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1993

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Publication details

Saenger, P 1993, 'Some environmental considerations in aquaculture planning and operation', in S Al-Thobaiti et al. (eds), *Proceedings of the First International Symposium on aquaculture technology and investment opportunities*, Riyadh, Saudi Arabia, 11-14 April, Ministry of Agriculture and Water, Riyadh, Saudi Arabia, p. 53.

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Some Environmental Aspects in Aquaculture Planning and Operation.

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Introduction

Aquaculture now comprises a major coastal activity bringing numerous socio-economic benefits to regions by creating local employment, stimulating local economies, generating foreign exchange, stimulating improvements to local transportation infrastructure and, of course, providing a source of food.

Coastal areas such as estuaries, lagoons, coral reefs, islands and bays are the major focus for aquaculture and these areas are coming under increasing pressure from the aquaculture industry. Because of the significance of the natural resources at many potential aquaculture sites, important biological resources also may be damaged by poorly planned and/or managed aquaculture operations e.g. South-east Asia (Saclauso 1989, Eng et al. 1989), the Caribbean (Katz 1989) and Africa (Rasowo 1992). Some of these adverse impacts of aquaculture are highlighted and examined with special emphasis on coastal projects in tropical regions.

The impacts of aquaculture can be subdivided into those impacts resulting from the construction of aquaculture facilities and those from the on-going operation of an aquaculture plant. The impacts of aquaculture development need to be addressed largely in the planning stages of a project, while the impacts from the on-going operation can be controlled by the day-to-day management of the facility.

Some Common Characteristics of Aquaculture Facilities

Most aquaculture presently consist of pond-based systems for prawns and/or fish. These have been considered (Table 1) under three categories depending on the scale and nature of the operation.

	Extensive	Semi-intensive	Intensive
Pond Size (ha)	5+	1-8	<0.5
Stocking per ha	20,000	80,000	300,000
Fry source	wild	wild/hatchery	hatchery
Feed source	Natural	Natural/Supplement	Artificial
Crops per year	1-2	2-3	2+
Survival	<50%	70-80%	70-80%
Production(kg/ha/yr)	200-400	1000	4000-8000
Water Management	tidal exchange	tidal/Aerators	Pumps/filters
Effluent Volume	Large	Smaller	Least
Effluent Quality	Acceptable	Poor	Variable

Other types of aquaculture facilities are not as readily prescribed but include floating or fixed raft, cage or pen culture, and fish aggregation devices (such as artificial reefs or the 'acadja' fishing techniques in Benin).

Impacts of Aquaculture Development

Direct Effects on the Biota

The direct effect of aquaculture developments includes a loss of habitat in a specified area which invariably leads to a reduction in species diversity in and around that area, and may lead to the loss of a particular species from a region depending on the extent or intensity of land-use changes.

Loss of terrestrial habitat results from the clearing of upland vegetation as part of the site preparation prior to the commencement of construction. While landscaping is now generally practised and may partially offset losses, some permanent loss of habitat is invariably involved. As most aquaculture developments are in coastal ecosystems, interference with existing vegetation may lead to destabilisation of dune systems or shorelines which may be both difficult and expensive to restabilise.

For intertidal areas, aquaculture developments often involve losses of mangroves, seagrasses or other shallow-water communities in relatively sheltered sites. While these communities are generally widely distributed, the extent of losses to aquaculture has recently caused some concern (Kapetsky 1987; Saclauso, 1989). Where mangroves are limited, as in Saudi Arabia (Ormond et al., 1988), their use for aquaculture should be avoided altogether (Saenger et al., 1983).

In offshore areas, habitat losses usually result from dredging or reclamation works associated with the landward facilities or from changed circulation patterns as a result of water-based facilities. Dredging, reclamation and siltation are known to adversely affect most inshore ecosystems and the resources and services provided by these communities. Earthworks on land in close proximity to the shoreline may have similar effects and are estimated to have caused, for example, the loss of over 3000 ha of coral reef and seagrass habitat in Bahrain (Madany, 1987). Dramatic changes in coral species diversity and coral cover in the adjacent reefs are generally immediately apparent and fish standing stocks show an equally rapid decline (Amesbury, 1981; Hodgson and Dixon 1988). For localized dredging operations near coral reefs, a number of ameliorative measures may be used to contain the effects of the resultant sedimentation including silt 'geotextile' curtains (Gabrié et al., 1985).

Altered Hydrological Regimes

Dredging at the mouth of rivers or in coastal lagoons is often necessary to allow boat access. When such dredging is undertaken without adequate knowledge of the dynamics of sediment movement in the area, the resultant instability of nearby channels, sand-bars or beaches can have undesirable environmental effects which may be costly to rectify. The hydraulic consequences of dredging operations also need to be considered as changed natural flow patterns, tidal circulation or wave energy conditions may have far-reaching consequences on nearby ecosystems; these

consequences may result indirectly through abiotic changes (e.g. changed salinity gradients in estuaries or erosion patterns on beaches) or directly from such factors as altered recruitment or mortality patterns, or growth conditions.

Other Indirect Effects on Biota

Other indirect effects resulting from aquaculture developments include shading, night illumination, and noise and vibrations.

Floating structures such as pontoons, cages or aeration pumps can shade significant areas of seabottom. Where such shading occurs over coral reefs or seagrass beds, significant ecological changes can be induced. For example, some corals are adversely affected by shading. Under natural shading by tabular *Acropora* colonies, branching corals had low growth rates and high mortalities while massive and encrusting species were unaffected (Stimson, 1985). Physiological studies have shown that in shade-tolerant corals, low light conditions stimulate the accumulation of zooxanthellae in the polyp endoderm, increase the size of the zooxanthellae and lead to increases of the photosynthetic pigments (Titlyanov et al., 1981). These adaptations result in a more efficient absorption and utilization of light in these shade-tolerant species; although only branching corals were investigated, it seems likely that these adaptations may be even better developed in slow-growing massive corals.

The feeding capability of some corals are also be light-dependent. For example, in *Pocillopora damicornis* colonies exposed to identical densities of *Artemia salina* nauplii, those colonies maintained at low light were unable to ingest as many nauplii as the colonies maintained under high light levels (Clayton and Lasker, 1982). Clearly, the amount of zooplankton available to the colonies maintained at low light levels was insufficient to meet their metabolic requirements, suggesting that feeding in this coral was dependent on the photosynthetic subsidy from the zooxanthellae.

In contrast to shading, shoreline night lighting or illuminated floating structures may influence the movement of light sensitive species including fish, squid and turtle hatchlings. Night lighting on foreshores, for example, attracts turtle hatchlings resulting in an inland movement rather than towards the water. A recent study with the loggerhead turtles hatchlings, however, seems to suggest that the use of low-pressure sodium lights induces a negative reaction to the monochromatic yellow light (Anon, 1989) and may reduce turtle hatchling disorientation.

Noise or vibrations from pumps or aerators may cause behavioural changes such as avoidance in locally resident or migratory species of invertebrate, fish, birds and marine mammals (Mills and Renouf, 1986; Bleckmann and Lotz, 1987; Hanlon and Budelmann, 1987; Heinisch and Wiese, 1987).

Impacts from Aquaculture Operations

Effects on natural resources

Probably the single most important effect of aquaculture operations is that of a decline in local water quality. This decline takes a number of forms including

acidification where acid-sulphate soils are present, nutrient enrichment from fertilisation and pelletised feed, and increased organic loading.

Acidification: Where acid-sulphate soils are used for ponds, sulphuric acid may be produced during periods when ponds or pondwalls are dry. Apart from the direct effects of the leaching of sulphuric acid, the lowered pH may render nutrients, essential for growth of algal cells and thus, primary productivity, unavailable because of the high adsorptive capacity of the soil - particularly for phosphates. Low pH can also inhibit conversion of ammonium ions to nitrate (Bloomfield and Coulter 1973) which is the most readily assimilated form of nitrogen for plant growth. Liming pond waters to neutralise the acid is costly, and brings additional environmental problems.

Nutrient Enrichment: High levels of phosphates, nitrates and ammonium commonly occur in effluents from aquaculture operations and often lead to eutrophication of coastal waters. Such nutrient enrichment often results in nuisance algal blooms (Bach and Josselyn, 1978) with a corresponding loss of species diversity - particularly in coral communities.

Quite apart from the eutrophication effects described above, phosphate enrichment of coral reef waters may directly inhibit hard coral growth through phosphate inhibition of calcium carbonate deposition (Simkiss, 1964), an essential process of healthy coral growth.

Seagrass and mangrove systems appear to be less susceptible to damage from nutrient enrichment, as they have a capacity to absorb high levels of nutrients (Nedwell, 1974a; Montgomery and Price,1979). Nevertheless, high organic loading to these systems may cause anoxia and increase the turbidity to levels where the resilience and diversity of these systems is adversely affected. Furthermore, as Nedwell (1974b) pointed out, where the discharges contain significant amounts of heavy metals or pesticides, toxic bioaccumulation may occur, particularly in fish, crustaceans and molluscs, through the adsorption and subsequent release to the foodchain of these compounds (Montgomery and Price, 1979).

High Organic Loading: Aquaculture ponds and their effluents typically have a high particulate and dissolved organic loading. This is commonly indicated by the highly reducing conditions (highly negative Eh values) within the sediments of aquaculture ponds and their high uptake rates of oxygen from the overlying water. Effluents from such ponds may induce reducing conditions in adjacent shallow communities, particularly where dispersion is limited.

It should also be noted that the decreased coastal water quality resulting from the discharge of domestic, agricultural and industrial wastes into coastal waters may, in turn, affect aquaculture production and profitability.

Effects on other users

The effects of aquaculture operations need to be considered in terms of other present users, and on potential effects on future users of the particular resource. The concerns of present users are mainly centred on the sustainability of coastal resources, continuing access to the coast, and equity considerations arising from conflicting uses among different user groups.

The sustainability of resources (and thus, those activities depending on them) can generally be assessed by some measure of carrying capacity, environmental capacity for the tolerance of pollutants by aquatic systems, or 'ultimate environmental thresholds' for specific environmental features (Yapp and Barrow, 1979; Jackson, 1986; GESAMP, 1986; Rosier et al., 1986; Sowman and Fuggle, 1987). Assessing the sustainability of particular coastal activities requires that some or all of the above measures are considered at the planning stages of an aquaculture development, and adjusted through prohibition or regulation in the day-to-day management of aquaculture operations.

One of the major effects of aquaculture on other users is through the pre-emption of access, either by design, congestion or by ignorance of local usage patterns. Exclusive use of foreshores of estuaries and bays generally leads to conflict with other local users. On the other hand, some other users may be affected by aquaculture operations through the increased incidence of red tides which pose serious threats to mollusc cultivation and human health.

Some aquaculture activities may be incompatible or compete with the activities of other user groups, thus giving rise to conflict; aquaculture may compete with an artisanal fishery, or the collection of spawning adults may conflict with recreational activities, while decreased water quality may interfere with conservation or touristic objectives. Many of these conflicts can be resolved through suitable zoning arrangements and by involving a range of other user groups in aquaculture planning. It should be pointed out that situations also arise where, after aquaculture developments have been established, other and conflicting uses may affect the aquaculture operation.

The effects of aquaculture on future users is often overlooked in impact analyses. However, any allocation of land (or sea) involves choice. For example, whether establishing an aquaculture development is the best use for a particular area will depend on the total costs and benefits associated with that development compared with the potential costs and benefits that would have been attainable with some other use of the area. This concept of 'opportunity cost' can also be applied to future uses (or users) of the particular area. Thus, the benefits and costs of using a particular area for a particular purpose now, must be considered against the benefits and costs which are potentially attainable for a particular use of the area in the future. McNeely (1988) has defined opportunity cost as 'the benefit foregone by using a scarce resource for one purpose instead of for its best alternative use'. The cost of foregoing a future benefit needs to be considered during aquaculture planning.

Effects of Aquaculture on Local Communities

Flow-on effects

A specific aquaculture development may require the development of some specific infrastructure to support it. For example, the construction of airports, roads and/or port facilities may have separate and distinctive impacts on the local community over and above those of the aquaculture development itself (Wohlwill, 1982). Where such flow-on developments are foreseeable or predictable, they should be assessed as part of the overall impact of the specific aquaculture development, in that they add to the overall costs and benefits to the local community.

Cumulative effects

Cumulative effects are those resulting from the accumulation of effects from a number of small developments, where the environmental impacts of individual developments are negligible, but where the sum of numerous small developments is significant on the local or regional community. Odum (1982) has termed this the 'tyranny of small decisions' whereby significant decisions are made concerning natural resources by the cumulative effect of numerous almost insignificant decisions. In this way, numerous major decisions on land-use or life-style, for example, may be made without the central issues really being addressed. Obviously, these cumulative effects must be addressed prior to the detailed planning stages, and preferably through broad-scale or strategic regional planning instruments.

Social costs

Aquaculture brings with it a number of socio-economic costs which require consideration both at the planning and day-to-day management stages of any project (Barbier, 1987; Bailey, 1988). Some of the major effects are altered patterns of wealth distribution, increased land prices, denials of traditional rights for local communities to coastal resources, loss of local employment opportunities and the increased dependence of unskilled workers on low-paid, seasonal jobs (Meltzoff and LiPuma, 1986; Bailey, 1988).

These effects may be particularly pronounced on small rural communities although many of these problems can be mimimised or avoided through adequate public participation in all stages of the planning process.

Effects of Aquaculture on National Interests

Earning foreign exchange is probably the most beneficial impact of aquaculture. Because of the dependence of aquaculture on 'wild' marine resources, aquacultural activities can complement those concerning marine conservation. Given this relationship to marine and coastal protected areas, it is obvious that national policies are needed to ensure the sustainability of the resource, the resultant activity, and ultimately the aquaculture industry. To assist in the formulation of such policies, Barbier (1987) has defined sustainable economic development by suggesting that a

number of human ascribed goals must be met; for the biological system, these goals must include:

* Maintaining the genetic diversity of the area or region involved;
* Maintenance of the resilience of the ecological systems affected; and
* Maintaining the biological productivity of the area or region.

Four general principles ensure that aquaculture developments are linked with the conservation of natural resources, to achieve the above biological goals:

* Planning for aquaculture development must be integrated with other planning efforts, particularly for marine parks and other natural areas;
* Aquaculture authorities should determine the level of shoreline use that an area can accommodate, and to ensure that this level is not exceeded;
* National policy should require environmental impact assessment for all aquaculture development projects or programs, and specify the ways and means that the aquaculture development can provide economic benefits to both the local people and those natural areas supporting the aquaculture industry; and
* For each major aquaculture project, a management plan should be developed to specify objectives for both aquaculture and resource management, and to determine how sufficient income from aquaculture can be provided to the natural area to provide an incentive for improved management.

The goals to be achieved for the socio-economic system (Barbier, 1987; Bailey, 1988) must include:

* Satisfying the basic needs of the resident population and reducing poverty;
* Enhancing equity through ownership, management responsibility and participation in decision-making, employment and training;
* Increasing the useful goods and services available in the area or region;
* Sustaining local and national institutions and traditions;
* Ensuring social justice; and
* Maintenance of the cultural diversity of the area or region;

If aquaculture, coastal conservation and national interests are to beneficially co-exist in the long-term, the above goals must be incorporated into all aquaculture developments and be supported by appropriate policies of national governments.

Concluding Comments

The introduction of management measures to mitigate deteriorating coastal water quality and the adverse environmental impacts of aquaculture development has now become a matter of urgency. Given the potential environmental impacts of new auaculture developments, one of the first questions to be addressed is - are there already existing aquaculture operations that can accommodate the new requirements or be upgraded or modernised to meet current needs? A second question is - are there existing operations (e.g. aquaculture, solar salt production) which can be

diversified by the addition of crops or activities to meet current demands? For example, the diversification of solar salt ponds for shrimp, oyster, fish, carotene or *Artemia* production (Jones et al. 1981; Sammy and Taylor 1986; Littlewood, 1988; Rasowo, 1992) should be evaluated.

Finally, if there is a need for new areas for an aquaculture facility, siting should avoid some of the following areas to (i) minimise losses of significant coastal resource areas, and to (ii) minimise the likelihood of conflict with other users via water pollution or loss of access:

(i) Adjoining major river systems; adjacent to productive fry, spawning or fishing grounds; significant natural areas such as coral reefs, seagrass beds, primary and dense mangroves; areas where the potential for erosion or 'acid-sulphate' soils is high; around small islands.

(ii) Adjacent to populated areas or urban centres where other traditional uses occur; areas where limited tidal circulation or poor dipersion is likely to lead to eutrophication and/or 'red tides'; areas where pre-existing uses or traditions are likely to conflict with aquaculture operations.

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