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Desert aquaculture & environmental sustainability

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Aquaculture in semi arid regions has increased social and economic impact through the production of food, contribution to livelihoods and generation of income. The main goal of aquaculture in the desert is to utilize productively and maximally the water resources for an integrated aquaculture-agriculture system. Desert aquaculture increases the water resource's an economical value rather than a serious competition in water consumption between aquaculture and agriculture. The aquaculture-agriculture system in the desert produces quality sea food all the year round. However, when badly managed, aquaculture can affect the ecosystems functions and services, with negative environmental, social and economic consequences. Under the right conditions and with careful preparation, desert aquaculture can be made sustainable and profitable without causing disturbances to the ecosystem. In the present review, the factors required for semi arid integrated aquaculture system towards sustainable production are discussed with its various components.

[**Keywords:** Desert aquaculture, Environment, sustainability]

Introduction

Due to the continuous decline in fishery harvests and an effort to meet seafood consumption, aquaculture has become the world's fastest growing sector of food production, increasing nearly 60-fold during the last five decades[1,2]. The success of aquaculture is closely dependent on aquatic ecosystems and a range of other natural resource inputs, which require continuous support from the natural resource base. On the other hand aquaculture has a great potential to damage the natural resource base, diminishing environmental quality and societal benefits. The success of aquaculture, therefore, depends upon its ability to produce quality sea food as well as to maintain the sustainability of its resource base[3,4]. Tremendous developments have been achieved in this sector especially in the uninhabited zones of coastal deserts of countries in Middle East, Africa, America and Australia[5]. Sustainable aquaculture has emerged as a key issue of farming systems, research and development, and the concept of sustainability includes the notion of conservation of natural resources[6]. Though the impact of aquaculture activities to the environment were considered, the impact of total amount of waste discharged from aquatic farms on ecosystem sustenance were not recognised, particularly from the sustainability point of view[7].

Aquaculture development in semi arid coastal areas has been one of the major obstacles for environmental sustainability in Caribbean, Mediterranean, Persian Gulf and Red sea coastal belts. In an attempt to develop a global partnership for development through aquaculture, many factors need to be considered in the management process. The concept and definition of sustainable development requires an understanding of issues concerning natural resources, economic output and human/social welfare and the exchanges between them. It also encompasses providing undiminished assets to future generations and maintaining human and ecological equity. Many governments have recognized the potential benefits of promoting the use of indicators in the assessment and management of the sustainability of the aquaculture sector[8]. This paper addresses the issues pertaining to the ecological impacts of desert aquaculture in Middle East and African countries and recommends the strategies required to ensure environmental sustainability in these semi arid coastal areas.

Status of aquaculture in Middle East and North African countries

The Middle East and North African region is characterized by extremes of climatic conditions with an air temperature ranging from about 52 °C in summer to 0 °C in winter. Seawater temperature ranges from 35 °C in summer to 16 °C in winter. Seawater salinity ranges from 39 to 45 ppt. Average annual rainfall is less than 15 cm and with virtually no runoff flow except in the northern part of Arabian Gulf [9]. Except for Iran, Iraq, Oman and Saudi Arabia, where freshwater aquaculture is prevalent, in rest of the countries aquaculture is limited to brackish water or seawater. Aquaculture development has been relatively a recent event in the Middle East and North African countries and began in 1980 [10]. Aquaculture in the region is dominated primarily by production of finfish, but also crustaceans for local consumption and export. The most important species groups are Tilapias, Carps and a number of marine fish species. The only crustacean of significant economic importance at present is the Indian white prawn, *Penaeus* (*Fenneropenaeus*) *indicus*. Within the region, many different aquaculture systems are practiced, from extensive to semi-intensive and intensive [9]. Holding facilities range from land-based culture to sea cages. The greatest diversity of systems could be seen in countries with the greatest variety of geography and weather conditions. In some countries, integrated agriculture aquaculture is practiced, most commonly involving Tilapia in Kuwait, Oman, Saudi Arabia, and the United Arab Emirates. Bahrain a small island country possesses limited land resources for development.

There are different methods of aquaculture in Oman and these include marine cages, earthen ponds and cement ponds. In Qatar, irrigation ponds are used as an extensive way of culturing fresh water tilapia, *Oreochromis niloticus*, but there are no mariculture projects as yet. In Kuwait, Tilapia culture is carried out on 56 farms. Iraq's Fisheries Department started pilot-scale fish farms in 1965 to test culture systems and suitable species [11]. Commercial activities started only in late70s and early 80s, recording 3800 t of production in 1983. The first documented report on inland fish breeding in Iran dates back to 1922 at an Ichthyological center near the Caspian Sea[12]. Serious efforts started with attempts to culture rainbow trout (*Oncorhynchus mykiss*) at Karaj, near Tehran in 1959 and with establishment of a carp culture research station in Guilan province in 1970. In Yemen, the first full-scale commercial shrimp farm was set up by Hodeidah based Musallam group, in Lohayya along the Red sea and started production in 2005[9]. The Arab states such as Egypt, Sudan, Iraq and Syria with significant fish supply from capture fisheries resources from inland water bodies have also resorted to aquaculture in order to increase local supplies of fish[3]. Even the states with rich marine fisheries resources such as Morocco, Algeria, and Tunisia have also started to practice aquaculture in their fresh or marine waters[13,14]. Total capture fisheries implies inclusion of aquaculture during 1998-2008 in Middle East and North African countries is shown in Table 1.

Table 1— Total capture fisheries implies inclusion of aquaculture in Middle East and North African region[15] (Feisal, 2010).

Country	Total Capture Fisheries (MT)	Total Aquaculture (MT)	Aquaculture share (%)
Morocco	995,773	1,399	0.14
Iran	407,842	154,979	38.0
Egypt	373,815	693,815	185.6
Oman	145,631	120	0.08
Algeria	138,833	2,781	2.0
Yemen	127,132	0	0
UAE	74,075	1,206	1.63
Saudi Arabia	68,000	22,253	32.73
Libya	47,645	240	0.50
Iraq	34,472	19,246	55.83
Qatar	17,688	36	0.20
Bahrain	14,177	2	0.01
Syria	6,996	8,595	122.86
Kuwait	4,373	360	8.23
Lebanon	3,811	803	21.07
Palestine	2,843	0	0
Jordan	500	540	108.0
Tunisia	10,241	3,328	3.32

Aquaculture Development in Saudi Arabia

The Kingdom of Saudi Arabia on the Arabian Peninsula is surrounded on three sides by water, with the Arabian Sea to the southeast, the Red Sea to the west, and the Persian Gulf to the east. The nation's lengthy coastline and proximity to water moderates portions of the climate, but most of the country is hot and arid, with summer temperatures reaching 46°C (115°F), average rainfall of only 12 cm per year and water shortages and desertification are pressing environmental problems[16]. Significant seasonal and even diurnal fluctuations in temperature result in extreme climatic conditions in many areas of the country. With a difficult environment such as Saudi Arabia's, one might think that aquaculture an industry that requires extensive water resources, delicate ecosystem maintenance and a variety of saltwater and freshwater fish and crustacean species would be ignored[17].

Aquaculture development in Saudi Arabia began in 1980, with the establishment of the Fish Culture Project at the Saudi Arabian National Centre for Science and Technology (now called the King Abdulaziz City for Science and Technology) in Riyadh. Currently there are 125 aquaculture farms in Saudi Arabia, 56 of which are fully operational, producing marketable tilapia and shrimp. There are two large freshwater farms, in Qassim and in Dammam and several large shrimp farms on the Red Sea coast [18]. World's largest fully integrated aquaculture project, National Prawn Company situated at the Red Sea coast produces Indian white shrimp, *Fenneropenaeus indicus* by following quality and environmentally sustainable methods [19]. Over the past few years, special attention has been directed at boosting commercial aquaculture production and government has been encouraging the aquaculture projects and also supporting the aquaculture project investors by providing free land, interest-free loan for 10 years, and subsidies for fish farming equipments instruments and chemicals [20].

Ecological impacts of semi arid aquaculture

Although aquaculture is considered to be the solution to the declining fish stocks in the countries laying the coastal belt of Mediterranean, Persian Gulf and Red Sea, its ecological impacts are posing major threats to the sustainability of the environment [21,22]. These impacts have been mainly associated with high-input high-output intensive system effects which include discharge of suspended solids, nutrient and organic enrichment of recipient waters resulting in the build-up of anoxic sediments, changes in benthic communities and the eutrophication of lakes[4]. For example, large-scale shrimp culture has resulted in physical degradation of coastal habitats through conversion of mangrove forests and destruction of wetlands[7]. These farms are not helping to reduce poverty levels of the coastal zones as the income directly goes to elite shrimp farmers. Evidence shows that in many parts of the world, these shrimp farms cause high salinity levels in agricultural and drinking water supplies [23]. Most of the local poor agricultural farmers who have no way to avoid polluted drinking water from ground water sources are further affected[7]. The damage to mangrove forests in the coastal zones will have a chain effect, not only on available fish, but also damaging the sustainable coastal ecosystem through alteration of seabed fauna and flora

communities [24]. Further, misapplication of husbandry and disease management chemicals, collection of seed from the wild and use of fishery resources as feed inputs are also causing concern in the coastal zones [25].

Aquaculture, like any other food producing sector, uses natural resources and interacts with the environment. Aquaculture is increasingly confronted with issues of environmental protection, compared to other sectors [22]. However, aquaculture is considered to be the only way to satisfy the increasing demand of fish products in a situation where ocean fish stocks are deteriorating at an alarming rate [26]. The challenge for the next decade is to produce more fish in aquaculture with increasing efficiency in resource use and minimising adverse environmental interactions. This will be the major goal in aquaculture development which will require commitment and willingness to collaborate by all those involved. Much of the current controversy is centred on resultant environmental degradation, in some cases, from inadequate coordination and management of development. Methods are needed to measure irresponsible aquaculture practices and to avoid negative externalities of aquaculture production which is the key to aquaculture sustainability[27]. Environmental degradation is causally linked to problems of poverty, hunger, gender inequality and health. Protecting and managing the natural resource base is essential for economic and social development. Similarly, the changing consumption and production patterns, particularly in wealthy nations, are directly linked to the environment [28]. Integrating the principles and practices of environmental sustainability into country policies and planning programmes is therefore the key to success.

Strategy for sustainable aquaculture production in arid and semi arid area

In order to achieve environmental sustainability in coastal deserts, the following strategies are recommended for aquaculture production.

Integrated approach

Limited water is the biggest constraint for aquaculture in arid/semi-arid regions. Before taking an approach to desert aquaculture, we should identify sites where aquaculture and agriculture can be integrated[29,30]. We should evaluate local environmental conditions including water quality and quantity, soil condition, topography, and climate. In arid regions, aquaculture will need modifications to become a promising production system according to each environmental situation. Aquaculture practices should be based on a balanced ecosystem management approach, the basic premise is to incorporate the biological and environmental functions of a diverse group of organisms into a unified system. Good management is often considered to be the same as practical experience in the application of aquaculture technologies in the field. Proper and timely maintenance of the farm and its installations, successful methods of broodstock management, selective breeding, seed production, pond preparation, stocking, feed and feeding, water quality management, disease control by biosecurity measures, harvesting, processing and marketing are the major elements of this concept of management. For the purpose of increasing production, an integrated approach would be ideal by connecting the operations viz., brood stocks, hatchery, nursery, grow out, feed production and processing phase.

Schematic model for an integrated coastal desert aquaculture approach for sustainable production is presented in Fig. 1.

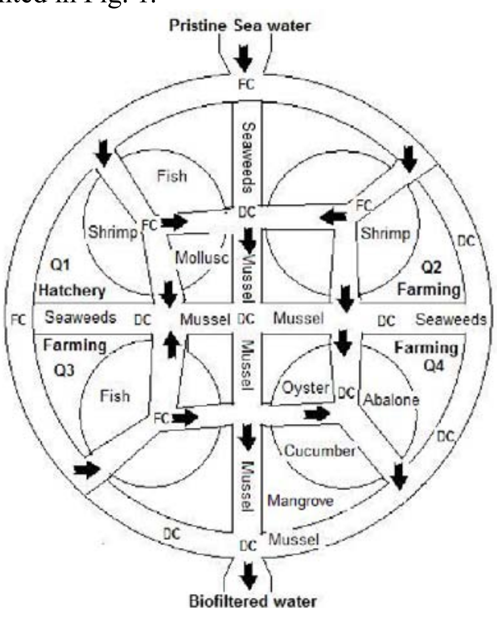

Fig. 1— Model for integrated aquaculture approach

The model shows a homogeneous growth of all individuals in a sustainable manner. The system consists of four quarters (Q1, Q2, Q3 and Q4) and each quarter is employed for the operation of hatchery (Q1), farming of shrimp (Q2), fish (Q3) and the cultivation of molluscs and sea cucumber (Q4). Required juveniles of fish, shrimp, mollusc and sea cucumber can be produced in the hatchery and the rearing of fish and shrimp are done in respective farming quarters. Quarter 4 is used to raise oysters, mussels, sea cucumber and mangrove plants. Bio filtering of drain water can be done by seaweeds and mussels in drain canals (DC). For the operation of system, pristine seawater is taken through feeder canal (FC) and the drain water from the three quarters is lead to Quarter 4 for complete settlement of organic load and nutrients. The system discharges bio filtered sea water and it minimise the stress of coastal ecosystem. According to Saenger and Siddique shrimp farms require a mangrove area that is 35-190 times larger than the surface area of the pond[31]. This will act as the breeding and nursery ground for the indigenous species of fish and shrimp [32,33]. Aquaculture system using mangroves, oyster and seaweed as bio filters was found to be effective to reduce the environmental load [34]. Seaweeds absorb their nutrients directly from the surrounding seawater and grow fast in shallow water bodies [35,36]. Sea cucumber digests sessile diatoms, organic detritus and decaying seaweeds and is a potential candidate for culture in effluent treatment ponds of aquaculture operations[37]. The production of halophytes using saline waters is the most sustainable way of conserving desert ecosystems and food production for people living in coastal areas [38]. The biofiltered water which is coming out from the proposed system can be fruitfully utilized for the irrigation of coastal halophytes.

Broodstock and Hatchery Management

The foundation of a successful hatchery is the use of high quality disease free broodstock. In order to minimize stress, damage, mortality and infection of broodstock with pathogenic diseases, the collection, holding, preparation, transportation, maturation and spawning of broodstock should be done as carefully and efficiently as possible [39,40]. Hatcheries should be designed to ensure biosecurity, efficiency, costeffectiveness and should implement good management practices aimed at producing high quality seeds. The success of seed production depends to a large extent on the quality of broodstock selected for maturation [41]. Every effort should be made to ensure that only large, productive, healthy, disease-free animals are selected. Each broodstock should be checked to ensure that it is free from disease (Viral, bacterial and fungal etc.). Broodstock must be maintained, spawned and hatched individually so that any infected broodstock cannot infect the others in the facility [42]. To optimize water quality and reduce disease and stress levels for the growing larvae, it is important to stock the correct number of larvae and exchange sufficient water to maintain optimum water quality conditions throughout the larval rearing process [43].

Routine assessments of shrimp health are important to ensure that any potential problems are recognized early and solutions employed to rectify the underlying causes and thereby increase productivity [44]. Larval growth and survival and the water quality of the larval rearing tanks depend to a large extent on the quality and quantity of food offered to the larvae. Optimization of feeding regimes based on live feeds helps maintain good water quality, whilst promoting fast growth and high survival of the larvae and hence optimal production from the hatchery. Specific *Artemia* egg hatching procedures should be used to obtain the highest number of *Artemia* nauplii from each can of cysts hatched. These techniques are necessary to produce clean *Artemia* for feeding the larvae at the lowest possible cost. For sustainable production, antibiotics should not be used in hatchery. The use of effective probiotics is recommended than using antibiotics[45,46]. Implementing standard operating procedures is advisable for sustainable production of juveniles in hatchery.

Grow out operation

Grow out requires large amounts of clean water to support the farmed animals, replenish oxygen and remove wastes [47]. The culture ponds especially in areas of poor (sandy/loam) soils or high temperatures, evaporation and seepage is increased and as much as 1-3% of the pond volume may be lost in this way each day [48,49]. The site chosen should take into consideration tidal amplitude in order to utilize tidal energy for water exchange or harvesting. The grow-out ponds must be of simple design, rectangular in shape with size about 1-10 hectare, and depth 1.2 -1.7 meters. Each pond must have its own inlet and outlet gates to facilitate water exchange, pond preparation and harvesting [50,51]. Two weeks before stocking, the pond must be thoroughly drained and sun-dried until the mud in the pond bottom cracks. In the meantime, both the inlet and outlet gates are to be enclosed with a layer of fine nylon netting of mesh size 0.5 mm to prevent escape of fry and entry of predators or other undesirable aquatic organisms. The purpose of water exchange in addition to maintaining water quality is also to stimulate moulting of the animals, resulting in acceleration of growth [52]. However, this procedure also drains out some of the natural food and reduces pond fertility. Hence, in order to maintain natural productivity, the pond water is regularly enriched with organic manure after the last day of water exchange. Supplementary feed shall be given only after 60 days of culture. Formulated pellet feed with 35-38% crude protein may be used to feed the growing juveniles in the pond. Feeding strategy should be based on the higher food intake after moulting [53]. Natural food production can be maintained through continuously fertilizing the pond. This would helps to minimize the use of supplementary feed. The feeding rate on the third month may be 6% biomass and 4% from the fourth month until harvest. Efficient feeds improve performance, reduce production costs, improve water quality and reduce use of scarce marine proteins [54].

Harvest and Processing

Harvest machine with drain harvest collector, specially designed pump which can transfer live shrimp with no damage, dewatering tower to separate shrimp from pond water, and insulated totes with ice water to receive shrimp is ideal [55]. Mechanical harvesting transfers live shrimp from the pond drain to insulated totes filled with ice water in a matter of seconds. This chill-kill process assures that top freshness and quality is delivered to the processing plant. Transfer of harvested shrimp from ice water totes directly into ice water wash tank at processing plant [56,57]. Ideally, processing plants are to be located near the ponds such that shrimp/fish can be received within minutes of harvesting. Use of the mechanical harvesting systems and ice water totes eliminate all handling until the product enters the plant. Mechanical grading within the plant further minimizes handling, temperature increase, and product deterioration. This assures premium freshness and quality for discriminating markets that demand optimum flavor and texture.

Data management and Marketing

A comprehensive database would help to store daily operating parameters of breeding facility, grow out, feed mill, diagnostic lab, hatchery and processing plant. The database allows trace back of each processed lot to the pond, raceway, nursery tank, larval tank, spawner, and breeder from which it originated. It also tracks water treatments, feed raw materials, feed production, harvest and stock of products. This minimizes risk of operation and allows complete traceability [58]. Product needs to be sold directly to long term clients according to predetermined specifications and prices. Long term relationships with premium buyers allow both the supplier and the buyer to negotiate reasonable prices, target preferred product sizes and forms and work toward mutually acceptable goals.

Biosecurity Umbrella

In aquaculture, biosecurity can be defined as "an essential group of tools for the prevention, control, and eradication of infectious disease and the preservation of human, animal, and environmental health" [59]. Therefore, excluding infectious agents and reducing stress are important in preventing disease outbreaks. Biosecurity can be applied to aquaculture production systems through a variety of management strategies and by following internationally agreed upon policies and guidelines. In addition, there are a variety of risk assessments that can be used for aquatic animal diseases of finfish, molluscs, and crustaceans [60]. The key elements of biosecurity can be summarized as reliable sources of stock, adequate diagnostic and detection methods for excludable diseases, disinfection and pathogen eradication methods, best management practices, and practical and acceptable legislation. Nevertheless, it is almost impossible to determine the economic benefits of a biosecurity program if there is no disease outbreak and aquaculture producers may be reluctant to adopt biosecurity measures that appear to be an additional cost. A disease outbreak in one area, however, in addition to its economic consequences in that area, may cause unintended consequences in other parts of the world. Early detection of a pathogen incursion into a farm system allows for more effective control of the establishment or spread of a pathogen for more effective response. Surveillance to detect incursions can be either targeted to specific pathogens or more general [61]. For example, for pathogens of particular concern and for which there are diagnostics tests available, animals can be periodically tested, ensuring the number of animals sampled are enough to provide an acceptable level of confidence in detecting the agent were it to be present. The health status of farm animals can also be monitored more generally through gross and microscopic examination including histology. Both targeted and general surveillance requires a degree of specialised expertise, although much can be done with minimal training. An effective disease response plan has three key aspects like surveillance/monitoring, containment and eradication. Each of these is associated various activities aimed at eliminating the pathogen of concern from the system.

Environment conservation and waste management

The rapid development of intensive fed aquaculture (finfish and shrimp) is associated with concerns about the environmental impacts of such often mono specific practices, especially where activities are highly geographically concentrated or located in suboptimal sites whose assimilative capacity is poorly understood and, consequently prone to being exceeded [62]. One of the main environmental issues is the direct discharge of significant nutrient loads into coastal waters from open-water systems and with the effluents from land-based *sys*tems [63]. In its search for best management practices, the aquaculture industry should develop innovative and responsible practices that optimize its efficiency and create diversification, while ensuring the remediation of the consequences of its activities to maintain the health of coastal waters. To avoid pronounced shifts in coastal processes, conversion, not dilution, is a common-sense solution, used for centuries in Asian countries. By integrating fed aquaculture (finfish, shrimp) with inorganic and organic extractive aquaculture (seaweed and shellfish), the wastes of one resource user become a resource (fertilizer or food) for the others [64]. Such a balanced ecosystem approach provides nutrient bioremediation capability, mutual benefits to the co-cultured organisms, economic diversification by producing other value-added marine crops, and increased profitability per cultivation unit for the aquaculture industry [1]. Moreover, as guidelines and regulations on aquaculture effluents are forthcoming in several countries, using appropriately selected seaweeds, molluscs and sea cucumbers as renewable biological nutrient scrubbers represents a cost-effective means for reaching compliance by reducing the internalization of the total environmental costs [65]. Performance of treatment systems for farm discharge water may be improved by incorporating active nutrient removal strategies such as planting of mangrove forests, culture of bivalves, macro algae, fish and nitrifying bacteria [66-70].

One of the most difficult tasks of resource managers and policy advisors is understands the assimilative capacity of coastal ecosystems under cumulative pressure as competing anthropogenic activities increase in the coastal zone (sewage effluents, urban/ rural effluents, precipitation, agricultural/industrial runoffs, aquaculture, etc.). Most impact studies on aquaculture operations have typically focused on organic matter/sludge deposition because they are easily noticeable and measurable[71]. Inorganic effluents, such as nitrogen and phosphorus, which are neither visible nor easily measured, have generally received much less attention because of the common human attitude of "out of sight, out of mind." Moreover, it is difficult to measure small long-term changes, and past studies, focusing on local measurements, have often failed to document dispersal patterns of dissolved nutrient fractions. The inorganic output of aquaculture is emerging as a pressing issue as nutrification of coastal water is a worldwide phenomenon [1-4].

Advantages of desert aquaculture

Desert aquaculture has been able to play a key role in transforming the economies for many countries. Apart from meeting the increasing demands for sea food, this method has been able to contribute towards some social benefits as well. A lot of job opportunities have been created and the dietary needs of the people have also been taken care of due to this development. Due to the large amount of production, shrimp and fish is becoming more and more affordable and are within the reach of the common masses. The aquaculture-agriculture system in the desert produces quality sea food all the year round. Apart from the social benefits, there are a lot of environmental benefits which are being offered such as utilization of barren coastal deserts, conversion of *Sabha* areas to productive agriculture lands and minimize the disease spread due to extremes of climatic factors. There has been a considerable amount of decrease in the pressure on wild fisheries. Desert aquaculture could prove to be less harmful to the eco system than a few other traditional fishing techniques and is therefore a significant source in combating poverty in rural areas of coastal deserts.

Conclusion

In this study, an attempt was made to discuss about the environmental concerns judiciously with desert aquaculture and to specify the conditions under which aquaculture could proceed in the arid / semi arid environment while ensuring least harm to environment. Better management of the environment for aquaculture development should go hand in hand with the protection and development of natural aquatic resources, as well as coastal mangrove ecosystems and underground freshwater which is a limited factor in arid-semi arid regions. Other recommendations include enforcement of existing legislation and introduction of environment-friendly aquaculture that are compatible with mangroves within the broader framework of community-based and integrated coastal area management program.

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