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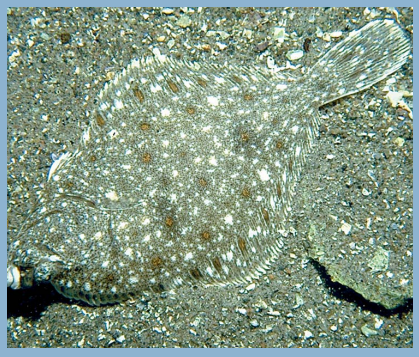
Technical Final Report
2001



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1 Executive summary

The Project problem is algae in excess. Filamentous algae grow fast during the summer months and form dense mats covering large parts of shallow coastal bays in the Archipelagos in Bohuslän, on Sweden's West Coast and in Åland in the Baltic. The algal mats are decreasing the biological diversity and destroying the nurseries of several species of fish. The value of the bays in terms of outdoor life and tourism is decreasing. The rapid growth of algae is one of the results of the increasing amounts of nutrients in coastal waters and in the bottom sediments. The bays have become eutrophicated.

The Project concept is based on the hypothesis that eutrophication and its negative effects on shallow bays will decrease if

- the algal mats are removed by harvesting and
- water circulation is improved by taking measures to increase water flow through road embankments.

At the same time harvesting will have the effect of removing nutrients from the bays so that the problem of eutrophication gradually disappears.

An innovative technique for harvesting algae has been developed and tested. The result is a functional algae harvester prototype that can take up floating algae in bays where the water is more than 30 cm deep without disturbing the bottom or plant and animal life to any considerable extent. It has three main components: a hydraulic engine that drives the other two components; a platform and three conveyor belts that pull up, dewater and buffer-store the algae. The algae are subsequently loaded onto a barge for transportation to dry land for recycling in suitable processes.

Meaningful use of algae, for example as fertilizers, as raw material for the manufacturing of paper and for production of biogas, has been investigated and tested. This depends on the fact that harvest of algae on a large scale restoring the shallow water areas results in a large amount of algal mass, which must be taken care of in an economical and environment friendly way. The tests and the use of algae in practice have given contradictory results. In the future more efforts must be made to solve the problems in relation to storage and use of algal masses.

Two new models have been developed that increase our understanding of the ecological role of shallow bays.

The shallow bay model shows how the supply of nutrients and harvesting of algae can limit the algal growth. The modelling has so far resulted in two main conclusions. Supplies of nutrients to coastal waters must be decreased generally, but local measures can make valuable contributions in certain cases. Harvesting carried out twice a season during the growth phase can lead to less extensive algal covering later during the season.

The fish recruitment model describes how plaice recruitment is affected by algal mats and shows that the amount of juvenile plaice decreases significantly when the extent of algal covering increases.

Harvesting is cost-efficient if it significantly improves the recruitment of plaice. Calculations made show that the algal covering may reduce the potential catch of adult plaice to an annual sales loss of about SEK 60 million.

Increased water flow through road embankments and inlets in shallow waters has been calculated by the use of a water flow model. The calculations have already led to a number of measures being taken to increase water flow in the Bohuslän Archipelago and thus decreasing the algal cover.

Statutes and regulations are affecting the possibilities of harvesting, storing and using the algae and also the possibilities of increasing the flow of water through road embankments. Owners of property and water rights must be requested to grant permission for measures to be carried out on their land and in their waters. Permission is also normally required from the relevant supervisory authorities according to the laws on the environment, waters, roads and constructions.

Integrated Project management and co-operation between two regions and various different organisations in finding solutions for environmental problems are valuable Project experiences and recommended working strategies. Reducing and, in the long term, eliminating eutrophication requires international, regional and local co-operation and agreements on water quality and emission limits. The EC's Framework Directive on Water and proposed Integrated Coastal Zone Management (ICZM) will have significant effect on the understanding of the need for uniform action rules.

The Layman's report, *Algae in excess – harvesting for Life,* presents the highlights of the Project in an easily understandable way. It is, together with the Project video, the new web site http://www.o.lst.se/projekt/eulife-algae and the concluding Programme Conference 2001, the final part in a wide continuous dissemination and demonstration of the development and results of the *EU Life algae* Project on all levels in the European Community.

The total expenditure of the Project, up to 31 May 2001 is SEK 13 032 377, i.e. almost exactly 100 % of the total eligible costs of SEK 13 033 603/Euro 1 560 372,35. The EC co-financing is 45,78 % of the eligible costs of the Project budget as stated in the Commission's original budget decision of 29 November 1996, revised 18 December 1998 and 23 August 2000.

2 General Project description

2.1 Background

Increased loads of nutrients (eutrophication) are a serious environmental problem along the coasts of Europe. In recent years even larger sea areas, for example, the Kattegatt-Skagerrak, the Baltic, the Northern Adriatic and the Wadden Seas, have suffered from this problem. In areas where eutrophication has been observed, higher production of algae and oxygen consumption have been registered which is thought to be the cause of structural and functional changes to coastal ecosystems. These changes are similar for marine sessile plants worldwide, although species may differ. This implies a shift in composition from the dominance of long-lived foliose algae to short-lived opportunistic macro-algae. A historical increase of short-lived opportunistic macro-algae has been documented in several shallow coastal areas and estuaries, e.g. the Venice lagoon (Italy), the Wadden Sea (The Netherlands), Scotland, Åland (Finland) and along the coast of the Skagerrak (Sweden). Such changes have been shown to negatively affect biodiversity, fish-egg survival, recruitment and foraging of commercially important fish species in for example the Baltic Sea, Kattegatt-Skagerrak and the North Sea and will affect the Community's fishery sector as a whole. In addition, many of these nursery grounds in shallow waters are suggested to be protected under the habitat directive as Natura 2000 sites, and are recognised as providing shelter for birds and are listed as CW-areas in the Ramsar Convention. Drifting masses of short-lived opportunistic macro-algae also play havoc with human activities, to fishery by clogging nets and to recreation through the pollution of beaches and unpleasant odours. Due to the diffuse nature of the sources and the dispersion patterns in the sea, the spread of excessive amounts of nutrients and their effects are of concern all over Europe.

As healthy nurseries and feeding grounds are fundamental to sustaining any fishery, important for bird conservation and essential to tourism, it is a management priority to reduce the source of the eutrophication. The principal sources of nutrients in rural and "semi-urban" coastal areas are land-based: agriculture, intensive livestock farming, forestry and municipal wastewater. In the Baltic and the North Sea region air pollution and the resultant deposits from air to marine areas contribute significant proportions of the total load of for example nitrogen. Recently and in addition to these sources, Swedish scientists reported that there were signs of increased loads of nutrients (accumulation) in shallow water sediment. Repeated and enhanced blooms of short-lived opportunistic macro-algae over the last decades may have created a pool of carbon and nutrients stored in the vegetation itself and in the sediments, and in the enclosed and semi-enclosed water systems. This pool may act as a local source of nutrients for new algal production. In this way the system could be self sustained and further reduction of nutrients from external sources will probably have limited effect on the development of blooms. Therefore, removing the algae and thereby reducing the local nutrient input might be necessary to improve the condition in such areas.

The international goal of reducing nitrogen and phosphorus from anthropogenic land-based sources to the sea by 50 % during the years 1985 - 1995 (the North Sea Convention and OSPAR) has not been reached and there is still a need of innovative efforts to achieve this. In this endeavour, not only phosphorus but also nitrogen is now being removed from municipal sewage effluent along the coasts from the Norwegian border to the Åland Sea. With regard to agriculture, Sweden, for example, has set a national target to reduce nitrogen losses from arable land by 30% by the year 2010.

This is to be achieved by a combination of measures covering legislation, advisory services, grants and levies. In addition to source related strategies, environment related management strategies are becoming increasingly important for regulating authorities both at local, regional, national and international levels. This type of management relies on for example quality objectives, quality criteria, impact assessment, restoration and receiving ecosystem monitoring. The Nordic countries have also tried to integrate these two approaches. An example is the steps that have been taken to restore lost wetlands along streams and rivers, which drain farming areas.

2.2 The problem with short-lived opportunistic macro-algae

The effect of eutrophication in shallow areas is primarily abnormally high production of short-lived opportunistic macro-algae. These algae grow not only on previously un-vegetated soft bottoms, but also on other long-lived algae and sea grass. By rapid growth, which is due to the efficient intake of nutrients, these short-lived opportunistic macro-algae out compete other vegetation by shading. The change in habitat structure caused by the algae occurs on both hard and soft bottoms. This change is critical in the life cycles of flatfish, e.g. plaice, sole and flounder, as it interferes with the settling of larvae. The changes also make foraging difficult for other species, e.g. cod, eel and trout, which forage in these shallow bays and inlets. The blooming of short-lived opportunistic macro-algae starts in the spring from spores or filaments attached to larger structures. Within a month algal mats may cover the surface of shallow bays. Underneath these mats water aeration slows down and low oxygen levels occur which severely affect the biota, e.g. increases egg mortality of herring.

A 1994 survey of shallow coastal areas in the Bohuslän Archipelago on the Swedish West Coast (Skagerrak) showed that 30-40 % of the assessed area was covered by short-lived opportunistic macro-algae (see Fig. 1). The inner part of the Archipelago of Strömstad and the fjord Stigfjorden, south of the island Orust, where most of the bays were dominated by floating masses of algae, were also most seriously affected. Monitored again in 1995, the coast showed an even higher algal cover. In the Strömstad Archipelago road embankments and bridges, constructed in the 1960s, lead to decreased water exchange, which further aggravates the problem. This, possibly together with the postglacial rising of land (ca 3 mm/year), has led to stagnant water conditions and increased sediment accumulation.

Figure 1. Algae covered bay in the Strömstad Archipelago

Reports since the 1980s have indicated increasing amounts of short-lived opportunistic macro-algae covering substantial parts of the available hard substrates of the Baltic Sea and the vegetation that plays an important part in nursery and feeding areas for fish. A tenfold increase in these macro-algae is estimated for the south coast of Finland. In the Archipelago of Åland, shallow areas have been severely affected from proliferation by short-lived opportunistic macro-algae, which have partly been related to enhanced nutrient load from increasing fish farming activities. Extensive algal mats have been recorded during several years, especially in areas where the water exchange is reduced by road embankments. The phenomenon of macro-algae blooms in the Baltic coincides with the spawning of herring and studies show a positive correlation between huge amounts of opportunistic macro - brown algae, oxygen depletion, and egg mortality. Moreover, negative effect on recruitment of flounder and bivalves has been related to the occurrence of algal mats. In addition to the negative consequences on fisheries, in the area of the Åland Islands the problem of short-lived opportunistic macro-algae bloom has been reported to have negative effects on harbour management, recreation and navigation.

2.3 The Project

The aim of this Project has been to reduce the negative effects of eutrophication on biodiversity, fisheries and recreation by harvesting short-lived opportunistic macro-algae in ecologically important soft-bottom areas in shallow waters, for which a new technology has been developed and tested. The Project has also assessed the effects of harvesting on reducing nutrients including those accumulated in the sediment that may act as local sources, and followed up the recovering process in the demonstration sites. Poor water circulation is thought to stimulate algal blooms. Therefore measures that improve water circulation have been investigated through model work. Further, the Project has explored possible uses of the harvest in agriculture, for energy production and papermaking.

Modelling cause and effect relations has been an important component of the Project with focus on:

- the identification of the important processes and factors that control growth of short-lived opportunistic macro-algal blooms,
- the effect of algal blooms and their harvesting on biological diversity and fish recruitment and,
- the effects of measures to improve water circulation such as reconstructing the water flow through culverts in road embankments.

In addition the Project has provided a basis for:

- a comparison of the cost-effectiveness of different management strategies in addressing the problem of eutrophication in coastal areas and its secondary effects,
- the development of new instruments to assess environmental effects of future infrastructure Projects such as new road embankments in semi-enclosed coastal areas,
- the incorporation of new knowledge to the process of coastal area planning and management.

The Project experience and its results have been and will be available to local, regional and national authorities within the Community with focus on member states confronted by similar problems, or where similar soft-bottom in shallow water areas is present.

The Project has been working in two regions, the most northern part of the Bohuslän Archipelago in the Skagerrak and the Åland Archipelago in the Baltic Sea, Finland; see Fig 2.

Figure 2. The Project regions

The criteria for site selection was based on: the willingness of the local and regional authorities in the area of the Project to take prompt actions, the magnitude of the dominance of short-lived opportunistic macro-algae and the significance of the problem in relation to fisheries, conservation and tourism.

The issue addressed by the Project is however relevant to many European seas, e.g. the whole Baltic Sea region, the North Sea, the Wadden Sea area, the Northern Adriatic Sea and the Balearics.

The Project has been executed by the County Administration of Västra Götaland and implemented by a group of Swedish and Finnish organisations, which represent different levels and interests.

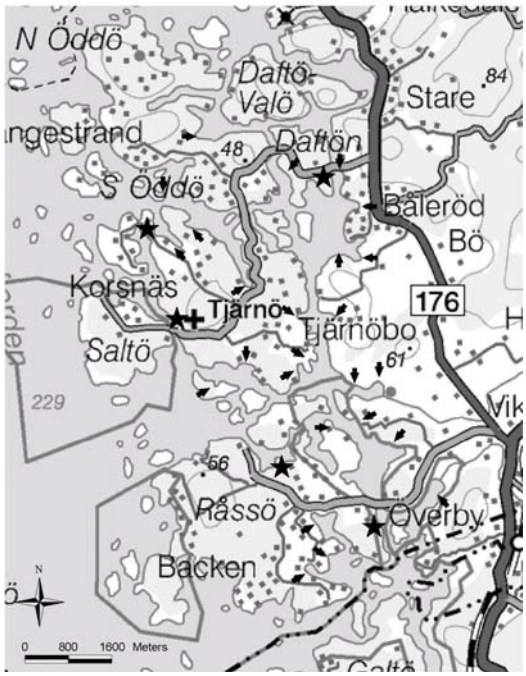


Figure 3a. The test site in Sweden. Shallow bays with an algae cover > 60% are indicated with arrows.

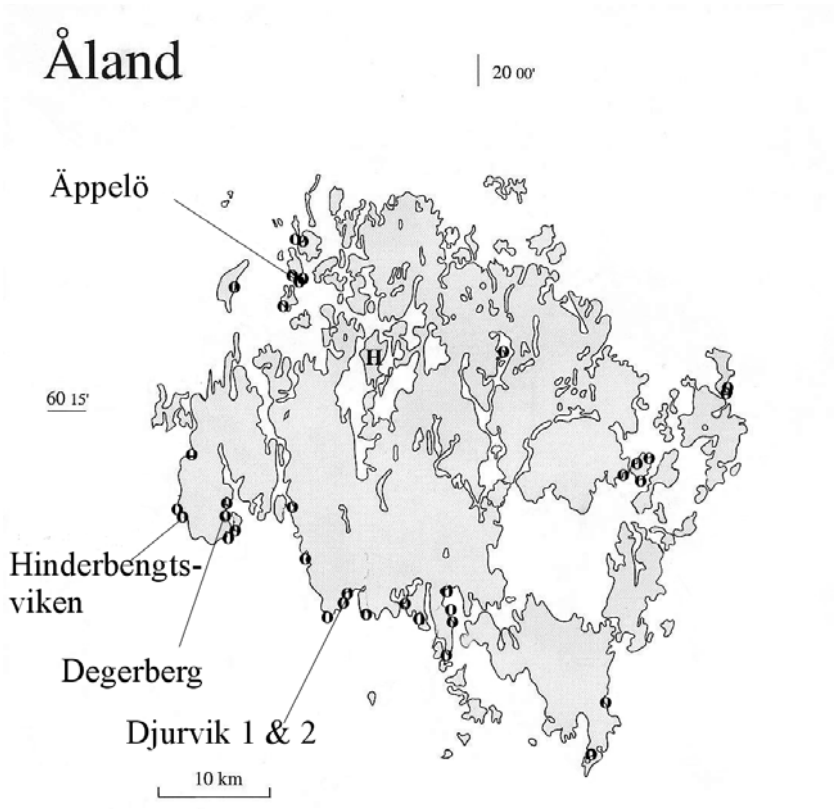


*Figure3b. The test site in Åland. Shallow bays surveyed by aerial photography for algal cover is indicated with **o**. The experimental bays where algae were harvested are indicated with names.*

2.4 Project objectives

The Project had a set-up with development (long-term), medium-term and immediate objectives.

Development objectives

To contribute to sustaining European fishery
To avoid problems for tourism
To limit biodiversity losses

Medium-term objectives

To restore the functionality of soft bottoms in shallow water areas as nursery and feeding grounds for juvenile fish
To locally reduce the nutrient load in coastal areas
To develop new instruments to improve coastal management strategies, with focus on the regulation of emissions and environmental impact assessments
To find opportunities for algae recycling

Immediate objectives

To develop and test a new method to harvest large quantities of short-lived opportunistic macro algae from shallow coastal areas
To assess the utility and effectiveness of a new environment management strategy: the harvest of short-lived opportunistic macro-algae
To develop methods for alternative uses of collected algae
To exchange information with other European States suffering from similar problems.

The Project includes three phases: an implementation phase, an evaluation phase and an action-planning phase. The following sections present detailed descriptions of the Project organisation, management, dissemination, subProjects and general conclusions and follow-up actions.

3 Project organisation and management

3.1 Participants

The participants represent the following national, regional and local authorities and universities in Sweden and Finland. The representatives of the participants are listed in Annex 1.

Länsstyrelsen Västra Götaland, *Project owner*
County Administration, Sweden
Ålands Landskapsstyrelse, *Government of Åland, Finland*
Västra Götalandsregionen, *Regional Council, Sweden*
Strömstads kommun, *The Municipality of Strömstad, Sweden*
Göteborgs Universitet, *Göteborg University, Sweden*
Kristinebergs Marina Forskningsstation, *Kristineberg Marine Research Station*
Tjärnö Marinbiologiska Laboratorium, *Tjärnö Marine Biological Laboratory*
Åbo Akademi, *Åbo Akademi University, Finland*
Husö Biologiska Station, *Husö Biological Station, Åland*
Fiskeriverket, *National Board of Fisheries, Sweden*
Vägverket, *National Board of Road Administration, Sweden*

3.2 Pilot areas

The pilot areas and sites are situated in the Bohuslän Archipelago on the Swedish West Coast and in the western part of the Åland Archipelago; see Figure 3a and 3b.

3.3 Project period and Time Schedule

The Project period is four and a half years from 1 January 1997 to 31 May 2001 including an extension of six months. The main activities are followed up and recorded in the principal Time Schedule, see Annex 2.

3.4 Project organisation

The Project organisation consists of
the Project Management Board (PMB),
the Advisory Committees (AC),
the Project Management Unit (PMU) and
13 subProjects: Dissemination Tasks 1-2, Tasks 1-3 and Tasks 5-13.
The manpower is listed in Annex 1.

Figure 4. Project organisation

3.5 The Project Management Board

The Project Management Board (PMB) was constituted in February 1997. The PMB members represent the financial partners of the Project in Sweden and in Åland/Finland as well as scientific expertise and the Swedish Environmental Protection Agency; see Annex 1. The PMB followed the progress made by the Project, provided advice and made decisions about the economy and the main directives of the development of the Project. The PMB refers to Management Task 2 in the Project plan. Led by the President of the Board, Axel Wenblad representing the County Administration of Västra Götaland (formerly The Provincial Government of Göteborg and Bohus), the PMB has had regular meetings two times a year during the period. At the meeting in Åland in April 1999 the Board decided to extend the Project period until 31 May 2001. At the same meeting Axel Wenblad resigned as President and Sven Swedberg, representing the County Administration of Västra Götaland, was appointed as the new President for the following years. The last meeting was held in Göteborg in May during the Programme Conference 2001.

3.6 The Advisory Committees

Advisory Committees (AC), with representation from Sweden, Åland /Finland, EU-Life and other member states, have been formed to inform and give advice on specific topics such as marine biology-ecology, harvesting techniques, technical development, transport logistics and algae use, see Annex 1. AC has been called in successively to the PMB meetings.

3.7 The Project Management Unit

The office of the Project Management Unit (PMU) has been established at the County Administration of Västra Götaland. The PMU has co-ordinated the implementation of the whole Project including the Åland component. The PMU has consisted of the President of the PMB and one additional member of the PMB, the Project Director, the Project Managers, the Dissemination Manager, the Project Controller, the Project Secretary and the Conference Secretary, see Annex 1. The PMU refers to Management Task 1 in the Project Plan. During the period Mattias Sköld and Anna Jöborn have been alternate Project Managers.

The PMU has had meetings regularly each month where the day-to-day follow-up of the Project has been discussed; see Annex 2. During these meetings experts on special matters have been called in. Further, the PMU has had additional meetings and regular contacts with the Task Project Managers to co-ordinate the different Tasks. Meetings with the PMU and the Finnish representatives in the Project have been arranged in Åland at the Landskapsstyrelse. Regular meetings with Trans-Mond Environment Ltd have taken place during the period. PMU has had regular contacts with the EU Life Administration through the progress reporting and otherwise.

The PMU has followed and adjusted the Task descriptions, the Project activities, time schedule and budget in accordance with the problems and results of the progress of the different Tasks to fit an adequate development of the total Project; see Annex 2. Task Project Managers have been appointed in due time. As a result of the co-ordination activities in the beginning of 1999, the PMU proposed a six-month extension of the Project period. During the first half of 2000 the PMU focused on planning the final phase of the Project and in June 2000 suggested some budget adjustments within the total budget to the Commission.

The PMU has processed the public purchasing of the method and prototype for removing algae from shallow bays. Moreover, the PMU has processed the evaluation of the construction of an algae-harvester prototype and appointed a technical co-ordination group to serve as advisers to Tech Aim AB in the construction of the algae-harvester prototype. The group has continuously followed the work with the prototype development.

Seminars and workshops about the algae biology-ecology, the harvesting of the algae, the construction of the prototype, the logistics and technique related to the transport of algae and the use of the algae have been arranged by the PMU. The planning and the realisation of the concluding Programme Conference 2001 and the finalizing of the dissemination activities called for a strengthening of the PMU resources with a conference secretariat and a team for the report layout and web site design.

The management of the activities in Sweden has been easier than the management of those in Åland depending on initial decisions about the Project's aim and direction, the geographic distance between the regions and the fact that the PMU and the Task Project Managers were appointed only among the Swedish partners. Looking back it might have been a better solution to establish a Project manager at Landskapsstyrelsen, as a part of the PMU, responsible for all the activities in Åland.

3.8 Economy

Situation 31 May 2001

The total expenditure of the Project, up to 31 May 2001 (including final auditing and printing costs for the Final Report incurred after 31 May as per agreement with the Commission), is SEK 13 032 377, i.e. almost exactly 100 % of the total eligible costs of SEK 13 033 603/Euro 1 560 372,35. A detailed description and comments on the financial transactions are included in the Financial Final Report.

BREAKDOWN OF EXPENDITURE			
Item	**Amount initially provided for in national currency***	**Amount of expenditure incurred in national currency[6]**	**%[7]**
1. Personnel	5 300 000	-5 667 818	106,9%
2. Travel	484 452	-363 035	74,9%
3. Outside (external) assistance	3 930 513	-3 847 201	97,9%
4. Durables/Capital expenditure: total nondepreciated cost	1 268 531	-1 268 791	100,0%
- Infrastructure sub-tot.	0	0	
- Equipment sub-tot.	0	0	
- Prototypes sub-tot.	1 268 531	-1 268 791	100,0%
5. Consumables	215 069	-212 533	98,8%
6. Dissemination	1 820 038	-1 664 061	91,4%
7. Other costs	15 000	-8 938	59,6%
SUM TOTAL (SEK)	**13 033 603**	**-13 032 377**	**100,0%**

* In accordance with the new revised budget (Commission decision 23 August 2000).

Auditor

The approved independent auditor appointed to certify the final statement of expenses for the Project, Arne Månberg of The National Swedish Audit Bureau (Riksrevisionsverket), has given his approval of the statement of accounts.

4 Dissemination

4.1 Task 1 Information, Workshops and Programme Conference

Dissemination Manager:
Hans G. Oscarsson, Länsstyrelsen Västra Götaland, County Administration
Time schedule: February 1997 – May 2001
Activities: see Annex 2 Time Schedule
Deliverables: see Annex 3 List of Publications and Report Series

Task objective

To introduce the Project and its results to different interested target groups within the European Community, to promote dialogue about methodological, technical and management solutions to the problem of eutrophication, to receive feedback from the Community's expertise.

Dissemination at a technical level

The Project has arranged seminars and workshops to collect information and gain more knowledge from technical experts. As an example a number of seminars have been arranged to discuss possible modifications, improvements of the harvesting technique and the ecology of shallow bays and inlets. The Project has also participated with posters and presentations at a number of conferences at EU-level (see Annex 3) as well as national and regional levels.

Dissemination at a popular level

To disseminate the Project to the general public a number of activities have been arranged including press conferences, interviews and seminars. The pamphlets, the videos and the Layman's report have been produced for the purpose of informing the general public about the Project (Annex 7 and 8).

Dissemination from the local level to the EU-level

The Project has disseminated the Project on a local, regional, national and international level. This has been a strategy to prepare for the implementation of the Project methods and results but also to seek new contacts and knowledge.

Seminars and workshops arranged by the Project

Arranging workshops and seminars for scientists and government officials has been an important aspect of the Project process. It has been important for developing the measures and for strengthening the partnership within the Project.

Media coverage

The Project has arranged three press conferences, two in Sweden and one in Åland, to inform the public about the results of the Project. These occasions ended in a good coverage of the Project in national and regional newspapers and broadcasting on television and radio. For the Project duration journalists who have contacted the Project have written a number of newspaper articles and made commentaries on television and radio.

Participation in conferences and EU activities

The Project has actively looked for suitable conferences to disseminate the Project results. Both posters and presentations have represented the Project on three international conferences and the EU weeks in Brussels and Sweden. The Project has also participated in several conferences at a national and regional level and has given lectures at the universities involved.

Programme Conference 2001

The concluding symposium, the *Programme Conference 2001,* was held in Göteborg at Länsstyrelsen Västra Götaland 9-12 May 2001. The first three days the conference covered five main sessions:
1 Eutrophication and Coastal Ecosystems,
2 Measures against Eutrophication,
3 Use of Filamentous Algae,
4 Eutrophication and Coastal Management,
5 Future Perspectives on Eutrophication and Integrated Coastal Zone Management (ICZM).
The sessions were supplemented by demonstrations of the *Functional Algae Harvester Prototype* in action in the canal, the photo exhibition *Rose-red Sea* about combating algae on a seashore in Åland, a poster exhibition, video sessions and excursions in the southern part of the Bohuslän Archipelago. The forth day was an all-day excursion in the Bohuslän Archipelago; see Annex 4 Conference Programme.

The conference gathered about 100 participants. Politicians, government officials and scientists at national, regional and local levels met in performances and discussions about how to solve the eutrophication problem. Mass media covered the activities. The conference was a success. The audience as well as the speakers came from various sectors and professional categories and both men and women participated in almost equal numbers. The conference language was English. An interpreter translated contributions to the discussions made in Swedish into English. Conference documentation; see Annex 5 Summary & Abstracts.

The participants at the Programme Conference 2001 in Göteborg.

4.2 Task 2 Web site, Video, Posters and Publications

Dissemination Manager:
Hans G. Oscarsson, Länsstyrelsen Västra Götaland, County Administration
Time schedule: February 1997 – May 2001
Activities: see Annex 2 Time Schedule
Deliverables: see Annex 3 List of Publications and Report Series

Task objective

To disseminate information about the progress and results of the Project.

Project web site http://www.o.lst.se/projekt/eulife-algae

The Project has developed and used a web site to disseminate information. The web site was also used to advertise and inform of the Programme Conference 2001. An extensive update of the web site has been made to prepare for presentation of the Project's final results and to enable visitors to download the technical reports as well as the Layman's Report and order other deliverables.

Video

The Project has produced three videos. The first in Swedish, *Algskörd för fiske och bad – en film om Projektet EU-Life algae, 1999,* and the second in English, *Eutrophicated waters – a film about the EU-Life algae Project, 2000*. Both present the background and the Project goals. The third in English, *Eutrophicated waters – a film about the EU-Life algae Project, 2000* (see Annex 6), presents the Project as a whole including the results. The videos have been used to disseminate the Project at exhibitions, conferences and seminars. They will also be used in exhibitions after the Project and can be ordered by filling in a form on the Project web site.

Posters

Three posters with dimension 90 x 120 cm have been produced to disseminate the Project and its results at seminars, conferences and at the visitor centres of the partner organisations.
A new approach to combat macro-algae blooms gives a general overview of the Project. *New technique will combat macro-algae blooms* presents the harvesting technique innovation. *Testing new methods of restoring algae-covered coastal bays* shows measures, new models and results.

Publications

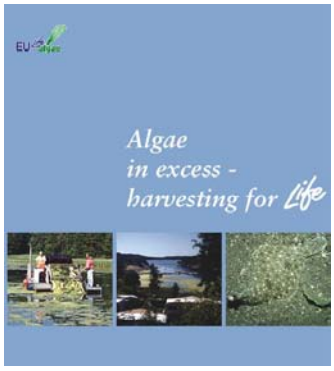
All main reports and publications produced during the Project are registered in *Annex 3 List of Publications and Report Series*. Some of them are available on the Project's web site and all can be ordered by filling in a form. See Annex 10 – 35.

Pamphlets

Three different pamphlets in Swedish and English have been produced during the duration of the Project. The pamphlets have contained a short overview of the Project and contact information. They have been widely used and spread by all organisations participating in the Project and also distributed at the visitor centres of the organisations.

Layman's report

The Layman's report, *Algae in excess – harvesting for Life,* has been produced both in Swedish and in English. It presents the highlights of the Project including the Project background, Project ideas, results and a vision in an easily understandable way. The report includes plenty of photographs and illustrations and is available on the Project web site. See Annex 7 - 8.



5 Technical development

5.1 Task 1 Design, test and refining of new technology

Task Project Manager:
Harald Sterner, Länsstyrelsen Västra Götaland, County Administration
Time schedule: February 1997 – May 2001
Report: Sterner, H. 2001. *Teknikbeskrivning. Annex 10.*

Task objective

To develop, design and test an algae-harvester prototype to be used for the removal of large quantities of floating short-lived macro-algae from shallow bays in coastal areas.

Project method

Sweden
Development, design and tests of an algae-harvester prototype.
The harvester prototype technique has been developed and tested in the shallow coastal areas in the Bohuslän Archipelago, Sweden. In the first half of 1997 an algae-harvester was constructed by Tech Aim AB (the technical design consultant) and was tested during the summer of 1997. The prototype included a small movable harvester 'head' and a platform equipped with a larger harvester unit, which also de-watered the harvest. The algae were meant to be transported from the movable harvester head, via a tube, to the larger harvester unit. A temporary harvester based on a mussel uptake conveyor belt was developed in co-operation with Tjärnö Marine Biological Laboratory and used in combination with a beach seine during the harvest 1997.

The concept was not very successful in the tests and a new design idea became the result of the tests and the further discussions and consultations during 1997. A technical co-ordination group was established to supervise the further design. SSPA Sweden AB was attached to the group to improve its qualifications in marine technique and engineering.

The discussions resulted in the construction of a second prototype finalised during the last week of May 1998. The propeller-driven prototype included a platform equipped with a harvester unit, which de-watered the algae, and was complemented by a number of floating storage/transport containers. The prototype was tested and modified in June and a press conference was arranged on 7 July 1998 to demonstrate the technique.

The overall judgement based on the use of the algae-harvester prototype during the summer of 1998 was encouraging. The harvest of algae worked satisfactorily, the working depth of the harvester was about 30 cm, the harvesting capacity was adequate and 1-2 persons were able to manage and run the machine. However, the evaluation by the technical co-ordination group, at the end of the harvest season, showed that the prototype needed further modification regarding de-watering and transportation of harvested algae. There was also a request for a type of catching arms working together with the front conveyor belt.

The Project Management Unit decided to secure that a functional algae-harvester prototype could be in use during the coming harvest seasons. It was evident that this involved some budget relocations within this Task. More resources were needed for material and less for the actual design work. A complementing agreement was signed between the Project (County Administration) and Tech Aim AB on 1 October 1998 to specify the remaining activities in more detail and to make better use of the remaining budget. A workshop on how to transport algae from the harvest site to its final destination was arranged on 27 October 1998.

The proposed modification of the prototype was designed and the equipment applied to the prototype and finely tested in May 1999 before the start of that year's harvest season. The prototype was equipped with a new set-up for transitory storage of de-watered algae during harvest. The algae were put in textile bags, at the rear end of the prototype. The bags were subsequently hauled to a barge with a crane. The barge was used for temporary storage and transport of algae from the site of harvest to the shore. The evaluation by the technical co-ordination group concluded that the new technique was an improvement compared to the floating container system used the previous year. However, it was time consuming to go back and forth to unload the small textile bags on the barge. A better solution could have been to put the crane on the barge and haul the algae directly from the rear conveyor belt into small containers on the barge.

A new set-up for transitory storage of de-watered algae during harvest was constructed before the summer of 2000. The algae mass would now instead end up on a hydraulically regulated conveyor belt at the rear end of the prototype that is able to deposit the algae directly either to a barge or to a landing site.

There was also a need to further improve the capacity to take up the algae by the conveyor belt in the front. Several solutions have been discussed during the Project and at last the most simple one was chosen, an articulated and adjustable plate on each side of the front conveyor, constructed and applied before the demonstration during the Programme Conference in May 2001.

Åland
The Project budget could not afford the development of a second prototype for use in Åland. As a complement the Project planned tests of other and more conventional techniques of harvesting algae in the selected bays and on the shores in the Åland Archipelago where the algal mats float into bays and may be washed up onto the beaches.

In 1998 an oil-clearing vessel was to be tested in the harvest but this year there were no algal mats to be collected. Instead a mud suction pump and rakes were tested. In 1999 rakes and an improved beach-seine were used in combination. In 2000 there were no algal mats in the selected bays and a beach restoration was planned and implemented. An excavator equipped with a special digger modified to act as a sieve separated the algal masses from the sand on the beach.

Project output

The development, design and construction of the prototype fulfil the objectives of the Task description and the special prerequisites set up in the agreement signed between the Project and Tech Aim AB.
The latest prototype functions well in waters deeper than 30 cm, the harvester of algae - the front conveyor belt with the catching arms - has a large enough capacity, the de-watering process is efficient as well as the buffer-store and unloading unit.

A combination technique between the harvester and the improved beach-seine can reach and gather algae in areas with a water depth between 0 – 30 cm and is functional. Equipped in this way the prototype itself can be managed by one man but two men are needed for harvesting in combination with the beach-seine in waters shallower than 30 cm. There are possibilities of further detailed development of the prototype principle to reach a final design adapted for flexible use during changing conditions in the Archipelagos, future serial production and marketing.

The test of techniques modified for beach restoration shows the possibility to halt the algal infiltration of the beaches and to further develop the technique.

Evaluation/comments

Algal mats also cover large areas of water shallower than 30 cm. These mats cannot be harvested efficiently using this prototype alone. In this case an amphibious harvester with caterpillars or wheels and another type of front-head for the uptake has to be developed and the physical damage of the bottoms needs to be evaluated.

In fact the Project prototype can be amphibious driven by caterpillars or wheels instead of propellers, which also will give the opportunity to unload the algae directly on land and easily transport the harvester on land between harvesting areas. In this case unloading and transporting on land may physically damage only some part of the bay bottom, but this still needs to be evaluated.

5.2 Task 2 Harvest of filamentous algae

Task Project Manager:
Lars Afzelius, Göteborg University, Tjärnö Marine Biological Laboratory
Time schedule: May – September every year 1997 – 2000.
Report: Jönsson, B. 2000. *Teknisk rapport för algskördare och skörd, under perioden 1997 – 2000. Annex 11.*

Project objective

To remove filamentous opportunistic macro-algae from two selected areas, one in the Strömstad Archipelago (Sweden) and one in the Åland Archipelago (Finland).

Project method

The harvest (removal) of algal mats in the Project was based on the demands

- on one hand to monitor the environmental effect of the harvest (Task 3) and
- on the other to use and test the harvesting, de-watering and transporting technique developed (Task 1).

The Project Plan implied that a functional harvester prototype for the first time could be used in the harvest season 1998 and that the harvest had to be carried out with other techniques the first harvesting season 1997. The monitoring programme for the two selected areas was based on monitoring in four completely harvested bays and in four other not harvested as reference-bays. However, the tests of the prototype could be done anywhere in algal covered waters.

In practice during the four seasons the algae appeared as floating algal mats covering the selected bays in the Bohuslän Archipelago. In Åland the algal masses mainly occurred on the bottoms and washed ashore.

The season 1997
A full-scale harvesting programme, including eight bays, was carried out in the Strömstad Archipelago, whereas a pre-study was performed in the Åland Archipelago.

The harvest was mainly done manually by the use of beach-seines and a supporting vessel. A temporary harvester based on a mussel uptake conveyor belt was also used in combination with the seines. At this time the developed algae-harvester was not able to give support to the harvesting activity. None of the harvesting methods used this year was efficient due to a too large manual effort and long transport of harvested algae.

The season 1998
The full-scale harvesting programme, including eight bays, was carried out in the Strömstad Archipelago. This harvesting was carried out by the use of the algae-harvesting prototype. The prototype was able to harvest approximately 1 hectare covered with algae (≈ 1 bay) in 2 hours.

A similar full-scale study, including six bays, was planned in the Åland Archipelago. However, the supply of algae was too low to allow for continuous harvest, hence only one manual harvest with beach-seines was performed.

The season 1999
A full-scale harvesting programme was attempted in the Strömstad Archipelago. However, the low water levels in combination with technical drawbacks resulted in a somewhat curtailed programme. About 23 m^3 de-watered algae were harvested by the use of the algae-harvesting prototype. Due to lack of algae only one manual harvest was performed in Åland resulting in about 40 m^3 algae (not de-watered).

The season 2000
Continuous harvest has been performed in the Swedish pilot area during the summer. The main focus was to perform a complete harvest of a limited number of bays. This was achieved by using a combination of manual harvest with beach-seines and the algae-harvesting prototype. The algae harvest was initiated already in mid-May.

The removal of algae in Åland has been carried out manually during the Project duration. However, it turned out that most algae were hard to remove from the water since the masses were not forming floating mats until late summer.

The Ålands Landskapsstyrelse (The Government of Åland) initiated a small-scale study testing a new technique of algae harvesting in the beach zone. An excavator equipped with a special digger modified to act as a sieve separated the algae masses from the sand. About 70 m^3 algae (not de-watered) were removed from the beach.

Project output
A complete harvest of floating algal mats in shallow bays can be carried out by the approved technique with a combination of the functional harvester prototype and a beach-seine. Harvesting by use of the prototype alone is limited to the water areas deeper than 30 centimetres. The weather conditions are decisive factors for the planning and realisation of the harvesting.

Evaluation/comments
When algae are harvested, many other organisms are harvested too, mainly sticklebacks, thus reducing the biomass in the bays. By choosing the right time for harvesting these unwanted secondary catches could probably be minimised. When harvesting is carried out on a large scale there are also other important biological factors to be taken into consideration, including the time for recruitment of plaice and nesting of birds.

5.3 Task 3 Monitoring harvesting effects

Task Project Manager:
Leif Pihl, Göteborg University, Kristineberg Marine Research Station
Time schedule: June 1997 – May 2001
Report:
Berglund, J. 1998. *Kartering av makrofyter och drivande alger på grunda mjukbottnar i Ålands skärgård. Annex 12.*
Berglund, J.and Heikkilä, J. 2000. *Rapport över det biologiska kontrollprogrammet på Åland 1999, samt en jämförelse över 1997-1999. Annex 13.*
Heikkilä, J. 2001. *Rapport över det biologiska kontrollprogrammet på Åland 2000. Annex 14.*
Heikkilä, J. and Mattila, J. 2001. *Slutrapport över det biologiska kontrollprogrammet på Åland 2000. Annex 15.*
Pihl, L., Svensson, A., Moksnes, P-O. and Wennhage, H. 1997. *Utbredning av fintrådiga grönalger i grunda mjukbottnensområden i Göteborgs och Bohus län under 1994-1996.* Länsstyrelsen i Göteborgs och Bohus län, 1997:22. *Annex 16.*
Pihl, L., Svensson A., Moksnes, P-O. and Wennhage, H. 1999. *Distribution of algal mats throughout shallow soft bottoms of the Swedish Skagerrak Archipelago in relation to nutrient sources and wave exposure.* Journal of Sea Research 41 (1999 281-294). *Annex 17.*
Rönnberg, C. and Genberg, J. 1998. *Biologiska effekter av algskörd. Kontrollprogram på Åland 1997. Annex 18.*
Sundbäck, K., Miles, A., Pihl, L., Selander, E., Svensson, A., Hult, S. and Engström, P. 2001. *Significance of benthic nutrient regeneration for the development and growth of macroalgal blooms in shallow-water embayments. Annex 19.*
Svensson, A. and Pihl, L. 2000. *Biologiskt kontrollprogram 1997-1999. Annex 20.*
Svensson, A. and Pihl, L. 2001. *Biologisk undersökning av grunda havsvikar, effekter av* fintrådiga alger och skörd. Annex 21.
Österling, M., Pihl, L. 2001. *Effects of filamentous green algal mats on benthic macrofaunal functional feeding groups.* Journal of Experimental Marine Biology and Ecology 263: 159-183. Annex 22.

Task objective
To follow up the biological effects of removal of short-lived macro algae from shallow bays.

Project method
General
The algae harvesting and the biological follow-up have been performed at two test sites, one in Sweden and one in Åland (see Figure 3 a and b). The development of the method to harvest floating algal mats took place in parallel with the realisation of the harvesting programme. Thus the harvest had partly to be performed manually at the two test sites.

The biological monitoring programme studied the effects of the treatment of bays i.e. algae removal, compared to reference bays. The following variables were monitored:

- biomass of algae,
- nutrient status of the sediments and
- community structure of epibenthic and benthic fauna.

A number of seminars and workshops have been arranged by the Project both on Åland and in Sweden about effects of eutrophication on shallow bay ecosystems and possible measures to save and restore these important areas.

Sweden
The monitoring programme in Sweden has been performed with full intensity for the duration of the Project, 1997-2000. However, during the first two years of study, the harvest of algae was partly prevented by the lack of a fully operational algae-harvesting prototype. Moreover, the first scheme with harvest at selected times during the summer was hard to accomplish due to the great variations in water-level in the bays, thus preventing the algae harvester from operating in weather situations with high pressure due to low water-level. In 1998 to 2000 the Project attempted to perform harvest continuously throughout the growth season but was not successful in keeping the bays free from algae at all times. The Project only managed to perform a full scale, intensive harvest during the last year of the Project. The results from the monitoring programme should thus be evaluated with caution.

Åland
The Project ambition was to carry out the algae harvest and the monitoring programme with full intensity at the test site in Åland from 1998 to 2000. However, it turned out that very little algae appeared in the selected area during 1998 and 1999. The algae that appeared in the bays did not form floating algae mats and harvest was not possible to achieve until the algae were washed ashore in the late summer. At that time the algae were removed manually from the shallow waters and from the beach. Accordingly, the monitoring programme was performed with full intensity only during 1998 and 1999.

Based on these changed circumstances the Project management had to reconsider the accomplishment of the harvest and the monitoring programme in Åland for the summer 2000. The management decided to focus on finding out more about the apparent great variation in algae appearance and to develop the method of algae survey further to better meet the need for information about algae appearance to base future harvesting programmes on. It was also decided that a small workshop should be arranged during 2000 to find out more about how much nutrients leak out from the algal masses and when, to be able to optimise the algae harvesting method in the future.

Project output

Sweden
Information about the effect of algae removal on the biology of shallow bays has been gained at the Swedish test site. On four out of seven sampling occasions the algal covering was reduced as a direct result of harvest. Algal mats appeared to have a significant effect on the sediment characteristics and the structure and function of the faunal communities but the Project was not able to show any long-term positive effects by algae harvest on these characteristics. The most obvious effect of algae harvest was the reduction in the density of the fauna, mainly sticklebacks (a small fish that nests and feeds among filamentous algae). However, the intensity of the harvest was not able to keep the bays free of algae long enough for more desired species to become established, e.g. flat fish larvae. The settlement of new fauna takes place before the development of thick algal mats in the spring and at times of natural wind induced harvest. This result indicates that there is a potential for recovery of the fauna if the shallow bays are kept free from vegetation during longer periods of time. These results points out the necessity of repeated, intensive harvesting to be able to restore the ecosystem of these shallow areas. Further development of methods to restore these important areas has to be made.

Åland
At the test site in Åland the unexpected low amounts of algae and the great variation in the algae occurrence has made it hard to link the harvest of algae to actual effects in the bay ecosystem. The monitoring programme has substantially increased the knowledge about the ecosystem composition in various types of bays ranging from exposed to sheltered bays.

This information can be used to support the work to identify important areas for biodiversity and fish recruitment. Moreover, the Project has gathered important new knowledge about algae occurrence in Åland to be used for future implementation of a harvesting programme. A surveying method for the presence of algal mats (aerial photography) has also been developed. It will be used in Åland in the future or elsewhere.

In Åland the main interest of the Landskapsstyrelse (the Government of Åland) is the problem with algae masses on sandy beaches that creates a situation where these beaches become overgrown with weeds. A small workshop on algae degradation on sandy beaches was arranged earlier in 2001.

Evaluation/comments

This Task has been performed as planned but did not give the expected output. The original goal to follow up algae harvest during four seasons failed due to lack of a fully developed harvesting technique. It is therefore important to continue the development of the restoration method and to perform a follow-up to gain information about the real effect in nature.

Sweden

The Project includes four harvesting seasons, but only one season of intensive harvesting has been performed at the Swedish test site. It can be argued that this is too short a time to be able to see an effect on the ecosystem in the bays. However, it is known that the recovering capacity of shallow bays may be rather fast e.g. a few years in the case of dredging activities. The modelling of shallow bays indicates that it may take a number of years to remove the nutrients stored in the bottom of the bays by algae harvest (see Task 10). Thus it may not be possible to detect an immediate effect of the harvest. However, more important the algae harvest is not only a way to break the vicious circle of buffering nutrient emissions but also a way to remove the algae which present a physical hindrance for the fauna (e.g. flatfish larvae see Task 11) in the bays. In any case further attempts to restore these very valuable areas must be made.

Åland

The Project has not been able to correlate algae removal with any effects on the ecosystem in shallow bays in Åland. This is mainly because harvest was not performed at the test site because little algae appeared in the bays. The years before the start of the Project these bays had large amounts of algae.

5.4 Task 5 Developing, testing alternative uses of filamentous algae

Task Project Manager:
Åke Lindén, Västra Götalandsregionen, Regional Council
Time schedule: July 1997 – May 2001
Report:

Ascue, J. and Norberg, Å.1998. Jord t. *Kontinuerlig rötning av grönalger och källsorterat hushållsavfall, slutrapport 98-04-17. Annex 23.*

Boman, U. *Försök med användning av alger och blåstång som gödselmedel i jordbruket. 1998-2000. Annex 24.*

Melin, Y. 2000. *Alternativ användning av marina fintrådiga makroalger. Annex 25.*

Melin, Y. 2001. *Can marine filamentous algae be used as fertiliser? An analysis of heavy metal and nutrient content.* Göteborg University. *Annex 26.*

Olrog, L. 2000. *Fintrådiga alger som gödselmedel .Sammanställning av försök genomförda av HushållningsSällskapet i Göteborg och Bohuslän 1997-99. Annex 27.*

Task objective

To develop and test alternative uses of short-lived filamentous macro algae.

Project method

The Project has investigated different areas for use of algae: one was to develop a measure that is environment friendly, that is, to take care of the algae masses to minimise the risk of nutrient emission and recycle the nutrients back to land. The work has been performed in co-operation with technical schools and consultants tied to different universities. The small budget only made it possible to perform small-scale experiments.

A mid-term seminar was arranged to discuss the various possibilities to use filamentous algae. Regional representatives from biogas and sewage treatment plants, paper manufacturers and agricultural experts were invited. Valuable information was gained and a network was developed to prepare for future implementation.

The alternative use of algae has also been investigated in the economic feasibility study Task 6 and 7. Furthermore, the legal possibilities and constraints of algae use have been discussed within Task 8.

The nutrient and metal content of the algal masses was investigated to find out if this could be a problem when used as fertilisers. Finally, a literature study was made to relate the Project results to other studies performed and suggest future method development.

Project output

The Project has investigated methods for alternative use of the harvested algae. The conclusion is that the use of algae as fertiliser on autumn wheat has low potential for further development. However, the algae can be used as soil improving material along roads, in parks and public areas or as a complement to other fertilisers rich in phosphorus. The biogas experiments show the need to further develop and improve the methodology by combining various raw materials to optimise the fermentation process. The use of algae in paper manufacturing works well on a small scale and may also be used on an industrial scale. The algae cannot be used for making egg cartons.

Evaluation/comments

This Task follows the principal plan except that the Task has been extended to include a few extra studies: algae in paper manufacturing; algae for production of egg cartons; and discussions about making crystalline cellulose from filamentous green algae.

The algae can be used in many ways. However, there is little economic gain to be made so far from these applications since the algae are a limited resource that is only available during the summer. Nevertheless it is important to find good ways to take care of the algal masses to be able to develop an environment friendly measure.

The Project had dedicated a relatively small portion of the total budget to develop methods of alternative use of the algae. When the discouraging results from the biogas experiment came the Project decided that further studies on this subject were not achievable within the Project budget. At the seminar about algae use the Project found out that it is possible to find a combination of raw material to optimise the biogas gain. The further development of biogas production from algae was, however, postponed to the time of implementation of the measure. The Project found out in 2000 that the company Biomil in Trelleborg, Sweden, had developed a biogas reactor using algae

and other solid waste in batch fermentation during 1998 to 2000. The method used by Biomil suits the seasonal occurrence of algae well. Biomil were invited to give a presentation on the subject "algae for biogas production" at the Programme Conference 2001.

When the disappointing results from the test of algae as fertilizer on autumn wheat came during 2000 the Project had no time to test other crops. The use of algae as fertiliser and soil improving material must be further developed to find the crops best suited to the salt content. Other studies show optimistic results using algae for cultivation of crops such as white cabbage and beets.

It is important to be able to take care of the algae during the summer season. Composting of algae is one way of solving the time laps between the harvesting of the algae and the use as fertiliser on fields in spring. The Project studied the possibility to combine algae and reed in composts but this gave no satisfactory results. Therefore, further studies to find better combinations of organic material and algae are needed. When depositing or performing large-scale composting of the algae masses it is important to consider the environmental laws. The large-scale compost study planned to take place in Åland during the Project failed due to problems with authorisation. There is a need for further development before implementation in large scale of the methods. It would be valuable to further develop many of the ideas developed and discussed in this Project in new Projects. In many areas in Europe there is an urgent need to take care of excess algae on beaches, in the sea or in lakes. From January 2005 it will be forbidden within the EU to deposit these masses. Depositing the algae will create a new environmental problem e.g. bad odour and the risk of leakage to the ground water of nutrients and other substances produced during degradation.

5.5 Task 6 and 7 Economic feasibility study of harvesting and algae uses

Task Project Manager:
Anneli Harlén, Länsstyrelsen Västra Götaland, County Administration
Time schedule: September 2000 - May 2001.
Report: Harlén, A. and Zackrisson, A-C. 2001. *Ekonomisk analys för algskörd och användning av fintrådiga alger. Annex 28.*

Project objective

To prove the economic feasibility and cost-effectiveness of on one hand harvesting algal mats and, on the other hand proposed uses for the collected algae.

Project method

In this study economic analyses have been made for

- harvest of algae in Strömstads kommun with the prototype developed within the Project and with a modified prototype,
- nitrogen uptake as a result of algae harvesting, compared with other measures to reduce nutrients in the coastal waters in the County of Västra Götaland,
- the potential impact of algal harvest on the recruitment of flatfish (plaice) in the Bohuslän Archipelago,
- the use of algae as fertiliser and soil improving material and as components in production of biogas and paper
- increased water flow through road embankments.

The study is a result of a co-operation between Strömstads kommun, Ålands Landskapsstyrelse, the Task Project Managers concerned, the PMU and Länsstyrelsen Västra Götaland. Two workshops, the first in September 2000 and the second in March 2001, have discussed the matters. A proposed analysis of potential user willingness to adopt the proposed methods and measures could not be realised because of lack of available experts in the field at that time.

Project output

Harvest of algae in bays with more than 60 % covering of algae in Strömstads kommun would imply an expenditure of approximately SEK 660 000 per year.

An estimate of the costs of nitrogen uptake as a result of algae harvesting, compared with other measures such as sewage treatment or the establishment of wetlands, reveals that the costs are relatively high, about SEK 600 per reduced kg of nitrogen.

If harvesting algae significantly improves the recruitment of plaice it is without a doubt a cost-efficient measure. Assuming that the shallow bays in the Bohuslän Archipelago are responsible for one fourth of the recruitment of plaice to the Skagerrak, and that the increased occurrence of algal mats decreases the recruitment with 50 % the potential catch of adult plaice will be reduced with 1 250 tonnes. This corresponds to a sales loss of ca. SEK 60 million.

A good way of using the algae is as fertiliser and soil improving material in parks, camping areas or on golf courts, although it is not economically profitable. The biogas studies show that algae in combination with other raw materials can achieve acceptable results, but more studies are needed. It seems promising to use filamentous algae in the paper making industry and in the pharmaceutical industry, but further studies are needed.

Costs for some measures being taken to increase water flow through road embankments and inlets in Strömstads kommun have been estimated. As an example, the cost to fit a badly constructed road embankment over an inlet with two cylinders was SEK 250 000.

Evaluation/comments

There are a number of positive effects that favour algae harvesting. If correctly performed, harvesting can probably halt algal growth in a bay at least on a seasonal basis and thus favour the return of its earlier flora, fish stocks and fauna. However, supplementary studies are needed to verify that the effects of harvesting will be those intended.

Harvesting filamentous algae covering the waters of bays may appear to be the only means of restoring the ecosystem until the time when other measures eliminate eutrophication problems in coastal waters.

However to estimate if the algae harvest is socio-economically profitable, further studies on the positive and negative effects of the measure as well as on the use of algae are needed.

5.6 Task 8 Legal and institutional opportunities and constraints

Task Project Manager:
Lena Thulin-Plate, Länsstyrelsen Västra Götaland, County Administration
Time schedule: September 2000 – May 2001.
Report: Thulin Plate, L. et al., 2001, *Rättsliga förutsättningar för att skörda alger och öka vattenflödet genom vägbankar. Annex 29.*

Project objective
To visualise possible institutional and legal constraints and opportunities for wider implementation of measures tested by the Project.

Project method
Seven lawyers at the County Administration have gone through the Swedish legal instruments concerning

- owners of property and water rights, the Right of Public Access,
- the algae harvest technologies and the harvest, transport and storeage of algae,
- improving the flow of water through road embankments and
- case studies of harvest of algae and road embankments in Strömstads kommun.

Institutional arrangements, which may delay a wider implementation of the measures developed and the technologies tested by the Project, have been identified and discussed. Issues related to the use, Project results in environmental decision-making and institutional responsibilities have been highlighted. Two workshops, the first in September 2000 and the second in March 2001, have discussed the matters.
A short overview of the corresponding legal instruments in Åland has been made by the administration of Ålands Landskapsstyrelse and discussed at a meeting at the Landskapsstyrelsen in March 2001.

Project output
Owners of property and water rights must be requested to grant permission for algae harvesting to be carried out in their waters. Permission is also normally required from the relevant supervisory authorities, which may take the form of exemption from protective regulations or announcement of consultations with them. Subsequent treatment of the algae harvested is also regulated in this way.

Under Swedish law, an embankment, in or adjacent to water, is a water installation. Building an embankment or taking other steps in connection with one is a water operation. Legislation relating to roads and constructions may also be applicable, depending on whether the road in question is a public or private road.

The legislation in Åland has a similar construction in the above cases as the Swedish one.

Evaluation/comments
There are many statutes and regulations affecting the possibilities of harvesting algae and increasing the flow of water through road embankments, even though such measures are designed to help preserve and reconstitute natural environments that are very important to biological diversity, fishing and outdoor recreation. If harvesting of algae is likely to be necessary for a long time to come, it might be necessary to revise legislation in order to facilitate the measures in connection with the harvest.

5.7 Task 9 Modelling improvement of water exchange in pilot areas

Task Project Manager:
Sture Lindahl, The Swedish Meteorological and Hydrological Institute, (SMHI)
Time schedule: February 1998 – October 1998, May 1999 – September 1999, May 2000 – June 2000.
Report: Lindahl, S. 2000. *Vägbankars inverkan på vattencirkulationen i grunda havsvikar.* SMHI. *Annex 30.*

Task objective
To model possible ways of improving water exchange at selected sites.

Project method
Road embankments that hinder water circulation sometimes negatively influence shallow parts of coastal areas. The Swedish Meteorological and Hydrological Institute (SMHI) was invited by the Project to study this issue, both by identifying problems and by suggesting how to handle them in a case study including five defined locations in the Bohuslän Archipelago.

The five cases originate from a list of problematic road embankments that was put together by the National Board of Road Administration (Vägverket). To identify the most interesting cases a collaborative work was performed between SMHI and the Länsstyrelsen Västra Götaland (County Administration). The analysis of the cases was carried out using hydraulic relations together with a model for hydraulic calculations, the HEC2 model. Calculations have been made and circulation models have been prepared for the five selected sites suffering from poor water circulation due to road embankments. The circulation model will serve to promote new decisions on the reconstruction of road embankments and future road constructions in the coastal zone. The model is generally valid for any road embankment or sound and thus applicable anywhere in Europe. One limitation is that it does not take into account tidal fluctuations or wind force. The most critical situations with minimal water circulation seem to occur in the summer at times with high pressure and constantly low water levels and weak winds. The circulation is in this situation predominantly driven by tidal forces, which are very weak both at the Swedish west coast and in the Baltic Sea. This situation has been used as a case study to examine how road embankments may reduce the circulation of water in a bay. When analysing the water movements in a strait crossed by a road embankment we have been working with small differences in water level between the two ends of the strait. Those differences are often caused by local winds.

Project output
The results show that the conditions are acceptable at two of the analysed sites. At two other sites it is quite evident that simple removal of sediment, mussels and stones will lead to better conditions. At the fifth site a construction work to further open the section through the embankment is suggested to enable good water circulation. The report shows the effects of different actions at the sites where measures seem to be necessary.

To avoid future problems regular inspections of road embankments, including pipes and ditches arranged for water circulation, are of great importance. When designing new embankments in sensitive coastal areas, arrangements must be made to guarantee good water circulation even at low water levels and weak winds.

The model HEC2 used by SMHI for hydraulic calculations is presented in the report of Task 9. In the context of improving water circulation through road embankments this model works well and is a valuable tool when taking measures aimed at increasing water circulation through road embankments and establishing new ones.

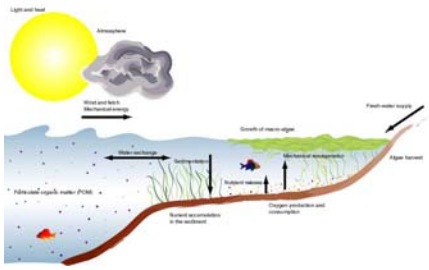
Evaluation/comments

This Task followed the plan, but the opening of road embankments as proposed in the original application to EU-Life has due to the initial budget reduction not been performed within this Project. However, the implementation of the Project results is presently taking place in local Projects managed by the coastal municipalities. Among others, the road embankment at the Project test site in Sweden has been opened during the spring of 2001. The monitoring programme initiated by the EU-Life Project in this area will be continued by the local Project to follow up the effects of the measure on growth of filamentous algae, ecosystem recovery and improvement of sediment status.

The Project suggests that new policies and management plans are implemented when building new road embankments in the future. The Project results are applicable anywhere were roads hinder water circulation. We also would like to emphasise the importance of good water circulation in eutrophicated areas to reduce the negative impact on the ecosystem and also to reduce the risk of creating bad odour.

5.8 Task 10 Modelling algae removal, sediment/water quality

Task Project Manager:
Anders Stigebrandt, Göteborg University, Geovetarcentrum
Time schedule: September 1998 –May 2001
Report: Eilola, K. 2001. *Shallow bay model –case studies. Marine Systems Analysis Report Lnr 101/01. Annex 31.*
Stigebrandt, A. and Eilola, K. 1999. *Modelling filamentous algae mats in shallow bays. Annex 32.*



Task objective

To develop an empirical model relating the removal of algae to changes in water and sediment quality.

Project method

To take measures preventing the development of algae mats one needs to know under which conditions the mats develop. The Project tried to find out these conditions using available information and based on this knowledge a model was developed to predict the development of algal mats in shallow bays. In order to understand how different external variables influence the development of filamentous algal mats and sediment quality in shallow bays relevant information on a large number of randomly chosen shallow bays in Bohuslän was put together. The dependent variables are occurrence (percentage of covering) of undesired short-lived filamentous algae, more desired long-lived algae and measurements of sediment quality. Most of the information on external and dependent variables was possible to find in the literature. However, excursions to the shallow bays were necessary to collect information about the structure and quality of the sediments and the initiation of the algal growth in the spring.

Project output

The Project has developed an empirical model that can serve as a tool to promote new decisions on the removal of algae and regulations of the land-based discharges.

Nutrients are transported into the bays with coastal waters

The results indicate that, to a large extent, the development of algal mats is dependent on the sedimentation of small particles of organic matter that contain nutrients. This material is produced in surface water outside bays, and transported from there into the shallow waters where it settles on the bottom and releases nutrients as it decomposes. The concentration of nutrients in coastal waters is thus of the greatest importance to the development of filamentous algal mats.

Local supply of nutrients is also important

The results also indicated that nutrient supply from local drainage areas can be an important factor in certain cases, while other cases were less sensitive to this source of supply, depending on size of drainage area, use to which the land was put and dominant type of soil.

The conclusions from simulation of algal growth using the model indicate that supplies of nutrients to coastal waters must be decreased generally, but that local measures can make valuable contributions in certain cases.

The model has also been constructed to make it possible to predict the effects of harvesting algae. The simulations made during the course of the Project indicate that strategic harvesting carried out twice a season during the growth phase can lead to lower algal covering later during the season (broken green line, see fig 5). This is explained by the fact that harvesting reduces the supply of nutrients in a bay with the result that algal growth is postponed to a period when rate of growth is also slowed by other limiting factors.

In some cases there is also a tendency of decreased algal growth the years following harvest. This is explained by the fact that algae that otherwise are stored in the sediment as nutrients instead are removed from the bay. The conclusion is an important one, since it suggests that harvesting could affect recurrent massive algal blooms.

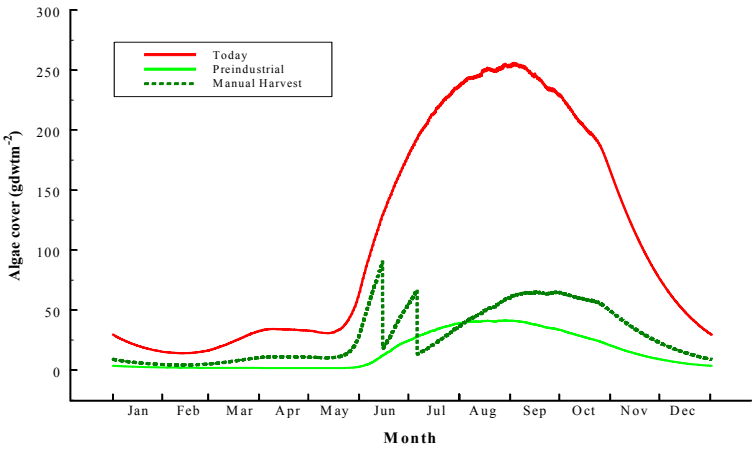


Figure 5. Filamentous algal cover in the bay Kingeleran. The model results were obtained using coastal nutrient concentrations observed today (red solid line), and pre-industrial conditions (green solid line) where we have assumed a 50 % reduction of the coastal nutrient concentrations. The dotted green line indicates model results obtained for the conditions of today if 80 % of the algae are removed twice each summer by harvest in mid June and early July.

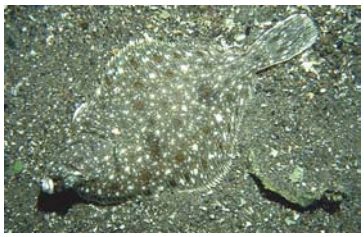
Evaluation/comments

This Task follows the principal plan and has due to very good results been extended to include some interesting case studies using the developed bay model. These studies have been performed during 2000 and 2001. The model uses data from the literature in combination with new empirical data gathered in the bays at the test site. When putting together the model it became evident that the data on nutrient fluxes from the sediment was lacking. To get more input data to the model a workshop on the subject was arranged during the summer of 2000. See dissemination.

The model can be applied to shallow bays in the Baltic Sea or elsewhere. The reason that it has not yet been tested in Åland is the lack of data from this region. The model can be used as a tool to design relevant measures. The Project suggests that this model is further developed. We would also like to see it applied in the Baltic Sea region.

5.9 Task 11 Modelling algae removal, recruitment of juvenile fish

Task Project Manager:
Leif Pihl, Göteborg University, Kristineberg Marine Research Station
Report: Pihl, L. 2001. *Effekter av fintrådiga alger på rekrytering av rödspätta – en numerisk modell. Annex 33.*



Task objective

To model the relationship between algae removal and recruitment of juvenile fish.

Project method

The original plan was to prepare a model relating the significance of the ecosystem's recovering in supporting fisheries based on the results from the monitoring programme performed in the pilot areas for algae harvest. However, the harvesting method was not developed enough to enable a study in the pilot area thus resulting in a slight change in the original plan.

Flatfishes were used as examples because soft bottom areas in shallow waters are their natural nursing and feeding grounds. The recruitment of plaice was studied in Sweden and flounder in Åland. In the study in Åland the number of fish was too low to enable modelling based on the results. The data has thus been presented in conjunction with the other monitoring data in the report for Task 3.

In Sweden the number of plaice larvae was very high during the two years of study thus giving good opportunities to develop a model based on the data. The input of fish larvae to nurseries and their survival rate related to different degrees of algal covering was studied in the bays. An empirical model estimating the fish recruitment success was developed based on the results.

The intention of the Project was that this type of model would serve to promote new decisions on the restoration of coastal ecosystems that function as nursery areas for juvenile fish.

Project output

The results from running the fish recruitment model show that plaice recruitment could be reduced by 40 to 60 %, when having an algal cover in the nurseries the size

of which was observed during the mid 1990s. This means that if algae are removed it may be possible to improve the chances for plaice recruitment in these shallow water areas.

Evaluation/comments

This Task followed the plan. Due to high numbers of plaice larvae in 1998 the Swedish study was initiated one year earlier than planned. The model provides valuable information to be used for decisions about measures to save these important nursing and feeding areas. The method can most likely be applied for other species of fish too. It is important to have an ecosystem approach when introducing measures.

With the important knowledge of the relation between algal cover and plaice recruitment it is obvious that we have to continue to try to decrease the growth of filamentous algae.

5.10 Task 12 Evaluation of the effects of the management measures in pilot areas

Task Project Managers:
Anders Carlberg, Ideella Föreningen Västerhavet
Karin Pettersson, Länsstyrelsen Västra Götaland, County Administration
Timeschedule: September 2000 – May 2001
Report: Pettersson, K. and Carlberg, A. 2001. *General assessment. Annex 9*

Project objective

General assessment of the effects of the management measures in the different pilot areas.

Project method

Project results from the different Tasks have been interpreted. The Task was divided in two parts:

- analysis of the Project results.
  The evaluation was mainly focused on Tasks 1, 2, 3, 5, 9, 10 and 11, i.e. those Tasks of the Project that produced new results and was not aimed at evaluating the feasibility, economy, legal constraints or producing guidelines based on Project results. The original plan to accomplish this was to arrange a workshop. However, this was not possible due to late deliveries of several reports from the Project. Individual experts have instead evaluated each report.

- analysis of the management of the Project and the organisation.
  The management of the Project was evaluated using a questionnaire that was sent out to personnel on all levels and involved in different parts of the Project.

Project output

The EU-Life Project has fulfilled its overall aim successfully and has demonstrated a number of new measures and tools that can be put to use in designing measures to combat blooms of filamentous macro algae. A problem not anticipated at an early stage of the Project was the development of the harvesting technique (Task 1). This turned out to be expensive and time consuming and partly affected the results of other Tasks (2, 3 and 11). The Project has generated new knowledge in many different areas. Particularly the model work of Task 10 and 11 has extensively increased the understanding of how shallow bays work and the functionality of these ecosystems. Task 9 has demonstrated an operative method for identifying water circulation problems in relation to hinders such as road embankments and also suggesting measures for improvement.

The general result from the questionnaire was positive. For the people involved, the Project have generated many new experiences and contacts, and many of them want to see the Project continued. Several participants are also positive to work in similar Projects in the future.

Evaluation/comments

This Task principally followed the plan but the original plan to accomplish this Task by arranging a workshop had to be omitted due to late deliveries of several reports from the Project. Individual experts have instead evaluated each report.

5.11 Task 13 Guidelines and management strategies at the local, provincial and national level

Task Project Manager:
Harald Sterner, Länsstyrelsen Västra Götaland, County Administration
Time schedule: September 2000 – May 2001
Report:
Dåverhög, M. and Lindström, Å. 2001. *Remote sensing of filamentous algae in shallow waters along the Swedish West Coast.* Uppsala University. *Annex 34.*
Sterner, H. 2001, *Rekommendationer för planering och förvaltning. Annex 35.*

Project objective

To prepare guidelines for incorporation of Project results in existing coastal management strategies.

Project method

A team of planners and marine biologists at the Länsstyrelsen Västra Götaland and a marine biologist at the Åbo Akademi University with experience from coastal management, planning and work in other EU Projects concerning Integrated Coastal Zone Management (ICZM) was initiated in September 2000.

The team began to study the working papers produced by the relevant Project Tasks and other coastal eutrophication Projects. Two workshops, the first in September 2000 and the second in March 2001, have discussed the matters. In March 2001 two seminars were arranged in Göteborg and in Åland. The one in Göteborg discussed the EU proposal concerning the ICZM methodology from a Scandinavian and a North Sea perspective. The other in Mariehamn at the Landskapsstyrelse examined the planning and management situation in Åland from a Baltic Sea perspective together with representatives from municipal and regional levels.

During the Programme Conference, Session 4 and 5, the integrated planning and management of the coastal zone was penetrated in a number of presentations followed by a final discussion and a vision of the future, see Annex 4 and 5.
After the Conference the result of the total teamwork has been documented in the Task Project report. At the same time two students from Uppsala University finished their Master's degree Project, a study of remote sensing of filamentous algae in shallow waters along the Swedish West Coast, a tool for monitoring algae and planning the harvest of algae.

Project output

Reducing and, in the long term, eliminating eutrophication requires international co-operation and agreements on water quality and emission-limits for activities and operations both on land and in the sea. Institutions and commissions, e.g. OSPAR and HELCOM, capable of providing this international co-operation are already in place. Several EU Projects and national research programmes concerning eutrophication and development in the North Sea, the Skagerrak and the Baltic Sea work on the subject. The EC's Framework Directive on Water will be implemented in the course of the next few years, and will demand that measures are taken to guarantee good water quality. The proposed Integrated Coastal Zone Management (ICZM) recommendations will also have significant effect on the understanding of the need for uniform action rules.

Regional and local co-operation and responsibility
Water management under the terms of the EC's Framework Directive, ICZM and the Comprehensive Planning in the regions and municipalities help to create fora in which measures for dealing with the local eutrophication in the shallow bays can be formulated to meet the specific prerequisites in each area, such as outlets, water quality, increased water flow through road embankments and inlets and protection of sea-grass meadows and the nurseries of fish.

Remote sensing
It is possible to detect areas with filamentous algae along the Swedish West Coast using satellite remote sensing. But it is not possible as in this case, with a Landsat-7 image, to quantify the cover of algae. A regular monitoring of the growth of filamentous algae is thus not recommendable if one uses a satellite with a spatial resolution of 30 m.

Evaluation/comments

The effect of eutrophication in coastal areas is threatening to knock out whole ecosystems, and with them the reproduction of commercially important species of fish. During the course of the Project, new measures have been developed and tested with a view to counteract the negative effects of eutrophication in shallow coastal bays. Consequently there are no simple solutions to the problem. It is necessary to combine a number of measures, both onshore and in the water of the bays if optimum results are to be achieved. And, in selecting the measures to be taken, the particular conditions in each case must be taken into account. For example, priority must be given to retain the sandy shore in one spot for bathing and outdoor-recreation, while in another it is given to protect the nurseries of commercially important species of fish and biodiversity.

Measures designed to protect and restore the rich ecosystems in these shallow coastal waters need to be based on documented knowledge of the very best quality. The *Shallow bay model* provides a simplified description of the way in which a bay works and will be further developed into a valuable tool for planning future measures.

There is a demand for more research being done on the replenishment of fish stocks, the dynamics of ecosystems, the composition of flora and fauna and the value of the bays for recreation and tourism. To take a further step in planning the remedy of algae covered shallow water areas it is also necessary to evaluate and set a price on their proper function and on the value of biological diversity in comparison with other, and sometimes competing, interests.

Finally it is important to adopt a holistic approach to the whole chain of measures, from the uptake to the final use of the algae. The harvesting technique has to be combined with knowledge of the conditions in the shallow water areas and with a long-term sustainable management and use of natural resources.

6 General conclusions and follow-up actions

6.1 Introduction

The negative effect due to eutrophication in coastal areas is a global problem. The massive growth of filamentous algae in coastal waters is, however, mainly a problem concentrated to areas with low water turnover, i.e. areas with many islands and bays, shallow waters and low tidal amplitude. Both the problem and the experience are relevant to many coastal areas in Europe including the Bohuslän Archipelago in the Skagerrak and the Åland Archipelago in the Baltic Sea.

The overall aim of the *EU Life algae* Project has been to attain the best environmental benefit and sustainable development in the coastal waters by reducing the negative effects of eutrophication on biodiversity, fisheries and outdoor recreation. The holistic approach needs to be used to solve environmental problems today and in the future in the co-operation between nations, regions and local communities as well as between scientists, authorities and stakeholders.

Harvesting algae and increasing the water circulation through road embankments are the two principal measures that have been investigated and developed in the Project to counteract the negative effect of eutrophication. The elaboration of the measures has comprised several harvesting techniques, uses of algae, modelling and monitoring the effect of the measures, costs-benefit analysis and analyses of implementation, constraints, possibilities and management.

6.2 The harvesting technique

6.2.1 The prototype

The development of the harvesting technique has been based on one principal criterion:

- the algae harvester must be able to harvest floating algae in shallow water without disturbing the water and the bottom or plant and animal life to any considerable extent.

The result of the Project is a prototype driven by propellers and it works well in water deeper than 30 cm. It unloads the de-watered algae-mass to a barge for storage and further transport to land. The algae which have drifted in towards shallower water along the shoreline can be hauled out to the harvester with a beach-seine and taken up by the harvester.

Possibilities

The prototype is designed to sustain operation in a saline environment and it can thus be used in the sea as well as in freshwater environments. The prototype is equipped with conveyor belts originally used in the fish processing industry and the structure of the surface can be changed to suit harvest of different types of algae, plants or other similar materials floating in the water. Algae harvesters designed on the base of the prototype can be produced in different sizes to fit the scale of the area that it operates in and the standards for public cleaning and refuse collection systems used in the coastal municipalities.

The prototype can also be amphibious equipped with caterpillars instead of propellers. This will give the opportunity to unload the algae directly on land and to transport the prototype on land between harvesting areas.

Another possibility is to further develop the technique of using a beach-seine or similar gear to gather the algae in shallow waters and then take them up using the prototype.

Constraints

Large areas with water less than 30 cm deep are during the growing season covered by algae and cannot be harvested efficiently using the prototype. In this case an amphibious harvester driven by caterpillars and with another type of front-head for the uptake has to be developed.

Harvesters driven by caterpillars may physically damage the bottoms and this is not only an environmental problem but also a problem for the owners of property and water rights.

Follow-up actions

Investigate the distribution of the algal covering on shallow waters (normal water level) less than 30 cm deep and deeper than 30 cm in order to

- calculate the total amount of algal mass in the different areas and
- show the distribution of the areas along the coast or in the Archipelagos.

Investigate and evaluate the effects, on the animal and plant life in the water and the bottoms in shallow water areas, of the different harvesting approaches; amphibious harvesters driven by caterpillars compared with harvesters driven by propellers and harvesters driven by propellers in combination with a beach-seine. The investigations will give the prerequisites for the future development of the harvesting technique.

6.2.2 Harvesting

The shallow bay model

The shallow bay model (Task 10) can be used to optimise the measures in local bays. The effect of various measures can be estimated by running different scenarios in the model. The outcome of such exercises may be for example that in one bay the optimal measure may be to reduce the outflow of nutrients from a local sewerage, and in another to harvest algae. In this way bays that benefit the most from algae harvest can be selected, enabling the local community and municipality to reduce the overall cost for the measure.

Restoring biological diversity

Results from the monitoring programme show that the number of species is markedly reduced in the algae-covered bays. The model studies estimated that harvesting algae during the growth phase could inhibit their continued growth considerably. These circumstances indicate that harvest in the long run may well provide better conditions for the biological diversity. However, field studies carried out in Åland showed that harvesting could also result in increased growth, probably due to the decreased competition for nutrients and light.

The results from the empirical fish recruitment model (Task 11) emphasise the need to remove algae to improve the chances of plaice survival in shallow bays. Based on the knowledge that

- the shallow bays in the Bohuslän Archipelago are responsible for at least one fourth of the recruitment of plaice to the Skagerrak and
- the increased occurrence of algal mats decreases the recruitment with 40 %

the potential catch of adult plaice will be reduced with 1 250 tonnes. This corresponds to a sales loss of ca. SEK 60 million. The overall conclusion is that it is without a doubt a cost-efficient measure.

The effect of algae on the recruitment of plaice was not evenly distributed in the Bohuslän Archipelago according to the results from the empirical model developed in Task 11. Up to 70 % of the reduction in juvenile plaice occurred in the northern quarter of the Archipelago. Therefore, actions taken to reduce algal distribution should be concentrated mainly to the northern region, to optimise the cost benefit of invested resources.

When algae are harvested, many other organisms are harvested too, mainly sticklebacks, thus reducing the biomass in the bays. By choosing the right time for harvesting these unwanted secondary catches could probably be minimised. When harvesting is carried out on a large scale there are also other important biological factors to be taken into consideration, including the time for recruitment of plaice and nesting of birds.

The shallow bay model and the model approach for fish recruitment can with minor modifications be used in other geographical areas where opportunistic algae have a negative impact on the biological diversity.

Reducing the nutrient concentrations

Case studies run by the shallow bay model

- support the hypothesis that it may be possible by algal harvest to decrease the re-circulation of nutrients in the system and in this way also decrease the growth of filamentous algae considerably
- indicate that nutrients stored in the sediment from the previous year may in some cases be reduced by algal harvest. This will improve the situation and lead to less algal growth the following season.

Harvesting algae may thus be efficient in reducing nutrients on a local scale but the model analyses also clearly show that the nutrient rich coastal water is one of the most important nutrient supplies.

Cost/benefit analysis has shown that harvest of algae in bays with more than 60 % algal covering in Strömstads kommun would imply an annual expenditure of approximately SEK 660 000. In relation to other measures aiming at reducing nitrogen and phosphorus, e.g. sewage treatment and the establishment of wetlands as nutrient sinks, harvesting algae is a rather expensive measure from a regional perspective.

Improving the recreational status of the areas

Removing algal mats improves the attractiveness and the availability of recreational areas.

Possibilities

There are a number of positive effects in support of algae harvesting. If correctly performed, harvesting can probably halt algal growth in a bay and thus favour the return of its earlier plant life, fish stocks and fauna. The models will hopefully serve to promote new decisions on the removal of algae and regulations of land based nutrient discharges.

Constraints

The Project has not been able to show any positive effect due to the measures taken in the pilot areas. This may partly be explained by the low intensity of the algae harvest due to the methodological problems with the algae harvesting prototype, but also the slowness of the response of the ecosystem.

It is not yet possible to anticipate the time necessary to perform algae harvest to see any improvement on the ecosystem level in bays suffering from problems with algal mats.

There are many statutes and regulations affecting the possibilities of harvesting algae. Owners of property and water rights must be requested to grant permission for algae harvesting to be carried out in their waters. According to the laws, in Sweden and Åland, on the environment and water, permission is also normally required from the relevant supervisory authorities.

Follow-up actions

The most important follow-up action that needs to be taken is to continue the evaluation of the efficiency and effects of harvesting algae using the developed prototype.

The model results predict that strategic harvesting of algae in their growth phase can be efficient, but the predictions need to be validated. In addition, due to the delay in achieving an efficient harvesting technique, the negative and positive effects on the flora and fauna by harvesting algae could not fully be evaluated within the time frame of this Project.

- Strömstad municipality will take the responsibility for the future use and maintenance of the prototype as a part of the municipal Coastal Service.
- Länsstyrelsen Västra Götaland is planning experimental harvest of algae using the prototype, for a period of at least two years, and monitoring the re-growth of algae and the impact on benthic and epibenthic flora and fauna and to verify the effects of harvest.
- Additional studies using the shallow bay model are needed to evaluate how and when harvesting should be conducted to render it efficient.
- Continued field studies are needed to confirm the positive effect of algae harvest on fish recruitment.
- Further studies are needed to predict the relation between costs of measures and environmental benefit.

If the results from further experimental harvesting using the prototype are positive, the harvesting technique should be developed further and can be recommended as a measure to be taken in shallow bays where algal mats constitute a problem.

Harvesting for Life

The main conclusion is that harvesting mats of filamentous algae appears to be the only way of restoring the desired ecosystems in the eutrophicated coastal waters, until other measures sufficiently have decreased the eutrophication of coastal waters and drainage areas.

6.3 Taking care of the algae

Harvest of algae on a large scale as a way of restoring bays and other shallow areas involves investigations to find an environment friendly way of taking care of the algae. Therefore, the Project has investigated different areas of use for algae, e.g. as fertilisers, as raw material for the manufacturing of paper and egg cartons and production of biogas. Several tests have been carried out.

The experiments using algae as fertiliser for autumn wheat have shown disappointing results. However, algae can be used

- as fertiliser and soil improving matter in public parks, camping areas or on golf courts. This could be a good way of taking care of the algae, although it is not to financially profitable.
- as fertiliser for certain salt tolerant crops such as white cabbage, beetroots and celery.
- in combination with other fertilisers. Because of their relatively low content of phosphorus, the algae cannot completely replace other fertilisers. If very large amounts of algae are used, the algae's content of cadmium, nickel, chromium and lead may become a problem.

Algae in paper production works very well and there are good possibilities of using algae as a component in paper even on an industrial scale, but as a raw material for egg cartons the algal fibres are too week to give the needed durability of the product.

The biogas experiments performed on a laboratory scale show that algae are not suitable for this kind of process. However, other studies have shown that in combination with other raw materials better results can be achieved, but more studies are needed.

The possibility of using the algae as raw material for extraction of microcrystalline cellulose, which is used for production of tablets in the pharmaceutical industry, has also been discussed. In the case of use it must be possible to obtain cellulose powder with characteristic physical properties and stipulated purity.

There are problems in relation to the storage of algal mass e.g. unpleasant smell and leakage of nutrients. The environmental laws regulate the storage and treatment of the algal masses. If harvesting and storing of algae is likely to be a necessary measure for a long time to come, it might well be a good idea to revise the legislation in order to facilitate it.

Follow-up actions

Future tests have to be carried out using algae

- as fertiliser for other crops than autumn wheat
- as raw material in combustion together with other material, e.g. in refuse incineration producing energy

Methods, as well as legal aspects, for the long time storage of algal mass have to be investigated.
Further studies are needed to predict the relation between the costs of algal use and environmental benefit.

6.4 Increasing the water circulation

By using a model approach (Task 9) the installation of culverts to improve upon water transport through road embankments can be optimised. The optimal size of the culverts can be estimated by making a simple inspection at the site and then run the data in the HEC2 model. In this way a sound use of resources for this kind of measures can be assured.

Model calculations of water flow through road embankments and inlets have already led to a number of measures being taken to increase the water flow in the Bohuslän Archipelago. The results to date have been positive: the algal covering has decreased but the effects of the measures have not yet been fully evaluated.

The model approach used to optimise the water transport through road embankments in situations with low water levels is introducing a new way of thinking. It highlights the need to create conditions that sustain good water transport through road embankments also at low water levels.

Introducing culverts and in some cases widening sounds can be an important measure to restore and sustain important nursing and feeding areas along the coast as well as preventing mass growth of filamentous algae and bad odour. The model used by the Project can be applied to any sound in Europe to calculate transport of water.

Constraints and possibilities

There are many statutes and regulations counteracting the possibilities to increase the flow of water through road embankments, even though such measures are designed to help preserve and reconstitute natural environments that are very important to biological diversity, fishing and outdoor recreation.

Under the laws in Sweden and Åland an embankment in or adjacent to water is a water installation. Building an embankment or taking other steps in connection with one is a water operation. Legislation relating to roads and constructions may also be applicable, depending on whether the road in question is a public or a private road. In the case of an embankment, it is the infilling that has the greatest influence, since flow of water is impaired, and the owner of the water rights and the owner of the embankment are the ones responsible for taking measures.

Follow-up actions

The Project has demonstrated a method to evaluate the impact of road embankments on water circulation in shallow areas and also to suggest how to design the measures to be taken. The important follow-up action is to disseminate this information and monitor the effects of measures taken on the benthic and epibenthic flora and fauna when water circulation is increased.

6.5 Working together

Partnership

The Project has developed the partnership between the organisations participating in the Project on a local, regional and national level. The international network developed by the Project will be valuable for future work with measures to solve problems caused by eutrophication. The Project approach to co-operate between various different organisations in finding solutions for environmental problems is a valuable experience that will be used in the future. The Project has strengthened the co-operation and information exchange between the scientific community and the governmental organisations in a positive way.

International co-operation

Reducing and, in the long term, eliminating eutrophication requires international co-operation and agreements on water quality and emission-limits for activities and operations both on land and in the sea. Institutions and commissions, e.g. OSPAR and HELCOM, capable of providing this international co-operation are already in place. Several EU Projects and national research programmes concerning eutrophication and development in the North Sea, the Skagerrak and the Baltic Sea work on the subject. The EC's Framework Directive on Water will be implemented in the course of the next few years, and will demand that measures are taken to guarantee good water quality. The proposed Integrated Coastal Zone Management (ICZM) recommendations will also have significant effect on the understanding of the need for uniform action rules.

Regional and local co-operation

Water management under the terms of the EC's Framework Directive on Water, Integrated Coastal Zone Management and the Comprehensive Planning in the regions and municipalities will help to create fora in which measures for dealing with the local eutrophication in the shallow bays can be formulated and discussed. In this way the measures can be adapted to the specific prerequisites in each area.

A holistic approach

Finally it is important to adopt a holistic approach to the whole chain of measures, from the uptake to the final use of the algae. The harvesting technique has to be combined with knowledge of the conditions in the shallow water areas and with a long-term sustainable management and use of natural resources.

Harald Sterner
Project Director

Anna Jöborn
Project Manager

Mattias Sköld
Project Manager

Technical annexes

Annex 1. List of Participants of the Project
Annex 2. Principal Time Schedule 1997-2001
Annex 3. List of Publications and Report Series
Annex 4. EU Life algae, Programme Conference 2001, Conference Programme
Annex 5. EU Life algae, Programme Conference 2001, Summary & Abstracts
Annex 6. Video 2001
Annex 7. Layman's report, *Algae in excess – harvesting for Life.*
Annex 8. Layman's report, *Alger i överflöd – skördas för livet.*
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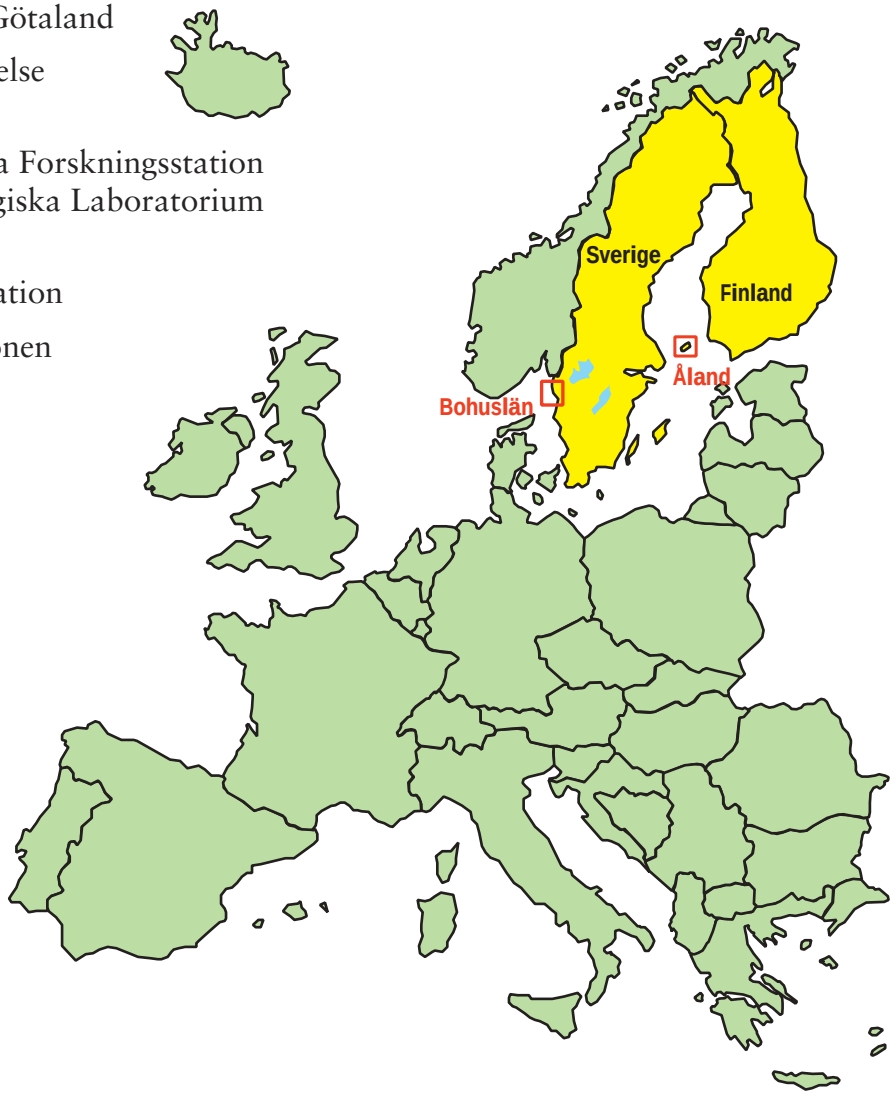

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