FAO CORPORATE DOCUMENT REPOSITORY

Produced by: Fisheries and Aquaculture Department

Title: Technical resource papers <(>seaweed culture<)>...

More details

ENVIRONMENTAL ASPECTS OF SEAWEED CULTURE

M. J. PHILLIPS

Institute of Aquaculture
University of Stirling
Stirling FK9 4LA
Scotland

The impact of aquaculture on the environment and effects of environment on aquaculture production have become important issues in recent years. There is evidence from many countries that environmental deterioration is a major threat to aquaculture production and product quality. There is also evidence that marine and freshwater aquaculture can cause environmental change, which in some cases may adversely affect the long-term viability of the aquaculture operation itself, or result in serious conflicts with other users of aquatic resources. These problems have led to a need to consider aquaculture as one component in the aquatic ecosystem and to plan aquaculture development in a way which makes efficient use of resources. There have been several recent reviews of impacts associated with finfish (Beveridge, 1984; NCC, 1989), mollusc (ICES, 1989; NCC, 1989) and crustacean (Phillips et al, 1990) culture but there is little information on seaweed culture.

The main environmental impacts caused by aquaculture have been reviewed in several recent publications (NCC, 1989; ICES, 1989; NCC, 1990) and can be summarised as follows:

i. physical effects, including effects on water movement, the physical structure of terrestrial and aquatic habitats and aesthetic impacts;

ii. ecological effects, including changes in water quality, primary and secondary productivity and native fisheries.

These effects have arisen in many forms of aquaculture, although impacts vary considerably depending on the nature of the culture system and species cultured, plus the environment where the culture system is located. The main impacts and problems come from intensive aquaculture with high stocking densities and supplementary feeding, but problems have also arisen in extensive aquaculture systems.

Seaweed culture has expanded rapidly over the past few years, and in 1987 3,139,473 tons (wet weight) of seaweed were produced throughout the world, the bulk produced in Eastern Asia (FAO, 1989). This expansion has brought benefits in terms of income, employment and foreign exchange, but has also been accompanied by some conflicts with other users of the coastal zone and concerns over potential environmental impacts. The aim of this review is to consider some of the environmental implications associated with seaweed culture and ways in which issues may be resolved.

Physical aspects of seaweed culture

Seaweed culture is practiced using a very diverse range of culture methods and each of these methods will interact with the environment in different ways. The nature of this interaction and environmental impact will depend on the method of culture, the surface area (and three dimensional volume) of the farm, and the site where the farm is located. In general, several physical impacts can be recognized, which may have both positive and negative effects on the environment (Table 1).

The main impact of pond culture is the space used for ponds, which is unlikely to cause significant harm where ponds are located in unfertile and underutilised land. Gracilaria culture has been developed in abandoned shrimp ponds in the Philippines, Thailand and Indonesia, thus making use of otherwise wasted resources.

The main physical impact of sea-based systems probably stems from the large surface area required for viable seaweed culture in many areas but there may be others caused by site preparation, routine management and the culture system.

Site preparation of some species involves removal of rocks and other obstructions and potentially competitive grasses or predators (Juanich, 1988). Such operations could result in some damage to coastal ecosytems, and in some instances the loss of some species of conservation interest, such as seagrasses (Pullin, 1989). The routine management of seaweed farms in shallow waters, such as Gracilaria or Eucheuma farms, can result in additional damage through trampling and accidental damage.

The physical shading of an area by seaweed farms may also occur, resulting in changes in benthic communities and primary production in the water column (later section) although these effects have not been well studied.

There is also some potential for large scale farms, such as the large areas covered by Laminaria japonica culture in China, to influence coastal water movement. There is the possibility of enhanced sedimentation but also that seaweed farms can protect coastal areas from erosion. Large seaweed farms may also help to protect other more sensitive culture species and systems. For example, in China, Laminaria japonica culture zones are used to shelter areas where more fragile and sensitive culture species and systems, such as mussel or scallop culture are located.

Introduction of seaweed culture rafts, ropes, anchors and other structures can increase the surface area of substrate, which particularly in open waters may enhance production of other marine organisms, particularly in otherwise barren areas, much in the same way that artificial reefs have been shown to do (see below). Seaweed culture may also be used very effectively to rehabilitate degraded coastal areas and enhance production from otherwise unproductive and barren environments.

Aesthetic aspects and multiuser conflicts

The potential aesthetic impact of aquaculture has dominated arguments over aquaculture development in some countries and aquaculture planners are having to ensure that potential aesthetic changes are considered during the development of new aquaculture ventures in order to avoid conflicts with other users (Dixon et al., 1990). The recent conflict over the development of seaweed farming on Tubbataha Reef in the Philippines is probably one example where some of the user conflicts were derived from concern over potential aesthetic impacts.

The large area required for economically viable seaweed culture is in some countries resulting in significant conflicts with users concerned with visual impact and others such as fishermen and tourists concerned with access (Merrill, 1990). The potential 'space' implications for seaweed culture may become an important constraint to development in some areas in Asia and other parts of the world as competition for coastal and near-shore resources intensifies. These problems could perhaps be resolved by strategic planning or use of appropriate culture technologies. The use of submerged culture techniques or careful site selection could be used to avoid some visual impacts in sensitive locations. Development of offshore culture zones could also reduce conflicts, as well as making more efficient use of offshore resources.

Ecological aspects of seaweed culture

The positive and negative ecological aspects are summarised in Table 2.

The use of supplementary feed in intensive aquaculture systems results in a net increase in nutrient levels and primary productivity in waters receiving effluent (NCC, 1989). Seaweed culture is an extensive culture system which relies mostly on a natural nutrient supply. For example, studies in Republic of Korea and Japan have shown a good correlation between nutrient concentrations and Undaria production (Chung, 1986). The reliance on natural nutrient supply is such that there is potential for seaweed culture to deplete coastal waters of nutrients. Studies in China show reduced nutrient levels in Laminaria japonica culture areas (UNDP/FAO, 1989). The effects of nutrient depletion have not been well-studied, but nutrients diverted through the macroalgae, rather than phytoplankton food chains could affect patterns of nutrient recycling and secondary productivity. The removal of nutrients in high density culture areas also has implications for the long-term viability of seaweed farming itself.

There are examples from extensive finfish and mollusc aquaculture where overstocking of culture areas has resulted in a decline in natural productivity and eventual decrease in aquaculture production. Milkfish culture in Laguna de Bay is a classic example of overstocking in relation to the 'carrying capacity' of the environment (Beveridge, 1984) and there are other examples from Europe, Asia and North America where mollusc production has suffered badly following a few years of operation, as a result of overstocking (ICES, 1989). There are indications that it is also possible to over-intensify seaweed farming and that in some locations over-production is resulting in outbreaks of disease and production losses. Studies in China show that outbreaks of disease in seaweeds may be linked to nutrient decline (UNDP/FAO, 1989) and over-intensification in the Republic of Korea is blamed for the serious disease losses in Undaria and Porphyra culture (Gong, 1990). These problems, which may grow as the seaweed industry continues to develop, highlight the need to carefully consider the 'carrying capacity' of the local coastal environment which balances the ecological requirements of the cultured seaweeds with the capacity of the environment to provide these needs.

In some areas, problems of nutrient depletion are reduced by fertilization. For example, studies in China have shown that fertilization of Laminaria japonica culture areas may be necessary when nitrate levels fall below 20 ug/1 (UNDP/FAO, 1989). Fertilization is normally with inorganic fertilizers or occasionally with organic manure. This fertilization has a positive benefit on the growth of seaweed and has been shown to enhance the productivity of phytoplankton and invertebrates in the culture zones (UNDP/FAO, 1989). The wider environmental effects are unknown.

In intensive and semi-intensive aquaculture, various chemicals have been used for the prevention and control of disease, water treatment, removal of predators and prevention of fouling organisms. In some cases concern has arisen over the potential impacts of such chemicals on the environment and the health of farm workers and consumers. So far, there are only a few reports of chemicals used in seaweed culture to control disease, remove fouling organisms and predators and to assist processing. Formaldehyde has been used for controlling the growth of epiphytes on Gracilaria (Santelices and Doty, 1989) and slaked lime has been used to control other predators (North, 1987). It is important to ensure that practices continue to be conducive to production of a healthy project with minimal environmental impact.

The influence of seaweed culture on benthic communities has not been well studied. Shading or smothering by large scale seaweed farming could potentially reduce benthic productivity in shallow inshore areas. Increased sedimentation of organic matter from seaweeds and associated organisms could also increase benthic production in areas with low current velocity, although there may be some community changes. The area below seaweed culture areas can be used very positively for production of other aquatic animals. For example, farms in Republic of Korea, Japan and China find that the benthic area below seaweed farms can be used for culturing of invertebrates, such as abalone or sea cucumber, thus maximising the production and profit per unit area.

The seaweeds and farm structures (ropes, buoys, rafts, etc.) may also have a significant influence on coastal invertebrate and vertebrate populations. The introduction of seaweed and structures can considerably enhance the productivity of invertebrates and fish much the same way as artificial reefs, due to increased availability of shelter and food organisms. Studies in Japan have shown that Laminaria japonica farms act as shelters for commercially important fish fry and workers in China have shown increased numbers of fish, sea urchins, sea cucumbers and abalones in giant kelp culture areas (Ruying et al., 1986). The attractiveness of seaweed farms can also cause problems for seaweed farmers, by attracting invertebrates and finfish which may predate on the seaweed (North, 1987).

Impacts of environment on seaweed culture

The culture of seaweed is also significantly influenced by environmental factors in several countries in Asia. Turbidity, nutrient levels, phytoplankton blooms, temperature, salinity fluctuations are all significant factors in the successful development of culture areas. Many of the broad ecological requirements are well known (eg Trono, 1986). However, the deteriorating water quality in some coastal locations is also a threat to present and future seaweed culture, as a result of increased turbidity, pollution by heavy metals and organic pollutants. It is well known that seaweeds are efficient at absorbing heavy metals (Cajipe, 1990) and any benefits obtained from hypernutrification (nutrient enrichment) could easily be offset by a loss of product quality when enhanced nutrient loadings are also accompanied by high levels of heavy metals and other industrial, agricultural and domestic pollutants. It is therefore advisable to site seaweed farms away from areas with heavy pollutant loads. There appears to be little information on pollutant residues in seaweeds cultured in Asia but close attention by producers and researchers to the potential problems is warranted to avoid future problems.

Introduction of non-native species and other interactions between cultured and wild stocks

The world-wide expansion in aquaculture has resulted in a very significant increase in the number of species of aquatic animals and plants which are moved beyond their native ranges for the purposes of aquaculture (Welcomme, 1988). These translocations in many instances bring positive improvements in aquaculture production, but also carry the risk for potential adverse effect on aquaculture and wild species, either through introduction of new diseases or competition with native species. The concern is such that Codes of Practice are now being drawn up by the ICES and EIFAC to try and mitigate potentially harmful effects (Turner, 1988).

In common with other aquatic organisms, seaweeds have also been accidentally or deliberately transplanted beyond their native range, with positive and negative impacts. Laminaria japonica is native to Japan. It was accidentally introduced to the northern Yellow Sea in 1927, and further deliberate introductions established it in the marine flora of China, where it forms the basis of the largest seaweed industry in the world. Introduction of species into other parts of the world has been more controversial. For example, there is concern over impacts of recent introductions of Sargassum muticum and Undaria pinnatifada in Europe (probably introduced on molluscs from Japan). Sargassum muticum has spread throughout much of Western Europe in recent years, from

Northern Spain to Sweden, and is now regarded as a major nuisance species in Western Europe causing significant problems to navigation in some areas (Rueness, 1989). Experiments in France with the culture of Macrocystis pyrifera were abandoned in the 1970s due to concern over potential adverse impacts (Rueness, 1989). The ecological implications of introductions are difficult to assess but the potential risks are such that careful assessment of potential impacts should precede the introduction of any new species (Turner, 1988).

The selective breeding of aquatic organisms has been an important factor in the success of aquaculture, but there is concern that the increasingly selective breeding may result in loss of native local species through competition or genetic changes, but these effects have not been studied.

There is no evidence that seaweed diseases have been transferred as a result of seaweed culture, unlike other forms of finfish, crustacean and mollusc culture where there are many documented examples of translocation of pathogens as a result of movements of cultured animals (Welcomme, 1988; NCC, 1989).

Polyculture with seaweeds and integrated seaweed culture

There is potential with some culture systems to integrate seaweed culture with other forms of aquaculture to make better use of marine resources and reduce the impacts of more intensive forms of aquaculture (Table 3).

The polyculture systems developed in Eastern Asia, with Laminaria - abalone, Laminaria - scallop and Laminaria - Undaria can be used to improve the productivity and profitability per unit area. There is also good evidence that polyculture of seaweeds with mollusc may also enhance the production of both Laminaria and mollusc in comparison with monoculture systems (UNDP/FAO, 1989).

There is also scope for improved integration of seaweed culture with other forms of aquaculture. Seaweed farming is generally an extensive farming method involving a net uptake of nutrients from coastal environment. In contrast, coastal ecosystems through addition of nutrients derived from uneaten feed, faeces and dissolved excretory materials (NCC, 1989). There is therefore some scope for integrating intensive culture of finfish with seaweed culture to reduce hypernutrification resulting from cage culture and to improve seaweed production. Experiments in Japan have shown that cage culture of yellowtail (Seriola quinqueradiata) and red sea bream (Pagrus major) can be successfully integrated with Laminaria culture. Environmental studies have shown that alternate rows of seaweed and finfish cages help to improve dissolved oxygen concentrations during daytime hours and reduce levels of potentially harmful ammonia. Recent studies by Levin (1990) have also demonstrated that Porphyra palmata reduced ammonia concentration by 60% and phosphorous by 32% in effluent from land-based salmon mariculture systems. Neori (1990) has also shown that Ulva lactuca and Gracilaria conferta can be used to remove ammonia from effluent from intensive Sparus aurata ponds. In Thailand, polyculture of Gracilaria on grouper cages can yield 16–20 kg (fresh weight) of seaweed per month in a 5 x 6 x 2 m cage, providing an extra source of income for the farmer, as well as possibly improving conditions for the caged fish.

The uptake of nutrients by seaweeds offers scope for improving the quality of effluent discharged from land-based aquaculture operations. In Thailand, experiments are being carried out using Gracilaria to remove nutrients from effluent water in attempts to reduce the impact of effluent on receiving waters. In Thailand and Taiwan, experiments are underway to assess the potential for using Gracilaria to improve the quality of water entering shrimp ponds. Unpublished studies in Taiwan indicate that Gracilaria can be used to remove ammonia, heavy metals and trace organics before water enters the shrimp ponds.

These forms of integrated aquaculture offer good scope for the development of techniques which make efficient use of the coastal environment and maximising the production per unit area and in some cases for reducing some of the environmental impacts associated with intensive aquaculture.

Discussion

This review highlights some of the positive and negative environmental aspects of seaweed culture. The most important impact probably derives from the surface area needed to develop viable operations in some locations. This space requirement has resulted in conflicts with other coastal zone users, and will continue to do so in the future as pressures on the coastal zone intensify. These conflicts could be avoided by a balanced approach to development on the basis of sound scientific data on impacts and strategic planning, which optimises the socio-economic benefits of alternative development strategies. The adoption of zoning policies for seaweed and other aquaculture development could be advocated as one approach to a more balanced use of coastal resources for aquaculture.

There are also indications from some countries that some culture areas are suffering disease outbreaks and production decline which may be linked to overstocking in relation to the 'carrying capacity' of the coastal environment. Site requirements need to be modified to better understand the carrying capacity of culture zones to avoid longer-term environmental changes which may be detrimental to seaweed culture itself. The wider environmental impacts associated with seaweed culture should also be examined to ensure that resource use is based on a sound scientific basis.

There also exists potential for integration of seaweed culture with other forms of aquaculture to increase the productivity and socio-economic benefits per unit coastal area and to reduce impacts associated impacts associated with more intensive finfish and crustacean culture. The further development of these techniques on the basis of sound ecological and economic data is also recommended as a means of making efficient use of coastal resources for sustainable aquaculture development.

References

Beveridge, MCM. 1984. Environmental impact of cage and pen culture. FAO Fisheries technical paper.

Cajipe, G.J.B. 1990. Utilization of seaweed resources. In: Culture and use of algae in Southeast Asia. pp 77–79. Proceedings of the symposium on culture and utilization of algae in Southeast Asia, SEAFDEC AQD, Iloilo, Philippines.

Chung S.H. 1986. Comparative studies on the relationship between the laver production and environmental characteristics of laver farming area in the Republic of Korea and Japan. Bulletin of Fisheries Research and Development Agency, 37, 157–178.

Dixon, F. Cox, R. and Bourne, N. 1990. Shellfish and marine plant aquaculture in British Columbia - conflicts and solutions. Paper presented at World Aquaculture '90. June 10–14, 1990, Halifax, N.S. Canada.

FAO. 1989. Aquaculture production, 1983–87. FAO Fisheries Circular No. 815, Revision 1.

Fridley, R.B. and Scholz, P.M. 1989. Opportunities and constraints to development of marine aquaculture in the United States. Paper presented at World Aquaculture '90. June 10–14, 1990, Halifax, N.S. Canada.

Gong, Y.G. 1990. Status of production and utilization of seaweeds in the Republic of Korea. Paper presented at the 1st Asia-Pacific Workshop on Culture and Utilization of Seaweeds, 27–31 August 1990, Cebu City, Philippines.

ICES. 1989. Environmental impact of mariculture. International Council for the Exploration of the Sea, Mariculture Committee.

Juanich G.L. 1988. Manual on seaweed farming. 1. Eucheuma spp. ASEAN/SF/88 Manual No. 2, April 1988. ASEAN/UNDP/FAO Regional Small-scale Coastal Fisheries Development Project, Manila, Phil.

Levin, J. 1990. Salmon-macroalgae polyculture. Paper presented at World Aquaculture '90. June 10–14, 1990, Halifax, N.S. Canada.

Merril, J.E. 1990. The introduction of Porphyra (Nori) mariculture to Western North America. Paper presented at World Aquaculture '90. June 10–14, 1990, Halifax, N.S. Canada.

NCC. 1989. Fish farming and the safeguard of the Scottish marine environment. Nature Conservancy Council of the United Kingdom, Edinburgh, U.K.

Neshul, M., Amsler, C.D., Read, D.C. and Lewis, R.J. 1988. Dispersal of marine plants for aquacultural purposes. J. Shellfish Res, 7, (3), 555.

Neori, A. 1990. Seaweed biofilters in intensive mariculture. Paper presented at World Aquaculture '90. June 10–14, 1990, Halifax, N.S. Canada.

North, W.J. 1987. Oceanic farming of Macrocystis, the problems and non-problems. Seaweed Cultivation for Renewable Resources (ed. K.T. Bird and P.H. Benson, pp 39–68. Elsevier, Amsterdam.

Phillips, M.J. 1990. Lessons to be learned from world aquaculture's largest growth sector - brackishwater shrimp culture. ICLARM Conference on Third World Aquaculture and the Environment. Bellagio, Italy, 17–22 September 1990.

Pullin, R. 1989. Third World Aquaculture and the Environment. NAGA, ICLARM Newsletter.

Rueness, J. 1989. Sargassum muticum and other introduced Japanese macroalgae: biological pollution of European coasts. Marine pollution bulletin, 20, (4), 173–176.

Suo, R. Liu, G., Shi, Z., Wang, F., Zhang, S. and Liu, T. 1986. Cultural test with submerged floating rope on giant kelp in South Huangcheng Island. Marine Fisheries Research, 7, 1–7.

Santelices, B. and Doty, M.S. 1989. A review of Gracilaria farming. Aquaculture 78, 95–133.

Trono G.C. 1986. Seaweed culture in the Asia-Pacific region. RAPA Publication, 1987/8. Regional Office for Asia and the Pacific, UNFAO.

Turner, G.E. 1988. Codes of practice and manual of procedures for consideration of introductions and transfers of marine and freshwater organisms. EIFAC/CECPI Occasional Paper, No. 23, 44 p.

UNDP/FAO. 1989. Culture of Kelp (Laminaria japonica) in China. Prepared for the Laminaria polyculture with mollusc training course conducted by the Yellow Sea Fisheries Research Institute in Qingdao, China and organized by the Regional Seafarming Development and Demonstration Project (RAS/86/024).

Welcome, R.L. 1989. International introductions of inland aquatic species. FAO Fisheries Technical Paper, (294): 318 p.

Table 1. Potential physical issues associated with seaweed culture indicating their potential positive and negative effects.

OPERATION AND ISSUES	POSITIVE EFFECTS	NEGATIVE EFFECTS
Cleaning and preparation of culture areas * > **	Improved production and management	Potential loss of native species and habitat diversity
Routine management (weeding, harvesting) * > **	As above	As above
Shading by growing seaweed * > **	Reduced competition	Reduced water column and benthic production
Attenuation of waves and water currents * > ***	Shelter for sensitive species	Increased sedimentation
Aesthetic issues * > ***	Enhanced coastal productivity in degraded ecosystems	User conflicts Loss of resource value
Space * > ***	Enhanced productivity of barren or degraded ecosystems	User conflicts (e.g. with fishermen)
Substrate area and volume * > ***	Enhanced productivity of barren or degraded ecosystems	Ecosystem changes

*= minimal effects
**= potential for significant effects

Table 2. Ecological issues and seaweed culture, indicating their potential positive and negative benefits.

OPERATION AND ISSUES	POSITIVE EFFECTS	NEGATIVE EFFECTS
Water quality * > **	Enhanced oxygen, removal of nutrients, seaweed production	Reduced coastal phytoplankton
		Nutrient cycling
		'Diseases'
Fertilization and chemical treatments	Seaweed production	Product quality
* > **	Enhanced polyculture production	Water quality changes
Benthos * > **	Enhanced polyculture polyculture (e.g. with mollusc)	Changes in benthic species and production
Water column productivity * > ***	Enhanced production of invertebrates and finfish	Predators Changes in community structure
	Shelter of fish fry	
	Polyculture	

*= minimal effects
**= potential for significant effects

Table 3. Polyculture and integrated culture systems involving seaweed

CULTURE SYSTEM	BENEFITS
Laminaria - abalone	Efficient use of 3-D water column
Laminaria - scallop	Increased production per unit area

Laminaria - Undaria	Increased production of each species
Laminaria - finfish cage culture	Enhanced productivity of seaweed and finfish culture operations. Increased income per unit area
Gracilaria - grouper cage culture	Increased dissolved oxygen Reduced ammonia and other nutrients Reduced environmental impact
Gracilaria - shrimp pond culture	Removal of toxic metabolites from ponds and effluent water Improved quality of inflow water after removal of heavy metals, organic pollutants and nutrients.