

# SIXTH FRAMEWORK PROGRAMME



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## **THRESHOLDS** **Thresholds of Environmental Sustainability** **INTEGRATED PROJECT**

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<p><b>Stream 1 – D1.2</b> <b><i>Thresholds and Marine Ecosystems – Application of Theoretical Framework of Valuation</i></b></p>
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# 1. Introduction

From a theoretical perspective thresholds create impacts that require special treatment when valuing externalities (Markandya et al, 2005). If a particular activity creates an environmental pressure such that it changes the ecological regime, there will be a discontinuity in the valuation function. (Arrow *et al*, 1995). These effects arise when there is a discontinuity:

- i. In the activity-environmental pressure relationship
- ii. In the pressure-ambient state relationship.
- iii. In the ambient state-valuation relationship

In a previous paper, a general framework was presented to assess the impacts of thresholds through environmental valuation (Markandya et al, 2005). The framework was based around a four-quadrant diagram illustrating the different interlinkages between the above relationships – with environmental values or damages associated with different levels of activity making up the fourth quadrant. Key issues of hysteresis and uncertainty were included in this framework.

In this paper, the more general framework is developed for different ecosystem impacts identified in the FP6 Thresholds project. In particular, the impacts of nutrients and contaminants on coastal systems are examined. The aim of this paper is not to arrive at specific values for the various ecosystem impacts, but to provide a framework for future valuation work within the Thresholds project. As such, the focus is rather more on bringing together in general terms the linkages identified above – rather than specifying in exact terms the levels of thresholds or the values per se associated with threshold effects.

The paper is structured as follows. First, a brief introduction to the overall framework is made – drawing heavily on Markandya et al (2005). The impacts or industries under investigation are then identified and the linkages between them are then presented within the systematic framework. Finally, some conclusions are drawn as to areas for further work and for the implementation of this framework in detailed case studies later in the THRESHOLDS project.

## 2. Overview of Theoretical Framework

The theoretical framework applied in this paper was presented in Markandya et al (2005). This section summarises the framework developed in that paper as an introduction to more detail case studies that apply this framework to detailed examples arising from the THRESHOLDS project in marine ecosystems.

### 2.1. Taxonomy of nonlinearities in the analysis of coastal ecosystems

From a theoretical perspective thresholds create impacts that require special treatment when valuing externalities. Put simply, if a particular activity creates an environmental pressure such that it changes the ecological regime, there will be a discontinuity in the valuation function. (Arrow *et al*, 1995). The figure below shows how these effects arise when there is a discontinuity:

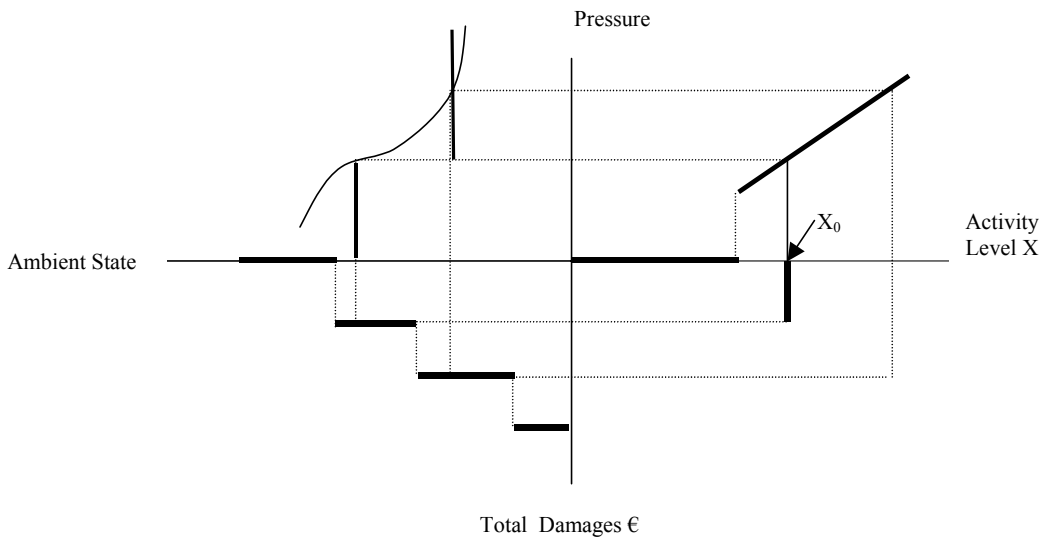
- i. In the activity-environmental pressure relationship
- ii. In the pressure-ambient state relationship.
- iii. In the ambient state-valuation relationship<sup>1</sup>

The figure below shows multiple thresholds, ie in the extreme case where there are thresholds in all the relationships shown above. For a more detailed account of the construction the reader is directed to Markandya et al (2005). In the case shown below the inter-relationship between the threshold effects is key to the valuation – if, as shown by the bold lines in the top left quadrant, there is a step-type change in the ambient environment resulting from a change in pressure and this does not then deteriorate further with increased pressure then such a step change dominates the other changes in terms of the valuation and would be the only threshold-effect of interest to the policy maker. In reality, multiple step-functions may exist or there may be other complexities in moving from one state of nature to another (eg points of no return or hysteresis). For example, a sigmoid type pressure-state relationship would mean that other thresholds would also take effect – and this is shown by the curved line in the top left quadrant.

The framework also allows for the treatment of two key elements that arise when considering thresholds in marine ecosystems – those of uncertainty and hysteresis.

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<sup>1</sup> With three possibilities there are in fact 7 combinations of discontinuities to consider. Discontinuous functions and valuation functions are shown in bold



**Figure 2.1: Valuation in the presence of multiple discontinuities**

## 2.2. Treatment of Uncertainty

A number of uncertainties exist in the analysis. For example, we may be uncertain as to the exact level of the threshold of nutrient flow (or type of nutrient) that may lead to the growth of algal blooms. The marine ecosystem is a complex system, with a number of exogenous factors - such as climate - influencing the state of nature at any one time.

Uncertainty can be considered through introducing stochastic elements into the assessment framework developed in this section. Introducing probabilities would lead to the consideration of expected values of different activity levels and associated environmental impacts. If, for example, one is uncertain as to the pressure that will lead to a change in the ambient state – but think that it lies between certain pressure levels then one may define the pollution loading as a distribution function rather than a deterministic value. The joint probability distribution of the outcome of interest (e.g willingness to pay for the abatement of impact for a particular activity ) can then be quantified using Monte Carlo simulation of the distributions involved. Bayesian belief network models may be used to update such probability distributions as new observations become available, demonstrating the value of information in reducing uncertainty. Of course, this gets all the more complex as one adds additional uncertainties.

## 2.3. Hysteresis and Discounting

Marine ecosystems are often characterised by a degree of hysteresis – i.e. there may be significant time lags between removing the pressure and a return to the original state of nature. The rate of time preference is normally reflected through the use of discounting. Hence, we would take the net present value of the project inputs and outputs across time. Hysteresis may also increase the difference between compensating and equivalent variation welfare measures of nutrient abatement policies on either side of the threshold (e.g. a survey of willingness to pay to avoid future nutrient loading should produce lower values than willingness to pay to reduce existing nutrient loads once the threshold has

been crossed if respondents are aware of hysteresis in the system but still willing to deal with the problem).

The use of discounting in this context also throws up some interesting questions in terms of policy applications that may mirror the debate in the climate change literature on the discounting of longer term impacts. It implies a limited “policy-relevance” of restoring ecosystems to their previous state in the case of a threshold that exhibits hysteresis. This may lead some to suggest that such longer term benefits of ecosystem restoration should be considered differently to normal project impacts – e.g. through use of a different discount rate or a declining discount rate over time to promote sustainability (see eg HM Treasury Green Book which proposes this for climate change projects).

It should be noted that the framework presented in this paper is essentially static. It is clear from analysis of the scientific literature that a more dynamic framework may be needed, and here we deal with dynamic aspects in an ad-hoc manner so that they are not ignored. Further work may include the development of a dynamic model to link emissions to impacts – which will emerge from case studies to be developed as part of the THRESHOLDS project.

We now present case studies of the application of this methodology for four main impact categories:

- harmful algal blooms;
- foodweb disruption and jellyfish abundance;
- anoxia; and
- *Posidonia oceanica* decline.

Finally an attempt at drawing together different pressures, impacts and economic values is presented for one of the case studies to be conducted in the THRESHOLDS project, that of fish farming.

## 3. Case Studies

### 3.1. Valuation of regime shifts in ecosystems: Ringkjoebing Fjord

Changes in nutrient loading or contaminants can lead to an ecosystem being susceptible to a regime shift. Such regime shifts are, by nature, complex and valuation is also complicated. To assess the total economic impact of a regime shift it is necessary to estimate the Total Economic Value of the given ecosystem under both regimes.

An example is given in the THRESHOLDS project by the Ringkjoebing Fjord case study in Denmark. Here, a change in salinity caused a dramatic shift in regime with a heavily eutrophic water body with a high level of organic matter becoming clear. This shift was caused by a rapid increase in the population of clams in the system. The clearing of the water in term had impacts on the benthic vegetation of the Fjord and on bird and fish populations.

The difficulty in assessing these impacts in economic terms are clear. There are positive impacts for recreational walkers and local residents in having clear water, but negative impacts in terms of the reduction in bird and fish populations. A full assessment of these values will be required in later stages of the THRESHOLDS project. In addition, the damages may not be permanent – there is some evidence that the benthic system is recovering and that bird populations may return to the pre-regime shift levels.

A cost-benefit analysis of this change in salinity would have to consider the dynamic aspects – noting the following:

1. Initially the regime shift leads to a decline in benthic flora leading to a reduction in bird numbers. This has a negative impact on the total economic value of the system;
2. The improved clarity of the water affects recreational enjoyment, leading to higher benefits being associated with trips to the site and potentially more trips to the site. A link between secchi depth and valuation of bankside recreation has been shown in the literature;
3. The improved clarity of the water increases the value of houses around the fjord;
4. The increased salinity in the fjord reduces the quantity of fish in the lagoon and reduces recreational angling pleasure and potentially affects the use of the lagoon by fishermen;
5. Long term recovery of the system, with benthic flora returning and return of bird and fish stocks, with a higher overall Total Economic Value that at the beginning as the water clarity remains high.

We now examine one particular shift in ecosystems that may have significant economic impacts – that of increased abundance of jellyfish.

## 3.2. Valuing Food Web Disruption: Gelatinous Zooplankton

### 3.2.1. Linking Activity to Emissions

The abundance of jellyfish in an ecosystem is an important factor in determining the level of ecosystem service provided by that system. Here, an overview of the causal drivers and the consequential values of damages is presented. Gel abundance is one of the factors being investigated in the THRESHOLDS project, mainly through analysis of food-webs and nutrient impacts on these. Outbreaks of gelatinous zooplankton have been linked to food web disruption, which may be linked to increased nutrient loading from land-based sources.

### 3.2.2. Linking Emissions to Environmental Quality

The linkage between jellyfish abundance and emission is complex. A number of causes have been identified, including:

- Eutrophication caused by agricultural, industrial and urban activities (Boero, 2001 and Mutlu, 2001);
- Invasion of species through transfer in ballast water (Mutlu, 2001);
- overfishing leading to a gap in the food web;
- Hypoxia, caused by eutrophication, leading to declines in populations of pelagic species (eg anchovy, horse mackerel) (Mutlu, 2001); and
- Salinity increases leading to a wider geographical coverage of saline-sensitive species (Harbison, 2001);

In the Black Sea, *M. leidyi* increased in abundance rapidly towards the end of the 1990s, with significant impacts on the food web. However, in recent years another ctenophore (*Beroe ovata sensu*) has been introduced. This is a predator of the *M. leidyi* and reductions in populations have been observed (Harbison, 2001). This has been linked to an increase in fish eggs and larva and planktivorous fish have also increased in population (Shiganova, 2001).

This may suggest that the ecosystem in the Black Sea is moving towards another steady state – with *M. leidyi*, *Beroe ovata* and fish stocks co-existing to a greater extent.

### 3.2.3. Linking Environmental Quality to Valuation

Linking gel populations to values of the environment is complex. It may be suggested that a mixed ecosystem is likely to be valued higher than a gel-dominated system, because of the anthropogenic benefits of improved recreation and fisheries. However, hysteresis is present in the system – as artisanal skills and fisheries will continue to be impacted through the loss of a skilled workforce.

The Millennium Ecosystem Assessment highlighted the impacts that the introduction of *Mnemiopsis leidyi* had caused in the Black Sea in terms of the rapid loss of 26 major fisheries species and its links to continued growth of the oxygen-deprived “dead” zone (MEA, Ecosystems and Human Well Being – Biodiversity Synthesis). Knowler and Barbier (2000) estimated the losses to anchovy fisheries in the Black Sea of the introduction of the comb-jellyfish at \$17 million annually.

The effects of the invasion of *M. leidyi* on fish and other species are extensive. Causation may be linked to other negative environmental attributes that coincided with the *M. leidyi* increase, but the following have been associated particularly with the invasion of *M. leidyi*:

- reduction in species diversity of zooplankton and ichthyoplankton (Shiganova et al, 1998, cited in Shiganova, 2001);
- decline in stocks of zooplanktivorous fish (anchovy, horse mackerel, sprat) which is associated with food competition and predation of fish eggs (Shiganova, 2001). Boero and Briand (2001) suggest that mortality of larvae and juveniles is possible but that it is hard to link this to specific causes. They highlight the fact that it is relatively simple to quantify the impacts when effects are catastrophic, but less in cases where causes are mixed. This calls for integrated modelling of ecosystem processes, which is a key part of the current THRESHOLDS project; and
- Fisheries have been impacted by net clogging and damage to fishing equipment. The closure of fishing grounds results, leading to lost fish catch (Boero and Briand, 2001).

In terms of tourism impacts, Boero and Briand (2001) identify potential impacts on tourism revenues from the literature. In the short term and in exceptional cases, jellyfish abundance has been associated with increased tourism incomes – as in the cases of Aurelia lake and Palau. The overwhelming impacts are likely to be negative, as impacts on bathing water and potential closure of beaches for recreational purposes reduce tourism enjoyment. This may exhibit hysteresis – as tourist perception exhibits this to a certain extent.

For the USA, Lipton and Kirkley (1995) suggest the most important benefit from oyster populations may be reductions in jellyfish abundance and reductions in welfare losses to boaters, fishermen and bathers. Hicks, Haab and Lipton (2004) suggest that “although it has not been quantified these groups may have a significant willingness-to-pay to enjoy there [Chesapeake] Bay experience with reduced jellyfish populations”.

### **3.3. Valuing Hypoxia**

#### ***3.3.1. Linking Activity to Emissions***

Hypoxia – a low level of dissolved oxygen in waters – has significant impacts on the ecosystem and on the environmental attributes of waters. Conley et al (2005) present an overview of the determinants of hypoxia and its impacts on Danish coastal waters. They find that the driving forces for hypoxia in the estuaries and coastal waters of Denmark include total nitrogen (TN) input into waters and wind speed, whereas for deep seas the determinants include TN input, advective transport of water and Skagerrak water temperature. Thus, the main driver that can be affected by policy is TN input, which includes N from land-based sources such as agriculture. This would determine the upper right hand quadrant of the framework to value threshold effects, with the TN input being determined by the activity level.

#### ***3.3.2. Linking Emissions to Environmental Quality***

TN leads to hypoxia, which has a number of impacts on water quality and ecosystems. These impacts include:

- biodiversity impacts resulting from changes in benthic communities; and
- increased nutrient concentrations in the water column resulting in phytoplankton production (leading to water clarity impacts and potential blooms).

For the 2002 event in Denmark, Conley et al (2005) report that the impacts may be particularly acute with long lasting episodes – with macrofauna sampling indicating a collapse of the benthic community in areas with 4-6 weeks of hypoxia. This shows a time dimension may be important in the link between loading and impacts.

Phytoplankton blooms were experienced in the Skive Fjord in 1994 as a result of an hypoxic event. Blooms are associated with a deterioration in environmental quality, including their impacts on water clarity, the deposit of blooms and decay in coastal areas affecting recreation and amenity, and potential impacts on fisheries (ECOHARM, 2005).

#### ***3.3.3. Linking Environmental Quality to Valuation***

The above impacts associated with hypoxia could be valued using a water quality ladder as suggested in Markandya et al (2005). As environmental quality declines in its initial stages, minor biodiversity impacts (from the point of view of valuation) may occur. Once major biodiversity impacts (associated with a longer time duration of event) or phytoplankton blooms are generated then more socio-economic impacts are experienced. This then leads to a step-function in the environmental quality-valuation quadrant of the theoretical framework.

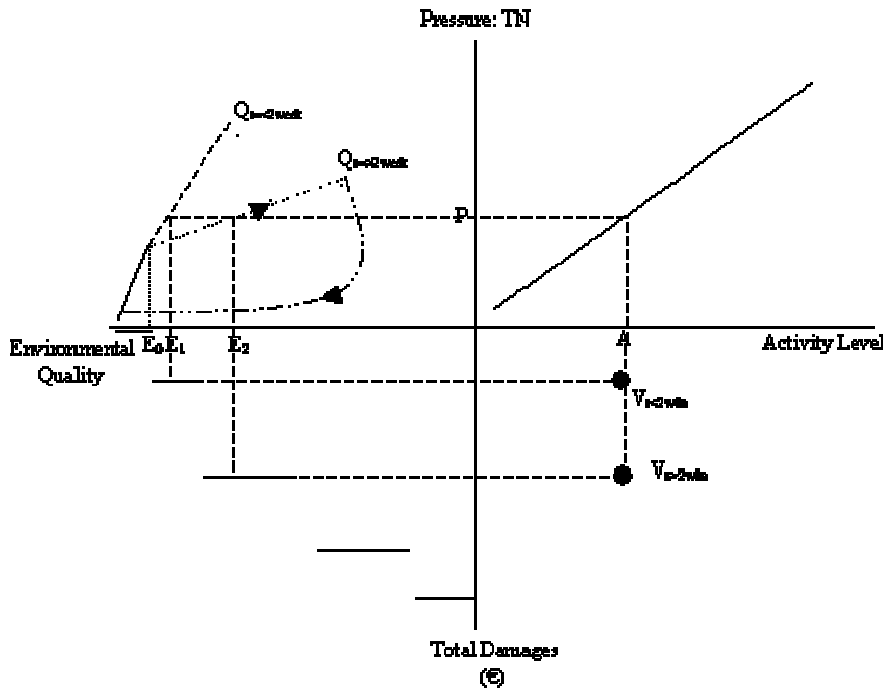
In one applied example, bioeconomic modelling has been used to value the impacts on fisheries of hypoxia in the Neuse River Estuary in North Carolina, USA (Smith and Crowder, 2005). They found a

discounted net present value of fishery rent increase of \$2.56 million for a 30% reduction in nitrogen loadings.

**3.3.4. Complete Framework**

Figure 3.1 presents an illustrative framework to assess the impacts of hypoxia. This is only for illustration purposes, but could be further developed in later work to fully model the impacts of activity on TN loading and of TN loading on environmental quality.

As can be seen from the figure, little impact is experienced up to  $E_0$ , the hypoxia “threshold”. After this,  $Q_{t < 2wks}$  indicates the response of the environment of an hypoxia event up to 2 weeks in duration (of course, this is a gross simplification). Over a two week duration, more dramatic impacts are experienced as shown by the line  $Q_{t > 2wks}$ , which indicates that there is a substantial decline in environmental quality with any increase in TN loading for a longer duration. Recovery from hypoxia may be characterised by hysteresis, as indicated by the curve with a backward arrow. If TN loading rises to such a pressure for a sustained period then the ecosystem will take longer to recover and hence even with subsequent declines in TN loading there are not is not a dramatic recovery.



**Figure 3.1: Valuing Hypoxia in an Economic Framework**

### 3.4. Valuing Benthic Systems: *Posidonia Oceanica*

*Posidonia Oceanica* is an important habitat and provides a number of ecosystem services. It provides:

- habitat for species such as macro-invertebrates (Ismail et al, 2005) and for fish species it is an important spawning ground;
- carbon fixing;
- oxygen production – reducing risk of hypoxia and anoxia;
- Stability for sea bed and shores – including reduced erosion (Basterretxea et al, 2004; Gacia and Duarte, 2001); and
- Export of detritus.

It is a long-lived species, with a life of up to 30 years. It is characterised by low growth rhythms and flowers and seeds are few in number (Gobert, 2005 presentation). Remediation is not easy, though recent work has shown that there is potential for the use of transplantation. This transplantation process is difficult, and there is a decline in initial population before robust plants establish themselves. There is some evidence that after transplant it may take up to five years for the *Posidonia* to obtain full coverage. The costs involved are also significant – with up to 7 hours being spent to replant a 4m<sup>2</sup> area, some of which has to be done under water (Gobert et al, 2005). As a consequence, the authors conclude that “projects for protection and conservation of existing *Posidonia* beds should be of high priority and are preferable to transplantation efforts” (op.cit. p471).

#### 3.4.1. Linking Activity to Emissions

A number of activities can have significant impacts on *Posidonia* populations. These include, but are not limited to:

- coastal construction;
- anchoring;
- sewage outflows;
- dumping at sea;
- fish farming;
- dredging for sand; and
- illegal trawling.

A recent paper highlighted the significant impacts that dredging for sand for improving tourist resorts can have on the population of *Posidonia* (Gambi et al, 2005). This study – which evaluated the populations both before and after extraction over a period since 2001 – shows the dramatic impact that dredging for sand can have on the marine ecosystem. This was due to both direct uprooting of *Posidonia* by the dredging process and the burying of shoots by sandy sediment which was redeposited on the meadow after being suspended. The impacts show a large degree of hysteresis – with the 4 hectares under consideration being characterised by a dead mat and after two years the size of the meadow was reduced to about 2 ha. This meadow was patchy in coverage and its nature was such that it may not be as resistant to future disruption as before as the shoots have become elongated and so may be more sensitive. The gains in terms of beach formation were also short lived, as the sand deposited eroded swiftly (Gambi et al, 2005).

A major sector that will be examined as part of the THRESHOLDS project is that of aquaculture. The impacts of fish farming in the Mediterranean on *Posidonia* were investigated by Holmer, Perez and Duarte (2003)

### 3.4.2. Linking Emissions to Environmental Quality

The linkage between emissions and environmental quality in this case, as with others, is complex. It is important that integrated analysis be performed to assess the impacts of different stressors on *Posidonia* populations. These are being assessed as part of the THRESHOLDS project.

The evidence on the links between fish farming and *Posidonia* declines was reviewed by Holmer, Perez and Duarte (2003). Key findings include:

- that there are significant impacts of emissions of fish farms on *Posidonia* either through organic input to sediments (and consequential deterioration in sediment conditions) or through impacts on sea urchins that are attracted either through increased nitrogen contents of food or through fish farm generated organic matter settling on the *Posidonia*.
- That there is a large degree of hysteresis in terms of the impacts after the removal of fish farms. Delgado et al (1999) identify declines in seagrass populations continuing up to 3 years after the removal of fish farms and the fact that the *Posidonia* rarely reproduces sexually (Hemminga and Duarte, 2000) and there are impacts on rhizome growth affecting clonal recolonisation of the sea bed, means that natural recovery times may be in the order of centuries (Duarte, 1995; Marba et al, 2002).
- Fish farming reduces the carbon reserves of the *Posidonia*.

Cancemi, De Falco and Pergent (2003), for the case of a bay in Corsica find that organic content of sediments around fish farms are significantly higher than those in a reference case (24-21 compared to 2%), ammonium is significantly higher (19.5-8.4 compared to 1.8 $\mu$ M) and organophosphorous levels in pore water may be higher (5.2-1.3 compared to 1.7 $\mu$ M). Seagrass densities fell from 466 shoots to 108 per m<sup>2</sup>. They suggest the plant competition with epiphytes leads to greater fragility of leaves and to a decrease in available light.

### 3.4.3. Linking Environmental Quality to Valuation

There is a strong perception that the value of *Posidonia* is not perceived. Despite being a protected species, actions such as dredging still impact significantly on *Posidonia* beds and the consequent ecosystem collapse is not taken into account. Impact analyses are not sufficiently conducted, though a methodological approach has been developed (Fanelli et al, 2003). Whatever the case it is clear that there are values attributable to *Posidonia*. These are impacted in a non-linear fashion in some cases.

Carbon fixing is directly related to the quantity of *Posidonia*. This can be valued using the social cost of carbon, as highlighted in Taylor et al (2005). This is likely to be linearly related to the population of *Posidonia*.

Values for recreation may also be important. For one, scuba diving is likely to be impacted. This will be due to a number of factors, including increased suspended sediments impairing visibility as the

sediments erode due to the lack of *Posidonia*. In addition, the impact on the *Posidonia* population, unless in the extreme case such as highlighted by the sand dredging, is likely to be perceived in a non-linear fashion. In some cases, values may be attributed to less dense sea grass as this enables better visibility of benthic species. However, as the population becomes sparse the ecosystem may collapse, leaving clumps of *Posidonia* with limited associated fauna or flora. This will negatively impact on willingness to pay for scuba diving.

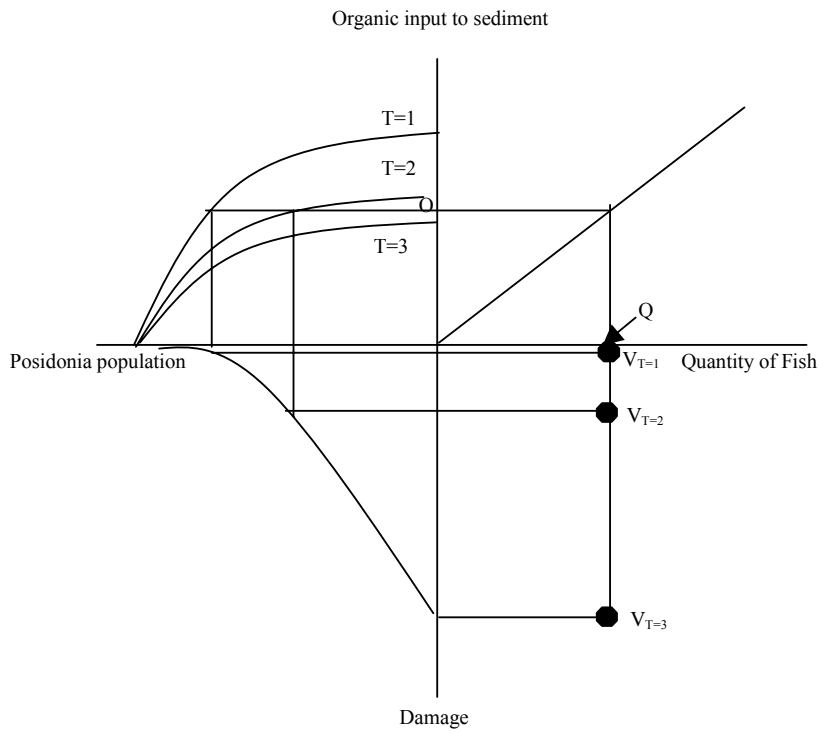
Coastal erosion will increase, again reducing recreational and amenity values.

Impacts on fisheries may be significant, as spawning grounds are lost or degraded. The increased likelihood of hypoxia or anoxia may also reduce fish stocks and biodiversity.

#### **3.4.4. Complete Framework**

A framework to link *Posidonia* populations to anthropogenic activities, emissions and damages is presented below. As in the case of hypoxia, there is a strong degree of hysteresis in the system, that would need to be taken into account in a systematic cost-benefit analysis framework – this is not shown in the below. It may be the case that the system exhibits a “point-of-no-return” for policy purposes, since losses are essentially irreversible within operational time frames. In addition, value functions also would exhibit hysteresis, as it takes time for tourists to realise that the systems have recovered. There is uncertainty in the linkage between *Posidonia* and nutrient loadings shown below. To our knowledge, little work has been done as yet to establish the shape of this relationship – though it is anticipated to involve a threshold and this relationship is to be studied as part of the THRESHOLDS project.

In the below, a farm with  $Q$  stocks of fish outputs  $O$  as input to sediment, through eg feed falling to bottom and faeces from fish. The damages associated with this depend on the duration the fish farm is in place. In the example below, in the first year the damage curve is shown by  $T=1$ , and associated damages are given a value equal to  $V_{T=1}$ . If the fish farm stays in the same location, then in the second year the damage curve is represented by  $T=2$ , and the associated damages are higher at  $V_{T=2}$ . In the third year, an input of  $O$  to the sediment results in the population of *Posidonia oceanica* falling to zero, and the impact in terms of value of this activity is then equal to the total economic value – or  $V_{T=3}$ .



**Figure 3.2: Valuing Damage to Posidonia from Fish Farming in Economic Framework**

### 3.5. Fish Farming – Analysis of Impacts and Economic Value of Ecosystem Disruption

Marine fish farming is increasing around Europe's coastline. In the North Sea salmonid farming is growing in importance. In the Mediterranean, the harvesting of sea bream and other species is increasing, and there are efforts to develop farming processes for tuna for high value export to Japan. Fish farming has a number of significant environmental impacts, many of which may exhibit "threshold" type relationships. This section overviews an approach to value such impacts.

#### 3.5.1. Linking Activity to Emissions

Fish farming activities, in terms of tonnes of fish harvested, are associated with a number of significant emissions or direct impacts on environmental quality. Direct emissions include:

- nutrient flows – due to fish food and faeces from fish;
- organic matter;
- medicines and pesticides; and
- other chemicals used in the fish farming process.

Tacon and Forster (2003) provide an inventory of chemicals used in the fish farming process.

#### 3.5.2. Linking Emissions to Environmental Quality

Holmer, Perez and Duarte (2003) present a review of the impacts of fish farms on the environment. Building on the emissions listed above, they identify a number of major impacts, including:

- increased phytoplanktonic and bacterial activity as a result of increased nutrient flows;
- organic enrichment of sediments and consequential severe impacts on benthic systems – including benthic meiofaunal and macrofaunal communities;
- increased bacterial and anaerobic activity;
- increased levels of macroalgae near to fish farms; and
- negative impacts on *Posidonia oceanica* (highlighted above).

In addition to the above, some studies have highlighted the impacts of antibiotics in terms of the production of resistance strains of bacteria (Chelossi et al, 2003). The aesthetic impact of fish farms may also be significant (Read and Fernandes, 2003), though this is less of an issue in the Mediterranean as fish farms are located far enough out to sea to not impact on recreational enjoyment.

Read and Fernandes also highlight a number of other impacts on environment of fish farming:

- Fish farms have been associated with impacts on wild fish through genetic interactions with farmed fish that escape or through ingestion of contaminated waste (Heggberget et al, 1993).
- It has been noted by some that the proportion of nutrients provided by fish farming is marginal compared to other sources, including waste water treatment (Black, 2001).
- Impacts on world fish supplies of use of fishmeal, though Read and Fernandes note that these impacts may be mitigated by the fact that some fish used for fishmeal (for which aquaculture provides one-third of the demand) is not fit for human consumption.

Anoxic conditions may also follow the changes made in sediment chemistry as a result of fish farming.

Modelisation of the emissions and settling of sediments, for example, is difficult. However, studies of the impacts derived from observation conclude that the highest impacts are directly below the cages used in fish farming and a moderate impact is experienced within a 50 metre radius. Beyond the 50 metre radius, no impacts are observed (Porello et al, 2005). One study by Perez et al (2002) linked a model based on a distribution equation to a Geographical Informational System, developing contour maps for dispersion under water. Similar maps were developed under the ExternE and GARP projects (see e.g. ExternE, 1995 and 1999; Markandya and Pavan, 1999; Markandya and Tamborra, 2005). This model was validated using real carbon values and there was found to be a strong relationship between the modelled and real carbon values. This linkage may provide a way ahead in the modelling and presentation of results of the impacts of marine fish farms.

### ***3.5.3. Linking Environmental Quality to Valuation***

The impacts of a change in environmental quality linked to fish farming can be valued as shown in Table 3.1 below. Differential impacts will be experienced depending on the scale of the fish farming activity and on production methods. Threshold type effects may be experienced in the link between environmental quality and valuation depending on aspects such as olfactory sensitivity and the levels of contaminants in fish.

**Table 3.1: Linking Environmental Quality to Valuation**

<b>Impacts</b>	<b>Valued effects</b>	<b>Methods</b>	<b>Potential Thresholds</b>
<i>Visual Amenity</i>	Impacts on house prices and recreation	HPM, CVM	Distance from land. Size of site.
<i>Odour</i>	Impacts on house prices and recreation	HPM, CVM	Olofactory sensitivity.
<i>Disease spread to neighbouring cages and to wild population</i>	Loss of productivity	PCM	
<i>Increase in wild stocks</i>			
-gains to recreation	Increased recreational enjoyment, trips	CVM	
-gains to fisheries	Increased fish catch per unit effort	PCM	
<i>Contamination of marketed fish with PBTs</i>	Reduced productivity, health effects if reach market	PCM, Health impacts	Thresholds for contaminant levels in fish.
<i>Escape of farmed fish to wild population</i>			
-inbreeding and disruption to spawning grounds	Loss of productivity	PCM where marketed	
-negative impacts on recreational anglers	Reduced recreational enjoyment	CVM, TCM	Perception of anglers determined by level of farmed fish and impacts on catches.
<i>Impacts on benthic system</i>			
-seagrasses	Value as for <i>Posidonia oceanica</i>	Various	Thresholds have been suggested in the amount of organic matter deposited from fish farms to the benthic system.
-benthic system disruption	Impacts through anoxia, fish productivity etc	Various	Thresholds have been suggested in the amount of organic matter and other emissions deposited from fish farms to the benthic system.

## 4. Conclusions

Marine ecosystems provide a number of services that are of socio-economic value. These values are associated with a number of attributes that may make up what is broadly defined as “environmental quality”. Discontinuities exist in a number of forms in the linkage between the value of ecosystem services and activity levels. The importance of these discontinuities may be assessed through valuation of the impacts on services and comparison of these impacts with remedial measures to mitigate nutrient or contaminant loads. In later stages of the THRESHOLDS project the threshold effects and industry linkages to emissions and impacts will be better defined through use of the impact pathway approach.

Key areas for future research on economic valuation of threshold effects include the establishment of a water quality/valuation ladder for coastal ecosystems, linking ecosystem services to environmental quality. In part, a paper being prepared simultaneously with this paper will go some way to identifying key gaps between the services provided and values. However, the linkage between services and environmental quality is somewhat harder to define (with the exception of eg blanket bans on fish extraction above a certain limit value of pollutant). More research is needed in this area in particular.

## 5. References

- Arrow, K. *et al.* (1995), "Economic growth, carrying capacity and the environment" *Science*, 268, 520-521.
- Basterretxea, G., Orfica, A., Jordi, A., Casa B., Lynett, P., Liu, P.L.F., Duarte, C.M., Tintore, J, (2004) "Seasonal dynamics of a microtidal pocket beach with *Posidonia oceanica* seabeds (Mallorca, Spain), *Journal of Coastal Research*, 20(4), 1155-1164.
- Black, K.D. (ed) (2001) *Environmental Impacts of Aquaculture*. Academic Press, Sheffield. Cited in Read and Fernandes (2003).
- Boero, F. (2001) "Adriatic ecological history: a link between jellyfish outbreaks, red tides, mass mortalities, overfishing, mucilages, and thaliacean plankton?" in CIESM (2001) *Gelatinous zooplankton outbreaks: theory and practice*. CIESM Workshop Series number 14, Monaco. Available online at [www.ciesm.org/publications/Naples01.pdf](http://www.ciesm.org/publications/Naples01.pdf).
- Boero, F. and F. Briand with Bone, Q., G. Gorsky and T. Wyatt (2001) "Executive Summary" in CIESM (2001) *Gelatinous zooplankton outbreaks: theory and practice*. CIESM Workshop Series number 14, Monaco. Available online at [www.ciesm.org/publications/Naples01.pdf](http://www.ciesm.org/publications/Naples01.pdf).
- Cancemi, G., G. De Falco and G. Pergent (2003) "Effects of organic matter input from a fish farming facility on a *Posidonia oceanica* meadow" *Estuarine, Coastal and Shelf Science* 56:961-968.
- Chelossi, E. *et al.* (2003) "Antibiotic resistance of benthic bacteria in fish-farm and control sediments of the Western Mediterranean" *Aquaculture* 219: 83-97.
- Conley, D.J., Cartensen, J., Ærtebjerg, G., Christensen, P.B., Dalsgaard, T., J.L.S. Hansen and A.B. Josefson (2005) "Long-term changes and impacts of hypoxia in Danish coastal waters". Paper prepared as part of THRESHOLDS project.
- Delgado, O., Ruiz, J., Perez, M., Romero, J. and E. Ballesteros (1999) "Effects of fish farming on seagrass (*Posidonia oceanica*) in a Mediterranean bay: seagrass decline after organic loading cessation" *Oceanol Acta* 22, 109-117. Cited in Holmer, Perez and Duarte (2003).
- Duarte, C.M. (1995) "Submerged aquatic vegetation in relation to different nutrient regimes" *Ophelia* 41:87-112. Cited in Holmer, Perez and Duarte (2003).
- ECOHARM (2005) ECOHARM: The Socioeconomic Impact of Harmful Algal Blooms on Marine Coastal Waters. Report prepared for European Commission under contract EVK3-CT-2001-80003.
- ExternE, 1995 *Externalities of Energy – EXTERNE Project – Volume 2: Methodology*. European Commission. Available online from [www.externe.info](http://www.externe.info).
- ExternE, 1998 *Externalities of Energy - Methodology Update*. European Commission. Available online from [www.externe.info](http://www.externe.info).

- Fanelli, E., Nicolletti, L., Franceschini, G., Giovannardi, O., Gabellin, M., Preti, M. (2003) « Environmental impact assessment after sand extraction for beach nourishment : a methodological approach » in E. Ozhan (ed) *Proceedings of the Sixth International Conference on the Mediterranean Coastal Environment, MEDCOAST 03*, 7-11 October 2003, Ravenna, Italy. MEDCOAST, METU, Ankara, Turkey, vol 2, 951-958.
- Gacia, E. and C.M. Duarte (2001) “Sediment retention by a Mediterranean *Posidonia oceanica* meadow: the balance between deposition and resuspension” *Estuarine, Coastal and Shelf Science* (2001) 52:501-514.
- Gambi, M.C., Dappiano, M., Lorenti, M., Iacono, B., S. Flagella and M.C. Buia (2005) “Chronicle of a Death Foretold” – Features of a *Posidonia Oceanica* Bed Impacted by Sand Extraction” pp441-450 in E. Ozhan (ed) *Proceedings of the Seventh International Conference on the Mediterranean Coastal Environment, MEDCOAST 05*, 25-29 October 2005, Kusadasi, Turkey, MEDCOAST, Middle East Technical University, Ankara, Turkey, Volume 1.
- Gobert, S., G. Lepoint, J-M Bouquegneau, D. Vangeluwe, M. Eisinger, M. Paster, H. Schuhmaker and P. van Treeck (2005) “Restoration of seagrass meadows: Means and limitations” pp461-473 in E. Ozhan (ed) *Proceedings of the Seventh International Conference on the Mediterranean Coastal Environment, MEDCOAST 05*, 25-29 October 2005, Kusadasi, Turkey, MEDCOAST, Middle East Technical University, Ankara, Turkey, Volume 1.
- Harbison, G. R. (2001) “The catastrophic invasion of the Black Sea by *Mnemiopsis Leidy*: is it only doing what other ctenophores did long ago?” in CIESM (2001) *Gelatinous zooplankton outbreaks: theory and practice*. CIESM Workshop Series number 14, Monaco. Available online at [www.ciesm.org/publications/Naples01.pdf](http://www.ciesm.org/publications/Naples01.pdf).
- Heggerget et al (1993) “Interactions between wild and cultured Atlantic Salmon – A review of the Norwegian Experience” *Fish. Res.* 18(1-2):123-146.
- Hemminga, M.A. and C.M. Duarte (2000) *Seagrass Ecology*, Cambridge University Press, Cambridge. Cited in Holmer, Perez and Duarte (2003)
- Hicks, R.L., Haab, T.C., Lipton, D., (2004) “The Economic Benefits of Oyster Reef Restoration in the Chesapeake Bay”, Final Report for the Chesapeake Bay Foundation.
- Holmer, M., M. Perez and C.M. Duarte (2003) “Benthic Primary Producers – A Neglected Environmental Problem in Mediterranean Maricultures?” *Marine Pollution Bulletin* 46, pp 1372-1376.
- Ismail, D. B., K. Telahigue, N. Chebbi, T. Hajji and O.K.B. Hassine(2005) “The macro-invertebrates of *Posidonia Oceanica* in the Tunis Gulf” pp495-500 in E. Ozhan (ed) *Proceedings of the Seventh International Conference on the Mediterranean Coastal Environment, MEDCOAST 05*, 25-29 October 2005, Kusadasi, Turkey, MEDCOAST, Middle East Technical University, Ankara, Turkey, Volume 1.
- Knowler, D., and E. Barbier (2000), “The economics of an invading species: a theoretical model and case study application” in C. Perrings, M. Williamson, and S. Dalmazzone, editors. *The economics of biological invasions*. Edward Elgar Publishing, Cheltenham, UK.

- Lipton D., and Kirkley, D., (eds.), (1994). *A Profile of the Oyster Industry: Northeastern United States*. Gloucester Point, VA: Maryland and Virginia Sea Grant Marine Advisory Programs.
- Marba, N., Duarte, C.M., Holmer, M., Martinez, R., Basterretxea, G., Orfila, A., A. Jordin and J. Tintore (2002) Effectiveness of protection on (*Posidonia oceanica*) populations in the Cabrera National Park (Spain). *Environ. Conserv.* 29, 509-518 cited in Holmer, Perez and Duarte (2003).
- Markandya, A., and M. Pavan (eds) (1999) *Green Accounting in Europe – Four Case Studies*. Kluwer Academic Publishers, Dordrecht.
- Markandya, A. and M.L. Tamborra (2005) *Green Accounting in Europe: A Comparative Study, Volume 2*. Edward Elgar, Cheltenham.
- Markandya, A., Taylor, T., A. Longo and D. Barton (2005) “Marine Ecosystem Thresholds – Towards an integrated theoretical framework for valuation”. Pp127-138 in E. Ozhan (ed) *Proceedings of the Seventh International Conference on the Mediterranean Coastal Environment, MEDCOAST 05*, 25-29 October 2005, Kusadasi, Turkey, MEDCOAST, Middle East Technical University, Ankara, Turkey, Volume 1.
- Mutlu, E. (2001) “Distribution of gelatinous macrozooplankton and ecosystem change in the Black Sea” in CIESM (2001) *Gelatinous zooplankton outbreaks: theory and practice*. CIESM Workshop Series number 14, Monaco. Available online at [www.ciesm.org/publications/Naples01.pdf](http://www.ciesm.org/publications/Naples01.pdf).
- Perez, O.M., Telfer, T.C., M.C.M. Beveridge and L.G. Ross (2002) “Geographical Information Systems as a Simple Tool to Aid Modelling of Particulate Waste Distribution at Marine Fish Cage Sites” *Estuarine, Coastal and Shelf Science* 54: 761-768.
- Read, P., and T. Fernandes (2003) “Management of environmental impacts of marine aquaculture in Europe” *Aquaculture* 226:139-163.
- Shiganova, T. (1998) “Invasion of the Black Sea by the ctenophore *Mnemiopsis Leidyi* and recent changes in pelagic community structure” *Fisheries Oceanography – GLOBEC Special Issue* pp305-310. Cited in Shiganova (2001).
- Shiganova, T. (2001) “Impact of the invaders ctenophores *Mnemiopsis Leidyi* and *Beroe ovata* on the pelagic food web and biodiversity of the Black Sea” in CIESM (2001) *Gelatinous zooplankton outbreaks: theory and practice*. CIESM Workshop Series number 14, Monaco. Available online at [www.ciesm.org/publications/Naples01.pdf](http://www.ciesm.org/publications/Naples01.pdf).
- Smith, M.D. and L. B. Crowder (2005) “Valuing Ecosystem Services with Fishery Rents: A Lumped-Parameter Approach to Hypoxia in the Neuse River Estuary” *FEEM Nota di Lavoro* 115.2005. Available from [www.feem.it](http://www.feem.it)
- Tacon, A.G.J. and Forster, I.P. (2003). Aquafeeds and the environment: policy implications. *Aquaculture*, 226(1-4): 181-189.

Taylor, T., A. Markandya and H. Walton (2005) “Review of Literature on Valuation of Coastal Ecosystem Services”. Report prepared for the European Commission – Deliverable D.1.1.3 of the THRESHOLDS project.