluted waters. Considering the primary of production of these plants (5 to 30 kg per $m^2$ per yr.) a significant concentration of nutrients, carbon (C/N~21) and possibly heavy metals could be removed from the coastal waters. Technology exist for conversion to biogas or methanol, and the nutrients and other elements could be removed and recycled from the residue. When used for energy purposes such effort may also form a contribution to the reduction of global warming gas emissions from Europe, by replacing the use of fossil fuels. Further it may be possible to increase the protein synthesis of these plants, by stimulating growth mechanisms that favour protein formation. *However research is needed on plant physiology, growth technology and socio-economic effects of large scale implementation.*

Growing and harvesting resources lower down in the food chain also represents an interesting solution/opportunity for the bioremediation of nutrient-rich waters, and for increased aquaculture. In both cases there is *a need to find the optimum growth conditions, and to test this in experimental systems.* Mussels and oysters are examples of such organisms, and represent an attractive protein source for human consumption.

It must however be strongly underlined that cultivating living marine resources for food purposes demands an intensified European clean-up operation regarding land-based use and discharges of environmental toxins as well as of heavy metals. A beneficial result of a decision to utilise marine systems for food production more fully, could well be a change in attitude towards better marine environmental management and the prevention of pollution from harmful substances. *This work has begun, and will undoubtedly go on anyway, but the focus should be strengthened in parallel with research programmes.*

To make new solutions sustainable for the future there is *a strong need to focus on environmental perspectives e.g. biodiversity, as well as other socio-economic implications, such as optimising for multiple use, rights to harvest, ethical questions and international regulation.* Before implementing large scale cultivation measures of migrating species, the problem with over-fishing and international regulation of fisheries must be solved, a pressing matter for Europe anyway.

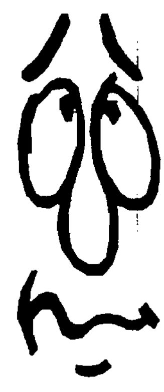
**Utilising potentials**

Finally the role of industry is to exploit the commercial opportunities that will arise as result of targeted research with high ambitions and long perspectives. We are confident that these will occur, as long as the focus of the research is to find possibilities and identify their constraints, in contradiction to the traditional focus on focussing on problems instead of solutions. There are possibilities for companies engaged in food production over a wide range, in green technology, in advanced monitoring technology and in marine construction, among others. We believe however that it is possible to make early decisions on what the commercial outcome of any research effort will be. Important opportunities could be missed if we take a too blinkered view. Within our activities related to marine resources Norsk Hydro, as an example, is likely to find several profitable applications, as yet unidentified, that could be utilised in a sustainable manner.

If industry is expected to take part in long-term, strategic research, the risks are likely to be higher than in ordinary technology development projects, thus a lower industrial share of the projects should be allowed. The virtual absence of industrial partners in the past, and present, MAST and Environment programmes could be due to the need to provide 50% of the research costs, combined with the fundamental nature of the research, and difficulties to implement applied research within and across the programmes. *Greater efforts should be put into collating and making available the research information from both previous and future research activities.*

# The role of industry in enhancing the harvest of the ocean

- Why industry interest in sustainable harvest of living marine resources?
- Pointing at needs to increase the marine harvest
- Observing variable efficiency and asking questions
- Initiating research
- Closing loops
- Utilising potentials



# Why?

- Significant changes has occurred since the days of; make profit, dump your wastes
  - Business on global food demands the last 100 years, continuing the next 100 years! Cannot be based on polluted and degraded environment
- Hydro's environmental principles;
  - care for the environment and the well-being of future generations
  - a strong sense of responsibility for people and the environment
  - product design to have minimum adverse effect throughout their entire life cycle
  - promotion of correct and appropriate use of our products to minimise pollution and risks
  - encouraging reuse and recycling of our products
  - knowledge expansion through research and development, to ensure appropriate solutions in the long term
  - management responsibility for integrating the environmental principles into long term objectives and strategies.
- Hydro's business activities;
  - salmon, alginates at world scale, omega-3 fatty acids, chitosan, marine biochemichals, fish feed,
  - agriculture and food production world-wide

Needs to increase the marine harvest

# Global food supply next generations

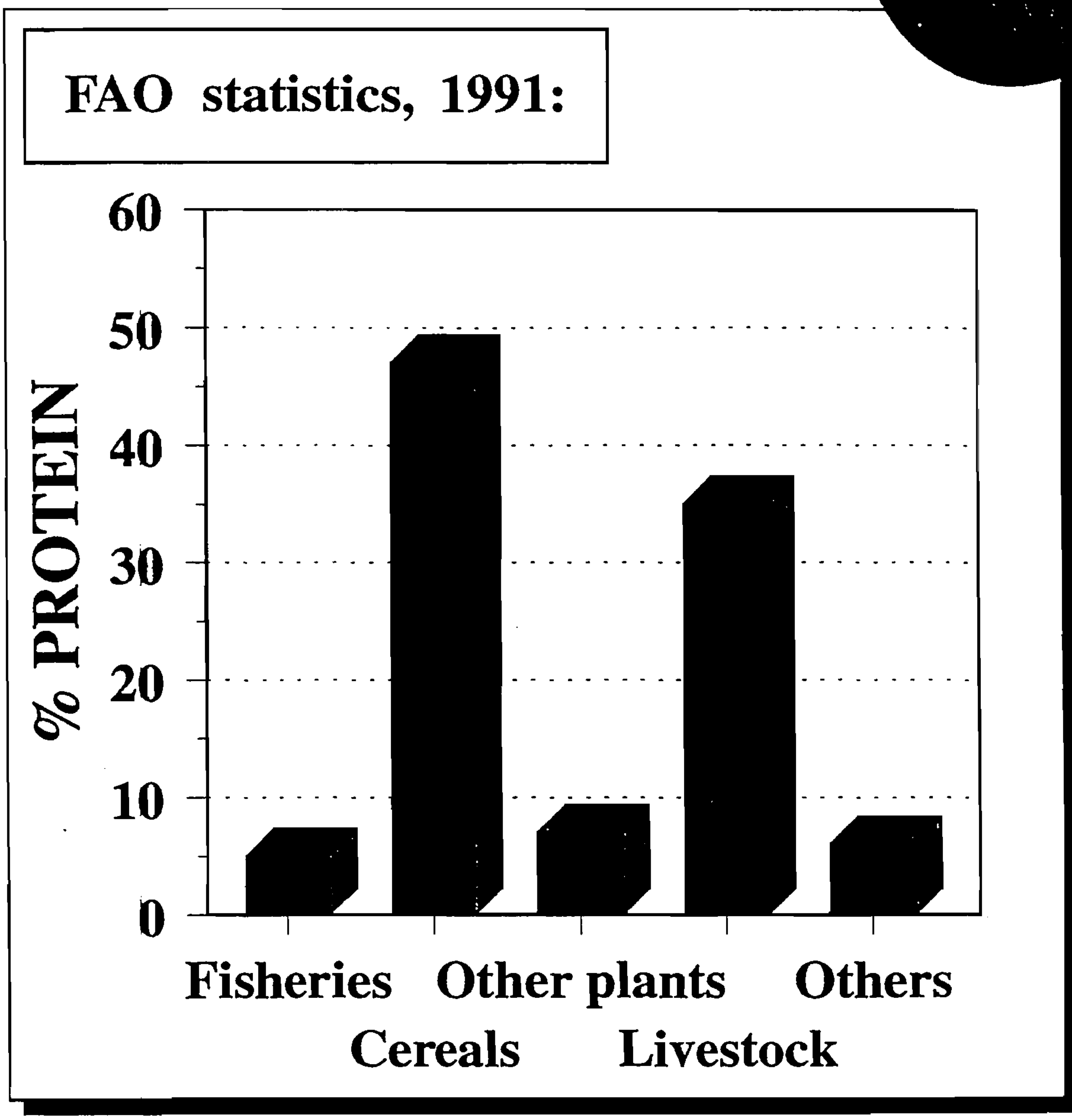
- FAO optimistic about 10 billions, but
  - Significantly more cultivated land is needed.
  - Problems connected to freshwater supply, irrigation and groundwater table.
  - Even higher productivity of agricultural land is needed, using modern technology and at the same time reducing losses and environmental impact of agriculture
  - Changing the human diet towards more grain and vegetables and less meat consumption per capita.
- World Watch - food production today at limit of carrying capacity.
- Reality somewhat in between?

# Needs to increase the marine harvest

## Fisheries limitation..........

- Fisheries today are at or above the limit of sustainable harvest
  - Besides strictly regulating and down sizing the fishing fleet, the only way to increase the harvest; investigate new methods of increasing the fish stock productivity
- Aquaculture - one of the few bright spots, rapidly growing, but availability of fish protein for feed production a limiting factor
  - Finding new sources for protein rich marine feed
- Degradation of coastal ecosystems has affected spawning, depleting many fish stocks?
  - A strong need to find ways for their remediation
  - Substrate improvements, artificial constructions, restoring nutrient balance and composition, recycling of nutrients
- Initiate targeted, fundamental ecological research with long perspectives,
  - learn from mistakes by agriculture and human exploitation of the marine environment

# Observing variable efficiency, asking questions

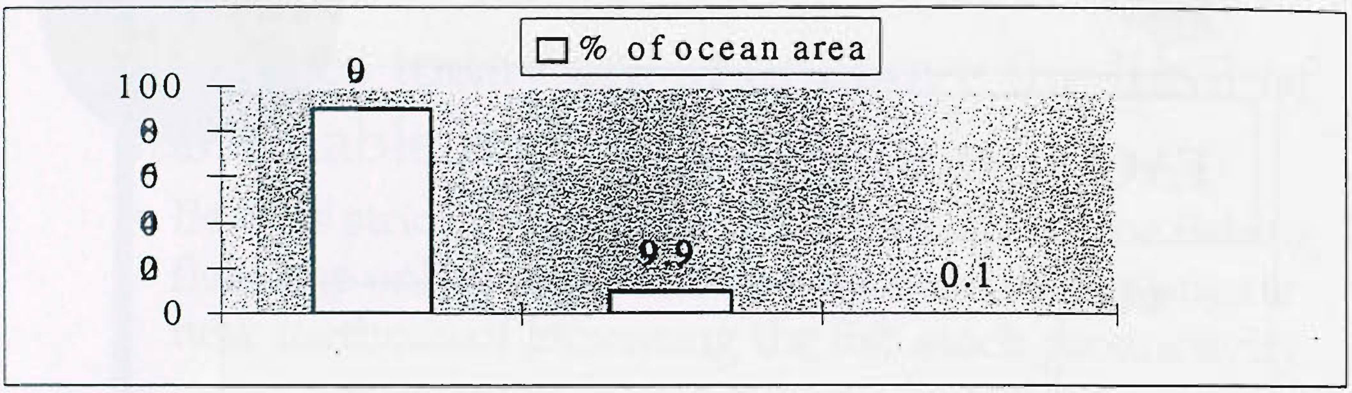


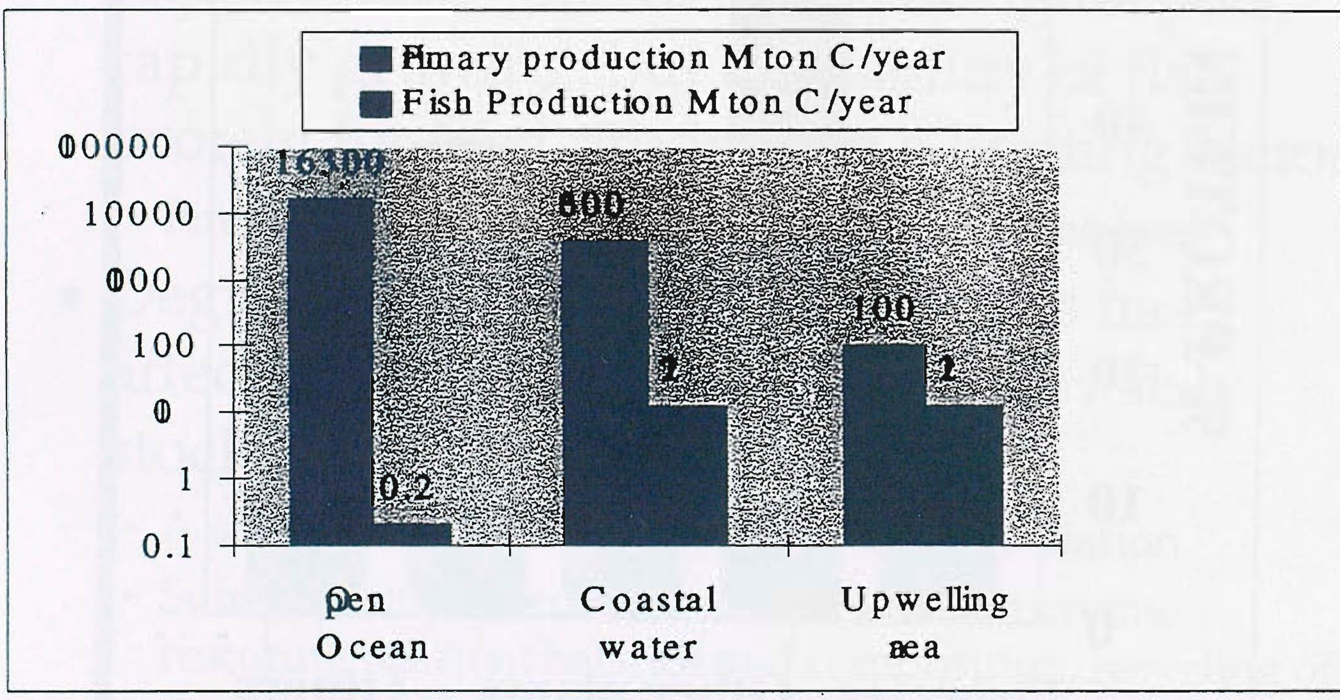

Ocean area > land, primary production equal

Can we cultivate parts of the marine system and its resources ?

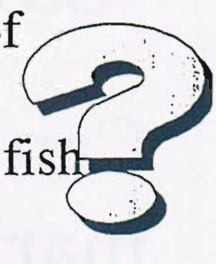
# Observing variable efficiency, asking questions

(Lally&Parsons 1993; Biological Oceanography)




- High and continuos nutrient input, balanced composition, high productivity, short food chains and few environmental problems.
- Can simulate the dynamics, function and efficiency of upwelling systems?
- A doubling of the "upwelling" area - 50% increase in fish production?



# Observing variable efficiency, asking questions

- Efficient channelling of primary production via zooplankton to fish in spring bloom situations
  - Basis for rich fisheries
  - This new production empty nutrients from upper waters
  - Regenerated production and microbial loops in summer
- Barents sea high productivity due to regular passage of polar low's
  - Alternating stratified and mixed waters
  - Pulsed nutrient supply
- Spawning timed to spring bloom, match mismatch, good and poor yearclasses
- Spawning represent significant transport of nutrients and organic matter to coastal water

Prolong spring bloom, channelling more into the food web? Pulse the nutrient supply and set up efficient productivity? Reduce mismatch and get more good yearclasses? Has reduced spawning intensity reduced the number of good matches?

# Initiating research

- Natural for a world-wide company with high ambitions in its areas of major importance
  - Long perspective res. have given good payback earlier
  - Developing knowledge the fundament for all our activities
  - New knowledge provides business opportunities
- Maricult programme running in Norway 1996 - 2000
  - Critics: a nasty attempt to make profit on destroying the marine environment
  - Reality being a serious initiative to investigate sustainable harvest enhancement possibilities, the first steps
- Initiative to and support for Ocean Harvest 97
  - Hoping to see a targeted research activity within framework 5. with good science dominating over politics
  - Opportunity orientation and experimental activity to trigger interest of European industry
  - Include expertise of major food and marine related industries in programme planning and proposal evaluation
- A concentrated targeted research activity in Europe!
  - Involving a major fraction of scientists over a significant period of time

# Closing loops

- Europe's leading supplier of nutrients -
  - Fully aware of the negative environmental effects related to excess consumption in agriculture
- Product responsibility for a decade
  - Reduce excess consumption programmes
  - Improved utilisation of nutrients in agriculture
  - Development of good agricultural practices, precision farming, soil quality testing, balanced fertiliser composition
- Nutrient recycling in our thinking, but extremely difficult
  - Widely distributed, integrated in many streams of society
  - Must also include the marine system
  - Redistributing, restoring balance, using biological production
- Research needed on
  - how nutrients structure the functioning of the food web
  - the systems carrying capacity
  - how to channel productivity from eutrophication to harvestable resources
- Not a task for industry alone!

# Closing loops - II

## Possible options

- Growing seaweed's
  - High primary production, removing nutrients, carbon, heavy metals
  - Biomass conversion to biogas or methanol, Subtraction of nutrients and other elements from the residue. A contribution also to mitigate climate change if replacing fossil fuels
  - Increased protein synthesis for fish feed production?
  - Research needed on plant physiology, growth technology and socio-economic effects of large scale implementation
- Growing and harvesting low down the food chain
  - Mussels and oysters.........
  - Research needed to find optimum growth conditions, tested in experimental systems
- Cultivating marine species demands an intensified European clean-up operation
  - Land based use and discharges of environmental toxins and heavy metals
- Strong need to focus on environmental perspectives (biodiversity...........)

# Utilising potentials

- Industry will exploit the commercial opportunities as they arise from targeted research with high ambitions and long perspectives
  - Focus on possibilities and their constraints in contradiction to problems
- Opportunities for companies within
  - Food production in a wide range, green technologies, advanced monitoring, marine constructions
- Not recommendable to make early decisions on the commercial outcome
  - Losing opportunities because of "blinkers"
- Norsk Hydro are likely to find several profitable possibilities
- Reduce the commercial risk of long perspective R&D
  - Lower funding share, include applied aspects, experimental activities
- Systemize and make R&D information available to industry, previous and coming
  - Specially important for SME's

# 6. General Summary and Synthesis of Workshop Discussions

The Workshop was arranged to address the issue of ocean harvesting from a variety of perspectives. The first perspective was global; the consideration of the protein demands of the human population and setting out the case of significant enhancement of global food production. Secondly, the regional perspective was provided by consideration of the yield, social and economic objectives governing the development of policies on the exploitation of living resources. In general, there is little indication that regional objectives for marine harvesting are being effectively coordinated to meet the global demands.

## 6.1 Summary of Plenary Discussions
**Overall Workshop Rapporteur - Dr Mike Heath, Marine Laboratory, Aberdeen**

### 6.1.1 The Global Perspective

The continued growth in global human population has led to an ever increasing shortfall between food requirements and production. The shortfall is not only a consequence of the increasing human population, but also of factors such as loss of agricultural land to urban development, and economic development of nations leading to changes in diet composition. It is well known that existing resources are very unevenly distributed between developed and developing nations, yet calculations show that closing the projected future gap between demand and production on a global scale cannot be achieved by redistribution of resources. More fundamental solutions will be required.

Significant increases in the area of terrestrial production probably cannot be achieved, so if the demand is to be met from terrestrial sources then it must be achieved by increasing the yield per unit area. There was some doubt as to whether this is feasible. Water, temperature and disease are the main limitations on yield. Most of the gains due to selective breeding for disease resistance have probably already been achieved, and water resources are coming under increasing pressure for human consumption. Intensive cultivation by the use of artificial fertilisers has been questioned with regard to sustainability. The role of climate change in influencing future yields could be through retreat of polar and subpolar climatic zones, and changes in rainfall pattern, but no expertise was available to comment on this aspect.

In contrast to terrestrial production, marine food products currently meet only a small (1%) of the global human consumption of energy, although the proportion is much higher in some regions. Traditional harvestable resources from the seas are clearly under extreme pressure and are unlikely to yield the scale of harvest increase that is required under existing exploitation strategies. Yet, the yield from the oceans is extremely low compared to the global ocean primary production. This is partly because marine resources are traditionally exploited as higher trophic levels with consequent low percentage conversion of primary production. There is a clear need for a strategic examination of the way in which mankind makes use of living marine resources to determine whether alternative approaches might not produce dramatically different yield of human consumption products. This should include assessment of the marketability of new marine products.

Global marine production is highly unevenly distributed, being concentrated into upwelling systems and continental shelf seas were the flux of nutrients to the euphotic zone is highest. The rate of nutrient supply, complexity of the pelagic food web, and the potential yield of fish resources are all closely interrelated. Essentially, fewer trophic levels are involved in transferring nutrients from the dissolved phase to harvestable fish biomass in upwelling and coastal systems than in open oceanic regions. This is partly due to physical interactions - low vertical mixing oceanic environments favour small-cell phytoplankton which sink only slowly and outcompete larger cells in low nutrient situations where production is based on recycling. Production by small-cell species inevitably implies increased trophic transfers before nutrients are incorporated into fish. In contrast, high nutrient, high mixing environments favour large-cell phytoplankton (diatoms) with fewer trophic transfers to fish.

Opportunities for increasing marine harvests can be broadly grouped into those involving artificial enhancement of lower trophic level production, and those involving optimising the exploitation of higher trophic levels. In both cases, extensive and intensive approaches should be considered. Extensive approaches include engineering systems to create artificial upwelling for natural nutrient rich water from depth to the euphotic zone, or cultivation systems for shellfish that feed on the naturally occurring phytoplankton. Intensive approaches include traditional cage based aquaculture where high stocking densities are sustained by artificial feeding and husbandry. In general, as in terrestrial agriculture, intensive approaches have been shown to have impacts on the ecosystem (heavy metal and toxin accumulation) which in the long term may cause the approach to become unsustainable. However, returns from extensive approaches, such as ranching, have so far been generally disappointing. Genetic enhancement programmes may be considered to span both the extensive and intensive approaches. Breeding programmes on tropical intensive aquaculture species (especially *Tilapia*) have shown high potential to improve productivity. Extensive ranching of genetically enhanced salmonids has been carried out in some areas but there is strong evidence that the release of such fish can have a detrimental effect on wild stocks.

The ability to predict the consequences of intervention in the ecosystem was seen as a major limitation to developing strategies for managing marine systems. Several examples were presented which illustrated the non-deterministic response of ecosystems to disturbance. There are strong indications of multiple stable states with inherently unpredictable switches between states. The time scales required to monitor the species succesional consequences of large scale disturbances are often long in relation to human lifespans, extending to thousands of years in extreme cases. In part, this is due to interactions between organisms at the individual level which limit the ability of species to recolonise a system following catastrophic disturbance. These processes often bear little or no relation to trophodynamics. Critically, there are almost no quantitative data on the consequences of human harvesting activities on the oceans because of the time scales involved and the difficulties of disaggregating anthropogenic consequences from changes due to natural climatic fluctuations. Thus, all attempts at manipulating the marine ecosystem to increase yield should be treated as experimental

The role of large-scale physics in controlling the productivity of ecosystems was illustrated by a presentation on the Benguela Upwelling System. Here, spatial and temporal variability in upwelling intensity is controlled by regional patterns of wind stress. Upwelling stimulates new (nitrate based) primary production of diatoms in the euphotic zone which transfers efficiently to enhancement of mesozooplankton which are the food of small pelagic fish in the region. However, the key point was that the long term (year-to-year) response of for example anchovy spawning stock biomass to the annual new production was highly non-linear due to the interaction of trophodynamic factors with physical processes operating at the individual level - in this case probably the over-dispersal of larvae and depression of prey captures success by turbulence at high wind stress. The lessons to be learnt from the study are that 1) ocean basin scale meteorology and physical oceanographic processes have an overwhelming influence on the productivity of marine ecosystems and the capacity of mankind to influence or override these factors is slight, and 2) the temporal consequences of productivity fluctuations within an ecosystem for higher trophic level populations may have as much (or more in some cases) to do with the behaviour and biology of individuals as with trophodynamics.

### 6.1.2 Regional Management Objectives

There were conflicting views as to the objectives of regional harvesting policies. One perspective concerned application of the Precautionary Principle, as enshrined in OSPAR Convention for the Protection of the Marine Environment, which was interpreted by some to state that intervention in the ecosystem should be forbidden whenever there are reasonable grounds for concern regarding unintended consequences. However, there was widespread concern that such interpretations could be taken as the basis for a zero-intervention policy. The argument was put strongly that non-intervention is not an option.

The stated aim of some Non-Governmental Organisations is to allow damaged ecosystems to return to their 'natural' state or close to it, but there is no theoretical basis for assuming that the 'natural' state is an identifiable stable condition, or that un-exploited ecosystems will gravitate towards such a state within a given time scale. There are few, if any, areas left in Europe which could be said to be in anything close to a pre-human influence state. Yet further growth in human population numbers, and the consequential demands for food, is a reality that must be faced along with the inevitable consequences for the environment. The oft-stated idea that the problem can be solved by redistribution of existing resources from developed to developing nations was refuted. The notion which crystallised from the discussion was that the Precautionary Principle may be a philosophical rather than a scientific concept, which is concerned not only with avoiding environmental damage but also with shifting the accountability for the state of the environment onto those who wish to exploit it.

The role of science should be to translate the Principle into an operational tool. This requires the user community (society) to state its demands of the management process - e.g. maximise yield, zero risk of resource collapse, constant total allowable harvest, no loss of biodiversity. The scientific role should be to determine which objectives are compatible and realisable within set ranges of probability of success. It is important to emphasise the inherent element of risk taking involved in developing new harvesting strategies where the consequences cannot be confidently predicted. Nevertheless, without taking such risks it is difficult to see how progress towards the goal of meeting global food demands can be achieved. Acceptance of the extent of exposure to risk, combined with planning, monitoring of progress and evaluation of the outcome are necessary aspects of this process. Basic research into ecosystem structure and function, at a variety of space and time scales, is pre-requisite to risk assessments and there was a strong body of opinion that it is entirely reasonable to expect that the economic beneficiaries of any successful exploitation plan should be prepared to commit funds to support such underpinning activity.

Integrating the social, economic and environmental aspects of harvesting strategies to achieve overall optimal utilisation of renewable resources was a theme of some keynote presentations on the second day. The point was made that in economic terms the sustainability of harvesting refers to the uptake by mankind of material created by the ecosystem, not to the standing stocks. In a system with multiple end-users of multiple resources from an ecosystem there will inevitably be conflicts of interest requiring trade-off's and compromises to achieve a sustainable management solution. In the past, socio-economic approaches to resolving conflicts between users have been largely divorced from ecological consideration of whether the ecosystem can sustain the required flows of resources. The case was made for closely integrating these processes in the future in order to find the optimal solution in any given situation. There was some concern as to the reconciliation of conflicting demands and impacts on ecosystem qualities which cannot be expressed in equivalent 'currencies', for example, biodiversity of the system vs. economic value to one particular species. No clear solutions to this problem were forthcoming, in particular there was no indication of how the legal structures to implement the theoretical integrated management approach might be set up in practice.

The potential interactions and conflicts between end-user interests impacting the coastal zone were discussed in one keynote address, with particular emphasis on the role of aquaculture. The conflicting interests include agriculture, forestry, shipping, tourism, leisure and recreation, as well as aquaculture and the social and service needs of local populations. Particular attention was devoted to the role of ballast water as a vector for species introductions with aquaculture playing a possible intermediate-vector role by providing a sheltered habitat for invading species to adapt to new conditions before fully establishing in the ecosystem. The ecological damage caused by such introduced species was illustrated with example of the Zebra Mussel in North America, but there are many other instances. The role of integrated systems to obtain an optimal mix of resource utilisation for an ecosystem was illustrated with examples of sewage-fed fish pond developments. The risk with such developments is that diversity of utilisation will be lost.

Sustainability is increasingly an aspect of economic thinking in many industrial sectors. Industrial research is being focused on optimisation of resource utilisation, maximising cost benefit for particular sectors of the end-user community, and minimising environmental impact. This requires basic research into the structure and function of ecosystems, but targeted on answering specific questions with long-term perspectives. However, in the ensuing discussion the point was made that the temptation for global industries to compromise social responsibilities in the interests of financial returns to shareholders can be very great, especially when the social impact of the activity is remote from attention of, and has little impact on, the shareholders. By no means all industries are guilty of such practices but there are several well documented examples in which the interests of some end-users of the resources available from the system have been ignored. The key point to emerge was that in many areas of the world there seems to be no basis for planning, monitoring and evaluating the multi-user interests in utilising natural resources. This has been especially true in the developing world where the capital resources of some user sectors are overwhelmingly greater than those of others. Clearly, industry has a key role to play in this process but it may not always be in the best interest of long-term sustainability for them to take the lead.

## 6.2 Synthesis - Recommendations for Components of a Science Plan

These recommendations are abstracted from those identified in working groups and plenary discussions:

There is still a clear need for basic research into the structure and function of marine ecosystems, targeted on specific questions with long-term perspectives, especially for improved understanding of the mechanisms of flow through food webs, allowing for features such as toxic blooms, the role of jellyfish etc. Responses of higher trophic levels to effects at lower levels are particularly important. Such understanding is particularly necessary for the development of better models for predicting the outcome of perturbations (both natural and man-made).

In addition to observations of natural systems, experimental approaches extending from small scale experiments in simple systems, to larger and more complex systems could be more extensively employed. However, "natural experiments" could also be better utilised to improve the scientific ability to predict the outcome of ecosystem manipulations.

The technology for remote sensing from airborne vehicles (possibly remotely controlled) to fly sensors around survey areas, so that remote sensing could be done at a smaller scale than by satellites, and under cloud cover, has not been fully exploited as yet, and could be extremely valuable.

It would be of great significance to the understanding of marine productivity - and the possibilities of enhancing this - if a controlled upwelling experiment and/or an artificial production enhancement experiment, could be arranged, possibly as part of the Fifth EU Framework Programme. Such an experiment would require a substantial amount of planning, modelling and preliminary background studies over 2 - 3 years, followed by an experimental period of 3 - 5 years, to allow time for a recovery study after the experiment. Ideally the experiment should be conducted so that the hypothesis of increased fish larval survival could be tested. The experiment would require an integrated approach of physics, chemistry and biology, as well as environmental science, and would require the involvement of a significant proportion of Europe's marine scientific community. The benefit of such an experiment could be substantial, but it requires longer research perspectives than traditional projects, similar to those of a Grand Challenge programme.

The potential of artificial reefs in highly eutrophicated areas for enhanced and directed harvestable production (e.g. of bivalves) thus removing undesired and excessive production should be investigated. Gaps in knowledge include a thorough understanding of habitat requirements for target species and the impact of non-reef fish populations. Similarly artificial systems for growing seaweeds might be used directly as well as serving as a habitat for juvenile stages of pelagic fish species, thus also potentially enhancing their harvestable biomass. These and other innovative concepts for nutrient recycling for bioremediation should be actively pursued, realising that this is an area which will require an integrated approach, also including the political and regulatory aspects.

Artificial systems for Seaweed production could also have potential for sequesting atmospheric carbon, if implemented on a sufficiently large scale in an ocean farm programme. The first crucial step is to determine the productivity of these plants under various nutrient regimes, and to develop test scale farm constructions. The growing of Seaweeds on rafts in upwelling zones in particular seems to have interesting potential. The environmental consequences would need to be thoroughly evaluated and a means for permanently removing carbon so fixed from the biosphere is clearly needed. In this area there are potentials for research cooperation with US marine science.

The most promising opportunities for increased production within coastal areas are believed to be within mussel and macroalgae farming, and it would therefore be desirable to initiate research into the technology for such breeding, as well as into the socio-economic implications of such systems.

There may be opportunities for innovative programmes concerning the release of hatchery reared juvenile species into over-exploited ecosystems. For such programmes to have increased potential for success, more information is required on the habitat requirements of the various life stages concerned, the food requirements of the reared species, the carrying capacity of the areas considered, and the interaction of wild and hatchery-reared animals including genetic differences.

Methods are needed for assessing whether the extent of impacts resulting from an experiment or some production enhancement measure are within acceptable limits. There is a clear need for identifying ecosystem level properties which are sensitive to perturbations.

It is necessary to incorporate the social, economic, aesthetical and technical issues involved in large scale intervention, and establish procedures for doing so. This also applies to the present unintended interventions in the marine ecosystem!

Management decisions are too often made on a poor scientific basis, and are not properly followed by adequate monitoring of the resulting effects, and there is a need for research into improved monitoring techniques utilising new statistical and sampling designs and power analysis. Observations which will be made as part of the EUROGOOS system are vital in this respect. There is a need for socio-economic models which take into account the system variability, and management models that conserve the structure and function of processes for biological production, and facilitate multicriteria decision making. Marine systems provide various "service" functions which have not yet been fully evaluated. There is a need for research into such evaluation, and into acceptable risk levels of management intervention.

There is a clear need for a strategic examination of the way mankind makes use of living marine resources to determine whether alternative approaches might not produce a substantially different yield for human consumption. Improved technology for the utilisation of discards and bycatch into animal feed or direct human food consumption should be developed. Management tools for fisheries management that allow better ways of attaining sustainable stock sizes must be improved, incorporating socio-economic aspects.

There is a need for strategic research to improve marine resource production in different regions of the world, taking account of practical constraints. This should be related to applied research on resource management, focussing on how science can assist developing nations in achieving enhanced sustainable and optimal use of their potential marine resources.

The interests of European industries are expected to be excited by applied experiments with potential for increasing the harvestable biomass of valuable resources, by the development of the various technologies needed for such enhancement, and for monitoring the ecosystem quality and resources.

**Outline of Suggestions for Components of the Science Plan**

The wide range of topics covered in the plenary sessions may be summarised by grouping under headings of resource productivity, and resource management.

RESOURCE PRODUCTIVITY

A. PHYSICAL PROCESSES

**Domination of regional ecosystem productivity by ocean basin scale physics**

- The fundamental processes determining the productivity of most shelf sea ecosystems is large (ocean basin) scale meteorological and hydrographic forcing, for example upwelling systems.
- it is extremely unlikely that mankind can ever intervene to influence such processes.

B. BIOLOGICAL PROCESSES - HOW TO ENHANCE PRODUCTIVITY?

**Biogeochemical approach**

- There are clear cross-ecosystem relationships between the efficiency of marine food webs and the harvestable yield per unit area of resources.
- Relationships between trophic efficiency and yield are strictly dependent on taxonomic composition of the ecosystem.
- Biogeochemical, biomass-based analyses of ecosystems generally fail to account for the effects of disturbances on the harvestable higher trophic levels.

**Population dynamics approach**

- population dynamics approaches to analysing ecosystem structure and function were not well represented in the discussions.
- There are clear signs that interactions between physics and higher trophic levels occur at the individual level, and are reflected in behavioural responses which ultimately determine population dynamics.

- Discussion of the role of compensatory feedback (density dependence) in population dynamics was not discussed but is very important in determining carrying capacity. This is a very weak area of marine science.

**Combined trophic and population dynamics**
- Combining population dynamics of higher trophic levels with more biomass based, biogeochemical approaches to the lower trophic levels may be a useful way forward in ecosystem research.

**Role of spatial and temporal variability**
- spatial and temporal patchiness in the ecosystem may be of critical importance in determining productivity. How to organisms integrate their exposure to patchiness?
- This aspect was lacking from the discussions.

## C. RESOURCE UTILISATION

**Elimination of losses in existing harvesting**
- Discards of non-marketable fish by existing harvesting practices is a major waste of resources. Effectively utilising this component of the resource has the highest potential of all possible actions to produce a significant increase in yield.
- the limitation of utilisation of discards is primarily technological.

**Possibilities for new resources**
- Several components of the ecosystem which are not currently exploited for human consumption may have potential for this purpose, for example seaweeds, and a variety of benthic organisms.

## D. PREDICTABILITY

**Consequences of disturbance are highly non-deterministic and unpredictable**
- The general consequences of disturbance may be predictable in some circumstances, for example increased dominance of short food chain, diatom dominated systems when nutrients are injected into well mixed ecosystems. However, detailed taxonomic responses, and especially long term changes following major disturbance, such as recolonization, cannot be predicted at present.

Temporal variability in recruitment to marine populations is not deterministic, but carries high stochasticity.

Humility needed with respect to our ability to predict the consequences of perturbation.

# RESOURCE MANAGEMENT

## E. OBJECTIVES

**Failures of existing approaches**
- existing single resource, single user, yield per recruit based schemes for managing offshore resources have not be very successful for a variety of reasons.
- management systems for inshore and coastal zone environments are not well developed and have usually not been able to resolve conflicting interests.

**The Precautionary Principle**
- should not be seen as the basis for non-intervention.
- must involve a debate on the ethics of intervention in the ecosystem.

**Burden of accountability**
- one aspect of the precautionary principle involves moving the burden of accountability for impacts on the ecosystem from the state to the user community.

**Lack of predictability of management strategies**
- lack of predictability of ecosystems means that the development of management strategies carries the risk that the intended outcome may not materialise.
- risk should be seen as inherent in management and costed appropriately.

**Need for large scale experimentation**
- the lack of predictability means that experimentation on a variety of scales will be necessary to develop robust management plans.

F. FEASIBILITY
Proposals to enhance production need to be economically feasible and socially acceptable.

G. INTEGRATED SYSTEMS
**Single resource vs multi-resource management**
- multiple resource harvesting from an ecosystem may lead to unforeseen interactions due to the internal dynamics of the ecosystem.

**Single user vs multi users**
- Multiple user demands will almost inevitably lead to conflicts of interest.

**Feasability**
- economic, social and technological viability of strategies needs to be evaluated.

**Sustainability**
- intensive practices have resulted in the build up of toxic residues.
- long term production of resources by the ecosystem, rather than maintenance of biomass or population size is the criterion to be used for assessing sustainability.
- In a multi-resource scheme, maintenance of ecosystem integrity will be critical.

**Social responsibility vs financial objectives**
- the temptation for user interest with the greatest financial backing to exploit the ecosystem at the expense of other, less financially equipped users has been a major problem.
- the development of corporate ethics in relation to resource harvesting is important.

**Theory - Implementation**
- so far, theory as to how to develop integrated multi-user, multi-resource management systems has been developing, but the legal framework for implementing such schemes in practice is lacking.

FUTURE ACTIONS

**On resource utilisation.....**
Food technology - new food sources.
New technology for utilising wasted resources (discards).

**On intervention in ecosystems.....**
Large scale experiments with planning, prediction, long-term monitoring and objective evaluation.

**On resource management.......**
Explicit focus needed on the coastal zone.
New approaches to harmonise management strategies to those aspects of the large scvale physical forcing of the ecosystem which are predictable. This may be especially true at low latitudes.
New integrated social-economic-ecological models needed.
Legal framework for implementing integrated management plans (multi-resource/multi- user).
Actions to raise public awareness of the issues at stake - especially the need for risk taking.

**On the functioning of ecosystems.....**
New understanding of higher trophic level population dynamics.
Long-term committment of funding for monitoring.
Archaeology of long-term historical data.
Offshore oceanographic research interests need to by integrated with research in the coastal zone.

## APPENDICES

A - Programme

B - Participants

C - Working Group lists

D - EMaPS

HYDRO

Southampton
Oceanography
Centre

# Workshop - Ocean Harvest 97

"New concepts to increase the sustainable use of marine biological resources.

Can we increase the harvest?
What are the opportunities and the constraints?"

## Southampton Oceanography Centre

## 11 - 13 June 1997

### Organising Committee

Franciscus Colijn
Carlos Duarte
John S. Gray
Espen E. Hoell
Harald Rosenthal
Katherine Richardson
John G. Shepherd
Tasso Tselepides
John Woods

The workshop is being supported by the European Commission Marine Science and Technology (MAST) Programme and the European Marine and Polar Sciences Secretariat (EMaPS).

## Background for the workshop

The ocean is an important protein source for mankind and will become increasingly important as it becomes more and more difficult for agriculture to meet the nutritional demands of a growing world population. Harvest levels of most of the wild fish species currently exploited appear to be at, or over maximum acceptable levels for sustainable fisheries. Thus, a number of different activities with the aim of increasing the potentially harvestable biomass from the ocean have been initiated or are being contemplated. Examples here include exploitation of currently non-harvested organisms, stock enhancement (sea ranching), establishment of new habitats (i.e., artificial reefs), aquaculture, food web manipulation, artificial upwelling and selective nutrient enrichment. Knowledge about the feasibility of these initiatives and how they may impact the environment and interact with other resource users is still a matter of debate.

It seems clear that, in the next century, a specific management strategy with respect to exploitation of the ocean will be required and that this management strategy must be based on sound scientific knowledge concerning the ecosystem implications of various activities. The European scientific community should actively address these issues by proposing an effective research programme for the next decade which, in addition to suggesting and testing new ways of harvesting the ocean on a sustainable basis, should quantify the ecosystem interactions that these different activities elicit. The knowledge arising out of this research should provide a test of our capacity to understand, model and predict the functioning of marine ecosystems. The scientific community should be prepared to provide the necessary scientific background to evaluate the initiatives and interest of European industry regarding the use of marine biological resources and to ensure that industrial initiatives are not in conflict with the concept of sustainable use and management of ecological systems.

### Goal of the workshop

The goal of the workshop is to examine our present knowledge, and identify strategic research needed to predict the ecosystem consequences of various initiatives to increase the potential harvest from the sea.

The results of the workshop will be considered by the EU-commission for implementation under the 5th framework programme.

The participants are affiliated to the Working Groups according to their stated interest or expected contribution.

The progress of the workshop will follow the set-up below. The working group reports shall include a summary of identified cross sectional topics (t1 - t5).

- Possibilities (Intended effects) [t1]
- Constraints (Unintended effects) [t2]
- Interaction with other use(r)s [t3]
- Predictability [t4]
- Research needs [t5]

The workshop progress is planned along the following schedule:

| | Wednesday | | | | | Thursday | | | | Friday | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | am1 | am2 | pm1 | pm2 | a.d. | am1 | am2 | pm1 | pm2 | am1 | am2 | pm1 | pm2 |
| | 9.00 | 11.00 | 14.30 | 17.30 | 20-> | 9.00 | 10.30 | 14.30 | 17.30 | 9.00 | 10.30 | 14.00 | 15.00 |
| Edit.B. | Plan | | | | | | | | | | | | Min |
| Plenary | | I/K | | Su | I/disc | K | | | Su | K | | Su | |
| WG1 | | | I/t1-2 | | | | I/t3 | t4 | | | t5 | | |
| WG2 | | | I/t1-2 | | | | I/t3 | t4 | | | t5 | | |
| WG3 | | | I/t1-2 | | | | I/t3 | t4 | | | t5 | | |
| WG4 | | | | | | | I/t1 | t2-3 | | | I/t4-5 | | |

Plan=workshop planning, I= Introduction/prepared presentation, K= Keynote(s), Su= summary of WG's, disc= open discussion, Min = preparing for the minutes of the workshop.

Participants of WG 4 will join WG 1-3 during Wednesday.

## Venue:

The workshop is organised at Southampton Oceanography Centre as a 3 day (Wednesday to Friday) meeting 11 to 13 of June 1997. Accommodation will be organised at local hotels in vicinity.

## Financial and scientific support for the workshop

The workshop is supported by the European Union, DG XII - MAST, and the industrial company Norsk Hydro.

The workshop is supported scientifically by the European Marine and Polar Science (EMaPS) board of the European Science Foundation. The International Council for the Exploitation of the Sea (ICES) are observing the result of the workshop.

## Editorial board

The editorial board will include members of the organising committee, the WG chairpersons's and appointed rapporteurs. Proceedings will be published as a Southampton Oceanography Centre report.

## Workshop structure and progress

The workshop will have alternating plenary sessions, parallel working group sessions for drafting recommendations and plenary sessions for reporting and discussing results from the working groups. The organising committee, the working group chairpersons and the editorial board will prepare the workshop report at the end of the workshop.

The meeting will be chaired by Prof. John G. Shepherd, Southampton Oceanography Centre.

The keynote speakers have prepared extended summary of their presentations in advance of the workshop. Introductory speakers and short presentations are expected to prepare a written contribution.

Participants will be allocated to one of the following working groups:

WG1; Productivity regulation and ecosystem variability: Ecosystem manipulation.

WG2; Productivity regulation and ecosystem variability: Ecosystem exploitation.

WG3; Optimal use of marine resources: Interaction between various initiatives to increase the harvest from the sea.

WG4; Optimum use of resources: Integrating the needs of society

## Workshop programme:

5 minutes are reserved for discussion after each keynote speaker.

Overall rapporteur; Dr. Mike Heath, Marine Laboratory, Aberdeen.

### Wednesday 11.6

8.45 and 9.45 Coach leaves Hotel IBIS.

09.00 - 10.30 Organising committee, chairpersons, editorial board; Preparing for the workshop.

10.00 - 10.50 Registration and Coffee.

11.00 Welcome by Professor John Shepherd, Chairman.

11.05 - 11.15 Address; "Expectations to the workshop". Speaker: Dr. Jean Boissonnas, DG XII.

11.15 - 11.45 Keynote; "Food for an increasing population". Speaker: Professor Kaare Ringlund, Norwegian Agricultural University.

11.50 - 12.20 Keynote; "Opportunities for increasing biological production". Speaker: Professor Yngvar Olsen, Univ. of Trondheim.

12.25 - 12.55 Keynote; "Limits to predicting the consequences of managing marine systems". Speaker: Professor Tony Underwood, Univ. of Sydney.

13.00 Information about SOC, Antony Jensen.

13.00 - 14.30 Lunch (SOC Cafeteria).

14.30 - 17.00 Working groups 1-3 parallel session I.

14.30 - 14.45 Introduction to the working groups.

WG1: "Productivity enhancement in the Japanese Marino Forum programme, e.g. artificial upwelling / nutrients additions". Speaker: Professor Shinji Morimura, Japan.

WG2: "Modelling ocean productivity". Speaker: Dr. Villy Christensen, DK.

WG3: "Harvest enhancement by artifical ecosystems". Speaker: Dr. Antony Jensen, SOC.

15.30 Tea for the Working Groups.

17.00 - 17.45 Summary of working groups in plenary (chaired by Professor John Shepherd).

18.00 Coach to the Hotel IBIS.

19.15 Coach returns to SOC.

19.30 Light dinner/evening meal at the Southampton Oceanography Centre (Cafeteria).

20.30 After dinner discussion session (Lecture Theatre) chaired by Professor John Shepherd; "The politics of intervention". Introduction "The precautionary principle in marine environmental policy - constraint to ecosystem manipulation." Speaker: Dr. Stephan Lutter, WWF International.

Panel: Speakers of the day.

Coach returns to Hotel IBIS.

**Thursday 12.6**

Chairman: Espen Hoell

09.00 - 09.30 Keynote; "State of the art in understanding productivity regulation; Existing research programmes". Speaker: Professor John G. Field, Univ of Cape Town.

09.35 - 10.05 Keynote; "Optimal use of resources in the context of sustainabillity". Speaker: Professor Peter Burbridge, Univ. of Newcastle.

10.15 - 10.30 Coffee break (outside Lecture Theatre).

Chairman: David Billett

10.30 - 11.05 Keynote; "The role of industry in enhancing the harvest of the Ocean". Speaker: S.Sci. Espen Hoell, Norsk Hydro.

11.05 - 11.20 Introduction to Socio-economic implications of marine cultivation by Professor Harald Rosenthal.

11.30 - 13.00 Working groups 1-4. Parallel session II.

11.30 - 11.45 Prepared paper / Introduction to the working groups.

WG1: "Experiences from Ironex". Speaker: Professor Andrew Watson, UEA.

WG2: "Testing the feasibility and potential benefits of open-ocean macoalgal farming". Speaker: Professor Arne Jensen, Institute of Biotechnology, Trondheim.

WG3: "Sustainable aquaculture, theoretical vision or commercial reality?". Speaker: Dr. Torjan Bodvin, Marine Production AS, Norway.

WG4: "Exploitation of marine resources and environmental conservation". Speaker: Dr. Sidney Holt, Italy.

13.00 - 14.30 Lunch (SOC Cafeteria).

14.30 - 17.00 Working groups 1-4 parallel session III.

17.00 - 17.45 Summary of working groups in plenary (Working Group Rapporteurs).

17.50 Coach to the Hotel IBIS.

19.00 Coach for Portsmouth from IBIS.

19.30 Workshop Dinner on board *HMS Warrior.*

Midnight Return by coach.

**Friday 13.6**

9.00 - 10.30 Working Group parallel session IV.

10.30 - 10.45 Coffee break (outside Lecture Theatre).

10.45 - 12.00 Working groups. Drafting Report from the Working Groups.

12.00 - 13.00 Lunch (SOC Cafeteria).

13.00 - 14.30 Summary of the working groups. Recommendations for a science plan. Summary by the overall rapporteur (Chaired by Professor John Shepherd).

14.30 Tea and goodbyes for those leaving.

14.45 Coach leaving for Railway Station and Hotel.

14.45 - 16.00 Preparing for the minutes of the workshop. Organising committee, editorial board.

The Working Group and overall reports should be completed the 13 June.

## WG 1 Productivity regulation and ecosystem variability: Ecosystem manipulation.

Chairperson: Prof. Victor Smetacek
Rapporteur: Dr. Martin Angel

The working group will address research needs concerning possibilities for harvest enhancement by ecosystem manipulation and our abilities to predict the consequences of such initiatives. The trophic for this WG could be seen as bottom up influence of the ecosystem, concentrated on the lower tropic levels. Examples include nutrient enrichment, creation of new habitats (i.e. artificial reefs) and food web manipulation. What are the possibilities and their constraints?

Key themes:
a) The functioning of foodwebs and the role of nutrients, channelling productivity.
b) Artificial upwelling, ocean fertilisation, nutrient recycling.
c) Improving predictive capabilities with respect to ecosystem responses
d) The need for experimental design and ecosystem/field experiments to assist predictive modelling.

## WG 2: Productivity regulation and ecosystem variability: Ecosystem exploitation.

Chairperson: Prof. John Shepherd
Rapporteur: Dr. Niels Daan

The working group will address research needs concerning possibilities for harvest enhancement by ecosystem exploitation and our abilities to predict the consequences of changed activity with respect to harvesting the biological resources. The topic for this WG could be seen as top down influence of the ecosystem and concentrate on the higher trophic levels and the output of the systems. What are the possibilities and their consequences?

Key themes
a) Fisheries, sea ranching and exploitation of currently non harvested resources.
b) Predator removal, Changed competition.
c) Modifying marine populations: selective stocking and harvesting
d) Possibilities for reduction of natural variability in recruitment.
e) Natural variability as a source of uncertainty in decision making

## WG 3 Harvest enhancement by creation of artificial ecosystems.

Chairperson: Prof. Harald Rosenthal
Rapporteur: Prof. Patric Sorgeloos

This working group will concentrate on the heavily modified and artificial systems, such as aquaculture, coastal modification, artificial reefs, sea-ranching and species restocking. The working group will address research needs concerning our ability to develop and predict the outcome of such modifications and their environmental interaction. What information do we need to achieve an optimum sustainable mix of various harvesting initiatives.

Key themes:
a) Alternative concepts for the use of the oceans for biological production
b) Habitat improvements: Artificial reefs, artificial upwelling, habitat and substrate modifications, recovery measures.
c) Interaction between and integration of different biological production systems
d) Modifying marine populations: selective stocking and harvesting

## WG 4 Optimum use of resources: Interaction between users and society.

Chairperson: Prof. Ulf Lie
Rapporteur: Prof. John Gray

The working group will address research needs concerning our ability to develop an optimum management strategy for various harvest enhancement initiatives, interactions between different initiatives and with the environment. The group will discuss research needs concerning our ability to integrate the needs for biological production with the needs for conservation of natural environments. What information do we need to develop a management programme with multiple strategies for harvesting the ocean. What legal, ethical and social questions must be answered in order to optimise the use of the ocean and its resources? How can we ensure proper transformation of knowledge from scientists to end users?

Key themes:
a) Preserving ecosystem integrity; risk assessment of various uses.
b) Integrated/cross sectional coastal zone management.
c) Interaction with other resource users, identifying the potential conflicts, indicators for sustainabillity.
d) Environmental economics.

e) Licensing and legal aspects of resource use, international implications, regulative harmonisation.
f) Making science applicable and building bridges between science and end users.

## Ocean Harvest 97
## 11 - 13 June
## Participant list

| | |
|---|---|
| Dr. Tom Anderson | George Deacon Division for Ocean Processes<br>Southampton Oceanography Centre |
| Dr. Martin Angel | George Deacon Division for Ocean Processes<br>Southampton Oceanography Centre |
| Dr. Cedric Bacher | IFREMER<br>Centre National de la Recherche Scientifique |
| Dr. Richard T. Barber | Duke University<br>NSOE Marine Laboratory |
| Dr. Klaus Guenther Barthel | European Commission<br>DG XII/MAST |
| Prof. Jarle Berntsen | Dept of Mathematics<br>University of Bergen |
| Dr. David Billett | Challenger Division for Seafloor Processes<br>Southampton Oceanography Centre |
| Dr. Tom Bockmann | Research Director<br>Norsk Hydro Research Centre |
| Dr. Antonio Bode | Instituto Espanol de Oceanografia |
| Dr. Torjan Bodvin | Marine Productions A/S<br>Norway |
| Dr. Jean Boissonnas | European Commission<br>DGXII/MAST |
| Dr. Tor Bokn | Norwegian Institute of Water Research, Norway |
| Dr. Willem Brugge | European Commission DG XIV-C2 |
| Prof. Peter Burbridge | Dept. Marine Sciences and Coastal Management<br>University of Newcastle |
| Prof. Villy Christensen | ICLARM |
| Dr. David Cushing | United Kingdom |
| Dr Laurent d'Ozouville | European Secretariat for Ocean and Polar Sciences, European Science Foundation |
| Dr. Niels Daan | Netherlands Institute for Fisheries |
| Dr. Ian Davies | Fisheries Research Services,<br>Marine Laboratory, Aberdeen |
| Dr. Ies de Vries | National Institute for Coastal and Marine Management/RIKZ, Netherlands |
| Prof. John Field | University of Cape Town |
| Prof. John S. Gray | Institute of Biology<br>University of Oslo |

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|---|---|
| Dir. Sigurd Gulbrandsen | R & D Staff, Norsk Hydro ASA |
| Dr. Trond Robert Gulbrandsen | Hydro Agri Europe |
| Dr. Roger Harris | Plymouth Marine Laboratory |
| Prof. Stephen Hawkins | School of Biological Sciences<br>University of Southampton |
| Dr. Mike R. Heath | Fisheries Research Services,<br>Marine Laboratory, Aberdeen |
| Dr. Wolfgang Hickel | Biologische Anstalt Helgoland<br>Germany |
| Dr. Espen Hoell | Senior Scientist<br>Norsk Hydro Research Centre |
| Dr. Sidney Holt | Italy |
| Dr. Cecilie Hongslo | Natural Science Technology,<br>The Research Council of Norway |
| Dr. David Hydes | George Deacon Division for Ocean Processes<br>Southampton Oceanography Centre |
| Dr. Robbert Jak | TNO Laboratory for Applied Marine Research |
| Prof. Arne Jensen | Institute of Biotechnology, Norway |
| Dr. Antony Jensen | Department of Oceanography<br>Southampton Oceanography Centre |
| Prof. Ulf Lie | Centre for Studies of Environment and Resources, Norway |
| Dir. Oleh Lie | R & D and HMS Norsk Hydro ASA |
| Dr. Bente Lomstein | Department of Microbial Ecology<br>University of Aarhus |
| Dr. Stephan Lutter | WWF International |
| Dr. Nina Hedlund Markussen | The Research Council of Norway |
| Prof. Jacqueline McGlade | Biological Science Department<br>University of Warwick |
| Prof. Shinji Morimura | International Food and Aquaculture Society<br>Japan |
| Dr. Thom D Nickell | Coastal Impact Research Group<br>Dunstaffnage Marine Laboratory |
| Prof. Victor Oiestad | The Norwegian College of Fishery Science, Tromso |
| Prof. Yngvar Olsen | Trondhiem Biological Station<br>Norwegian University of Science and Technology |
| Dr. Dag Oscar Oppen-Berntsen | Norsk Hydro Research Centre, Porsgrunn |
| Dr. Oddmund Otterstad | Centre of Social Studies Research<br>Allforsk, University of Trondheim |

| | |
|---|---|
| Prof. Carlos Pedrós-Alió | Instituto de Ciencias del Mar, Spain |
| Dr David Pugh | IACMST<br>Southampton Oceanography Centre |
| Dr. Jake Rice | Department of Fisheries and Oceans Canada |
| Prof. Kaare Ringlund | Agricultural University of Norway |
| Mr. Howard Roe | George Deacon Division for Ocean Processes<br>Southampton Oceanography Centre |
| Prof. Harald Rosenthal | Institute for Marine Science, Germany |
| Prof. Rui Santos | University of the Algarve<br>Portugal |
| Mr. Mitsuru Sasaki | Minato Shinbun, Press |
| Prof. John Shepherd | Director<br>Southampton Oceanography Centre |
| Prof. Victor Smetacek | Alfred Wegener Institute for Polar and Marine Research<br>Germany |
| Prof. Patrick Sorgeloos | Laboratory of Aquaculture & Artemia Reference Cte.<br>University of Ghent |
| Dr. Einar Svendsen | Institute of Marine Research<br>Norway |
| Dr. Tasso Tselepides | Institute of Marine Biology of Crete |
| Prof. A. J. Underwood | Marine Ecology Laboratory<br>University of Sydney |
| Dr. Terje van der Meeren | Marine Research Institute, Norway |
| Prof. Andrew Watson | School of Environmental Sciences<br>University of East Anglia |
| Mr. Nigel Williams | European Correspondent for Science |
| Dr. Phil Williamson | Natural Environment Research Council |

# Ocean Harvest 97 Working Groups

**WG 1**

**Node 7 Level 4**

Smetacek
Anderson
Angel
Barber
Jarle Berntsen
de Vries
Field
Harris
Hongslo
Hydes
Jak
Lomstein
Olsen
Svendsen
van der Meeren
Watson

**WG2**

**Node 4 Level 4**
**Board room**

Shepherd
Daan
Barthel
Bode
Brugge
Christensen
Cushing
Heath
Kelly-Gerreyn
Oiestad
Pedros-Alio
Rice
Roe
Tselepides
Williamson

**WG3**

**Node 5 Level 4**
**Swallow room**

Rosenthal
Sorgeloos
Antony Jensen
Arne Jensen
Bacher
Bodvin
Boissonnas
Burbridge
Davies
Hickel
Hoell
Morimura
Nickell
Oppen-Berntsen
Santos
Underwood
Sasaki

**WG4**

**Node 6 Level 4**

Ulf Lie
Gray
Bockmann
Bokn
d'Ozouville
Holt
Lutter
Markussen
McGlade
Ole Lie
Otterstad
Ringlund
S. Guldbrandsen
T. Guldbrandsen

# European Marine and Polar Science (EMaPS)

The EMaPS Marine Board and the EMaPS Polar Board were created in response to a perceived need for improved coordination between European organisations in marine and polar science and for the development of common strategies in Europe.

The Marine Board identifies the facilitating of the implementation of the scientific marine grand challenges as its main priority. The grand challenges are in marine biodiversity, ocean forecasting, coastal research and the deep-sea floor.

The Polar Board has produced databases of Arctic programmes and of national programmes to which further European additions would be welcomed. Work is also underway on a database of polar large facilities with a view to facilitating the sharing of major polar equipment in Europe.

## Main Aims of the EMaPS Marine Board and Polar Board:

- to facilitate the implementation of European and international research networks and projects
- to examine research issues of strategic importance, where relevant in close association with the European Commission
- to facilitate the shared use of research facilities
- to promote joint activities in the technology of new instrumentation and platforms for research and monitoring the marine and polar environment
- to be a source of advice on science policy matters
- to organise a biennial conference if appropriate

Membership is open to organisations which are based in Europe and are either ESF member organisations, major national marine or polar scientific institutions, or groups of national relevant scientific institutions which combine to form a single membership to the Boards.

## The Structure of the European Boards for Marine and Polar Science:

The Boards form an informal non-governmental body under the auspices of the European Science Foundation. Each Board has an Executive Committee, consisting of a Chairperson and two Vice-Chairpersons. The Executive Committees of the two Boards meet together and form the Joint Executive Committee of the Boards.

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