SNF Report No. 26/05

How to estimate costs from harmful algal blooms - Economic impacts on wild fisheries, aquaculture and commercial tourism

Torbjørn Lorentzen
Lasse H. Pettersson

SNF Project No. 5305: HABILE
The project is funded by the European Commission

INSTITUTE FOR RESEARCH IN ECONOMICS AND BUSINESS ADMINISTRATION

BERGEN, NOVEMBER 2005

ISBN 82-491-0380-7 Trykt versjon
ISBN 82-491-0381-5 Elektronisk versjon
ISSN 0803-4036

European Commission

Programme for Research, Technological Development and Demonstration under the Fifth Framework Programme 1998 – 2002

Theme 4: Energy, Environment and Sustainable Development

Key Action 3: Sustainable Marine Ecosystem

Contract Number: EVK3-CT2001-00063

Harmful Algal Bloom Initiation and Prediction in Large European Marine Ecosystems - HABILE

coordinated by
Nansen Environmental and Remote Sensing Center

Deliverable D.10 under WP10

HAB-ECONOMICS

How to estimate costs from harmful algal blooms -
Economic impacts on wild fisheries, aquaculture and commercial tourism

Authors: Torbjørn Lorentzen
and Lasse H. Pettersson

NERSC

Plymouth Marine Laboratory

CSIC

Bio/consult as

SMHI

DLR

SNF

Contract number: EVK3-CT2001-00063

TITLE: Harmful Algal Bloom Initiation and Prediction in Large European Marine Ecosystems

COORDINATOR:
NANSEN ENVIRONMENTAL AND REMOTE SENSING CENTER (NERSC)
Thormøhlensgate 47
N-5006 Bergen
Norway

Lasse H. Pettersson
E-mail: lasse.pettersson@nersc.no
Phone: +47 55 20 58 39
Fax: +47 55 20 58 01

CONTRACTORS:
Plymouth Marine Laboratory
Prospect Place, West Hoe
PL1 3DH Plymouth
United Kingdom

Steve Groom
E-mail: sbg@pml.ac.uk
Phone: +44 1752 633150
Fax: +44 1752 6331501

Instituto de Investigaciones Marinas
Eduardo Cabello 6
36208 Vigo
Spain

Dr. Francisco Figueiras
E-mail: paco@iim.csic.es
Phone: +34 986 23 19 30, ext. 372
Fax: +34 986 29 27 62

Bio/Consult AS
Johannes Ewaldsvej 42-44
8230 Aabyhoej
Denmark

Dr. Per Andersen
E-mail: pa@bioconsult.dk
Phone: +45 86 251811
Fax: +45 86 258173

Finnish Institute of Marine Research
PO Box 33, Lyypekinkuja 3a
00931 Helsinki
Finland

Dr. Seppo Kaitala
E-mail: seppo.kaitala@fimr.fi
Phone: +358 9 6139 4417
Fax: +358 9 6139 4494

Institute of Marine Research
PO Box 1870 Nordnes
5817 Bergen
Norway

Dr. Einar Svendsen
E-mail: einar.svendsen@imr.no
Phone: +47 55 23 85 00
Fax: +47 55 23 85 84

Swedish Meteorological and Hydrological Institute
Nya Varvet 31
SE-42671 Västra Frölunda
Sweden

Dr. Bengt Karlson
E-mail: bengt.karlson@smhi.se
Phone: +46 31 751 8958
Fax: +46 31 751 8980

DLR – Remote Sensing Technology Institute
Rutherfordstr. 2
12489 Berlin
Germany

Dr. Andreas Neumann
E-mail: andreas.neumann@dlr.de
Phone: +49 30 67 05 56 40
Fax: +49 30 67 05 56 42

Foundation for Research in Economics and Business Administration
Centre for Fisheries Economics
Breiviksveien 40
5054 Bergen
Norway

Torbjørn Lorentzen
E-mail: torbjorn.lorentzen@snf.no
Phone: +47 55 95 92 58
Fax: +47 55 95 94 39

EC Scientific Officer:
European Commission
CDMA 03/162,
200 rue de la Loi
B-1049 Brussels
Belgium

Piia Tuomisto
E-mail: Piia.Tuomisto@cec.eu.int
Phone: +32 2 299 2138
Fax: +32 2 295 0568

Nansen Environmental and Remote Sensing Center
Thormøhlensgate 47
N-5006 Bergen
NORWAY
Phone: +47 55 20 58 00 Fax: +47 55 20 58 01
E-mail: admin@nersc.no http://www.nersc.no

a non-profit environmental research center affiliated with the University of Bergen

REPORT IDENTIFICATION

PROJECT NAME **Harmful Algal Bloom Initiation and Prediction in Large European Marine Ecosystems - HABILE**	**CONTRACT No.** EVK3-CT2001-00063
DELIVERABLE TITLE HAB-ECONOMICS - How to estimate costs from harmful algal blooms. Economic impacts on wild fisheries, aquaculture and commercial tourism.	**DELIVERABLE No.** **D.10**
CLIENT and CONTACT PERSON European Commission DG Research - Environment Mrs. Piia Tuomisto (CDMA 03/162)	**AVAILABILITY** Open
AUTHORS / EDITORS Torbjørn Lorentzen [9] and Lasse H. Pettersson [1]	**DATE of DELIVERY** February 28th 2005
PROJECT PARTNERS 1. Nansen Environmental and Remote Sensing Center, Norway 2. Plymouth Marine Laboratory, U.K. 3. Instituto de Investigaciones Marinas, Spain 4. Bio/Consult AS, Denmark 5. Finnish Institute of Marine Research, Finland 6. Institute of Marine Research, Norway 7. Swedish Meteorological and Hydrological Institute, Sweden 8. DLR – Remote Sensing Technology Institute, Germany 9. Foundation for Research in Economics and Business Administration, Norway	
APPROVAL Lasse H. Pettersson, project co-ordinator	Ola M. Johannessen, director

EXECUTIVE SUMMARY

The background for the analysis is the increased registration of harmful algal blooms (HABs) in different sea areas, for example in Skagerrak and along the coast of Norway. There exists about 4000 algae species, and the micro organisms play normally an important role in the ecosystem. But under certain conditions the algal can bloom and be harmful for other species and inflict economic losses. The report is addressed to methodological questions where we ask how to estimate the economic effects of HABs on for example the aquaculture and tourist industry. The report refers to case studies in USA, Norway and EU-countries, which assess the socio-economic damages due to HABs.

TABLE OF CONTENTS

1 INTRODUCTION

For years everybody have heard about poisonous shellfish, and that both the commercial and recreational part of the shellfish sector are negatively affected. The increased frequency of Harmful Algae Bloom (HAB) events and their negative effects during recent years, especially in the fish-farming industry, have made “HAB-economics” topical.

The main objective of the report is to present a methodology that can be applied in estimating economic damages caused by harmful algae blooms (HABs). In this presentation we discuss how we theoretically and empirically can handle consistently the costs due to HAB-events on wild fisheries, aquaculture and commercial tourism.

This report is structured as follows. The Second Section gives a short presentation of the HAB taxonomy. Section Three defines economic welfare as the sum of consumers’ and producers’ surplus. A change in either consumers’ or producers’ surplus, or both, will change the economic welfare. In this part of the analysis we deduce expressions that can be used for measuring changes in welfare caused by HAB-events. Section Four deduces expressions for estimating HAB-induced costs on human health and productivity. Section Five discusses how to estimate welfare effect on consumers. Section Six describes the methodology, which is used for appraising the willingness to pay (WTP) for environmental goods, i.e. goods that have public good character, and are not sold in a market. We also present some examples that illustrate the methodology and the willingness to pay for different environmental goods in Norway. Section Seven presents various case studies on impacts of HAB events. We describe mainly registered HAB-events along the coast of Norway. We also present some results from economic analyses of HABs in respectively USA and along the coast of the EU-countries. Unfortunately, the lack of data gives us limited opportunity to measure the economic effects in each case in Norway. Section Eight discusses briefly the economic rationale behind establishing a warning and forecasting system for HABs. In the last section conclusions and recommendations are given.

2 TOXIC PRODUCING ALGAE – A TAXONOMY

There exist about 4000 algae species and about 75 of them are toxic (Dahl, Aune and Tangen 1999). At least 80% of the toxic algae are members of the alga-class Dinoflagelates (Dinophyceae). Along Skagerrak and the rest of the coast of Norway we find about 50% of the described toxic algae. Ten of these toxic algae have so far caused trouble. The content of poison in the algae can be classified according to the kind of physiological symptoms they give.

Group 1: Poison that gives paralytic effects – “Paralytic Shellfish Poisoning” – PSP.
Group 2: Poison that gives diarrhoea – “Diarrhoea Shellfish Poisoning” – DSP.
Group 3: Poison that gives amnesia – “Amnesic Shellfish Poisoning” – ASP.
Group 4: Poison that threatens lives to fish and other organisms – “Ichthyotoxins”.

All forms of poison described in each group are first of all accumulated in shellfish and in organisms, which eat the phytoplankton. But high concentration of toxic algae in the water can result in death of wild and farmed fish. In the last part of this paragraph it is emphasized that it is not only toxic algae that induce socio-economic problems. High concentration of non-toxic algae can also cause harm for living species.

2.1 Algae with Paralytic Shellfish Poisoning (PSP)

About the turn of the twentieth century two people died of PSP in Norway. They had eaten mussels (blue mussel) from the inner part of Oslofjord. During the 90ties several people was seriously sick from PSP in Norway, due to consumption of shellfish. Other places around the world have reported serious cases of PSP. In Norway it is first of all algae classified under Alexandrium that gives PSP-problems. The frequency of high concentration of PSP in shellfish is relatively high in Norway, and it has negative effects on both the commercial and the recreational part of the shellfish industry.

2.2 Algae with Diarrhoea Shellfish Poisoning (DSP)

In Norway it is high risk of DSP in the mussel, generally speaking, and the phenomenon has for longer or shorter time hindered the shellfish industry – and resulted in economic problems. During the autumn of 1984 at least a hundred of people got sick of DSP in mussel along the coast of Skagerrak. Globally the frequencies of DSP are highest in Europe, but DSP has increased in other areas around the world. Along the coast of Norway the density of DSP is highest in Skagerrak and along the West Coast of Norway (Sognefjorden).

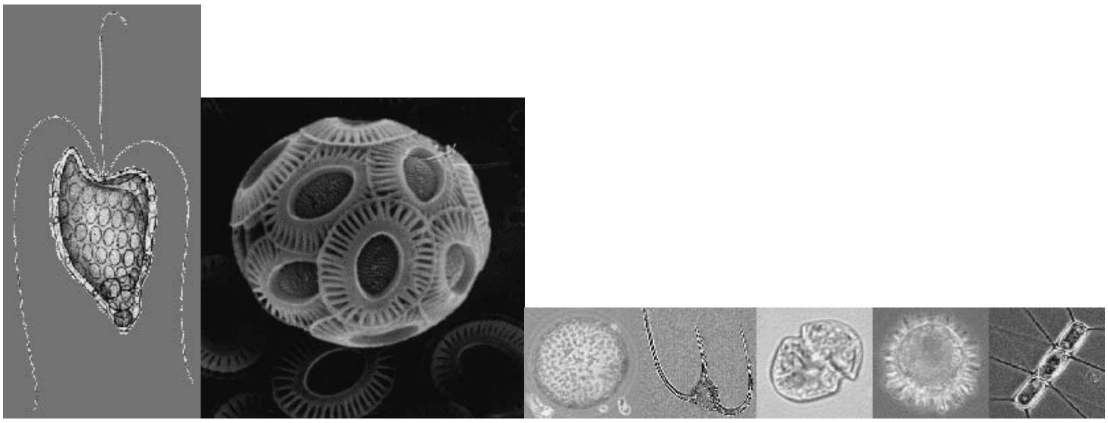
2.3 Algae with Amnesic Shellfish Poisoning (ASP)

ASP was first registered in Canada in 1987. A couple of hundred people were affected. Some of the patients got a permanent amnesia. The ASP-generating alga, for example *Pseudo-nitzschia* has spread continuously from the first observed case in Canada. Today we can find it at the west coast of USA, New Zealand, Japan, and Spain and along the coast of the Netherlands. It has also been registered in the Oslofjord of Norway.

2.4 Algae with Ichthyotoxins

Algae that kill fish (Ichthyotoxins) represent a global problem, and the blooms cause economic losses for the fish farmers. Also wild fisheries are affected. The most dangerous species are *Gyrodinium, Chattonella, Chrysochromulina* and *Prymnesium*. These species induce big economic problems for fish farmers. *Gyrodinium aureolum* has killed farmed fish in plants from Skagerrak in the south to Senja in the north of Norway. Fish farmers located at Senja were hit in 1982. *Chrysochromulina polylepis* caused a massive death of wild and farmed fish along the coast from Gøteborg in Sweden to Haugesund in Norway. *Chrysochromulina leadbeateri* caused a huge loss of wild and farmed fish in Lofoten in the north of Norway, and Vestfjorden during May-June 1991. The alga caused also a local loss of fish along the coast of Troms county in 1998. Locally in Ryfylke, also a county in Norway, mainly in the fjords Hylsfjorden and Sandsfjorden the algae *Prymnesium* (spp) has caused loss of fish in the same period, every year from July to August 1989 to 1996. At the coast of the middle of Norway a bloom of *Alexandrium* caused a considerable loss of both farmed and wild fish, mainly sprat and flatfish, in 1992. *Alexandrium* gave a deadly PSP-effect, i.e. a pure poisoning effect. Extremely high concentration of PSP was found in mussel along the coast of Norway in 1992 – especially in shellfish in the sea-area not far from the town Trondheim. A huge bloom of mainly *Chattonella* spp., but also *Heterosigma akishiwo* and *Distephanus speculum* caused both loss of farmed fish in Norway and a loss of wild fish in Denmark in 1998. Figure 1 shows samples of algae, respectively *Chrysochromulina, Cocco* and *Femfina* planktons.

Figure 1: Sample of algae. Source: NERSC/SMHI



An alternative way of categorizing HABs is made by Scatasta et al. 2004, p. 13. Four categories are used, respectively: (1) Seafood Toxic Blooms (STB): These are HABs characterized by a high level of toxicity and low level of biomass. (2) Fish Killing Blooms (FK): These are HABs causing mass fish mortality. (3) High Biomass Non-Toxic Blooms (HBNT): These are HABs characterized by a high level of biomass but non-toxic. (4) High Biomass Toxic Blooms (HBT): These are HABs characterized by high level of biomass and a high level of toxicity.

This Section shows that algae in whatever category are potentially harmful, and that they induce costs on society. In the following we will discuss in detail how costs from HABs can be estimated. It should be mentioned that algae have always been an integrated part of the ecosystem, but on the other hand the economic institutions have not been there for ever. When economic actors plan to invest in an eco-based industry (shellfish, aquaculture or tourist industry) they have to incorporate the risk of being hit by HABs as a part of the economic analysis. The insurance industry will search for all factors that cause a breakdown for example in the aquaculture industry. But we must not run into the similar argument that boreal geographical areas are inflicted a welfare loss because the weather is too cold to produce bananas.

3 WELFARE ECONOMICS

Generally we can express the change in economic welfare (ΔW) as the sum of changes in producers' (ΔPS) and consumers' surplus (ΔCS). Producers' surplus is a measure that expresses how much input factors, respectively labour and capital, de facto earn over or beyond the best alternative allocation of the productive resources. Consumers' surplus is a measure that expresses the difference between what the consumers are willing to pay for the good and what they actually pay for it in the market. $W_t = PS_t + CS_t$ expresses the welfare level at time *t*. The welfare level is changed permanently during a time period if either producers' or consumers' surplus or both are changed. This relation can be expressed in the following way:

$$\Delta W = \Delta PS + \Delta CS$$

We relate the cause of the welfare changes to HAB-events. In the following we will analyse in detail what is behind these expressions and how we can apply them in an empirical analysis.

3.1 What do "Harmful algae" mean?

The term "harmful" covers a set of micro-algae species that share one characteristic: They can cause damage to marine living resources and ecosystems, and directly and indirectly create a negative impact on human welfare. How does the latest literature define 'harmful'? Scatasta et al. 2004, p. 6 define harmful algae blooms in the following way:

"Harmful algae blooms (HABs) occur when microscopic photosynthetic organisms, commonly known as algae or phytoplankton, grow at a rate that is harmful to other living forms. Harmful algal blooms may be characterized by a high level of toxicity and/or a high level of bio-mass."

According to the definition algae are harmful when they cause problems for other living forms in general. When we focus on society we conclude that HABs have negative impact on social welfare. In that matter it is possible to be more specific. Hoagland et al. (2002) and Scatasta et al. (2004) consider all costs induced from

HABs, for example; lost revenues, lost wages, medical expenses, monitoring and management costs and similar costs associated to HABs. In this part of the report it is no intention to analyse the causes behind HABs, but it should be mentioned that HABs are explained among other factors by increased run off, climate change, spread of algae through ballast water from intercontinental freight vessels (Bergh et al. 2002). A policy which main objective is to affect the frequencies of HAB must be directed toward these mentioned sources.

3.2 Producers' surplus

Let us first look closer at the changes in producers' surplus. Afterwards we will relate the discussion to the effects HAB-events could have on commercial activities, for example on wild fisheries.

3.2.1 Problem definition

Proposition: The economic impacts or consequences are dependent on whether the HAB-event induces (1) a shift in the marginal costs or (2) just induces a change along the marginal cost curve.

3.2.2 Shift in the marginal cost curve

A HAB-event induces higher production or fishing costs at every production or catch-level. We expect that HAB will have a general negative effect on productivity. Let us handle the problem under a short run horizon. In the short run one or more production factors are fixed, and we have to handle a so-called restricted cost function.

Definition: Short run cost function: $c(y,w,\bar{x})$ is defined: $c(y,w,\bar{x}) = \min\{wx\}$ s.t. the production function $f(x) \geq y$ and $x_i = \bar{x}_i \forall i = 1,2,...,m$ are the m fixed factors, y: quantity supplied, w: vector of input prices, x: vector of input factors. Let us in the first part of this section operate with a restricted cost function: $c(y,w,\bar{x}) = y^{\alpha}\Phi(w)\lambda + \sum_{i}^{m} w_i \bar{x}_i$ and $\alpha > 1$. The last term on the right side represents the fixed costs. We obtain the expression above if the production function is respectively homogeneous of degree $1/\alpha$ and homothetic.[1] $\Phi(w)$ is the unit cost of production, and it is a constant for given factor prices (*w*). λ is the shift-parameter related to HABs in the following way:

$$\lambda = \begin{cases} \lambda > 1 \text{ if HAB} \\ \lambda = 1 \text{ if no HAB} \end{cases}$$

We can interpret the shift parameter λ as the percent increase in marginal costs for all level of production, i.e. if the marginal costs increase by 10 % then $\lambda = 1.1$. The supply function for the whole industry is the horizontal sum of the individual marginal cost curves. Suppose that $c(y, w, \lambda, \bar{x})$ is the short run industry cost curve. The supply curve is induced from the marginal industry cost curve:

$$c_y = \frac{\partial c(y, w, \lambda, \bar{x})}{\partial y} = \alpha y^{\alpha-1}\Phi(w)\lambda \text{ and } \alpha > 1.$$

A HAB-event induces a shift in the supply curve, and the production will be lower than initial production level. Let y_1 indicate supply under a HAB-event. It follows from profit maximization behaviour that *p* equal marginal costs, i.e. $y_1 = \left[p_0 / \alpha\Phi(w)\lambda \right]^{\frac{1}{\alpha-1}}$, and we can conclude that the supply under a situation with HAB is *lower* than without HAB. Now we can deduct the change in producers' surplus as the change in profit ($\Delta\pi$) or producers' surplus: $\Delta\pi = p^0 \Delta y + \Phi(w)[y_0^\alpha - y_1^\alpha \lambda] < 0$, where p_0: is the constant market price of the product. If HAB-event, $\Delta\pi < 0$.

More generally we can express the change in producers' surplus in the following way:

$$\Delta PS = \pi_1 - \pi_0$$

[1] Homogeneity refers to degree of scale economics. If $\alpha < 1$, then it exists increasing returns to scale. $\alpha = 1$ implies constant returns to scale and $\alpha > 1$ implies decreasing returns to scale. Homothetic means that any production function that can

Profit π is the difference between total revenue and total cost, and the subscripts "0" and "1" indicate respectively before and after the HAB-event. Given that the individual producer is a price taker, the change in producers' surplus can be expressed in the following way:

$$\begin{aligned}\Delta PS = \pi_1 - \pi_0 &= p_0 y_1 - c(y_1, w, \lambda, \bar{x}) - \left[p_0 y_0 - c(y_0, w, \bar{x})\right] \\ &= p_0 \Delta y + c(y_0, w, \bar{x}) - c(y_1, w, \lambda, \bar{x}) < 0\end{aligned}$$

It is a priori likely to expect that a HAB-event will result in a reduction in the quantity supplied compared to a non-HAB situation, i.e. $\Delta y < 0$, and variable costs in the HAB-case will always be higher compared to the non-HAB case for all values of output *y*, and that is the main cause behind the loss in producers' surplus and value added. For the aquaculture industry we must also take into consideration whether the plant had to be moved from one location to another to prevent or reduce the possible damages from HABs. In this case the cost function must reflect induced moving costs, included the value of lost fish caused by transportation.

Remark: In aquaculture industry producers *accumulate* costs, for example feeding, labour costs and other intermediates, during the production process. If HAB-events induce significant loss of fish during the time period where the producer planned to sell the fish, the costs of a HAB attacks can be expressed as the value of the accumulated resources. Suppose: (1) the cost function reflects the opportunity value of the resources. (2) The total production of the industry is y^T, y^S is quantity sold and y^L is lost quantity. The expression for lost fish is $y^L = y^T - y^S$. If the industry were *not* "attacked" by HABs, then it would realize profit:

$$\pi_0 = p_0 y^T - c(y^T, w, \bar{x})$$

The industry manages to sell y^S during the period. They have lost $y^L = y^T - y^S$, and realized profit:

$$\pi_1 = p_0 y^S - c(y^T, w, \bar{x})$$

be expressed as a monotonic increasing function of a homogeneous function is called homothetic.

The change in profit indicates that the industry's total change in producers' surplus is:

$$\Delta PS = \pi_1 - \pi_0 = p_0 y^S - p_0 y^T - c(y^T, w, \bar{x}) + c(y^T, w, \bar{x})$$
$$= p_0 (y^S - y^T) = p_0(-y^L) = p_0 \Delta y < 0$$

Example: Suppose $c(y, w, \bar{x}) = y^{\alpha}\Phi(w)\lambda + \sum_i^m w_i \bar{x}_i$. $\alpha = 1.5$, $\Phi(w) = 1$ and $\lambda \geq 1$. The cost function: $c(y, w, \bar{x}) = \lambda y^{1.5} + \sum w_i \bar{x}_i$. The marginal cost equal: $\frac{\partial c}{\partial y} = 1.5\lambda\sqrt{y}$. Suppose that the producer is a price taker. Maximizing profit implies producing at a level where the price is equal marginal costs. The market price is p_0. The quantity which maximizes the profit is given by: $y = \left[\frac{p_0}{\lambda\alpha\Phi(w)}\right]^{\frac{1}{\alpha-1}}$. Without HABs, $\lambda = 1$ and the quantity supplied is $y = \left[\frac{p_0}{1.5}\right]^2$. The change in quantity due to HAB is: $\Delta y = \left[\frac{p_0}{1.5\lambda}\right]^2 - \left[\frac{p_0}{1.5}\right]^2$. The loss in producers surplus is: $\Delta PS = p\Delta y = \frac{p_0^3}{[\alpha\Phi(w)]^2}\left[\frac{1}{\lambda^2} - 1\right]$. Assume that the price $p_0 = 1$ and $\Phi(w) = 1$, we get $\Delta PS = \frac{1}{(1.5)^2}\left[\frac{1}{\lambda^2} - 1\right] < 0$ for $\lambda > 1$. The expression shows that the loss in producer surplus increases with how severely the producer is hit by the HABs, i.e. the size of λ maps how hard the producer is hit. The result follows from $\frac{\partial PS}{\partial \lambda} = -\frac{2p_0^3}{[\alpha\Phi(w)]^2\lambda^3} < 0$. If $\lambda = 1.1$, it implies that HAB increases the marginal cost by 10 %. If $\lambda \to \infty$, then $\Delta PS \to -\frac{p_0^3}{[\alpha\Phi(w)]^2}$. The expression for the change in producer surplus also shows that the loss is dependent on price level, degree of homogeneity and the unit cost of production (relative prices on production factors). If the industry affects the market price, the change in producers' surplus (aggregated for the whole industry) can be expressed in the following way:

$$\Delta PS = \pi^1 - \pi^0 = p^0(1 - \frac{1}{|\varepsilon|})\Delta y + \Delta c(\cdot)$$

The last expression shows that the change in revenue, as a consequence of a change in aggregated quantity supplied $\Delta y < 0$, is a function of the absolute value of the demand elasticity $|\varepsilon|$. If $|\varepsilon| > 1$, then the change in revenue will be negative, but if $|\varepsilon| < 1$, then a reduction in quantity will induce a positive change in revenue. This argument presupposes that the individual producer has no opportunity to affect the market price.

3.3 Conclusion

In the first scenario, when the industry is a price taker, we can unambiguously conclude that a significant cost inducing HAB event, i.e. $\lambda > 1$, will reduce the producer surplus. It indicates that $\Delta PS < 0$. But in the second scenario, when the *aggregated* industry in some way can affect the market price, the net effect is ambiguous: On the one side a HAB event reduces the quantity supplied, and the reduction increases the market price. How strong the positive price effect is, depends on the size of the aggregated demand elasticity $|\varepsilon|$. On the other hand the HAB event increases the production costs on all level of production, $\lambda > 1$. It is not possible a priori to conclude whether the increased revenue effect is bigger or smaller than the increased production costs, but we expect that the increased revenue is too small to compensate the negative cost- and quantity-effect. We suppose that the producers in the first place, and before the HAB-event, are optimally accommodated, and that the positive price effect induced by the reduction in the aggregated supply only reduced the loss. Conclusion: $\Delta PS = p^0(1 - \frac{1}{|\varepsilon|})\Delta y + \Delta c(\cdot) < 0$. We can conclude that in situations where the industry has accumulated value during the production process which and suffer a loss close to the delivery, we are able to express the change in producers' surplus as $p\Delta y < 0$, i.e. the loss is equal the market value of the lost fish.

3.4 Change along the marginal cost curve

In this Section we analyse the impact on the producers' surplus given that the HAB-event induces changes along the marginal cost curve. According to point (2) above, it was mentioned that we could have a situation where HAB events did not cause any shift in the costs, but that HAB events just induced changes along the marginal cost curve – or along the industry supply curve. We relate this problem definition to a situation where the fishery is closed, or alternatively where a part or section of the fishery is closed. We can imagine that part of the fishery is closed as a consequence of monitoring and a HAB-attack is expected. The consequence is that it will be caught a smaller quantum of fish and, not least, the industry will use less resources because of the reduction in the activity. But on the other hand lower activity will also reduce the sales and income. Above we formulated the industry's restricted cost function $c(y, w, \bar{x})$. We can derive the supply function from the cost function by differentiating it:

$$\frac{\partial c(\cdot)}{\partial y} = c_y(y, w)$$

Suppose the industry can not supply more than TAC (Total Allowable Catch), which we define as y^{TAC}. The argument is applicable on both wild fishery and fish farming. The industry supply curve can be expressed in the following way:

$c_y(y, w)$, given that $y \le y^{TAC}$.

More precisely the industry supply can be formulated in the following way:

$$c_y = \begin{cases} c_y = \text{Monotonic increasing if } y < y^{TAC} \\ c_y = \text{Vertical if } y = y^{TAC}.\ \text{Supply elasticity is infinitely high if } y = y^{TAC} \end{cases}$$

Suppose HAB events, or expected HAB events imply closing a part of the fishery so the industry can only catch or harvest $y^H < y^{TAC}$. We also assume that the given market price (p_0) is sufficiently high so the profit is positive, $p_0 \ge C_y$ given that

$y \leq y^{TAC}$. If the industry can catch, in the meaning produce and supply, y^{TAC} , then they realize profit π_0 :

$$\pi_0 = p_0 y^{TAC} - c(y^{TAC}, w, \bar{x})$$

If they only can catch or produce $y^H < y^{TAC}$ because of HAB events, then they realize profit π_1 :

$$\pi_1 = p_0 y^H - c(y^H, w, \bar{x})$$

The change in producers' surplus caused by HAB events can be expressed in the following way:

$$\begin{aligned} \Delta PS = \pi_1 - \pi_0 &= p_0(y^H - y^{TAC}) - c(y^H, w, \bar{x}) + c(y^{TAC}, w, \bar{x}) \\ &= p_0 \Delta y - c(y^H, w, \bar{x}) + c(y^{TAC}, w, \bar{x}) \end{aligned}$$

We know that $y^H < y^{TAC}$ and $c(y^H, w, \bar{x}) < c(y^{TAC}, w, \bar{x})$. The revenue value is obviously reduced, but the reduction in production has also reduced the costs. Two opposite effects are presence, but we can argue that $\pi_0 > \pi_1$ and $\Delta PS < 0$, because π_0 was the "global" optimum, given $y^{TAC} > y^H$ and the market price p_0 is constant.

Example: If we use the homogeneous production function above, the change in profit or producers' surplus can be expressed in the following way: $\Delta\pi = p_0 \Delta y + \Phi(w)[y_0^\alpha - y_1^\alpha]$. If the technology is pari passu, i.e. $\alpha = 1$and constant returns to scale, the change in producers' surplus is: $\Delta\pi = [p_0 - \Phi(w)]\Delta y$, and $\Delta y < 0$ implies that $\Delta\pi < 0$.

If the market structure is concentrated, it gives the aggregated industry the possibility to indirectly influence the price by coordination because of changes in the quantity, and then we can express the change in producers' surplus in the following way:

$$\Delta PS = \pi_1 - \pi_0 = p_0(1 - \frac{1}{|\varepsilon|})(y^H - y^{TAC}) - c(y^H, w, \bar{x}) + c(y^{TAC}, w, \bar{x})$$

As mentioned before it is a priori not possible to conclude whether ΔPS is negative or positive without knowing the value of the demand elasticity. Shellfish industry is occasionally stopped or closed because of poisoning of the shellfish. The harvesting of the shell is postponed until the shell is poison free. The income is not necessarily lost, but postponed in the future. The firm is incurred costs because of lack of cash flow. It should also be mentioned that closing a fishery (for example the shellfishery) can influence the price level in the market if the industry represents a high enough share of the total market.

4 HAB INDUCED COSTS ON HUMAN HEALTH AND PRODUCTIVITY

We have so far not discussed the possibility that HAB events can cause diseases. Eating tainted seafood or drinking contaminated water caused by harmful algae has negative effect the human health. In the most fatal case a poisoned person can die. If a person is poisoned, it will induce a set of costs, e.g. medical and hospitalisation costs, transportation costs, loss of productivity due to sick days. Suppose that toxic algae affect *n*-persons. A rough estimate of the economic costs of illness (C_I) can be expressed in the following way:

$$C_I = \sum_{i=1}^{n} w_i t_i + \sum_{i=1}^{n} M_i$$

where:

$$\begin{aligned} w_t &= \text{wage rate per day for sick person } i = 1,\dots,n \\ t_i &= \text{number of lost work days for sick person } i = 1,\dots,n \\ M_i &= \text{costs of medical treatment for sick person } i = 1,\dots,n \end{aligned}$$

In this model we expect that the wage rate per day reflects the market value, included taxes e.g. VAT, of the physical output for person $i = 1,\dots,n.$ We leave, for the time being, out of account the possibility of death as an outcome. And we also presuppose that the number of lost workdays is less than a year so we do not discount the economic effects.

4.1 Case: Socio-economic effects due to diarrhoetic shellfish poisoning toxins in Cancer pagurus Linnaeus, 1758 in Norwegian waters in 2002.

During July to October 2002 about 200 and 300 persons were seriously poisoned by eating contaminated brown crabs (Cancer pagurus). The crabs had high concentration of DSP-toxin. The brown crab had eaten shellfish (mussel) which had accumulated DSP-algae. The accident took place at the coast of the Southern Norway.

It is unusual that brown crabs are poisoned. Only once (in a while) is it reported a similar accident in Portugal in 2001 (Castberg et.al. 2004).

We use this accident as an example on how we can estimate the costs algae can inflict on human productivity. Assume that 250 adults were poisoned and that these persons were employed in paid work. The poisoned persons were sick for on average three days (Castberg et.al. 2004).

According to Statistics Norway the average labor cost per hour in the Norwegian industry was on average about 180-200 Norwegian kroner in 2000. Assume that a work day last for 7.5 hours. By applying the expression for the costs of the poisoning, we get;

$C_I = 250x180x7.5x3 = 1012500$ Norwegian kroner.

According to our assumptions the costs are over 1-1.5 million Norwegian kroner, or about 0.1 million US dollar.

In addition to the above effect, we must also take into consideration that immediately after the poisoning epidemic, it was very difficult to market brown crabs. Because of spreading rumour of poisoned brown crabs, the demand side of the market “disappeared” for period. It implied a reduction in income for the part time fishermen. There exists no data over the volume of the market for brown crab. Nevertheless there is no doubt that the disappearance of the local market inflicted a loss on the local fishermen which is bigger than the costs associated to the costs of illness.

5 ESTIMATION OF CHANGES IN WELFARE FOR CONSUMERS

The change in economic welfare is the sum of changes in producers' and consumers' surplus, and we can express it in the following way:

$$\Delta W = \Delta PS + \Delta CS$$

Above we discussed how we theoretically and empirically can express changes in producers' surplus. The expressions are capable of capturing the negative effects from HAB events on wild fisheries, aquaculture industry, and commercial tourism and if a person in the labour market is "hit" by HABs.

In the further work we shall discuss how we can analyse the effects from HAB events on consumers. We shall focus on changes in consumers' surplus. Suppose that all consumers are identical and have the same preferences. In the analysis it is sufficient to look at one representative consumer.

HAB events cause a set of negative effects, i.e.: negative aesthetic effects, negative health effects, negative recreational effects, and reduction in the supply of affected commercial goods can increase the prices, and it implies higher expenditures for the consumers. Methodically it can be a hard task to measure how the utility is changed for the consumer. An alternative way to measure the negative welfare effects the HAB events have on consumers is to combine the expenditure and the compensated demand function. For the time being we will not present this theory in detail – just sketch the solution of the problem. The theory is presented in Appendix A.

5.1 Consumers' surplus

Consumers buy a good for a price p. We expect that they purchase the good because they realize a utility worth at least the price. We suppose that the marginal consumer is indifferent between buying and not buying it. Each consumer buys an amount of the good up to a level where value of the marginal utility is equal to the price. We assume that the consumer's preferences are concave. Irrespective whether or not the economy consists of different or identical consumers, the demand curve will be downward sloping. If the market price is fixed, and the price is lower than the willingness to pay for all except the marginal consumer, consumers realize a consumers' surplus. More precisely, it can be expressed as the difference between the aggregated willingness to pay for the good and the actual amount paid for the good. The willingness to pay has a geometrical interpretation. It is the area under the demand curve. The actual expenses for the consumers are the market value of the good, px, i.e. price multiplied by quantity.

Remark: In situations where the demand elasticity is infinite, it means consumers can find perfect substitutes for the good we analyse, the consumers do not suffer any welfare loss due to changes in supply and price, i.e. the change in consumers' surplus is zero $\Delta CS = 0$.

5.2 HAB's effect on consumers' welfare

The main objective in this section is to evaluate how HAB events affect the commercial traded good. So far we will only focus on goods that are traded in a market. It implies that we do not analyse welfare effects induced from loss of goods which are not traded in the economy, for example value of pure nature, aesthetic value of nature and so on. We will return to this issue in a separate Section.

We have the following chains of "cause and effect": (1) HAB events lead to loss or reduction in the supply of the affected good, and the price is expected to increase. If the price increases, marginal consumers will "fall" out of the market, and expenditure increases for the consumers who still are in the market. We suppose the two groups, marginal consumers and consumers who still consume the good after the HAB-event, will suffer a welfare loss because of the increase in price. (2) HAB-events can change the preferences for the good in question. Consumers do not want to buy goods that might be affected by HABs, and the consequence is that the demand is reduced for all price levels.

We want to attach a money value on the effects HAB events have on the consumers' welfare. There are two common ways of doing this. We can ask what *change* in income, with prices remaining at old level, would be equivalent to the proposed price change. This change in income is known as the *equivalent variation* (EV). Alternatively we can ask what increase in income would "*compensate*" for the price change, i.e. what change in income at the new prices would return the consumer to the old level of utility. This measure is known as the *compensating variation* (CV).

In the following we will apply the concept "compensating variation" (CV). In the appendix we have defined the indirect utility and the expenditure function. These functions and concepts are central when we analyse the welfare changes induced by for example HAB events.

Let respectively $v(p,m)$ be the indirect utility function and $e(p,u)$ be the expenditure function. We define p^0 and p^1 as prices on the good before and after HAB events. The income m is not changed between the two situations and u is the utility level. The CV-compensation variation is thus defined by:

$$v(p^1, m + \mathrm{CV}) = v(p^0, m)$$

If $e(p,u)$ is the consumer's expenditure function and we write $u^0 = v(p^0, m)$ and $u^1 = v(p^1, m)$, then we have $v(p^1, m + \mathrm{CV}) = u^0$, hence $e[p^1, v(p^1, m + \mathrm{CV})] = e(p^1, u^0)$ and thus

$$\begin{aligned} &m + \mathrm{CV} = e(p^1, u^0), \text{ and} \\ &\quad \mathrm{CV} = e(p^1, u^0) - m, \text{ and } m = e(p^0, u^0) \\ &\quad \mathrm{CV} = e(p^1, u^0) - e(p^0, u^0) \end{aligned}$$

The expression shows how much the consumer must, in money value, be compensated to return to the old level of utility. But we are not finished yet. If we consider a change in the price in one of the goods, say the good i, from p_i^0 to p_i^1 as a consequence of HAB events, we can express CV according to the definite integral

$$\mathrm{CV} = \int_{p_i^0}^{p_i^1} \frac{\partial e(p, u^0)}{\partial p_i} dp_i \,,$$

and it follows from Shepherd's Lemma that partial derivative of the expenditure function is equal the Hicksian compensated demand function.

$$\frac{\partial e(p,u^0)}{\partial p_i} = x_i^H(p,u)$$

Compensation variation can be written as:

$$\text{CV} = \int_{p_i^0}^{p_i^1} \frac{\partial e(p,u^0)}{\partial p_i} dp_i = \int_{p_i^0}^{p_i^1} x_i^H(p,u^0) dp_i$$

The equation offers a monetary measure of the change in the consumer utility due to the change in price. The difficulty in applying this expression is that it involves the unobservable Hicksian demand. It is common to use approximations to these expressions, by replacing the Hicksian by the observable Marshallian demand functions. We thus obtain the following Marshallian approximation to the compensation variation:

$$\text{CV} \cong \int_{p_i^0}^{p_i^1} x_i^M(p,m) dp_i$$

CV expresses the change in willingness to pay (WTP), i.e. a change in welfare, as a consequence of change in consumers' surplus. We can also express WTP as the maximum an individual is willing to pay for *not* having HABs. If the good i is normal, the CV based on the ordinal, observable demand curve, has a tendency to overestimate the true effects. But a sufficient condition that the Marshallian approximation is equal to the true effect is that the marginal utility of money is constant. If we have an expression for the demand for the good, we can calculate the CV, given a change in quantity or price. Below we refer to some analyses that estimate the willingness to pay for environmental improvements. *Example*: If the observable demand function can be expressed in the following way: $x = \alpha p^{\gamma}$, and α: constant, γ: price elasticity. The integral of the function is: $({}^{\alpha}\!/\!_{\gamma+1})p^{\gamma+1}$. We do not include the constant. Suppose that $\alpha = 1$, $\gamma = 1$, $p_0 = 5$ and $p_1 = 6$. The increases in price induces a loss in consumers' surplus equal: $\frac{5^2}{2}-\frac{6^2}{2}=-\frac{11}{2}$. The loss in consumers' surplus represents the compensation variation, i.e. $CV=\frac{11}{2}$.

5.3 Conclusion

We have so far discussed how we can estimate the economic welfare effects from HAB-events on producers and consumers. For the producers we have taken into consideration that the extent of the welfare loss is dependant on whether HAB (1) directly influences the variable costs, i.e. shifts the marginal cost curve by affecting negatively the productivity or (2) induce changes along the marginal cost curve for example when HAB-events induce closing of the fishery or limit the commercial recreation-market. We have seen that the net effect depends on whether changes in quantity can influence the market price. We have also discussed the possibility that HAB can cause diseases, and how we can estimate costs from that outcome.

In the last paragraph we discussed how we could estimate the welfare effects from HABs on consumers. We asked: What is the welfare effect on the consumers if HABs reduce the aggregated supply, and induce an increase in the market price? We concluded that a combination of information on the observable demand curve and price (or a change in quantity), gives us the opportunity to estimate the welfare effect. We used the compensation variation to express the welfare effect. We have not taken into consideration the possibility that the consumers fear that HAB can poison them by eating contaminated fish and that this fear may generate a negative shift in the demand for farmed or wild fish.

6 ESTIMATION OF WELFARE EFFECTS FROM CHANGES IN PUBLIC GOODS

6.1 Problem definition

It was mentioned in the introduction that we can identify a subgroup of goods or amenities that are not exchanged in a market with prices, and that it is correspondingly difficult to evaluate what impact a change in “supply” or quality will have on welfare, particularly in monetary terms.

Most of the environmental goods have an element of “collective” or “public” good character. A public good is a commodity or service, which if supplied to one person can in most cases be made available to others at no extra cost. A public good is thus said to exhibit non-rival consumption; one person’s consumption of the good does not reduce its availability to anyone else. These goods have also the characteristic of non-excludability; if the good is provided or exists it is almost impossible to prevent anyone from consuming it. Access to the good is not privatised, and the public authority guaranties by law free access in using them. The element of non-excludability prevents private markets from both functioning and supplying the good. These goods have obviously a value, but the “commodities” are not bought and sold in a market. For analytical purposes: It is a problem to evaluate or analyse changes in respectively “supply”, access, quality or possibility to consume these goods when they are not consumed in a market with prices.

Previously we have clarified how changes in commercial activities induced by changes in environmental conditions can be estimated. But problems show up when we evaluate environmental changes in public goods which we have no market prices on, e.g. recreational activities, cultural and historical objects, landscape aesthetics, water quality and the ecosystem in general.

6.2 A solution of the problem

In general the monetary value of a good, also included a public good, can be estimated from the consumers willingness-to-pay (WTP). The area under the aggregated demand curve represents an estimate of the willingness to pay for the good and, accordingly, it represents the value of the good. We can infer that a change in the supply of the good will induce a change in the willingness to pay, and subsequently it also represents a change in the value of the good. A reduction in the supply or access to the environmental goods will give a loss in utility or welfare, measured as changes in WTP. The problem is to identify or estimate the WTP for public goods. In the previous paragraph we have mentioned that there is a relation between compensation variation (CV) and WTP.

In this case we have a causal relation between HAB events and changes in environmental conditions, which in the end have negative effects on a set of human activities. The result is a loss in utility and welfare – measured in the form of WTP. There are developed different methods to estimate the WTP for environmental goods. Two approaches are applied, respectively a direct and an indirect method.

6.3 Direct and indirect methods to estimate WTP

In the direct method people are asked directly about their WTP. The indirect approach derives the WTP by analysing people's behaviour in markets for related private goods, and these private goods are priced in a market. People's relation and valuation of the environment has two aspects, respectively a use-relation and a non-use relation. The use-value refers to situations where people *physically* use or have the option to use the environment, e.g. the recreational value of fishing, bathing/swimming/beaching, boating etc. The non-use value refers to the (altruistic) value of *preserving* the environment for respectively the existing generations and for the future generations. According to the last mentioned classification, we divide the non-use value in respectively existence value (for example the value of biodiversity), option value and bequest value.

On the other hand, the direct approaches, which are applied to derive the WTP, estimate both use and the non-use values. The indirect methods appraise the use value.

The contingent value method (CVM) seems to be the most used direct approach to measure the WTP for the environment – or changes in the environment. CVM reveal the preferences to the consumers with the use of surveys or experimental settings. The structure of the questions is; "if this or that happen, what are you willing to pay?" Based on these types of questions, a hypothetical market is constructed. These methods have biases. For discussion on that topic we will refer to Mitchell and Carson (1989).

The transport or travel cost method (TCM) is an indirect valuation technique to estimate the current use value of e.g. a recreational area. The method is based on the existing behaviour in the market for services and goods related to the area. There exist a set of recreational activities (walking, swimming, surfing, fishing, boating etc.) For each of these activities the resulting benefit is assumed to exceed the "travel cost", consisting of respectively the monetary travel cost, the opportunity cost of time, and the additional expenses linked to specific recreational activities (Römer & Pommerehne 1992). Both the TCM and hedonic price method (HPM) are based on behaviour in markets that are correlated to the environmental good in question. E.g.: Differences in property prices could be modelled as a function of changes or level of air quality, air/road traffic noise levels (Iten 1990).

The mentioned methods are not suited for measuring the value of future environmental changes. The advantage for the indirect methods is that the starting point is observed data from related markets. We will not go deeper into this subject. In the next paragraph we present some examples of studies which try to estimate the value of environmental goods.

6.4 Studies in WTP for environmental goods – examples from Norway

The environmental studies where the WTP-method is an the intergraded part of it, started in the early eighties. Most of the environmental studies in Norway attempt to assess the effects of changes in water quality – especially effects on fish stocks.

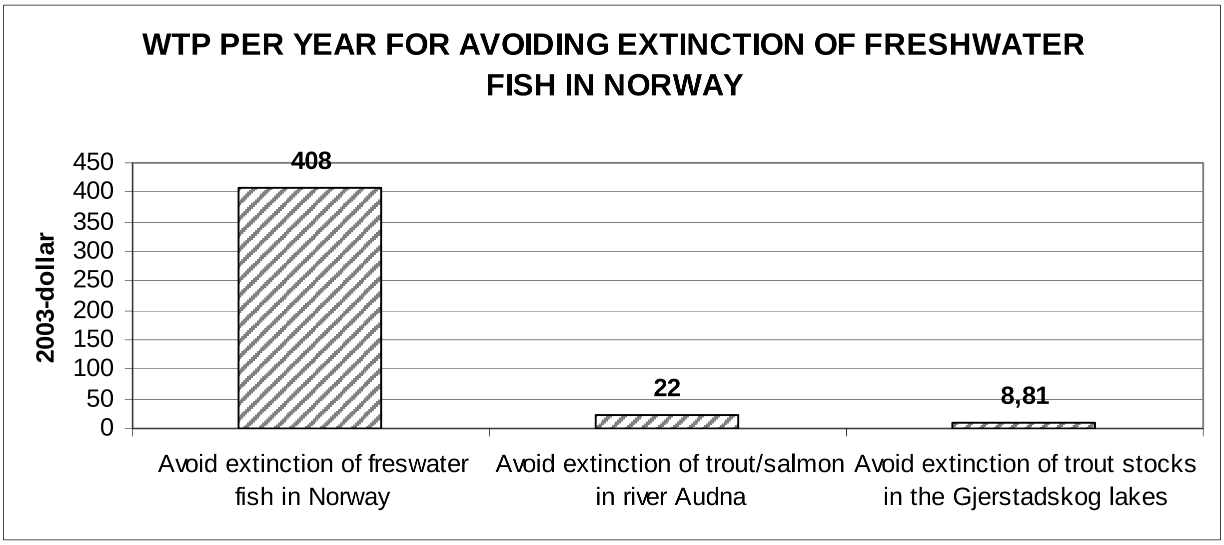
The first environmental studies were done by Strand (1981a, b). He analysed the welfare effects induced by acid rain, and how it damaged water quality and recreational fishing (Strand 1981a). He estimated the willingness to pay (WTP) for avoiding total extinction of freshwater fish in Norway due to acid rain, over a period of about 10 years. The result indicated that the average WTP could be in the neighbourhood of 1700 to 2750 NOK (Norwegian kroner) per year for persons over 15 years of age. All figures stated here are in 1991-values. Strand (1981b) estimated with the use of the TC-method the average recreational valuation per angler per fishing day in Gaula (river) to about 335 NOK. Most of the studies estimated the WTP for recreational fishing/angling in fresh water (Navrud 1990, Rolfsen 1990).

Navrud (1991b) estimated with the use of CVM the recreational value per day (use value) of angling in the sea to about 40-65 NOK per person. If the TCM is applied the WTP is about 27 to 56 NOK. During the period 1981-1991 11 studies of the recreational value of freshwater and saltwater angling have been done. The average recreational value (use value) per angling day is about 185 NOK. The estimated figures represent the average of the estimates in each study.

Navrud has done two studies on the non-use values of freshwater fish stocks (Navrud 1991 a, b). The studies estimate respectively; the WTP per individual per year to avoid the extinction of the current salmon and sea trout stocks in river Audna (local), and avoiding the extinction of current trout stocks in the Gjerstadskog lakes (local) by neutralization of acid depositions. The estimates were calculated to respectively 120 and 48 NOK (1991-NOK).

Among other (old) studies addressing different aspects of water quality are for example Heiberg and Hem (1987, 1988), Aarskog (1988), Dalgard (1989) and Magnussen and Navrud (1991). Heiberg and Hem (1987) estimated the mean, annual willingness-to-pay (WTP) per local household per year for improved water quality in Kristiansand Fjord. The user and non-user value (weighted average) was estimated to 447 NOK (1991-NOK). Aarskog (1988) and Heiberg and Hem (1988) estimated the mean WTP per local household per year for better water quality in the inner Oslo Fjord to respectively: users 942 NOK and non-users 522 NOK (all figures in 1991-NOK). Dalgard (1989) estimated the WTP per household per year for improved water quality in the Drammen Fjord to respectively: users 883 NOK and non-users: 433. All figures are in 1991-NOK. Figure 1 and 2 are based on the referred articles in this paragraph. Figure 2 shows the willingness to pay (WTP) for avoiding extinction of freshwater fish in Norway. The average willingness is 15.3 dollar per year (2003-value).

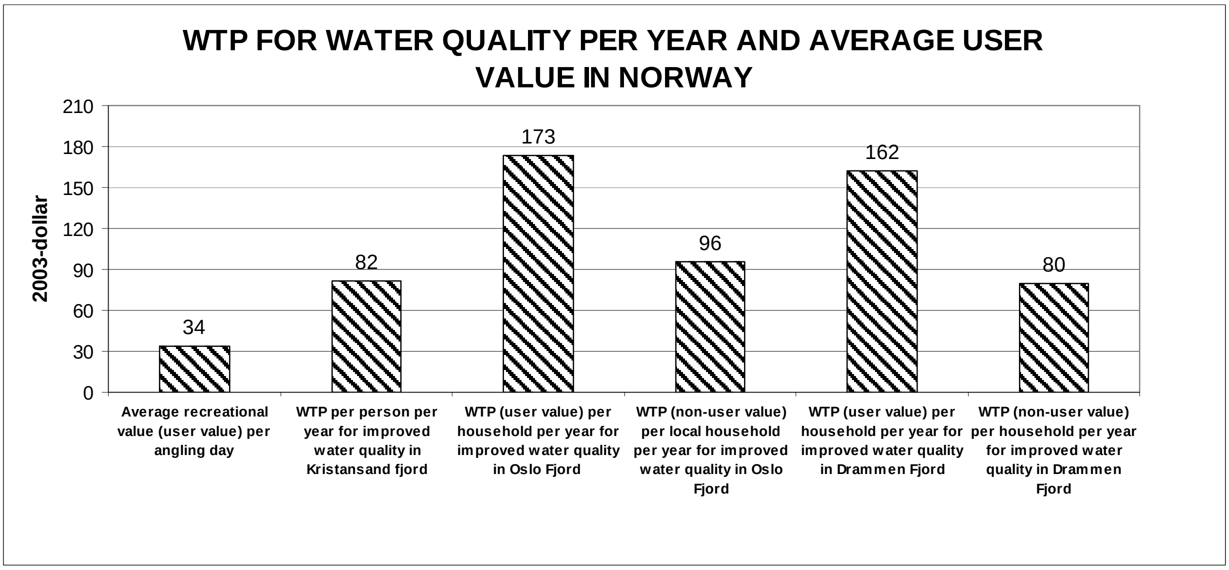
Figure 2: Willingness to pay for avoiding extinction of fish.



Source: Based on Navrud 1992

Figure 3 shows the willingness to pay (WTP) for water quality and recreation per year in Norway. The numbers are measured in 2003-dollar value (7.04 Norwegian kroner per dollar). The average WTP is 103 dollar per year.

Figure 3: Willingness to pay for water quality in Norway.



Source: Based on Navrud 1992

6.5 Conclusion

The main reason for presenting these analyses and figures is to illustrate how people valuate the environment, and to show the selected estimation method. We can question whether these analyses and estimated figures are representative or valid for today’s value on water quality (in fjords) and recreational use and non-use value of freshwater fish stock. We must be aware of that the methods are connected with biases, and we doubt that the preferences for environmental quality are invariable during a period of 15 years. On the other hand we think that people’s preferences for environmental quality are stronger to day compared to 15 to 20 years ago.

7 CASE STUDIES IN HAB-EVENTS ALONG THE COAST OF NORWAY, USA AND MARINE WATERS OFF EU-COUNTRIES

7.1 Introduction

In the following paragraph we present some examples of HAB-events mainly along the coast of Norway, USA and marine waters off EU-countries during the last 15 to 20 years.

If we partly follow Scatasta et al. (2004) and combine our theoretical and principle findings, we can in table 1 present the following accounting framework. The accounting framework is constructed with respect to be applied in a systematic assessment of different effects induced by algae blooms. The upper part of the table is applied for registering the point of time of HABs, which geographical area and what sector of the economy is affected. The third column refers to type or category of alga bloom. The lower rows are used for identifying what type of losses the alga bloom induces.

Table 1: Suggested accounting framework for HAB events.

ECONOMIC IMPACT FROM HARMFUL ALGAE BLOOMS (HABs)

Time ***t***	**Geographical region** ***j***	**Bloom type**	**Public health** (Loss of production, medical care)	**Commercial fisheries** (Reduced production, negative effects on quality and price, bad reputation, negative stock dynamic effects, increased economic risk, reduced future potential)	**Aquaculture industry** (Reduced production, bad reputation, negative effects on quality and price, negative stock dynamic effects, moving costs, increased economic risk, reduced future potential)	**Commercial tourism** (Fouling the beaches, negative aesthetic effects, running the risk of being poisoned, negative reputation, negative effect on demand)	**Recreation** (Fouling the beaches, negative aesthetic effects, running the risk of being poisoned, negative reputation, negative effect on demand)	**Biodiversity** (HABs may endanger species)	**Monitor and management costs**	**Total**
t	***j***	**STB**: Seafood Toxic Blooms								
t	***j***	**FK**: Fish Killing Blooms								
t	***j***	**HBNT**: High Biomass Non-Toxic Blooms								
t	***j***	**HBT**: High Biomass Toxic Blooms								
Total loss in direct use values (individuals make actual use of the resources)										
Total loss in indirect use values (the society benefits from a well functioning ecosystem, and the resource is a part of the system)										
Total loss in option use values (individuals are willing to pay for the option of using the resource in the future)										
Total loss in bequest values (individuals are willing to pay to ensure that future generations will be able to use the resource in the future)										
Total loss in existence values (for example in biodiversity)										

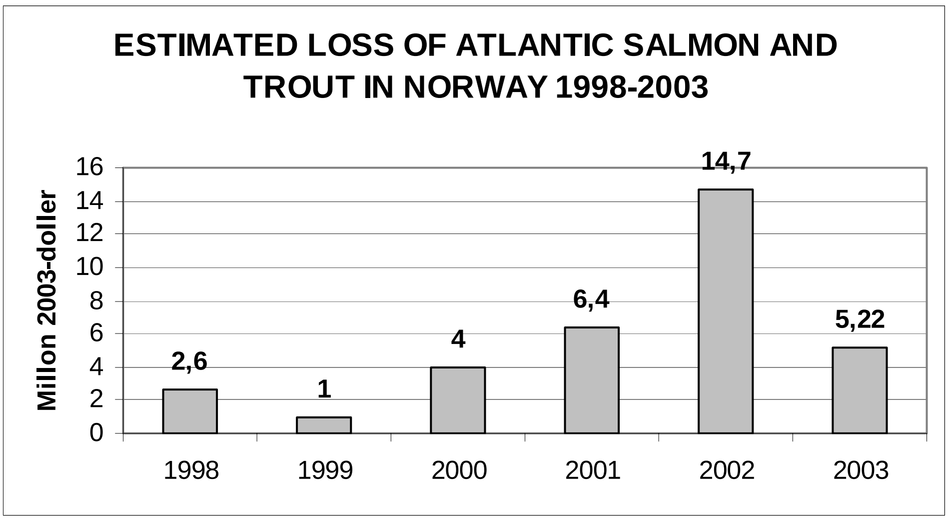
7.2 Norway

Since the 70ties the alga *Chattonella* spp. has caused problems for the aquaculture industry in Japan. *Chattonella* was first observed in the North-European coastal waters of the Netherlands and Germany in the early 90ties. The first big bloom of *Chattonella* in this geographical area took place in 1998 (Naustvoll et al. 2002). High concentration of *Chattonella* has dominated the sea waters from the coast of Germany, along the coast of Denmark, Skagerrak and along the coast of Norway to the outlet of Boknafjorden. The second big bloom took place in the spring of 2000. The third big bloom of *Chattonella* and *Heterosigma akishimo* started in Skagerrak in the spring of 2001. The bloom in 2001 had negative effects. It was registered that the alga killed wild fish along the coast of south- and west coast of Norway. The fish farmers of salmon lost about 1100 tons of fish. If we apply the expression deduced in the methodology paragraph for changes in producer's surplus $\Delta PS = p^0 \Delta y$, we can estimate the loss. The bloom caused direct loss to several fish farmers and also other mitigation actions caused direct losses or reduced profit to the industry. The average market price for salmon was about 25 NOK per kilo (slaughtered fish). The loss in producer's surplus is; $\Delta PS = (25\text{NOK/kilo})x(1100000\,\text{kilo}) = 27.5\,\text{mill. NOK.}$ We have no figures that give us information whether other commercial activities, for example traditional fisheries, were inflicted economic losses. We have heard that people were warned not to bath in particular, local coastal areas during the bloom. This gives us an indication that the bloom had some negative effects on recreation, but it is so far impossible to quantify this effect.

The Norwegian Directorate for Fisheries started in 1999 to register the main causes behind losses of farmed fish, i.e. losses of Atlantic salmon and trout in plants along the coast of Norway. In 1999 the loss of farmed salmon caused by algae and/or jellyfish was estimated to 178 000 individuals. The relative importance between jellyfish and HAB is unfortunately not reported in the referred statistics. The average weight of the fish was 1.69 kilo, and the average price was 21.62 NOK/kilo. The estimated loss in producers' surplus is $\Delta PS = p^0 \Delta y$, and if we substitute for the figures we get: $\Delta PS = 21.62\,x\,1.69\,x\,178\,000 \cong 6.5$ million 1999-NOK. During 2000 it was reported losses of fish caused by HAB and/or jellyfish in the area of Flekkefjord and minor losses along the coast of Rogaland and Hordaland . It was reported a loss of 1.323 000 individuals, mostly salmon, during 2001. The average price was 18.71 NOK per kilo, and the average weight per fish was 1.76. The estimated loss in producers' surplus was that year about $\Delta PS = 18.71\,x\,1.76\,x\,1.323\,000 \cong 43.6$ million 2001-NOK. About 30 of these millions were losses of salmon caused by HABs. During 2002 the loss caused by HAB or /and jellyfish was respectively 2670513 salmon and 373444 trout individuals. Because we don't have price-figures for 2002, we use the 2001-prices when we estimate the value of the losses and we also use the same figures for trout: $\Delta PS = (2.670513 + 373444)18.71\,x\,1.76 \cong 100$ million 2001-NOK. The huge loss is first of all caused by jellyfish. During 2003 it was reported a loss of 1.048 000 salmon individuals and 150 000 trout individuals. Average price is respectively 16.20 and 17.84 kroner per kg. Average weight is respectively 2 and 1.46 kg per individuals. The economic loss of salmon and trout is respectively 33 and 3.9 million Norwegian kroner (nominal). The main causes behind the losses are jelly fish. During this short time period the variance in yearly losses is quite big. Figure 4 summarizes the losses in the Norwegian aquaculture industry (salmon and trout). The losses due to jelly fish and algae amount on average to about 0.5 % of the first hand value per year.

June 2005 it was reported a huge loss of about 650 tons of farmed salmon due to alga bloom (Heterosigma). Two plants were hit, and the plants are located at the coast off Vest-Agder county. The loss is estimated to about $\Delta PS = 20$ NOK/kg x $650.000 \cong 13$ million Norwegian kroner. The 2005-loss is not integrated in figure 4.

Figure 4: Estimated loss of salmon and trout in Norway.



Source: Directorate of Fisheries in Norway.

7.2.1 The coast of Oslofjord and Rogaland

The alga *Chrysochromulina* caused mortality of fish along the coast of Skagerrak in 2000. The alga *Polykrikos* caused mortality of farmed fish in the area of Flekkefjord during the autumn of 2000. It was also high concentration of HABs (Dinophysis acuta which is a Diarrhetic Shellfish Poisoning – DSP alga) in shellfish along the coast of Skagerrak. The frequencies of these HABs are of course a problem both for the recreational and commercial shellfish industry. We have so far no figures that illustrate the economic welfare effects.

It was also reported that a minor loss of farmed fish (salmon) along the coast of Rogaland and Hordaland caused by HABs (Polykrikos). Mainly DSP (Diarrhetic Shellfish Poisoning) and PSP (Paralytic Shellfish Poisoning) were registered in shellfish along this part of the coast.

7.2.2 Chattonella – a new HAB along the coast of Norway?

During May 1998 *Chattonella* spp. caused a loss of about 350 tons farmed salmon in the area around Farsund and Flekkfjord in Norway. It was the first time *Chattonella* was registered in high and harmful concentration, and it caused fish mortality. The hypothesis is that *Chattonella* was imported into the sea area by ballast water. If we apply the expression deduced in the methodology paragraph for changes in producer's surplus $\Delta PS = p^0 \Delta y$, we can estimate the loss. In addition many farmers had to move plants from areas were they expected high concentration of HABs. The average unit export price for salmon was about 35,50 NOK per kilogram, 1998-value. The loss is estimated to about ΔPS = 35,50NOK/kg x 350.000 kilogram $\cong$ 12.8 mill. Norwegian kroner, and adjusted with the consumer price index, it represents about 18 million 2003-NOK.

During May *Chattonella* also caused a loss of wild fish species (tobis, garfish, herring and mackerel) along the coast of Denmark. For the time being we have no figures to assess the quantitative effects or the loss in monetary value. The high concentration of *Chattonella* was explained by irregular high concentration of nitrate and phosphor emission in the southern part of the North Sea (Aure, 2000).

The loss of salmon and trout has varied a lot during the time period 1999-2003. The main cause of the losses is on average jellyfish. The loss relative to the total production of salmon is marginal, and it is definitely not to expect that the market price is influenced by the marginal change in quantity supplied generated by HABs and jellyfish. The estimation of the loss by using the formulae $p\Delta y$ is a valid approximation to the actual loss.

7.3 Empirical analysis of HABs in USA

In this Section we present an analysis of HABs in USA and the economic effects. Anderson, et al. (2000) has estimated the annual economic impact from harmful algae blooms (HABs) in the United States. The study is based on observations of harmful algae blooms, or "red tides", during the six-year interval 1989-92. The authors emphasize that the selected HAB-events represent a subset of all outbreaks that occurred during the reporting period, thus the aggregated economic impacts underestimates the true impacts.

The authors conclude that HABs have increased steadily in both species complexity and geographical extent over the last seven decades. In turn, the range of harmful effects and the magnitude of economic costs have also widened.

The economic impacts are grouped into four basic categories, respectively; (1) public health impacts, (2) commercial fishery impacts, (3) recreation and tourism impacts, and (4) monitoring and management costs. Table 2 summarises their findings.

Table 2: Estimated Annual Economic Impacts from Harmful Algal Blooms (HABs) in the United States (estimates is of 1987-1992 period, reported in 2000 dollars).

	Low	**High**	**Average**	**% of total**
Public Health	18,493,825	24,912,544	22,202,597	45%
Commercial Fishery	13,400,691	25,265,896	18,407,948	37%
Recreation/Tourism	-	29,304,357	6,630,415	13%
Monitoring/Management	2,029,955	2,124,307	2,088,885	4%
TOTAL	33,924,471	81,607,104	49,329,845	100%

Source: Anderson et al., 2000.

These figures represent the annual aggregate economic impacts (in millions of 2000 US-dollars) of HABs in the United States during 1987-92. The total costs average is $ 49 million per year, ranging from $ 34 million to $ 82 million. Public health impacts represent the largest component.

7.4 Harmful algal blooms in the European marine waters

Scatasta et al (2004) has analyzed the socio-economic effects of HABs in European marine waters. The results are presented in two of five reports, respectively the third and fifth delivery. In the following we refer to the third delivery: “Harmful Algal Blooms in European Marine Waters: Socio-economic analysis of selected case studies”, and the fifth delivery “The Socio-Economic Impact of Harmful Algal Blooms in European Union Countries”.

The third delivery is based on case studies from the following geographical regions in EU; Galicia (Spain), the province of Rimini (Italy), Galway (Ireland), Zandvoort (The Netherlands), Hanko (Finland) and Les Pradet, Hyéres, and Corquieranne (France). The analysis focuses on the impact of HABs on mussel aquaculture and tourism. The authors have assessed the negative welfare effects induced by HABs by using different methods to measure changes in consumers’ and producers’ surplus. Table 3 presents the negative effects measured in monetary terms.

Table 3: Socio-economic effects from HABs in selected European marine waters.

GEOGRAPHICAL REGION	**SECTOR**	**WELFARE EFFECTS DUE TO HABs**: $\Delta W = \Delta PS + \Delta CS$
Galicia (Spain)	Mussel aquaculture sector	Between 56 and 255 million Euro per year. Based on case studies during the period 1989-1998.
Rimini (Italy)	Mussel aquaculture sector	1.7 million Euro per year
Riccione (Italy)	Tourism sector	0.9-4.8 million Euro per year
Galway (Ireland)	Tourism sector	8.8-16.1 million Euro per year
North-Holland (The Netherlands)	Tourism sector	9.6-16.8 million Euro per year
Hanko (Finland)	Tourism sector	85-538,000 Euro per year
La Pradet, Huéres and Corquieranne (France)	Tourism sector	4-433,000 Euro per year

Source: based on Scatasta et al 2003, third delivery.

The negative welfare effects are the sum of revenue losses in the shellfish industry, the tourism industry and the loss in consumers' surplus. The analysis shows that HABs have negative welfare effects on business and recreation in the coastal areas. It is no doubt about that. On the other hand we can question the reliability and validity of some of the methods the authors apply in the assessment of the effects, especially when they estimate the welfare losses on tourism. The specification and evaluation of the econometric models are insufficient. The authors measure the impacts of HABs by asking consumers (tourists) questions to reveal what they are willing to pay (WTP) for a 25% reduction in the frequencies of HABs, and 50% immediate reduction in the risk of getting shellfish poisoning when eating mussels. It is criticisable to apply a contra factual analysis to analyse the costs of HABs. The argument is that HABs may actually be a natural part of the ecosystem and it is therefore irrelevant to ask the question, because it can be practically impossible to eliminate HABs. The element of absurdity in such questions reveals itself if we for example try to find out what inhabitants and tourists are willing to pay for a 25% reduction of rainfall in Bergen in Norway where it normally rain heavily during a year. The authors do not ask the question whether HABs are a natural part of the ecology or whether it is a result of human activity (pollution, run off, emission of ballast water etc) and can be controlled by policy. The WTP is an estimate for the impact of HABs on a representative consumer (or tourist). WTP is estimated between 10 and 71 Euro per visitor per year. When there are about 23 million coastal visitors in EU in 2000, and about 40% of them experience problems with HABs, they find it easy to extrapolate the welfare loss due to HABs. According to these figures the HABs impact on tourism in 2000 is between 494 and 880 million Euro (Scatasta et al, fifth delivery 2003 p. 21). The socio-economic impacts of HABs in European Marine Waters are summarized in table 4.

Table 4: The Socio-Economic Impacts of HABs in European Marine Waters (yearly average in million EURO)

PUBLIC HEALTH	**COMMERCIAL FISHERY**	**RECREATION AND TOURISM FOR 2000**	**MONITORING AND MANAGEMENT COSTS**	**TOTAL WELFARE EFFECTS DUE TO HABs**: $\Delta W = \Delta PS + \Delta CS$
0.12	158	687*	19	864

Souce: Scatasta et al, fifth delivery 2003 p. 36

* Given that about 40 % of the coastal visitors have experienced HABs

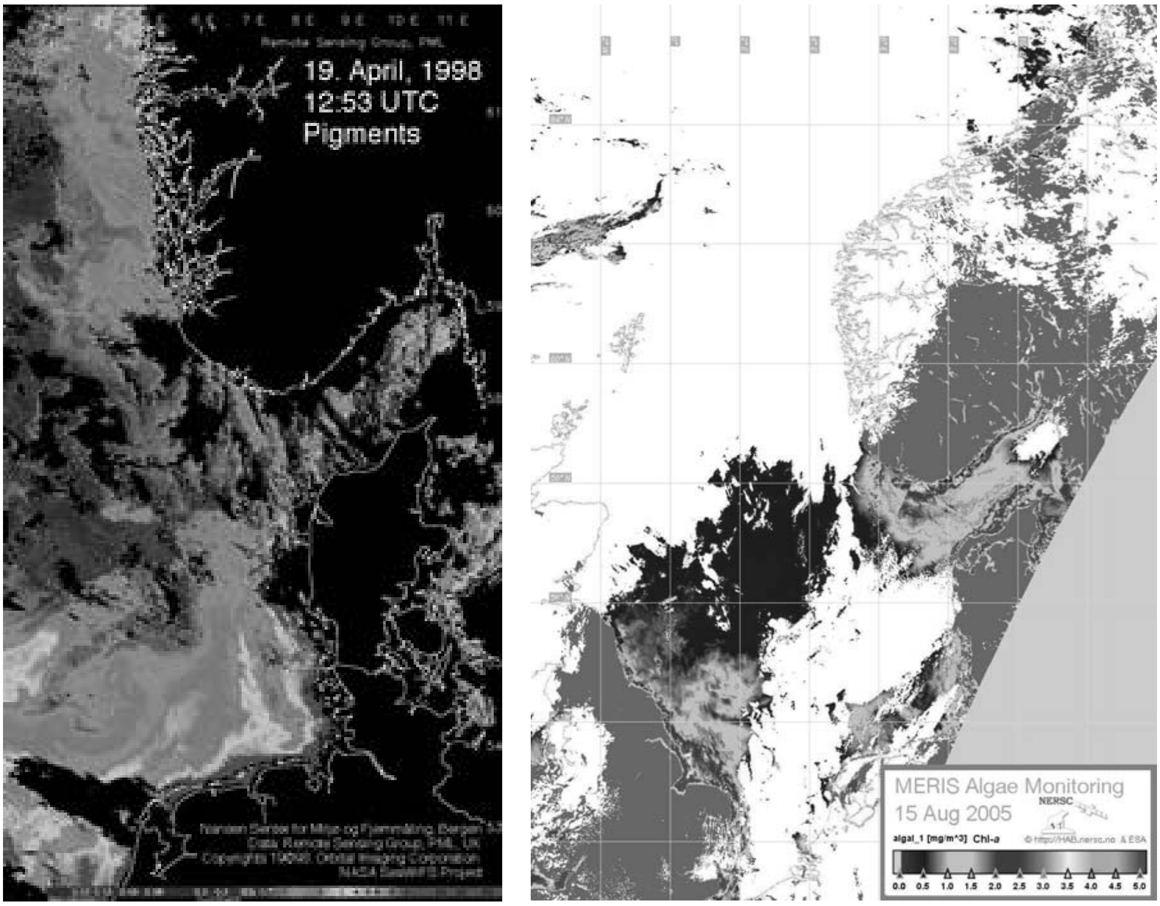
The analyses indicate that the total welfare costs due to HABs in European marine waters summarize to above 800 million EURO per year. The greatest losses are to be found in the tourism sector, followed by consumer losses in the mussel sector. The county with the greatest losses appears to be Spain immediately followed by France and Italy (Norway was not included in this study). The losses in the commercial fishery (mussel sector) are estimated to 158 million EURO per year, and it should be noted that over 70 % of the losses in the mussel sector are losses in consumers' surplus.

8 THE ECONOMIC RATIONALE BEHIND OPERATIONS OF A MONITORING AND EARLY WARNING SYSTEM

The cases and examples presented in the previous sections document that HABs induce different types of costs on society. It is to expect that a future increase in HABs also will affect the probability for losses in the aquaculture industry, and it will also influence the value of the firm. The insurance industry will revalue or reprice the insurance contracts if the frequency of HABs shifts. Let us for the moment neglect the causes behind the HAB-events, but rather ask: Is it possible to build up a warning system for HABs that can contribute to reduce the losses? If it is possible to build a , HAB-forecasting system, analogous to the weather forecasting, than it is potentially profitable. In the following we discuss the economic criteria for a HAB-warning system.

Example: Institute of Marine Research (IMR) in Norway started to build up a system to monitor or detect algae in the 1980ties. Because of “early” problems with algae the Institute of Marine Research in Norway has built up a system for measuring the concentration of different types of algae. The monitoring system was established in 1981, and the main objective was to monitor *Gyrodinum aureolum*, which in high concentration cause brown sea and fish mortality. In 1984 it was monitored high concentration of *Dinophysis*, and it can cause diarrhoea. *Example*: The Nansen Environmental and Remote Sensing Center (NERSC) in Norway started to use remote sensing to analyse Skagerrak and the coastal waters off Norway for among other monitoring of algal blooms in coastal waters. NERSC gives information to the Directorate of Fisheries in Norway of potential bloom situations in order to initiate dedicated sampling or monitoring actions. Daily image information and an assessment bulletin are produced and disseminated via the direct e-mail distribution and a dedicated web-system, http://www.nersc.no/HAB. Example: Figure 5 shows an example of remote sensing of chlorophyll in the southernmost sea areas off Norway and Skagerak region.

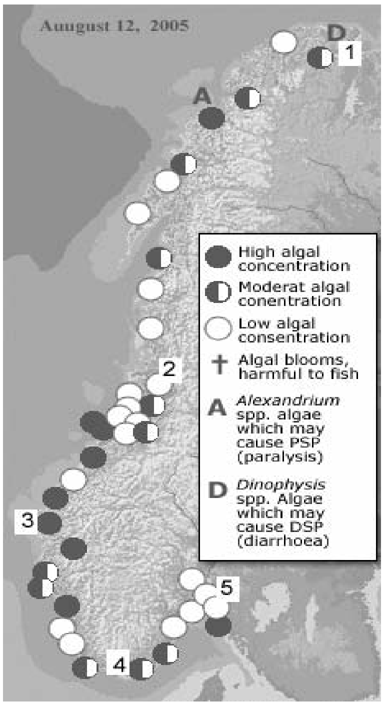
Figure 5: Remote sensing, chlorophyll concentration in the North Sea and Skagerrak 19th of April 1998 and 15th of August 2005.



It should also be mentioned that many countries have instituted monitoring programs and action plans to provide early warning to their fishermen and to guide mitigation strategies. For an overview see Andersen 1996 and Anderson et al 2001.

After the big and damaging bloom of *Chrysochromulina polylepis* in 1988, which caused high mortality in both wild fish species, and losses of farmed fish, *Chrysochromulina* was also integrated in the warning system. Since 1988 Institute of marine Research, Directorate of Fisheries in Norway, Oceanor AS, NIVA (The Norwegian Institute of Water Research), Norges Veterinærhøgskole (The Norwegian Veterinary College), Næringsmiddelkontrollen (the local food control) i Midt-Rogaland and Statens Næringsmiddeltilsyn (SNT-The Norwegian Food Control) are taking part in the nation-wide monitoring system from 27 stations along the coast from Sweden to the coast of Finnmark in the north of Norway. This information is published weekly at http://algeinfo.imr.no. *Example*: Figure 6 shows algae information in Norwegian waters off Norway (12th of August 2005).

Figure 6: Algae information in Norwegian waters



The monitoring is systematic and time series give the opportunity to test hypothesis whether the sequences of algae blooms are induced by human activity. The system is concentrated to the Skagerrak area because the sea-stream starts in this region, and transports water masses along the coast of Norway. So far we neither have any information on what the investment costs of the monitoring and warning system are, nor what the yearly operational costs are, which are included in the regular budgets of operations for the participating institutions with limited dedicated funds available. Below we discuss in general terms the rationale behind a commercial oriented warning system for HABs.

In it self it is important to monitor the quality of the coastal water and whether "vital" and "dangerous" substances increase or decrease – included HABs. A warning system has also a commercial value. If the warning system can spread information about a coming HAB-attack, the fish farmers can have an option do move the caches to a safer place. A simple example illustrates the economic argument for a warning system.

$$
\begin{aligned}
I &= \text{investement costs of the warning system} \\
p_0 &= \text{probability for costs } C_0 \text{, given HABs} \\
p_1 &= \text{probability for costs } C_1 \text{ caused by HABs after implementing the information system} \\
n &= \text{number of identical producers} \\
E &= \text{expectation operator}
\end{aligned}
$$

It is profitable to invest in the monitoring and warning system if the expected gains are higher than the investment costs, i.e.

$$E\{C_0 - C_1\}n > I \Rightarrow (p_0 C_0 - p_1 C_1)n > I$$

If we take time into consideration, and presuppose that prices are constant and no dependency between the periods, the reduction in losses is identical with higher profits compared with no warning system. Let us define $\Delta\pi_t = (C_0^t - C_1^t)$, where t is period $0,\ldots,T$. r : constant real interest rate over all periods. The criteria for a profitable investment in a warning system can be expressed in the following way:

$$I < \sum_{t=0}^{T} \frac{E\{\Delta\pi_t\}}{(1+r)^t}$$

From the criteria, we will conclude that it is profitable to invest in a warning system if the discounted expected gains are higher than the investment costs. We have the impression that the HAB-events have increased over time, and we cannot disregard the possibility that the increased frequency of HABs make particular areas along the coast unproductive and useless for location of aquaculture industry – or other marine activities. In such cases the option value of these areas are zero.

The value of information and a warning system can be illustrated in the following alternative theoretical example. Assume two outcome or events, respectively a situation with HABs or a situation without HABs. The actors in for example the aquaculture industry can choose to take action or not take action to reduce the damages from HABs. The outcomes; profits with and without HABs and with or without taking action are summarized in table 5.

Table 5: Expected outcome with or without HAB events and respectively actions or no-actions are taken.

EVENT	ACTION	
	Action	No action
HABs	π_A^H	π_{NA}^H
No HABs	π_A^{NH}	π_{NA}^{NH}

Suppose that there are two outcomes, respectively HAB-event or not HAB, and the associated probabilities $(1-p)$ and (p). Table 5 and 6 show respectively the outcomes, probabilities, profits with or without action and expected profits.

Table 6: Expected probabilities and profits with or without HAB events and respectively actions or no-actions are taken

EVENT	ACTION			NO ACTION	
	Probability	**Profit**	**Expected profit**	**Profit**	**Expected profit**
No HABs	p	π_A^{NH}	$p\pi_A^{NH}$	π_{NA}^{NH}	$p\pi_{NA}^{NH}$
HABs	$(1-p)$	π_A^H	$(1-p)\pi_A^H$	π_{NA}^H	$(1-p)\pi_{NA}^H$
Totals		Expected profit with action: $E_A = p\pi_A^{NH} + (1-p)\pi_A^H$		Expected profit without action: $E_{NA} = p\pi_{NA}^{NH} + (1-p)\pi_{NA}^H$	

Based on information from the table 5 and 6 we can conclude that it is not rational to take action, for example move the aquaculture plant to a safer place (another fjord) if the expected profit by doing *nothing* (no action) is higher than the expected profit by taking action, i.e. if the probability of no HAB is p (or HAB is $1-p$)

$$p\pi_{NA}^{NH} + (1-p)\pi_{NA}^H > p\pi_A^{NH} + (1-p)\pi_A^H$$
$$\Downarrow$$
$$p\pi_{NA}^{NH} - p\pi_{NA}^H - p\pi_A^{NH} + p\pi_A^H > \pi_A^{NH} - \pi_{NA}^H$$
$$\Downarrow$$
$$p > \frac{\pi_A^{NH} - \pi_{NA}^H}{\pi_{NA}^{NH} - \pi_{NA}^H - \pi_A^{NH} + \pi_A^H}$$

The result says that if the probability p for *no* HABs is greater than $\frac{\pi_A^{NH} - \pi_{NA}^{H}}{\pi_{NA}^{NH} - \pi_{NA}^{H} - \pi_A^{NH} + \pi_A^{H}}$ it is *not* rational to take action with respect to accommodating to HABs. On the other hand if the difference between the expected profit with and without action is big enough, it is to expect that the firm will have incentive to do something. Suppose that the costs (operational costs per year) of having access to a information and warning system is c_W and that the costs associated with the action is c_M. It is to expect that the aquaculture industry will have incentive to invest in an information and warning system, and take action if the difference between respectively expected profit with and without action is greater than the costs of information and action costs, i.e.

$$E_A - E_{NA} > c_W + c_M$$

The theoretical model shows that the value of information and a warning system is dependent on different factors, first of all; the probability of HABs $(1-p)$, the costs of operating the warning system (c_W), the costs of action (c_M) and not least the difference between expected profit with and without action $(E_A - E_{NA})$.

9 SUMMARY

The last part of the analysis shows that HAB-events causes new and severe impact on human activities along the coastal areas in Europe. The first registration of HABs was in the 80s with a direct economic impact, and in particular aquaculture and tourism industries are hampered by HAB events. The analysis also shows that the monitoring and forecasting of both harmful algae and frequencies of harmful algae blooms in Norway – and other places – have increased during the last 10 to 15 years. The exception is the commercial and non-commercial shellfish industry in Norway, which has had problems with harmful algae for a much longer period. Calculations indicate that the HABs and jellyfish induced yearly loss in the Norwegian aquaculture industry amounts to less than 0.5% of the production value.

It is claimed that the frequencies of HAB-events have increased, and the explanation is, among other factors, increased euthrophication of the coastal waters, changes in climate and spread of alien algae species through ballast water. We must also take into consideration that the monitoring system for detecting algae was built up during the 80ties. In addition we must also mention that the aquaculture industry has expanded during the last 20 years, so it is inevitably that high concentration of harmful algae will have greater negative impact today than it had earlier.

It is beyond doubt that the increase in HAB-events has also increased the economic losses. The description of cases in Norway confirms that. The empirical analysis of HAB-events and their economic effects in USA during the six-year interval 1989-92 is an example of one of the very few analyses in this field. The yearly average loss is estimated to about 50 million dollar. Analyses of HABs along the coast of the EU-countries show that HABs have negative effects on especially the tourism and mussel industry. The HAB induced costs amount between 0.3 and 0.6 % of total tourism expenditure in EU.

10 REFERENCES

Andersen, P. (1996): Design and Implementation of some Harmful Algal Monitoring Systems. Intergovernmental Oceanographic Commission technical series. UNESCO 1996.

Anderson, D.M, P. Andersen, V.M. Brecelj, J.J. Cullen and J.E. Jack Rensel (2001): Monitoring and Management Strategies for Harmful Algal Blooms in Coastal Waters. UNESCO 2001.

Anderson, D.M., P. Hoagland, Y. Kaoru and A.W. White (2000): Estimated Annual Economic Impacts from Harmful Algal Blooms (HABs) in the United States. Woods Hole Oceanographic Institution. WHOI-2000-II.

Aure, J. et al. 2000: Chattonella – en ny skadelig alge i norske kystfarvann. Havets Miljø 2000, Særnummer 2: 2000. Havforskningsinstituttet, Universitetet i Bergen.

Aarskog, E.M. 1988: Betalingsvillighet for ytterligere rensing av Indre Oslofjord (Willingness to pay for cleaning up the Inner Oslo Fjord). M.SC. thesis, Department of Economics, University of Oslo, *Centre for Industrial Research, Report no. 871013-2,* March 1988, 42 pp.

Bergh, Jeroen, P.A.L.D. Nunes, H.M. Dotinga, W.H.C.F. Kooistra, E.G. Vrieling, L. Peperzak (2001): Exotic harful algae in marine ecosystems: an integrated biological-economic-legal analysis of impacts and policies. *Marine Policy* 26 (2002) 59-74.

Braden, J. B. & C.D. Kolstad (eds.) 1991: Measuring the demand for environmental quality. Contribution to economic analysis 198. Elsevier Science Publishers B.V. (North-Holland), Amsterdam, 370 p.

Castberg, T., T. Torgersen, J. Aasen, T. Aune and L.J. Naustvoll (2004): Diarrhoetic shellfish poisoning in Cancer pagurus Linnaeus, 1758 (Brachyura, Cancridae) in Norwegian waters. Published in *SARSIA* 89:1-8 – 2004.

Cummings, R.G., Brookshire, D.S. & W.D. Schultze (eds.) 1986): Valuing environmental goods. An assessment of the Cintingent valuation method. Rowman & Allanheld Publishers, Totowa, N.J., 270 p.

Dahl, E., T. Aune, K. Tangen 1999: Giftalger og algegifter i norske farvann. Havets Miljø 1999. Havforskningsinstituttet, Universitetet i Bergen.

Dalgard, M. 1989: Drammensvassdraget – en undersøkelse av betalingsvillighet. (Willingsness to pay for regulatory actions towards water pollution in the Drammen Fjord). M.Sc. thesis, Department of Economics, University of Oslo. Centre for Industrial Research, Report no. 881108-2, August 1989, 95pp.

Diamond, P. A. 1993: "Testing the Internal Consistency of Contingent Valuation Surveys". Working paper, MIT, 1993.

EUROHAB (1998): Harmful Algal Blooms in European Marine and Brackish Waters. Report of an international workshop organised jointly by the MAST Programme of the European Commission, DG XII, NUTEK (Swedish National Board for Industrial and Technical Development) and University of Kalmar, Department of Marine Science. Edited by E. Granéli, G.A. Codd, B, Dale, E. Lipiatou, S.Y. Maestrini, H. Rosenthal. Delivery one to five.

Havforskningsinstituttet 2001: Skadelige alger. Havets Miljø 2001. Universitetet i Bergen.

Heiberg, A. & K.-G. Hem 1987: Use of formal methods in evaluating countermeasures to coastal water pollution. In H.M. Seip & A. Heiberg (eds.) 1989: *Risk management of chemicals in the environment*, Plenum Press, London.

Heiberg, A. & K.-G. Hem 1988: Tiltaksanalyse for Indre Oslofjord. En sammenlikning av tre forskjellige analysemetoder. Regulatory Impact Analysis of the Inner Oslo Fjord. A Comparison of three different methods. In Norwegian. *Centre for Industrial Research, Report no. 880105-1*, September 1988, 67 pp.

International Council for the Exploration of the Sea – ICES (2003): Environmental Status of the European Seas.

Iten, R. 1990: Die mikroökonomische Bewertung von Veränderungen der Umweltqualität. Dargestellt am Beispiel der Stadt Zürich (The Microeconomic Valuation of Changes of the Environmental Quality. Demonstrated at the Example of the City of Zurich. In: Schriftenreihe des Instituts für empirische Wirtschaftsforschung der Universität Zurich, Bd. 20, Schellenberg, Winterhur, 142 p.

Johansson, P. -O. 1989: The economic theory and measurement of environmental benefits. Cambridge University Press, Cambridge, 233 pp.

Magnussen, K. & S. Navrud 1992: Verdsetting av redusert forurensning til Nordsjøen (Valuing reduced pollution of the North Sea.) In Norwegian. English Summary. Report B-015-92. Norwegian Agricultural Economics Research Institute.

Mitchell, R.C. & R.T. Carson 1989: Using surveys to value public goods. The Contingent valuation method. Resource for the future, Washington D.C. 463 p.

Naustvoll, L. J., Danielsen, D., Dahl, E., Aure, J. , Skogen, M. and Budgell, P. (2002): Chattonella I Skagerrak – en trussel for oppdrettsnæringen? Havets Miljø 2002. Fiskeridirektoratet.

Navrud, S. 1990: Nytte-kostnadsanalyse av vassdragskalking. En studie i Audna. (Cost benefit analysis of river liming. A case study of river Audna). In Norwegian. Directorate for Nature Management, Report 1990-1996.

Navrud, S. 1991a: Samfunnsøkonomisk lønnsomhet av å kalke utvalgte aurevann I Agderfylkene. (Social profitability of liming selected trout lakes in the Agder counties.) In Norwegian. Report from the Directorate for Nature Management, 51 pp.

Navrud, S. 1991b: Samfunnsøkonomisk lønnsomhet av å kalke Audna. Social profitability of liming River Audna. An extended analysis). In Norwegian. Report from the Directorate for Nature Management, 35 pp.

Navrud, S. 1992: Pricing the European Environment. Scandinavian University press.

Pommerehne, W.W. & A.U. Römer 1992: Ansätze zur Erfassung der Präferenzen für öffentliche Güter, (Approaches to Measure Preferences for Public Goods). In: Jahrbuch für Socialwissenschaften.

Rolfsen, J. 1990: Rekreasjonsverdi av laks- og sjørretfiske på TOFA's soner i Gaula sesongen 1990. (Recreational value of Atlantic salmon and sea trout angling in parts of River Gaula in 1990). In Norwegian. M.Sc. thesis, Agricultural University of Norway.

Scatasta et al (2004): "Harmful Algal Blooms in European Marine Waters: Socio-economic analysis of selected case studies. Ecoharm-project, contract n. EVK3-CT-2001-80003. By Scatasta, S. W. Stolte, E. Granéli, H. P. Weikard and E. van Ierland. Environmental Economics and National Resources Group, Wageningen University, The Netherlands. Department of Biology and Environmental Science, Kalmar University, Sweden".

Strand, J. 1981a: verdsetting av ferskvannsfisk som kollektivt gode I Norge. Resultater fra en intervjuundersøkelse. (Valuation of freshwater fish populations as a public good in Norway. Result from a survey.) In Norwegian, English summary. Department of Economics, University of Oslo, Working paper, 111 pp.

Strand, J. 1981b: Beregning av samfunnsøkonomisk verdi av fisket i Gaula-vassdraget. (Valuing benefits from recreational fishing in the River Gaula). In Norwegian. Department of Economics, University of Oslo. Memo. Norember 18, 1981. English short version: "Valuing benefits of recreational fishing in Norway: the Gaula case, In Carlsen, A. J. (ed) 1987: *Proceedings UNESCO Symposium on Decision Making in Water Resource Planning*, May 5-7, 1986, Oslo; 245-278.

APPENDIX A: THE THEORY BEHIND PARAGRAPH "ESTIMATION OF CHANGES IN CONSUMER'S SURPLUS"

The expenditure function $e(\mathbf{p},u)$ expresses the minimum money expenditure the consumer has to pay for realizing a particular utility level u, given the price vector $\mathbf{p}$.

Definition no 1: The expenditure function $e(\mathbf{p},u)$ is defined by $e(\mathbf{p},u)$ = minimum level of $\mathbf{px}$ satisfying the constraint $u(\mathbf{x}) \geq u$.

The expenditure function is derived from minimizing the expenditure ($\mathbf{px}$), given that the consumer wants to realize a particular utility level u. The utility function can be expressed as $u = u(\mathbf{x})$. First we solve the problem:

$$\text{Maximize}: -\mathbf{px} \text{ s.t } u(\mathbf{x}) \geq u$$

The solution on this problem gives us the optimal consumption levels as functions of parameters $\mathbf{p}$ and u. Thus we obtain n functions: $x_1 = x_1(\mathbf{p},u)$, $x_2 = x_2(\mathbf{p},u)$,……, $x_n = x_n(\mathbf{p},u)$. The result can be written in the following way in vector form

$$\mathbf{x} = \mathbf{x}(\mathbf{p},u)$$

These functions represent the demand for commodities as a function of prices and a given utility level. On the other hand the *conventional* demand functions are functions of $\mathbf{p}$ and a given income m, i.e. $\mathbf{x} = f(\mathbf{p},m)$. The conventional demand functions show how the demand changes when a price on a commodity changes, and given a constant income. But the compensated demand function $\mathbf{x} = \mathbf{x}(\mathbf{p},u)$ measures how the demand responds to a change in price given that the utility is constant. It implies that the consumer is income compensated when the price changes to realize the same utility level as before the price change. The Hicksian demand curve or compensated demand curve takes only into consideration the substitution effects induced from price changes.

Definition no 2: The income compensated demand functions, also called Hicksian demand function) $h(\mathbf{p},u)$, is defined by

$h(\mathbf{p},u) = \text{Maximize } -\mathbf{px}$ satisfying the constraint $u(\mathbf{x}) \geq u$.

Definition no 3: The conventional demand function, also called Marsallian demand functions, is defined by

$f(\mathbf{p},m) = \text{Maximize level of } u(\mathbf{x})$ satisfying the constraint $m - \mathbf{px} \geq 0$

Definition no 4: The indirect utility function $v(\mathbf{p},m)$ is defined by

$v(\mathbf{p},m) = \text{Maximum value of } u(\mathbf{x})$ subject to the constraint $m - \mathbf{px} \geq 0$.