

Bio-production and ecosystem development in saline conditions

Knowledge and innovation challenges

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ISBN: 90 - 5059 - 113 - 2

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NRLO report no. 2000/10E, The Hague, June 2000

Foreword

The debate about the potential of saline agriculture has taken place in the context of the forecast explosive growth of the world's population in the coming decades and the expectation that in the long term the food supply will become one of the world's greatest concerns. Fresh water is becoming scarce as a result of increasing domestic and industrial use, with the result that less and less fresh water is available for agriculture. The amount of farmland available for food production will also decline because of salinification.

It is against this backdrop that the potential has been highlighted for the reuse of saline soil for food production or other purposes by using salt-tolerant plant species (halophytes). Some halophytes yield edible products. It would be worthwhile investing in research in order to identify the potential of halophytes for supplying food and for other goals.

At the request of the Ministry of Agriculture, Nature Management and Fisheries (LNV), the NRLO has conducted a brief quick scan of the subject. It was decided to adopt a broader approach in order to evaluate the potential of saline agriculture in relation to the world's food supply in a wider context. Other options for bio-production were also reviewed briefly. However, LNV's request to investigate the potential of saline agriculture maintained a central place in the activities.

Currently the significance of halophytes for the food supply is limited. Salinification problems are indeed acute, but they also represent new opportunities. This is also the case for Dutch coastal areas. Reutilization of saline soil using salt-resistant crops (including halophytes) is a new challenge. The opportunities offered by saline environments (saline land and salt water) for bio-production and ecosystem development are underestimated and should be put on the international agenda.

Dr A.P. Verkaik,
NRLO Director

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Policy summary

- 1. All over the world fresh water is becoming increasingly scarce and agricultural areas are becoming brackish. Brackish areas are also increasing in temperate climate zones. This justifies greater attention for bio-production and ecosystem development in saline conditions.**

Domestic, industrial and agricultural use of fresh water is increasing so quickly that water shortages can be expected all over the world.

Surface water and groundwater in agricultural areas in many places in the world are becoming increasingly brackish and saline. Furthermore, salt deserts (caused by a lack of fresh water) and saline inland basins (causing by the level of saline groundwater rising as a result of leakage of drainage water) are being created. The salinification of groundwater and surface water throughout the entire coastal area of the Netherlands will increase as a result of subsidence, rising sea levels and possibly a different water policy. *A new approach is needed that is based on the utilization of saline environments for bio-production and ecosystem development.*

- 2. The cultivation of salt-tolerant crops on saline soil (saline agriculture) has significant social and economic potential that needs to be further explored and developed.**

For the time being the prospects for halophytes as commodities for food, animal feed and fine chemicals on the world market appear to be limited. Certain products could serve as a surprising broadening of the range of vegetables in “western” markets. Some applications are suitable for regional markets anywhere in the world.

Halophytes can also make a real contribution to achieving social goals like reforestation or replanting and ecological recovery of saline areas that have fallen into disuse, coastal development and protection, low cost biomass production for renewable energy, climate improvement and CO₂ sequestration. This approach requires an international context.

- 3. Knowledge development relating to the field of saline agriculture is relatively limited at both international and national level, it is not really focused and it has a marked scientific bent. This represents an opportunity for the Netherlands to play a significant international role in applied innovation-driven knowledge development.**

The scientific literature on halophytes is extensive. The utilization of this knowledge is minimal. Knowledge institutes in many countries are involved in national salinification problems, but there are no major international research programmes or networks

concerned with halophytes. Agricultural development programmes are focused on land use, crop expertise and irrigation management, and do not include the use of halophytes under saline conditions. This research has no priority in European programmes.

Generally speaking Dutch agricultural and biological knowledge institutes are of a high level, are very application-driven and have widespread international networks. They are capable of rapid involvement in saline agriculture. There are moreover a number of Dutch enterprises (small and medium-sized businesses, consultants and multinationals) that can reap the benefits of certain innovations in due course.

4. It is desirable to develop the broad theme of *“bio-production and ecosystem development in saline conditions”* in order to seize the opportunities for the production of biomass and the development of ecosystems in saline conditions. Different activities can be formulated under this theme:

a. an innovation programme relating to:

“Bio-production and ecosystem development on saline soils”

b. a foresight study of:

“Bio-production and ecosystem development in marine and estuarine systems”

The innovation programme includes defining a number of challenging pilot projects. It is on the basis of the detailed definitions of these pilot projects that decisions can be made regarding which follow-up actions by LNV and other players, market players or knowledge institutes for instance, are desirable. Examples of pilot projects are:

1. A polder with saline seepage
2. Zeeland as a regional concept
3. Halophytes as biomass for energy purposes
4. Halophytes as raw materials for fine and other chemicals
5. Utilization of halophytes in salinity gradients of irrigation Systems
6. Utilization of halophytes in projects for integrated coastal protection and development

Collaboration between parties is a requirement when setting up and implementing an innovation programme. The government can initiate, but others (corporate sector, social organizations, knowledge institutes) have to recognize the urgency and be willing to invest in it. The innovation programme cuts across the areas of several ministries (Transport, Public Works and Water Management; Housing, Spatial Planning and the Environment; Economic Affairs; Foreign Affairs-DGIS).

It will take 6 to 9 months to define an innovation programme in detail.

It is not worthwhile giving consideration at this stage to physical research facilities (testing station or experimental farm) in the Netherlands for saline agriculture. The content and scope of the innovation programme need to be established first. There are moreover sufficient possibilities to dovetail with the existing research and innovation infrastructure.

The opportunities for bio-production and ecosystem development in *saline environments* also deserve closer scrutiny. As things stand now there is too little information about this area in the current knowledge infrastructure and further foresight is needed.

...I am very happy that the NRLO is taking up a detailed study on "agriculture under saline conditions". *This is a timely initiative.*

Dr M.S. Swaminathan (godfather of the Indian green revolution) in a letter to the NRLO

Research on the salt tolerant halophytic species has so far been devoted to biological and eco-physiological inquiries but their exploitation for rehabilitation of salt-affected wastelands has not fully attempted. Many halophytic plants have industrial applications in the form of essential oils, medicinal, alcohol, fiber, latex, pulp, cosmetics etc. These species grow mostly in the wild on salty lands and are of economic value. *However, these halofytes continue to be either under or unexplored. Thus, it seems to be the time to initiate research efforts in this direction.*

Dr R.S. Paroda (Director-General of the Indian Council of Agricultural Research) in a letter to the NRLO

Halophytes are non-conventional crops and it would take a little to make people believe that they are good food for them. However, there are potentials to extract good quality oil from them and this would not have any problem of acceptability. Same would be true for feed, fiber and forage crops. *There is no doubt that saline agriculture is here to stay. It would need fine tuning in different ecological situations. Basic and applied research is needed.*

Professor M. Ajmal Khan (University of Karachi) in a letter to the NRLO

1. Introduction

In recent years there has been increasing recognition that the scarcity of fresh water and the salinification of agricultural areas are becoming much more serious global problems. Both trends represent a threat to the world's food supply. At the same time there are growing indications that the cultivation of crops with a high salt tolerance can be seen as an interesting option for utilizing saline soils and conserving fresh water (1, 2, 3, 9, 10, 11, 12, 17). This type of cultivation is called *saline agriculture* and salt-tolerant plants are referred to as *halophytes*. In the Netherlands Ocean Desert Enterprises B.V. (ODE B.V.) of Amsterdam has been a particularly strong advocate for putting this subject on the agenda in the corporate sector, political circles and knowledge institutes. If these prospects for the cultivation of crops on saline soils are indeed realistic, the question then arises as to whether the Dutch knowledge infrastructure should respond more proactively.

This was why the Ministry of Agriculture, Nature Management and Fisheries (LNV) asked the National Council for Agricultural Research in March 2000 to conduct a foresight study of the prospects for saline agriculture and the desirability of a knowledge and innovation programme in this field. Because of its short duration (3 months), the foresight study was a quick scan encompassing a brief outline of some main themes.

The main question was formulated by LNV as follows:

What is the potential of saline agriculture for the Netherlands with regard to building up expertise about saline agriculture for knowledge exports in a global or European context?

Four parallel activities were conducted in the quick scan:

1. An essay about the prospects for saline agriculture.
2. A literature scan intended primarily at identifying and analyzing national and international networks and research activities,
3. Twenty interviews with representatives of different organizations (Appendix 1).
4. A working visit to two locations in Mexico—one where glasswort is produced and one where salt-loving plant species are selected and improved (ODE B.V. and Saline Seed Mexico Inc., Mexico).

A group has been set up to act as a sounding board and contribute to the thinking and to challenge the ideas (Appendix 2).

The essay, the literature scan and the reports of the interviews and the working visit have been published as NRLO Report 2000/11.

This current report is structured as follows. The context is described in chapter 2: the growing scarcity of fresh water in the world and the salinification of soils. Chapter 3 then addresses the potential of saline environments. Saline soils and salt water are both discussed as production environments. Chapter 4 gives an impression of the knowledge sources and infrastructure, and the knowledge and innovation challenges are outlined in chapter 5. Finally, chapter 6 analyzes the role of the different players and a proposal for action by LNV is put forward.

2. Global fresh water use under pressure

World

Local fresh water shortages and the salinification of agricultural land have been known throughout recorded history. Entire cultures owed their existence to the ability to create and operate efficient water management systems. In some cases cultivation in fresh water has been going on for centuries, rice production for instance. Currently the domestic, industrial and agricultural use of fresh water is increasing so quickly that fresh water shortages can be expected all over the world. This is already the case in several different places. Surface water and groundwater in agricultural areas in many places in the world are rapidly becoming increasingly brackish and saline, particularly in arid tropical and subtropical areas. Furthermore, salt deserts (caused by a lack of fresh water) and saline inland basins (causing by the level of saline groundwater rising as a result of leakage of drainage water) are being created. FAO data show that at least 40% of the world is affected by salinification in some form (8). The actual impact of this estimate is not entirely clear. However, it is known from various sources that large areas in Australia, India, Pakistan, Egypt, Central Asia, South America, Mexico and the United States (1, 2, 11) are faced with salinification to a greater or lesser extent.

It was clear during the World Water Forum in The Hague in March 2000 that the problems of water shortages and salinification are recognized at a global level. Solutions are being sought in a number of different ways (7).

1. Efforts are being made all over the world to utilize fresh water stocks more efficiently, for example by improving irrigation technologies. In India and Pakistan alone there are tens of thousands of irrigation channels in which more than 50% of the water is lost through leakages. Examples, primarily in Israel, have demonstrated that irrigation efficiency can be dramatically improved through good irrigation management and precision (drip) watering.
2. The desalination of salt water is also a possibility. This is presently still rather expensive, but breakthroughs that will enable costs to be reduced significantly are expected. For example, solar-energy-based ultra filtration can produce fresh water at relatively low cost. This method is currently under development.
3. Another option is to reduce the water consumed by different crops through advanced cultivation techniques and improvement, in rice growing for example (7). However, this is not just a matter of technology. Social and cultural changes are also needed in local communities.

4. Furthermore, attempts are also being made to desalinate saline areas by technical means (such as flushing with fresh water), but this is a very costly method and large quantities of fresh water have to be used. This approach does not look promising. Attempts are being made to transport the water in large, low-lying saline areas (such as the inland basins in Pakistan and India) to the sea. Costly and extensive infrastructure is required.
5. There are also many possibilities in the world to concentrate the production of food and biomass in areas where there are not yet any salinification problems, such as Eastern Europe (including the Ukraine and Russia), South America and North America.

Given the magnitude and urgency of the issue of the availability of fresh water it is prudent to direct efforts both to the prevention of salinification and to the utilization of saline environments.

Netherlands

A battle against the salinification of agricultural land has been going on in the Netherlands for centuries. Advantage was also taken of the delta projects – which were built primarily as sea defences – to try to desalinate inland waters (including Grevelingen, Volkerak and Haringvliet), but with little success. Many polders close to the coast are being flushed with fresh water in order to combat salinification, which will increase as a result of expected rises in sea level. This is leading to a tremendous waste of fresh water. Plans to save fresh water are being prepared whereby there will be scope for certain areas to become saline (5, 13, 16). New uses need to be developed for these areas. Current water management in deep polders like the Wieringermeer is also leading to subsidence and salinification as a result of saline seepage.

This means that the Netherlands will also be afflicted by salinification in the entire coastal strip because of a number of causes (subsidence, sea level rises, other water management). This should not be seen as a threat, but as a new and challenging prospect. Recent advice from the NRLO, RMNO and AWT ("*Over stromen*" – "Flow and over flow") relates to these challenges (NRLO Report 2000/4).

Conclusion

The problems of fresh water shortages and salinification are recognized at a global level. All over the world methods for better and more efficient utilization of fresh water are being worked on. Salinification in temperate climate zones, and therefore in the Netherlands, is less marked in terms of nature and extent than in the arid and semi-arid areas of the world. Saline agriculture could be one of the options for utilizing saline soil, in the first place in a global context and in the second place in a national context too. The issue is to identify what the practical potential of saline agriculture is.

3. Potential of saline environments

3.1. Utilization of saline land with halophytes

Saline agriculture is a type of agriculture on saline soil in which crops (halophytes) that can withstand a higher salt content than normal agricultural crops are grown. We can make a broadbrush distinction between different types of halophytes on the basis of the salt content of the water they can withstand (13):

1. Plants with a high salt tolerance: they grow in water with salt contents equal to or even higher than seawater.
2. Crops with average salt tolerance: they grow in brackish water.
3. Crops with moderate salt tolerance: they grow in slightly brackish water that is not suitable for conventional agriculture.

The first category contains the salt water halophytes that are found right on the sea (low on the tidal marshes) and that have very specialized mechanisms for dealing with salt.

Glasswort, spartina grass and seablite are examples. Sea lavender, sea beet and sea kale come into the second category, and the mangelwurz is an example of a crop in the third category.

Some halophytes stand out because of their spectacular growth and production in saline conditions. Nevertheless, the number of examples where halophytes are actually employed for a particular practical purpose is extremely low. It is moreover only possible to describe many of the possible applications and the potential of saline agriculture in qualitative terms. The most important cause of this limited utilization is that, so far, there was virtually no urgency anywhere because agricultural crops met the needs.

Essentially all halophytes are species that occur naturally. There has been virtually no selection or improvement of halophytes with a view to practical applications (see 4.1.). It is not unthinkable that as soon as real research efforts are started, halophytes with unique properties can be found.

The following overview ranks the potential uses of halophytes in terms of possible market and social needs as perceived in local, regional, national and international contexts (1, 2, 3, 6, 8, 10, 11, 12, 13).

Food

Numerous publications contend that in the long term increasing salinification will threaten the world's food supply. The cultivation of certain halophytes could contribute to the solution of this problem. However, the number of specific leads supporting this assertion is limited.

Only two plant species are generally known as salt vegetables: glasswort and sea aster (*Aster tripolium*). Both are eaten in the Netherlands and a few other European countries. Many products are harvested from the wild and sold on the market, but a few growers have started cultivation and established a market position. Glasswort and sea aster occur along coasts all over the world and are eaten by local populations. These crops can be expected to establish places for themselves in the market for special vegetable and salad products. Ideas about the number of hectares needed for production vary widely—from a few hectares for the Dutch market to several thousand hectares for the European market. The American market appears to be virtually untapped.

The seeds of halophytes (or in any event of some of them) are essentially salt free, unlike other parts of the plant. These seeds could be used for processing, like cereals and rice. There are essentially no known halophytes that could serve as a staple food (like cereals, rice and potatoes). The rare examples include a salt-tolerant guava and a tomato.

It is expected that more halophytes can be identified and acquire a position in the food market, primarily as luxury vegetables. In a more general sense halophytes are rich in proteins, oils and fats that are suitable for human consumption.

Animal feed

A number of halophyte species can be used as animal feed. Examples are to be found all over the world, such as Kallar grass in Pakistan and various *Atriplex* sp. in Australia. Sheep that graze along the French and Dutch coast produce meat that is sold on the market as a regional speciality (*d'agneau pré salé*). There are also limits to this incidentally because the consumption of certain salt-tolerant crops may lead to livestock needing more fresh water (in the Dutch province of Zeeland there are sources of fresh water, called *hollestellen*, close to the sea but well above sea level that are known for serving this purpose). There are also certain substances in the plants (saponins) that stunt growth.

Chemicals and fine chemicals

Numerous possible interesting applications relating to chemicals and fine chemicals are referred to in publications about the potential of halophytes. These include different oils (replacements for other vegetable oils), fats, resins, proteins and substances for use in cosmetics. These are usually qualitative indications. It is not clear to what degree these substances possess unique properties or represent unique values. There are many chemicals sold on the world market as commodities and this means that substances from

halophytes will have to compete on existing markets (in terms of cost, properties, quality, purity etc.). However, certain products have a high value to local communities that have no access to commodities on world markets.

Fibres and building materials

There are many references in the literature to the fact that certain halophytes are very high fibre and that there are many possible applications as fibres and in building materials. Such applications are primarily of interest to the local communities in the saline areas.

Ornamental plants

Some halophytes or parts of them can be used as ornamental plants. The dried flower stems of sea aster are an example.

Energy

The cultivation of biomass for energy production is a potentially interesting option. There are references in the literature to production levels of certain halophytes (50-60 tonnes fresh material per hectare) that are of sufficient interest to explore in more detail the possibilities of using halophytes to produce biomass. Scenarios published by Shell for the supply of energy in 2050 are based on approximately 20% of the world's energy needs being supplied by biomass. This alone is enough reason according to the Sustainable Chemicals Development Trust (*Stichting Duurzame Chemie Ontwikkeling*) to invest in the potential of certain halophytes for the production of biomass. The production of cheap raw materials (biomass) on saline land that is not suitable for other purposes is an attractive prospect for large multinationals like Shell. Shell already has technology to convert biomass directly to oil.

Coastal development and protection

Attempts are being made in different places throughout the world to establish new forms of coastal development and protection. There are also important examples in the Netherlands (coastal extension of the Maasvlakte and the coast of South and North Holland, see 20). It is essential to have an understanding of how the dynamic of the water and the land can be harnessed in order to make nature an ally rather than a foe. Concepts that come under this heading include "living rivers", "growing with the sea", estuarine development off the coast of Voorne (a consequence of the Maasvlakte) and the outward movement of the coast from the Hook of Holland to IJmuiden. There can be an express place for brackish and saline environments and for exploration of salinity gradients with opportunities for development of the countryside, as well as marine and estuarine developments. These concepts go beyond the straight technology of constructing dykes or using other technical means to protect coasts.

A number of different projects are being implemented in the provinces of Zeeland, Friesland and Groningen whereby brackish protected wetlands are being created in polders along the Eastern Scheldt and the Waddenzee. In Groningen and Friesland dykes are even being breached in order to promote salinification and once again create salinity gradients. The combination of the development of nature conservation areas and the production of halophytes like glasswort and sea aster has been studied in Groningen. Currently, however, there are no plans beyond the development of brackish wetlands. Mangrove tidal forests along coasts in the tropics are an example of natural coastal protection. Mangroves are without doubt halophytes—they are evergreen trees or shrubs that thrive in saline environments. Mangrove systems are in fact tidal forests on the boundary between fresh and salt water. They also play an important part as a biotope for a large number of species of fish and crustaceans (see 3.3). The integration of knowledge and understanding relating to the possibilities of natural saline ecosystems and technical expertise can form a rich source of new coastal development and its management.

Combating desertification

Salinification is threatening current land use functions in different parts of the world and destroying them in some locations. This process is even irreversible in some areas, depending on the type of soil. There are also areas where rehabilitation is conceivable, particularly where there is lighter sandy or loamy soil and where fresh or saline groundwater is available.

A number of examples can be found in the deltas of large rivers (Nile, Colorado). The Colorado delta in Mexico is an example of a manmade salt desert that is encroaching steadily northwards and is devouring Mexican farms by covering them with layers of sand and salt borne along by southerly winds. So much water is taken from the Nile for irrigation that downstream the river is becoming more and more saline, and this has dramatic implications for the vast areas of agricultural land in the delta.

Halophytes also include many species of tree and shrub that flourish surprisingly well in saline areas. One of the most striking examples is in the salt desert in the north of Chile, where the government has planted approximately 20,000 hectares of salt desert with the tree species *Prosopis sp.* Experiments with this tree are currently being conducted in India and researchers are extremely surprised about the positive results (Swanminathan, personal communication). This is being confirmed in Mexico, where very remarkable results have also been obtained with *Tamarisk aphylla*, which also develops well with only seawater as source. Promising results have moreover been obtained in India and Egypt with *Jujuba sp.* with oil-rich seeds. It is now also known that these species of tree have roots that go down several metres and can consequently make use of saline groundwater. This offers intriguing opportunities for replanting saline areas that are presently empty and

deserted. There is hope that the impending desertification of areas can be avoided and that the quality of life of the inhabitants can be improved.

The problems confronting people in Egypt are associated with how to prevent salinification and with the question of how certain saline areas can be improved in terms of both landscape and ecological values in order to create more attractive areas for tourism.

Climate

Planting in saline areas can have major benefits. Besides ecological recovery (involving both flora and fauna) and the formation of new local biological ecosystems, there can also be enrichment of the local population's quality of life. In a broader context it can also contribute to improvement of the world's climatic conditions. Finally it would appear to be possible to respond to an international goal, namely the sequestration of CO₂, by planting on a large scale on otherwise worthless saline ground.

Conclusion

As things stand now the prospects for halophytes in the world markets for food, animal feed and fine chemicals seem limited. However, certain products could serve as a surprising broadening of the range of vegetables in "western" markets. Halophytes can play an important role in local and regional communities in western, tropical and subtropical areas as a source of food, animal feed, chemicals, fine chemicals and other raw materials.

Halophytes have their greatest potential not so much in contributing to the world's food supply but primarily in their contribution to utilization of the growing area of saline land for a range of different goals. The most important opportunities relate to reforestation or replanting and ecological recovery of saline areas that have fallen into disuse, coastal development and protection, and the production of cheap biomass for renewable energy, climate improvement and CO₂ sequestration. The further development of this potential requires an international context.

3.2. Utilization of saline land with crops

The growth and development of normal crops declines as the salt content of the growing medium (soil, substrate) increases. This means that these crops are not really part of the picture for cultivation on saline land. There is a degree of variation in the salt sensitivity among different crops. For example, the family of plants that includes the beet (*Beta* sp) is known to have some tolerance to salt (17). There is also a measure of variation within a family of plants. Growers are now taking advantage of this by selecting on the basis of salt tolerance. This aspect is quite well known in the glasshouse growing industry with regard

to a number of different types of vegetables (the usual range of tomatoes, peppers, lettuce etc.) and flowers. This is because the salt content of the substrate has a major impact on production and product quality.

It is becoming necessary in more and more cases in many areas to reuse drainage water. The upshot is that this irrigation water is often much more saline. It would then need to be possible to utilize the differences in salt tolerance among halophytes and crops.

It is important to establish with greater accuracy the differences in salt tolerance between crops.

Conclusion

There is limited variation in salt tolerance among the usual commercial crops. It is probably possible to acquire more knowledge about this. For the time being this variation is not enough to tackle salinification.

3.3. Utilization of salt water as a production environment

Microalgae and macroalgae

Macroalgae species are collected from coastal areas in various parts of the world and produced in sea cultures for a variety of purposes (foodstuff ingredients, chemical components like agar etc.) (18, 21). This is quite common along rocky coasts. There are also experiments involving cultures on polystyrene plates in the sea in order to breed marine algae. These developments are most advanced in Japan, South and East Asia and California. A range of dried or processed products is exported from these areas all over the world. The Netherlands imports some tens of tonnes of algae in dried form (ground or in tablet form) (15). Most of these products are sold in health food shops. Seaweed is mainly collected along the European Atlantic coasts (Portugal, Spain and France). In France there is an experimental facility for algae production and the products are valorized. There is not much interest in algae in the Netherlands. Fresh seaweed is imported from France and mainly used to garnish seafood products. Experiments have been conducted in Zeeland with harvesting sea lettuce from the Veerse Meer for human consumption and as animal feed. It has been found to be very easy to grow in closed systems. However, the "fresh vegetable" market was too limited. One Dutch business is trying to launch a number of innovative seaweed-based products on the market. The target is the health market because seaweed has high natural levels of iron and iodine. One of the problems of growing algae in coastal waters is that seaweed readily absorbs heavy metals and other contaminants from the seawater.

Here too according to several entrepreneurs the most critical problem is not so much producing the seaweed but developing a market for it.

The use of microalgae (plankton) is still effectively in its infancy. However, this field has significant potential if only because of the huge surface area of the oceans. One of the ideas is to use microalgae for energy production.

Bioproduction of animal organisms in salinity gradients

Estuaries, bays, lagoons, inlets and deltas are among the most productive natural ecosystems in the world (18, 21). The production levels of biomass (fish and crustaceans) that are achieved are at the very least comparable with those in modern agricultural systems. These areas can be considered as natural "factories". These areas are the major breeding grounds for all the life in the seas and oceans and they therefore also contribute to the diversity of the natural ecosystem. No other natural system on earth has such a variety of life or can offer such huge potential for food production.

The most important reason behind the productivity of these areas is that fresh river water meets saline seawater in them. The salinity gradients that are created form the basis for this stupendous productivity. On the one hand marine and fresh water organisms die off in these gradients, but on the other hand the large mass of organic material that this creates serves as food for all sorts of marine life.

This rich type of bio-production is used on a local scale as a food source. Promising areas can be identified all over the world.

In this context it is also important to point out the potential of tidal mangrove forests along coasts in tropical areas. These tidal forests perform numerous functions, such as coastal protection, as biotopes for animal organisms and as a source of products for local consumption.

Industrial protein production with microalgae

As a follow-up to the sustainable technology development programme, small-scale research is being conducted in the Netherlands into producing (fresh water) algae in bioreactors because of their potential for protein production. The potential impact on the food supply is expected to be substantial. This subject was not included in the quick scan.

Marine aquaculture in closed systems (marine agriculture)

A number of different types of aquaculture have been developed to farm saltwater fish. The most developed is the use of sealed inlets or fjords. Fish farming on land in closed systems (marine agricultural) may be of interest in the Netherlands. One entrepreneur has taken the lead in this field in the Netherlands. Thus type of marine bio-production was not

incorporated in the quick scan (see the interviews in the background document NRLO Report 2000/11).

Conclusions

The potential of microalgae and macroalgae as sources of food, foodstuff ingredients and natural chemical raw materials is of little interest here. In Japan and Southeast Asia, on the other hand, they are a source of rapidly growing commercial activity.

Estuaries and deltas can be of great significance to the world's food supply in the form of the opportunities they offer for bio-production and ecosystem development through the utilization of the salinity gradients that occur in them. Coastal tidal mangrove forests are another case in point.

The most critical problem is not so much production technology but developing a market.

Roelof Hoogland (businessman) in a telephone interview

Science often produces many positive functions without a product concept being present. It also appears to be the case that marine agriculture is a science-driven technology with many possible functions. If you want to be successful, you need to find potential customers and develop the desired product applications with them.

J.H. Voûte (DIMI) in an interview

It is not just a matter of valorizing seaweed products. *It is also a matter of creating a new sector on the basis of healthy saline products.* It is based on a broad concept of foodstuffs and health products produced from marine raw materials.

M. Stevens (entrepreneur)

Shell is assuming that within a few decades biomass will provide approximately 20% of energy needs. The question is whether there will be cheap raw materials. *If biomass production is possible on saline land that serves no other functions or is valueless, it is an interesting option.*

J.J.M. Mulderink (DCO) in an interview

The possible utilization of saline land and learning to utilize saline vegetation are essential. *Salinification problems should be viewed primarily in local and regional contexts.* It is often a matter of the basic needs of the people who live there and who have no other source of food or raw materials.

Dr E. Erasmus (ODE B.V.)

Between them the seas and oceans cover three-quarters of the earth and they have been a source of life and a resource for the living since time immemorial. It is no coincidence that 60% of world's population lives less than 60 km from a coast. World population forecasts include a doubling of the number of people in coastal regions within the next 25 years. Coastal waters were a rich source of marine production for this population.

J.C.J. van Zon (Arcadis/Euroconsult) in his essay "De zee van bron tot hulpbron" "*The sea—from source to resource*"

It is because the role of marine production can become significant in the future that it is prudent to have a debate now about the potential role that can be played by agricultural research in the Netherlands. This admired research organization acquired its reputation before, during and shortly after the green revolution. The question is whether the present research topics are still economically relevant and whether a switch to the blue revolution would be more appropriate.

J.C.J. van Zon (Arcadis/Euroconsult) in his essay "De zee van bron tot hulpbron" "*The sea from source to resource*"

A battle against the salinification of agricultural land has been going on in the Netherlands for centuries. This is the basis of the policy of water boards to flush in coastal areas using fresh water from rivers. *This makes the government the biggest waster of fresh water in the Netherlands. We have to accept salinification, devise new types of use and facilitate their creation. We have to opt for healthy saline environments and transitions from fresh to salt water. This can result in areas with high protein production that is simple to harvest.*

Professor H. Saeijs (EUR) in an interview

The seas contain much more than the many types of fish and crustaceans that are currently being caught. There are also other organisms that are of potential use to humans as food and for other purposes too. There are moreover opportunities to make better or different use of biomass that is currently being utilized. *In other words the marine ecosystem has a range of interesting potential opportunities. What has to happen before better use can be made of the existing biomass?*

Dr A.P. Verkaik (NRLO) in the NRLO Report "Zeeën van mogelijkheden" "*Opportunities from coast to coast*" (98/10)

Marine process technology is concerned with translating advances in marine biology into processes or systems that can be used to make products on a practical scale through efficient and effective production of marine biomass in bioreactors under controlled conditions. *Marine bioprocess technology therefore builds a bridge between oceans and industry.*

J. Tramper (Wageningen University and Research Centre) in the essay "Concepten voor een nieuw elan in de Nederlandse landbouw" "*Concepts for a new elan in Dutch agriculture*"

4. Knowledge sources and infrastructure

4.1. Halophytes on saline soils (8)

World

Research in special institutes that is completely focused on “normal” agriculture in saline conditions is being conducted in a number of countries where salinification has reached major proportions. The research, which is being carried out by both institutes and companies, concentrates primarily on producing fresh water crops with a more and more saline water/soil system. Use is made of small differences in salt tolerance between crops or between varieties of one crop. No attention was paid to halophytes until recently. This is now beginning to change.

Initiatives are springing up in many places to evaluate the utilization options of halophytes now that salinification is becoming a major problem. The countries involved include Australia, Pakistan, India, Saudi Arabia, Chile, Mexico and the USA (California).

Europe

There is limited interest in salinification problems in Europe. Over the last 10 years 20 projects relating to salt tolerance have received EU funding. One saline agriculture project, in which several countries participated, received support. The Ministry of Agriculture, Nature Management and Fisheries also provided financing for this project. The funding was used to construct the infrastructure for a trial field in Burgh Haamstede (Zeeland). After four years the funding for this project was not extended by the EU because of too few results. The research stopped at this point.

A European network of halophyte researchers was recently set up. Researchers at the University of Osnabrück, Germany, are coordinating it.

Netherlands

Halophyte expertise in the Netherlands is limited to a few researchers in three institutions: the NIOO in Yerseke, the Free University Amsterdam and Plant Research International in Wageningen. These researchers only spend a limited part of their time on this subject. The firm of Rijk Zwaan (De Lier, Netherlands) in collaboration with Scrops B.V. in Zeeland has carried out some plant breeding activities involving sea aster (*Aster tripolium*) in order to improve its utilization (growth, production, the product's eating or application quality,

disease resistance etc.). ODE B.V. (Amsterdam) is working with Saline Seed Inc. in Mexico in plant breeding of glasswort (*Salicornia bigelovii*). As a spin-off from the EU project, a few Dutch and Belgian small and medium-sized businesses (see Appendix 1) have embarked on the production of glasswort and sea aster, although part of the production is outside the Netherlands in Portugal and Mexico. Their major concern is not so much cultivation but developing a market position.

Conclusion

International halophyte expertise is concentrated in the scientific world primarily in individuals and small groups of researchers. Recently the initiative was taken to set up a scientific network.

The scientific literature on halophytes is extensive. However, the number of practical applications so far is very limited. It seems as though there is a barrier between the existing farming culture and the scientific world of halophyte experts.

There are no major international research programmes in the fields referred to above. Agricultural development programmes are focused on land use, crop expertise and irrigation management, and do not include the use of halophytes under saline conditions. None of the research in the areas referred to above enjoys priority in European programmes.

The Dutch knowledge infrastructure can become involved in this field (utilization of saline land by using halophytes) by rapidly building up expertise.

4.2. Salt tolerance in commercial crops

A number of institutions spread around the world are working on unravelling the different salt tolerance mechanisms. Efforts are also being made to identify the genetic basis of salt tolerance in a variety of crops. Companies working on plant breeding point out unanimously that a greater understanding of the mechanisms of salt tolerance is required before it can be incorporated in improvement programmes for commercial crops. Compared with the scale of the problem, the effort in this field worldwide (and in the Netherlands) is limited.

Conclusion

Despite the limited priority, the Dutch knowledge infrastructure is in a position to respond immediately.

4.3. Marine cultivated crops

Utilization of microalgae and macroalgae

The expertise relating to algae cultivation in seawater for production purposes is concentrated primarily in Japan, India, South and East Asia and California (8). The only activity in this field in Europe is a French test station. It is playing a part in the regional development of marine products as regional specialities.

Utilization of algae for protein production in industrial systems

As a follow-up to the sustainable technology development programme, small-scale research is being conducted in the Netherlands into producing microalgae in bioreactors because of their potential for protein production (19). The research on this is taking place in a number of different universities. There does not appear to be any coordination.

Salinity gradients and tidal mangrove systems

It was not possible in this quick scan to compile relevant information about institutions that are active in these fields. Knowledge about tidal mangrove forests is available from Wetlands International (located in Wageningen and supported by the Ministry of Agriculture, Nature Management and Fisheries). Tidal mangrove forests are attracting greater international attention and financing is becoming available. It is known that some Dutch consulting firms (DHV, Arcadis) are involved in mangrove rehabilitation programmes.

The varied nature of the Dutch delta offers good opportunities to acquire expertise about salinity gradient utilization (18).

Conclusion

The Netherlands can play a significant part at global level in the development of the potential of each of the fields mentioned. Use can be made of the existing knowledge infrastructure in this regard.

4.4. Fresh water use

Responsible land use and fresh water use are on the agenda virtually everywhere in the world where there is farming. There is a growing focus on water, including fresh water, management, i.e. optimization of irrigation techniques in the local context. Dutch research institutes and consultants are very active in this area.

Efforts are being made to become involved wherever salinification of land or drainage water plays a role. So far this has been approached primarily on the basis of the possibilities offered by local water management.

Institutions associated with large international organizations (CGIAR, IFPRI, UNEP programmes) are also actively involved in this field. The World Bank is often associated with the financing of regional projects relating to water management, irrigation etc. As a rule research is conducted in local agricultural research institutes.

Conclusion

The Dutch knowledge infrastructure is already very much involved in this field. Additional efforts do not appear to be necessary.

5. Challenges for knowledge development and innovation

5.1. Halophytes on saline soils

Knowledge development and innovation are needed in a number of different areas in order to be able to fully utilize the potential of saline agriculture, and halophytes in particular.

A number of these areas are discussed below. Many areas need primarily applied research and innovation-focused activities, with emphasis on fundamental research in some cases.

Increase in the number of usable species

One challenge is to identify and develop a broad palette of salt-tolerant crops for a variety of applications. The number of plant species is currently still very limited.

Development of edible crops

Sea aster and glasswort are receiving increasing attention everywhere as edible crops, whereas Kallar grass and *Atriplex sp.* are being used as animal feed and *Tamarisk*, *Prosopis* and mangrove dominate as species of tree. The botany of halophytes is well documented, but their nutritional qualities have not been sufficiently evaluated. Generally speaking halophytes are rich in proteins, oils and fats that are suitable for human consumption. It is expected that more halophytes can be identified that can acquire a position in the food market, primarily as vegetables.

Development of chemical and fine chemical applications

It is not clear to what degree substances from halophytes possess unique physical and chemical properties or represent unique values that make them interesting candidates for specific applications in chemicals, fine chemicals, pharmaceuticals or cosmetics. The sustainable chemicals development approach of analyzing all parts of a plant for usable substances can also be used for halophytes (4).

Plant breeding and cultivation

It is necessary to improve halophytes by selection and plant breeding, not so much to enhance salt tolerance but to improve utilization-related qualities (growth, production, nutrition or application quality of the product, disease resistance etc.). Knowledge about

plant breeding and cultivating salt-tolerant crops is at a primitive stage. There are many questions about cultivation techniques, fertilization and crop protection.

Marketing

There is only limited knowledge and experience relating to marketing the products of saline agriculture. Some businesses have organized production along commercial lines. Their greatest challenge is not production as such but marketing. How can a new product with a specific taste be launched on the market and how can the logistics process be organized in the chain?

5.2. Commercial crops: salt tolerance improvement by plant breeding

Salt tolerance

The mechanisms of salt tolerance in halophytes are very varied and complex, and so far little is understood about them (17). An understanding of these mechanisms is needed in order to improve the salt tolerance of commercial crops.

However, efforts to improve the salt tolerance of traditional commercial crops by plant breeding have had few striking results so far. Some institutions report a measure of progress. In Wageningen, for example, some breeding in the salt tolerance of tomatoes has been achieved and in India there are claims about the successful transfer of salt tolerance genes from mangrove to rice (7, 14).

Developments in biotechnology could lead to new breakthroughs. There is a major challenge for fundamental research here.

5.3. Marine cultivated crops

Further foresight is necessary to specify in more detail the role of Dutch knowledge institutes and companies in each of the areas discussed below. This quick scan has only been able to indicate the potential.

Macroalgae

Coastal waters have enormous potential for macroalgae production. In Japan and California their use is already widely accepted and there is also expertise in extracting substances that can be of use to people. The relatively modest amount of research and development work that has been carried out in this field has already resulted in a series of usable new products, or to the production of known products in a cheaper way or with

fewer deleterious side effects. The compounds in the marine environment that have not yet been discovered probably represent one of the greatest treasures on earth (NRLO Report 98/10 "Zeeën van mogelijkheden" "*Opportunities from coast to coast*").

Salinity gradients

There is substantial potential for bio-production of animal organisms in salinity gradients in deltas and in tidal mangrove systems. There seem to be opportunities for operation on a larger scale than at present. One problem is that small-scale local coastal ecosystems in a number of different areas are being threatened by overexploitation. It is necessary to develop stable marine ecosystems for sustainable bio-production (including in the Dutch delta).

Thanks to the presence of rivers, deltas and inlets, the Netherlands has a splendid opportunity to play a major role in this area and to develop expertise that can be used all over the world.

International initiatives to make better use of, strengthen or rehabilitate the functions of tidal mangrove forests can be supported.

Microalgae for industrial protein production

The translation of marine agricultural crops to industrial processes or systems is still at a primitive stage. There is potential for major breakthroughs.

Marine aquaculture in closed systems (marine agriculture)

This development is at a very early stage. The Netherlands is lagging behind developments elsewhere in the world and Europe.

5.4. Fresh water use

As discussed in paragraph 4.4, very many research institutes are actively involved in improving the efficiency with which fresh water is used. There are also many international programmes on this topic.

There is no reason to launch additional initiatives for knowledge development and innovation in this field.

The contents of a research programme on saline agriculture can be:

- generation of database on the range of adoption of different halophytic species to saline situations under different agro-ecological conditions
- the next step should be generation of information with respect to their agronomic practices towards effective rehabilitation of salt lands
- generation of basic information on mechanisms of salt tolerance etc.
- research to identify and transfer genes and gene systems that confer salt tolerance in these wild species
- conservation of biodiversity through development of gene banks and multiplication of rare and useful species

Dr R.S. Paroda (Director-General of the Indian Council of Agricultural Research) in a letter to the NRLO

6. The next step: proposals for action

6.1. The roles of knowledge institutes, companies and government

The preceding paragraphs outlined a brief sketch of a growing shortage of fresh water worldwide and the growing need to utilize saline environments (dry and wet) for bio-production and ecosystem development.

The focus then shifted to the prospects of saline agriculture and in particular the potential for halophytes on saline land (in accordance with the request from the Ministry of Agriculture, Nature Management and Fisheries). There is potential – primarily in an international context – but further exploration and development is required. Dutch knowledge institutes can make a meaningful contribution and companies (multinational corporations and small and medium-sized businesses alike) could reap the benefits in due course. However, market prospects are not yet sufficiently firm to attract major investments from companies. This, together with the fact that possible applications of halophytes could serve a number of social goals (primarily combating climate change and desertification), justifies active involvement on the part of the Dutch government.

The national prospects for saline agriculture with halophytes are more limited, although the number of regions in the Netherlands where this type of farming is possible will increase in the future. The increasing salinification of the Dutch coastal zone demands greater attention for the utilization of saline ground for different purposes, of which saline agriculture is one. The development of nature conservation areas is certainly another option.

There are moreover important opportunities for the Netherlands with regard to the utilization of the capacity of marine and estuarine salt water environments for bio-production and ecosystem development.

The successful development of the range of potential opportunities requires input from a number of different parties in the business community, the knowledge institutes and government.

Role for knowledge institutes

Knowledge institutes can strengthen the study of the problems of saline land, marine crop cultivation and algae-based industrial production in the programming. There are a number of different options for this:

- intensifying the international network;
- strengthening the applied research;
- strengthening the scientific research in the areas mentioned.

Role of the corporate sector

Companies have a particular role in the development of markets for specific products. Most of the small businesses operating in this area are very individual and they could benefit from setting up an industry organization for small and medium-sized firms with "salt" products. Large enterprises (for example the Dutch multinationals with their own research potential) could analyze the potential of halophytes and the rehabilitation of saline land and set up projects on their own or against the backdrop of the development of sustainable chemicals. Co-operation programmes with government and the knowledge institutes could be developed for projects with a time horizon of several decades.

Role of government

The government has a specific task. This is concerned primarily with putting desirable innovations on the agenda based on a vision of future developments. The issue is to promote a change in conceptual thinking with a view to the longer term: or in other words in this situation learning to think in terms of saline conditions for bio-production and ecosystem development. It is a matter of putting salt problems and the associated challenges on the agenda in international forums and in bilateral agreements with various countries. The government can take the initiative to bring parties together and to develop a joint programme with these parties.

6.2. Proposal for action by the Ministry of Agriculture, Nature Management and Fisheries

It is proposed that the initiative should be taken to develop the following theme:

bio-production and ecosystem development in saline conditions

Two core activities can be developed under this theme:

1. an innovation programme relating to:

bio-production and ecosystem development on saline land

2. a foresight study of:

bio-production and ecosystem development in marine and estuarine systems

Both activities are discussed briefly below.

1. Development of an innovation programme entitled “Bio-production and ecosystem development on saline soils”

The proposed innovation programme includes defining a number of challenging pilot projects. The results of these pilots can be used to decide which follow-up activities are desirable. The government can initiate, but others (corporate sector, social organizations and knowledge institutes) have to subscribe to the urgency and be willing to invest in it. A standard bearer will have to be found from among these parties. This programme contains a national and an international component. Each of the pilots may require a different consortium of “developers”.

When it comes to implementation it needs to be borne in mind that the innovation programme cuts across the areas of several ministries (Transport, Public Works and Water Management; Housing, Spatial Planning and the Environment; Economic Affairs; Foreign Affairs-DGIS).

It will take 6 to 9 months to define an innovation programme in detail.

The programme should be assessed in terms of the following criteria:

- the future prospects (market potential and contribution to social goals);
- the contribution to sustainable development;
- the need for co-operation between parties.

There also needs to be an evaluation of whether a contribution will be made to:

- the broadening of the relevant Dutch knowledge portfolio;
- the possibility of utilizing the knowledge acquired on a worldwide basis.

It does not appear to be worthwhile giving consideration now to physical research facilities (testing station or experimental farm) in the Netherlands for saline agriculture. The content and scope of the innovation programme need to be established first. Furthermore, there appear to be sufficient possibilities to dovetail with the existing research and innovation infrastructure.

The following challenging pilot projects could be implemented in an innovation programme:

National

1. A polder with saline seepage

Challenge: if in 2010 only brackish water is available in the polder, which functions can be developed and which players (businesses, government agencies, knowledge institutes, social groups) are needed?

2. Zeeland as a regional concept

Challenge: if the province of Zeeland changes its stance from being a region with agriculture to a region with salt water, what should we do to achieve and strengthen this picture? Which new functions relating to salt water and saline ground can be brought to value?

Examples include additions to or broadening of the existing package of recreation, countryside and nature conservation, production and ecosystem development with new functions (production of sea aster and glasswort (saline agriculture)) or ecosystems (salinity gradients).

International

1. Halophytes as biomass for energy purposes

Challenge: to increase the productivity and energy value of halophytes for the purposes of their utilization as energy crops.

2. Halophytes as raw materials for fine and other chemicals

Challenge: to identify unique and interesting inherent substances with their own specific value (biocascade investigation)

3. Utilization of halophytes in salinity gradients of irrigation systems

Challenge: to reduce the salinification problem in irrigation water by integrating halophyte cultivation into irrigation management.

4. Utilization of halophytes in projects for integrated coastal protection and development

Challenge: to integrate halophytes into coastal development projects.

2. Carry out a foresight study

“Bio-production and ecosystem development in marine and estuarine systems”

The challenges in this area are inspirational. This quick scan has not been able to pursue this line in sufficient depth. It is proposed to conduct partial foresight studies in two areas:

- marine and estuarine bio-production and ecosystem development;
- microalgae as a source of industrial protein production.

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Appendix 1: Overview of the people interviewed

Research and consultancy

H.W. Denecke	International Institute for Land Reclamation and Improvement (ILRI)
W. van Dieren	Institute for Environmental and System Analysis (IMSA)
Dr W.F.W.M. van Heugten	Sustainable Chemicals Development Trust (DCO)
Dr A.H.L. Huiskes	Netherlands Institute for Ecological Research (NIOO)
Dr P. Kamermans	Netherlands Institute for Fisheries Research (RIVO)
Professor M.J. Kropff	Wageningen University and Research Centre/ C.T. de Wit Graduate School
J.J.M. Mulderink	Sustainable Chemicals Development Trust (DCO)
H.P. Ritzema	International Institute for Land Reclamation and Improvement (ILRI)
C.W.J. Roest	ALTERRA
Professor J. Rozema	Free University Amsterdam (VU)
Professor H. Saeijs	Erasmus University Rotterdam (EUR)
J.H. Voûte	Dutch Institute of Management & Innovation (DIMI)
Professor R.E. Waterman	Integrated coastal policy and development consultant

Business people in saline agriculture (including marine production)

J. Bogemans	Scrops B.V.
A. Bout	Seafarm B.V.
Dr E. Erasmus, Ph.D., M.B.A.	Ocean Desert Enterprises B.V. (ODE)
R. Hoogland	Hoogland
Dan Murphy	Saline Seed S.A. Mexico
José Noriega	Saline Seed S.A. Mexico
G. O'Reilly	Coastal Harvest B.V.
B. Schot	Seafarm B.V.
M. Stevens	Stevenshield

Improvement companies

J. Berg	Rijk Zwaan Nederland B.V.
J. Dourleijn	Advanta Nederland
Dr H. Pennings	Seminis Vegetable Seeds
Dr O.M.B. de Ponti	Nunhems Zaden B.V. (Aventis)

Environment and nature conservation

T. Kramer	Zeeland Environmental Federation
G.J. Sterkenburg	The Groningen Countryside Trust

Internationale references (written)

Professor M. Ajmal Khan	University of Karachi, Karachi, Pakistan
Dr P.K. Ghosh	Director of the Central Salt & Marine Chemicals Research Institute, Gujarat, India
Dr S.R. Grattan	University of California, Davis
Dr S.H. Lips	J. B. Laustein Institute for Desert Research, Ben Gurion University of the Negev, Sede Boqer, Israel
Dr R.A. Mashelkar	Director General of the Council of Scientific & Industrial Research, New Delhi, India
Professor Mona El Qadi	Natural Water Resource Centre, Cairo, Egypt
Dr R.S. Paroda	Director-General of the Indian Council of Agricultural Research, New Delhi, India
Dr M. Poole	CSIRO Centre for Mediterranean Agricultural Research, Wembley, Australia
Dr M.S. Swaminathan	M.S. Swaminathan Research Foundation, Madras, India

Dutch agricultural attachés:

G.A. Kostwinder	New Delhi, India
B.B. van der Meer	Cairo, Egypt
J.G. van der Vooren	Riyadh, Saudi Arabia

Appendix 2: Members of the sounding board group

J. van Dijk	Former member of the Groningen Provincial Executive Member of the Water Management in the 21 st Century Committee
Professor M.J. Kropff	Wageningen University and Research Centre/ C.T. de Wit Graduate School
J.J.M. Mulderink	Sustainable Chemicals Development Trust (DCO)
Professor H.L.F. Saeijs	Erasmus University Rotterdam
G.H.J. Titulaer	Western Agriculture and Horticulture Organization (WLTO)
Professor P. Vellinga	Institute for Environmental Issues/ Free University Amsterdam (IvM/VU)
J.C.J. van Zon	Arcadis-Euroconsult B.V.
Dr H.J. van Oosten (project manager)	Bureau NRLO
Dr J.G. de Wilt	Bureau NRLO