SIXTH FRAMEWORK PROGRAMME

Project contract no. 003933

THRESHOLDS

Thresholds of Environmental Sustainability

INTEGRATED PROJECT

Priority 1.1.6 "Sustainable Development, Global Change and Ecosystems"

Sub-Priority 1.1.6.3 "Global Change and Ecosystems"

Publishable Final Activity Report

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Project coordinator organisation name: CSIC-IMEDEA

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PUBLISHABLE EXECUTIVE SUMMARY

The *Thresholds IP* aims at contributing to the progress of Sustainability Science and to the improvement of Sustainability Policy formulation. It aims at developing a target setting process that integrates scientific knowledge on thresholds of environmental sustainability with the evaluation of externalities associated with the affected socioeconomic activities. The *Thresholds ip* confronts complex behaviour of ecosystems, such as regime shifts between alternative stable states and complexity in valuation of the activities affecting environmental quality, such as non-linear cost-pressure relationships and multi-sectorial situations. The methods and tools developed have been applied to case studies in the European coastal zones, where policy needs are pressing, involving increasing levels of complexity, from local to pan-European. *Thresholds* draws on extensive data sets and research results produced on the basis of national efforts as well as previous framework programmes, which have focused on major environmental problems and have delivered models and data which can be used to define Thresholds. The *Thresholds IP* therefore builds on the European Research Area concept and adds value to the application of results derived from national and FP6-funded research.

In this context, *Thresholds* was set out to:

- **Develop the scientific tools to identify Thresholds of Environmental Sustainability**. These refer to the pressures that can be imposed on a given resource while maintaining acceptable levels of environmental quality. A threshold is defined as a critical value of a driver beyond which the shifts to a different regime of a state indicator shows resistance to return to the original state as the driver is reduced again below the threshold. The science required to identify such thresholds should be quantitative and predictive, while coping with the complexity and non-linear behaviour of environmental systems. However, the final project results shows that complex system behaviours may escape from being predictable, and the demand for exact information on the boundaries between different classes of ecological status – as for examples those required by the implementation of the EU Water Framework Directive and in legislation concerning contaminants – may be misleading. Resources used for identifying limits and for monitoring the state of the system with reference to pre-specified limits do not necessarily advance knowledge of why and how changes occur, which would be instead the only relevant and useful information for policy makers (coastal managers). There is the risk that fixed "ecological thresholds" – which are in reality highly dynamic and dependent on specific circumstances, as it has been demonstrated by the Thresholds case studies and by many other studies found in the literature – can become a bureaucratic point of reference rather than encouraging an understanding of the dynamics of the system.
- **Perform externality valuations** to estimate the monetary value of the impacts associated to threshold exceedance. External costs are those generated by a given activity without being reflected in market prices or/and in the decision process of socio-economic players. Failure to consider social external costs leads to market distortions, to sub-optimal investment and fiscal policies and, ultimately, to non-sustainable development processes. However, within *thresholds*, externality valuation had to take account of non linear phenomena and discontinuity in valuation functions, so as to allow for the accurate estimation of the socio economic costs of exceeding sustainability thresholds. The use of market based instruments to "internalise" external costs in the consumers' decisions is challenging when thresholds-related environmental problems occur. Ideally the costs of activities should increase well before the pressure they cause reach thresholds values, thereby encouraging innovations that reduce the pressure, but due to thresholds effects scarcity may not develop and hence costs do not increase before it is too late. Any system that exhibits time lags and thresholds of irreversible change is susceptible to unintended deterioration under extreme deregulated regimes because the information gathering and the modification of behaviour is unable to cope with the dynamics of the system.

The evaluation techniques experimented in Thresholds only partially helps to address this problem. Indeed, social costs and benefit evaluation of any activity causing an environmental pressure reflects only those effects that it gives rise to that agents in the economy are aware of and care about. For instance, human agents will care about the pollution of coastal waters, as this could impact on the beach quality and the amenity services that the site delivers. In such a case, external costs would arise as the monetary valuation of the damage done to those services. This approach has been applied to the Thresholds case studies, estimating external costs of algal blooms by figuring out what those affected (the beach users) would be willing to pay to avoid the damage. Besides the problems of lack of comparability of the willingness to pay evaluations in different contexts – which have been shown by choice experiments undertaken in the North Sea case and Varna Bay in Bulgaria – one main problem with the standard monetary evaluation is that it takes account of pollution only to the extent that somebody is willing to pay to avoid it. Pollution that does not give rise to any effects that anybody cares about may well, nevertheless have implications for the future ability of the joint economy-environment system to satisfy human needs and desires. This is particularly true when the harmed organisms may be members of keystones species, the loss of which would lead to an irreversible loss of ecosystem resilience, but that nobody except a biologist has ever heard of.

- **Produce policy recommendations** that would help coastal managers to deal with thresholds of environmental sustainability. Such recommendations include general guiding principles, to be applied by coastal managers throughout Europe, and specific policies recommended as an outcome of scenario evaluation cases studies, performed by Thresholds in the Southern North Sea (France, Belgium, Netherlands), Varna Bay (Bulgaria), Mallorca (Spain), and related to Marine Fish farms (in the Mediterranean sea). Policy guidance is provided also by a "generalised" case study which produced a pan-European map of "hotspots", i.e. coastal waters which are both highly sensible to eutrophication - due to hydrodynamic conditions measured by a physical sensitivity index - and subject to potentially high nutrient loads due to high emissions in the river catchment areas (the generalisation case study considered approximately 35.000 European-wide catchments, each represented as a simple box model for which nutrient input, potential denitrification rates as well as derived nitrogen (N) and phosphorus (P) loads to coastal zones were calculated). As it concerns the general guiding principles, one key message emerging from our research is that thresholds may be a useful concept in developing and implementing regulation, but **the context-dependency of thresholds has to be recognised**. The health of coastal and marine waters cannot be guaranteed by European legal documents only. Adaptive governance mechanisms should be put in place. A regime that stresses adaptive governance is also likely to emphasise social learning more than centralised and rigid regimes. It can put more weight on new information made available by different social actors and can develop towards governance which also delegates responsibilities to actors outside the public administration. This means that great emphasis should be put on harmonisation of methods for obtaining and storing information, but less on the exact interpretation of data as the interpretation would be part of a social learning process. Finally, processes supporting societal learning on how to manage systems with thresholds will only develop through active stakeholder participation. The regulatory systems should provide flexible frameworks to make local and regional participation meaningful.

The analysis and examples of thresholds and regime shifts phenomena studied and collected in the Thresholds-project show that the variability is real and that **one cannot legally define universal thresholds**. There is always a need to relate the threshold to the specific management context. This suggests that if ecological thresholds are to be given an operational and instrumental role in developing and implementing environmental policies, then there is a need to:

- Develop policies that encourage the use of systematic methods for dealing with thresholds: monitoring requirements; careful ex-post evaluation measures, including natural science, economics and other social sciences to improve understanding of shifting baselines and key processes; and detailed ex-ante evaluations of additional measures that may increase the risk of trespassing thresholds or that aim at returning pressures to levels below observed thresholds.
- Revise standard indicators so that adequate attention is paid to the possibility of non-linear or discontinuous change; this includes a recognition of the need for systematizing data and making data available. The development and application of models should be encouraged by the policies.
- Explore in advance possible policy responses in a thresholds framework: how does one act if a threshold is about to be trespassed? How does one prepare for surprises? The hot-spot approach can be useful in guiding policy development: special attention can be focused on systems that appear to run a high risk of non-linear change in the face of increasing pressures. For example, the Mallorca case illustrates the risks of major developments in coastal areas with specific hydrographic and hydrological conditions.

Thresholds can be used as a conceptual reference point in justifying the application of a precautionary approach. A conceptual use does not require rigorous definition or specification of actual threshold values, but may nevertheless be important as it highlights the risks and possibilities that are inherent in systems displaying non-linear behaviour or discontinuities.

1 PART 1: PROJECT EXECUTION

1.1 GENERAL OVERVIEW OF THE THRESHOLDS PROJECT (OBJECTIVES, CONSORTIUM, STRUCTURE AND MAIN ACHIEVEMENTS)

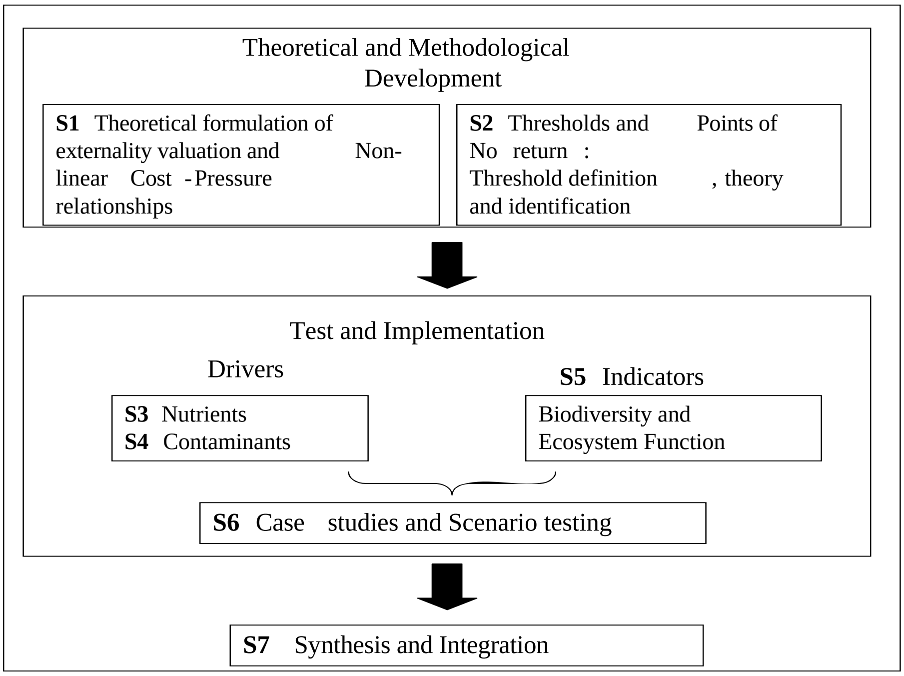
The *Thresholds IP* aims at contributing to the progress of *Sustainability Science*, an emerging discipline which seeks to bridge the gap between Science and Sustainability Policies, and of its role in support of Sustainable Development, through the establishment and testing of an innovative policy formulation mechanism based on the integration of: a) a target setting process driven by novel scientific knowledge on environmental sustainability indicator thresholds, b) the assessment of socio-economic costs and impacts associated to such targets and c) policy guidance for the application of tools and criteria for sustainable coastal ecosystem management.

The *Thresholds* team includes 27 partners, representing 12 EU Member States. Prof. Carlos Duarte (CSIC-IMEDEA, Spain - carlosduarte@imedea.uib.es) is the Scientific Coordinator and Mr. Andrea Ricci (ISIS, Italy – aricci@isis-it.com) is the Project Manager. The whole partnership includes:

- Consejo Superior de Investigaciones Científicas (CSIC, Spain).
- Istituto di Studi per l´Integrazione dei Sistemi (ISIS, Italy)
- University of Stuttgart (IER, Germany).
- University of Uppsala (UU, Sweden).
- National Environmental Research Institute (NERI, Denmark).
- The Joint Research Centre (JRC-IES, EU).
- Finnish Environment Institute (SYKE, Finland).
- University of Southern Denmark - Institute of Biology (USD, Denmark).
- University of Kalmar (UNIK, Sweden).
- Universitat de les Illes Balears (UIB, Spain).
- Université Pierre et Marie Curie (UPMC, France).
- The Norwegian Institute for Water Research (NIVA, Norway).
- Institut Français de Recherche pour l´Exploitation de la Mer (IFREMER, France).
- Université Libre de Bruxelles (ULB, Belgium).
- University of Oslo (UO, Norway).
- Ringkøbing County (RC, Denmark).
- University of Bath (UBath, United Kingdom).
- TerrAquat - Consultants for Soil, Water, Nutrients and Contaminants (TerrAquat, Germany).

- Centrale Recherche SA (ERASME/CRSA, France).
- Ecole de mines (ARMINES/France)
- Institute of Oceanology, Bulgarian Academy of Sciences (IO-BAS/Bulgaria)
- University of Tartu (UT/Estonia)
- Universitet Lund (LU/Sweden)
- Bioforsk (Bioforsk/Norway)
- Danish Ministry of the Environment (REC/Denmark)
- Aarhus Universitet (NERI/Denmark)

The *Thresholds* project has been articulated in **7 Streams** of research activities, connected in common structure and workplan as illustrated in the flow diagram below.



In this context, *Thresholds* **objectives** were set out as follows:

- Develop the scientific tools to identify Thresholds of Environmental Sustainability. These refer to the pressures that can be imposed on a given resource while maintaining acceptable levels of environmental quality. A threshold is defined as a critical value of a driver beyond which the shifts to a different regime of a state indicator shows resistance to return to the original state as the driver is reduced again below the threshold. The science required to identify such thresholds should be quantitative and predictive, while coping with the complexity and non-linear behaviour of environmental systems.
- Perform externality valuations to estimate the monetary value of the impacts associated to threshold exceedance. External costs are those generated by a given activity without being

reflected in market prices or/and in the decision process of socio-economic players. Failure to consider social external costs leads to market distortions, to sub-optimal investment and fiscal policies and, ultimately, to non-sustainable development processes.

- Produce policy recommendations that would help coastal managers to deal with thresholds of environmental sustainability.

The **main achievements** of Thresholds in relation to the above objectives are summarised below:

- As it concerns the development and application of scientific tools for the prediction and management of thresholds of environmental sustainability, Thresholds research results show that complex system behaviours may escape from being predictable with enough confidence, and the demand for exact information on the boundaries between different classes of ecological status – as for examples those required by the implementation of the EU Water Framework Directive and in legislation concerning contaminants – may be misleading. Resources used for identifying limits and for monitoring the state of the system with reference to pre-specified limits do not necessarily advance knowledge of why and how changes occur, which would be instead the only relevant and useful information for policy makers (coastal managers). There is the risk that fixed "ecological thresholds" – which are in reality highly dynamic and dependent on specific circumstances, as it has been demonstrated by the Thresholds case studies and by many other studies found in the literature – can become a bureaucratic point of reference rather than encouraging an understanding of the dynamics of the system.
- As it concerns externality evaluation, *Thresholds* research had to take account of non linear phenomena and discontinuity in valuation functions, so as to allow for the accurate estimation of the socio economic costs of exceeding sustainability thresholds. The use of market based instruments to "internalise" external costs in the consumers' decisions is challenging when thresholds-related environmental problems occur. Ideally the costs of activities should increase well before the pressure they cause reach thresholds values, thereby encouraging innovations that reduce the pressure, but due to thresholds effects scarcity may not develop and hence costs do not increase before it is too late. Any system that exhibits time lags and thresholds of irreversible change is susceptible to unintended deterioration under extreme deregulated regimes because the information gathering and the modification of behaviour is unable to cope with the dynamics of the system. The evaluation techniques experimented in Thresholds only partially helps to address this problem. Indeed, social costs and benefit evaluation of any activity causing an environmental pressure reflects only those effects that it gives rise to that agents in the economy are aware of and care about. For instance, human agents will care about the pollution of coastal waters, as this could impact on the beach quality and the amenity services that the site delivers. In such a case, external costs would arise as the monetary valuation of the damage done to those services. This approach has been applied to the Thresholds case studies, estimating external costs of algal blooms by figuring out what those affected (the beach users) would be willing to pay to avoid the damage. Besides the problems of lack of comparability of the willingness to pay evaluations in different contexts – which have been shown by choice experiments undertaken in the North Sea case and Varna Bay in Bulgaria – one main problem with the standard monetary evaluation is that it takes account of pollution only to the extent that somebody is willing to pay to avoid it. Pollution that does not give rise to any effects that anybody cares about may well, nevertheless have implications for the future ability of the joint economy-environment system to satisfy human needs and desires. This is particularly true when the harmed organisms may be members of keystones species, the loss of which would lead to an irreversible loss of ecosystem resilience, but that nobody except a biologist has ever heard of.

- Finally, the policy recommendations based on the lessons learned from Thresholds research include general guiding principles, to be applied by coastal managers throughout Europe, and specific policies recommended as an outcome of scenario evaluation cases studies, performed by Thresholds in the Southern North Sea (France, Belgium, Netherlands), Varna Bay (Bulgaria), Mallorca (Spain), and related to Marine Fish farms (in the Mediterranean sea). Policy guidance is provided also by a "generalised" case study which produced a pan-European map of "hotspots", i.e. coastal waters which are both highly sensible to eutrophication - due to hydrodynamic conditions measured by a physical sensitivity index - and subject to potentially high nutrient loads due to high emissions in the river catchment areas (the generalisation case study considered approximately 35.000 European-wide catchments, each represented as a simple box model for which nutrient input, potential denitrification rates as well as derived nitrogen (N) and phosphorus (P) loads to coastal zones were calculated). As it concerns the general guiding principles, one key message emerging from our research is that thresholds may be a useful concept in developing and implementing regulation, but **the context-dependency of thresholds has to be recognised**. The health of coastal and marine waters cannot be guaranteed by European legal documents only. Adaptive governance mechanisms should be put in place. A regime that stresses adaptive governance is also likely to emphasise social learning more than centralised and rigid regimes. It can put more weight on new information made available by different social actors and can develop towards governance which also delegates responsibilities to actors outside the public administration. This means that great emphasis should be put on harmonisation of methods for obtaining and storing information, but less on the exact interpretation of data as the interpretation would be part of a social learning process. Finally, processes supporting societal learning on how to manage systems with thresholds will only develop through active stakeholder participation. The regulatory systems should provide flexible frameworks to make local and regional participation meaningful.

Special efforts have been made to ensure that the target setting procedure developed within *Thresholds* can be adapted to the multi-facet consensus dimension of policy making considered as a social process, and disseminated appropriately. *Thresholds* will enhance its dissemination capabilities through close interaction with other IPs funded within the program.

1.2 OVERVIEW OF THE RESULTS ACHIEVED BY THE PROJECT RESEARCH STREAMS

1.2.1 Stream 1: Theoretical formulation of externality valuation and non-linear cost-pressure relationships

Synopsis of Stream 1 key results:

- new advances in methodology to assess thresholds in an economic framework;
- applied choice experiments to value algal bloom in 3 locations and tested the potential for "benefit transfer";
- linked values resulting from choice experiment in Belgium to ecological conditions in the coastal area;
- policy analysis of the use of thresholds; and
- guidance notes on use of economic valuation in the context of coastal areas.

1.2.1.1 General methodology and brief description of the work carried out

As it concerns the **general methodology**, Stream 1 builds on theory from environmental economics and the social sciences to assess the values of externalities in the coastal zones and to assess the implications for policy. A method for linking emissions to state to values was developed, along with a literature review of environmental valuation that had previously been conducted. Key to the work was the application of choice experiments to assess the values associated with algal blooms in coastal areas of the North Sea, Mallorca and Bulgaria. Following on from this, benefit-transfer testing assessed the degree to which results from Bulgaria and Mallorca differed, taking into account social factors that differed between sites. The link between economic valuation and ecology in the Belgian case was made through use of a "mental model" developed by partners in Streams 3 and 6. The use of thresholds in policy was evaluated using document analysis and critical assessment of legal frameworks.

As it concerns **the work carried out**, Stream 1 has been articulated in three Workpackages (WPs):

- **WP 1. Theoretical Framework.** WP leader: UBATH (Anil Markandya and Tim Taylor), aiming to provide developments in the theory as to how thresholds are assessed using economic techniques. This included the application of the theory to a number of case studies and a literature review of existing work on valuation in the coastal zone context.
- **WP 2. Empirical valuation of key externalities.** WP leader:UBATH (Anil Markandya and Tim Taylor), aiming to provide primary data on the valuation of key externalities where thresholds play a role in coastal ecosystems. Here, choice experiments were applied to estimate values for algal bloom and benefit transfer tests conducted to assess transferability. An evaluation was conducted of the linkages between economic and ecological modelling inputs and end-points in the areas selected, so that a externality valuation could be properly integrated in analysis of policy alternatives. The latter only proved possible in the case of Belgium because of a lack of data on the ecological linkage between emissions and algal bloom in Varna and Mallorca.
- **WP 3. Thresholds in social perception, attitudes towards environmental quality and in policy formulation.** WP leader: SYKE (Mikael Hildén). Here the aim was to provide an analysis at the EU-level on how thresholds of environmental change have entered policies and policy interventions related to issues studied in THRESHOLDS.

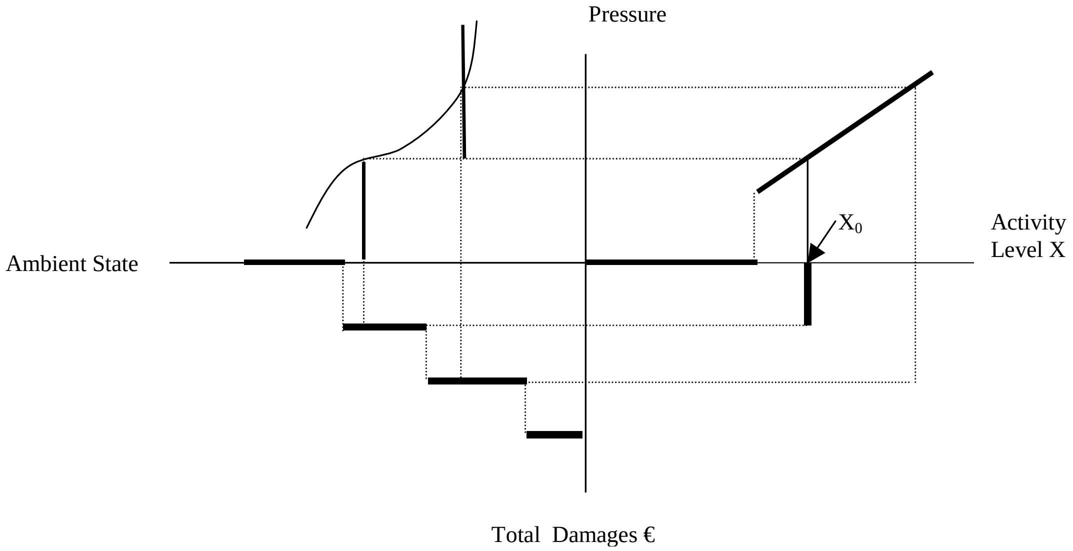
During the course of the project, S1 has held a number of teleconferences and linked face-to-face meetings with project meetings to save on budgets. Extensive use of electronic communication also aided the communication. There have been intensive interactions with other streams and the work not always run to schedule, due to gaps in scientific knowledge and also the need for as much consistency as possible between the survey instruments. In all, 10 deliverables have been presented from S1. It should also be noted that S1-partners have been involved in deliverables of Stream 6 in particular.

1.2.1.2 Brief description of the main outputs

Theoretical Developments

The major theoretical advance in the valuation of threshold effects in Stream 1 was based around the four quadrant diagram shown below. Using this, methods for assessing the impact of hysteresis, uncertainty and thresholds were developed and illustrated in a number of case studies.

Figure 1 – Theoretical framework for the evaluation of thresholds effects



Values for Algal Bloom

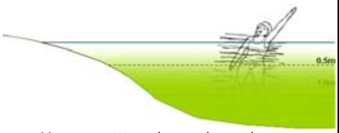
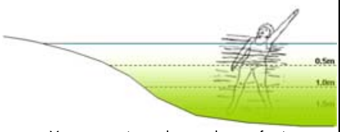
Choice experiments were used to value algal bloom events in Mallorca, Varna Bay and Belgium. Algal bloom has a number of impacts, depending on the type of bloom. The major impacts studies were foam (in the case of Belgium, see picture below) and visibility in the case of Bulgaria and Mallorca.

Figure 2 - Example of foam on beach in Belgium

The questionnaires were carefully developed to elicit values for visibility impacts, for duration and for beach congestion. An example choice card is shown below.

Figure 3 - Example Choice Set (Varna)

Choice Set 4

	Project G	Project H	No Project
Visibility	 You cannot see beyond your knees (1 m deep)	 You cannot see beyond your feet (1.5 m deep)	 You cannot usually see beyond your waist (0.5 m deep)
Duration	4 weeks	6 weeks	Usually 6 weeks
Congestion	 The nearest person (or group of people) is more than 30 m away from you	 The nearest person (or group of people) is more than 30 m away from you	 The nearest person (or group of people) is between 3 and 30 m away from you
Price	35 leva	50 leva	0 leva

The choice experiment conducted for the Santa Ponca bay in Mallorca showed significant willingness to pay to avoid algal blooms. The effects of algal blooms were felt mainly to be in terms of visibility in the water and duration of the bloom – with potential side impacts on congestion at the beach. A bi-monthly payment vehicle was used.

High visibility was judged important, with the WTP for reducing such blooms attaining a value close to €13 for a period of 8 weeks. The WTP for medium visibility increases with duration as well, but at a very slow pace. The implicit price of medium visibility, when the duration of the bloom is 8 weeks, was €1.65.

We found that there are significant welfare losses from algal blooms in Varna. The key findings are:

i) the amount of bloom is important: respondents are willing to pay for a program that entails 1 week of algal bloom about 33 Leva, or €17, when there is high visibility; 21 Leva, or €10.75, with medium visibility and 9 Leva, or €4.60, with low visibility;

ii) Duration is important: respondents are willing to pay more for programs that offer shorter duration of algal bloom; and

iii) Congestion of the beach may be significant: The marginal price for one metre of extra space between the respondent and the nearest person is equal to 0.38 Leva

These results are lower than those for previous studies on algal bloom in the context of ECOHARM and for the North Sea case above, but it must be borne in mind that this study did not consider toxic algal blooms and was also based in Bulgaria. The attitudinal aspects of the survey show that respondents were more willing to swim in discoloured water than was the case in a similar study in Mallorca (Torres et al, 2007). To aggregate the above across the population of Varna suggests that if there were 1 week of bloom and a high level of visibility compared to the current situation then residents would be willing to pay €2.2 million for this[1], which is not an insignificant sum, particularly bearing in mind we do not include the additional welfare costs of tourists and also other economic effects of the blooms.

The bloom-causing nutrient enrichment of the Belgian Coastal Zone waters results largely from the release of nitrogen and phosphorous compounds by human activities taking place on the continent, throughout the Seine, Somme, Yser and Scheldt watersheds.

For Belgium, the main effect of the algal bloom was felt to be foam deposits on the beach. Belgian beach users are willing to pay €43.57 per year to reach a level of low algal bloom, while they request a payment of €144.23 to accept the current level of algal bloom. To aggregate, assuming one million beach users in the Belgian population gives a benefit of €44 million for low algal bloom and a willingness to accept compensation of €144 million for a high level of bloom.

Benefit Transfer Validity Testing

The testing of the validity of "benefit transfer", the taking of results from one study and applying with adjustments in another context, shows that beach users in Mallorca and Varna do not have the same willingness to pay for the combined effect of algal bloom duration and resulting sight depth, nor for other beach quality characteristics such as congestion levels. Detailed choice model comparisons show that differences in implicit prices for attributes are to a large extent caused by differences in the marginal utility of income between sites, and to a lesser extent differences in utility of the water quality and congestion attributes. Comparing the transfer of compensating surplus over a range of models we also find that "attributes only" models do better than models adjusted for population characteristics (income) in this case. Such distinctions have thus far not been made in benefit transfer testing of choice experiments. This is a similar finding to the literature on benefit transfer of contingent valuation estimates. Models adjusting for site attitudes to water quality (visibility thresholds for bathing) do better than attributes only model. A model accounting for non-linearities using effects coding has lower transfer errors than a model using continuous attributes. We also see some indication that transfer errors are sensitive to scope, in that they are lower for policy scenarios that offer large improvements in environmental quality versus small improvements.

From the point of view of linking non-market valuation estimates to water quality model scenarios the message is that high temporal and spatial resolutions models will be excessive relative to the water quality changes that can be evaluated with any reliability using our choice experiment results. Our

[1] This takes the population of Varna is 357,270 and the average household size in Bulgaria as 2.7.

choice experiment results can be coupled to large changes in bloom intensity and duration with some confidence, but much less so for small changes. This argument is strengthened by the fact that the science linkage between nutrient loading and bloom intensity and duration is relatively weak, such that integrated pressure-state models predict water quality changes with wide confidence intervals, being able to distinguish only extreme policy scenarios.

The table below shows mean absolute error across a gradient of water quality (assuming congestion is constant at a low level independent of water quality). In broad terms transfer errors drop as duration of algal blooms falls, except in the worst visibility state. This indicates that for large water quality improvements the choice model has relatively low transfer errors, i.e. respondents' preferences are more similar. For smaller partial improvements respondents' preferences are more dissimilar. The fact that transfer errors are lower for policy scenarios that offer large improvements in environmental quality versus small improvements is an indication that transfer errors may be sensitive to scope. This would be expected in case where preferences are in fact similar across sites, but where choice models perform poorly for small changes in attribute levels. High attribute levels of visibility and the interaction of high visibility with duration tended to have higher part worths and be more significant than medium levels of visibility in the models we evaluated

Figure 4 - Mean absolute transfer error

Bloom duration **Visibility**	**8 weeks**	**6 weeks**	**4 weeks**	**3 weeks**	**1 week**
Low (0.5m)	Baseline	2.370	3.286	9.741	0.258
Medium (1m)	39.955	2.034	1.206	1.027	0.812
High (1.5m)	1.433	0.964	0.649	0.523	0.310

Note: errors are given as proportions (1=100%). Transfers of compensating surplus evaluating using effects coded models without interaction with population variables:

Varna: V= **- 0.33074*ascsqV + 0.312336*E_higvisV** - 0.08343*E_medvisV **+ 0.011166*I_hvisdurV** + 0.006368*I_mvisdurV

- **0.0786*at_durV** + 0.055473*E_locongV **+ 0.162994*E_medcongV - 0.07904*at_costV**

Mallorca: V= **-0.69908*ascsqM** + 0.123726*E_higvisM + 0.089971*E_medvisM **+ 0.073291*I_hvisdurM** + 0.006412*I_mvisdurM - **0.05905*at_durM** + 0.042616*E_locongM + 0.043021*E_medcongM **- 0.04871*at_costM**

<u>Linking Economics and Ecology</u>

The economic values given for the North Sea case above need to be put into the context of the ecological make up of the area. A mental model was developed by Christiane Lancelot and colleagues at ULB as shown in the Box below.

Box 1: **Mental model – nutrients, Phaeocystis blooms and Foam events**

Underlying conditions (for foam formation)

If wind speed daily average > 20 km h^{-1} then foam accumulation is possible

Emissions level for Phaeocystis bloom formation

If winter Redfield Ratio N:P> 25 then Phaeocystis blooms can occur => Foam => traffic light warning)

And

If winter N>Nlow then low level of bloom and low level of foam possible (wind>20km h-1)

If winter N>Nmed then medium level (Phaeocystis and foam) possible (wind>20 km h-1)

If winter N>Nhigh then high level of bloom and of foam possible (wind>20 km h-1)

Critical Levels

	Winter concentration, µM
Nlow	8
Nmed	20
Nhigh	50

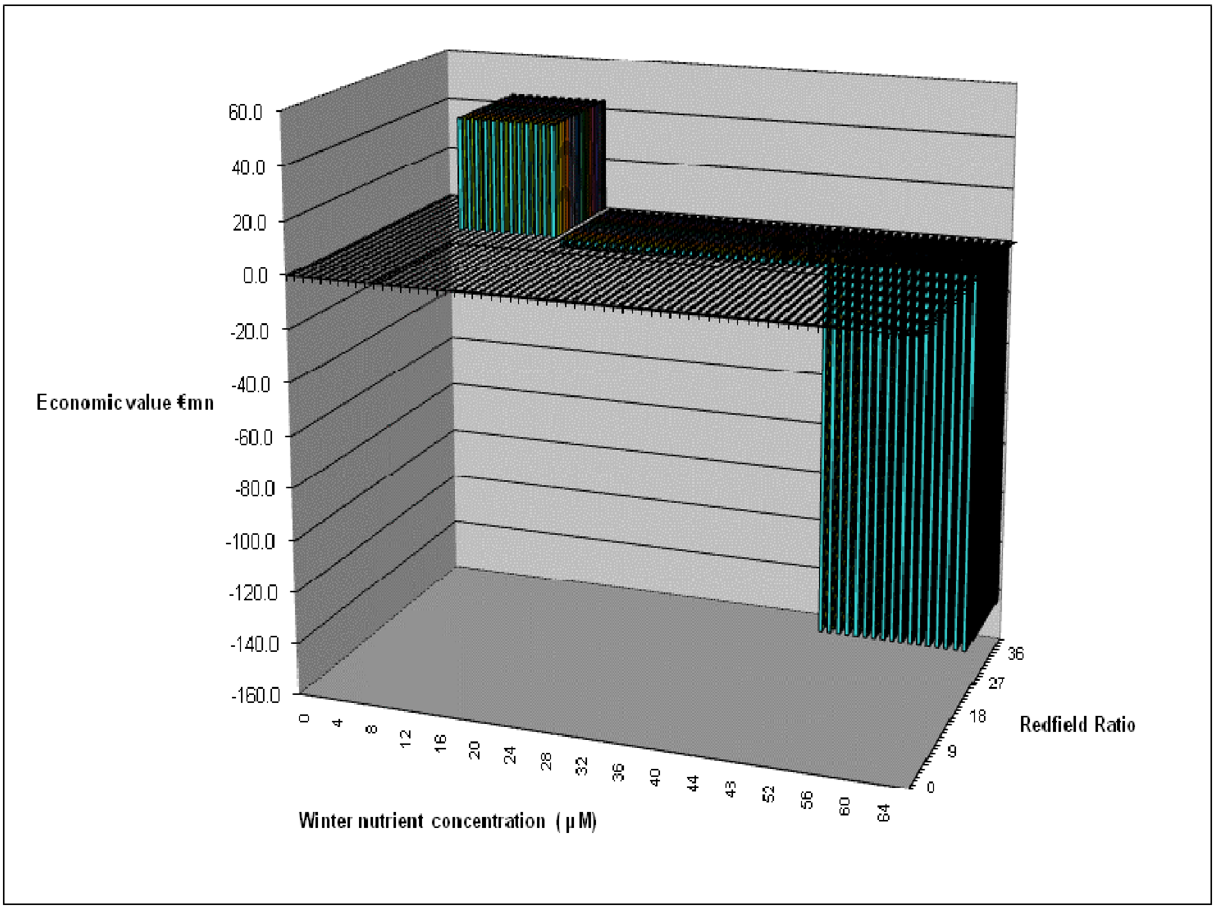
Using this model, we can estimate the costs associated with different levels of emissions and different Redfield ratios as shown in the figure below. It can be seen that, if wind conditions are conducive, the most significant effects arise in the case of a high level of bloom, with a low level of bloom attracting a benefit (i.e. people are willing to pay for the bloom – there is some indication of people playing with the foam in small quantities), a medium level a cost of €3.3 million and a high level a cost of €144.23 million[2].

What does this imply for policy? First, we can say that people are not much impacted below emissions levels of 48.03562 kt/year. This implies that costly efforts to reduce emissions to this level may be appropriate – but reducing beyond this level seems to imply little benefit. Second, these benefits are not that large compared to the costs attributed in Stream 6 of the Thresholds project. However, it must be realised that these costs do not capture effects on riverine systems, non-use values or other effects of eutrophication in the coastal zone. As such, they underestimate the true cost.

[2] Note, this assumes that one million Belgians use the beaches. This may be an optimistic estimate.

Second, we need to consider wind. If the wind is not conducive to foam, then this will lead to a zero level of foam – and hence zero value. This could be integrated in a probabilistic manner if the wind conditions could be assessed – i.e. if there were an 80% chance of a wind conducive to foam, then the expected cost would be 80% of the values shown.

Figure 5 - Nutrient concentrations, Redfield Ratio and Economic Value for Recreational Users in Belgium (when wind conditions amenable, else zero).



Guidelines on valuation

Guidelines on methods that can be used in valuing environmental damages in coastal ecosystems were developed. These included specific notes on the valuation of habitat and biodiversity, health, recreation and amenity, cultural objects and travel or work time.

1.2.2 Stream 2: Thresholds and points of no return: threshold definition, theory and identification.

Synopsis of Stream 2 key results:

- New tools developed to detect thresholds (e.g., ThEnhancer).
- Better overviews achieved for both advanced and basic statistical tools/methods.
- Higher predictive power and generality for both statistical and process-based dynamic models.
- Recommendation for more extensive sampling plans in coastal monitoring (small n and big N) to better detect thresholds and points of no return.

1.2.2.1 General methodology and brief description of the work carried out.

As it concerns the **general methodology**, Stream 2 made an intensive use of the mathematical theory of bifurcations, a classification of threshold phenomena in terms of the qualitative features that would appear in the corresponding time series, and the relation of this with representations in terms of driver-response curves. Examples of theoretical ecosystem models leading to different types of thresholds have also been compiled. Systems crossing an ecological threshold exhibit several characteristics, such as changes in mean values and variances of individual system components, as well as changes in the mass flows and functional relationships between them. Most of the reported structural changes in marine systems have been inferred just from apparent step changes in the mean values of time series of observations. While a change in the mean value of a single component can be a simple and intuitive indicator of structural change, the proper statistical testing of the existence of such a change-point is a non-trivial task, which requires quantitative tools for separating random fluctuation from true changes.

As it concerns **the work carried out**, Stream 2 has been articulated in seven Workpackages (WPs):

- **WP 1. Regime modelling.** WP leader: IMEDEA (Palma), Emilio Hernandez-Garcia, aiming to provide an overview of models for thresholds, ecosystem stability and threshold theory.
- **WP 2. Statistical identification of thresholds.** WP leader: UO (Oslo), Tom Andersen, aiming to provide an overview of methods for non-linear behaviour and ecosystem stability. Evaluations of pro and cons regarding practical utility of statistical tools.
- **WP 3. Uncertainty evaluation.** WP leader: UU (Uppsala), Lars Håkanson, aiming to provide an overview of uncertainty components in models and provide coefficients of variations for key variables needed to run and validate coastal models.
- **WP 4. Theoretical synthesis of mathematical and statistical methods.** WP leader: NERI (Denmark), Jacob Carstensen, aiming to provide operational definitions of thresholds. State-of-the-art evaluations of pro and cons regarding the practical utility of mathematical and statistical methods for thresholds and points of no return for coastal science and management.
- **WP 5. Modelling cases for nutrient driven thresholds.** WP leader: UU (Uppsala), Lars Håkanson, aiming to provide an overview of eutrophication modelling – including links between nutrient inputs and ecosystem responses - and the ability to reflect thresholds. The predictive power of models and their practical use from scenarios on coastal eutrophication has been assessed.
- **WP 6. Modelling cases for contaminant driven thresholds.** WP leader: JRC (Ispra), Jose-Manuel Zaldivar, aiming to provide an overview of models for contaminants – including links

between discharges and accumulation (biota, sediments, etc.) - thresholds and predictive power. Scenarios on coastal contamination of toxic substances have been assessed.

- **WP 7. Modelling cases for biodiversity and ecosystem function.** WP leader: UU (Uppsala), Lars Håkanson, aiming to provide an overview of models for biodiversity and ecosystem structure – links between drivers, ecosystem indicators and thresholds. Critical evaluations have been done, related to predictive power of models and their practical use from scenarios on coastal function.

During the course of the project, S2 has held one to two annual meetings to co-ordinate the work and plan future actions. There have been intensive interactions with other streams and the work has run on schedule. The main emphasis related to the first round of deliverables concerned methodological reviews and state-of-the-art compilations concerning methods to define and identify thresholds for sustainable coastal management and the main emphasis for the second round of deliverables concerned the applications and practical use of the methods discussed and developed during the first phase of the work. In all, 29 deliverables have been presented from S2. It should also be noted that S2-partners have been involved in many deliverables of other streams.

1.2.2.2 Brief description of the main outputs

Stream 2 has addressed a key methodological question: how do inherent variations and uncertainties in empirical data constrain approaches to predictions and possibilities to identify critical thresholds and points of no return? To answer this question, Stream 2 has investigated issues related to the balance between the changes in predictive power and the accumulated uncertainty as model grow in size, how inherent uncertainties in empirical data depend on sampling effort and useful strategies to reduce inherent uncertainties (for example expressed by the coefficients of variation, CV = SD/MV; SD = standard deviation and MV = mean value). Approaches to maximize the predictive power of regression models (by transformations and by creating mean values for different time periods) have been assessed too, to produce better methods to measure variations in standard water variables within and among coastal systems.

The concept of "Optimal Model Scale" (OMS) has been introduced, together with an algorithm to calculate OMS, which accounts for key factors related to the predictive power at different time scales (daily to yearly prediction) and uncertainties in predictions in relation to access to empirical data and the work (sampling effort) needed to achieve predictive power at different time scales. For any target variable in water management, there is an optimal size of the predictive model, as given by the ratio between the r^2-value when modeled values are compared to empirical data, and the accumulated uncertainty in the model (CV).

Thresholds models are inherently non-linear. Methods for detecting four general types of threshold mechanisms have been synthesized and described. Stream 2 has also used empirical data on chlorophyll-a concentrations, concentrations of bluegreen algae (cyanobacteria), concentrations of nutrients and different forms of nutrients, water temperature and salinity from several data bases. The data concerns more than 500 aquatic systems covering a very wide domain in terms of nutrient concentrations and salinity. The focus has been on identifying the factors regulating and limiting the predictive power of models for variations among systems in median summer values of chlorophyll-a concentrations and concentrations of bluegreens.

The main result of such investigation was the evidence that there is no simple relationship between the TN/TP-ratio and empirical chlorophyll concentrations or concentrations of bluegreens. If the classical Redfield ratio would be the criteria for nutrient limitation, then practically all systems have TN/TP-ratios higher than 7.2 and there would be very few nitrogen limited systems. We have presented a model to predict concentrations of bluegreens from data on TP, the TN/TP-ratio, salinity and temperature.

A general model for coastal eutrophication has been developed and tested with good results against empirical data from over 20 different coastal areas. This coastal model is based on mass balances for phosphorus and driven by phosphorus loading data from tributary rivers and phosphorus exchanges with the open sea. The model calculates internal fluxes regulating how the given coastal system would respond to changes in loading (sedimentation, resuspension, diffusion, mixing, etc.). The basic aim is to use the model as a tool for remedial strategies to avoid critical thresholds. Key questions that can be answered are: 1) How would a coastal area respond to changing phosphorus loading, e.g. 30% reduction in tributary inflow? 2) How would this reduction influence phosphorus concentrations and important bioindicators or ecosystem effect variables included in the model, such as algae biomass, water clarity or oxygen concentration in the deep-water zone regulating the survival of zoobenthos? It is important in all science to gain understanding why thresholds or regime shifts appear, and why there may be compensatory effects preventing them from appearing. One important way to explain, understand and predict mechanisms behind desired - or undesired - changes in concentrations of nutrients and toxins in aquatic systems, and drastic changes in key biotic variables (functional species or groups) related to such changes in chemical concentrations (drivers or abiotic variables), is to conduct proper mass-balances for the chemical variables. This model is such a tool for coastal ecosystems that are controlled by phosphorus loading.

Stream 2 has also developed a 1D-3D coupled hydrodynamic and fate model to simulate the spatio-temporal variability of contaminants in coastal ecosystems. The model takes into account the role of atmospheric processes as well as sediments and includes the selected contaminants in the Thresholds project (see Stream 4): PCBs, PAHs and PBDEs. The model has been validated with experimental data in Stream 4.

1.2.3 Stream 3: Nutrient-driven thresholds of environmental sustainability.

Synopsis of Stream 3 key results:

- Analysis of eutrophication and toxic algal blooms
- Analysis of thresholds and shifts in ecosystem structure (from benthic to planktonic)
- Analysis of thresholds for disruptions in food webs
- Analysis of thresholds for shifts in sediment biogeochemistry and benthic faunal communities

1.2.3.1 General methodology and brief description of the work carried out

As it concerns the **general methodology**, Stream 3 focused on some of the most important parameters that respond to the pressures of nutrient loading in coastal ecosystems. The general ecosystem characteristics that are most often affected by eutrophication include algal blooms and harmful algal blooms, changes in ecosystem structure, disruptions in food-web structure, and changes in sediment communities. A concept known as meta-analysis has been used, which combines the results of studies published in the scientific literature to address a set of related research hypotheses to identify thresholds. In addition, the toolbox of statistical and mathematical techniques developed in Stream 2 has been used to identify thresholds for coastal ecosystems.

As it concerns **the work carried out**, Stream 3 has been articulated in four Workpackages (WPs):

- **WP 1. Development of thresholds for algal blooms and harmful algal blooms.** WP leader: UNIK, aiming to investigate the thresholds in the discharge of N and P from land at which HABs occurrence may start.
- **WP 2. Development of thresholds and shifts in ecosystem structure (benthic to planktonic).** WP leader: IMEDEA, aiming to investigate the thresholds and points of no return for shifts in the structure of coastal ecosystems from those where primary production is based on benthic vegetation to those where it is based on phytoplankton.
- **WP 3. Development of thresholds for disruption in food webs.** WP leader: ULB, aiming to develop nutrient thresholds for food-web bifurcation based on a comprehensive ecosystem analysis of historical data in aquatic systems where regime shifts were observed and making use of Flow Network Analysis and mechanistic modelling of the river catchment-coastal waters continuum.
- **WP 4. Development of thresholds for shifts in sediment biogeochemistry and benthic faunal communitiers.** WP leader: USD, aiming to examine nutrient loading as drivers of shifts in benthic faunal communities and benthic nutrient regeneration processes.

1.2.3.2 Brief description of the main outputs

The occurrence of harmful algal blooms (HABs) is intermittent and it was difficult to find thresholds where HABs occur. A number of important thresholds for changes in ecosystem structure have been found, and a robust demonstration has been given that seagrasses and perennial macroalgal populations decline in response to excess of nutrient inputs to coastal waters. Empirical models have been produced that can predict the occurrence of macrophytes at depths from water nutrient concentrations.

Our analysis has shown that relationships between algal abundance (Chlorophyll a) and total nitrogen exhibit convoluted trajectories rather than linear predictable relationships. These changes are driven by changes in the amount of algae produced per unit of TN nutrient over time, a trend that appears to be similar across systems and therefore may signify a global change trend. These trends, or shifting baselines, result from combined effects of climate change, overfishing and other components of global change. Ecosystem management must, therefore, develop adaptation strategies to face shifting baselines and maintain ecosystem services at a sustainable level rather than naively striving at restoring an ecosystem state of the past.

Trophic bifurcations causing disruptions in food-web structure have been also detected. A shift towards the dominance of harmful gelatinous organisms (jellyfish) and the shift towards the dominance of a microbial food-web of lower trophic efficiency was observed. These pathways contrast to the highly productive linear food-web. The structural network analysis demonstrates that nutrient enrichment favours the dominance of harmful gelatinous organisms over the desirable ones at the same trophic position. This analysis also provide evidence for the role of overfishing, which might exacerbate eutrophication when the target fish is planktonivorous.

In addition, a number of important thresholds were observed related to changes in sediment communities. Our analysis shows that with increased organic matter loading, sulfate reduction becomes the major metabolic pathway predominating over oxic (aerobic) respiration. We show how biogeochemical variables used to measure these processes are linked to changes in marine benthic community structure along an organic enrichment gradient continuum.

Finally, we demonstrate that strong thresholds occur with coastal hypoxia. Repeated hypoxic events lead to an increase in susceptibility of further hypoxia and accelerated eutrophication with ecological mechanisms sustaining the occurrence of hypoxia. Once hypoxia occurs, reoccurrence is likely and may be difficult to reverse.

1.2.4 Stream 4: Thresholds and drivers of contaminants

Synopsis of Stream 4 key results:

- Analysis of effects of contaminants for different levels (molecular, individual, population, ecosystem)
- Effects of mixtures
- Role of atmospheric inputs
- Spatial-temporal variability of pollution
- Combined effects of nutrients/contaminants

1.2.4.1 General methodology and brief description of the work carried out

Pollutants enter the environment by a number of pathways and affect marine ecosystems at different levels. Even though pollution is regarded as one of the major anthropogenic pressures on the environment, the knowledge available for defining thresholds of non-return was very limited at the beginning of this project. The objective has been to develop the tools, knowledge and data sets needed to define pollutant effects thresholds in the marine environment.

As it concerns the **general methodology**, several families of organic contaminants and two metals were selected to demonstrate the methodological approaches that have been used and developed in the study of contaminant related thresholds. The contaminants include: polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) and polybrominated diphenyl ethers PBDEs). The two selected metals are cadmium (Cd) and mercury (Hg). PAHs are produced by anthropogenic activities involving the combustion of coal, oil, wood, diesel and gasoline. PCBs were used as cooling and insulating fluids by electrical industry and PBDEs are used as flame-retardants in a wide group of household and industrial products. Cadmium is mainly used in batteries or for pigments, whereas mercury is used in the manufacture of industrial chemicals and in electronic industry. Several groups of compounds in these families are known for their environmental persistency, ubiquity and their toxic and/or carcinogenic effects. Furthermore, they may bioaccumulate in organisms and ecosystems, including humans.

As it concerns **the work carried out**, Stream 4 has been articulated in three Workpackages (WPs):

- **WP 1. Intercomparison between contaminant thresholds at molecular, individual, population and ecosystem levels.** WP leader: JRC, aiming to compare and assess the differences between contaminant thresholds for selected substances at several levels (micro, meso and macro).
- **WP 2. Effects of spatio-temporal distributions, and atmospheric deposition of contaminants on thresholds values, ecosystem shifts and non-return points.** WP leader: IIAQB-CSIC, focusing on the following aspects: air-water-phytoplankton (bacteria) diffusive exchange; influence of atmospheric dry deposition of aerosols on phytoplankton and bacterial dynamics; the effects of spatial and temporal patchiness.
- **WP 3. Uncertainties in thresholds for contaminants due to the combined effects with nutrients.** WP leader: NERI, aiming to an integrated study of eutrophication and contaminants aspects, by means of tests performed with algal, bacterial and zooplankton communities in their natural (water) environment.

1.2.4.2 Brief description of the main outputs

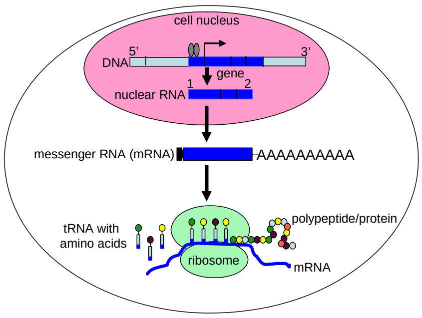
1.2.4.2.1 The effects of contaminants

The effects of contaminants can be analysed at several levels. The classical way to investigate (eco)toxicological effects of environmental pollutants is to look for acutely toxic effects. Thresholds explores methodologies that allow effects to be determined at several levels by focusing on coastal organisms, using individual species as well as mesocosms experiments with species mixtures.

Molecular level effects

The expression of genetic information is the first step in a series of cellular processes that are translated into structure and function of cells and then to the organism (**Errore. L'origine riferimento non è stata trovata.**).

Figure 6 - Principle of genetic transcription and translation (in eukaryotic cells. Contaminants may affect at different steps in the whole process.



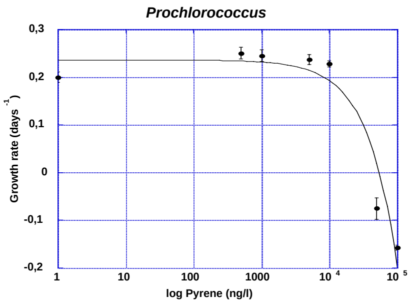
Environmental perturbations and stresses (e.g. chemical pollutants, temperature change, low nutrients etc.), may induce gene expression changes. These changes could thus be used as early indicators of effects on the organism.

The effects of polycyclic aromatic hydrocarbons (PAHs) in the marine diatom *Thalassiosira pseudonana* was analysed for gene expression level changes. Our experiments showed that some genes involved in the formation of the silica shell of the diatom as well as genes involved in photosynthesis, were down-regulated by PAH exposure. This could impair the cellular integrity as well as energy production.

Toxic effects at individual/population level

Laboratory experiments were performed with phytoplankton cultures to analyze the lethal concentration of PAH's for populations of these organisms. Solutions of pyrene and phenantrene dissolved in DMS were added. The results indicate that most species were highly resistant to pyrene and phenantrene, except *Prochlorococcus* and *Synechococcus*, which showed lethality at high concentrations of pyrene and phenantrene. The threshold concentration of pyrene was 80 µg/L for Prochlorococcus, whereas for phenantrene it was between 100 µg/L, (toxic) and 500 µg/L, (lethal). Figure 7.

Figure 7. Variability of Prochlorococcus marina growth rate growing under a gradient of Pyrene concentrations dissolved in DMSO.



Experiments on natural communities

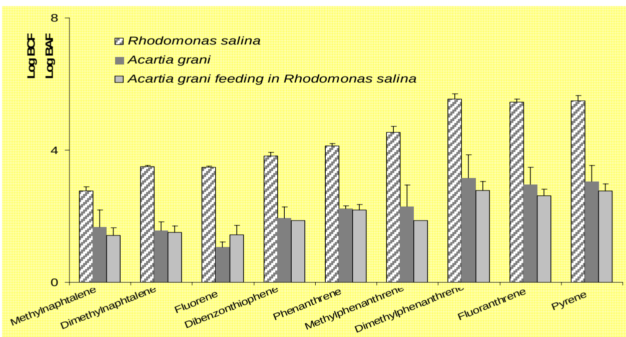
Experiments to analyze the lethal threshold of PAH's and metals on natural populations of phytoplankton were performed with coastal Mediterranean plankton. Preliminary results indicated that pyrene and phenantrene appeared to be toxic above 50 μg/L and lethal at 100 μg/L in both *Prochclorococcus sp* and *Synechococcus sp* populations. Metals also caused toxic effects at concentrations ranging from 1.12 ppb for cadmium and 12 ppb for lead. Lethal concentrations were 12 ppb for cadmium and 112 ppb for lead. These levels are well above the concentrations normally observed in waters, which have been 3.4-30.4 ng/l. However, it has been found that thresholds for mixtures of pollutants are at lower concentrations, thus closer to environmental levels.

The role of zooplankton in contaminant cycling

Even though several studies have dealt with the bioconcentration of polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) in phytoplankton, much less is known of processes driving POP accumulation in zooplankton. Indeed, it is not clear whether zooplankton, and other heterotrophic organisms, accumulate POPs from feeding on phytoplankton or passively from surrounding waters. Furthermore, it still remains unclear whether these POPs introduced in zooplankton by dietary uptake biomagnificate, or are eliminated through egestion of fecal pellets or metabolization. As part of the THRESHOLDS project, uptake and depuration constants have been measured for PAHs in zooplankton (

Figure 8).

Figure 8 - Bioaccumulation factors of PAHs in phytoplankton (Rhodomona Salina), zooplankton due to diffusive uptake and zooplankton feeding on phytoplankton.



Determining the level of no effects

Chemicals effects assessment comprises two steps of the risk assessment procedure: hazard identification and dose-response assessment. The Predicted No Effect Concentration (PNEC) is determined as the thresholds below which no unacceptable effects are detected. The methodology to derive PNECs is based on a European consensus (European Commission, 2003).

The approach has been applied to the selected substances in the project. Unfortunately, there is not sufficient data available in the literature to perform a complete assessment. Table 1 summarizes the main findings that have been obtained so far.

Table 1: Overview of thresholds of no effect reported in the present study. AFM: Assessment Factor Method; SEM: Statistical Extrapolation Method; EqPM: Equilibrium

Chemicals	Thresholds of no effect for			Overall threshold of no effect for the marine environment
	Pelagic organisms	benthic organisms	marine top predators	
	$ng.L^{-1}$	$\mu g.kg^{-1}$ dw	$\mu g.kg^{-1}$ ww	$ng.L^{-1}$
PCB 105	-	-	-	-
PCB 118	-	-	1.1 (low reliability)	-
PBDEs	53	310	333	12.2 (←top predators)
Fluoranthene	100	155	11,500	32 (←sediment)
Benzo[a] pyrene	5	-	-	0.005 (←seawater)
Benzo[k]fluoranthene	3.6	60 (AFM) 38-537 (EqPM)	-	0.4 (←sediment)
Benzo[g,h,i] perylene	0.8	-	-	0.8 (←seawater)
Cadmium	1.6 (AFM) 210 (SEM)	-	-	210 (←seawater)
Mercury	1(not relevant)	-	-	-

1.2.4.2.2 Spatio-temporal variability of pollutants in coastal systems

High temporal variability and spatial patchiness have been observed in the occurrence of pollutants in the marine environment and atmosphere. This variability affects the threshold level and has practical consequences for pollutant monitoring. Furthermore nonlinearities present at several levels affect the pollutant distribution and, hence, the risk of exceeding a threshold.

Phase speciation is also linked to the entry route. Diffuse air-water exchange and wet deposition are important pathways for the input of pollutants to aquatic environments. A combined approach using monitoring and modelling was chosen to gain better understanding of the variability

Monitoring has been carried out to support the development of contaminant thresholds at Thau lagoon (France) (Figure 8), Far Ses Salines (Mallorca, Spain), and during two Mediterranean cruises (Figures 9 & 10).

Figure 8 - Etang de Thau (France) and its watershed. Connections with the Mediterranean Sea are located at the extremities: in the Sète city and near Marseillan village.

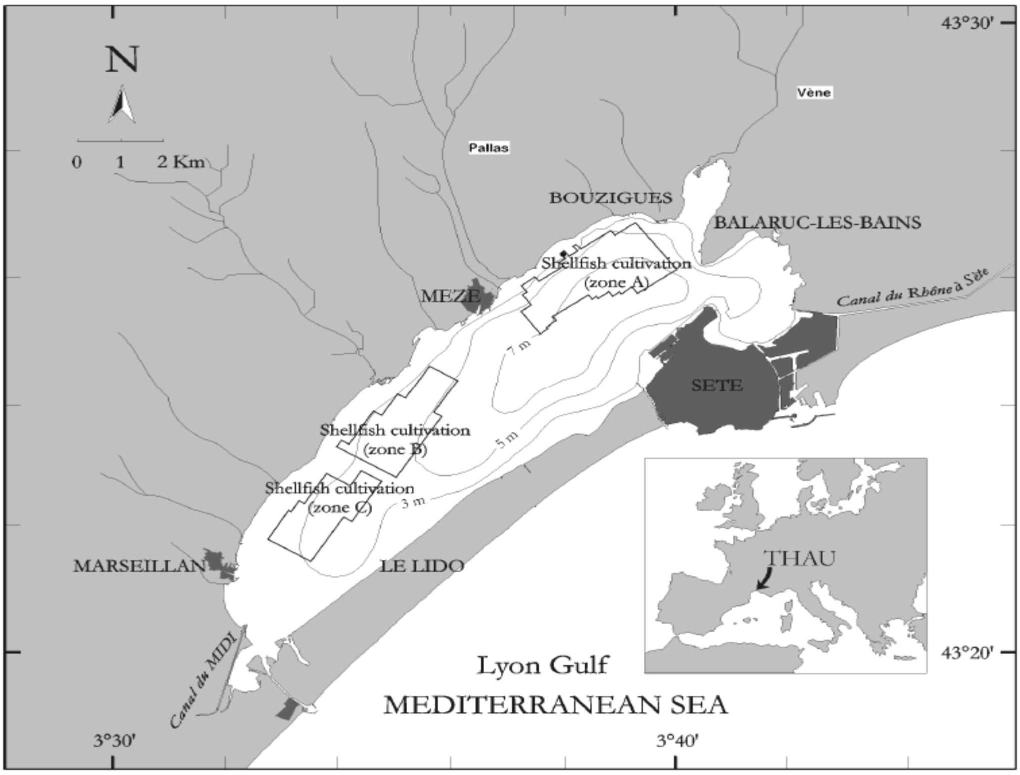


Figure 9 - Mediterranean cruise 2006: Route from Barcelona to Istanbul & Black Sea back to Barcelona.

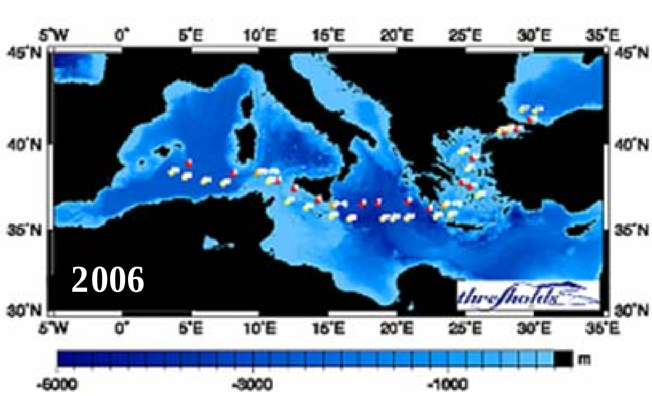
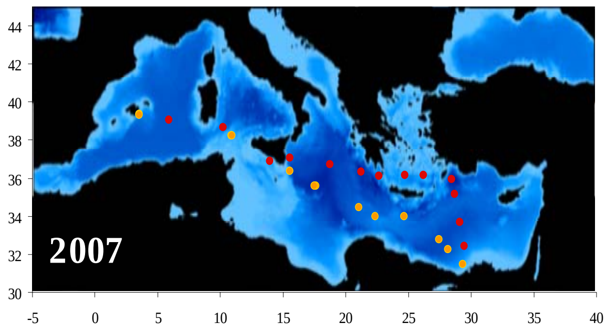


Figure 10. Mediterranean cruise 2007: Route from Barcelona to Alessandria (Egypt) back to Barcelona.



Thau lagoon (France):

Monitoring has been carried out in Thau lagoon both for selected organic contaminants including PCBs, PCDD/Fs (Figure 11), PAHs and PBDEs and metals, including mercury (Figure 12) and cadmium.

Figure 11 - Etang de Thau (France). Air-Sediments-Mussels concentrations of PCBs and PCDD/Fs.

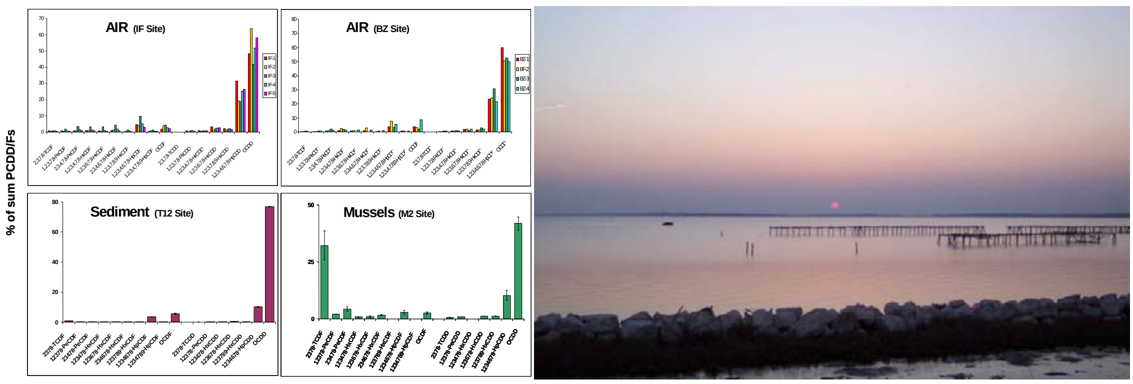
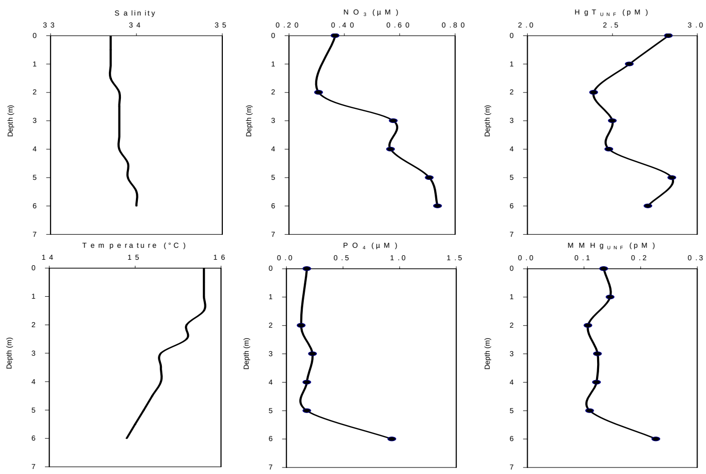
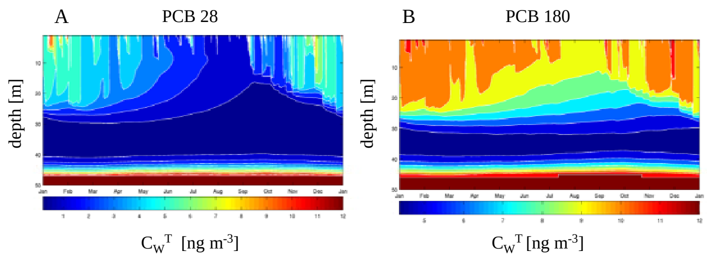


Figure 12 - Vertical profiles for salinity, temperature, nitrate, phosphate, total mercury (HgT) and monomethylmercury (MMHg) in unfiltered samples of the water column at station C5 of the Thau Lagoon.



In order to study the spatio-temporal distribution of contaminants a one-dimensional dynamic coupled hydrodynamic-contaminant model has been developed and applied to a Mediterranean continental shelf environment. In this case, the effect of vertical turbulent mixing on the dynamics of Persistent Organic Pollutants has been assessed. The simulation highlights the role of the turbulent processes in determining the POP distribution and variability in the water column (Figure 13).

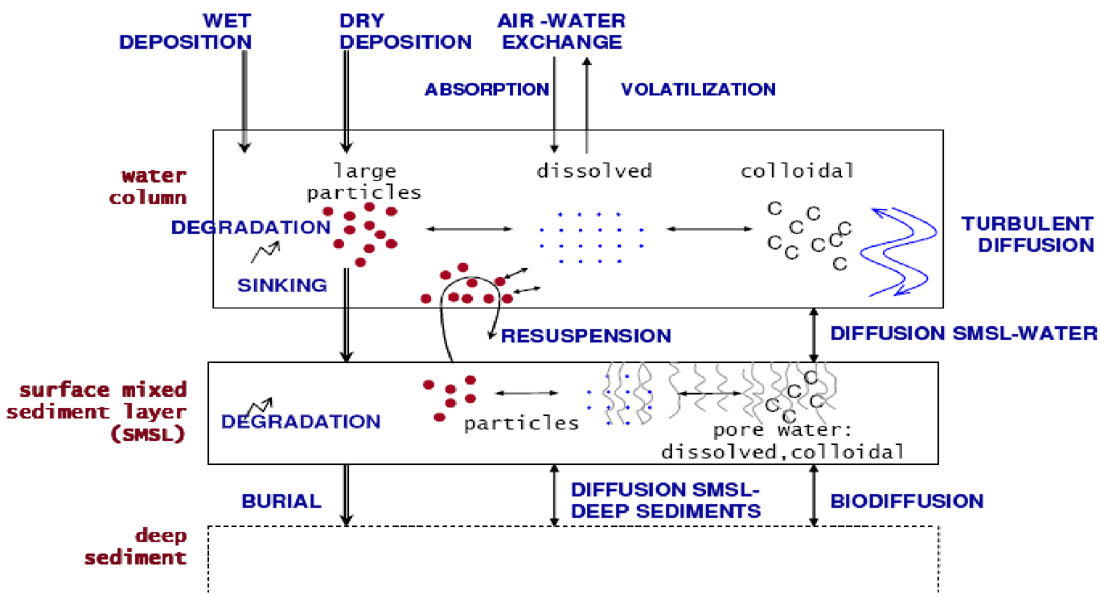
Figure 13. Depth-time distribution of total concentration in the water column for PCB 28 and PCB 180



A turbulent flux of contaminants strengthens the upward diffusion of contaminants in the sediment and determines the extent to which inputs from the atmosphere mix into the water column. It acts in parallel with degradation and sinking fluxes. The combined effect yields a surface enriched – depth depleted – benthic layer enriched region distribution. The model results are very similar to reported experimental measurements. This model is being coupled with an ecological model to analyse the effects at ecosystem level.

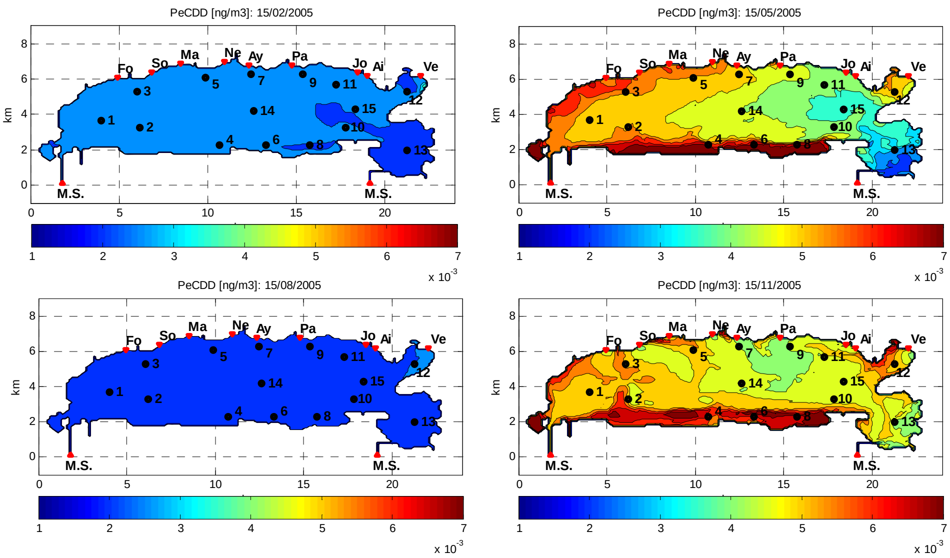
In addition, a 3D fate and transport model for analyzing the dynamic behaviour of PCBs (Polychlorinated Biphenyls) and PCDD/Fs (Polychlorinated dibenzo-p-dioxins and dibenzofurans) in Thau lagoon has been implemented and assessed (Figure 14).

Figure 14. Overview of the processes included in the POP fate model (adapted from Jurado et al. 2007).



The simulation results are in agreement with experimental measures even though a complete validation of the model was not possible due to the scarcity of the experimental data available. The model results point out the complex spatial and temporal variability of contaminants in these systems even though this variability is reduced in confront with other type of pollutants in which air is a less dominant entry route and sources are not only diffuse, for example, in plant protection products. Furthermore, for PCDD/Fs the air-water exchange seems to be the main source of contamination in this lagoon as showed for the scenarios simulation results (see Figure 15). Therefore, air pollution control rather than water pollution control would be the main process for reducing the load of contaminants reaching Thau lagoon ecosystem. These results call for the development of integrated environmental protection policies when setting environmental quality standards that are consistent amongst compartments.

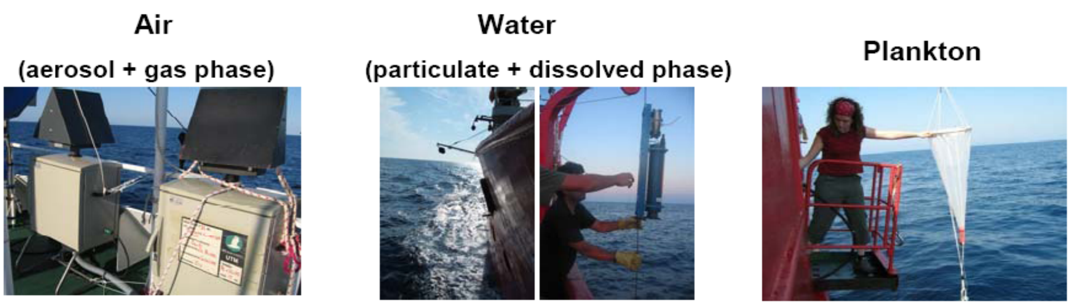
Figure 15: Spatial variability of the concentration of PeCDD in Thau Lagoon during the simulated year



Mediterranean cruises:

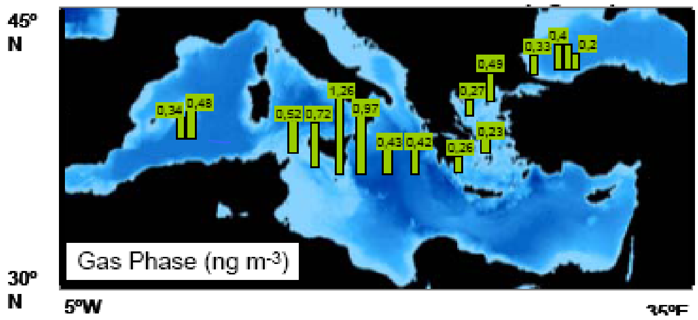
Within the framework of the Threshold project, two sampling cruises were performed in 2006 and 2007 (see above Figures 5 and 6). During these cruises, and for the first time, simultaneous samples of atmospheric, seawater and plankton samples were taken (Figure 16).

Figure 16. Sampling of dissolved, atmospheric and plankton samples during the Thresholds Mediterranean sampling cruises.



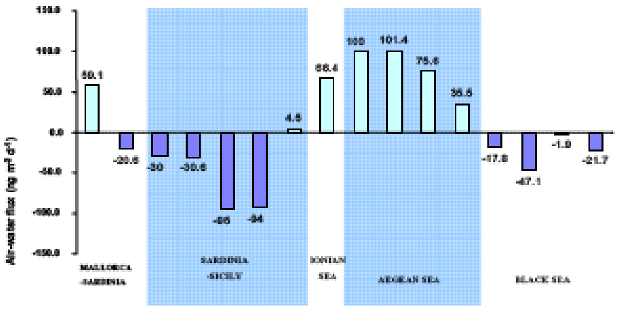
These samples were analyzed for PCBs, PAHs, and PBDEs, as well as in addition to the selected POPs for thresholds also for polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs). The results show that there is certain regional variability in POP concentrations for the Mediterranean Sea as shown in Figure 17 for the sum of 41 PCB congeners.

Figure 17. Spatial variability of gas phase PCB congeners (sum of 41 congeners).



With both gas and dissolved phase concentrations known it is possible to estimate the diffusive fluxes between the atmosphere and seawater (Figure 18). These fluxes show that there is a clear regionality in fluxes with net absorption fluxes in the western Mediterranean, Black Sea and Marmara Sea, and net volatilization in the Aegean Sea.

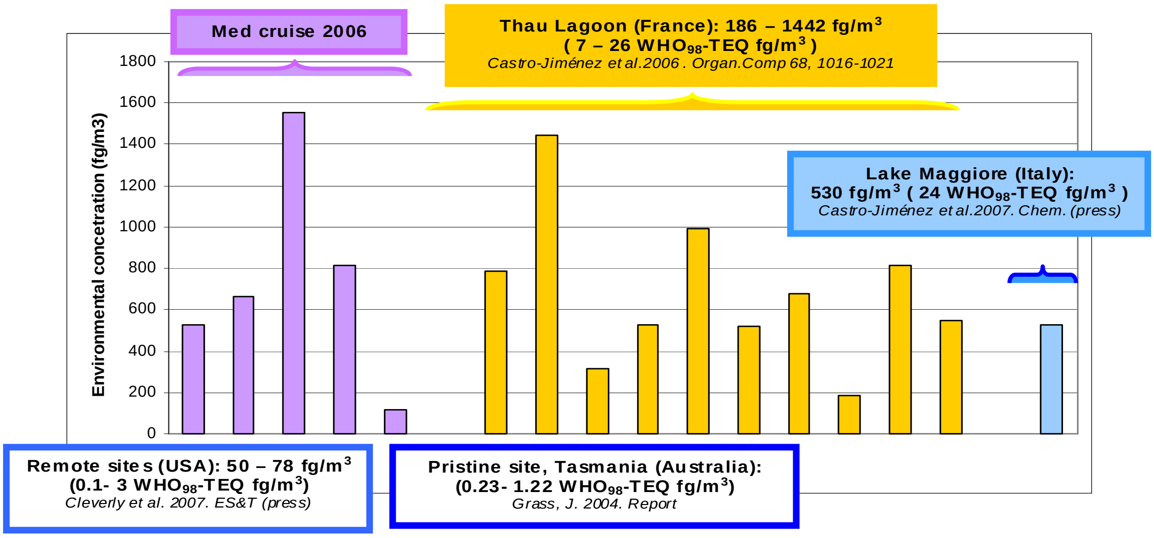
Figure 18. Spatial variability in air-water fluxes of PCBs (sum of 41 congeners).



Polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs) are a family of POPs constituted by 210 congeners. Seventeen of these congeners have been described as the most toxic ones (2,3,7,8-substituted congeners) being able to bioaccumulate and enter the food webs (Van den Berg et al., 1998). There is an increasing global concern regarding the presence of PCDD/Fs in the marine environment. Prove of that is that PCDD/Fs have been included as priority for monitoring and impact assessment in the main international programmes such as, OSPAR, HELCOM, and the Barcelona Convection. However, very few experimental data on PCDD/Fs ambient levels and behavior far from the shore line (open seas) have been reported up-to-date and no data is available for the Mediterranean Sea to our knowledge. In addition, atmospheric input has been identified as one of the PCDD/Fs sources to marine environments (OSPAR, 2007).

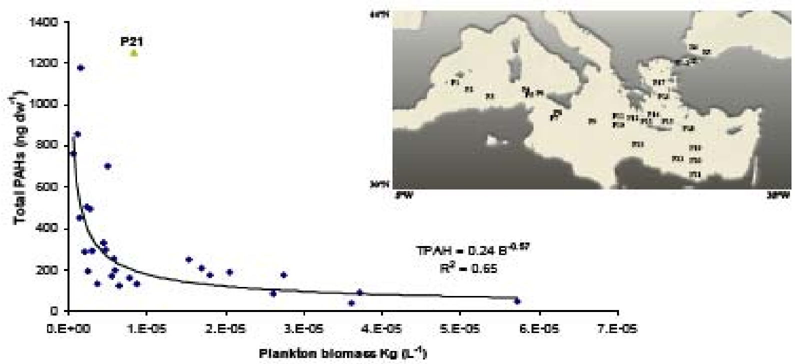
Results on polychlorinated PCDD/Fs air concentrations for five transects during the first Mediterranean campaign in 2006 are shown in Figure 19 (on the left). PCDD/Fs (17 toxic congeners) air (gas + particle phase) concentrations ranged from 114 to 813 fg/m^3 (3 – 7 WHO$_{98}$-TEQ fg/m^3) in the Mediterranean sea whereas the transect sampled in the Marmara and Black seas exhibited a higher concentration of 1555 fg/m3 (15 WHO$_{98}$-TEQ fg/m^3). PCDD/F levels in air were comparable to the concentrations observed in the Thau lagoon watershed and for an alpine Lake watershed (Lake Maggiore, Italy), but clearly higher than those reported for some remote or pristine areas around the world.

Figure 19. Air concentrations of Polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs) during the first Mediterranean cruise 2006 compared to other sites around the world.



In terms of pollutant concentrations in plankton, the concentrations decrease at higher plankton biomass (Figure 20). This dependence of POP concentrations in plankton is due to air-water interactions and depletion of POPs in eutrophic environments due to metabolization. This result has important implications for the definition of "clean sea status" for the open sea waters.

Figure 20. PAH concentration in plankton against plankton biomass for the Mediterranean and black seas. The map shows the position of the sampling stations.



Moreover, samples were also taken and analyzed for emerging pollutants such as perfluorinated acids. First results indicate riverine inputs as main source of these chemicals to the marine environment including open sea waters.

1.2.4.2.3 Combined effects of pollutants and nutrients

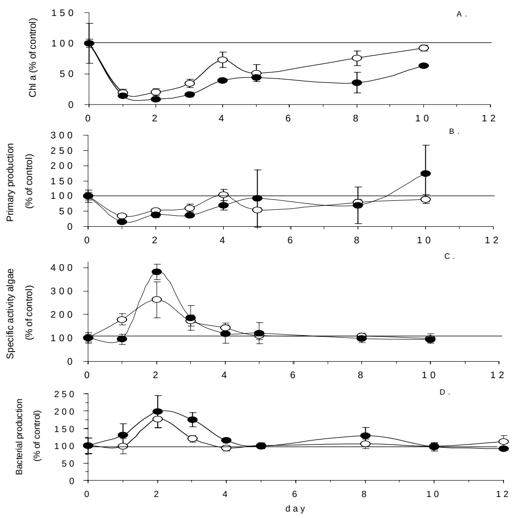
Contaminant sensitivity may depend on nutrient conditions among other factors. Therefore, understanding how ambient nutrient conditions interact with chemical toxicity is critical in order to make accurate risk assessment. Nutrient conditions and other physico-chemical conditions fluctuate temporally and therefore it is expected that sensitivity of organisms and communities to contaminants will also fluctuate.

In one study, the sensitivity of phytoplankton activity and structure to pyrene (100nM) exposure over 96 hours was investigated in relation to seasonal variation of nutrients, DOC and phytoplankton community composition. Water samples were collected from March-May and in November 2007 in Roskilde fjord, Denmark. The results show that toxicity does change with environmental factors and although no single factor could be identified as being the most important, availability of nutrients and phytoplankton community composition did play a role. Furthermore, total primary production and Chl a was not affected to a large extent whereas specific primary production was more heavily affected indicating that pyrene exerts a selection pressure on certain species.

In addition, several mesocosms experiments (12 days) have been performed, to investigate the combined effects of pollutants and nutrients on natural communities.

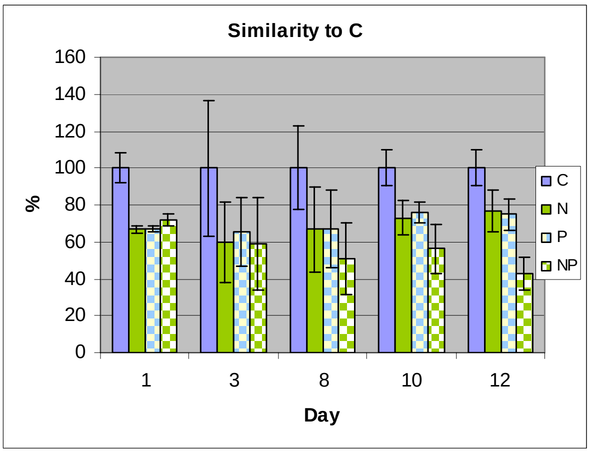
Pyrene had different effects in nutrient enriched and non-enriched communities. The effects were stronger in the enriched community in all the investigated trophic groups, but at different points in time (Figures 21 & 22).

Figure 21. Development of variables in communities exposed to 50 nM (10.1 µg L-1) pyrene as % of control during the mesocosm experiment.



Chlorophyll a (A), phytoplankton specific activity (B), total community activity of phytoplankton (C) and bacterial production (D). Open circles are non-enriched communities and closed circles are enriched communities. Data are shown as means ± SD (n=3).

Figure 22. Development of adult zooplankton community in relation to the control community (C) without additions of nutrients (N) and Pyrene (P).



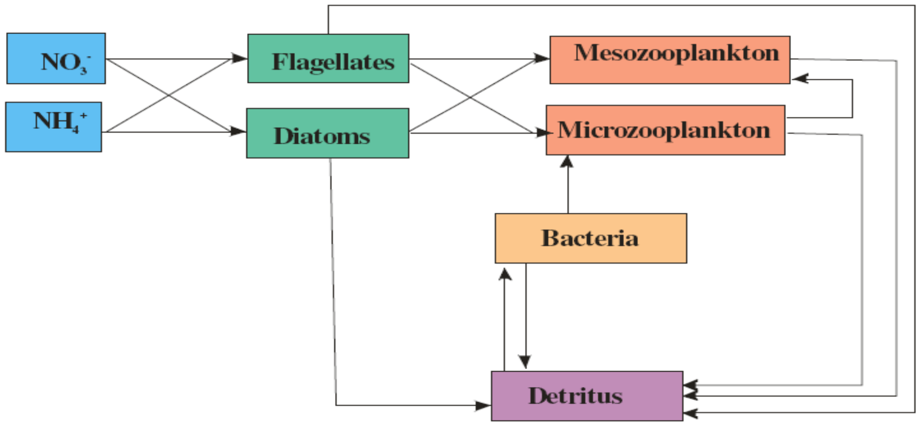
Despite the almost double amount of chlorophyll a in the enriched community, concentrations of chlorophyll a decreased to the same levels as the non-enriched community during the first day after Pyrene exposure, indicating a more severe effect and quicker rate of decline in the enriched community than in the non-enriched community.

Under the investigated conditions of biomass and nutrient status, there were no dilution effects of Pyrene due to higher initial biomass. Diatoms showed to be the least sensitive algae to Pyrene exposure in both non-enriched and enriched communities. Indirect effects on zooplankton caused a lower abundance of zooplankton and thereby differences in grazing pressure, which in turn resulted in differences in phytoplankton responses to Pyrene exposure between the enriched and non-enriched communities at the end of the experiment. The results show that interactions between trophic levels and their relation to abiotic factors have to be investigated in efforts to understand effects of contaminants.

In another study, the influence of key environmental factors on toxicity of pyrene was investigated in order to find an explanation for limits and variation in toxicity threshold for pyrene due to these factors. For this, the effects of pyrene on phytoplankton primary production were investigated during the spring and autumn of 2007 using phytoplankton communities from Roskilde Fjord, Denmark. Nutrient concentrations, temperature, plankton community structure, total Chlorophyll a and dissolved organic matter were included as key environmental factors. The sensitivity of photosynthetic activity to pyrene (100nM) exposure over 48 hours was investigated in relation to nutrient availability and community composition. Preliminary results suggest that pyrene toxicity may be linked to silicate and ammonium, indicating that it is the combination of nutrient availability and algal groups present that determines the size of the effect.

Finally, a new integrated model that includes a hydrodynamic model coupled with a contaminant fate and effect sub-model and an ecological sub-model is presented and validated using data from mesocosm experiments. The main compartments and interactions implemented in the model are represented in Figure 23.

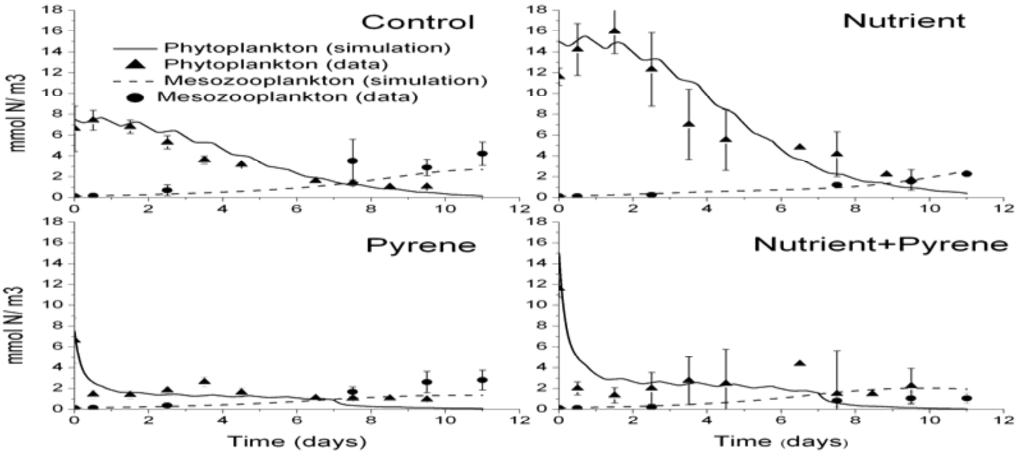
Figure 23 - Simplified flow diagram in the marine ecosystem.



The phytoplankton compartment was subdivided in two groups, diatoms and flagellates. Similarly, zooplankton was also split into two groups representing microzooplankton (< 200 μm) and mesozooplankton (0.2-2 mm). Moreover, the microbial loop accounting for the mineralization of dead organic matter, called detritus, performed by the bacteria, was incorporated in the model.

The experiments were carried out in the Isefjord (Denmark) and include the combined effects of nutrients and pyrene addition on the lower trophic levels of bacteria, zoo- and phytoplankton. The model was able to correctly represent the main dynamics observed in the mesocosms during the 11 days of the experiment and thereby confirmed that it is possible to represent short-term changes in the system with a simplified food-web model on a small spatial and temporal scale (Figure 24). Finally, the validated model was used to carry out a scenario analysis to investigate the effects of a contaminant pulse at different pyrene concentrations and different release timings. Results showed that the ecosystem's vulnerability to a pyrene pulse depends on the initial condition of the system. Stronger biomass reduction was observed when the pulse was released during the zooplankton bloom. Conversely, when the pulse was added at low biomass and before the bloom, the system showed a tendency to behave non-linearly.

Figure 24. Comparison of simulation results and experimental data for the four different treatments



1.2.5 Stream 5: Definition of thresholds of key indicators of biodiversity and ecosystem function

Synopsis of Stream 5 key results:

- Development of models for obtaining phytoplankton nutrient limitation indicators, and demonstration of their thresholds for changes in limitation patterns
- Thresholds for hypoxia for marine benthic macrofauna
- Thresholds for relationship between seagrass colonization depth and light attenuation
- Demonstration that microbial diversity in natural systems relates to basic functional properties of the communities (resource use efficiency, stability).

1.2.5.1 General methodology and brief description of the work carried out

Stream 5 was established to study and develop indicators describing the functioning and diversity of planktonic and benthic compartments of the coastal ecosystems. The work was arranged into 2 main phases: A general indicator survey based on existing knowledge (WP1), whereafter indicator development and analysis of their thresholds continued in planktonic (WP2) and benthic (WP3) work packages throughout the project. These WPs initiated their work by compiling spatially and temporally extensive data sets (from previous EU-projects and literature) as their first Deliverables, and focused on the performance on specific indicators in Deliverables to follow. The analyses were widely published already during project duration in leading journals, including 2 articles in Proceedings of the National Academy of Sciences, USA.

The following Deliverables summarized the Stream 5 research in respective Work Packages:

WP 5.1: Catalogue of potential proxies for ecosystem functioning and biodiversity (Leader: UT)

- D5.1.1 Literature data base of indicators of ecosystem functioning and biodiversity
- D5.1.2 Thematic catalogue of univariate indicators

WP 5.2: Information value of robust indicators for ecosystem functioning and biodiversity (Leader: UO)

- D5.2.1 Test data sets for all levels ready for utilization
- D5.2.2 Testing the applicability of quantile regression analysis for obtaining indicators of phytoplankton community structure
- D5.2.3 Testing the applicability of AIC-based selection of a priori linear models for obtaining indicators of phytoplankton nutrient limitation
- D5.2.4 Analysis of planktonic mass flow networks: Comparing system-level and mechanism-level indicators for assessing ecosystem structure and function
- D5.2.5 Performance of several derivatives of the Redfield ratio as thresholds for phytoplankton nutrient limitation

WP 5.3: Evaluation of selected indicators of species diversity and ecosystem function for threshold analyses in benthic communities (Leader: CSIC)

- D5.3.1 Preliminary identification of the indicators of benthic biodiversity and ecosystem function for the test phase in different case studies
- D5.3.2 Testing thresholds of hypoxia for various indicators of benthic macrofauna
- D5.3.3 Testing the predictive power of seagrass depth limits as indicator of benthic status
- D5.3.4 Thresholds of sediment characteristics for eelgrass depth limits
- D5.3.5 Effects of sulfide levels on thresholds of hypoxia for various indicators of benthic macrofauna status

1.2.5.2 Brief description of the main outputs

The indicator survey based on existing knowledge (WP1) resulted in 2 deliverables, an EndNote database on indicators derived from several hundred sources, mostly regular articles in scientific journals. This document (Deliverable 5.1.1) was conceptually linked to another (Deliverable 5.1.2), which provided a thematic catalogue of ecosystem functioning and biodiversity indices.

The subject of ecological indicators is both complex and technical. Indicators are low signal/noise read-outs from systems reflecting deeply embedded processes. Informal, single factor indicators reflect superficial properties. Complex systems require formal, multifactor measures. Conceptual basis, importance and bandwidth of variables, reliability and statistical properties, data and skill requirements, data quality and archiving, robustness under technology change, and cost/benefit issues are factors in indicator design (Patten 2006). The survey stage documents assembled hierarchically, and discussed the capabilities of different indicator families (univariate, complex, species-based, physiological etc.).

The main body or work in Stream 5 took place in the planktonic (WP2) and benthic (WP3) work packages. Both WP's assembled large data sets for coastal environments to carry out threshold analyses for selected indicators.

Planktonic community structure, nutrient limitation, function and diversity

Focus of planktonic threshold studies was on indicators of phytoplankton community structure and nutrient limitation. The first objective was to test the power of modelling indicator responses by quantile smoothing regressions with two examples of predicting a particular ecological indicator, the cyanobacterial fraction of total algal biomass (Deliverable 5.2.2).

Predicting the average response of an ecological indicator may not be very useful in situations where major events with possibly large consequences happen only rarely, such as blooms of particular harmful algal species. Quantile regression modeling was shown to give a tool for predicting the conditional probability distribution rather than the conditional mean of an indicator. This allows making inferences on the probability of exceeding a certain indicator level, which may be useful in practical policy making. It was also shown that accounting for uncertainties by bootstrap resampling makes it possible to attach confidence limits to policy targets determined from quantile regression curves.

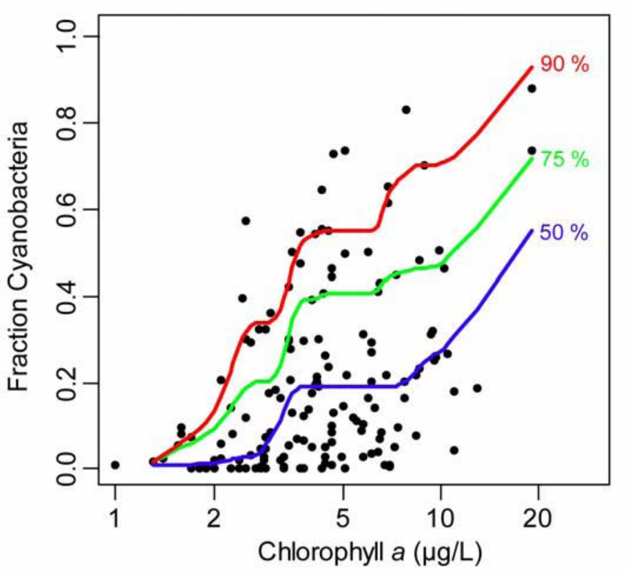


Figure 25. The fraction cyanobacteria of total phytoplankton biomass in relation to chlorophyll concentration (153 summer samples from Finnish coastal stations in the Baltic Sea). Quantile smoothing regression curves indicate 50% (blue), 75% (green), and 90% (red) percentiles of the conditional distribution

Regarding nutrient limitation thresholds for phytoplankton communities, we first described a novel method for statistical analysis of bioassay experiments with natural plankton communities, including a publicly available software tools for performing the statistical nutrient limitation classification procedure for experimental time series data (Deliverable 5.2.3; multimedia appendices in Andersen et al. 2007, containing both a modifiable Matlab source code, and a ready-to-run application for one particular design implemented as an Excel add-in generated with the Matlab Excel Builder). The capabilities of the classification procedure was demonstrated on a comprehensive set of 163 bioassay experiments with N and P additions to natural phytoplankton communities from the coast of Finland (NE Baltic Sea).

The rationale behind this work is that it is often not the actual quantitative response itself, but some derived nominal classification such as “P limited”, “N limited”, etc., which is of interest when analyzing a factorial nutrient limitation bioassay. We presented a statistical model selection procedure which implicitly classifies a factorial experiment response into a small number of biologically interpretable limitation classes, without the need for arbitrary and heuristic decision rules.

These limitation classes were then utilized for threshold analyses summarized in a successive Deliverable (5.2.5). We aimed to define the best nutrient limitation indicator predicting phytoplankton biomass increase due to increased availability of inorganic nutrients (N, P, or both). We therefore compared the performance of several novel derivatives of the Redfield ratio, based on chemical measurements of nitrogen (N) and phosphorus (P) fractions in the initial plankton community, in predicting the limiting factor for phytoplankton growth, as inferred independently from short-term laboratory experiments on the same natural communities in a data set from NE Baltic Sea (Tamminen and Andersen 2007). The best overall performing indicator, DIN:TP, had chlorophyll-response based threshold ratios far below Redfield, with N limitation below 2:1 and P limitation above 5:1 (by atoms). Based on the high prediction performance, analytical considerations, and general data availability, the DIN:TP ratio appears to be the best indicator for inferring in situ N vs. P limitation of phytoplankton from chemical monitoring data.

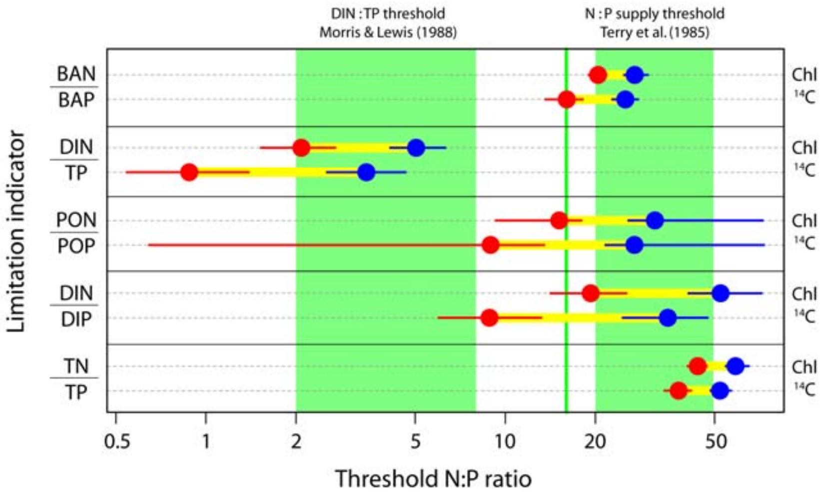


Figure 26. Thresholds for the transitions from N to N + P limitation (red symbols) and N + P to P limitation (blue symbols) according to equation (3). Only the 5 indicators with the Redfield ratio (16:1 by atoms; indicated by the green vertical line) as nominal value are shown. Shaded green areas correspond to published N:P thresholds for bioassays using the DIN:TP indicator (Morris and Lewis 1988), and for the N:P supply ratio in continuous cultures (Terry et al 1985). For each indicator, the upper part shows thresholds estimated using chlorophyll a as response parameter, while the lower part shows the corresponding thresholds from the 14C uptake response. Error bars are 95% confidence limits based on 1000 bootstrap samples from the original data set (Ptacnik et al. submitted).

Further progress in connections between phytoplankton biodiversity and ecosystem functioning was made in a large-scale analysis of coastal and lake communities (Ptacnik et al. 2008), where it was shown for the first time that microbial diversity in natural systems relates to basic functional properties of the communities. Moreover, stabilizing effects of diversity and destabilizing effects of enrichment or trophic state ("paradox of enrichment") have been hitherto reported independently from each other. This is the first study showing that stabilizing effects of diversity interact with resource levels in natural systems. Successive analyses have revealed that long-term data sets reveal considerable diversity shifts (Olli et al. 2009), in obvious connection to threshold-type shifts in nutrient levels and limitation indicators.

To compare system-level and mechanism-level indicators of coastal planktonic food webs, for describing how planktonic ecosystems respond to nutrient enrichment, a mass flow network approach was used for analysis of experimental mesocosm data (Deliverable 5.2.4). The mechanism-level indicators studied seemed to deliver rich and interpretable information about the studied ecosystems and their parts, and how they responded to fertilization - for instance, how nutrient perturbations affect the channelling of gross primary production, food choices of crustaceans, zooplankton assimilation efficiencies, and detritus metabolism. These outcomes from flow network analyses seem to be of significant value for understanding the mass transfer efficiency of these ecosystems, and hence the channelling, circulation and distribution of both the added nutrients and other elements in the system.

<u>Hypoxia and benthic fauna, light attenuation, sediment characteristics and seagrass depth limits</u>

Hypoxia is a mounting problem affecting the world's coastal waters, with severe consequences for marine life, including death and catastrophic changes. Hypoxia is forecast to increase owing to the combined effects of the continued spread of coastal eutrophication and global warming. A broad comparative analysis across a range of contrasting marine benthic organisms (Deliverable 5.3.2; Vaquer-Sunyer & Duarte 2008) showed that hypoxia thresholds vary greatly across marine benthic organisms and that the conventional definition of 2 mg O_2/liter to designate waters as hypoxic is below the empirical sublethal and lethal O_2 thresholds for half of the species tested.

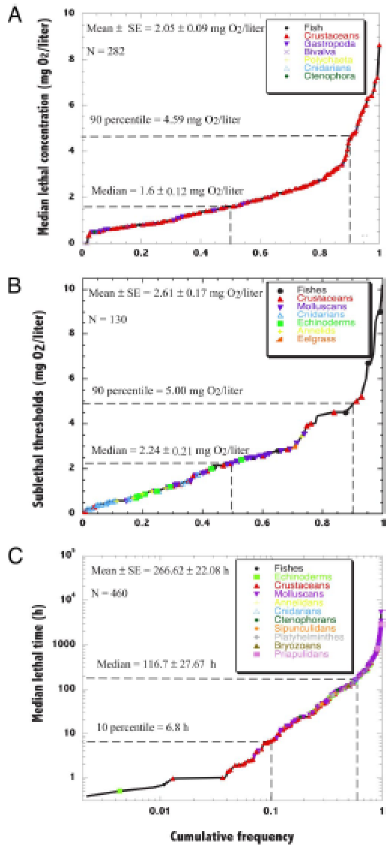


Fig. 27. Cumulative distribution of (*A*) LC50 (mg O_2/liter), (*B*) SCL50 (mg O_2/liter), and (*C*) LT50 (h) for marine benthic communities (Table S3, Table S4,and Table S5). The mean ± SE, median ± SE, 90th percentile (10th percentile for LT_{50}), and number of experiments are indicated. From Vaquer-Sunyer & Duarte (2008).

These results imply that the number and area of coastal ecosystems affected by hypoxia and the future extent of hypoxia impacts on marine life have been generally underestimated. In a further Deliverable (5.3.5), it was shown that organisms exposed to hydrogen sulphide are more vulnerable to oxygen deficit than if they were exposed only to low oxygen content of the waters.

Study on relationship between seagrass colonization depth and light attenuation revealed thresholds in seagrass light requirements (Deliverable 5.3.3; Duarte et al. 2007). The power of equations predicting seagrass depth limit (Z_c) from light attenuation (K_z) was tested on a dataset collected from the literature comprising 424 reports of seagrass colonization depth and water transparency, including data for 10 seagrass species. This data set confirmed the strong negative relationship between Z_c and K_z. These results indicated that seagrass colonizing turbid waters (K_z > 0.27 m^{-1}) have higher light requirements than those growing in clearer waters. The relationship between seagrass colonization depth and light attenuation shifts at a threshold of light attenuation of 0.27 m^{-1}, requiring separate equations to predict Z_c for seagrass growing in turbid and clear waters, and to set targets for seagrass restoration and conservation efforts.

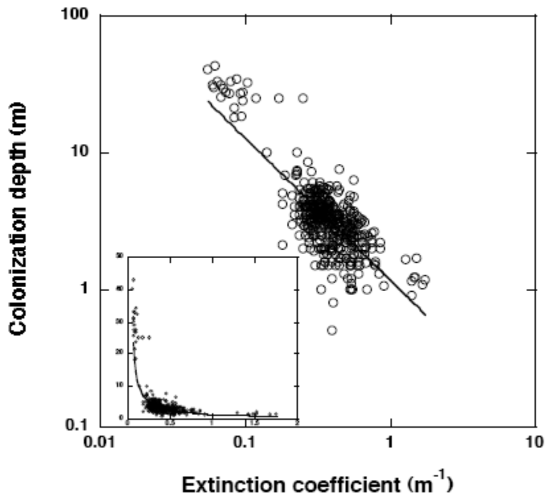


Figure 28. The relationship between seagrass colonization depth and the light extinction coefficient. The solid lines show the fitted regression equation, and the insert shows the data in arithmetic units (Duarte et al. 2007).

A successive Deliverable (5.3.4) confirmed that light attenuation is the main predictor of eelgrass depth limits, but that sediment characteristics also play a regulating role. It was found that depth limits were slightly but significantly lower in areas where the seabottom was characterised by low C/N-ratios. The effect was non-linear, showing a threshold at a C/N-ratio of 9.4 above which there was no effect. A low C/N-ratio is an indication of easily degradable sediments likely to show a large oxygen demand and thus at risk of turning anoxic. Apparent light demands of eelgrass in the field were found to average 22-33% of surface irradiance and thus are very high relative to light demands determined experimentally for Danish eelgrass populations which equals only about 11% of surface irradiance. Unfavourable sediment conditions may be part of the reason for this pattern.

1.2.6 Stream 6: Integration and application of thresholds methodologies on case studies

Synopsis of Stream 6 key results:

- compilation and further development of databases within the different case studies
- compilation of mitigation measures and database of impacts from literature
- examination of nutrient driver and pressure relationships
- advancement of existing tools (SENEQUE/RIVERSTRAHLER-MIRO)and development of new approaches (e.g. hotspot approach) within the single case studies
- testing of different policy options with future alternative scenarios within selected case studies (Southern North Sea, Varna Bay, Mallorca)

1.2.6.1 General methodology and brief description of the work carried out

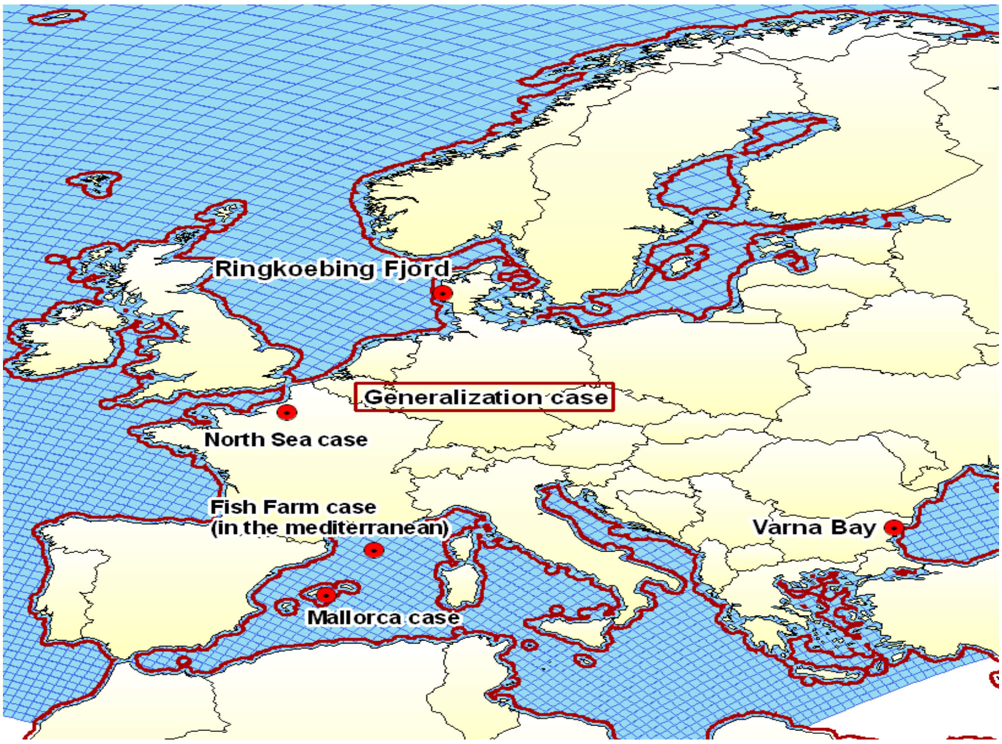
The aim of Stream 6 was to bring together the methods, models, tools and thresholds developed in the Stream 2- 5 and apply them to specific case studies. These case studies have been chosen to represent a diversity of different driving forces and pressures on the coastal zone and to represent a range in scales from local to the entire European coastline.

The following case studies were regarded:

- North Sea case study (lead partner: UPMC)
- North western Black Sea, "Varna Bay case study" (Lead partner: IO-BAS)
- Marine fish farms in Europe (Mediterranean) (Lead partner: USD)
- Case study of Mediterranean island, "Mallorca case study". This case study focuses on Santa Ponça Bay (Lead partner: UIB)
- Generalisation case study (Lead partner: IER-USTUTT)

An overview of the case studies is given in the following figure:

Figure29 - Overview of the case studies



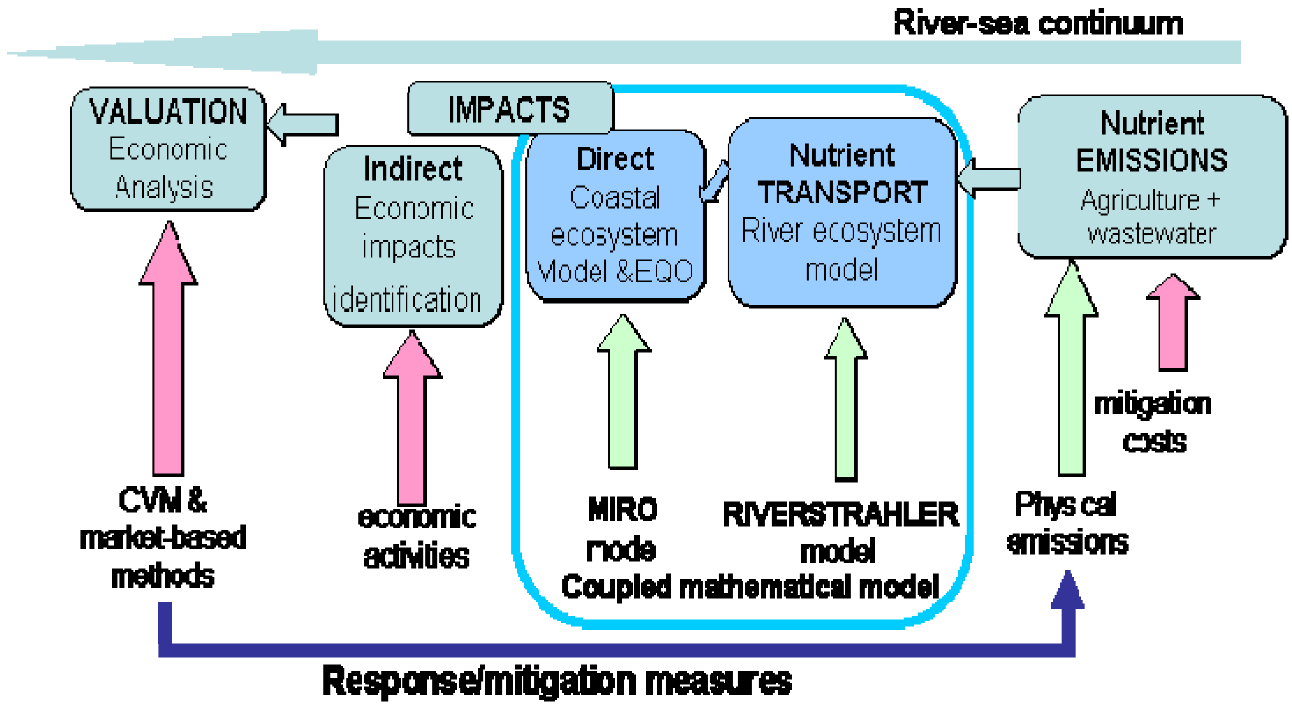
Each of these case studies has its own characteristics:

- The **North Sea Case study** focuses on the three watersheds of the rivers Seine, Somme and Scheldt and their nutrient input in the Eastern Channel and Southern Bight of the North Sea zone. In this case study, especially nutrient input from agriculture but also from point sources, i.e. from waste water treatment plants (WWTP) have been regarded and different scenarios have been tested, also regarding the objectives of the Water Framework Directive (WFD).
- The **Varna Bay case study** is similar to the North Sea case study in terms of investigating riverine loads to coastal ecosystems in which algal blooms and other species abundance shifts occur. Important drivers are first of all industry, but also agriculture and other anthropogenic pressures (especially insufficient wastewater treatment). At both sites, contingent valuation surveys have been carried out within Stream 1.
- The **Marine Fish Farm case study** examines the local input from fish farms (e.g. the effect of deposition of feed and excrements to benthos on sea grass decline) as the one major driving force. Aquaculture has an important economic dimension, especially for sustaining local economy. But it may be also in conflict with other sectors, especially the environment. Different technical mitigation measures have been tested within this case study.
- The **Mallorca case study** faces a number of constraints due to its limited size. The coastline is the basic resource that contributes to its GDP. Tourism industry has been identified as one of the most important driving forces, but also agriculture and the effects of irrigation have to be regarded.
- The **Generalisation case study** acknowledges that pressures to coastal zones may be caused by emissions being hundreds of kilometres away from the coastal zone. The feasibility of this case study is strongly dependent on data availability but a European-wide approach based on pressure and driver relationship (as main output from WP6.2) could be developed. In an approach where watersheds with potentially high nutrient loads are adjacent to sensitive coastal

zones, so called "hot spots", could be identified. Here action is needed most and further investigation should be conducted.

The **general methodology** is exemplarily presented for the North Sea Case Study (see the following figure). Nutrient emissions from agriculture and wastewater follow the river-sea-continuum. During the transport to the coastal area different chemical processes take place within the rivers and coastal zones which are modelled (in this case) with coupled mathematical models. Afterwards, impacts at the coastal zones are estimated. These impacts are then evaluated by transferring them into monetary values (damage costs) or by evaluating the costs of avoiding the emissions (avoidance costs). In a further step, mitigation measures which have been identified are applied and their effects are examined. Ideally, a cost-benefit-analysis can be conducted as a tool for a decision-support system to better find the best solution.

Figure 10: The integrated approach exemplarily presented for the North Sea case study [slightly modified after Garnier, J; Thieu, V. & Lancelot, C. et al).



As it concerns **the work carried out**, Stream 6 has been articulated in four Workpackages (WPs):

WP1: Definition, elaboration and application of the THRESHOLDS methodology to case studies in the European coastal zone (Partners: IER-USTUTT, IMEDEA, IO-BAS, ISIS, REC, SYKE, UBATH, UIB, ULB, UPMC, USD, UU, ERASME, NERI), aiming to bring together the methods, models, tools and thresholds developed in Stream 1 to 5 and apply them to specific case studies. The scope of this WP and the case studies have been already described above.

WP2: **Connecting pressures to drivers** (Partners: NIVA (later Bioforsk), UBATH, IER, NERI, UU, UPMC, USD, JRC, TERRAQUAT, CSIC), aiming to assess the methodologies and data to be used with the WP1 case studies to link drivers to pressures, by means of four tasks:

- Emission quantification
- Connecting proximate drivers to pressures
- Assessment of impacts – implementation
- Generalisation case study

First, the sources and emissions of nutrients for the selected case studies were identified and qualified. For that already existing databases held by the partners as well as freely available data sources were compiled and utilised. These databases were also developed further and actualized during the course of the project (results were presented in D6.2.2). In another effort, the state-of-the-art of scientific knowledge about the various types of nutrient and pesticide contaminant driver and pressure functional relationships has been examined. Special attention was paid to empirical relationships between diffuse nutrient and contaminant emissions/losses from agriculture, municipal and industrial sewers, at various spatial scales (plot, field and catchment experiments), results were reported in D6.2.5.

A database of impacts and values from the literature and a methodology report for the implementation of such values using benefit transfer were developed and delivered as D6.2.3a and D6.2.3b respectively. These were applied in a limited sense to the case studies for Varna Bay and the Marine Fish Farming Case Study (presented as Annexes to Deliverable D6.3.2). Another important step was the collection of mitigation measures, their effectiveness and costs, when available. A database about different mitigation measures are presented in D6.2.4.

An attempt was made to generalize existing thresholds models. It was explored in what way the different driving forces and pressures can be modelled in order to set up a thresholds analysis tool for a larger spatial scope. For that, a simpler watershed-based model was developed based on statistical empirical relationships (presented in D6.2.5) and combined with a costal risk index. Approximately 35000 European-wide watersheds all directly adjacent to the coastal zone could be examined (base layer is the CCM2 model developed by JRC). The methodical approach and further results are reported in D6.2.6 and together in WP6.3 in Annex to D6.3.2.

WP3: **Scenario testing** (Partners: IER, ISIS, UPMC, NIVA - later Bioforsk, ULB, SYKE, JRC, IMEDEA, NERI (later LU), ERASME, UU), aiming to test a number of policy options identified in Stream 7 and mitigation measures by means of coherent scenarios to be developed for the different (WP1) case studies. In this work package, special attention was paid therefore to the conversion of mitigation measures and policy options into scenarios that were accordingly tested against what-if-considerations. Results of the scenario analyses are extensively reported in D6.3.2 as well in three annexes to this deliverable. Each case study had its own focal point:

- The North Sea case study tested nitrogen and phosphorous upgrading in waste water treatment plants, integrated fertilization and catch crop introduction. Also extensive farming, i.e. replacement of fodder corn crop surfaces by meadows was tested. In a further step, these scenarios were also combined, i.e. combined agriculture scenarios and combined WWTP and agriculture scenarios.
- In the Varna bay case study two scenarios were tested: A business-as-usual scenario (BAU) assumes no changes in WWTP as well as current state of industry and economic incentives. In a second scenario the "deep green" (optimistic scenario) it is assumed that the program for reconstruction of the WWTPs is fully implemented and the objectives of the Urban Waste Water Directive are met.

- In the Fish Farm case study three different options have been tested. These are filter feeders (mussel farms), moving out to sea and smaller farms.
- The Mallorca case study examined three further scenarios: Changes in population (an increase in resident population in coastal areas will enlarge in coming years, given the existing trend in these locations), climatic change (evaluates changes in 10% for precipitation, increasing in winter and decreasing in summer) and change in land use (given the increase in visitors' figures, it is foreseen that more municipal gardening areas will be built).
- The Generalisation case focused on a hot spot approach, where is shown in which coastal zones/watersheds action is needed and which sector is contributing to high nutrient loads in the rivers. In another step, different assumptions were tested in the waste water treatment plants, e.g. upgrading of nitrogen and phosphorous treatment as well as connectivity rates to WWTP up to 100%.

In a parallel step ERASME assessed the potential use of nitrogen, fertilizers and plant protection products by European agriculture over the period 2008-2025 (results are presented in D6.3.3), producing a pan-European scenario and overall picture, as a complement to the more specific case studies. As extensively described in D6.3.3 *'The Use of Nitrogen, Fertilisers and Plant Protection products in European Union over 2008-2025',* ERASME team employed the general economic model NEMESIS including a detailed modeling for agriculture, energy and multi-sectoral land-use, to evaluate the use of nitrogen, phosphates, potash and pesticides by European agriculture.

Such modelling develops notably a methodology for organic nitrogen, for which there exists no data at country level, based on a previous study by EUROSTAT[3] consisting in applying manure coefficients by category of animals to the composition of livestock.

WP4: **Consistency of the components in the integrated models and estimation of uncertainties** (Partners: ARMINES. IER, NERI (later LU), ISIS, UU, UPMC, ULB, NIVA –later Bioforsk, ERASME, JRC), aiming to verify that the components contributed by the different disciplines and work packages are consistent with each other when they are linked together and if necessary propose appropriate modifications. Generally spoken, it had to be examined if there are uncertainties, and if yes, how they effect the conclusions. This workpackage was subdivided into two tasks: consistency check of all the components and the estimation of the overall uncertainty of the analyses. Results are presented in D6.4.1.

1.2.6.2 Brief description of the main outputs

In the following, the main results from the single case studies will be presented. It has to be mentioned that a number of important interim results were developed within Stream 6 which are not presented here in detail. These are e.g. the compilation and structuring of data (D6.2.2), compiling a catalogue of mitigation measures (D6.2.4) as well as analysis of pressure and drivers relationship (D6.2.5).

<u>North Sea Case Study:</u>

[3] Hansen Jakob, 2000, 'Nitrogen Balances in Agriculture', *EUROSTAT, Statistics in focus, Environment and Energy, Theme 8 -16/2000.*

Within the North Sea case study a set of mitigation measures has been tested, including upgrading of nitrogen and phosphorous treatment in waste water treatment plants, integrated fertilization and catch crop introduction, extensive farming as well as combined scenarios. The corresponding reduction in nutrient loads to the Southern North Sea and the effect on Phaeocystis[4] colony magnitude and duration were evaluated making use of the coupled RIVERSTRAHLER-MIRO model. Altogether results show that the analysed agricultural measures are the most cost effective. Their effect is however more the reduction of Phaeocystis bloom duration (8 M€ for one day reduction) than the Phaeocystis bloom magnitude. Regarding the ecological effectiveness of mitigation measures the following conclusions were drawn:

- There will be a significant reduction of P loads by implementing tertiary treatment in WWTP's > 20000 IE (= inhabitant equivalents).
- There will be a significant reduction of N loads by adapting agricultural practices (e.g. integrated fertilisation, catch crop introduction etc.).
- However, the N:P-ratio of nutrient loads will be above 16 (above the so called Redfield ratio[5]) i.e. an eutrophication risk will still exist.
- Further, upgrading of WWTP up to 20000 IE will lead to a significant reduction of Phaeocystis maximal magnitude (17-22%) but there will be no reduction of bloom duration
- There will be little reduction of Phaeocystis maximal magnitude (5%) by changing agricultural practices but a significant reduction (8-11%) of bloom duration
- There will be an optimized reduction of both *Phaeocystis* maximal (i.e. magnitude) (25%) and bloom duration (19%) when WWTP and Agricultural scenarios are combined.

The economic valuation arrived at the following results:

- Agricultural measures (2-5 €/kg N abated) are more cost-effective than WWTP upgrading (30-100€/kg N abated)
- N and P upgrading of WWTP < 20000 IE is not relevant

So it can be concluded that a combination of measures in WWTP and agricultural measures are seen to be most ecological and cost efficient.

Varna Bay Case Study:

The Varna Bay case study focused on a deep green (optimistic) scenario assuming that the objectives of the urban waste water directive are met and the program for reconstruction of the waste water treatment plant is fully implemented till 2015. The model predictions suggest that a **decrease of N loads by a factor of ten** and **a decrease of P loads by a factor of two** would be necessary to reach and sustain good ecological conditions in Varna Bay especially during the warm months. These results are presented in Figure 31 and 32 below.

[4] *Phaeocystis* is an important unicellular, photosynthetic, eukaryotic algae distributed throughout the world's oceans.

[5] Redfield ratio: is the molecular ratio of carbon, nitrogen and phosphorus in phytoplankton. The stoichiometric is C:N:P = 106:16:1. The term is named after the American oceanographer Alfred C. Redfield

Figure 31 - Current phosphorous loads and prognostic loads for a "good" ecological state

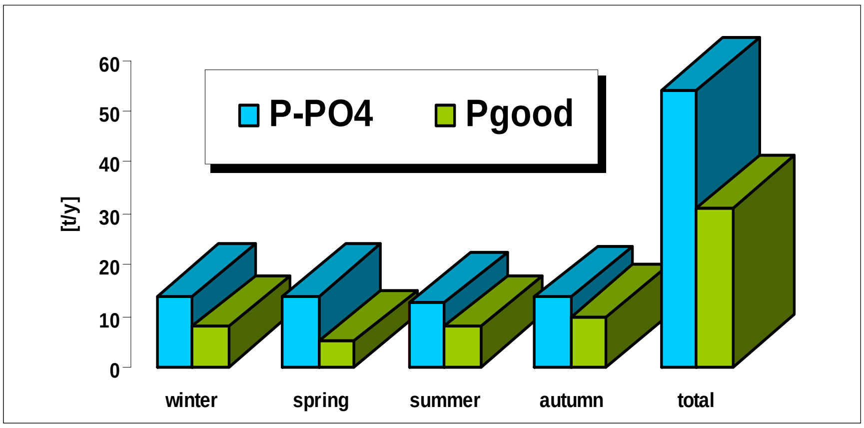
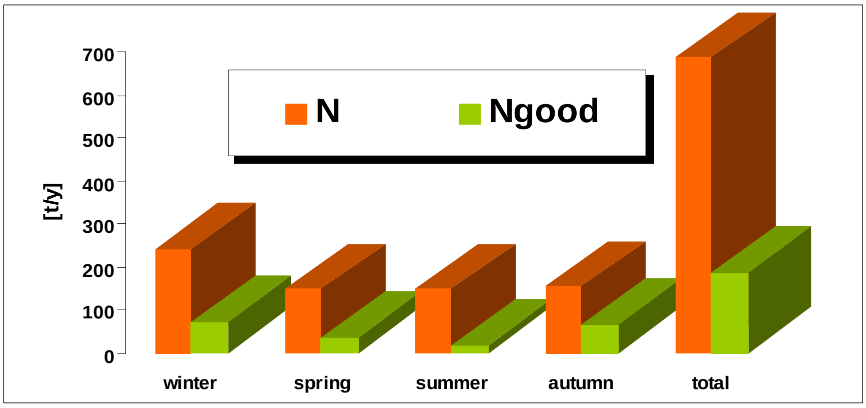


Figure 32 - Current nitrogen loads and prognostic loads for a "good" ecological state



<u>The Marine Fish Farm case study:</u>

The marine fish farm case study examined three mitigation options and assessed their costs. Options are mussel farms, locating the farms further out and smaller size of the farms. Mussel farms might be a win-win situation, as it might be possible to get a net profit by selling the mussels. Furthermore, locating farms further out to sea is more cost-effective than reducing the size of farms. An overview of these three options is given in the following table.

Table 1: overview of mitigation options for marine fish farms

Option	**Location**	**Staff level**	**NPV k€***	**Impact on seagrass (reduced loss in m²)**	**Cost effectiveness (€/m²)**	**Notes**
Locating further out	Country A: Farms located 1,000m out to the sea already	Low	-54	137183	0.39	No additional capital cost assumed. May be necessary to have
		High	-76	137183	0.56	

	Country B: Farms located close to shore	Low	-156	137183	1.14	a change of technology, but this is not considered as felt unlikely to be the case
		High	-221	137183	1.61	
Small Farms	Country A: Farms located 1,000m out of sea already	Assumes proportionate reduction in staffing – no differences in costs of staff	-315	119670	2.63	Large capital cost
	Country B: Farms located close to shore		-311	119670	2.60	Large capital cost
Mussel farms			Positive NPV if mussels sold	Changes damage profile		

* NPV = Net present value (in k€). The life of the project is 15 years - and the NPV discounts the values forward for that period. The NPV is in 2008€ in terms of pricing years (in €).

<u>The Mallorca case study:</u>

The Mallorca case study tested scenarios in population change, climate change and land use change. From these three scenarios tested, the change in land use appears to be most unfavourable for the coastal environment. Among other reasons because the effects other scenarios can be partially mitigated with available technology. In spite that other pathways such as runoff and point outfall discharges may be quantitatively more important, continuous nutrient-rich groundwater discharges along the coastline are proposed as the main forcing for harmful algal blooms occurrence at Santa Ponça Bay. The following conclusions could be drawn:

- In spite that other pathways such as runoff and point outfall discharges may be quantitatively more important, continuous nutrient-rich groundwater discharges along the coastline are proposed as the main forcing for harmful algal blooms (HAB) occurrence at Santa Ponça Bay.
- The enrichment of nutrients is generated by 2 main but related drivers: irrigated agriculture (including gardening) and wastewater losses + reutilization
- So, control on fertilizers, wastewater networks and treated water reuse coordinated with water abstraction policies are seen as the main abatement policies.

<u>The generalisation case study:</u>

The generalisation case study focused on a hot spot approach. This means that watersheds which are expecting potentially high nutrient loads from single sectors are combined with the sensitive coastal zones (using Geographic Information System). These are identified by the so called PSA-index (Physical Sensitive Index) showing European wide all coastal zones which are sensitive to eutrophication due to physical parameters. This PSA-index was developed by JRC and is provided within the emis-tool[6]. Secondly, different assumptions about treatment efficiencies in waste water

[6] Emis tool: http://emis.jrc.ec.europa.eu/4_1_gismap.php

treatment plants were tested and presented in different maps. The generalisation case study gives a European-wide overview where action is needed most and where further studies should be conducted with a higher spatially and temporally resolved data basis. Results are presented in Annex of D6.3.2 as well as in several GIS-maps.

Conclusions from the generalisation case study are:

- The same methodological approach was applied European wide → watersheds can be compared amongst others
- The application of the hot spots approach indicates where impacts are highly possible and identifies the driver.
- Results show, where a regional analysis (like the North Sea case study) is needed.

Regarding WWTP:

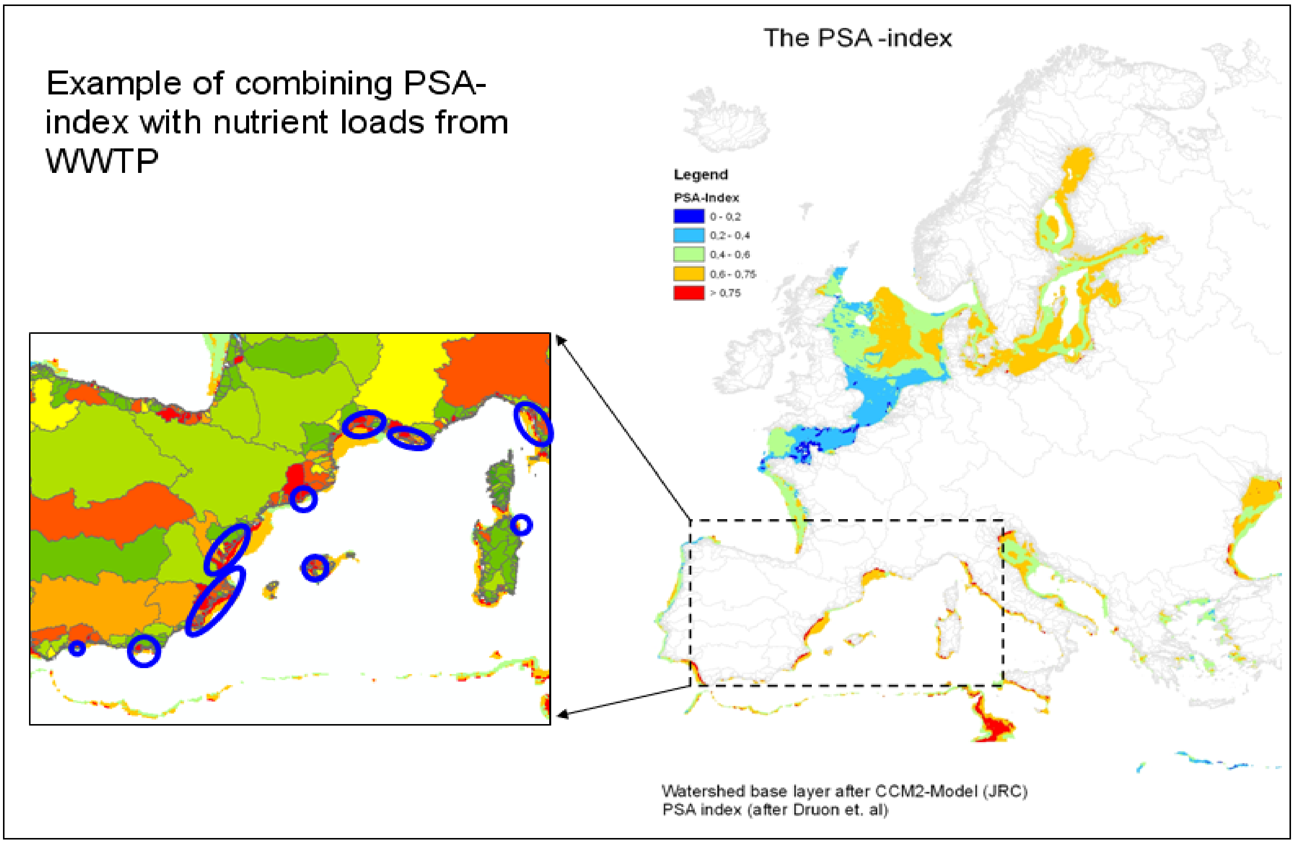
- Densely populated areas show (despite high treatment standards) in comparison high loads from point sources (e.g. Rhine) → a connectivity rate up to 100% should be aimed at.
- Settlements along seashore should be regarded carefully, especially where a high physical sensitivity is given (PSA – index near "1")
- Also watersheds characterized by low connectivity rates to WWTP have to be considered as they contribute to nutrient input, especially where high population density and relatively low connectivity rates are given, e.g. Gulf of Trieste, Italian southwest coast
- Testing upgrading of WWTP (P-elimination in tertiary treatment) showed an average P reduction of 30% and higher (e.g. 40% for the Ems catchment).

Regarding agriculture:

- Wide parts of Mid-Europe and West-UK are characterized by potential high nutrient loads from agriculture; especially when rivers are draining in higher vulnerable coastal zones (e.g. Baltic) action is needed
- In Mediterranean sensitive coastal zones there are also rivers draining whose watersheds are characterized by high percentage of agricultural area, e.g. Costa Blanca (Spain), West – Italian coast, Gulf of Trieste, Gulf of Lion (France), Southeast of Mallorca

The hot spot approach can be used to give a first rough estimate of numbers of hot spots at a European scale and it is also shown where the hot spots occur. With this information further studies should be conducted with a higher resolved database.

Figure 33: Example of the hot spot approach; the PSA-index (after Druon et al., 2004) is combined with potential high nutrient loads from waste water treatment plants (in comparison high loads are indicated by red colour).



<u>Pan-European scenarios of nitrogen, fertilisers and pesticides use by European agriculture</u>

Pan-European scenarios of nitrogen, fertilisers and pesticides uses by European agriculture are extensively described in D6.3.3 *'The Use of Nitrogen, Fertilisers and Plant Protection products in European Union over 2008-2025'*. After an introductive part, chapter 2 of D 6.3.3 describes the situation prevailing in 2008 for the use of mineral and organic fertilizers and pesticides in agriculture for every EU-27 Member States (except for Cyprus and Bulgaria). The second part of D 6.3.3 illustrates then a projection at horizons 2020 and 2025 of the consumptions of fertilizers and pesticides products, for a Business As Usual (BAU) scenario including current trends for oil and raw material prices, world GDP and population growth, and all EU and National policies already in place in mid-2007.

This projection - that relies for agriculture production on the CAPRI model used by DG AGRI - shows a moderate substitution of arable to grass land, provoked by an increase use on fodders for feeding animals, and the development of biofuels crops that take importance with the rising share of biofuels in energy used by transports sector (from 2.1% in 2008 to 6.1% in 2025). The continuation of current CAP policy in this BAU scenario, including Fisher 2003 reform, the improvement in yields and the increasing compliance with Nitrate (91/676/EEC) and Pesticides (COM(2006) 373 final) directives, allows nevertheless a slight decrease of nitrogen use compared to 2008 level (-1.7%), and a substitution of organic (+2%) to mineral (-5.1%) nitrogen, with much contrasts between Member States. For example, total (organic plus mineral) N consumption decreases by 16% in Finland and increases up to 12% in Lithuania, and the same applies to N and K consumptions as the study supposes constant N, P and K proportions. For pesticides, there are decreases in every Member States over 2008- 2025 period that range from -0.7% (Spain) and -11% (Slovakia).

The Chapters 3 to 7 of D 6.3.3 then investigate a set of countervailing scenarios, consisting in the introduction of new EU policies, shocks on oil price and taxation schemes for mineral fertilizers and pesticides that may influence importantly the use of fertilizers and pesticides over the next decades. The results of countervailing scenarios are systematically compared to those of the BAU scenario.

Chapter 4 anticipates on the new EU Financial Perspective for 2013-2020 period, that should involve an important reform of CAP policy. It simulates a radical reform of the CAP, with a total removal of CAP first pillar (suppression of all direct and market supports, about 43 billiards subsidies and also removal of tariffs and dairies quotas,…). The results show that the continuation of CAP second pillar impacts few on total EU agriculture output. Its suppression may decrease both animal and vegetal production by 2%, reduce total agriculture surface used by 3% and diminish respectively by 2% and 1% NPK and pesticides inputs by ha, with also few impacts on substitutions between organic and mineral nitrogen compared to BAU.

Chapters 5 focuses on the impact of rises in oil price up to 120 and 160 $\$_{2005}$ in 2025, as experienced in 2007-2008, against only 80 $ in the BAU, that corresponds to the medium term equilibrium price for International Energy Agency and OPEC countries, and Chapter 6 examines the consequences of the implementation of the EU 'Climate Actions and Renewable Energies Package' that was adopted by European Council in December 2008, and that may imply an important increase of carbon value in European countries. If increases in oil price have moderate impact on the development of biofuels and on European agriculture, the implementation of the EU Climate and Renewable Energies Package may increase until 16.6% in 2020 the share of biofuels in energy consumption by transports sector, against only 5.5% in the BAU scenario.

With in average about one hectare of arable land needed for producing one ton of biofuels oil equivalent, it should need about 100 millions ha, that is to say about 13% of total arable land area, if the required crops were integrally produced inside Europe. NEMESIS simulation results indicate that an increase in oil price up to 160 $ will decrease NPK use by 2.3% in EU-27 in 2020 compared to BAU scenario, and provoke substitutions of mineral nitrogen, that reduces only 0.8%, to organic one that decreases 4.4%.

The rise in oil and natural gas prices may therefore not have the important negative impacts on mineral N consumption that could, *a priori*, be expected, by rising N transportation and production costs. The reasons are the development of biofuels crops production that provokes substitutions of arable to grass land, particularly in Germany, France and UK. For the EU 'Climate Actions and Renewable Energy Package' case, the things are worth as total NPK use increases by 11% in EU-27 for 2020, and pesticides use by 24%, compared to BAU. Substitutions of mineral N to organic N are also very important, with respectively an increase of 22% and a decrease of 9%.

The mitigate impacts of CAP reform considered in Chapter 4 and of oil price rise studied in Chapter 5, on NPK and fertilizers consumption in Europe, and the sharp increase in their use that must occur in response to the implementation of EU 'Climate Actions and Renewable Energies Package' call therefore to specific fertilizers and pesticides policies, to obtain reduced utilizations like in the BAU scenario, that could also be re-enforced.

Chapter 7 of D 6.3.3 studied in that direction the impacts of a flat rate taxation of 50% on pesticides and mineral fertilizers (N,P and K) price. In the case of fertilizers, this taxation represents a cost of about 0.4 euro per kg, and its efficiency depends on the cost of changing agriculture practices that may be superior to 0.4 euro in many situations. The direct price elasticities of fertilizers and pesticides revealed actually as quite low in NEMESIS model, and there respective consumption were reduced only 8% and 12% by the introduction of this taxation at EU-27 level, compared to BAU.

The cost of such measure could be also very expensive for farmers, as fertilizers and pesticides expenditures represented respectively 20% and 10% of net agriculture income in EU-27 for 2008, and it was introduced in NEMESIS in a way that keep unchanged farmers revenue. It should therefore be used carefully, preferably at local level, and in a way that do not compromise agriculture yields, for example by increasing again the transfers of CAP subsidies from first to second pillar in the next EU financial perspective.

1.2.7 Stream 7: Synthesis and integration

Synopsis of Stream 7 key results:

- Identification of policy options available
- Development of a theoretical framework for the valuation and integrated assessment of marine ecosystems thresholds
- Analysis of policy implications of the scientific findings and achievements of the different thresholds streams
- General recommendations of a strategic nature
- Dissemination means and activities

1.2.7.1 General methodology and brief description of the work carried out

Stream 7 has introduced the **policy dimension** in the project on the basis of the work carried out in the project. All Streams have had a responsibility to deliver inputs to S7 which has the task to integrate the whole project and provide synthesis for policy development and implementation.

In such a framework of objectives, S7 has, during the reporting period:

- explored the development of the EU policies which require adequate scientific criteria for the assessment of water ecological and chemical status – e.g. Water Framework Directive, the daughter Directive on Environmental Quality Standards (EQS) in the field of water policy (2008/105/EC of 16 December 2008), the Marine Strategy Directive (2008/56/EC of 17 June 2008), and the recommendation on Integrated Coastal Zone Management. For the environmental hazard assessment of dangerous chemicals in the aquatic compartment there are links to the REACH regulation.
- defined a methodology for the probabilistic assessment of the costs of exceeding thresholds against the costs of programmes of water policy measures, using an expected utility approach. Both the assessment methodology and the policy review are presented in Deliverable D7.1.1. Methodological Paper on the definition of policy options.
- Identified and pooled measures into policy options , in cooperation with the Stream 6 case study teams. The results were summarised in Deliverable D7.1.2 Definition of Policy Options. The Case studies have been analysed further in deliverable D 6.3.2 in order to identify the key aspects that the cases raise.
- Investigated a precautionary and adaptive management approach, centred on the concept of managing for building ecosystem resilience and increase the ability to cope with, adapt to and shape change. Towards the end of the Thresholds project – whose scientific results have further demonstrated the inherent complexity and unpredictability of dynamic Socio-Ecological Systems (SES) – the focus is changed: we do no more strive for policies which try to fall back to pristine conditions (*neverland*), but to maintain the functional integrity and services of ecosystems co-evolving with human socio-economic systems, i.e. their resilience – the capacity to buffer perturbations, self-organise, learn and adapt.
- In D 7.3.8 the results of the project have been summarized as a Thresholds view of European Coastal Seas, with the aim to show the relevance of thresholds thinking in decisions affecting the future of European seas.

Specific policy recommendations have been formulated on the basis of short policy guidance conclusions that each stream has produced.

Concerning dissemination, S7 has, during the reporting period, and according to plans:

- Regularly updated the website, notably with mid-term synthesis, and pdf version of policy brief, which has also been printed.
- Collated key results by editing contributions from Streams into a coherent overview (D7.3.8).
- Produced popular articles on thresholds teams based on peer reviewed publications
- Maintained and updated the detailed dissemination plan

1.2.7.2 Brief description of the main outputs

As it concerns the **analysis of policy implications** (WP1 and WP2), besides providing the description of a number of policy options that have been considered in the scenario evaluation case studies undertaken in Stream 6 (policy options are extensively described in D7.1.2), Stream 7 has elicited a number of:

- Specific recommendations emerging from the results achieved in single Streams, which highlight possible implications and applications of the methods developed in Thresholds for sustainable coastal ecosystem management
- General policy recommendations concerning the most useful approach to be taken at EU level to better tackle with ecological thresholds and regime shifts in coastal waters.

These are presented in D7.2 Policy Recommendations and, considering that represent the conclusive findings of the projects, are integrally reproduced in the following sections of this report.

1.2.7.2.1 Specific recommendations

Stream 2, 3, 4, 5 and 6 produced a number of scientific results with policy implications, mainly in the form of warning and suggestions about the more or less reliable results and methods that should be taken into account for a sustainable coastal ecosystem management. These are presented below in relation to five management topics:

- Nutrient loadings
- Marine fish farming
- Treatment of contaminants
- Evaluation and assessment of thresholds in the context of EU Water Policy
- Towards a resilience management and adaptive policy approach

Management of nutrient loadings

Stream 2 compilation and testing of tools and methods for sustainable coastal management at local and regional scales (cfr. D2.5.4) found that:

- Although many scientists and managers may believe that information on coastal size and form is of interest mainly for descriptive purposes, a different and holistic perspective focusing on the structure and function of coastal ecosystems is needed. From that perspective it becomes clear that coastal morphometry influence almost all transport processes in coastal areas, such as sedimentation, resuspension, mixing, diffusion, burial and outflow. Therefore, morphometry regulates concentrations of pollutants in water and sediments, and hence ecosystem effects related to such concentrations. These transport processes are general and apply to all substances (nutrients, metals, organics, radionucleids, etc.), and coastal morphometry parameters – in particular those developed in Stream 2 to classify different coastal zones vulnerability – should be taken into account while planning remedial measures, to the extent such parametres contribute to regulate nutrient concentrations in coastal waters, and also primary production, and secondary production of zooplankton, zoobenthos and fish.

- the dynamic CoastMab-model – developed and tested in Stream 2 - better represent how morphometry influence key transport processes, such as sedimentation, resuspension, mixing, mineralization and outflow, in the different compartments of a coastal system, e.g the surface-water compartment, the deep-water compartment, the sediment compartment for shallow areas (where there is resuspension) and the accumulation-area compartment (where there is no wind/wave induced resuspension). The recommendations here is for coastal managers be induced to use such dynamic modeling approaches more extensively, to evaluate and test the possible effects of their policies in the context of the WFD and the Marine Strategy.
- It is possible to build a set of relatively simple operational bioindicators of coastal ecosystem quality – including Chlorophill-a, concentration of cyanobacteria, Secchi depth, Deep water oxygen saturation and macrophyte cover. Different abiotic factors (nutrient concentrations, salinity, temperature, coastal morphometry and water exchange) influence such indicators in a logical and predicable manner, conducive to reliable modeling applications. These bioindicators and the morphometric classification system are proposed therefore for wider application by coastal managers at local and regional scales.
- However, the only avenue for making more realistic the diffusion of the proposed modeling and monitoring approach is to collect new and better data. There is the need to revise ongoing monitoring programs so that TN and TP (rather than DIN and DIP) and the given operational bioindicators (rather that bioindicators with high coefficient of variation and/or those requiring special competence for sampling, analyses and interpretations related to individual species) in order to make them integral parts of all monitoring programs.

Stream 3 analysis of nutrient thresholds for disruption in food webs (cfr. D3.3.3) found that:

- Despite huge monitoring efforts by the countries, existing data are not suitable for identifying nutrient thresholds for planktonic food web disruption. Alternative methods such as the river-sea model reconstruction of long term series data and the structural network analysis conducted in Thresholds have found to be very valuable.
- Main achievements from the structural network analysis suggest that nutrient enrichment favor the dominance of gelatinous organism at every trophic level and can be exacerbated by the overfishing of planktonivorous fishes.
- Mechanistic model reconstruction of eutrophication in the Southern North Sea allowed for the first time the formulation of a critical nitrogen threshold of 60 kT per year, which was however specific to the Southern North Sea region and for the contemporary period when P loads had decreased by 50%. Nevertheless the proposed river-sea model approach is generic and could be transferred to other coastal zones.

Stream 3 analysis of thresholds for shifts in sediment biogeochemistry (cfr. D5) and related hypoxia events found that:

- Nutrients are present in the sediments as organic and inorganic species, and in dissolved and particulate forms. Sediments often serve as a reservoir of nutrients that regularly release nutrients to overlying waters and thus trigger algal blooms, which can result in an increase in productivity. Increased productivity may, however, reduce oxygen levels, which leads to hypoxia. Hypoxia or oxygen depletion occurs in aquatic environments as dissolved oxygen (DO) becomes reduced in concentration, falling below 2ml of O_2/liter, at which point benthic fauna show aberrant behaviour, culminating in mass mortality when DO declines below 0.5ml of O_2/liter.
- In most cases, hypoxia is associated with a semi-enclosed hydro-geomorphology that, combined with water-column stratification, restricts water exchange. Indeed, the ability of marine sediments to assimilate nutrient loads is variable, being affected by factors including physical-chemical characteristics of water and sediment, aquatic biota, etc. Notwithstanding therefore the simple systems of thresholds for assessing eutrophic status based on absolute level of P loads, N/P ratios etc., proposed by OECD firstly for freshwater systems, and then extended to estuaries, coastal waters and offshore waters (see table reproduced at page 21 of D5), it is not reliable to apply such generalized levels to specific locations.
- Hypoxia is becoming a more and more widespread phenomenon throughout the world and evidence for eutrophication as an important causal factor is increasing. Despite nutrient reductions in some areas affected by hypoxia there has still been no reported recovery from hypoxia in coastal ecosystems. This does not mean that nutrient reductions are not important for improving oxygen concentrations; the consequence is that hypoxia would have been even worse if nutrient inputs had not been reduced. Nutrient reduction is indeed the only realistic management option for improving oxygen conditions, although must be recognized that i) nutrient reductions may to some extent be counteracted by temperature increases caused by global climate change[7] and ii) by regime shifts in the sequestering of organic material making hypoxia a self-sustaining process. The latter means that nutrient reductions required to restore coastal ecosystem health may increase if thresholds of hypoxia are exceeded.

Stream 6 analysis of nutrient driver and pressure relationships (cfr. D.6.2.5) found that:

- on a global, a continental, and to some extent also a regional scale, the levels of riverine nutrient loads (pressures) can be derived from simple empirical relationships with driving forces such as population density and agricultural land use. This means that increased driving force emissions will increase the pressures, although other factors can be involved as well;
- by comparison, at river basin and smaller catchment scales, statistically derived relationships are typically much weaker or not evident. Associations between nutrient drivers and pressures in agriculture are particularly problematic, because they are due not only to the effects of human soil management (e.g., N inputs), but also to variation in N losses caused by natural factors like climate and geology.
- The above highlights the importance of considering all space-time scales when addressing the European Water Framework Directive. In other words, it is evident that in endeavours such as the development of WFD river basin management plans, the empirically derived relationships can only be applied to achieve an initial and descriptive screening and general characterisation at the overall river basin level. Thus other types of approaches will be needed to assess water bodies (single stream stretches) and small catchments.

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[7] Harris et al. (2006, mentioned in D5) calculated, using metabolic theory, that a 4° C increase in the summer water temperatures of a northeastern Atlantic estuary will result in a 20% increase in net primary production and a 43% increase in respiration, resulting in an increasing likelihood of system hypoxia.

- Often the data inputs for the explanatory variables are spatially too coarse (e.g., comprise only one static value per river basin and lack spatial upstream propagation) to have useful management implications. Moreover, empirical relationships are only true for the region for which it was developed for and within the range of values for parameters for which it was tested. Additional and more detailed information is needed, for example, regarding spatial location of arable lands, crop-types, harvest yields, agricultural practices, and degree of sewage purification. Such comprehensive spatial data are rarely available on a general river basin level.
- There is also a need for similar studies of substances other than nitrogen, and empirical models that incorporate multiple stressors on water quality will be increasingly required to aid development of water pollution policies. In addition to acquiring better input data and empirical tools, we must improve our understanding of the key temporal and spatial factors that influence nitrogen transport. Clearly, continued monitoring and more intensive research must be conducted to explore the following aspects: the dynamics of soil organic N; in-field, in-stream, and riparian denitrification; biological N fixation; the effects of the spatial distribution of nitrogen use on delivery to coastal zones and occurrence of harmful algal blooms.

Marine fish farming (aquaculture)

The Marine Fish farming case study brings some useful lessons for EU policy, which is still in a relatively embryonic state for the aquaculture sector.

Indeed, marine fish farming is already an important industry in Europe producing a total of about 1.2 million tonnes of fish per year. The production is at the moment dominated by salmon in the northern countries, but the production of particular sea bream and sea bass in the Mediterranean has shown almost exponential growth during the past decade. In the North Atlantic fish farms are located over bare bottoms, and the benthic impacts are primarily on benthic fauna abundance and biodiversity as well as microbial processes in the sediments. In the Mediterranean the seagrass *P. Oceanica* is widely distributed at depths from few to 30-40 meters in the clearest waters. As *P. Oceanica* favors growth under relatively exposed conditions, there is often a conflict between the presence of the seagrass and fish farms.

Fish farming activities are indeed associated with a number of significant emissions or direct impacts on environmental quality:

- emissions include nutrient flows (due to fish food and feaces from fish), organic matter, medicines and pesticides, other chemicals used in fish farming process;
- direct environmental impacts include increased phytoplanktonic and bacterial activity as a result of increased nutrient flows, organic enrichment of sediments, increased levels of macroalgae near to fish farms and reduction of *P. Oceanica* meadows.

There are also a number of other impacts to consider:

- aesthetic impact on recreational enjoyment;
- impacts on wild fish through genetic interactions with farmed fish that escape from cages;
- market impacts on world fish supply.

The Marine Fish case study has employed an impact pathway approach to assess the impacts of marine fish farm to the benthic environment. Two mitigation options have been considered – moving farms further out to sea and employing smaller farms. The evidence seems to suggest that locating further out to sea is most cost-effective than using smaller farms, but this is based on a number of assumptions and so care should be taken in employing this for policy purposes.

Management of contaminants

Stream 4 findings have implications in relation to:

- **EU Water Framework Directive provisions for setting Environmental Quality Standards (EQSs)** in the field of water policy (i.e. those included in the daugther directive 2008/105/EC of 16 December 2008). EQSs are determined at an EU-wide level for Priority Substances (PSs) and Priority Hazardous Substances (PHSs) and at a Member State level for Specific Pollutants i.e. substances that are 'discharged in significant quantities'. They define threshold concentrations for chemicals that are used to designate the chemical status of a water body (PSs and PHSs) or to contribute to an assessment of ecological status (Specific Pollutants). Annex V, Section 1.2.6 of the Water Framework Directive establishes the principles involved in deriving EQSs but does not provide the necessary detail for practitioners to develop EQSs in a consistent manner, or cover all the scientific issues that may be encountered. In 2007, a technical group (EG-EQS) was therefore set up under Working Group E to develop technical guidance for deriving EQSs, including the need for guidance on the derivation of biota and sediment EQSs, and for setting EQSs for metals in ways that allow speciation and bioavailability to be accounted for. These have entailed considerable dialogue within EG-EQS and invited experts to ensure the guidance is sound and is consistent with other initiatives e.g. guidance on metal risk assessment and REACH.
- **EU Marine Strategy Framework Directive (2008/56/EC)** establishing a framework within which Member States shall take the necessary measures to achieve or maintain a « good environmental status » in the marine environment by the year 2020 at latest. The "good environmental status" shall be determined at the level of marine region or subregion on the basis of eleven qualitative "descriptors" specified in MSFD Annex 1. According to Article 9(3) of the Directive criteria and methodological standards to be used by the Member States in relation to these eleven descriptors shall be laid down by July 2010 in such a way as to ensure consistency and to allow comparison between marine regions and sub-regions of the extent to which good environmental status is being achieved. The following two descriptors are strongly related to the Thresholds Stream 4 focus on contaminants in the aquatic environment: "(8) Concentrations of contaminants are at levels not giving rise to pollution effects" and "(9) Contaminants in fish and other seafood for human consumption do not exceed levels established by Community legislation and other relevant standards"

In relation to the WFD policy provision concerning EQSs, the analysis of the methodologies for assessing EQSs in the water column and in the sediments (cfr. D4.2.5) provides the following interesting conclusions:

- From the analysis of a number of experimental and simulated data concerning concentrations in the water column and in the sediments, it is clear that even though there is a coupling between water column and sediments, it is not possible to assess the chemical quality status of sediments based on water column data and *viceversa*. At the moment EQSs have been defined for the water column and therefore these EQSs will assess only the compliance with good chemical status of surface waters. If EQSs were to be defined for sediments, these EQSs will not reflect systematically the surface water quality and therefore they could not be used for this purpose. By the same token, although in some cases it is possible to find a correlation between concentrations in the water column and in the sediments, these correlations cannot be approximated using the partitioning approach and therefore cannot be regarded as general. However, it is clear that the good chemical quality will depend on both the quality of the surface water and the sediments, and that to assess both it is necessary to take separate measurements in both media.

- The same EQSs developed for water could, in principle, be applied to porewater, hence, there is no need of another set of EQSs as established above for the sediments. If porewater could not be measured, then the partitioning approach to pass to sediment concentrations could be applied. However, in this case an additional uncertainty is added to the procedure and therefore it is necessary to develop new techniques and better databases since at the moment the predictions are between several orders of magnitude, which is not adequate for setting EQSs.
- In any case, in highly variable systems as transitional and coastal waters, dynamics has to be taken into account. For certain contaminants atmospheric inputs are known to be the main entry route to the aquatic environment and therefore, as atmospheric inputs are very dynamic and variable in time, they can induce temporally high concentrations in the water column. In a similar way more soluble contaminants that will reach the aquatic environment through the watershed will also have a high temporal variability depending on several factors (e.g. agriculture practices). As a consequence, the models needed for studying these interactions should be dynamic (not at equilibrium or steady state) in order to be able to predict the high observed environmental variability, and thus able to predict episodes were EQS limit values are crossed.
- A further and more promising approach would be the development of EQS in biota, being mussels a promising species since it has been extensively studied and, due to their feeding behaviour, they are filtering the water column and hence it could be possible to develop a correlation between water column EQSs and biota EQSs. However in this case literature is even more scarce than for sediments and there has not been systematic approach developed yet.

In relation to the MSFD policy provision, and in particular the descriptors related to the concentration and toxicity of contaminants, interesting implications can be drawn from the synthesis report on the thresholds obtained at different levels – molecular, individual, population, ecosystem (cfr. D4.1.5).

A fundamental problem in eco-toxicology is the prediction of long term population and ecosystem level effects of contaminant exposure based on dose response data of few individuals obtained over a short time period. In addition, environmental fluctuations will always affect significantly the population/ecosystem resilience, but these fluctuations are not taken into account under dose-response experiments on individuals. In the Thresholds D4.1.5 several open questions concerning the role and effects of contaminants in coastal ecosystems have been analysed through experiments, data analysis tools and modelling. Conclusions that may have important policy implications are summarised below:

- Molecular level effects are detected even at concentrations that did not affect the macroscopic end point studies, i.e. growth rate.
- Natural populations are more sensitive than populations in cultures.
- There are differences for the same species at different environments, e.g. Mediterranean, Black Sea and Atlantic Ocean.
- The environmental conditions and the time of release of the contaminant cause a variability of the response at ecosystem level that can reach 50% of the effects.
- The WFD defines five categories of ecological status: High, Good, Moderate, Poor and Bad. Concerning chemicals, and in particular priority substances (PS), the daughter directive 2008/105/EC of 16 December 2008 established a set of EQSs that refers to the concentration of the substance in the water column. If any of these concentrations is exceeding then the water body should be defined in bad status. However, since these concentrations have been chosen in basis of

ecotoxicological studies which are based on the results of acute and chronic toxicity texts in which mortality, reproductive effects or other end points have been measured for a relatively small number of organisms exposed, under controlled conditions, to varying contaminant concentrations, the nit is not clear to assess under which extent we are overprotecting the environment.

- On the other hand, if we consider that organisms are exposed to a myriad of chemical products and that regulations apply only to a few of them, we may also wonder if these measures are really underprotecting the environment.
- As a consequence, at the actual level of knowledge it is difficult to assess if the EU legal approach based on the current EQSs and the precautionary principle is over or under conservative, when considering molecular and its long term effects, the combined effects of mixtures and the environmental fluctuations that affect all ecosystems.
- As aquatic environments ecosystems experience the combined effects of mixtures, ecotoxicological risk assessment should be performed taking this aspect into account. However, with the amount of new chemicals being produced and the detection limits required, it is clear that new integrated indicators are necessary. Limiting the levels of certain chemicals in the environment is one step to improve ecosystem health but alone it will not prevent further deterioration.
- Due to practical limitations, knowledge on ecotoxicology is only available for a small fraction of the anthropogenic chemical pressure. The importance of this simplification has not been comprehensibly assessed and introduce uncertainty in the appropriate outcome of current legislation and managing practices.

Atmospheric deposition is an important entry route of pollutants to marine ecosystems. Thresholds D4.2.4 has therefore reviewed and summarised the work done on the issue of the role of the atmosphere supporting seawater and plankton concentration of Persistent Organic Pollutants (POPs), and the potential influence of these atmospheric inputs in the planktonic food web. It is shown that the results found for the Mediterranean Sea suggest that the atmosphere do indeed support the POPs concentrations in phytoplankton. Conversely, the concentrations of individual PAHs such as phenanthrene and pyrene are from 10^4 to 10^5 times lower than the thresholds values for effects of these chemicals to phytoplankton to be observable.

Therefore, according to these Thresholds findings, individual POPs seem to be much below thresholds values. However, the work performed on mixtures of PAHs and of total polar and non-polar PAHs show that their environment levels may be only 100 times below the thresholds, and even less doe coastal waters.

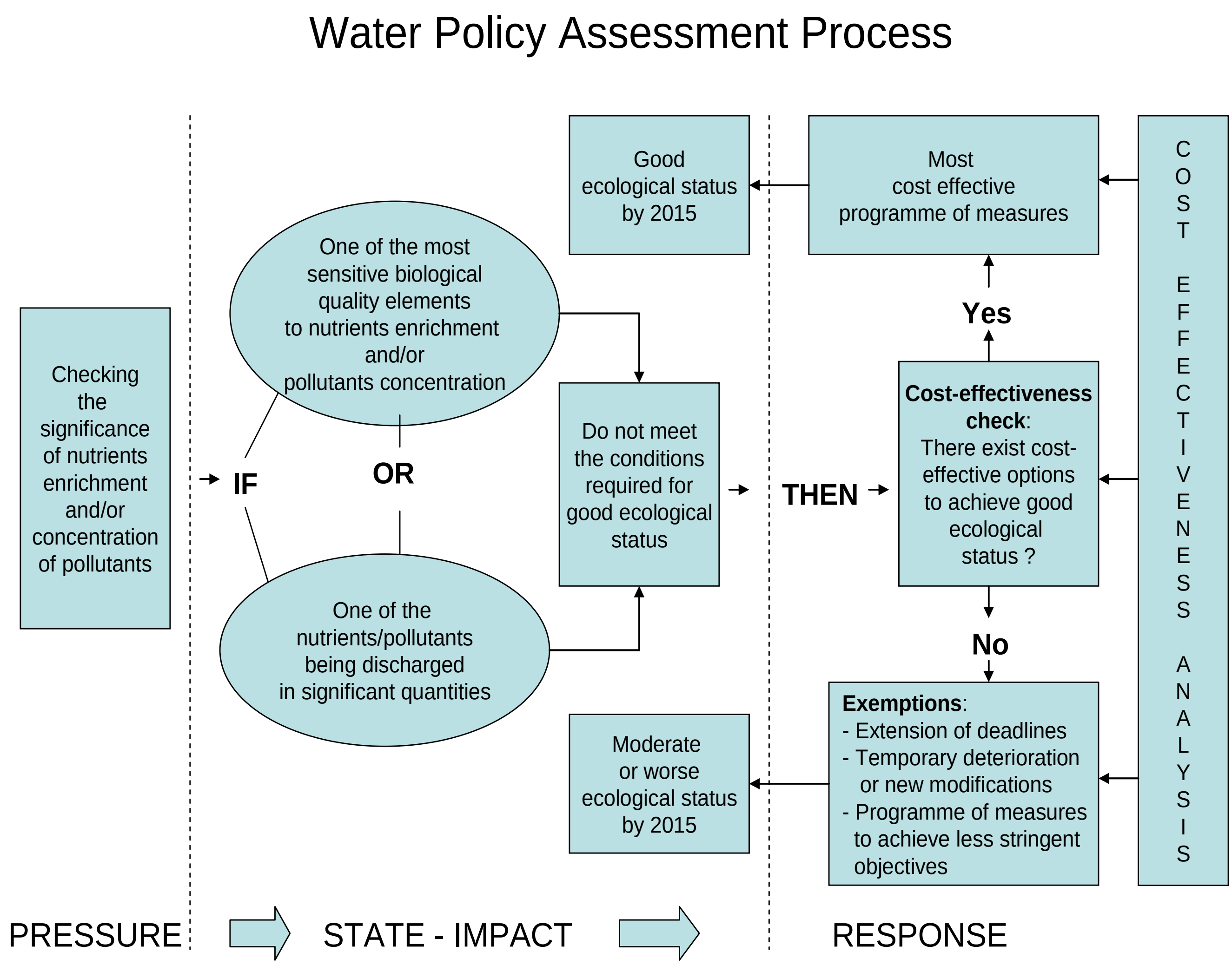
In order to better assess the effects of combined mixtures of PAHs, an integrated model, including fate of contaminants, ecological and bioaccumulation modules have been developed, implemented and tested against PAHs field measurements. The model allows to estimate the environmental concentrations of PAHs and the main fluxes between compartments, i.e. air/water/sediments and organisms. The approach developed is general and therefore its extension to other POPs families such as PCBs, PBDEs, PCCD/Fs, organochloride pesticides, etc. would be straightforward. However, the existing datasets focus normally on one or few environmental compartments and therefore it is difficult to have simultaneously data on environmental concentrations in air, water, sediments and biota.

It is strongly recommended, therefore, to develop integrated monitoring campaigns for assessing environmental status as well as for developing programmes of measures. Sometimes, partial impact assessment based on few data available on some media may be misleading since spatio-temporal variability, and the relative importance of the different media, is not taken into account.

Evaluation and assessment of thresholds in the context of EU Water Policy

The EU WFD and MSFD have introduced a whole water policy assessment process which is depicted in the figure below:

Figure 34 – The EU WFD policy assessment framework

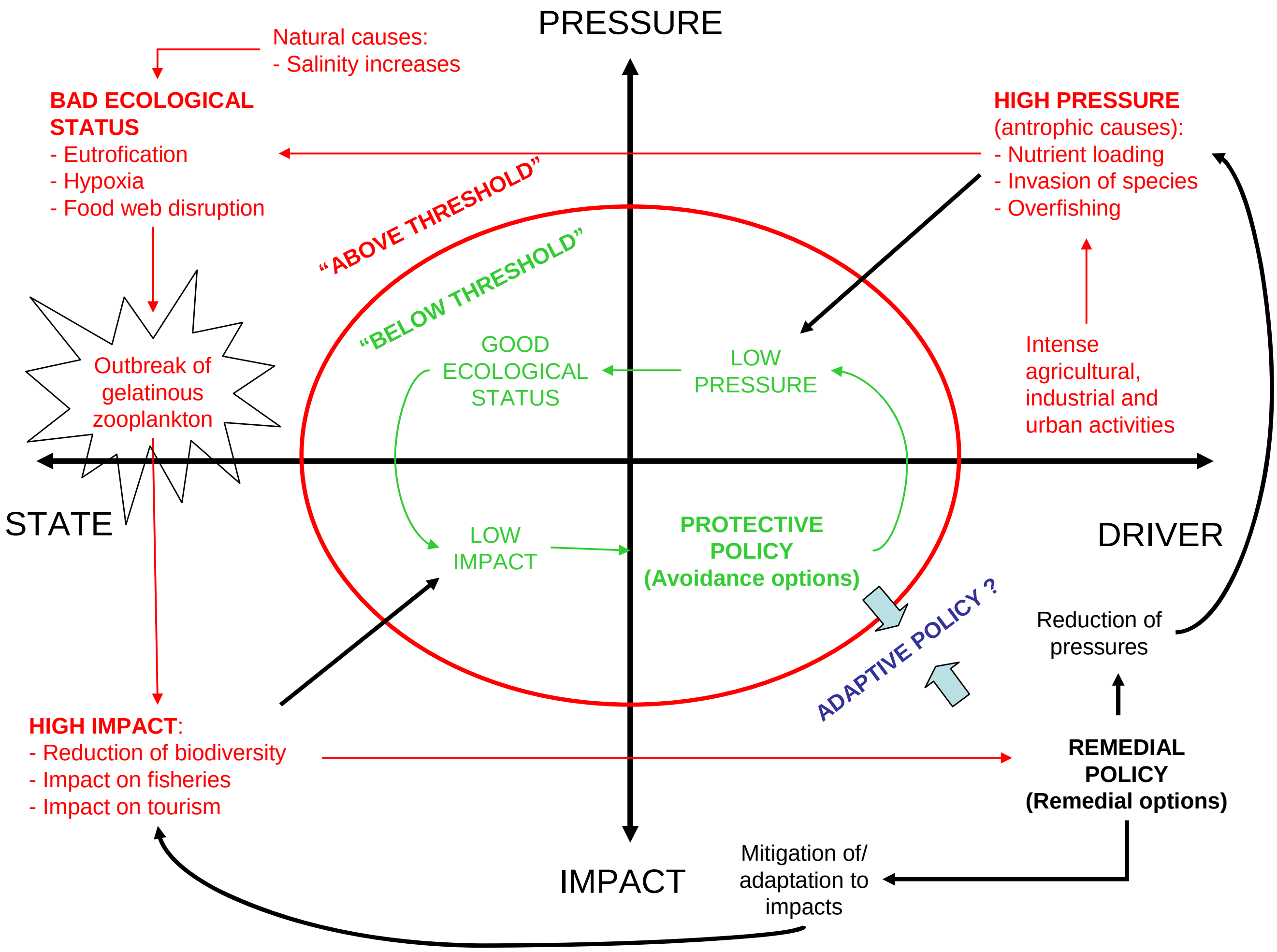


The outcome aimed with the application of this policy assessment process - in particular with the formulation of WFD River Basin Management plans which will influence the quality of downstream coastal waters, as well as of programme of measures for marine waters under the EU marine strategy – is the achievement of good environmental (ecological and chemical) status and the related benefits at a proportionate cost or the maintenance of the water body in a moderate quality status with reduced benefits, due to the disproportionate costs of achieving a better quality status.

In this context, Thresholds Stream 1 research focused in particular on the valuation exercises required to evaluate costs and benefits in coastal and marine ecosystems which exhibit a number of thresholds effects. Stream 1 provided at this regard a theoretical framework (Figure 1 of this report) for assessing the impact of hysteresis, uncertainty and thresholds in applied case studies.

An example of qualitative appraisal of impacts and costs based on such framework is provided in the figure below for the case of outbreaks of jellyfish in a coastal ecosystem.

Figure 35 – DPSR framework for the appraisal of threshold policies



In this framework we assume that the ecosystems boundaries are known – e.g. a coastal water zone with a relatively enclosed morphology – as well as the whole Driver-Pressure-State-Impact processes which underpin the thresholds shift, which in the mentioned case is the outbreak of gelatinous zooplankton (jellyfish).

Two alternative scenarios can be considered:

- a "below the threshold" scenario in which the ecosystems is maintained in good ecological status due to protective policies, which avoid any increase of the drivers and/or the related pressures, and with low impact on the environment (the "green cycle" scenario)
- an "above the threshold" scenario in which the ecosystem "jumps" in a different state, due to strong pressures caused by highly intensive driving forces which cause the ecosystem to fall in a bad ecological status, featured by eutrophication, hypoxia, food web disruptions, and eventually the outbreak of jellyfish with the consequent unintended impacts on biodiversity, fisheries and tourism (the "red cycle" scenario)

The main point to be stressed here is that, due to the fact that complex ecosystems are often characterised by a degree of hysteresis, the transition from the good ("green") to the bad ("red") ecological dynamics – i.e. crossing the red circle in the figure – cannot be reversed immediately, by implementing a remedial policy. The latter is represented in the bottom right quadrant of the framework as a number of remedial measures aiming to reduce the pressures and/or to mitigate or adapt to the harmful impacts of the threshold shift (black arrows). In the worst cases the regime shift could even be irreversible, provoking the definitive loss of ecosystems function and services.

Assuming now a perfect knowledge of:

- the threshold dynamics, including which are the causing factors (i.e. anthropogenic pressures and concomitant natural factors, as the nutrient loading and salinity increases in the example above), and at what measurable levels such factors will cause a regime shift;
- the costs and effects of the different policy measures, including any hysteresis to be expected in the system response to the remedial actions;
- the value of the ecosystems goods and services in the two alternative states of the system;

it would be in principle possible to make a policy assessment according to the WFD guidances briefly described above.

However, such perfect knowledge rarely exist, and it is in any case very difficult to obtain when dealing with complex system behaviours, as those of the coastal (and many other) ecosystems are. For instance, we may be uncertain as to the exact level of the threshold of nutrient flow – or type of nutrient – that may lead to the eutrophication, food web disruption and the outbreak of jellyfish. Or there may be a significant but unknown time lag between removing the pressure and a return to the original state of nature, which makes difficult to produce a reliable estimation of costs and benefits of remedial actions over time. Finally, last but not the least, there are a number of problems and difficulties in estimating the values of ecosystem services, especially using standard willingness to pay methods which take account of pollution only to the extent that somebody is willing to pay to avoid it. Pollution that apparently does not give rise to any effects that anybody cares about – e.g. when nutrient loading in the aquatic environment is approaching but still not overpassing a threshold of turbidity – may well have implications for the future ability of the joint economy-environment system to satisfy human needs and desires. These would be real costs, not accounted for in the WTP evaluation.

There is the need therefore to leave the "perfect knowledge" assumptions of standard economics aside, and fully acknowledge instead the <u>consequences for decision making of dealing with complex Socio-Ecological Systems (SESs)</u>.

In such systems, at any time a large number of factors may influence the outcome of a particular event, each one to a greater or lesser extent. At another time the strength of those same causative factors on the same event may be very different. The relative intensity of causal relations in the system changes from time to time. The behaviour of the system cannot be inferred from the behaviour of its components considered separately. This makes prediction of outcomes very difficult. Complex systems may even be inherently unpredictable: they may experience changes that are currently not envisaged, that have not been thought of as possibilities, i.e. really "surprising" behaviours.

The main consequence is to fully acknowledge that, at any point in time, we can only have an "imperfect knowledge" of complex systems' behaviour, and we need therefore a more prudent approach to management, which would allow time for the acquisition of understanding, than if all current and future impacts were fully understood and known.

However, as in many circumstances we still need to make decisions because doing nothing might make the situation worse, another consequence is that to be useful water policy assessment should more realistically apply rules of **decision making under imperfect knowledge**, to help to decide about future courses of action. Clearly, the degree to which knowledge is imperfect and the extent of the possible (positive or negative) impact of a decision very between situations. Some types of imperfect knowledge are much easier to deal with than others. For example, we may not have gathered all available information yet, but we could do so. Or we may be able to find out certain aspects of what we want to know, but not others, or the information which we get is contradictory. In other situations we may not even know the probabilities of the individual outcomes or what the possible outcomes are. Decision theory help us to classify the different forms of imperfect knowledge in four basic categories:

- **Risk**: the different possible outcomes are known exactly and a probability can be assigned to each possibility;
- **Ambiguity**: the probabilities are known but the outcomes to which they attach are not known exactly;
- **Uncertainty**: the different possible outcomes are known but probabilities cannot be assigned to them;
- **Ignorance**: the definition of a complete set of possible outcomes is problematic and probabilities cannot be assigned to them.

Decision making in the face of ambiguity, uncertainty and/or ignorance cannot be reduced to simple rules that apply in all circumstances.

For instance, when dealing with "uncertainty" – i.e. the different outcomes are known but not the probability of their occurrence – decision makers can find useful to organise the available information into a pay-off matrix, which states the possible decisions and the outcomes (costs) that go with them given the possible states. The decision if to take or not a given course of action might be then based on different criteria – e.g. the "minimax" rule (make the decision that leads to the least worst outcome) or the "maximax" rule (make the decision that gives the largest best outcome) - the choice of which ultimately depends on the risk attitude and judgement of the decision maker.

In the case of "ambiguity", the decision makers the probabilities of possible events but does not know for sure the impact or cost associated to some of these possible outcomes. In such case the decision may be taken on the basis of a sensitivity analysis which would show the consequences for a full range of possible impacts, but it will remain essentially a subjective matter, involving some kind of judgement.

Finally, in a state of "ignorance" the decision maker cannot say what all the possible outcomes are, let alone assign probabilities to them. In this case the decision maker may only know that a given course of action will cause an irreversible change for the environment, without knowing if this will be positive or negative, and apply the precautionary principle. This states that when the environmental consequences of an activity are (1) in some way uncertain/ambiguous but (2) non-negligible, precautionary measures should be taken, even if some cause and effect relationships are not fully established scientifically.

Depending on the state of the art of scientific knowledge, most of the circumstances surveyed in the Thresholds research, e.g. those related to the effect of a mixing of nutrients and contaminants in a water compartment, put the decision maker in face of conditions of uncertainty, ambiguity or even ignorance which would justify the application of a precautionary approach. One main conclusion of the project is indeed that thresholds may be a useful concept in developing and implementing regulation, but the context-dependency of thresholds has to be recognised. A corollary of this conclusion is that the decision maker should have enough degrees of freedom and room for manoeuvre to take the decision which she/he consider the most suitable based on the context and the information available to her/him.

However, it is also true that a huge number of comparable case studies and analysis which are continuously undertaken by the research community world-wide contributes to accumulate a growing body of knowledge about the coastal and marine ecosystems behaviour under different circumstances and pressures. Such growing body of empirical evidence contribute to create expectations about the evolution of such ecosystems, based on their behaviours observed or simulated in similar circumstances and/or in reaction to repetitive events. This may eventually develop into the much easier category of imperfect knowledge to deal with, i.e. the probabilistic risk-based approach.

For situations characterised by risk we said that probabilities can be assigned to outcomes. Where probabilities are assigned on the basis of experience, they are sometimes referred to as "objective" probabilities. In many environmental decision contexts such objective probabilities can be derived from models, which help us to develop in a structured way an understanding of a situation about which we have no relevant experience. If, for example, one is uncertain as to the pressure that will lead to a change in the ambient state – but thanks to the simulation undertaken with the help of a model (e.g. the river-sea continuum mechanistic modelling tested in the Southern North Sea study) one thinks it lies between certain pressure levels – one may define the pollution loading as a probability distribution function rather than a deterministic value. Introducing probabilities in the water policy assessment framework would lead therefore to the consideration of expected values of different activity levels and associated environmental impacts.

A **probabilistic risk-based approach** to deal with thresholds effects in the context of the EU WFD assessment framework has been proposed in the Thresholds deliverable D7.1.1. The idea is that it is possible to use the results of the scenario analysis to produce a matrix of probabilities of changing water quality status from one period of the scenario horizon to the next, as follows:

State j at period T+1: State I at	1. High	2. Good	3. Moderate	4. Poor	5. Bad	Probability of being in any of the five water quality classes

period T:						
1. High	P_{11}	P_{12}	P_{13}	P_{14}	P_{15}	$\sum_j P_{1,j} = 1$
2. Good	P_{21}	P_{22}	P_{23}	P_{24}	P_{25}	$\sum_j P_{2,j} = 1$
3. Moderate	P_{31}	P_{32}	P_{33}	P_{34}	P_{35}	$\sum_j P_{3,j} = 1$
4. Poor	P_{41}	P_{42}	P_{43}	P_{44}	P_{45}	$\sum_j P_{4,j} = 1$
5. Bad	P_{51}	P_{52}	P_{53}	P_{54}	P_{55}	$\sum_j P_{5,j} = 1$

The probability $P_{i,j}$ is the probability for the water body to be classified in the quality status class j at the period T+1 when it was in the quality status class at the period T. On the diagonal of the matrix there are the probabilities of remaining in the same status. Finally, the row sum of the probabilities to shift to any of the five water quality classes is equal to 1.

These probabilities change from period to period, depending on the levels of nutrients enrichment and/or pollutant concentrations and their effects on water ecosystem status variables, which ultimately determine the water quality class to which the water body belongs. In practice, the probabilities of interest for the purpose of WFD water quality assessment are those related to the transition from/to the good quality status to a moderate or worse status (shadowed area in the matrix).

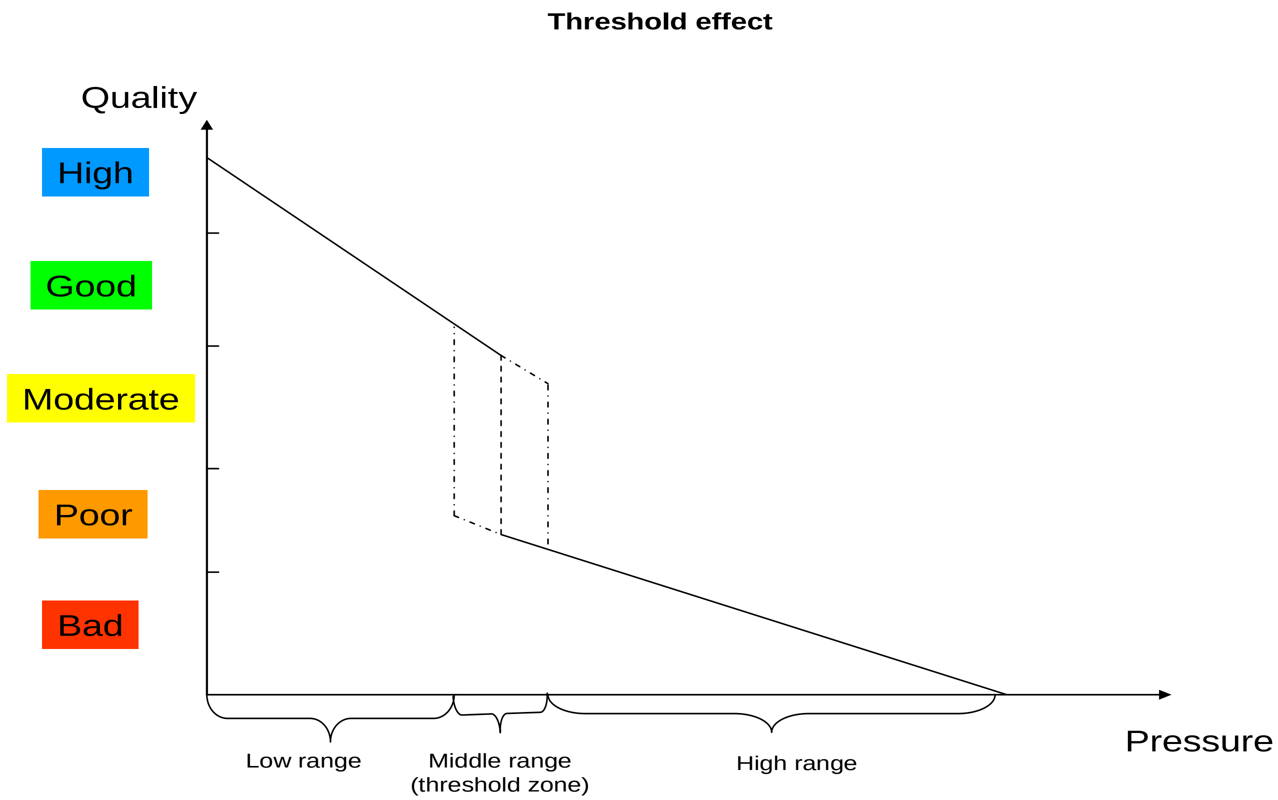
The "quality story" of the water body will be represented by the evolution of the probabilities of the different quality conditions varying as a function of the different ranges of pressures experienced by the aquatic ecosystem during the scenario horizon.

If the evidence – empirical or produced by mechanistic model simulations – shows that there is a clear and robust linear correlation pattern between the pressure (e.g. nutrient enrichment) and the quality of the water body as measured by a target bioindicator (e.g. Secchi depth), we can clearly detect three ranges of pressure and the related probabilities of the quality status:

- Low range of pressure: the quality of the water body will have a high probability (let say 80%) to remain in the high quality status, and a residual probability (e.g. 20%) to shift to the good status, to factor in any uncertainty there may be on the behaviour of the quality bioindicator within the low range of pressure.
- Middle range of pressure: the quality of the water body will have a high probability (e.g. 80%) to stay in the good quality status, and a residual probability to shift to the moderate status (e.g. 20%).
- High range of pressure: the quality of the water body will have a high probability (e.g. 80%) to stay in the moderate quality status, and a residual probability to shift to a worse status.

However, when the model detects a threshold effect for a given input variable - e.g. a relatively small range of variation of nutrient enrichment to which corresponds a non linear change in the water quality status - this can be formalised by a significant probability to "jump" from the good directly to the "poor" or "bad" quality status. Such circumstance is depicted in the following figure:

Figure 36 – Representation of a threshold effect in the WFD classification



In this case we can again detect three ranges of pressure and the related probabilities of the quality status as follows:

- Low range of pressure: the quality of the water body will have a high probability (let say 80%) to be "high" or "good", and a residual probability (e.g. 20%) to shift to the moderate status, to factor in any uncertainty there may be on the behaviour of the quality bioindicator within the low range of pressure.
- Middle range of pressure: this is now the threshold zone, where we assume the underlying modelling simulation has shown a discontinuity in the behaviour of the target water quality indicator. To factor in the uncertainty about when (at what pressure level) exactly the discontinuity occurs, we may assign in this middle range equal probabilities to stay in the good status (50%) or in the poor status (50%), "jumping over" the moderate status whose probability is equal to zero.
- High range of pressure: the quality of the water body will have a high probability (e.g. 90%) to be poor or bad, and a residual probability (e.g. 10%) to maintain a good ecological status (due the uncertainty of the threshold event, which may not happen even for relatively high pressure levels)

The probabilities show therefore a discontinuity in the threshold zone, where only the extreme quality conditions, "good" and "poor", have positive (and equal) probabilities, whereas the probability of a moderate status is negligible (set to zero in the example).

The availability of the matrix of probabilities of transition will allow to determine at each period of the scenario horizon a probabilistic water body quality status - namely the distribution of probability to shift from the current status to the five ecological classes. This information can be used to perform a cost-effectiveness analysis, as illustrated more in detail in D7.1.1.

Towards a resilience management and adaptive policy approach

As indicated by mentioning an "adaptive policy" question in the DPSR framework presented above (Figure 35), there is a different approach to cope with complex and unpredictable systems, which would imply a paradigm shift in policy making, from policies that seek to control and maintain/bring back the system to a desired stable state (e.g. the pristine natural conditions of a water body) to policies which maintain/enhance the capacity of the system to cope with, adapt to and shape change. This approach introduces the concept of **resilience** of the system as main goal of management. Managing for resilience enhances the likelihood of sustaining development in changing environments where the future is unpredictable and surprise is likely. **Active adaptive management** whereby management actions are designed as experiments encouraging learning and novelty, and thus increasing resilience in social-ecological systems, is an ancillary concept. We will discuss briefly these concepts below and the implications for policy making.

The Resilience Alliance (www.resalliance.org) defines ecosystems resilience as the capacity of an ecosystem to tolerate disturbance without collapsing into a qualitatively different state, that is controlled by a different set of processes and feedbacks. A resilient ecosystem can withstand shocks and rebuild itself when necessary. Resilience in social systems has the added capacity of humans to anticipate and plan for the future. Humans depend on ecological systems for survival and continuously impact the ecosystems from the local to the global scale. Resilience is a property of these linked social-ecological systems. "Resilience" as applied to ecosystems, or to integrated systems of people and the natural environment, has three defining characteristics:

- The amount of change the system can undergo and still retain the same controls on function and structure.
- The degree to which the system is capable of self-organisation.
- The ability to build and increase the capacity for learning and adaptation.

The amount of resilience a system possesses relates to the magnitude of disturbance required to fundamentally disrupt the system causing a dramatic shift to another undesirable state of the system. Reduced resilience increases the vulnerability of the system to smaller disturbances that it could previously cope with. Even in the absence of disturbance, gradually changing conditions can surpass threshold levels, triggering an abrupt system response. When resilience is lost or significantly decreased a system is at high risk of shifting into a qualitatively different state. Resilience in socio-ecological systems can be degraded by a large variety of factors including:

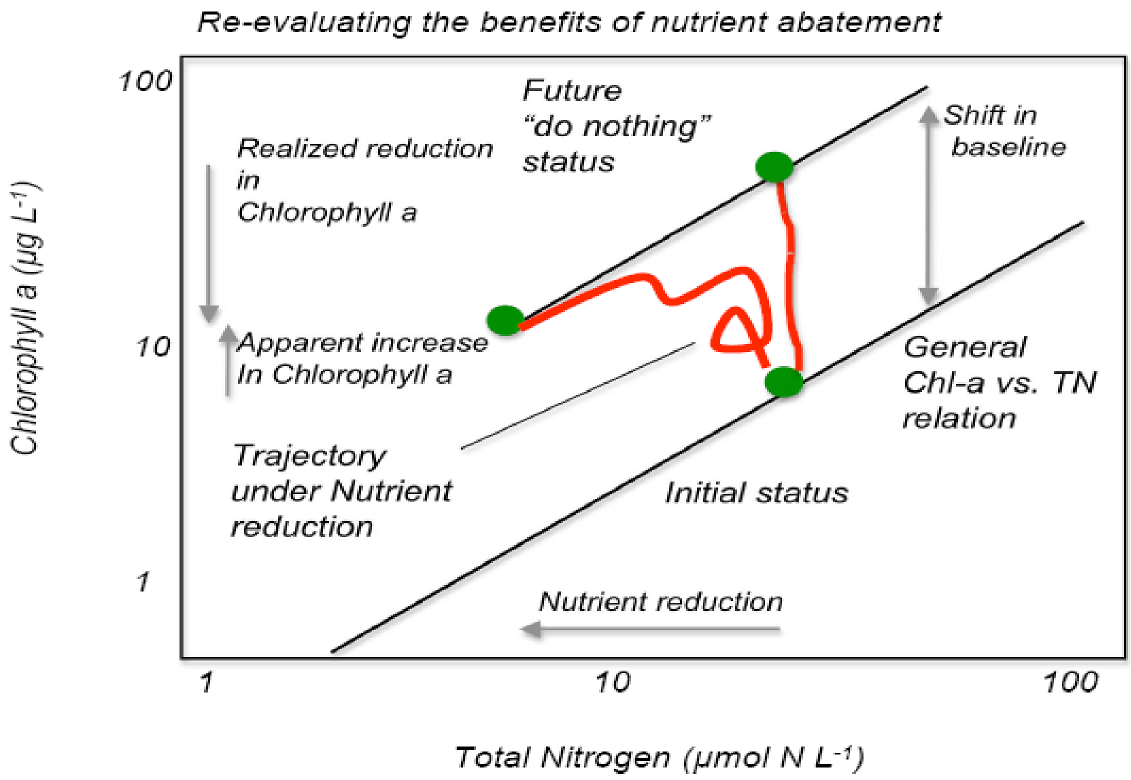
- loss of biodiversity
- toxic pollution
- inflexible, closed institutions
- perverse subsidies that encourage unsustainable use of resources
- a focus on production and increased efficiencies that leads to a loss of redundancy.

Natural systems are inherently resilient – this is mostly a consequence of natural evolution – but just as their capacity to cope with disturbance can be degraded, so it can be enhanced. The key to resilience in social-ecological systems is diversity. Biodiversity plays a crucial role by providing functional redundancy. For example, in a grassland ecosystem, several different species will commonly perform nitrogen fixation, but each species may respond differently to climatic events, thus ensuring that even though some species may be lost, the process of nitrogen fixation within the grassland ecosystem will continue. Similarly, when the management of a resource is shared by a diverse group of stakeholders (e.g. local resource users, research scientists, community members with traditional knowledge, government representatives, etc.) decision making is better informed and more options exist for testing policies.

The goal of resilience management is to prevent a social-ecological system from moving into undesirable configurations. Although this may seem a goal similar to the conventional aim of maintaining or bringing back a system to a desired stable state, it is not necessarily so. The goal of resilience management is actually wider. For instance, a fundamental lesson drawn from the Thresholds research is that we need to change our expectations about how to manage thresholds and regime systems in the coastal and marine ecosystems: the aim should be no more falling back to pristine conditions (*neverland*), but strive to maintain the functional integrity and services of ecosystems co-evolving with human socio-economic systems.

In the context of Thresholds research, this means to re-evaluate the benefits of nutrient abatement, and reconsider our goal: to prevent further deterioration and catalyse recovery, not to revert the systems to past conditions, as illustrated in the following figure:

Figure 37 – Re-evaluating the benefits of nutrient abatement (source Carstensen et al. – in prep)



Furthermore, we need to shift from the conventional decision analysis approach to support decision making towards a resilience analysis approach to support social learning and adaptive management of integrated coastal zones (land and water) systems.

Decision analysis is suitable to predict and improve system performance during times of stability and growth. In decision analysis, possible policies are evaluated using the probability distribution of system trajectories that each candidate policy generate. The decision analysis process identifies the policy that maximizes the expected utility, or minimizes expected regrets (losses). This analysis is supported by techniques as simulation gaming, integrated assessment, decision support systems, cost-benefit analysis and multi-criteria analysis. The "probabilistic risk-based approach" to deal with thresholds effects in the context of the EU WFD assessment framework proposed above is in this respect still a traditional assessment methodology. But these are techniques used to propose resource allocation that require the real system to be represented by a model that makes probabilistic predictions. If the actual system behaviour gets too far away from the model representation, the predictions fail. Moreover, the principle of allocative efficiency underpinning conventional cost-benefit analysis only refers to individuals' preferences and there is no reasons to assume that those preferences will always reflect the requirements of resilience. Individuals may be willing to pay nothing to preserve a keystone species, in which case correcting market failure by means of externality evaluation and pricing will not guarantee its survival, and hence does not guarantee the resilience of the relevant ecosystem.

The evidence of unexpected and unwanted outcomes in socio-ecological systems calls for the implementation of a **resilience analysis** approach. This starts from observing that, as a matter of fact, the assumptions underpinning conventional decision analysis frequently do not hold. On the contrary, a resilience-centered approach to management makes the following assumptions:

1. SESs may contain thresholds and can exhibit hysteretic and irreversible changes. Resilience assessment focuses upon identifying and understanding the processes that produce these thresholds.
2. Probability distributions for key decision variables are highly uncertain; both the functional form and parameters of distributions may be unknown. Moreover, the key parameters may change faster than we can update information. Although work has been done on decision making under dynamic and unknown probabilities, most of the resulting decisions are extremely cautious, which is itself a form of rigidity that forestalls innovation and undermines resilience. Rather, we need some way to move forward despite vast uncertainties.
3. Decision makers in social-ecological systems must make decisions based on imperfect knowledge, with limited resources. Furthermore, decisions do not solely concern the consumption of goods and services. Agents often do not make income-maximising decisions and the utility functions used to represent agent behaviour must be sufficiently rich to include this. Utility depends upon social context.
4. Market imperfections are the norm, not the exception, thus market-based valuations are usually distorted. Moreover, well-defined property rights do not exist for many important ecological goods and services and, therefore, markets do not exist in such cases.
5. Agents hold preferences, not just over outcomes (e.g. consumption bundles), but over the social, economic and political processes that govern those outcomes. Most stakeholders are not content to be represented in the process by a mere abstract utility function. Expert solutions may maximize something, but they rarely maximize legitimacy.

Where these five assumptions hold, the many management techniques that depend on the fact that they do *not* hold have much reduced value. For a resilience analysis, we need a process that simulates creative thinking about the future and allows both stakeholders and researchers to compare maps of various pathways to the future. Pathways that are robust to ambiguous and unforeseeable changes suggest actions that can be taken to increase the resilience of a given social-ecological system. The challenge, then, is to understand the biophysical and social components of resilience and bring them to the consideration of voters, interest groups, and politicians.

How can resilient pathways be discovered? Brian Walker and others (2002), borrowing from the adaptive management approach developed by Holling (1978) and Walters (1986) and from ideas of scenario planning (van der Heijeden), proposed a pragmatic enough procedure that consists of four steps as follows. First, representatives of stakeholders groups are involved in establishing the important attributes of the study system and the range of possible trajectories that the stakeholders might try to make this system follow (step 1 “resilience of what?” and step 2 “resilience to what?”). This information is then used for more specialized, quantitative analyses of where resilience resides (step 3 “resilience analysis”). Finally, an integrated evaluation of management and policy implications is developed with input from both scientists and stakeholders (step 4 “resilience evaluation and management implications”).

Defining the problem at the start involves identifying the critical, necessary stakeholders. Without their participation, achieving a collectively and socially desirable outcome is not possible, because key information resides in the knowledge and mental models of stakeholders, and because, without the inclusion that comes from participatory approaches, any proposed solution would face a legitimacy problem. Identify this group, in turn, requires knowledge of the institutional framework that determines the rules for ecosystem use, with particular reference to property or usage rights and the locus of decisions. A successful outcome of any procedure aimed at achieving social-ecological sustainability is fundamentally dependent on the active, positive involvement of all relevant stakeholders.

Finally, as the discussion above clearly points to recommend the resilience building management of marine and coastal ecosystems across Europe, we can conclude our analysis of the implications for EU policy asking to what extent does the EC WFD and MSFD build resilience.

We can report here the main conclusions of a paper of Victor Galaz R. (2006) that focused on this issue from the Swedish national perspective, as these conclusions are general and broadly valid also for the other EU Member States. According to the conclusions of this study, which were based on a number of interviews to coastal managers related to the ongoing implementation of the WFD in Sweden, collective action among water stakeholders continues to be important for the sustainable management of water resources, but has not been impressive so far. More precisely, all waters directors interviewed acknowledge the key role voluntary cooperation plays for the realisation of the intentions of the WFD, but none of them have an explicit plan for how to promote such processes. An issue related to collective action is the ability of actors to achieve *social learning*. Learning here is the development of a common framework of understanding, the creation of a joint basis for action, and the joint analysis of system dynamics – i.e. identifying feedbacks, driving forces, thresholds, possible regime shifts and major uncertainties. This learning should be the result of a "process by which institutional arrangements and ecological knowledge are tested and revised in a dynamic, ongoing, self-organised process of trial and error" (Folke et al. 2002).

Now the question is: how well does the current implementation of the WFD address this issue? The short answer from the interviewed water managers was: not at all. Their arguments have still a general validity, and are shortly summarised below:

- First, though citizens and stakeholders are expected to take part of various parts of the WFD water planning cycle, they are not likely to be invited in the authorities' attempts to understand system dynamics. The emphasis of stakeholder involvement is on supplying data and providing feedback to the plans presented by water authorities, not on inviting stakeholder groups to joint learning processes that deal with the joint analysis of water system dynamics and implications. The fact that water systems often are complex and embed vast uncertainties is not discussed at all, nor integrated into the stakeholder processes proposed by European authorities.[8] More precisely, there seems to be no preparation for how managers are supposed to tackle the fact that ecological systems are far from being fully predictable and under pressure from environmental change, or that promoting social processes such as stakeholder cooperation is far from a simple task under social and ecological uncertainty.
- Second, water authorities seem to put their faith in existing models as a way to deal with complexity and uncertainty. However, there are no operational plans on how to use these models in collaboration with stakeholders, nor to promote joint discussions and learning processes using these models. This state of affairs is troublesome considering the fact that stakeholders tend to disregard sophisticated, and what they regard as too generalizing models. Put bluntly, trying to use the models in a "top-down" manner without seriously opening up for two-way communication results in the absence of the analytical deliberation required hence blocking any attempt to understand system dynamics, and – what is perhaps more important – to legitimate regulatory actions.

[8] Cfr. CIS (2003). Public Participation in Relation to the Water Framework Directive. Guidance Document No. 8. European Commission.

- Third, although the use of various sorts of models in water planning might seem like the way to go for managers to deal with increased complexity and uncertainty, one largely ignored fact is that these models often must rely on simplified assumptions and data shortages that seriously limit their capacity to predict the impacts. This is particularly true in relation to the impacts of climate change, which has been left out of the scope of the WFD.[9] The predictions for hydrological changes in a specific catchment or region as a result of global environmental change are rather uncertain, as precipitation varies largely in different climate models due to uncertain and non linear processes in the atmosphere, and the coupling between climate and hydrological models is still a challenge as well.

Against the current state of the art, our specific recommendation for the EU policy makers and the coastal managers across Europe would be to experiment **participatory approaches of resilience management** that: 1) include local stakeholders' ecological knowledge into multilevel water governance, 2) takes uncertainty and complexity seriously, and 3) helps to build, rather than undermine social-ecological resilience.

As pointed out in Galaz (2006), four crucial differences between this resilience management approach to water planning and that proposed in the WFD are worth highlighting:

- First, while the WFD intends to promote stakeholder participation and social learning, a resilience analysis does this with the explicit intention to identify the major uncertainties in the system's future dynamics.
- Second, though various models are likely to be used by future water authorities, resilience analysis attempts to use models to describe the dynamics of the system and to identify through scenarios the components of the system's resilience, and how resilience may be lost or enhanced through management initiatives.
- Third, resilience analysis has an explicit ambition to try to identify the processes that drive the dynamic behaviour of water systems and to identify critical thresholds. These aspects are not an integrated part of the present WFD water planning cycle.
- Fourth, and perhaps most important, the aim of resilience management is to prevent water systems to move into undesired states in the face of external stresses and disturbances. In contrast to the WFD, the focus is not on monitoring activities and achieving a fixed water quality target, but rather on nurturing and preserving the elements that enables water systems to renew and reorganise following a disturbance.

1.2.7.2.2 General recommendations

The key lessons and implications for policy making at EU level are presented below:

- *Policy makers want exact information:* The demands for exact information can be seen in, for example, the implementation of the Water Framework Directive and in legislation concerning contaminants. Resources used for identifying limits and for monitoring the state of systems with reference to pre-specified limits do not, however, necessarily advance knowledge of why and how changes occur.

[9] It is remarkable that the term "climate" does not appear in the text of the Directive.

Ecological thresholds can thus become a bureaucratic point of reference rather than encouraging an understanding of the dynamics of the system.

- *Adaptive governance might be better:* A regime that stresses adaptive governance mechanisms is also likely to emphasise social learning more than centralised and rigid regimes. It can put more weight on new information made available by different social actors and can develop towards governance which also delegates responsibilities to actors outside the public administration. This means that great emphasis should be put on harmonisation of methods for obtaining and storing information, but less on the exact interpretation of data as the interpretation would be part of a social learning process.
- *"Getting the prices right" with thresholds may be more difficult:* The use of market based instruments to solve thresholds-related environmental problems is challenging. Not all economic instruments are adequate instruments for the management of thresholds-linked problems. Ideally the costs of activities should increase well before the pressure they cause reach threshold values, thereby encouraging innovations that reduce the pressure. Due to thresholds effects scarcity may not develop and hence costs do not increase before it is too late. This applies especially to those economic instruments, which use a flat rate based on an assumption that the environmental problem increases linearly with the pressure. Any system that exhibits time lags and points of nearly irreversible change at thresholds is susceptible to unintended deterioration under extreme deregulated regimes because the information gathering and the modification of behaviour is unable to cope with the dynamics of the system.
- *Managing complex socio-ecological systems:* Social and ecological systems interact, as humanity has powerful interactions with biogeochemical, hydrological and ecological processes, from local to global scales. The complexity of social-ecological systems makes it necessary to abandon the perception of a global steady state. Instead, managing complex, coevolving social-ecological systems for sustainability requires the ability to cope with, adapt and shape change without losing options for future development. It requires **resilience** – the capacity to buffer perturbations, self-organise, learn and adapt.
- *Management for resilience-building:* Management can diminish or build resilience. Rigid control mechanisms that seek stability tend to erode resilience and facilitate breakdown of socio-economic systems. There are many examples in the literature where management has altered slowly-changing ecological variables, inducing a critical vulnerability and eventually regime shifts into less productive and less desirable ecosystem states, which are difficult, expensive, or sometimes impossible to reverse. Although we may understand the mechanisms behind shifts in ecosystems, it will be difficult to predict such shifts – as also the Thresholds research has extensively demonstrated. Moreover, passive monitoring and control systems are unable to learn as fast as the thresholds move. In such situations, prediction and optimisation have little use, and will have to be replaced by "wiser" risk spreading and insurance strategies to maintain options and sustain socio-ecological systems in the face of surprise, unpredictability and complexity.
- *Stakeholder participation is vital:* Thresholds may be a useful concept in developing and implementing regulation, but the context-dependency of thresholds has to be recognised. The health of coastal and marine waters cannot be guaranteed by European legal documents only. Indeed, managing for social-ecological resilience requires understanding of ecosystems dynamics, incorporating also the knowledge and wisdom of local users and interest groups. Consequently, the spread of ecological illiteracy in contemporary society needs to be counteracted. Processes supporting societal learning how to manage systems with thresholds will only develop through active stakeholder participation. The regulatory systems should provide flexible frameworks to make local and regional participation meaningful.

- *Stimulate the implementation of resilience-building tools:* Two useful tools for resilience-building in complex, unpredictable systems are **structured scenarios** (e.g. those recommended as an outcome of Stream 6, see above) and **active adaptive management**. Structured scenarios attempt to envision alternative futures in ways that expose fundamental variables and branch points that may be collectively manipulated, whereas active adaptive management seeks a set of structured management experiments that could be more effectively designed if fed by structured scenarios exercises. These techniques should therefore work together and their implementation should be expanded across Europe – in the context of the river catchment and coastal water planning provisions introduced by the WFD – to help increase capacity to build resilience.

As it concerns the **dissemination activities** (WP3), the final year of the project has been particularly intense both in terms of activity and of the effort devoted to dissemination and promotion of project results. Partners published in scientific journals about 80 papers in the last reporting period. About 20 new papers have been submitted and several more will be submitted.

A representation of *thresholds* was ensured at the following scientific conferences:

- International Symposium on Effects of Climate Change on the World's Oceans, May 19-23, 2008, Gijón, Spain
- EurAqua Conference, Oslo, Norway. 24.10.08
- ASLO aquatic science meeting 27.1.2009 Nice, France
- 2nd Biannual and Black Sea SCENE EC Project Joint Conference, 6-9 October, 2008, Sofia, Bulgaria EAAE conference, Ghent, 26-29 August 2008.
- Stratégie pour le milieu marin et enjeux pour la Haute mer 09-11 Dec 2008
- European Association of Environmental and Resource Economists Conference, Gothenburg June 2008
- Training programme on regional ocean governance for Mediterranean and eastern European countries
- Towards A Holistic Maritime Policy, Malta, 16 November – 19 December 2008.
- 41st International Colloquium on Ocean Dynamics 05/05/2009
- 7th International Congress of Limnology-Oceanography 16/10/2008
- Seagrass Network Meeting, University of Odense, Denmark, March 2-3 2009
- Workshop Baltic-Mediterranean, Marseille 10.-11.6. 2008

In addition to this, Thresholds partners have actively participated in educational workshops at university level, engaged in providing expert services to policy makers and managers at EU, national and local levels, and been lecturing at universities.

2 PART 2: DISSEMINATION AND USE

2.1 SECTION 1: - EXPLOITABLE KNOWLEDGE AND ITS USE

It is worth underlying that this section has been mainly conceived for projects dealing with technological innovations and it is thus scarcely suitable to socio-economic projects. This is particularly true when reading the definition provided by the Commission Guideline to the exploitable knowledge that is defined as a: "*knowledge having a potential for industrial or commercial application in research activities or for developing, creating or marketing a product or process or for creating or providing a service"*. By its nature, THRESHOLDS doesn't have such industrial or commercial potentialities. Rather, the knowledge generated in THRESHOLDS is mainly supposed to feed the scientific and policy framework for better understanding and evaluating coastal water policies. An exception to this could be represented by some of the software tools developed by the project, which might acquire an autonomous market value in the future.

A brief outline of potentially exploitable knowledge from single streams of THRESHOLDS, and – if applicable - a description of what exploitable products (functionality, purpose, innovation, etc.) have been elaborated by single streams are provided in the following sections.

2.1.1 Stream 2: Thresholds and points of no return: threshold definition, theory and identification.

Stream 2 has developed and tested models and operational bio-indicators for sustainable coastal ecosystems management. In particular, the CoastMab-model is a tool exploitable to support the management of nutrient discharging and control the impacts on the ecological status of a number of coastal zones, and it is described in the section on publishable results below.

2.1.2 Stream 3: Nutrient-driven thresholds of environmental sustainability.

Although we have not produced knowledge with the potential for industrial or commercial application, Stream 3 has produced a number of important concepts that can be used for "creating or providing a service." Our exploitable results are the knowledge obtained regarding the use of thresholds in a management context. We have shown that many of the changes observed when nutrients are added to coastal ecosystems are non-linear and demonstrate clearly defined thresholds. We have shown that it is important to reduce nutrient loading so as to not surpass those thresholds, because restoring the system will become even more expensive and take a longer time than expected. However, we have also shown that ecosystems have experienced a "shifting baseline," meaning that the system will no longer go back to the state it previously occupied because many things have changed such as overfishing and climate change.

Although coastal ecosystems are not going back to their original state after nutrient reductions, our research demonstrates that the systems would have been much worse off if nutrients had not been reduced. This information should provide valuable scientific knowledge for managers for the need to continue to reduce nutrients to improve the health of coastal ecosystems. The research carried out in Stream 3 will contribute therefore to the development of EU Policies that includes the concept of thresholds into management of coastal ecosystems.

2.1.3 Stream 4: Thresholds and drivers of contaminants

Stream 4 has developed and tested in the Thau Lagoon case study an integrated modelling approach for predicting the spatio-temporal distribution of contaminants in shallow coastal ecosystems (including bioaccumulation). This is a tool exploitable for analysing other case studies as well, and it is described in the section on publishable results below.

2.1.4 Stream 5: Definition of thresholds of key indicators of biodiversity and ecosystem function

Stream 5 has produced novel results on planktonic nutrient limitation, seagrass colonization depth, and responses of benthic animals to hypoxia. Although their nature is not exploitable in direct economical, industrial or technical sense, they have a decisive role of creating services through having direct applications to the monitoring and assessment of the state of the coastal environment, and therefore to sustainable management of coastal zones. The results therefore possess potential socio-economic impacts.

Some of the exploitable products are software tools openly published. Stream 5 developed a novel statistical modelling tool for classifying experimental results into generic nutrient limitation classes (partners UO, NIVA and SYKE), described in more detail in the section on publishable results below.

2.1.5 Stream 6: Integration and application of thresholds methodologies on case studies

The exploitable results of Stream 6 are mainly data, models and provision of statistical empirical relationships that will be further used and applied in follow-up studies. However, the progresses within Stream 6 have shown that data availability is one of the main important issues. Although great efforts have been undertaken to compile and structure data, there are still gaps in databases, especially regarding temporal and secondly spatial resolution. Further additional research should focus therefore on filling these gaps.

Within the generalisation case study a methodology how to classify coastal zones was developed by UU (D6.2.1/D6.2.1b). Since data availability was limited this methodology could only be applied for coastal zones within the Baltic area. Hence, maps could only be provided for this part of the European coastal areas. For the hot spot approach in the generalisation case study for all European coastal zones a database was needed. That's why we were working with the PSA-index. It appears promising to further classify all European coasts with the UU methodology.

The results and scenario runs from ERASME about the use of Nitrogen, Fertilisers and Plant Protection products in European Union over 2008-2025 are a promising basis for further collaboration. Not only for substances leading to ecosystem damages but also for substances leading to effects on human health (e.g. pesticides) are of great interest.

The approach of the general case study should be further used to explore possibilities for N and P load reduction on a European level.

2.1.6 Stream 7: Synthesis and integration

Following the key recommendation emerging from Stream 7 analysis of policy implications – i.e. to experiment participatory approaches of resilience management as an innovative approach to the WFD water planning tasks – a number of Thresholds partners have promoted and now are involved in the FP7 Coordination Action AWARE, starting on next 1 June 2009, and aiming to develop and test a new approach to enhance connectivity between research and policy making for sustainable development of water ecosystems.

Based on the body of knowledge accumulated in Thresholds, and on the participatory planning case studies that will be developed in the context of the new project AWARE, the partners involved aim to further develop the capability of supporting coastal water managers across Europe, and orienting them to implement resilience management and policy.

2.2 DISSEMINATION OF KNOWLEDGE

The dissemination of the knowledge produced by the Thresholds project was undertaken following a plan which included as main objectives:

1. To ensure Threshold's contribution to the scientific discussion and debate on thresholds
2. To focus the delivery of specific information to key actors in field of coastal and marine policy development in the EU
3. To contribute to a general understanding of the importance of thresholds among the public

This was to be achieved through producing targeted dissemination means and undertaking specific dissemination actions. The main focus in the project has been on producing scientific publications for academics. During its lifetime the project has delivered more than 100 peer reviewed publications and there are more than 20 submitted manuscripts to scientific journals. In addition THRESHOLDs has actively presented results and concepts in workshops, conferences and more informal events. There has also been publications aimed at professionals, policy makers and the public at large as the following table demonstrates.

Overview table:

Date	Type	Title and references	Type of audience	Countries addressed	Size of audience	Partner responsible/involved
28 April 2005	Seminar	"Marine Ecosystem Thresholds: Towards and Integrated Theoretical Framework for Valuation" Internal Seminar Series, Centre for Public Economics at the University of Bath.	Academics	UK	20	UBATH
April 2005	Web site	Project web site: http://www.thresholds-eu.org/	General public for the *public area.* Project partners for the *reserved area*	Potentially all Countries	Not specified	Responsible: ISIS Other partners involved: CSIC-IMEDEA, SYKE
June 2005	Conference	Time scale in nutrient fate: examples from Eastern Europe. In: Proceedings of International Workshop on " Where Do Fertilisers Go?	Scientific	EE, LA, LT, PL, CZ, DE, RU, MC, AL	50	NIVA
September 2005	Brochure	A brochure describing the project aims, contents and partnership.	General public, researchers, policy makers	Potentially all Countries. Distribution focused on EU countries	Not specified	Responsible: SYKE Other partners involved: CSIC-IMEDEA, JRC-IES, NERI, IER, ISIS, UBATH, UU
2-5 October 2005	Project meeting	SENSOR project – Thresholds Module (M3) internal meeting	Academics	Location: Malta	15	UBATH
24-29 October 2005	Conference Presentation	Markandya, A., Taylor, T., Longo, A. and D. Barton (2005) "Marine Ecosystem Thresholds: Towards and Integrated Theoretical Framework for Valuation". Presented to MEDCOAST	Academics	Location: Turkey. International Conference.	20	UBATH

Date	Type	Title and references	Type of audience	Countries addressed	Size of audience	Partner responsible/involved
		conference.				
October 2005	Publication: Conference Proceedings	Markandya, A., Taylor, T., Longo, A. and D. Barton (2005) "Marine Ecosystem Thresholds: Towards an Integrated Theoretical Framework for Valuation" pp127-138 in Ozhan, E (ed) Proceedings of the Seventh International Conference on the Mediterannean Coastal Environment, MEDCOAST 05. MEDCOAST, Middle East Technical University, Ankara, Turkey. Volume 1.	Academics			UBATH
December 2005	Publication	Stålnacke, P. and Behrendt, H. 2006. Nutrient levels in Eastern European rivers and its response to large-scale changes in emissions. Manuscript	Sc	EE, LA, LT, PL, CZ, DE, RU, MC, AL		NIVA
Continuous	Brochure	Distribution of brochure to mailing list and contacts	Academics, policy makers	Wide international	Not specified	Responsible: ISIS and all partners
13-14 March, 2006	Conference	European Environment Agency Directors: The Thresholds research project. Vienna.	Policy makers	EU Member States	40	SYKE (7)
7-11 May, 2006	Conference	SETAC Annual meeting 2006 (Jurado, E., Dachs, J, Meijer, S., Marinov, D. and Zaldivar J.M., Fate of Persistent Organic Pollutants in the water column: does internal cycling matters?)	Environmental toxicology scientists	EU	~500	CSIC-IIQAB/JRC-IES
7-11 May 06	Poster	S. Bopp and T. Lettieri, Biomarkers at Gene Expression Level in the Diatom Thalassiosira Pseudonana. SETAC Europe 16th Annual Meeting , The Hague (NL)	Scientists			JRC-IES (6)
5-6 June	Conference	First open NoMiracle Workshop: Thresholds and Policy.	Academics, chemical	EU Member	80	SYKE(7)

Date	Type	Title and references	Type of audience	Countries addressed	Size of audience	Partner responsible/involved
2006		Verbania, Italy	industry	States		
20-23 June 2006	Oral presentation	"Thresholds and management – Eutrophication and salinity" at Symposium on Research and Management of Eutrophication in Coastal Ecosystems (EUTRO) in Nyborg, Denmark, 20-23 June	Academics	International symposium with 210 participants from 22 countries	100	RC (16)
20-23 June 2006	International Conference	Dueri, S. and Zaldivar J.M. Effects of contaminants and nutrients on the dynamics of different food webs in marine ecosystems. EUTRO 2006, Denmark	Scientists		150 participants	JRC-IES (6)
20-23 June 2006	Oral presentation	Daniel J. Conley, Jacob Carstensen, Raquel Vaquer, Carlos M. Duarte. Eutrophication and hypoxia. Research and Management of Eutrophication in Coastal Ecosystems. EUTRO 2006, Nyborg, Denmark.		International symposium with 210 participants from 22 countries		NERI (5), CSIC-IMEDEA (1)
20-23 June 2006	Oral presentation	Krause-Jensen, D., Middelboe, A.L., Carstensen, J., Dahl, K. 2006. Spatial patterns of macroalgal abundance in relation to eutrophication. EUTRO 2006, Nyborg, Denmark.	Academics	International symposium with 210 participants from 22 countries	40	NERI (5)
20-23 June 2006	Abstract	Holmer M, Marbà N, Lamote M, Duarte CM (2006) Effect of *Caulerpa* sp. invasion on sediment quality in *Posidonia oceanica* meadows. EUTRO 2006, Nyborg, Denmark	Academics	International symposium with 210 participants from 22 countries	100	USD (8), CSIC-IMEDEA (1)

Date	Type	Title and references	Type of audience	Countries addressed	Size of audience	Partner responsible/involved
20-23 June 2006	Abstract	Valdemarsen T, Holmer M (2006). Biogeochemical indicators of environmental stress in sediments associated with marine fin-fish aquaculture. EUTRO 2006, Nyborg, Denmark	Academics	International symposium with 210 participants from 22 countries	100	USD (8)
August 2006	Report	Stålnacke et al. Nutrient response in rivers on changes in emissions	Scientific	Europe	150	NIVA (12)
August 2006	Report	Stålnacke et al. Spatial nutrient driving force and pressure relationships	Scientific	Europe and N.America	150	NIVA (12), UPMC (11), IER-USTUTT (3), TerrAquat (18)
10-16 September 2006	Abstract	Holmer M, Marbà N, Lamote M, Duarte CM (2006) Effect of *Caulerpa* sp. invasion on sediment quality in *Posidonia oceanica* meadows. International Seagrass Biology Workshop, Zanzibar, Tanzania				USD (8), CSIC-IMEDEA (1)
8 October 2006	Conference	Moncheva S., V. Doncheva,V. Alexandrova, 2006. Regime Shifts Of Phytoplankton Communities in the North-Western Black Sea – Implications For Assessment of The Ecosystem Ecological State". Instanbul (Turkey)	Academic, policy makers	Black Sea	200	IO-BAS (22)
10-11 October 2006	Conference	Science Meets Policy: EU-Presidency event: Key issues in policy dialogues. Helsinki	Policy makers, academics	EU Member States	50	SYKE (7)
28 October- 1 November 2006	Poster	S. Bopp and T. Lettieri, Gene Expression Analysis in the Marine Diatom Thalassiosira Pseudonana to Assess Water Quality. Marine Genomics 2006, Sorrento (I)	Scientists			JRC-IES (6)

Date	Type	Title and references	Type of audience	Countries addressed	Size of audience	Partner responsible/involved
14 November 2006	Oral keynote presentation	"Thresholds for Ecosystems and Society" at Congress: "Baltic Sea and European Marine Strategy – Linking Science and Policy", EU Presidency Congress, Helsinki.	Academics, policy makers	International congress, participants from 18 countries	300	SYKE (7)
13-15 November 2006	Full conference paper	Markandya et al (2006) "Valuation of Marine Ecosystem Threshold Effects: Theory and Practice in relation to Algal Bloom in the North Sea". Conference: *Baltic Sea and European Marine Strategy - Linking Science and Policy*	Academics, Policy Makers	Baltic Sea states		UBATH (17), ULB (14)
13-15 November 2006	Conference	Baltic Sea Conference, EU-Presidency event: Economic aspects of thresholds; Science contributing to policy. Helsinki	Policy Makers, Academics, Industry (environmental protection)	EU Member States, Russia, Canada	250	SYKE (7), UBATH (17)
January 2007	Radio interview	Interview on consequences of a winter storm för the nutrient and oxygen situation in the Baltic Sea. Willem Stolte for January 2007 for a local radio network "P4".	General public	Sweden		UNIK
22-24 January 2007	conference	Krause-Jensen, D., Nielsen, S.L., Carstensen, J., Christensen, P.B. & Rasmussen, M.B.: Combined effects of light and sediments on eelgrass depth limits. Poster presented at Thresholds of Environmental Sustainability, General Scientific Meeting, Helsinki, Finland	academics		80	NERI
23-25 January 2007	conference	Krause-Jensen, D., Nielsen, S.L., Carstensen, J., Christensen, P.B. & Rasmussen, M.B.: Lys og havbundens sammensætning styrer ålegræssets dybdegrænse. Poster presented at the 14th Danish Marine scientists meeting (Havforskermøde), Syddansk Universitet, Odense.	academics		160	NERI
February	Seminar	"Valuation of Marine Ecosystem Threshold Effects: Algal	Academics	UK	20	UBATH: Tim

Date	Type	Title and references	Type of audience	Countries addressed	Size of audience	Partner responsible/involved
2008		Bloom in the Black Sea Coast of Bulgaria" Internal Seminar Series, Department of Economics and International Development, University of Bath.				Taylor
12-13 March 2007	Full conference paper	Longo et al (2006) "Valuation of Marine Ecosystem Threshold Effects: Theory and Practice in relation to Algal Bloom in the North Sea" ENCORA thematic conference, Milano. Accepted full paper.	Academics	All EU		UBATH: Anil Markandya, Alberto Longo(*), Tim Taylor, Marta Petrucci ULB: Veronique Choquette and Walter Hecq (* now Queens University, Belfast)
28-31 March 07	Conference/oral presentation	Symposium GLOBEC-IMBER	Scientists			IMEDEA-CSIC
19-20 April 07	Internal meeting	S4 meeting	Partners		13	JRC-IES/IIQAB-CSIC/NERI
27 April 2007	Policy briefing	Discussion with DG environment on thresholds in the context of the WFD and MSD	Policy makers	EU-commission	10	SYKE, UBATH, CSIC, ULB, NIVA
04 May 2007	Oral presentation	Eutrophication of the Eastern Channel & Southern Bight of the North Sea by the Seine, Somme and Scheldt Rivers	General public, PhD students	France	100	UPMC

Date	Type	Title and references	Type of audience	Countries addressed	Size of audience	Partner responsible/involved
20-24 May 07	Conference/poster	Multiple stressors for the environment - present and future challenges and perspectives SETAC Europe 17th Annual Meeting (Society for Environmental Toxicology and Chemistry)	Scientists		1500	JRC-IES
28-30 May 07	Conference/oral presentation	Persistent Organic Pollutants in the environment: Global distribution, transport and effects	Scientists		60	JRC-IES/IIQAB-CSIC
29-30 May 07	DG-Environment/oral presentation	Expert Group on Environmental Quality Standards (EQS), Kick-off Meeting. Common Implementation Strategy of the WFD	Policy makers, Commission and Member States representatives	EU27	42	JRC-IES/Ifremer
27-30 June 2007	Full conference paper	Longo et al (2006) "Valuation of Marine Ecosystem Threshold Effects: Theory and Practice in relation to Algal Bloom in the North Sea" European Association of Environmental and Resource Economists Conference, Thessaloniki.	Academics	All EU		UBATH: Anil Markandya, Alberto Longo(*), Tim Taylor, Marta Petrucci ULB: Veronique Choquette and Walter Hecq (* now Queens University, Belfast)
14 July 2007	Presentation	Algal blooms in the Baltic Sea and eutrophication. Edna Granéli	Policy makers from Germany (Minister of agriculture and other policy makers from Mecklenburg-Vorpommern,	All countries around the Baltic Sea		UNIK

Date	Type	Title and references	Type of audience	Countries addressed	Size of audience	Partner responsible/involved
9-12 September 2007	Workshop	Methods for regime shift identification in ecological data	Threshold scientists		12 participants	NERI, UO, V
September 2007	Report	Kamburska L., K. Stefanova, 2007. Zooplankton diversity in the Western Black Sea: recent state and trends. State of the Black Sea Environment Report, Black Sea Commission, Istanbul (in press)	Academics, managers	Black Sea		IO-BAS
September 2007	Report	**Moncheva S,** 2007. On the recent changes in the Phytoplankton along the Bulgarian Black Sea Shelf . State of the Black Sea Environment Report- Black Sea Commission, Istanbul (in press)	Academics, managers	Black Sea		IO-BAS
10-14 October 07	Conference/Poster presentation	4th International Symposium on Environmental Pollution and its Impact on Life in the Mediterranean Region (MESAEP)	Scientists		300	JRC-IES/IIQAB-CSIC
25-26 October 2007	Presentation	Algal blooms: Eutrophication, overfishing, climate change – is there only one cause? Edna Granéli at the Royal Marine Environment seminar (County boards of Sweden present to the 60th birthday of the King of Sweden. Kalmar (in Swedish)	General public, policy makers, and others (King Carl XIV Gustav of Sweden)	All countries around the Baltic Sea		UNIK
October 2007	Conference	SOLAS (Surface Ocean Lower Atmosphere) summer school	Scientists		70	IIQAB-CSIC
October 2007	Report	Seminar "The Problem of Domestic waste-water treatment along the Northern bulgarian Black Sea coast" Phytoplankton blooms in relation to nutrient enrichment – management scenarios	Policy makers, Academics, NGOs, Stakeholders, Public	Bulgaria	50	IO-BAS

Date	Type	Title and references	Type of audience	Countries addressed	Size of audience	Partner responsible/involved
		S. Moncheva				
October 2007	Presentation	Chapman Conference on "Long Time-Series Observations in Coastal Ecosystems: Comparative Analyses of Phytoplankton Dynamics on Regional to Global Scales" Rovinji, Croatia Moncheva S., N. Slabakova, V. Doncheva, 2007. On the Recent Shifts in the Coastal Black Sea Phytoplankton - a Transient to an Ecosystem Recovery, or a Response to Changing Drivers	Academics	ALL	100	IO-BAS
27-30 November 07	Conference/oral presentation	6th European Conference on Ecological Modelling (ECEM07)	Scientists		450	JRC-IES/ULB/NERI
November 2007	Presentation	BENA Conference "Quality of life and Environment in the Frame of E.U. Sustainability", 15-17 Nov'2007, Belgrade, Serbia Implementation of WFD for the Black Sea Bulgarian coast – Phytoplankton biological quality element accepted to be published in **JEPE**	Academics Stakehoders	Balkan countries	150	IO-BAS
Nov. 13-14 2007	Internal meeting	To harmonize the work in Stream 2	Threshold scientists		9 participants	UU, UO, CSIC-IMEDEA, NERI, RC-IES-IMW
2007	Presentation	Thresholds of environmental sustainability in coastal marine ecoystems. Conley, D.J. and C.M. Duarte. Chesapeake Bay Scientific Advisory Board, MD, USA.	Managers and Scientists	U.S.A.		LU
2007	Poster presentation	Interaktioner mellem jern og sulfid i organisk berigede marine sedimenter. (Interactions between iron and sulfide in organic loaded marine sediments). Valdemarsen T., Holmer M.	Managers and scientists	Denmark	300	

Date	Type	Title and references	Type of audience	Countries addressed	Size of audience	Partner responsible/involved
2007	Presentation	Nutrient driven regime shifts in coastal lagoons: A 3D modelling approach. Zaldivar, J.M., Marinov, D., Somma, F., Bacelar, F. Hernandez-Garcia, E, Puillat-Felix, I. and Viaroli, P. 3rd European Conference on Lagoon research, Naples, Italy	Academics, Managers		~150	JRC, CSIC
2007	Presentation	A modeling approach to nutrient and temperature driven thresholds in shallow coastal ecosystems: competition between seagrass and macroalgae. Zaldivar, J.M., Bacelar, F. Dueri, S., Hernandez-Garcia, E. and Viaroli, P. 6th European Conference on Ecological Modelling, Trieste, Italy	Academics		~450	JRC, CSIC
2007	Peer reviewed publication	Krause-Jensen, D., Carstensen, J., Dahl, K., 2007. Total and opportunistic algal cover in relation to environmental variables. Marine Pollution Bulletin 55, pp. 114-125.	academic	International		NERI
2007	Peer reviewed publication	Carstensen, J. 2007. Statistical principles for ecological status classification of Water Framework Directive monitoring data. Marine Pollution Bulletin 55, pp. 3-15.	academic	International		NERI
2007	Peer reviewed publication	Carstensen, J., Henriksen, P., Heiskanen, A.-S., 2007. Summer algal blooms in shallow estuaries: Definition, mechanisms and link to eutrophication. Limnology and Oceanography 52, pp. 370-384.	academic	International		NERI, JRC
2007	Peer reviewed publication	Håkanson, L. and Khalili, M., 2007. How important are local nutrient emissions to eutrophication in coastal areas compared to fluxes from the outside sea? A case-study using data from the Himmerfjärden Bay in the Baltic Proper. Manuscript (submitted).	academic	International		UU

Date	Type	Title and references	Type of audience	Countries addressed	Size of audience	Partner responsible/involved
2007	Peer reviewed publication	Håkanson, L., 2007. Reconstruction of the eutrophication in the Gulf of Finland using a dynamic process-based mass-balance model. Manuscript (submitted).	academic	International		UU
2007	Peer reviewed publication	Håkanson, L. and Blenckner, T., 2007. A review on operational bioindicators for sustainable coastal management – criteria, motives and relationships. Ocean & Coastal Management, 51: 43-72. Håkanson, L., Bryhn, A.C., and Eklund, J.M., 2007. Modelling phosphorus and suspended particulate matter in Ringkobing Fjord to understand regime shifts. J. Marine Systems, 68: 65-90.	academic	International		UU
2007	Peer reviewed publication	Håkanson, L., Bryhn, A.C., Blenckner, T., 2007. Operational effect variables and functional coastal ecosystem classifications – a review on empirical models for aquatic systems along a salinity gradient. Int. Rev. Hydrobiol., 92: 326-357.	academic	International		UU
2007	Peer reviewed publication	Håkanson, L., Bryhn, A.C. and Hytteborn, J.A., 2007. On the issue of limiting nutrient and predictions of bluegreen algae in aquatic systems. Science of the Total Environment, 379: 89-108.	academic	International		UU
2007	Peer reviewed publication	Håkanson, L. and Eklund, J.M., 2007. A dynamic mass balance model for phosphorus fluxes and concentrations in coastal areas. Ecol Res., 22: 296-320.	academic	International		UU

Date	Type	Title and references	Type of audience	Countries addressed	Size of audience	Partner responsible/involved
2007	Peer reviewed publication	Håkanson, L., 2007. A data reduction exercise to detect threshold samples for regression models to predict key water variables. Int. Rev. Hydrobiol., 92: 84-97.	academic	International		UU
2007	Peer reviewed publication	Lancelot C., Gypens N., Billen G., Garnier J. and Roubeix V. 2007. Testing an integrated river-ocean mathematical tool for linking marine eutrophication to land use: The Phaeocystis-dominated Belgian coastal zone (Southern North Sea) over the past 50 years. J. Mar. Syst. 64(14): 216-228.	academic	International		ULB/UPMC
2007	Peer reviewed publication	Conley, D. J., Carstensen, J., Ærtebjerg, G., Christensen, P. B., Dalsgaard, T., Hansen, J. L. S., Josefson, A. (2007). Long-term changes and impacts of hypoxia in Danish coastal waters. Ecological Applications 17(5), pp. S165-S184.	Academics	International		LU, NERI
2007	Peer reviewed publication	Billen et al. Nutrient transfers through the Seine river continuum: mechanisms and long term trends. The Science of the Total Environment, 375: 8097	Academics	International	-	UPMC
2007	Peer reviewed publication	Billen et al. River basin nutrient delivery to the coastal sea: assessing its potential to sustain new production of non siliceous algae. Mar. Chem, 106: 148-160. doi: 10.1016/j.marchem.2006.12.017	Academics	International	-	UPMC
2007	Peer reviewed publication	Garnier et al. Production vs. Respiration in river systems: an indicator of a "good ecological status" evaluation. The Science of the Total Environment, 375 :110124	Academics	International	-	UPMC

Date	Type	Title and references	Type of audience	Countries addressed	Size of audience	Partner responsible/involved
2007	Peer reviewed publication	Modulation of nearshore blooms by growth rate and water renewal. (Peer-reviewed paper, published)	Academics	Spain		CSIC
January 16 2008	Oral presentation	Status of the development of thresholds and shifts in ecosystem structure, ISIS, Thresholds General Assembly 2009, Rome, IT, 16.1.2008.	Scientists	Thresholds participants	Ca. 30	NERI
January 16 2008	Oral presentation	Status of the development of thresholds and shifts in ecosystem structure, ISIS, Thresholds General Assembly 2009, Rome, IT, 16.1.2008.	Scientists	Thresholds participants	Ca. 30	NERI
January 17 2008	Oral presentation	Empirical relationships linking macrophytes to nutrient enrichment - a literature compilation, ISIS, Thresholds General Assembly 2008, Rome, IT, 17.1.2008.	Scientists	Thresholds participants	Ca. 30	NERI
February 2008	Seminar	"Valuation of Marine Ecosystem Threshold Effects: Algal Bloom in the Black Sea Coast of Bulgaria" Internal Seminar Series, Department of Economics and International Development, University of Bath.	Academics	UK	20	UBATH: Tim Taylor
05/02/2008	oral presentation	Assessment of N and P abatement measures on three coastal watersheds (Annual meeting of the PIREN research program)	General public, French stakeholders	France	200	UPMC
May 2008	Conference/oral presentation	S. Dueri, J. Castro-Jiménez, J.-M. Zaldívar Comenges. Using the partition approach to derive environmental quality standards (EQS) for persistent organic pollutants (POPs) in sediments: A review.	Scientist		2000	JRC
June 2008	Full conference paper	Taylor and Longo "Valuation of Marine Ecosystem Threshold Effects: Algal Bloom in the Black Sea Coast of Bulgaria"	Academics	All EU		UBATH: Tim Taylor and Alberto Longo (*)

Date	Type	Title and references	Type of audience	Countries addressed	Size of audience	Partner responsible/involved
		European Association of Environmental and Resource Economists Conference, Gothenberg. Submitted full paper.				(* now Queens University, Belfast)
June 2008	Full conference paper	Barton et al: "Willingness to pay for reducing algal blooms at beaches – a benefit transfer test of choice experiment data from Varna and Mallorca" European Association of Environmental and Resource Economists Conference, Gothenberg. Submitted full paper.	Academics	All EU		NIVA: David Barton UIB: Dolores Garcia UBATH: Tim Taylor and Alberto Longo (*) and Olvar Bergland (UMB) (* now Queens University, Belfast)
June 2008	Oral presentation	Nutrient modelling on European scale and their input to coastal zones	Phd- students at University of Stuttgart	Germany	15	USTUTT-IER
11.6.2008	Workshop Presentation	Hildén, M. The costs of environmental degradation – a comparative view. Workshop Baltic-Mediterranean, Marseille 10.-11.6. 2008	Academics	International	Audience 30	
23-26 June 2008	Scientific conference	Advances in Marine Ecosystem Modelling Research (AMEMR), Plymouth (UK). Oral presentation: Coupling the RIVERSTRALER model to the 3D-MIRO&CO model to assess the present-day and future evolution of coastal eutrophication in the eastern Channel and Southern North Sea.	Academic	ALL	250	ULB/UPCM

Date	Type	Title and references	Type of audience	Countries addressed	Size of audience	Partner responsible/involved
25.7.2008	Newspaper article	Hildén, M. 2008. Miten tehdä Suomesta merentutkimuksen edelläkävijä? (How Finland can become a forerunner in marine research, in Finnish) Pohjolan Sanomat 25.7.2008	General public	Finland	Size of edition: 22000	SYKE
20.08.08	Press release	'Les zones mortes: une côte belge plutôt épargnée'. Interview of V. Rousseau. Newspaper 'Le soir'	General public	Belgium		ULB
19.09.2008	Seminar	The pool rules - metacommunities control diversity in aquatic microbes (oral presentation; weekly seminar at the CEES, Biol. Institute, Univ. Oslo)	Scientific	Norway/International	30	NIVA, UO, SYKE
4.10. 2008	Newspaper aricle	Lyytimäki, J. Ympäristön tilan monet totuudet (The many thruths on the state of the environment, in Finnish) Hämeen Sanomat 4.10.2008: 2	General public	Finland	Size of edition: 30000	SYKE
06-09.10.2008	Round Table With the Black Sea Commissioners Conference	2nd Biannual and Black Sea SCENE EC Project Joint Conference, "Climate Change in the Black Sea - Hypothesis, Observations, Trends, Scenarios and Mitigation Strategy for the ecosystem" (BS-HOT'2008) 6-9 October, 2008, Sofia, Bulgaria	Academics Policy makers	Black Sea +EU countries		IO-BAS
06-09.10.2008	Round Table With the Black Sea Commissioners Conference	2nd Biannual and Black Sea SCENE EC Project Joint Conference, "Climate Change in the Black Sea - Hypothesis, Observations, Trends, Scenarios and Mitigation Strategy for the ecosystem" (BS-HOT'2008) 6-9 October, 2008, Sofia, Bulgaria	Academics Policy makers	Black Sea +EU countries		IO-BAS

Date	Type	Title and references	Type of audience	Countries addressed	Size of audience	Partner responsible/involved
16/10/2008	oral presentation	Modeling nutrient transfers from land to sea for present day and scenarios exploration: the Seine, Somme, and Scheldt Rivers case study. In 7th International Congress of Limnology-Oceanography	General public, French stakeholders	France	200	UPMC, ULB-ESA, ULB-CEESE
November 4 2008	Oral presentation	Ålegræs som indikator (In Danish; translated title: Eelgrass as an indicator). Seminar given at the annual meeting on the Danish national Monitoring programme for marine areas. http://www.dmu.dk/NR/rdonlyres/BC5A4C09-3A17-45C4-A7BD-3FB59BF000B1/0/Marintfagmødenovember2008program.pdf	Managers	Denmark	Ca. 50	NERI
09.12.2008, Brussels.	Seminar	Moncheva S., L. Kamburska, 2008. Disastrous invasion of the non-indigenous macrozooplankton species in the Black Sea – a lesson for scientists and policy makers. Marine Science Contribution to Regional Seas Strategies. Seminar on Marine Science Contribution to Regional Seas Strategies, 09.12.2008, Brussels.	Academics EC officials	EU		IO-BAS
09-11 Dec 2008	Conference/oral presentation	« 2012 objectif mer »: stratégie pour le milieu marin et enjeux pour la Haute mer	Scientist		300	JRC
09-11 Dec 2008	Conference/oral presentation	« 2012 objectif mer »: stratégie pour le milieu marin et enjeux pour la Haute mer	Scientist		300	CSIC-IIQAB
15.-18.12. 2008	Lectures and tutoring	Hildén, M. Three lectures related to the importance of thresholds in the management of seas + student tutoring. Training programme on regional ocean governance for Mediterranean and eastern European countries	Professionals and students	International	Audience 25	SYKE

Date	Type	Title and references	Type of audience	Countries addressed	Size of audience	Partner responsible/involved
		Towards A Holistic Maritime Policy Malta, 16 November – 19 December 2008.				
27.12. 2008	Newspaper article	Lyytimäki, J. Ilmastonmuutos tiivistää ajan kulun (Climate change accelerates time, in Finnish). Hämeen Sanomat 27.12.2008: 2	General public	Finland	Size of edition: 30000	SYKE
2008	Peer reviewed publication	Petersen JK, Hansen JW, Laursen MB, Clausen P, Carstensen J, Conley DJ. 2008. Regime shift in a coastal marine ecosystem. . Ecological Applications 18(2):497-510.	Academics	All		REC
2008	Peer reviewed publication	Regime shift in a coastal marine ecosystem	Academics	Many		Petersen JK, Carstensen J & Conley DJ
2008	Peer reviewed publication	Sedimentary iron inputs stimulate seagrass (Posidonia oceanica) population growth in carbonate sediments. Marbà N, Carlos M. Duarte, Marianne Holmer, Maria Ll. Calleja, Elvira Álvarez, Elena Díaz-Almela and Neus Garcias-Bonet. Estuarine, Coastal and Shelf Science. 76 710-713	Academics	All		IMEDEA
2008	Peer reviewed publication	Submarine groundwater discharge to the coastal environment of a Mediterranean island (Majorca, Spain): ecosystem and biogeochemical significance (Peer-.reviewed paper, under review)	Academics	Spain		CSIC
April 7-10, 2008 (To be submitted to an	Conference, Publication	Torbjörn Jansson, Martha Bakker, Baptiste Boitier, Pierre Le Mouël, David Verhoog, Hans Verkerk: 'Dynamic impacts of a financial reform of the CAP on regional land use, income and overall growth', paper presented at EAAE conference, Ghent, 26-29 August	academics	Europe		ERASME 3/19

Date	Type	Title and references	Type of audience	Countries addressed	Size of audience	Partner responsible/involved
agricultural journal)		2008.				
2008	Peer reviewed publication	Garnier et al. Organic matter dynamics and budgets in the maximum turbidity zone of the Seine Estuary (France). Estuarine, Coastal and Schelf Sciences, 77: 150-162. doi:10.1016/j.ecss.2007.09.019	-	-	-	UPMC
2009	Peer reviewed publication	Berrojalbiz et al. Polycyclic aromatic hydrocarbons in the Mediterranean seawater and plankton. Environ. Sci. Technol (submitted)	Scientist	International		CSIC-IIQAB, JRC-ISPRA
2009	Exhibition	Lyytimäki, J., Furman, E., Hildén, M.: Jumping the thresholds Exhibition to take place in autumn 2009, www-version will be published on the web	General public + art	Finland + www-version		SYKE
2009	Peer reviewed publication	Echeveste, P. J. Dachs, S. Agustí 2009. Size dependent toxicity thresholds of polycyclic aromatic hydrocarbons to natural and cultured phytoplankton populations. Environmental Pollution (submitted)	Scientist	International		CSIC-IMEDEA, CSIC-IIQAB
2009	Peer reviewed publication	Hildén, M. 2009. Time horizons in evaluating environmental policies. New Directions for Evaluation (in print)	Academics	International		SYKE
2009	Peer reviewed publication	Testing relationships between macroalgal cover and Secchi depth in the Baltic Sea. Krause-Jensen D. Carstensen J, Dahl K, Bäck S, Neuvonen S. Ecological Indicators, In press; available online at: http://dx.doi.org/10.1016/j.ecolind.2009.02.010.	Academics	All		NERI
2009	Peer reviewed publication	Castro-Jimenez et al. Occurrence and atmospheric deposition oPCDD/Fs in the Mediterranean Sea. Environ. Sci. Technol (submitted)	Scientist	International		JRC-ISPRA, CSIC-IIQAB.

Date	Type	Title and references	Type of audience	Countries addressed	Size of audience	Partner responsible/involved
2009	Peer reviewed publication	Lancelot C., Rousseau, V. and N. Gypens. Ecologically-based reference for Phaeocystis colonies in eutrophied Belgian coastal waters (Southern North Sea) based on field observations and ecological Belgian. J Sea Res (2008). doi.1016/j.seares.2008.05	Academic	ALL		ULB
2009	Peer reviewed publication	Stelmakh L.V., I.I.Babich, S. Tugrul, S. Moncheva and K. Stefanova, 2009. Phytoplankton Growth Rate and Zooplankton Grazing in the Western Part of the Black Sea in the Autumn Period. Oceanology, 2009, Vol. 49, No. 1, pp. 83–92. © Pleiades Publishing, Inc., ISSN 0001-4370.	Academics	Black Sea +EU countries		IO-BAS
2009	Peer reviewed publication	Andersen, T, Carstensen, J., Hernandez-Garcıa, E, Duarte, C. M. (2009) Ecological thresholds and regime shifts: approaches to identification. Trends in Ecology and Evolution 24: 49-57	academics	International		CSIC, NERI
2009	Peer reviewed publication	Berrojalbiz et al., ACCUMULATION AND CYCLING OF POLYCYCLIC AROMATIC HYDROCARBONS IN ZOOPLANKTON, Environmental Science & Technology 43, 2295-2301, 2009)	Scientist	International		CSIC-IIQAB
2009	Peer reviewed publication	Marinov, D. Dueri, S., Puillat, I., Carafa, R., Jurado, E., Berrojalbiz, N. Dachs, J. and Zaldivar, J.M., 2008. Integrated modeling of Polycyclic Aromatic Hydrocarbons (PAHs) in the marine ecosystem: Coupling of hydrodynamic, fate and transport, bioaccumulation and planktonic food web models. Marine Pollution Bulletin (submitted).	Academics	International		
2009	Peer reviewed publication	Bacelar, F. S., Dueri, S., Hernández-García, E. and Zaldívar, J.M. Joint effects of nutrients and contaminants on the dynamics of a food chain in marine ecosystems. Mathematical Biosciences (in press).	Academics	International		CSIC- JRC

Date	Type	Title and references	Type of audience	Countries addressed	Size of audience	Partner responsible/involved
2009	Peer reviewed publication	Zaldívar, J.M., Bacelar, F., Dueri, S. Marinov, D. Viaroli, P., Hernandez, E. A modeling approach to nutrient and temperature driven regime shifts in shallow coastal ecosystems: Competition between seagrass and macroalgae. Ecol. Model. (in press)	Academics	International		CSIC-JRC
2009	Peer reviewed publication	Giordani, G., Zaldívar J.M. and Viaroli, P., 2009. Simple tools for assessing water qualità and trophic status in transitional water ecosystems. Ecological Indicators (in press).	Academics	International		JRC
2009	Peer reviewed publication	Carstensen, J., Henriksen, P. (Subm.) Phytoplankton biomass response to nitrogen inputs: A method for WFD boundary setting applied to Danish coastal waters. Submitted for Hydrobiologia.	Academics	International		NERI
2009	Peer reviewed publication	Krause-Jensen, D., Carstensen, J., Dahl, K., Bäck, S., Neuvonen, S. (Subm.) Testing a macroalgal eutrophication model across the Baltic Sea. Submitted for Ecological Indicators.	Academics	International		NERI, SYKE
2009	Peer reviewed publication	Conley, D.J., Bonsdorff, E., Carstensen, J., Destouni, G., Gustafsson, B. G., Hanson, L.-A., Rabalais, N. N., Voss, M., Zillen, L. (In press) Hypoxia in the Baltic Sea: Is large-scale engineering the solution? Accepted for Environmental Science and Technology.	Academics	International		LU, NERI

Date	Type	Title and references	Type of audience	Countries addressed	Size of audience	Partner responsible/involved
2009	Peer reviewed publication	. Conley, D. J., Björck, S., Bonsdorff, E., Carstensen, J., Destouni, G., and others (in press). Critical Review: Hypoxia in the Baltic Sea. Accepted for Environmental Science and Technology.	Academics	International		LU, NERI
2009	Peer reviewed publication	Møller, J.K., Carstensen, J., Madsen, H., Andersen, T. (in press). Dynamic two state stochastic models for ecological regime shifts. Accepted for Environmetrics.	Academics	International		NERI, OU
2009	Peer reviewed publication	Conley, D. J., Carstensen, J., Vaquer, R., Duarte, C. M. (in press). Ecosystem thresholds with hypoxia. Accepted for Hydrobiologia.	Academics	International		NERI, CSIC
2009	Peer reviewed publication	Duarte, C. M., Conley, D. J., Carstensen, J., Sánchez-Camacho, M., 2009. Return to Neverland: Shifting baselines affect ecosystem restoration targets. Estuaries and Coasts 32, pp. 29-36.	Academics	International		CSIC, NERI, LU
2009	Peer reviewed publication	Andersen, T., Carstensen, J., Hernández-García, E., Duarte, C., 2009. Ecological Thresholds and Regime Shifts: approaches to identification. Trends in Ecology and Evolution 24, pp.49-57.	Academics	International		OU, NERI, CSIC
2009	Peer reviewed publication	Conley, D. J., Carstensen, J., Vaquer, R., Duarte, C. M. (in press). Ecosystem thresholds with hypoxia. Accepted for Hydrobiologia.	Academics	International		NERI, LU, CSIC

Date	Type	Title and references	Type of audience	Countries addressed	Size of audience	Partner responsible/involved
2009	Peer reviewed publication	Håkanson, L., 2009. Factors and criteria to quantify the bioproduction potential of coastal areas and presentation of a simple operational Index of Biological Value (IBV) for coastal management. Open Marine Biology Journal, 3: 6-15.	Academics	International		UU
2009	Peer reviewed publication	Dueri, S., Hjorth, M., Marinov, D., Dallhof, I. and Zaldivar, J.M., Modelling the combined effects of nutrients and pyrene on the plankton population: Validation using mesocosm experimental data and scenario analysis. Ecol. Model. (accepted)	Academics	International		UU, JRC, NERI
2009	Peer reviewed publication	Dueri, S., Hjorth, M., Marinov, D., Dallhof, I. and Zaldívar, J.M., 2009. Modelling the combined effects of nutrients and pyrene on the plankton population: Validation using mesocosm experimental data and scenario analysis. Ecol. Model. (accepted)	Scientist			JRC-IES/NERI
2009	Peer reviewed publication	Dueri, S., Marinov, D., Fiandrino, A., Tronczynski, J., Zaldivar, J.M. 2009, Implementation of a 3D coupled hydrodynamic and contaminant fate model for the PCDD/Fs in Thau lagoon (France): the importance of atmospheric sources of contamination. Estuaries and Coasts (submitted).	Scientist			JRC-IES/Ifremer
2009	Peer reviewed publication	Echeveste et al., ORGANIC POLLUTANTS: A LETHAL COCKTAIL TO OCEANIC PHYTOPLANKTON, Nature (submitted)	Scientist			CSIC-IIQAB
2009	Peer reviewed publication	Loos et al., Perfluorinated acids (PFOS and PFOA) in Mediterranean Sea water, Chemosphere (submitted)	Scientist			JRC-IES/CSIC-IIQAB

Date	Type	Title and references	Type of audience	Countries addressed	Size of audience	Partner responsible/involved
2009	Peer reviewed publication	Marinov, D. Dueri, S., Puillat, I., Carafa, R., Jurado, E., Berrojalbiz, N. Dachs, J. and Zaldívar, J.M., 2009. Integrated modeling of Polycyclic Aromatic Hydrocarbons (PAHs) in the marine ecosystem: Coupling of hydrodynamic, fate and transport, bioaccumulation and planktonic food web models. Marine Pollution Bulletin (submitted).	Scientist			JRC-IES/CSIC-IIQAB

2.3 PUBLISHABLE RESULTS

Section 2.3, like section 2.1, is not strictly applicable to the THRESHOLDS project. The results cannot be classified as "products" in a strict sense, having functional characteristics and marketable potentialities. However, as already outlined, there are a number of tools developed and tested in Thresholds that can be exploited now to support new case studies and analysis of complex river, coastal and marine ecosystems. These tools are briefly described below.

2.3.1 The CoastMab-model: an operational tool for sustainable coastal management

When coastal monitoring and science reveal that something must be done to avoid critical thresholds related to the structure and function of coastal ecosystems, the basic action is generally to reduce the inflow of a water pollutant to the given coastal area. The most frequent and general problem in this context concerns the reduction of the anthropogenic nutrient loading to estuaries, i.e., to develop a strategy to decrease the eutrophication of the given coastal system. In this context, there are some key aspects, which will be discussed in this section. The CoastMab-model developed within the Thresholds-project is a general tool to optimize remedial actions.

Nutrient reductions are ultimately related to political decisions. For a given coastal area, one can safely assume that it is practically impossible to remediate all human emissions. To create operational tools and approaches for a sustainable coastal management may be visualized as a bridge between "ecology" and "economics". Fundamental concepts for coastal management, such as effect-load-sensitivity analyses, the index of coastal area sensitivity to anthropogenic nutrient loading (eutrophication), questions concerning variations and uncertainties in nutrient concentrations and possibilities to detect thresholds, predictive power of models for eutrophication, "limiting nutrients" and different forms of nutrients, operational bioindicators and an "index of biological value" of coastal areas have been developed within the Thresholds-project. Several case-studies have been discussed in the project using the process-based mass-balance model (CoastMab) for nutrients.

The Thresholds-project has demonstrated the importance to apply of a set of practically useful, operational bioindicators, for coastal management. It has been shown that such bioindicators must fulfill key criteria for being considered operational. Such bioindicators should be measurable, interpretable and predictable, relevant for the ecosystem function and internationally applicable. The following five operational bioindicators are complementary and characterize different aspects of water quality in coastal areas:

Chlorophyll-a:	phytoplankton biomass and production
Concentration of cyanobacteria	harmful algal blooms
Secchi depth:	depth of the photic zone; depth of macrophyte and benthic algal growth
Deep water oxygen saturation:	benthic fauna; anoxic sediments; diffusion of phosphorus from sediments to water
Macrophyte cover:	fish habitat and coastal fish production; the "biological value" of the coastal zone

Different abiotic factors (nutrient concentrations, salinity, temperature, coastal morphometry and water exchange) influence the selected bioindicators in a logical and predictable manner and such algorithms are incorporated in the CoastMab-model. Note that one would generally need a set of operational bioindicators to get an adequate framework to analyse changes in coastal ecosystem function and structure related to eutrophication, since one bioindicator cannot normally cover all relevant aspects. However, if asked if there is one candidate for a general operational bioindicator, one can argue that the Secchi depth, as a standard indicator of water clarity, would be a favorite for that role.

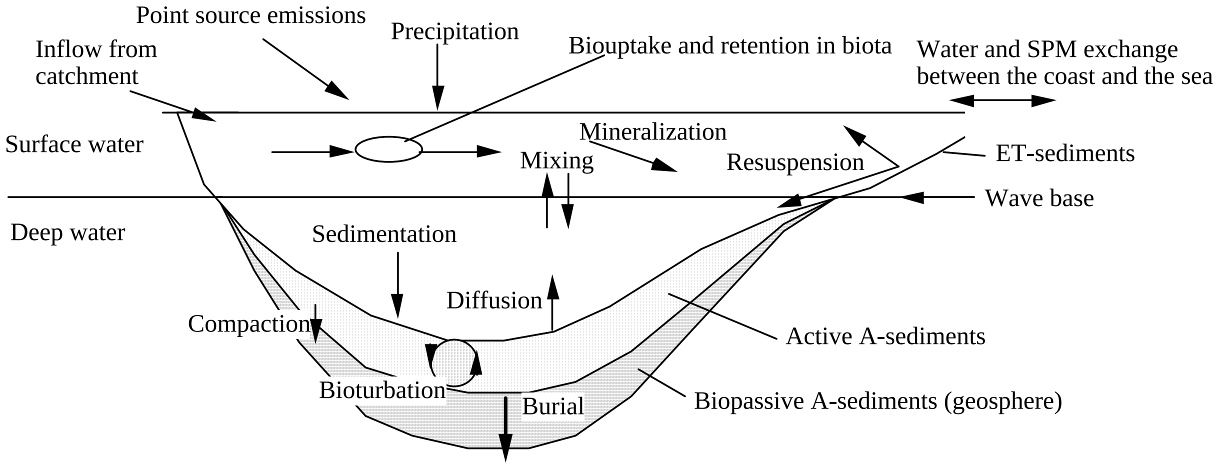
Within the Thresholds-project, we have discussed a functional classification approach for coastal areas, which is meant for coastal management and science. A morphometric classification system has been presented and examples of the practical use of the system have been given both at the European and at regional and local scales. General maps of several environmental variables have been given for as large parts of the European coastal zone as possible (restricted only by the data accessibility).

There are at least four basic criteria by which ecosystem models can be critically evaluated:

- By the predictive power revealed by validations.
- By the relevance of the target y-variable in disclosing fundamental ecosystem structures, functional aspects of aquatic ecosystems and threshold values related to operationally applied guidelines in water management.
- By the applicability and generality of the model, i.e., by the width of the model domain, and
- By the accessibility of the driving variables needed to make simulations.

Evidently, there exist many models for marine systems. At a first glance, such models may look the same, but there can also be fundamental differences between seemingly similar models because the basic structures, the equations and the model constants may be different. The CoastMab-model is new and no other models use the same sedimentological criteria as the CoastMab-model to define fundamental model structures, e.g., the surface-water compartment, the deep-water compartment, the sediment compartment for ET-areas (erosion and transport areas for cohesive fine material; where there is resuspension) and the accumulation-area compartment (where there is no wind/wave-induced resuspension of fine sediments). This also means that key transport processes (seee fig. x), such as sedimentation, resuspension, mixing, mineralization and outflow, are quantified differently in this modeling approach compared to most other models. All approaches to quantify these transport processes cannot be best or most relevant from a mechanistic point of view. Such a ranking of models cannot be done by arguments, only from critical validations using reliable empirical data from a wide domain of systems. No dynamic models that provide seasonal variations for variables such as phosphorus, suspended particulate matter and salinity based on other structures have been validated over such wide domains (i.e., for so many different coastal areas in terms of size, depth conditions, salinity ranges and nutrient loading) and given results even close to what has been reported for the CoastMab-model.

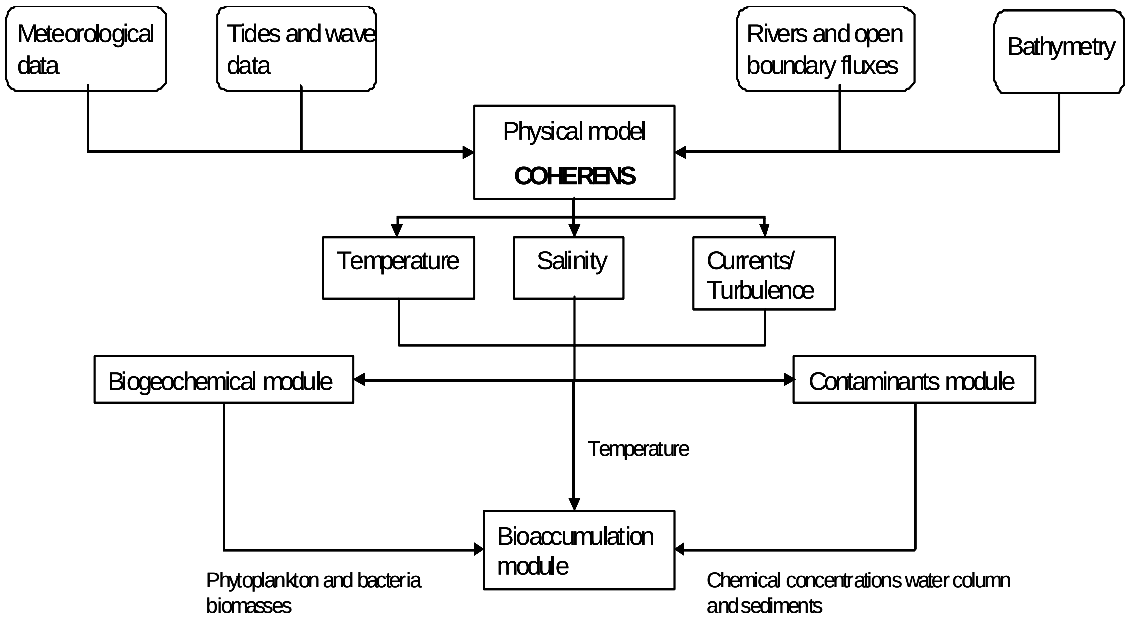
Figure 38 - An outline of transport processes and the structure of the dynamic coastal model (CoastMab)



2.3.2 Integrated modelling approach for predicting spatio-temporal distribution of contaminants in shallow coastal ecosystems

Figure 39 shows the integrated modelling approach for predicting the spatio-temporal distribution of contaminants in shallow coastal ecosystems (including bioaccumulation) that has been developed in Thresholds. The model uses, as a framework, the hydrodynamic model COHERENS (open source developed in several European projects). The model needs input data such as bathymetry, watershed inputs, exchanges with the open Sea and meteorological and oceanographic forcing (tides and waves). COHERES provides temperature, salinity and currents for the biogeochemical module of the coastal ecosystem and the contaminant fate module. The biogeochemical module produces simulated data on nutrient cycles (in water column and in sediments), oxygen, organic matter and biota, including phytoplankton, zooplankton, bacteria, and shellfish (for bioaccumulation), whereas the contaminant module gives concentration of contaminants in the water column and sediments. These simulated results from the hydrodynamics, the biogeochemical and the fate modules are used as input data for the bioaccumulation model (Figure 39).

Figure 39 - Integrated modelling approach using COHERENS.



The model has been employed in the Thau lagoon case study for analysing spatio-temporal distribution and the main sources of contamination in the lagoon. In addition a 1D water column version has been employed to simulate the fate of PCBs in the Adriatic Sea, the fate of PAHs in the Aegean Sea and the mesocosm experiments carried out at NERI.

2.3.3 Software tool for performing statistical nutrient limitation classification

Stream 5 developed a novel method for statistical analysis of bioassay experiments with natural plankton communities (Deliverable 5.2.3; Andersen et al. 2007, with multimedia appendices). It represents a statistical model selection procedure which implicitly classifies a factorial experiment response into a small number of biologically interpretable limitation classes without the need for arbitrary and heuristic decision rules.

The procedure allows unsupervised classification of the type of nutrient limitation in factorial experiments with 2 limiting nutrients, based on objective selection between 7 generic limitation patterns with direct biological interpretation, using the Akaike Information Criterion (AIC) which balances the concerns of model fit and model robustness.

Nutrient limitation is a generically non-linear process: limitation by essential resources is often found to be better described by a threshold model with abrupt switches at critical transition points. The novel method uses inference based on model selection rather than the hypothesis testing approach of classical statistics. As such, it follows a general trend in modern statistics. A main advantage of the method is that it is completely self-contained, in the sense that it bases decisions only on information contained in the data themselves. Thus it avoids the introduction of external, ad hoc-based decision rules, as well as the potential pitfalls of multiple comparisons: there are many ways of doing multiple comparisons, and most of them are too optimistic and often mutually inconsistent.

The method is implemented as **software for performing the statistical nutrient limitation classification procedure**, and it is published (open access) in *Limnology & Oceanography: Methods* (Andersen at al. 2007), with 2 multimedia appendices, containing modifiable source code and a ready to run software application. The modifiable source code (Multimedia Appendix 1) requires access to and some familiarity with Matlab (http://www.mathworks.com), whereas a stand-alone application was developed (Multimedia Appendix 2) in the form of a MS Excel plug-in for users who do not want to struggle with Matlab. The application is made from Matlab code using the Matlab Excel Builder from Mathworks, inc., which means that it can be distributed freely, without any need for having Matlab installed.

2.3.4 Coupled models describing nutrient-driven eutrophication processes in the river-sea continuum

RIVERSTRAHLER (Billen et al., 1994; Garnier et al., 2002) and MIRO (Lancelot et al., 2005; Lancelot et al., 2007) are two deterministic biogeochemical models describing eutrophication processes and nutrient transformations in the river system and the *Phaeocystis*-dominated coastal waters respectively. These models result of a coupling between a hydrological/hydrodynamic model and an ecological model. The latter (called RIVE or MIRO) is based on similar chemical and biological principles making relevant and easy their coupling. A first coupling between RIVERSTRAHLER and MIRO was initially performed at the scale of the Seine & Scheldt river basins and eastern Channel & southern Bight of the North Sea and run over the last 50 years (Lancelot et al., 2006). This preliminary coupling had several limits that bring uncertainties on the model outputs, which can however be solved by enlarging the coupled mathematical tool in the upstream and downstream direction. In the frame work of the Thresholds programme, we used the newly developed Seneque software that allows the user to derive all of the input files required for running the Riverstrahler model from a general GIS database covering the 3 S watersheds (Seine, Somme and Scheldt), and this for any portion of the drainage area, represented as a particular structure of basins and branches defined by the user according to the spatial resolution required for the user's application (Ruelland, 2004; Ruelland et al., 2007). Assembling a suitable GIS database is thus the key to running this generic software. Once implemented, the comparison of the Seneque/ Riverstrahler simulations with the observations (measurements of the variables) represents a validation of the model, e.g. its capability to describe the observed trends of discharge and nutrient concentrations at the outlet of the river systems (Billen et al., 2001, 2005). This coupling between Seneque/ Riverstrahler and MIRO models has been made possible because of a high similarity between their structure and parameterization were discussed and found.

More in detail, the Riverstrahler model (Billen et al., 1994; Garnier et al., 1995; 2002; Billen and Garnier, 2000; Garnier and Billen, 2002) describes the drainage network of any river system as a combination of basins, represented as a regular scheme of confluence of tributaries of increasing stream order, each characterized by mean morphologic properties, connected to branches, represented with a higher spatial resolution. The advantage of this representation of the drainage network is that it takes into account, with reasonable calculation time, both the processes occurring in small first orders (i.e., headwater streams) and those occurring in large tributaries. The water flows in the hydrographical network are calculated from the specific discharges generated within the watershed of the different sub-basins and branches considered. Specific discharges are calculated from rainfall and potential evapotranspiration by a simple two-compartment rainfall-discharge model that distinguishes two components: surface, or sub-root (hypodermic) runoff, and groundwater, base flow.

The essence of the model is therefore to couple these water flows that are routed through the defined structure of basins and branches with a model describing biological, microbiological, and physicochemical processes that occur within the water bodies. The module representing the kinetics of the processes is known as the Rive Model. The state variables comprise nutrients, oxygen, suspended matter, dissolved and particulate non-living organic carbon, and algal, bacterial, and zooplanktonic biomasses. Most processes important in the transformation, elimination, and/or immobilization of nutrients during their transfer within the network of rivers and streams are explicitly calculated, including algal primary production, aerobic and anaerobic organic matter degradation by planktonic as well as benthic bacteria with coupled oxidant consumption and nutrient remineralization, nitrification and denitrification, and phosphate reversible adsorption onto suspended matter and subsequent sedimentation. Garnier et al. (2002) provides a detailed description of the Rive Model and of the physiological parameters used. Besides morphological and climatic constraints, the Riverstrahler takes into account diffuse and point sources of nutrients from land-based anthropogenic sources. Diffuse sources of nutrients through surface and groundwater respectively are assigned a constant concentration for all nutrients. Point sources, which are typically wastewater discharges, must be specified by stream-order for the basins and at their exact location for the branches.

MIRO is a also a mechanistic biogeochemical model describing, N, P and Si cycling through aggregated components of the planktonic and benthic realms of Phaeocystis dominated ecosystem (Lancelot et al., 2005; Lancelot et al., 2007). Its structure includes thirty-eight state variables assembled in four modules describing the dynamics of phytoplankton (diatoms, nanoflagellates and Phaeocystis), zooplankton (copepods and microzooplankton), dissolved and particulate organic matter (each with two classes of biodegradability) degradation and nutrients (NO3, NH4, PO4 and Si(OH)4) regeneration by bacteria in the water column and the sediment. Equations and parameters were formulated based on current knowledge on the kinetics and the factors controlling the main auto- and heterotrophic processes involved in the functioning of the coastal marine ecosystem. The MIRO model is implemented in a multi-box frame delineated on the basis of the hydrological regime and river inputs. In order to take into account the cumulated nutrient enrichment of Atlantic waters by the Seine, Somme and Scheldt rivers, successive boxes, assumed to be homogeneous, have been chosen from the Seine Bight to the BCZ. Each box has its own morphological characteristics (see Lancelot et al., 2005) and is treated as an open system, receiving waters from the upward adjacent box and exporting water to the downward box. MIRO was first calibrated for 1989–1999 climatic conditions of river loads, global solar radiation and temperature calculated from available data and its prediction capability was demonstrated by its ability to reproduce the SW–NE nutrient enrichment gradient observed from the Western Channel to the Belgian Coastal Zone as well as the mean seasonal nutrient and ecological features recorded in the central BCZ during the last decade (Lancelot et al., 2005).

In the framework of the Thresholds programme, the coupled models were validated for a reference year (2000), and for two other hydrological years 1996 and 2001, representing respectively a dry and a wet situation (Thieu et al., 2009). Validated, the models – in the spatially implemented version of the watershed model- Seneque/Riversthraler – offered then an optimized tool to explicitly assess the impact of any change in human activity and to investigate management scenarios for recovering well balanced nutrient deliveries along the French and Belgian coastal zones (Thieu et al., submitted; Lancelot et al., in prep.).

2.3.5 Pan-European mapping of critical coastal zones (the "hotspot" approach)

In the generalisation case study different approaches have been developed to better estimate nutrient emissions and loads to coastal zones and to identify hotspots, i.e. to show coastal zones where negative environmental impacts are highly possible. The **hotspot approach** presents an initial approach applied European-wide which enables to get a rough overview where action is needed and where further examinations should take place, especially regarding regional specific conditions (e.g. precipitation).

Therein, two information layers, coastal zones and their sensitivity to eutrophication at the one hand and emissions/derived P and N loads from the watersheds at the other hand are combined.

As main emission sectors point sources (i.e. waste water treatment plants) and agriculture (distinguishing between nutrient input from livestock farming and arable farming) were defined. Since data availability is limited, a methodology was developed to compile European wide data for emissions from different sectors. Hence, a database was developed within the generalisation case study for a number of parameters for each of the approximately 35000 watersheds. A powerful tool for deriving the needed spatial data is a Geographic Information System (GIS) which offers besides data management also data analysis, calculations and presentations.

As important base layer, the CCM2 model[10] was used. It defines all catchments adjacent to the coastal zones which are presented as polygons. Our calculations were performed for approximately 35000 single catchments. Each catchment is considered as a simple box model, for which nutrient input, potential denitrification rates as well as derived nitrogen (N) and phosphorous (P) loads to coastal zones were calculated. Data about population density, land use classes, livestock density as well as information about sewage systems etc. were important input data. For deriving N and P loads in rivers empirical relationships developed in a previous stage of the project were tested[11]. Since these relationships seem to be valid only for larger catchments ("nutrient spatial paradox") a methodology for small catchments and a qualitative assessment matrix were developed.

The coastal part of this case study is examined by using the emis-tool[12] developed by JRC which indicates the physical sensitivity to eutrophication (PSA-index). It represents the coastal waters, whereas the derived results from the generalisation case study represent the land area. A linking of the PSA-index layer together with the derived single results from the watersheds is therefore particularly suited because the PSA index is independent from chemical values/concentrations data. The information about this index is presented in map format and is presented together with the derived results for the single watersheds within GIS.

A combination of both – the coastal part and the different emissions sources and derived P and N loads – can be put together in the hotspot approach. A hotspot possesses a low resistance to eutrophication (= PSA index "near" 1) and potentially high nutrient loads due to high emissions within the examined sector. The hotspot approach of the generalisation case study therefore shows in which coastal zones negative environmental impacts are highly possible and identifies the driver – an important basis for pointing out where action is needed and further more detailed studies with higher spatial and temporal resolved input data should be conducted.

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[10] CCM River and Catchment Database, © European Commission - JRC, 2007

http://agrienv.jrc.it/activities/catchments/; 23.06.2008

[11] Stålnacke, Per & Pengerud, Annelene et al. (2008): Nutrient driver and pressure relationship. THRESHOLDS project, FP6, Deliverable D6.2.5 - Project no: 003933.

[12] Emis tool: http://emis.jrc.ec.europa.eu/4_1_gismap.php