Description of the key hypotheses, study areas and experimental methods in KEYCOP

1. Objectives (Back to top)

1.1 Introduction (Back to top)

Much effort has been devoted to obtaining mass balances of nutrients and trace substances in areas such as the North Sea (North Sea Quality Status Report, 1993) and the physical forcing functions affecting these balances. However, physical forcing functions influence fluxes of materials (and hence mass balances) through a complex interlinking of physical, chemical, and biological processes. The urgent need for a better understanding of these processes and their interactions in coastal seas has resulted in two major initiatives in recent years: Land Ocean Interactions in the Coastal Zone (LOICZ) established by the International Geosphere-Biosphere Programme(IGBP, 1993), and the European Land-Ocean

Interaction Study (ELOISE) established by the European Union (Cadée et al., 1994). Both of these programmes highlight the need for better understanding of the processes affecting fluxes of organic matter, nutrients and trace substances and for a better understanding of the importance of spatial heterogeneity , which is great in the coastal system, in affecting fluxes. The ELOISE Science Plan identifies the fact that “coupling of processes on different scales tends to lead to non-linearities in responses of systems” and encourages studies of the link between species compositions and their functioning. A call is made for studies linking biogeochemical processes through pelagic-benthic coupling and on the bioavailability of trace substances through partitioning between particles and water.

The ELOISE Science Plan points out that “uncertainties exist regarding the dynamic interaction between processes acting on different scales and these need to be resolved” and that “models representing interactions of scales and processes are still to be developed”.

In order to address these questions, this project will focus on investigation and modelling of key processes that affect flow and cycling of carbon, nutrients and trace substances. In particular, we aim to study how processes change over scales from microns to tens of metres and along physicochemical gradients, and to compare processes under two contrasting situations, stratified and mixed water masses. By comparing the Skagerrak with the northern Aegean, we will be able to study differences in functioning between a mesotrophic and an oligotrophic system.

In this project modelling is an integral part of all activities and has not been identified as an entity in itself. Modelling will concentrate on local process studies, where both bulk and small-scale 1D-models will be applied for testing different hypotheses. Incorporation of these process models into larger scale 3D-models is a longer term aim which will not be addressed within the present project. The data that we obtain however, will be highly relevant to future integration into large-scale models and our data management protocols are designed with this in mind.

The Mediterranean Targeted Programme (MTP) has a regional programme directed at the Aegean Sea as a whole. We have, through our Greek partners at the National Centre for Marine Research, Athens (NCMR) kept a close liaison with the planning of the MTP and the MATER programmes. Our project will investigate only the shallow areas of the Northern Aegean and will concentrate on fluxes of materials and trace substances in these areas and will therefore, complement the other Aegean studies. This liaison by the Greek Partners will ensure that there is no overlap but only complimentarity of programmes.

The project involves 34 scientists and a minimum of 8 Ph.D. students from six countries (Denmark, Italy, Greece, Norway, Sweden and UK) and from 13 institutions.

1.2 Overall scientific objective (Back to top)

To understand and model the processes that determine flux of carbon, nutrients and trace substances in the water column and sediment in different hydrographic and nutrient regimes and the vertical and horizontal fluxes between the pelagic and benthic systems.

This objective will be addressed through a series of interlinked activities:

- Testing of a series of hypotheses in the Skagerrak and northern Aegean on:
- the degree of stratification and the vertical flux of particles in relation to the development of a microbial loop system
- nutrient delivery and cell sizes
- mixed water masses and sedimentation rates

- the interaction between pelagic predators and their prey in relation to turbulent fluid motion frontal systems and sedimentation rates
- predator-prey interactions and patchiness in stratified and mixed waters
- the effects of pelagic production processes on organic carbon and trace metal chemistry
- the importance of lateral advection for mineralisation and flux rates in bottom sediments
- burial rates of organic matter and trace substances in relation to vertical and laterally fluxed material
- Joint workshops and cruises by participants from all institutions in both the Skagerrak and northern Aegean
- Use of a wide variety of novel technologies and techniques, such as *in situ* benthic landers, high frequency acoustic techniques for zooplankton estimations, measurement of turbulence and biological processes at small-scales, *in situ* fluorimetry, aminoacid and urea turn-over rates in sediments, field flow fractionation techniques, *in situ* trace metal measurements, uranium:thorium disequilibria to determine *in situ* sedimentation rates of particles.
- Ecosystem modelling to explore the consequences of the results obtained and to investigate the interplay between the different processes studies.
- Training and technology transfer between the partners.

2. Work content (Back to top)

The project is formed around a set of hypotheses defined for each of the key processes identified in section 2.1. The sections which follow first introduce the hypotheses and then describe the methods which will be used to test them.

2.1 Detailed description of the key hypotheses (Back to top)

2.1.1 Turbulence characteristics in different physical regimes (Back to top)

The water column structure has been investigated by means of energy considerations, where mainly 1-D models has proven to give good quantitative results in describing the changes of stratification under forcing of different mixing conditions (Simpson and Bowers 1981). The model of Simpson and Bowers gives insight into the conditions determining the separation of well-mixed from stratified areas, where the key parameters were tidal mixing and heating processes. The addition of wind mixing to this front study (Pedersen 1994) resulted in a good agreement between the model prediction and observation. A similar model-approach has been used for the mixed layer including the effect of vertical shear and a horizontal density gradient (Simpson et al 1991). The shear effect can enhance or reduce the vertical density differences and can, thus, dominate locally the changes of stratification. Inclusion of unsteady terms such as wind mixing and pulses of low-salinity water into saltier estuaries have been made as well (Rodhe 1991, Rasmussen in press). In these bulk- model approaches the mixing due to tidal shear stress at the bottom and wind shear stress at the surface is only dealt with in terms of theoretical considerations, where a bulk-flux Richardson number is used to provide the theoretical change in the stratification due to vertical turbulent fluctuations in the density. In this investigation it will be attempted to describe the changes in the level of turbulent kinetic energy by measuring dissipation rates and their response to changes in the shear stress at the surface and at the bottom. Further the depth of the mixing layer, that is the layer of enhanced turbulence, is identified, and the turbulent density fluctuations are estimated from measurements of fluctuations in temperature and conductivity. Changes within this layer are then compared to model estimates, which include the vertical and horizontal buoyancy flux and the external energy supply. Thus, the following parameters: dissipation rates, turbulence intensity, density fluctuation characteristics, and mixed layer depth, are those essential for the different model approaches mentioned above and will be determined on the basis of the measurements. The investigations will be carried out in different areas covering both the well-mixed and the stratified regime, separated from each other by a frontal zone. The hypotheses are:

· The turbulence characteristics are governed by the competition between turbulence production by shear and turbulence suppression by density stratification.

· In the presence of horizontal density gradients, the density stratification is strongly affected by unsteady events in the horizontal advection.

Microscale turbulence may interfere with trophic interactions in the plankton by increasing the rate at which planktivorous predators encounters prey (Rothschild and Osborn 1988). Significant effects of turbulence on prey encounter rates and prey selection have been demonstrated in both copepods (Saiz and Kiørboe 1995, Kiørboe & Saiz 1995, Kiørboe*et al*. 1996) and larval fish (MacKenzie and Kiørboe 1995) in laboratory experiments, but assessments of the significance of this phenomenon *in situ* are rare (Sundby *et al*. 1994). Based on models and laboratory experiments one might hypothesise that planktonic predators feed more vigorously in the depth strata with moderately high turbulence, and that they will tend to aggregate here. At the same time, however, turbulent diffusion may redistribute planktonic organisms vertically, preventing their aggregation in high turbulence depth strata. Thus, potentially, turbulence affects both the rates of trophic transfer in the pelagic environment and the vertical organisation of pelagic food webs. We propose to examine the vertical distribution of abundance and of feeding activity (by means of gut or food vacuole content) of selected planktonic predators (copepods, large heterotrophic flagellates, e.g. *Noctiluca*) relative to the vertical distribution of prey and of turbulent dissipation and turbulent diffusion as measured by the Enhance Dissipation profiler and estimated by means of turbulent closure models. Field experiments will be conducted in situations with contrasting vertical density profiles (mixed water column, shallow mixed layer, deep mixed layer) in both the Skagerrak and in the Northern Aegean, and under conditions of varying external wind forcing. The hypotheses are:

***The hypotheses are*:**

Microscale turbulence enhances the feeding activity of mm-cm sized planktonic predators.

Turbulent diffusion prevents the aggregation of planktonic predators in high turbulent depth strata.

2.1.2 Plankton production and sedimentation flux in different physical regimes (Back to top)

Stratification of the water column reduces the vertical flux of nutrients into the photic zone. The reduced nutrient-levels select for a microbial loop dominated system with pico- and nano-sized autotrophs which are efficiently grazed by heterotrophic protists, mainly flagellates and ciliates, (e.g. Kiorbøe, 1993). The low settling rate of the small -sized primary producers, the tight coupling between primary production and protist grazing, the small faecal pellets of heterotrophic protists, and the limited amount of carbon available to larger zooplankton are all hypothesised to result in low vertical flux of particulate material and associated trace substances and increased importance of the microbial food web. This hypothesis will be tested across a gradient of different degrees of stratification where rates of different components in the food web are quantified and the rate of sedimentation is measured on short time scales in order to correlate differences in physical forcing and biological processes with vertical flux of particulate material. Components to be analysed include size-structured primary production, New/Regenerated production (*sensu* Dugdale and Goering, 1967), bacterial production, grazing rates by heterotrophic protists, copepods and appendicularians, distribution and abundance of jellyfish, euphausiids and fish at spatial scales relevant to each group of organisms.

Benthic community structure can be operationally defined as some function of species abundances, organism size distributions, biomass and/or the presence of certain functional groups such as conveyor-belt deposit feeders. Which functional groups dominate will depend on the quantity and quality of material sedimenting. Under stratified water masses with little horizontally advected material, where the microbial loop dominates, it is likely that little material will sediment and thus benthic community structure will reflect this and rates of algal pigment diagenesis and organic matter regeneration will be lower compared with those under mixed waters.

These processes are expected to be fundamentally different in the Skagerrak with much higher turbidity than in the northern Aegean. As a consequence the microbial system is expected to be more highly developed in the Aegean and will result in much lower rates of sedimentation. This will lead to effects on the benthos which has lower biomass but higher species diversity. Partitioning of settled material among the species is thus expected to be different in the two areas.

The hypotheses are:

· The degree of stratification affects the vertical flux of particulate material and thus benthic-pelagic coupling.

· Stratified water-columns induce development of a microbial loop dominated system with little vertical export of particulate material and associated trace substances.

Both the Aegean and Skagerrak systems are stratified during at least part of the year. Under such conditions, phytoplankton are predicted to be nutrient depleted in surface waters. Intermittent pulses of nutrients (via rain, upwelling etc.) will temporarily relieve the systems nutrient limitation. The frequency of pulses will vary depending on the cause of the pulse (i.e. frontal mixing, wind generated, upwelling, rain etc.) and the amplitude will vary according to local nutrient conditions. In both the Aegean and the Skagerrak, a variety in the frequency of nutrient pulses is observed. in the Aegean, however, the amplitude of the nutrient pulsing is small whereas, in the Skagerrak, it is generally higher. As small cells are more efficient in nutrient uptake than larger cells, we predict that small cells rather than large will be stimulated by small nutrient pulses under nutrient limited conditions. Under eutrophication, the amplitude of the intermittent nutrient pulse may increase. If, however, nutrient limitation of the system is not totally relieved, we predict the pulses will preferentially stimulate the growth of small cells. Thus, eutrophication may, in some hydrographic regimes not stimulate all size groups of algal cells equally but increase the number of small cells compared to large cells. Such changes in phytoplankton composition will potentially change carbon flow patterns in the system and have consequences for the structure of the food chain as well as the fate of trace substances entering the system. This may be particularly relevant in the Northern Aegean where the chlorophyll maximum is between 70 and 80m and where riverine and Black Sea inputs will vary seasonally.

The hypothesis is:

· Small pulses of nutrients in nutrient-poor environments will favour the development of small cells.

Depending on surface stickiness and contact rate seston tend to coagulate to form large aggregates, ("marine snow"). This process may significantly change the particle size structure with impact on carbon dynamics through increased sedimentation and changes in predation rate.

The large-sized material sediments rapidly and in so-doing undergoes little degradation on its way to the sea-bed. We predict that community structure will reflect whether the organic material on which it depends for food is transported vertically (high quality with low C:N) or advected horizontally (low quality with high C:N) and in turn the structure of the community will control the way that material (and hence trace substances) is mixed into sediments. We expect to find a relationship between mixing in the sediment and benthic community structure, but very little is presently known concerning the cause(s) and form of the relationship (Aller 1982; Forbes and Forbes, 1994).

In the more open sea areas sedimentation rates are expected to be higher in the mesotrophic Skagerrak compared with the northern Aegean. Mixing rates of this material into the sediments is expected to vary between the areas since the benthic fauna has fewer species and of larger size in the Skagerrak whereas the Aegean has many small species. The form of the relationships, however, is expected to be similar between areas across the size range of species present.

In the Skagerrak part of the project the mesocosms will play an important role in studies of benthic flux rates in response to large quantities of high quality sediment material. By adding centrifuged samples of natural plankton to the sediment we will be able to simulate processes that occur in the field with a high degree of control.

The hypothesis is:

· **Mixed water-columns with high nutrient availability induce the development of systems dominated by large cells, resulting in higher sedimentation rates through coagulation and production of large zooplankton faecal pellets**.

The structure (functional groups, size patterns) and biomass of the benthic communities, will be compared under stratified and mixed waters. Flux rates of materials to the sediment and degradation rates of material sediment will be measured using *in situ* benthic landers, incubated core samples. We expect that flux rates will be higher here than under mixed waters and that burial rates will also peak. Since the Skagerrak frontal system is in mesotrophic waters rates should be higher than that in the Aegean where nutrient levels are known to be much lower.

The hypothesis is:

· **Frontal zones support high productivity and high sedimentation with substantial entrapment of trace substances.**

Small-scale patchiness of resources in the water-column is still poorly described and understood. Depending on the scale and the type of organisms involved patchiness may affect the rate of predation in various ways. Some evidence exist that heterotrophic plankton may locate and stay in patches of prey. Adequate estimates of biological rates will critically depend on the spatial structure of the water-column and possible behavioural interaction. The degree of match / mismatch in distribution of producer and consumers, predator and prey, will influence the ratio between carbon cycling within the euphotic zone versus export by sedimentation.

The hypothesis is:

· The significance for predator-prey interactions of small-scale patchiness will differ between stratified and well-mixed water columns.

2.1.3 Chemical consequences of pelagic production processes (Back to top)

The total organic carbon (TOC) pool in the ocean is of comparable size to the continental pool although the oceanic biomass is estimated to less than one hundredth of the terrestrial biomass. Thus the oceanic organic carbon is an important part of the global carbon cycle (Woodwell and Houghton, 1977; Woodwell *et al*., 1978). Dissolved organic carbon (DOC) constitutes the dominant part, typically of the order of 90% or more in the open ocean (*e.g*. Carlson and Ducklow, 1995). A key component of the non-living organic matter, be it of terrestrial or aquatic origin, is the heterogeneous fraction of debris referred to as humic substances. This fraction is present in all natural waters where it constitutes between 10 - 20% and more than 80% of DOC (estimates for open ocean and coloured river or lake water, respectively, from Harvey *et al*., 1983; Buffle, 1988). Because of its complexity and heterogeneity, there is good reason to doubt that it will ever be possible to divide this fraction up into chemical substances with known structures. As a consequence, all estimates and measurements must rely on operational definitions.

Humic substances have been found to be formed in marine waters from primary production and microbial activity (Yentsch and Reichert, 1961; Sieburth and Jensen, 1969; Hedges, 1978; Harvey and Boran, 1985) as well as during mineralisation (Hayase *et al*., 1987; 1988; Chen and Bada, 1992; Momzikoff *et al*., 1994). Humic substances have been regarded as a pool of high molecular weight refractory organic matter. This might, however, not be the case in the aquatic environment, where the molecular weights found are rather modest (around 1000) and where many questions are left to be answered as to the degree of refractivity to degradation. The composition of oceanic dissolved organic matter is far from well-known, and the field is open for surprises that may turn traditional views upside-down. As an example, it is generally assumed that higher molecular weight substances are less available for utilisation by organisms than those with lower molecular weight. Recent findings contradict this view in that it was found that marine bacteria could rapidly utilise the organic matter fraction with molecular weight larger than 1000, whereas the lower molecular weight fraction was not utilised (Amon and Benner, 1994).

Results from many studies point to an intricate interplay between photochemical and biological processes in transforming DOC between the refractory, semi-labile and labile pools, and eventually to inorganic carbon (references above; Williams and Carlucci, 1976; Kramer, 1979; Geller, 1986; Mopper and Stahovec, 1986; Hayase *et al*., 1988; Kieber *et al*., 1989; Kouassi and Zika, 1990; Kouassi *et al*., 1990; Mopper *et al*., 1991; Allard *et al*., 1994; Skoog *et al*., 1996). It is very reasonable to assume that humic substances play a significant role in this context.

Humic substances are of interest not only as an important component of dissolved organic carbon, but also for their effect on trace metal speciation through the formation of metal-humic complexes. It is well known that total concentration is not the sole factor regulating the bioavailability of trace metals: extensive laboratory studies have shown that chemical speciation also plays an important role, and that for doubly charged metals it is the free metal ion activity which determines the bioavailability (Campbell, 1995). A careful analysis of this result has revealed that the metal species taken up need not be the free metal ion itself, since the uptake of any metal complex in rapid equilibrium with the free metal ion would give the same result. Although the details of the inorganic complexation of trace metals are now fairly well-established, the complexation of trace metals by natural organic matter such as humic substances is still poorly understood (see Turner, 1995) for a recent review). In order to understand metal-plankton interactions, the role of metals as toxicants or limiting nutrients, and the role played by natural organic ligands, it is essential to study the metals' chemical speciation in relation to the occurrence of humic substances and other binding agents.

The hypothesis is:

· Production processes in the euphotic zone strongly affect the concentration and speciation of organic carbon, which in turn affects trace metal speciation through complexation processes.

2.1.4 Burial and recycling fluxes in the sediments (Back to top)

A major task is to understand interaction between particle flux in the near-.bed flow and benthic suspension feeders, (Josefson, 1985). The mechanistic understanding of particle capture in passive suspension feeders is particularly wanting. A better knowledge about depth-specific horizontal flux of particles, particle size and quality, and capture rates by suspension feeders is necessary to predict the fate of settling particles. Methods will include field sampling of water characteristics, sampling of particles close to the sediment surface, chemical assessment of particles, and detailed analysis off particle flow patterns and capture rates by living suspension feeders. Sampling of particles in the near-bed flow will involve both direct sampling and video recording with image analysis. studies of encounter rate and retention efficiency must be performed in well-designed flumes to yield results which can at least approximately be extrapolated to field situations. This study will therefore use novel techniques and a carefully designed experimental approach.

The hypothesis is:

· Under certain hydrographic conditions lateral advection of particulate material may be more important than vertical flux, and this will affect mineralisation rates and flux of trace substances.

It is likely that there is a qualitative difference between material that is transported vertically and rapidly through the water column compared with advected material that is sedimented and resuspended many times. Few studies have been done to compare the quality of these two types of material.

The benthic fauna play important roles in trapping particles, both transported vertically and horizontally. Positive correlations have been observed between the biological mixing coefficient and both the total inventory of sedimentary organic matter and the degree to which particulate matter in the water column is incorporated into sediments (Forbes & Forbes, 1994; Aller et al., 1980). Despite the obvious biogeochemical importance of such relationships, a mechanistic explanation at the level of infaunal community structure has to date eluded investigators. Some deposit feeders show adaptations to feed on the organically enriched surface layers whereas others feed at deeper levels (conveyor-belt feeders) whereby material is returned to the sediment surface. It is also likely that the biological mixing of particles is a function of the body size of infaunal organisms; probably the square of animal length (Wheatcroft et al., 1990). Thus an allometric relationship should exist between deposit feeder body size and particle mixing rates in regions of the seafloor where biological mixing predominates. Predictive models of particle mixing rates will be developed from microcosm investigations of mixing rates, infaunal body size distributions, and deposit feeding rates (sensu Forbes & Kure, in press; Wheatcroft et al., 1990).

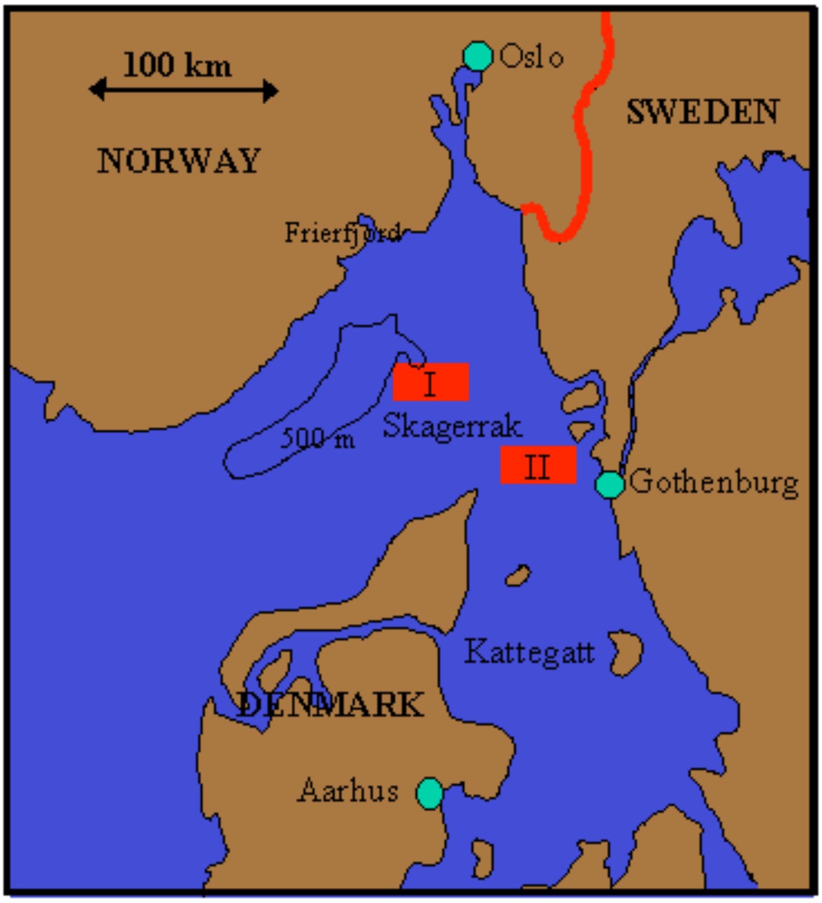
In particular suspension feeders may trap particles transported close to the bottom, a process that may be important for the benthic-pelagic coupling of organic material as well as for trace substances, (Bianchi et al 1988). Part of this material is likely to be resuspended from the bottom and is probably of lower quality compared to freshly deposited material.

The hypothesis is:

· Burial rates of organic material and trace substances (below the zone of bioturbation) vary in proportion to the amounts of vertically fluxed, high quality material compared with the laterally advected, low quality material.

2.2 Description of the study areas (Back to top)

2.2.1 Skagerrak (Back to top)



The Skagerrak is a deep basin (maximum depth 700m) with a mean depth of 200m and a sill to the south at 270m giving it a fjordic character (Fig 1a). The basic circulation is of a counterclockwise gyre (surface current speeds 10-20 cm s -1) which is dominated by outflowing Baltic water at the surface with a salinity of 25 to 30. Below this surface layer there is a layer of North sea water *with* salinity 33 to 35 and in the deepest parts salinity is over 35. Surface water salinities are highest in winter due to wind driven mixing. Temperatures range from 15 to 20 o C in summer and 0 to 5 o C in winter. During summer there is a marked salinity dome in the central part of the Skagerrak formed by water with higher salinities and lower temperatures and marked stratification during summer. Fig 1 a shows the general features.

The mean transport of water due to the cyclonic circulation is estimated at between 0.5 and 1.0 x 106 m3 s -1 giving a flushing time above the sill depth of around 100 days. There is vertical entrainment of deep water into the surface cyclonic circulation. The core of the cyclonic circulation consists of water from the central/northern North Sea. Yet the key feature is undoubtedly that most of the southern N. Sea and Jutland Water passes through the Skagerrak before leaving along the Norwegian coastal current. The Skagerrak (and Norwegian Trench) act as sinks for organic and inorganic suspended matter transported by the currents. It is estimated that probably 50-70% of all the suspended matter transported in the North Sea is deposited in the Skagerrak, Kattegatt and Norwegian Trench. Van Weering et al. (1987) estimated that 28 x 106 tons dry weight are deposited in Skagerrak annually and 17 x 106 tons are < 63 μm. Thus most of the trace substances discharged into the North Sea and which are not trapped within estuaries will be deposited in the Skagerrak making it the "dustbin" of the North Sea, (North Sea Quality Status Report, 1993).

Mean winter nitrate and phosphate concentrations in the Skagerrak proper are 8-10 and 0.7-0.9 μmol l-1 respectively in surface waters. Higher values are often found in the incoming surface waters from the southern N. Sea (up to 20 μmol l-1 nitrate).

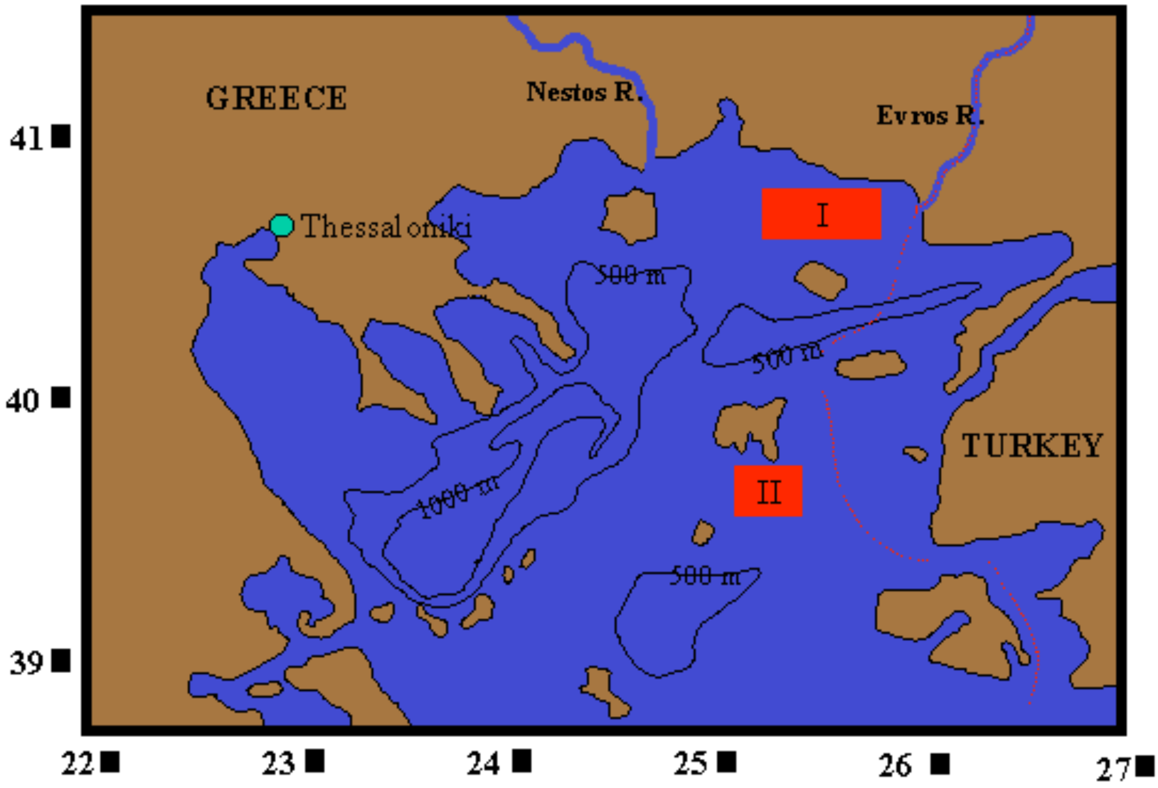
Surprisingly few studies concerned with energy flow in the pelagic have been carried out to date in the Skagerrak. Most of those that have focused primarily on phytoplankton activity and distribution. This area has been visited by a number of toxic or nuisance blooms in recent years and these have received considerable attention (i.e. *Gyrodinium aureolum* : e.g. Tangen, 1983; Dahl and Yndestad, 1985; *Chrysochromulina polylepis*: i.e. Maestrini and Graneli, 1991). The mechanism of bloom formation and the potential role of anthropogenically induced environmental changes in the development of these blooms are still unclear. However, it has been suggested that many of the blooms which plague coastal regions of the Skagerrak may have their source in sub-surface (pycnocline) populations originating in the more open regions of the Skagerrak (Richardson and Kullenberg, 1987). Subsurface phytoplankton peaks occur in this sea from late spring until early autumn and it is clear that interaction between hydrographic processes and these subsurface peaks influence the patterns of primary production observed in the Skagerrak (Richardson, 1985). At least one study (Kiørboe et al., 1990) also suggests that the very different hydrographic regimes observed in the Skagerrak lead to the development of different patterns of energy flow in the pelagic. These workers demonstrated that variations in water column structure (depth of mixed layer) through a transect in the Skagerrak could be directly related to average phytoplankton size and the structure of the food chain (up to and including mesozooplankton) (Tiselius et al 1991). Thus, there is good reason to argue that the Skagerrak offers the variety in water column conditions necessary in order to test the hypotheses presented in this proposal.

The dominant fish species in the Skagerrak are herring, cod and plaice, with average annual yields respectively of 146,503, 18,383 and 10,700 tonnes between 1987 and 1990). Norway lobster (*Nephrops norvegicus*) is also important with average annual yield of 2,574 tonnes in the same period.

The sediments of the Skagerrak are inhabited by an invertebrate fauna rich in species (>1000 species) and the biomass of the macrofauna varies between some 3 g afdw m-2 in the deepest parts up to some 100 g afdw m-2 at 50-100 m water depth. Macrofaunal abundance typically varies between 1000 and 10 000 individuals m-2, and the area contains a variety of different functional forms, i.e. passive filter feeders, notably ophiuroids (*Amphiura*), surface deposit-feeding polychaetes and bivalves, and head-down feeding conveyor-belt-species. Apart from being the base for a productive fishery for demersal fish, lobster and prawns, this fauna is likely to have a significant influence on cycling of C, N and trace substances (e.g. Josefson 1981, 1987,1990; Josefson et al. 1993).

Whereas most previous work on benthos in the area has concerned temporal and spatial dynamics in relation to environmental factors, little work has been done on the role of this fauna in affecting biogeochemical processes, (Rutgers van der Loeff et al. 1984). The wide range of faunal biomasses as well as the diversity of functional groups makes Skagerrak an ideal area to study such interrelationships.

2.2.2 Northern Aegean (Back to top)



The N.Aegean Sea is characterised by a relatively extensive shelf and a series of three aligned depressions (down to 1600m deep), that constitute the so-called N. Aegean trough. The shelf is a typical deltaic platform developed by delta progradation during late glacial sea-level stand (progressive type margin). Six rivers discharge to the N. Aegean (Axios, Aliakmon, Pinios, Strymon, Nestos and Evros) with a total suspended sediment supply in the order of 6-9 106 t yr-1. In the inner shelf prodelta deposits have been developed in "prismatic" geometry receiving almost the 80-90% of the discharged sediments (Lykousis & Chronis, 1989). The outer shelf consists mainly from relict muddy sands-sands. The thickness of Upper Quaternary sediments (128 ka-today) in the slopes and basins range from 20 to 50 m implying mean sedimentation rates from 10-30 cm ka-1. During Holocene (late 10 ka) the equivalent values are 0.5-1.5 m and 5- 15 cm ka-1 (Piper & Perissoratis, 1991). The subsidence rates for the N. Aegean basins have been calculated for the eastern part (0.95-1.8 m ka-1) and western part (0.3-1.5 m ka-1) (Lykousis, 1991).

In the northern Aegean, general circulation is cyclonic. In summer strong cold and dry northerly winds blow in the Aegean (Metaxas, 1973). This wind pattern leads to upwellings along the western Turkish coast and western coasts of the Greek islands at the Eastern Aegean Sea (Theocharis et al., 1995). The upwelled waters are of Levantine origin and nutrient depleted. During winter dense waters are formed over the Samothraki and Limnos plateau providing waters that sink down to deep troughs and basins contributing to the renewal of the deep water (Georgopoulos et al., 1992; Theocharis & Georgopoulos, 1993). Outflow of Black Sea water (BSW) from the Dardanelles (after Bosporus and Marmara Seas) is between 200 and 1000 km3 y-1 but in a recent study it was estimated at 300 km3 y-1 (Unluata et al., 1990). The main pathway of the BSW follows the periphery of the cyclonic gyre existing in the N. Aegean, deflecting branches in the Samothraki and Thermaikos plateau. During winter periods BSW flowed westward mostly along the northern coast of Limnos island, where it then bifurcated to the south and north. During the warm periods BSW after passing Dardanelles flowed southward and its core appeared south of Limnos island. The outflows of the River Evros, which drains part of Bulgaria, and

Nestos are 6.8 and 1.8 km3 y-1 respectively. The result is a winter-spring picture of colder brackish water in the Northern and Western parts and in the south east (off Limnos) warm higher salinity water (LIW).

The plateau between the rivers Evros and Nestos, Samothraki plateau, is the largest fishing area in Greece and frequented by trawlers. However, trawling is restricted to 7 months each year and between May and September is prohibited. The larger fishing effort is possible presumably because of nutrient inputs from the Black Sea and Evros and Nestos rivers. The dominant pelagic fish species in the N. Aegean are: sardine, anchovy, *Trachurus* spp. and *Scomber* spp. and the demersal species are: hake, blue whiting, poor cod and *Mullu*s spp. (Stergiou & Pollard, 1994). *Nephrops norvegicus* is also important.

The intermediate and deep waters of the Aegean Sea are characterised by the lowest concentrations of nutrients and the highest concentration of oxygen when compared with those of the other principal Mediterranean basins (Souvermezoglou, 1989; Souvermezoglou et al., 1992). During winter relatively high nutrient levels are observed in the surface layer of N. Aegean, while phosphates and nitrates are totally disappeared in summer (low silicate levels) (Boussoulengas et al., 1988). Maximum values recorded in deep layers were: 3.5 μmol l-1 for nitrates, 0.15 μmol l-1 for phosphates and 7 μmol l-1 for silicates. The increase of nutrient levels in the deep layers during summer is due to the sinking waters formed over the shelf areas in winter period. It is suspected that the system may be phosphate limited.

The chlorophyll maximum at typical stations in the N. Aegean is at 70- 80m depth in summer and has value of only around 0.3-1 μg l-1 (greatest recorded value: 1.6 μg l-1). The system during summer is flagellate dominated (small dinoflagellates and other flagellates) (Pagou et al., 1990) whereas during spring is dominated by small-cell diatoms. During the same period (spring bloom), chlorophyll varied between 3.6 and 9.7 μg l-1 outside and inside the Evros plume areas, respectively (Gotsis-Skretas et al., 1995).

Zooplankton abundances attain the higher values (1000-6000 ind. m-3) in the layer above the halocline in the north-eastern part. Generally numbers decrease rapidly with depth. Below 500m zooplankton number is low (2-10 ind m-3) but there is no clear difference between North and South Aegean (Siokou-Frangou et al., 1994a). The zooplankton and phytoplankton assemblages were differentiated in the area close to Dardanelles, due to the BSW influence (Siokou-Frangou et al., 1994b). The benthos is species rich (approximately 2500 species recorded in the Aegean) (Simboura & Nicolaidou, 1994; Zenetos, 1995; Simboura et al., 1995), small in size and with low biomass (though in N. Aegean higher than the respective values in the S. Aegean).

The sediments in the plateau off the Evros and Nestos rivers are principally pro-deltaic with muddy areas near the river mouths changing to muddy sand and sand further out. There is a probable erosion area along the outer shelf-shelf break (100-150 m depth). This area is adjacent to the North Aegean Trough (maximum depth 1550 m). On the middle-outer shelf between the Evros and Nestos river trawling activity is a significant contributor to sediment disturbance and resuspension supplying with suspended sediment the near bottom nepheloid layer. The mean annual catch density of fish in N. Aegean is 2.18 t km-2 (1982-1989), which is 2 to 4 times higher than those in the Ionian and S-SE Aegean. During March, maximum values recorded in the River Evros plume were 5.2 m l-1 for ammonium, 2.9 μm l-1 for nitrates, 11.9 μm l-1 for silicate and 0.24 μm l-1 for phosphate. Outside the Evros plume the values were 2- over 20 times lower.

2.2.3 Basic similarities and differences between areas (Back to top)

From the foregoing it is clear that there are a number of similarities between the areas which render the comparison a useful one. Firstly, they are of approximately the same size. The most important feature is that both areas have large brackish water influences from adjacent inland seas (the Baltic and Black Seas) and similar Corioli driven circulation patterns with north flowing surface currents from these seas. Both have freshwater inputs from rivers of comparable sizes. Both the Skagerrak and N. Aegean have deep basins (700m in the Skagerrak and 1100m in the N. Aegean). In both areas the low salinity surface waters and the circulation patterns leads to deep plankton maxima although the depths of the maxima differ (15-20m in the Skagerrak and 70-80m in the Aegean).

Yet there are fundamental differences which will enable us to better understand the processes that are the primary focus of this project:

- Nutrient regimes are very different with average winter nitrate and phosphate values for the Skagerrak at 8-10 μmol N l-1 0.7-0.9 μmol P l-1 in the open areas and 10-15 μmol N l-1 and 1-1.5 μmol P l-1 in the coastal areas. Corresponding maximum values for the N. Aegean are 3.5 μmol N l-1 and 0.15 μmol P l-1 . Thus the Skagerrak has approximately 4-5 times the amount of winter nitrate and phosphate than the N. Aegean, which is nevertheless the most nutrient rich area of the Aegean Sea. In summer phosphate values are usually undetectable in the N. Aegean and this is expected to lead to major differences in processes and fluxes between the two areas, such as primary production and vertical flux rates of particulate material to the benthic systems and nutrient cycling within the sediment..
- The salinity of the Skagerrak is between 25 and 30 whereas the N. Aegean is between 34 and 38. The Skagerrak is relatively turbid with high light attenuation whereas the N. Aegean has clearer water with extremely low attenuation. It is thus likely that not only will primary production processes be different but behavioural differences in zooplankton e.g. predator avoidance, vertical migration, grazing etc. The life-cycles of the copepods are in theory expected to differ between the two areas and this will be a primary focus of this study.
- Biological coagulation (packaging) processes are likely to be very different between the two areas and this is expected to have a major influence on flux rates.
- There are also important differences in sedimentological and geochemistry setting such as higher content of calcareous material in the N. Aegean which are expected to lead to different rates and processes of nutrient recycling, and erosion, transport, deposition, accumulation of particulate matter and trace substances.
- The benthic systems differ in that biomass and abundances are higher in the Skagerrak but species diversity is higher in the N. Aegean. Thus the processes and rates of mineralisation and material burial will vary.
- Plankton abundance and biomass are lower in the northern Aegean.
- Whereas contaminant loading is fairly well known in the Skagerrak information is lacking from the N. Aegean. Thus any information obtained will be new.

2.2.4 Selection of the sites for intensive investigation (Back to top)

Testing the hypotheses set out above will require field work in different hydrodynamic regimes (stratified and frontal), for which the following approximate locations have been identified (see Fig. 1):

- Stratified water stations: northern Skagerrak coastal region (Skagerrak); Samothraki plateau (N. Aegean)
- Frontal water stations: east of Skagen (Skagerrak, meeting of Baltic and Skagerrak waters); Limnos plateau (N. Aegean, meeting of Black Sea and Aegean waters)

Due to the high spatial and temporal variability in hydrographic conditions the exact locations will be determined during the cruises and side-scan sonar will be used to determine sea-bed characteristics. The locations will be more closely defined at the first workshop of the programme and will be finely adjusted during the cruises according to the prevailing conditions. An significant, though intermittent, input to the Skagerrak occurs via the Jutland Current flowing along the western Danish coast. Although not a priority for this project, comparative investigations in the Jutland Current will undertaken whenever practicable.

2.3 Experimental methods: (Back to top)

2.3.1 Measurement of turbulence (Back to top)

As a function of depth, the turbulent fluctuations of velocity, salinity and temperature will be measured from a stratified area, through a frontal zone to a mixed area. The measured turbulent fluctuations will be compared with existing theories of dissipation and buoyancy forcing (by heating and by velocity shear in the presence of a horizontal density gradient). The water column structure is described with respect to:

1. the mean profiles of temperature, salinity and velocity (CTD and ADCP)
2. the small-scale turbulence profiles with respect to the fluctuations of temperature, salinity and velocity

These two sets of profiles will be analysed to describe the length scale of the vertical excursion of a particle and the small-scale turbulent kinetic energy. Also the vertical extent of the well-mixed (turbulent) surface and bottom layers will be identified by using the high frequency sampler. within the stratified depth range the turbulence is reduced, but non-constant (in the vertical plane). It will be investigated where biological patches are found, and how these patches correspond to small-scale turbulent intensity at that depth range.

The changes in the turbulence intensity will be followed and attempts will be made to describe a function of the physical forcing.. The changes in the turbulence in the well-mixed surface and bottom layers as well as in the stratified ranges will be identified and compared to the changes occurring in the biological patches.

The microstructure measurements will be performed using the Enhanced Dissipation Profiler, which has been developed as prototype within the MICSOS project (EUREKA/EUROMAR). The EDP system has 3 main components: (1) The measuring probe, which is designed as a quasi-free rising/sinking profiler with microstructure and CTD-sensors as well as sensors to control the rising/sinking process; (2) the shipboard unit, which is the central data registration-, control- and operating-unit for the whole system and which includes computer capacity for on-line preliminary data evaluation; (3) a shipboard winch for top-down measurements, and/or a specially designed underwater which for bottom-up measurements.

2.3.2 Plankton production and sedimentation flux in different physical regimes (Back to top)

Primary production will be estimated with standard techniques using 14C-labelling of size fractionated water samples from different depths. The ratio between new and regenerated production is estimated from measurements of NH4 and NO3 uptake, respectively. Bacterial production is estimated from 3H-thymidine labelling of water samples from different depths. The ratio of active/inactive bacteria is determined with fluorescent molecular markers. Grazing rate of heterotrophic protists is calculated from uptake of isotope and/or fluorescently labelled bacteria and algae, while growth rate is measured in incubations of size-fractionated or diluted water samples, (Nielsen & Kiorbøe 1994). For copepods and appendicularians grazing rate is estimated from incubations of natural water or water spiked with tracer particles where particle uptake is measured with an electronic particle counter. Growth rate of selected copepods is determined from egg production, (e.g. Kiorbøe & Nielsen 1994). The vertical distribution and abundance of jellyfish, euphausiids and fish are estimated with video and net-hauls, acoustics and net-hauls, and acoustics respectively.

The response of autotrophs in natural water samples to the frequency of nutrient input will be studied through field measurements of relevant processes and determination of naturally occurring size distributions of phytoplankton. In addition, controlled experiments will be carried out to examine the influence of various sizes of nutrient pulses on the size structure of the phytoplankton. Size structure is determined using an electronic particle counter.

The abundance and size distribution of large aggregates as a function of water-column stability is determined from video-recorded sequences. These data together with measurements of small-scale turbulence, literature data on fall velocities and coagulation coefficients are used in a model analysis of the importance of coagulation as a mechanism for vertical transport.

An interplay between field observations, field and laboratory experiments is used to test this *(predator-prey interaction)* hypothesis. Different sampling programs in the field are employed to test for a match-mismatch between predators and prey at several spatial scales e.g. using multi-bottle sampler for bacteria, protists and small copepods (Bjornsen & Nielsen 1991), using video-recordings of large copepods and acoustics for euphausiids and fish. In particular, an *in situ* fluorimeter will be used to locate chlorophyll discontinuities which will be essential in the analysis of heterogeneities connected to the marked sub-surface chlorophyll maximum in the Aegean Sea. Depth-specific differences in rate parameters will be studied through *in situ* incubations of water samples. Laboratory experiments testing for responses of predators to prey patches will be performed in test systems with specified prey patchiness. The numerical response to the temporal frequency in food supply is also determined in laboratory experiments. Results from field distributions and behavioural experiments are used in computer simulations of individually based models to analyse different foraging strategies in terms of critical food concentrations, critical patch size and the risk of starvation.

Sediment fluxes will be measured using Th/U ratios (Aller et al 1980) and where possible using sediment traps, but there are concerns about the interpretation of trap data where advective processes dominate and in areas where there is intensive trawling.

Tests of model predictions are performed regarding the turbulent-induced switch in copepods between active capture of motile ciliates and the suspension feeding of non-motile autotrophs. A possible approach is offered by measurements of the relative uptake of diatoms and ciliates by omnivorous copepods in incubations of natural water samples at different turbulent intensities.

2.3.3 Chemical consequences of pelagic production processes (Back to top)

Total organic carbon (TOC) will be measured with the high temperature combustion method. The reason for measuring TOC (unfiltered samples) rather than DOC (filtered samples) is the considerable risk of contaminating samples during filtration (Sharp and Peltzer, 1993; Wedborg *et al*., 1996).

Humic substances will be measured as fluorescent dissolved organic matter (FDOM) in two ways. The use of 350/450 nm excitation/emission wavelengths with quinine sulphate standardisation will allow comparison with our previous results. A more detailed characterisation will rely on three-dimensional fluorescence spectra. Investigations of excitation-emission matrices (EEMs) at natural concentrations in ocean samples has proved to be a valuable tool for obtaining more detailed information about the FDOM (Coble *et al*., 1990; Poryvkina *et al*., 1992; Mopper and Schultz, 1993; Coble, 1996). The results will be analysed using multivariate statistical methods (principal component analysis, PCA, and partial least squares, PLS).

Two complementary techniques will be used for the investigation of colloid size distributions: field flow fractionation (FFF) (Beckett and Hart 1993), and tangential flow ultrafiltration (Benner et al. 1992). FFF allows both assessment of size distributions from a molecular weight of 500 up to 1mm (Beckett et al. 1987), and also the ability to collect material in different size fractions for further analysis. FFF is a chromatography-like elution technique in which colloids and macromolecules are eluted from a flat separation channel against a crossflow which presses them against a permeable membrane. UV absorption is commonly used for detection of the eluted material. Of the two main variants of FFF, sedimentation FFF provides excellent size resolution but very dilute fractions, while flow FFF has somewhat coarser size resolution but much reduced dilution in fractions collected: flow FFF has therefore been selected as better suited to this project. Tangential flow ultrafiltration will be used with filter cutoffs of 103, 104 and 105 Daltons to characterise colloid size distributions (Forbes et al. 1994). This technique allows concentration of colloidal material large than the filter cutoff, and will thus provide a valuable comparison with the FFF measurements. FFF has previously been applied to freshwater samples where it has been shown that molecular weights down to 500 can be selectively eluted; molecular size is determined after calibrated with synthetic standards. These measurements used membranes with a nominal cutoff of 10,000 Daltons: although these membranes appear to have relatively low permeability even for the smaller humic molecules, there are indications that significant sample loss can occur (Beckett *et al*. 1989). Recent improvements to the FFF technique including the use of membranes with lower molecular weight cutoffs and a sample focusing technique *(*Lee *et al*. 1995*)* allow dilute samples to be preconcentrated within the FFF channel, and in this way low organic carbon concentrations (down to 75mmol L-1) have been successfully size fractionated without the need for preconcentration.

Two approaches will be used for the measurement of trace metals. The first is measurement of total trace metal concentration by standard techniques (preconcentration followed by AAS and ICMP), and the second a new technique for *in situ* measurement of trace metals. The latter is based on microelectrode systems (Tercier *et al*. 1990) which are being developed for *in situ* use as part of the MAST-III project VAMP. The VAMP system consists of a mercury film on an iridium electrode, separated from the sample solution by a gel film. Since the gel film acts as a low molecular weight cutoff, the electrode measures only the free metal and small (largely inorganic complexes). Comparison of this measurement with the total metal will thus give valuable information on the metal speciation which can be correlated with the organic carbon and colloid data. The major focus of the work will be the mercury-soluble metals most readily measured by the VAMP sensor (copper, lead, cadmium and zinc) which are also important anthropogenic and/or bioessential metals.

This work brings together several novel techniques (three-dimensional EEM fluorescence characterisation of humic substances, FFF characterisation of colloidal material, cross-flow ultrafiltration and the VAMP *in situ* sensor) which, in combination with the biological studies, will provide new insights into the interplay between pelagic chemical and biological processes.

2.3.4 Burial and recycling fluxes in the sediments (Back to top)

The sediments will be characterised with respect to structure, organic C, N, Si, plant pigment budgets, (Sun et al. 1991), amino acid composition and organic matter turnover, (Mopper and Dawson, 1986). The studies will involve mixing, transformation of pigments and associated selected trace substances, (inorganic and some organic e.g. PCB. The approach of simultaneously studying pigments and trace substances has not often been used. These same elements will be analysed repeatedly in the near-bottom water and related to advective processes). The role of different faunal compositions will be assessed also taking into account, physical variables such as salinity, temperature and oxygen regimes, episodic events and if possible trawling activities. Finally, the role of benthic macrofauna in the organic matter turnover will be evaluated.

The geochemical and sedimentological work on the sediments will include grain size analyses, redox measurements, levels of organic matter (C, N and P), lead-210 and selected heavy metal and organic micropollutants (PCB, DDT etc.). Analyses of pore water will also be included to illustrate mineralisation of organic matter and the potential mobility of trace substances.

The C/N ratio in the sediment particulate organic matter pool is a measure of quality of organic matter, but represents an average of several different substrate pools of variable accessibility for mineralisation (Blackburn, 1986; Therkildsen & Lomstein, 1993). Both the particulate and the dissolved organic matter pools will be measured and compared with the C/N ratio of the effluxing material from the sediment (Walsh, 1989).

Use of chlorophyll as marker of faunal feeding, digestion processes has received increased attention in recent years. While most previous work in this field has been done on pelagic grazers some recent studies have involved benthic organisms (Hawkins et al. 1986, Bianchi et al 1988, Josefson et al. in press; Josefson et al in review). Some of these studies suggest that different chlorophyll degradation products are formed depending on which type of fauna is involved in the degradation processes (micro- or macro- fauna). For instance phaeophorbide may be a primary marker of macrofauna feeding, while other products such as phaeophytins may be more related to microbial activities. This may be a possible mean of separating effects of macro- and micro-fauna on degradation/transformation of chlorophyll and trace substances as well. Degradation rates and the distribution of pigments and trace substances in the sediments will depend on several fauna-generated processes such as feeding, irrigation and sediment mixing, which will be compared between areas having different rates of vertical and lateral organic matter flux.

The distribution of organic compounds, adsorbed to sediment particles and dissolved in porewater is a result of both biological and non-biological processes. Amino acids are of specific interest, as amino acids are the building-blocks of protein molecules and they make up a significant proportion of cellular nitrogen. The geochemical behaviour of amino acids are, however, complex, as dissolved free amino acids can be lost by both biological mediated turnover, (Burdige and Martens, 1988; Christensen and Blackburn, 1980; Lindroth and Mopper, 1979).

Surface sediment organic matter supplied by horizontal transport can be expected to be different in origin and/or composition compared to that supplied by vertical transport. These differences are hypothesised to be reflected in the molar composition of surface sediment amino acids and will be tested in sediments underlying different water column stratification regimes. Amino acids will be measured by HCl-hydrolysed samples.

We will use the well-studied 238-U: 234-Th disequilibrium to obtain an estimate of the degree of local horizontal exchange of particles. This will be done in both the Skagerrak and Aegean. If there is no horizontal exchange of particles on 234-Th decay time scales, the excess 234-Th in a given region of bottom sediment would be determined at steady state only by the production rate from 238-U in the immediately overly water. The nature of the graphical relation between 234-Thxs inventory in the sediment and water depth can be used to obtain an estimate of the degree of local horizontal exchange of suspended particulates. For example, a simple linear relationship between water depth and 234-Thxs is expected in the absence of significant horizontal exchange (Aller et al., 1980).

The adsorption of amino acids may be reversible or irreversible and it is important for the understanding of benthic organic matter turnover to quantify the binding capacity of sediment organics, (Hedges and Hare 1987; Hedges and Prahl 1993; Wang et al, 1993). The amino acid pool in the sediment will be estimated by use of appropriate extraction solutions as for instance artificial seawater or NaOH followed by high-performance liquid chromatography (HPLC), (Mopper & Dawson, 1986). The change in molar composition of amino acids with sediment depth compared to the original material supplied to the sediment gives indications on which amino acids are most accessible for degradation.

The overall rates of organic matter mineralisation will to a large degree be studied with an *in situ* benthic lander, (Tengberg et al 1995). The lander is an autonomous instrument that carries four chambers to the sea-floor and makes *in situ* measurements of benthic solute fluxes. Oxygen micro electrodes measure *in situ* benthic oxygen consumption. Further water samples can be taken at programmed time intervals and analysed at the surface for concentration changes with time, (carbon dioxide, nutrients, dissolved organic compounds, etc.). It is also possible to inject trace substances or biochemical inhibitors into the chambers to obtain *in situ* measurements of sediment-water fluid exchange (bioirrigation) and metabolic rates. After the incubation and measurements are fulfilled on the sea-floor, the lander drops its ballast weights upon acoustic signal and floats to the surface. It brings virtually undisturbed sediment with overlying water back to the research vessel.

HPLC with fluorescence detection will be used to quantify pigment concentrations and degradation under oxic and anoxic conditions will be measured. Algal pigments derived from phytoplankton will be mixed with 51Cr-labelled sediment in order to measure pigment degradation and biological mixing concurrently. Short-term physical and biological mixing of material into the sediment will be analysed from the field samples using 234Thxs. By combining this data with 210Pb data, which indicates long-term sedimentation rates, models will be developed and will be related to testing hypotheses relating mixing to pigment inventories and pigment fluxes.

The turnover of selected amino acids and urea will be measured in order to quantify important routes of ammonium production and factors regulating this production. The interrelationship between amino acid and urea turnover will thus be studied in details, (Price, 1987, Wang & Lee 1993). The turnover rates will be measured by 14C tracer additions by the method described for urea turnover in Lund & Blackburn (1989). Diffusive fluxes of organic nitrogen compounds will be calculated and compared with fluxes measured in the benthic lander.

Model construction for nitrogen processes in sediments will be done using the system-dynamic model environment Cellmatic in close collaboration with T.H. Blackburn. The system dynamic model is a model in which reaction- and diffusion problems can be solved in multiple layers (Blackburn & Blackburn, 1993 a,b). Pools of CO2, DOC, HS-, NH4+, NO3-, N2, POC, PON, O2, SO4 2- and porosity will be modelled. The dynamic of the model is described by specified reaction- and flow rates, which are mathematically defined functions. Cellmatic is thus an elegant tool to describe carbon and nitrogen dynamics in marine sediments under different conditions, as for instance mineralisation of organic matter under different conditions of organic mixing into the sediment.

A unique and large-scale mesocosm facility is available at the Norwegian Institute for Water Research and we will sample 0.5 m x 0.5m replicate box core samples from the field site which will be transported into the mesocosm in order to study benthic processes in detail. Earlier studies have shown that it is possible to maintain intact benthic faunal systems over periods of 3 months (Gray, 1987, Berge et al 1986). Since the patterns of bioturbation caused by the main bioturbating species are known it is possible to study the key processes affecting benthic fluxes at a variety of spatial scales. Bioturbation processes are known to influence trace substances in sediments both by increasing rates of burial and by remobilisation to the water column. New tracer methods have been developed to measure bioturbation and these will be used, (Wheatcroft et al 1994). The University of Athens will use direct measurement of bioturbation measuring turnover rates of sediment, sediment resuspension, sediment metabolism and mineralisation, and faecal pellet production. These processes are known to be species specific and mesocosms offer the opportunity to do controlled experiments on effects on trace substances and these will done in the mesocosms.

2.3.5 1-D Ecosystem Modelling (Back to top)

Objective: To investigate, via numerical modelling, the seasonal evolution and controls exerted by vertical mixing processes on the flow and cycling of carbon and nutrients in the water column and sediments in the different hydrodynamic and nutrient regimes of the Skagerrak and northern Aegean Sea. The work thus acts as a link between the subprojects outlined above and highlights the relationships between them.

The hypotheses are:

1. The degree of stratification affects the vertical flux of particulate material and thus the benthic pelagic coupling.
2. Stratified water columns induce development of a microbial loop dominated system with little vertical export of particulate material.
3. Mixed water-columns with high nutrient availability induce the development of systems dominated by large cells, resulting in higher sedimentation rates through coagulation and production of zooplankton faecal pellets.

The existing 1-D POM/ERSEM model developed during the MAST MERMAIDS II project will be applied to different regions of the Skagerrak and northern Aegean Sea to simulate a period spanning the field studies, (Ledwell et al 1993). To examine the aforementioned hypothesis, ERSEM will be expanded to increase the number of state variables describing pelagic particulate organic carbon POC. This will account for variations in the physiochemical properties of POC. The ecosystem model will be reparameterised in the light of the ongoing process studies/data collection within the project. Particular emphasis will be placed upon primary production and pelagic nutrient recycling mechanisms. The results of these models will be analysed in order to elucidate the controlling mechanisms of ecosystem dynamics in the regions of interest. Regional variations in carbon and nutrient fluxes through the ecosystem will be quantified. To simulate the stratification/vertical mixing at the survey sites detailed meteorological data will be required to force the physical model. The model system we propose to use is a synthesis of two well established modelling initiatives. A level 2.5 turbulence closure model (Mellor & Yamada 1982) determines the vertical temperature, turbulent kinetic energy, and diffusion coefficient profiles generated by a surface heat flux, salinity, tidal mixing and wind stress). Heat transfer is assumed to be via vertical diffusion processes. Other mixing processes (e.g. internal waves) are parameterised by a background viscosity. In this study the vertical diffusion submodel of the Princeton Ocean Model (Blumberg & Mellor 1980) will be used.

3. Benefits (Back to top)

The current state of the art, against which the scientific and technical benefits must be assessed, is first summarised briefly.

3.1 State of the art: Key processes to be investigated (Back to top)

3.1.1 Turbulence characteristics in different physical regimes(Back to top)

The upper layer of the ocean, the so-called mixed layer, is characterised by a highly dynamical behaviour with a competition between processes of mixing and stabilisation, depending on the relation between turbulent momentum flux on the one hand and buoyancy fluxes on the other hand (Imberger 1985, Shay and Gregg 1986, Brainerd and Gregg 1993). However, this competition is well understood theoretically and has been modelled in terms of basic parameters such as external energy supply when determining the location of fronts (Simpson and Bowers 1981). In the presence of horizontal density gradients, the effect of a baroclinic circulation on the stratification has been investigated by Simpson et al (1991). Similar regimes, but with unsteady events such as wind mixing (Rodhe,1991) and pulses of fresh water into saltier estuarine areas (Rasmussen, in press) have been studied using a 1D-bulk model. It should be emphasised however, that to a large extent, the understanding of the turbulent processes in the marine area is still based on laboratory measurements and theoretical work. This is true for well-mixed surface and bottom layers as well as for stratified layers. The transport physics within the upper and bottom boundary layers is of paramount importance for the ecosystem, where the dynamics of the ecosystem are closely coupled to that of the physics (Grebmeier et al 1988). The recent development of high frequency samplers (Stips et al 1994) enables "in situ" measurements of the turbulent microstructure (Prandke and Stips,1992, Stips et al, 1995), which can considerably improve our understanding of the vertical turbulent transport and help to gain better insight into the local physical processes and their influence on the local biological processes. Measurements in combination with suitable model based evaluation methods, will enable a description of the small-scale processes affecting the ecosystem. Regarding the physics, different sites, characterised by different physical forcing, will be compared. These are well-mixed areas, where processes of mixing dominate, frontal zones, where stabilisation and mixing are of a comparable magnitude, and finally stratified areas, where the vertical and horizontal buoyancy effects govern the water column structure. The different physical regimes are characterised by a highly turbulent water column on the well mixed side of the front, while the turbulence intensity will be damped within the stratified water column, which further causes the wind generated near-surface turbulence to be independent of the turbulence near the bottom. Hence large temporal and spatial variability in the near-surface turbulence is expected, which will be investigated on the basis of measurements and 1-D modelling.

3.1.2 Production and sedimentation flux in different physical regimes (Back to top)

The upper layer of the ocean, the so-called mixed layer, is characterised by a highly dynamical behaviour with a competition between processes of mixing and stabilisation, depending on the relation between turbulent momentum flux on the one hand and buoyancy fluxes on the other hand. This situation is still more complicated by the presence of fronts. However, this competition is well understood theoretically and depends on basic parameters such as external energy supply, stratification and location of fronts. Despite this, to a large extent, the understanding of the turbulent processes in the marine area is still based on laboratory measurements and theoretical work. This includes well-mixed surface and bottom layers as well as stratified layers. The transport physics within both the upper and the bottom boundary layer is of paramount importance for the evolution of the ecosystem, and the dynamics of physics and ecosystem are closely coupled, (Grebmeier et al 1988).

Where water masses are well mixed nutrient levels remain high with a high supply rate of "new" production derived primarily from transported nitrate, (Dugdale and Goering, 1967). Here production rates are high and flux of material from the euphotic zone to deeper water masses and the benthos are high. In contrast in stratified waters nutrients are used up rapidly and the system relies on internal cycling of nitrogenous material for production and is thus based on "regenerated" nitrogen usually in the form of ammonium. In stratified waters material is retained in the euphotic zone and there is little flux of material to deeper water masses. In summer the central Skagerrak has a large area of stratified water (varying from 10 to 30 m depth) but there are areas of mixing also thus it is possible to select areas showing different processes, (Kiorbøe et al. 1990). In the Northern Aegean stratification can extend to

60-70m depth and thus provides an interesting contrast to the Skagerrak.

Frontal zones, where two water bodies with different physico-chemical characteristics meet, are boundaries which influence the fate of organic carbon and trace substances, (Iverson et al. 1979). Here production is usually very high with high flux rates of material to deeper water masses and the benthos. Examples are the mixing zones between the Baltic and the Skagerrak water and the Black Sea and the Aegean Sea water. These will also be compared. In these comparative studies we will quantify the retention of organic carbon, trace metals and organochlorines in sediments.

Distributions of plant pigments in the sediment reflect the flux of phytoplankton to the bottom (e.g. Graf, 1989) as well as various mixing and transformation processes in the water column and sediment. Knowledge of sedimentary pigment concentrations, degradation rates and degree of particle mixing thus allows theoretical estimates of pigment flux to the sediment surface. This approach has been used successfully to estimate sedimentary chlorophyll flux in a shallow benthic habitat and will be applied here (Sun et al. 1991). Benthic macrofauna can significantly influence these sedimentary processes by their bioturbation and irrigation activities. Local species abundances are expected to strongly influence both the rate and character of bioturbation and irrigation activity (Forbes & Forbes, 1994; Wheatcroft et al., 1990). It is thus important to determine the functional groups of benthic organisms with respect to bioturbation and irrigation activities in order to predictively model their roles in biogeochemical cycles. Construction of predictive diagenetic models linking community structure with key biogeochemical processes will be attempted by combining measurements of community structure, flux rates of key chemical species (e.g., N, O) across the sediment water interface, and concomitant measures of bioturbation and irrigation rates.

3.1.3 Chemical consequences of pelagic production processes(Back to top)

The dependence of trace metal bioavailability on speciation was first recognised clearly in some 20 years ago, and has since been formalised in the "free-metal ion activity model" (see Campbell 1995 for a recent review). Although much of the research effort over the intervening period has focused on the uptake of toxic metals, the formulation (Martin *et al*. 1990) and subsequent tests (Martin *et al*. 1994) of the "iron hypothesis" (that low iron concentrations limit primary production in the high-nutrient areas of the Pacific and Antarctic oceans) have stimulated interest in trace metals as micronutrients. Recent laboratory work has suggested that low zinc concentrations may also limit phytoplankton growth under certain conditions (Morel *et al*. 1994).

Micronutrient limitations of this type are unlikely to be important in coastal systems where metal levels are much higher than in remote oceanic areas due to terrestrial inputs, both directly from freshwaters and from atmospheric particles. However, coastal systems provide an ideal environment for the investigation of the effects of production processes. Biological processes can affect trace metal speciation through the production of different types of organic ligand which bind the trace metals and thus reduce their bioavailability as the free metal ion activity is reduced.

A major drawback of many of the current techniques for investigating organic carbon and trace metal speciation in marine systems is that they rely on some form of preconcentration in order to obtain sufficiently high concentrations for investigation, e.g. extraction of humic materials on resins, or extraction of organically bound trace metals. Another popular technique for the study of trace metal speciation is the addition of a high concentration of a metal-binding ligand, following which the concentration of the metal complex with the added ligand is measured electrochemically (cathodic stripping voltammetry), and the speciation of the metal in the original sample estimated by a complexing capacity titration (Rue and Bruland 1995, Gledhill and van den Berg 1994). The reliability and accuracy of these techniques is limited by changes in the chemical speciation during the extraction, preconcentration or sample modification process, and by the likelihood that this process operates more efficiently for some fractions of the organic material or trace metal than others. There are thus considerable advantages to be obtained by studying organic carbon and trace metal speciation with more direct techniques which can be used directly on freshly collected samples or even *in situ*. A range of such techniques are proposed in section 2.3.3.

3.1.4 Burial and recycling fluxes in the sediments(Back to top)

Particulate organic matter is concentrated 10,000 to 100,000 fold in the sediment relative to the water and thus sediment biogeochemical activity is high. A significant proportion of organic matter mineralisation takes place in the sediment at water depth down to 200 m. Sediments of the continental shelf and of fjords and estuaries are therefore some of the most important areas of element cycling in the ocean.

Burial of organic matter can be considered as a loss mechanism of organic matter and nutrients from the biosphere, whereas sediment organic matter mineralisation and the flux of nutrients across the sediment-water interface can be important regulating factors for pelagic (and benthic) primary production. Processes in the organic part of the benthic nitrogen cycle are of major interest as these processes, their regulation and quantitative importance to a large degree determines the nitrogen sources that eventually will escape to the overlying water. Thus, knowledge on factors regulating processes of organic nitrogen turnover is necessary in the understanding of mechanisms regulating the internal loading. Further, this knowledge is indispensable in the construction of predictive models.

The sediment nitrogen cycle is mostly dependent on the quantity of degradable Particulate Organic Matter (POM) reaching the sediment and on its quality (basically it's nitrogen content), Lomstein et al. (1989). Blackburn & Blackburn (1993 a,b) showed by system dynamic modelling that the proportions of degradation products (DON, ammonium, nitrate and molecular nitrogen) effluxing to the overlying water depend principally on the distribution of the particulate organic matter within the sediment and on the diffusibility of sulphide and other reduced products. Benthic macrofauna can also enhance organic matter mineralisation (Kristensen & Blackburn, 1987; Lomstein et al., 1989, Therkildsen & Lomstein, 1993). There are few studies on routes of ammonium mineralisation in the sediment. However, urea can be an important intermediate in the production of ammonium, (Lund & Blackburn, 1989; Lomstein et al., 1989; Therkildsen & Lomstein, 1993; Pedersen et al. 1993).

The fate of trace substances accumulated in the sediments in stratified and non-stratified environments may also be different. The quality of the sedimenting material will affect the trapping of trace substances in the sediment. In areas with relatively little particulate organic matter (POM) sorption processes for trace substances will be different to those in areas with high POM and dissolved organic matter (DOM) loads. Likewise how the benthic fauna processes the material will also alter the uptake of trace substances. Studies will be done in mesocosms using radiolabelled materials and varying qualities and quantities of organic matter and these will be compared with field samples.

3.1.5 Ecosystem modelling (Back to top)

One of the aims of the second Mediterranean Eddy Resolving Modelling And InterDisciplinary Studies (MERMAIDS II) project was to understand the interactions of the physical system with its biogeochemical components by coupling ecological models to advanced hydrodynamic models and so describe the seasonal cycles of nutrients in the Mediterranean and its regional seas. To accomplish this, ERSEM, the European Regional Seas Ecosystem Model (Baretta et al., 1995) was combined with a fine scale vertical diffusion water column model driven by a turbulence closure scheme (Mellor & Yamada 1982) and run for different parts of the Adriatic basin, to simulate the seasonal cycles of the lower trophic levels, nutrients and oxygen. ERSEM has been show to be capable of successfully simulating the marine ecosystem in a wide range of physical and nutrient regimes ranging from well mixed, eutrophic (e.g. Baretta et al., 1995, Allen & Blackford. 1995) to strongly stratified oligotrophic (Allen et al., 1997).

The ecosystem described in ERSEM is considered to be a series of interacting complex physical, chemical and biological processes which together exhibit a coherent system behaviour and is overview by Baretta et al., 1995. State variables have been chosen in order to keep the model relatively simple without omitting any component which exerts a significant influence upon the energy balance of the system. ERSEM uses a 'functional' group approach to describe the ecosystem where by biota are grouped together according to their trophic level (subdivided according to size

classes or feeding method). The dynamics of the biological functional growth are described by both physiological (ingestion, respiration, excretion, egestion etc...) and population processes (growth, migration and mortality. The biological variables in the model are, phytoplankton, functional groups related to the microbial loop, zooplankton and benthic fauna. (Varela et al., 1995; Ebenhoh et al., 1997; Baretta-Bekker et al., 1995,1997; Broekhuizen et al., 1995; Ebenhoh et al., 1995; Blackford 1997). The chemical dynamics of nitrogen, phosphate, silicate and oxygen are coupled to the biologically driven carbon dynamics. The mineralisation of organic matter coupled to diagenetic nutrient processes in the sediments are included in the model (Ruardij & van Raphorst, 1995). The phytoplankton pool is described by four functional groups based on size and ecological properties (diatoms, flagellates, picoplankton and dinoflagellates). All phytoplankton groups contain internal nutrient pools and thus have dynamically varying C:N:P ratios. The nutrient uptake is controlled by the difference between the external nutrient concentrations and the internal nutrient pools. The microbial loop contains bacteria, heterotrophic flagellates and microzooplankton, each with dynamically varying C:N:P ratios. Bacteria act to decompose detritus and can compete for nutrients with phytoplankton. Heterotrophic flagellates feed on bacteria and picoplankton, and are grazed by microzooplankton. Microzooplankton also consume diatoms and flagellates and are grazed by mesozooplankton.

3.2 Wider justification (Back to top)

There have been recent attempts to assess the condition of the Skagerrak in relation to effects of anthropogenically derived nutrients and the levels of contamination (North Sea Task Force, 1994). Yet we do not have an adequate understanding of the fundamental processes that affect carbon and nutrient cycling and these are intimately bound up with contaminant cycling. Once these processes are better understood we will be better able to give an assessment of how nutrients and trace substances are cycled and stored and thereby their likely effects on biological systems.

The northern Aegean Sea is the richest fishing area in the eastern Mediterranean, presumably due to inputs of nutrients from rivers draining Bulgaria and from the Black Sea. Little is known of the processes that link carbon and nutrient flux to trace substances from these inputs. By contrasting the processes affecting carbon and nutrient fluxes in the Skagerrak with those of the northern Aegean where nutrient levels are less than a fifth of the Skagerrak we expect to find new and fundamental principles.

The present project will provide important background information on planktonic biomass and rates with high vertical resolution that is essential for a proper understanding, management and modelling of the fluxes within and export from the euphotic zone in stratified marine ecosystems.

The results of this study therefore, will be of benefit to managers of the coastal zone in general and for the Skagerrak and northern Aegean in particular. At the completion of the project we will be able to present data on the levels of trace substances and nutrients and carbon in sediments. We should have a good understanding of where and how material is incorporated in bottom sediments. This information is essential for monitoring trends in contamination and effects of nutrients on biological communities. We expect that the design and optimisation of monitoring programmes for both areas will be greatly improved.

In order to make the results available and intelligible to managers we will ensure that WWW pages containing a synthesis of the principle results are a displayed. This will ensure that immediate use can be made of the data.

4. Economic and social impacts (Back to top)

While this project has no socio-economic component, the data obtained are expected to be useful in that context. Whilst the results will be obtained from geographical areas they will be globally applicable since the project concentrates on key processes in contrasting environmental situations. The most relevant environmental aspects are those concerning the fluxes, deposition and burial of nutrients and trace substances. There are wide socio-economic implications of discharging nutrients and trace substances to sea. There is a need to regulate discharges in a cost-effective way, which requires in turn that potential contamination of food supplies or reductions in environmental quality must be quantified. Whilst much is known concerning the concentrations of trace substances and nutrients, flux rates are poorly known. Yet it is not concentration but flux that determines whether or not a given area will show symptoms of eutrophication, toxic algal blooms or contaminated food sources. The data obtained in this project are expected to help in better estimates of the risks of exposure and thereby to give the managers better tools with which they can undertake risk management. Another subject of economic importance is the world-wide increase in the number of noxious plankton blooms has been observed in recent years, which has had a particular impact on recreation, shell fisheries and fish farming. KEYCOP will provide a basis for future investigations of the physical-chemical-biological processes that affect such bloom formations.

The use of novel measurement technologies in an interdisciplinary context can be considered as an essential element for the proposed Global Ocean Observing System, GOOS and for the successors of the JGOFS project. For example, the development of new strategies to study physical-biological couplings and thus create markets for the MICSOS profiler.

So far Greek studies in the N. Aegean have been descriptive and there are no data on processes and flux rates. Thus the main aim of this study to measure flow and cycling of carbon and nitrogen and trace substances in the water and sediment will provide important new data which will be of relevance to better management of the environment including the fishing industry.

4.1 European dimension (Back to top)

Comparative studies of the type proposed here are highlighted as needed in the ELOISE science plan, and this proposal is designed to compare key processes in two contrasting nutrient regimes which have similar hydrographic forcing. Similar studies on the scale of that planned here have not been done anywhere, as far as we are aware. Thus this project should be unique both on a European and in a global context.

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Partners in the KEYCOP Project

Partners

- University of Oslo, (UO), Norway
- National Centre for Marine Research, (NCMR), Greece
- Danish Institute for Fisheries Research (DIFRES), Denmark
- National Environmental Research Institute (NERI), Denmark
- Göteborg University (GU), Sweden
- Space Applications Institute(SAI), Italy

Associate Partners and Subcontractors

- Plymouth Marine Laboratory, U.K. (associate partner, associated to GU)
- The University of Lund (UL), Sweden (subcontractor to GU)
- The Marine Biological Laboratory, University of Copenhagen (subcontractor to NERI)
- ME Meerestechnik- Elektronik GmbH (ME), Germany (H. Pranke, subcontractor to SAI,)

University of Oslo, (UO), Biology Institute, Section of Marine Zoology and Marine Chemistry:

Role: Project management and co-ordination. The U. of Oslo will also be involved directly with the benthic processes component.

Experience: The benthic research group at U. of Oslo has expertise in meio- and macrofaunal community analyses and experience in running mesocosm experiments using benthic communities. The research group has high competence in statistical analyses particularly in the use of multivariate techniques. Good facilities for benthic faunal and data analyses exist.

National Centre for Marine Research, (NCMR), Greece

Role: To organise and to co-ordinate the tasks concerning northern Aegean. To provide the R.V. Aigaio and to organise the deployment and retrieval of large instrumentation and arrays (e.g. sediment traps, currentmeters, CTD). To be involved directly with majority of the tasks concerning N. Aegean.

Experience: The activities of NCMR include the implementation of national and international development programmes, special studies for scientific purposes, consultant services for public and private institutions and organisation of special teams to deal with emergencies, such as pollution accidents. NCMR has a decade of experience in coastal and open sea research with the R/V Aigaio and many years experience in monitoring studies generally. At present 80 scientists carry out scientific research in NCMR. The Institute of Oceanography (Physical, Chemical, Biological Oceanography and Marine Geology and Geophysics) has expertise in multidisciplinary studies. The research groups of the Institute involved in the SkagerrakAegean project have a lot of experience in studying the oceanography of the open and coastal waters in Greece and especially the coupling between physical and biological parameters in the northern Aegean (POEM).

Danish Institute for Fisheries Research (DIFRES)

Role: provision of shiptime (Dana), contribution to studies on plankton production and sedimentation in different physical regimes.

Experience: DIFRES is a sector research institute under the Ministry of Food Products, Agriculture and Fisheries. It has a staff of over 300 including approximately 150 scientists and has a mandate to conduct research and to act in an advisory capacity on matters relating to fisheries, fisheries management, sea ranching, development of fish products and the marine environment. In the Department of Coastal and Marine ecology there are 15 scientists with expertise on biological oceanography, plankton production, physical-biological interactions in the pelagic, chemical oceanography and experimental physiology of plankton.DIFRES has a large research vessel "DANA" with modern hydrographic, chemical and biological sampling gear. Laboratory facilities at DIFRES are available for continuous culture of phyto- and zooplankton. The institute has been and is involved in many international collaborative projects including ELNA (Eutrophic Limits to the Northern Adriatic), ICOS, TASC and an EU-AIR Baltic Cod recruitment project.

National Environmental Research Institute (NERI), Denmark

Role: To investigate fine scale vertical distribution of biomass, grazing and production of heterotrophs at high spatial resolution under different hydrographic regimes. To investigate the influence of macrofaunal structure on mixing, transformation and recycling of organic matter and trace substances in and on the sediment. Pigment flux estimates in the Skagerrak. To perform gradient studies of trace substances. To co-ordinate the quality assurance work of the chemical analyses.

Experience: NERI is affiliated with the Danish Ministry of the Environment. NERI's mission is to provide the scientific basis and environmental information for decisions in areas where political, administrative and commercial activities are important to the environment. NERI performs strategic and applied research and is responsible for collection and overall management and co-ordination of data on nature and environment. As a research institute NERI is separated from the political/administrative system when carrying out research and monitoring. The department of Marine Ecology and Microbiology (HAMI) has about 60 employees that are responsible for marine and coastal research and monitoring. HAMI has a multidisciplinary approach with experts in nutrients and plankton dynamics, benthic-pelagic coupling, benthic communities and marine chemistry. HAMI has participated in several national, international (e.g. EU) projects and has more than a decade of experience in eutrophication related work.

Göteborg University (GU), Sweden (Department of Analytical and Marine Chemistry)

Role: Investigation of organic carbon, colloidal material and dissolved trace metals; benthic rate measurements by benthic lander; determination of fine scale vertical distributions of the full size range of zooplankton using a combination of video and acoustics; determination of relevant predator-prey relationships and their effect on the vertical flux under various hydrographical regimes; radiochemical measurements (subcontract with Lund University (LU), Sweden).

Experience: GU is a leading centre for marine research in Sweden and host to one of the three Marine Research Centres established by the Swedish government in 1989. GU researchers have extensive experience of work in the Skagerrak and other coastal waters and also in deep ocean environments, particularly at high latitudes. Facilities available include a wide range of analytical instrumentation, a benthic lander and a 38m research vessel 'Skagerak'. The university has two field stations on the coast of the Skagerrak at Kristineberg (run jointly with the Royal Academy of Sciences) and at Tjärnö (run jointly with Stockholm University).

Space Applications Institute (SAI), Italy

Role: Measurement of the turbulent microstructure in the upper ocean layer, in order to derive estimations of heat, mass and momentum fluxes in the water column and to conduct analytical/modelling work aimed at describing the vertical turbulence with respect to the forcing generating it. Modelling work describing the vertical turbulence structure as function of the driving forces (vertical and horizontal buoyancy flux, wind stress), making use of the microstructure measurements for validating the model.

Experience: SAI is one of 8 institutes of the Joint Research Centre of the European Union at ISPRA Northern Italy. The mission of IRSA is to develop, demonstrate and validate methodologies for the use of remotely sensed data. The mission of the marine environment unit of SAI is developing, demonstrating and validating methodologies for the use of data from space in both, operational applications and scientific investigations. Its activities include the development and application of algorithms for the processing of ocean colour and SST data, the preparation (also for derived parameters) of respective time series, mosaics and statistical images, the performance of in-situ measurements and the support/participation in cruises for validation purposes, the modelling of marine processes and further development of data assimilation techniques. SAI is involved in a number of international programmes/projects (EUROMAR, OCEAN, JGOFS, WOCE) and has collaboration contracts with many specialised institutes in different countries of the EU.

Associate Partners and Subcontractors

Plymouth Marine Laboratory (PML), U.K. (associate partner, associated to GU)

Role: Development of ERSEM for application to Skagerrak and northern Aegean

Experience: Plymouth Marine Laboratory is part of the UK Natural Environment Research Council, and undertakes inter-disciplinary research into estuarine, coastal, shelf and oceanic ecosystems. It is the lead laboratory for the UK Land-Ocean Interaction Study (LOIS), which is directly relevant to the present proposal. PML has organised and successfully administered a number of large multi-laboratory projects, and participated in many others including those sponsored by the EC (DGXII). The ecosystem modelling group at the PML has been successfully involved in MAST projects since their inception. We played a key role in both ERSEM I and ERSEM II being responsible for the management and quality control of the standard ecosystem model and the development of models of benthic biology. With the MAST MERMAIDS II project, ERSEM II and the NERC LOIS programme, we have developed considerable expertise in the coupling of hydrodynamic and transport models with ecosystem models.

The University of Lund (UL), Sweden (subcontractor to GU)

The Marine Biological Laboratory, University of Copenhagen (subcontractor to NERI)

ME Meerestechnik- Elektronik GmbH (ME), Germany (H. Pranke, subcontractor to SAI,)