



(REVIEW ARTICLE)



Marine ecosystem restoration and aquaculture-based stock enhancement for fishery resource conservation in Abu Dhabi Emirate, United Arab Emirates

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World Journal of Advanced Research and Reviews, 2022, 15(01), 382–390

Publication history: Received on 14 June 2022; revised on 16 July 2022; accepted on 18 July 2022

Article DOI: <https://doi.org/10.30574/wjarr.2022.15.1.0717>

Abstract

There is a necessity to protect and manage the marine ecosystem towards the conservation of the ecological equilibrium and in turn the sustainability of the fishery resources in Abu Dhabi, UAE. Marine stock enhancement (MSE) proved that releasing hatchery fingerlings of marine animals can improve the abundance of harvest beyond the level supported by natural recruitment. For such programme to be beneficial and economical, considerable investment and scientific efforts are required. Among the concerned entities in the United Arab Emirates, the Aquaculture and Marine Studies (AMSC) in Abu Al Abyad Island successfully released 59 million of juveniles of different finfish species and 96 million juveniles of prawn species in Abu Dhabi waters. In the context of conserving the ecological equilibrium, the AMSC was able to plant an area of 5,026 ha in various areas of Abu Dhabi Emirate with grey mangrove, *Avicennia marina*; culturing over 21,290 corals of *Acropora sp.*, *Porites sp.*, *Cyphastrea sp* and *Psammocora sp.* in an area of 0.5 ha nurseries in Abu Al Abyad and Yasat Islands which will later be transplanted in the degraded reef sites in both islands; and a well-established seagrass coverage of 2500 m² was achieved in affected areas in Abu Al Abyad Island.

Keywords: Marine ecosystem restoration UAE; Fishery resource conservation; Aquaculture-based stock enhancement; Restoration of mangrove

1. Introduction

Coastal marine ecosystems comprising seagrass meadows, marshes, coral reefs and mangrove forests serve many important functions in coastal waters. These ecosystems provide a wide range of services to nature which is essential for the preservation of the ecological equilibrium and bio-diversity and in turn for the well-being of the human population. Studies and observations conducted in many parts of the world have highlighted the role of these ecosystems as nursery habitats for the juvenile stages of many marine and estuarine fish and shellfish [1, 2]. Concern for marine ecosystem conservation is gaining increasing attention as these ecosystems are continuing to be affected by human influence.

The seascape ecosystem in the United Arab Emirates are under severe stress due to anthropogenic activities such as intensive fishing, environmental pollution due to dredging, marine and coastal habitat loss to urbanization, together with global climate change. Based on an assessment of climate change impact on marine biodiversity and fisheries in the Arabian Gulf, a higher local extinctions for UAE is projected, with an estimated more than 26% drop in future fish catches [3]. A new assessment on extinction risk of marine bony fishes occurring in the Arabian Gulf revealed that overfishing affects 47% of the bony fishes, while loss of habitat caused by coastal development affects 32% and about 8.2% of marine bony fish are severely threatened and are nearly on the brink of extinction due to a combined effect of overfishing, coastal development, climate change and pollution [4]. The UAE Sustainable Fisheries Program (2015-

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2018) undertaken in collaboration with the Ministry of Climate Change and Environment (MOCCA) brought out the need for strategic management measures to support the set target of improving the sustainable fisheries exploitation index from 12.6% to 20% by 2020 and facilitate fishery recovery by 2030 [5]. A series of firm managerial decisions have been implemented by the concerned agency over the years within the frame of long-term strategy aimed at achieving sustainable fish stocks in UAE. These measures included regulation or ban of destructive fishing gear, closed fishing seasons, enhancing fish stocks and developing aquaculture research and programmes to support fish stock improvement [6].

This article highlights the necessity of conserving and managing these ecosystems and their importance in maintaining ecosystem services and fishery resources through effective habitat restoration and stock enhancement. Although aquaculture is often considered at odds with conservation efforts, in this article, we are trying to highlight how aquaculture could help meet conservation goals. Our aim is to encourage those in the conservation community to take a deeper look into the potential benefits of integrating ecological conservation efforts and aquaculture based stock enhancement. Additionally, this offers them an opportunity to steer the emerging aquaculture industry towards sustainable practices, which could benefit both the industry as well as conservation goals.

2. Marine stock enhancement

Marine stock enhancement (MSE) is the practice of releasing hatchery bred fingerlings or farm reared sub-adults marine animals into a self-recruiting wild population, with the aim of increasing abundance or harvest beyond the level supported by natural recruitment [7]. The earliest initiatives on MSE programme were conducted in Japan, focusing mainly on demersal fish and shellfish, which do not migrate over large areas. Data till 2002 indicated that a total of 76 million juveniles from 37 finfish species, 221 million juveniles from 12 crustacean, 3213 million spat from 26 shellfish and 78 million juveniles from 8 invertebrates were produced in hatcheries and released into coastal waters [8]. The study results showed that released juveniles did survive and contribute to fishery production significantly but has not been quantified. In general it was assumed that the release of hatchery fish and marine invertebrates had augmented the catch [9]. The natural beds of windowpane oyster, *Placuna placenta*, (Kepis shell) was reported to deplete along Panay Gulf in Philippines due to overexploitation which led in 1987 to complete disappearance of this species. To restore the population of windowpane oyster in Panay Gulf, a restocking program was launched in 1999 and as a result it was observed later the occurrence of larvae and juveniles of the depleted shell [10]. In Korea, the National Fisheries Research and development institute embarked on a MSE programme in 1986 and between 1986 and 2012, 46 marine species including abalone, various flatfish, seabream were targets of production and a total of 1410 million juveniles were stocked in the sea leading to the enhancement of the fishery resources and increased income of fishermen [11]. In Belgium, local fishermen recaptured 30% of the released turbot that had migrated within one year from Belgium to all over the North Sea, indicating modest success in this programme [12]. Another successful MSE initiative is of the Southern scallop fishery in New Zealand, which was revived by an aggressive seeding programme, where hatchery produced juveniles contributed strongly to the initial recovery [13]. A study of salmon hatchery programmes found that hatchery fish have an important role in recovery and supplementation of wild stocks [14]. There are also instances where such large-scale MSE programmes are run by community-based aquaculture associations. One example is in Alaska, where the association produces and releases juvenile salmon and in return, gain exclusive rights to a share of the harvest in the form of “cost recovery fish” [15]. Another successful approach of replenishing natural stocks is the Crab Bank in Thailand, a voluntary programme through which hatchery operators released 10% of the crab fry produced to re-seed the natural population depleted by overfishing and by the 2004 tsunami [16]. In central Philippines, the New Washington Estuary was a productive fishing ground that has been suffering from degenerating brackishwater fisheries and estuarine environment. Aquaculture Department of the Southeast Asian Fisheries Development Center (SEAFDEC/AQD), along with support from the Research Institute for Humanity and Nature (RIHN) of Kyoto, Japan, conducted a pilot project for the stock enhancement of tiger shrimp *Penaeus monodon* in the Estuary and was found to be a viable intervention to restore livelihood and promote estuarine rehabilitation in the estuary [17]. In South Africa, the release of hatchery reared spats of perlemoen abalone, *Haliotis midae*, coupled with area protection successfully restored the depleting abalone fishery [18]. The release program of hatchery reared king prawn, *Penaeus plebejus*, in south-eastern Australia was successful in enhancing the recreational prawn fisheries [19].

It is now abundantly clear that restocking fish can be an effective strategy to fisheries managers, and at least in principle generate a wide range of benefits subject to certain conditions [15]. It was concluded that for stocking programmes to be successful and economical and contribute to the sustainability of wild stocks, their effective use warranted specialist knowledge and skills from diverse fields such as fishery biology, fisheries management, mariculture, population genetics, aquatic animal health, behavioral ecology, resource economics, statistics and experimental design, tagging and monitoring technology and communications and outreach. Thus considerable investment and scientific efforts are

required to elucidate all the relevant components of life history and refine the technology for releases at a meaningful scale in a responsible way [20].

Worldwide degradation of coral reef ecosystem has prompted worldwide responses to active reef restoration and this is particularly prominent in the Caribbean region where coral reef restoration is intensive [21]. Since 2004, the Nature Conservancy, Coral Restoration Foundation and Mote Marine Laboratory, Florida, USA have together transplanted more than 20,000 colonies of nursery cultured into the degraded reef with 80% survival rate during the first year. Similarly, in the Seychelles, Indian Ocean, one of the largest coral restoration project was undertaken in between 2011 and 2014 and over 24,000 nursery grown coral colonies were transplanted in 0.52 ha area [22]. In Okinawa, Japan, 10-16 years old transplanted coral colonies responded to the natural cue of the animal kingdom by having synchronous spawning in the degraded reef [23]. It is clearly evident that every continent in the world where coral reefs are present, reef restoration initiatives keep flourishing whether in the Atlantic, Indian or Pacific Ocean. However, there is very little such programme is underway in the Arabian Gulf. The only one such known programme currently being carried out is the restoration programme in Abu Al Abyad and Al Yasat islands, under the Private Department of the President of UAE [24].

Since 1997 seagrass restoration has been conducted at an increasing number of locations around the world, In USA a large scale eelgrass, *Zostera marina* restoration program in 1996 in Chesapeake Bay, had recorded high survival rate (73%) and rapid coverage using a simple transplanting method [25]. In Europe, since 1997 most of the seagrass restoration efforts were involved to restore *Z. marina* and *Z. noltii* or in the development of techniques to restore *Posidonia oceanica* in the Mediterranean Sea [26]. Over the last two decades seagrass restoration in Australia has been largely conducted in the western Australia with strong focus on developing of techniques to restore *Posidonia* spp. and *Amphibolis* spp. Large scale transplanting operation was conducted in southern Cockburn Sound, Australia to transplant sprigs of *P. australia* with 41% survival rate [27]. In another large scale transplantation program in Western Australia, required 2.1 ha area of seagrass habitat to be restored as a habitat compensation measure for nearby dredging operation. To achieve this compensation, the manual transplantation of sprigs of *P. Australia* and *P. sinuosa* was used. With an initial survival rate of 50%, the project is considered moderately success [28].

Major loss of habitat and realizing the potential as carbon sinks, has prompted Mangrove restoration worldwide. According to [29], since 1996, 8120 km² area of mangrove forest has been lost, however 6630 km² area can also be restored worldwide. South East Asian region is known as the largest mangrove restoration programme, primarily as a reactive measure to the habitat loss [30]. Similarly mangrove restoration is also being conducted in eastern Africa [31], South Asia [32] and North America [28].

3. Ecosystem conservation efforts and aquaculture based stock enhancement activity in UAE

Aquaculture research and development activities in the UAE was first initiated in 1984 with the establishment of the Marine Environment Research Department (MERD) in Umm Al Quwain, MOCCA, on the north east coast of the country mandated with conservation, replenishment and development of the marine resources in the territorial waters of the country. Among the extensive efforts of MOCCA to enhance the natural stocks of local fish species, in 2017 the Ministry in collaboration with the private company Fish Farm LLC., the municipalities and environmental authorities of the seven emirates released Goldlined seabream, *Rhabdosargus sarba* and Yellowfin seabream, *Acanthopagrus latus* in protected marine areas, with 30,000 of these especially cultured fishes released in each emirate [33]. Later in 1997 the Aquaculture and Marine Studies Center in Abu Al Abyad Island, Abu Dhabi (AMSC) was established with the goal of developing hatchery techniques for the commercially important marine finfishes and shrimp and to support the natural habitat through restocking programmes of produced juvenile fishes [34]. Since its inception, the AMSC has expanded today to include 4 hatcheries and grow-out facilities covering 40 ha of land area and 33.8 ha of sea area. Through all these years, the center has successfully developed and established the basic techniques of broodstock management, spawning, larval rearing and grow-out of marine fish and shrimp under the local conditions [35, 36]. The stock enhancement programme is primarily focusing on local population of the declining species (Goldlined seabream, *R. sarba*; Bluefin seabream, *Sparidentx hasta*; yellowfin seabream, *A. latus*; Whitespotted rabbitfish, *Siganus canaliculatus*; Spangled emperor, *Lethrinus nebulosus*; Blue-spot mullet, *Valamugil seheli*; Grey mullet, *Mugil cephalus*; green tiger prawn, *Penaeus semisulcatus* and the white prawn *Fenneropenaeus indicus*). The center also produces fingerlings of Cobia, *Rachycentron canadum*; Orange spotted grouper, *Epinephelus coioides* for supply to commercial farms as well as for stock enhancement. The number of fish fingerlings released by the center in the years 2021 and 2022 from the hatchery was 2.18 million of *R. sarba* and *S. hasta* and 2.66 million of *R. sarba*, *S. hasta* and *S. canaliculatus*, respectively. In a bid to further enhance the success of the release program, it was decided to diversify the sizes of the released fish by growing some of the fish juveniles to a larger sizes and then release them in the sea. In this context, 12 numbers of 15 meter diameter nearshore cages were launched in 2021 to grow the fish to sub-adult stage. The number of sub-adults

of *S. hasta* and *A. latus* released in the sea in 2022 was 0.067 million. From the initiation of the programme in 2000 until 2022, a total of 59 million of juveniles of finfish species and 96 million juveniles of prawn species were released in the coastal waters of the Emirate of Abu Dhabi, mainly around Abu Al Abyad Island (Figure 1). Today the AMSC has the necessary expertise to use aquaculture as an important tool to replenish the natural fish resources as well as to support the commercial aquaculture sector.

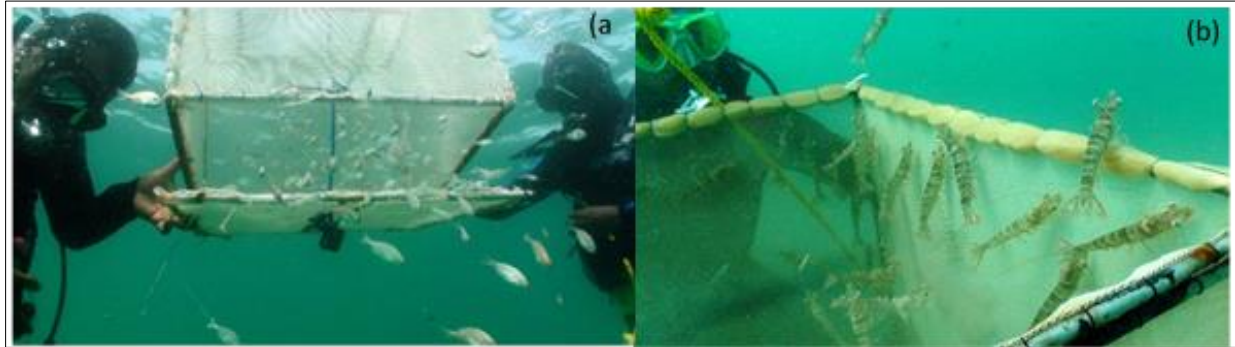


Figure 1 (a) Fish fingerling and (b) Shrimp release in Abu Al Abyad

4. Marine Ecosystem conservation and restoration activity in Abu Al Abyad

4.1. Mangrove restoration

The mangroves of UAE are comprised exclusively of the highly salt tolerant grey mangrove, *Avicennia marina* which play a vital role in sequestering of atmospheric carbon dioxide, coastal shoreline protection from erosion, sedimentation and natural calamities, providing natural nursery grounds for varied phyla etc. Despite these crucial importance, the mangrove habitat is steadily declining due to human activities such as land filling, dredging, foreshore construction as well as increased pressure from climate change. Understanding the long lasting value of this plant species for UAE, a number of projects for mangrove restoration have been initiated. In-fact UAE is one of the leading countries in the Middle East when it comes to mangrove restoration. Mangrove (*A. marina*) restoration is one of best and proven way to restore a forest or to create a new forest (afforestation) in a favorable environment.

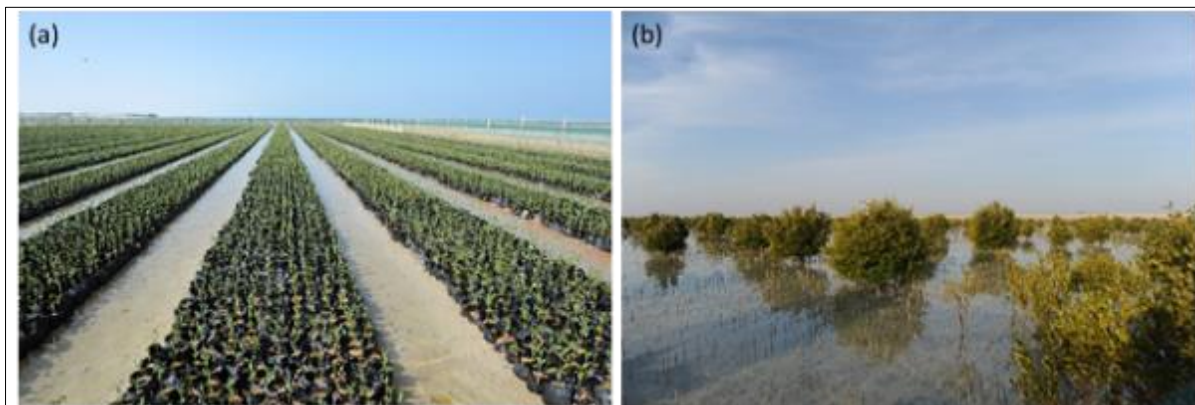


Figure 2 (a) A view of the mangrove nursery and (b) ten years old developing mangrove forest after plantation

The total mangrove area in the country was estimated at approximately 13,615 ha out of which 79.5 % is in the Emirate of Abu Dhabi [37]. The monetary value of mangrove ecosystem services in UAE is estimated to average AED 64 million annually (US \$ 17.4 million) for each one kilometer of mangrove trees. This vast area of mangrove vegetation in Abu Dhabi Emirate can be attributed to the restoration plantings undertaken since 1990's [38]. One of the strongest and successful mangrove restoration programs was initiated by the Marine Studies Unit of the AMSC at Abu Al Abyad Island situated west of Abu Dhabi. This unit consists of intertidal nurseries producing more than 1,200,000 plants annually. The reclaimed and planted area during the last 15 years of operation covers a total area of 5,026 hectares in various areas of Abu Al Abyad Island, Ras Ghanada and Yasat Island. In addition, another area of 3020 hectares have been reclaimed and made ready for new planting operations (Figure 2).

The red mangrove, *Rhizophora mucronata* has also been planted but in very limited numbers and areas. In 2008, Marine Studies unit, AMSC, Abu Al Abyad managed to successfully germinate the seeds of this species brought from Pakistan and cultivated a number of the seedlings in the open intertidal zones and another group was cultivated within the existing forests of the grey mangrove. The seedlings sowed inside the existing grey mangrove forests were successful and the trees that reached 2.25m started to flower during September and October and fruit formation was also observed. Further efforts are on to test the viability of re-establishing red mangrove in Abu Al Abyad Island. These findings are deemed encouraging to expand the cultivation of *R. mucronata* saplings in Abu Dhabi Emirate despite the prevailing harsh climatic conditions, thus restoring the species that was once extinct [39].

4.2. Coral reef and Sea grass restoration

The corals of the Arabian Gulf are a unique community, existing in an environment with stressors including extreme fluctuations in water temperature and high salinity. There are 44 coral species listed as either near threatened or vulnerable with either decreasing or unknown population trends on the IUCN Red list for the UAE. Predominant species include the Boulder coral (*Porites spp*), and Branching coral (*Acropora coral*). Corals form critical habitat for many species including reef dwelling fish species and the critically endangered Hawksbill turtle. Unfortunately, with all the pressures they face less than half the coral reefs in the waters of Abu Dhabi contain living corals, the total area of corals in Abu Dhabi Emirate was estimated at 310.66 km² [40]. The Environment Agency – Abu Dhabi (EAD) continued to advance the conservation, management and sustainable use of coral reefs and associated habitats, by ensuring the availability of accurate information for decision making. So far, some of the deliverables of this project have been a comprehensive coral reef map and a coral reef conservation plan. The findings include clear signs of the coral system’s resilience and active signs of regeneration [41].

In 2009 The AMSC started the coral restoration programme in Abu Al Abyad Island, Abu Dhabi. By the end of 2016, the Center had successfully cultured over 7500 corals in more than 150 nursery units with a mortality rate less than 5%, making it one of the largest coral nurseries in the Arabian Gulf [24]. These nursery grown corals (NGCs) were also transplanted to the degraded reef site as the final stage of the reef restoration and by the end of 2017, twenty thousand such NGCs were transplanted in an area of 0.3ha, making it one of the largest restoration program in Arabian Gulf (Figure 3).

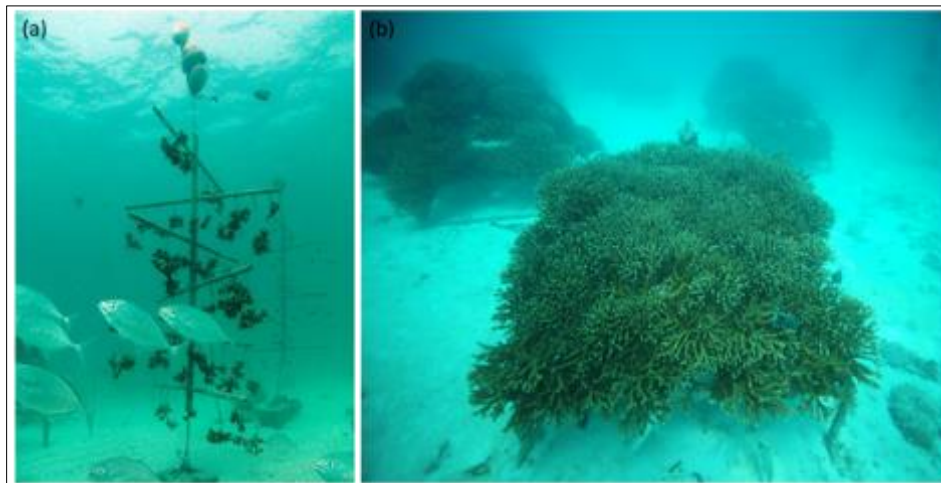


Figure 3 (a) A coral tree nursery in Abu Al Abyad and (b) artificial reef frame in Abu Al Abyad

They were also used for building artificial reefs (using three dimensional structures such as steel frames, building blocks etc. as substrate), particularly for improving the habitat for reef dwelling fishes. In 2021, 2,500 m² in Abu Al Abyad Island and 2,500 m² in Yasat Island were added as coral nurseries to support the existing restoration programme. Beside *Acropora sp.* and *Porites sp.*, two more species were transplanted in the nurseries, *Cyphastrea sp.* and *Psammocora sp.*

Seagrass is a critical habitat within Abu Dhabi Emirate because of the ecosystem services it provides to fish species, but also as the main food source for the world’s second largest population of dugong (*Dugong dugon*) in the western region of Abu Dhabi Emirate. Seagrass is also considered a “Blue Carbon” habitat type because it is a coastal and marine habitat that is able to sequester and store carbon. Seagrass species in Abu Dhabi consist of *Halodule uninervis*, *Halophila stipulacea* and *Halophila ovalis*. The seagrass meadows in Abu Dhabi Emirate are estimated to cover 158,262 ha extending around the islands and along the nearshore coastal plain [42]. Sea-grass restoration programme was initiated

in the year 2009, focusing primarily on the dredged channels of Abu Al Abyad Island. Due to lack of standardized procedure for restoring sea-grass meadow in the Arabian Gulf, successful restoration could not be achieved at the beginning. However, in the subsequent years, the methodology of restoration was modified and a successful procedure was established for restoring the sea-grass meadows resulting in high survival rates. A well-established sea-grass coverage (2500 m²) has been achieved in an area where otherwise it would have been bare sandy seafloor. Intensifying this activity could further increase the area covered, thus increasing the carrying capacity of the ecosystem (Figure 4)?

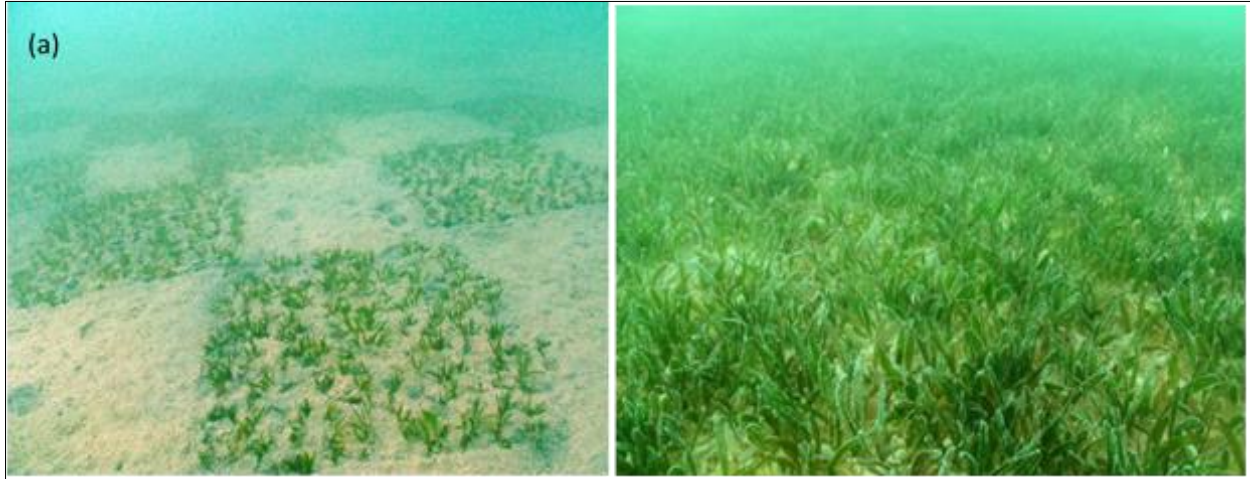


Figure 4 (a) Transplantation of seagrass on sandy bottom of dredged channel in Abu Al Abyad and (b) The same transplantation site after 22 months

4.3. Fish aggregating devices (FAD)

A total of about 2340 reef balls of different sizes have been deployed in and around the Abu-Al Abyad Island in six different locations in the deep channels surrounding the island. These are expected to serve as additional habitats for the wild fish fingerlings, juveniles and adult wild fish as well as those released from the hatchery. Besides, a total of 14019 reef balls of different sizes have been deployed between 2007 and 2015 around Al Yasat Island covering an area of 25,300 m². These reef-balls when fully colonized by corals and associated fauna could increase the carrying capacity of the ecosystem in supporting more marine life and as shelter for juvenile and adult fish (Figure 5).

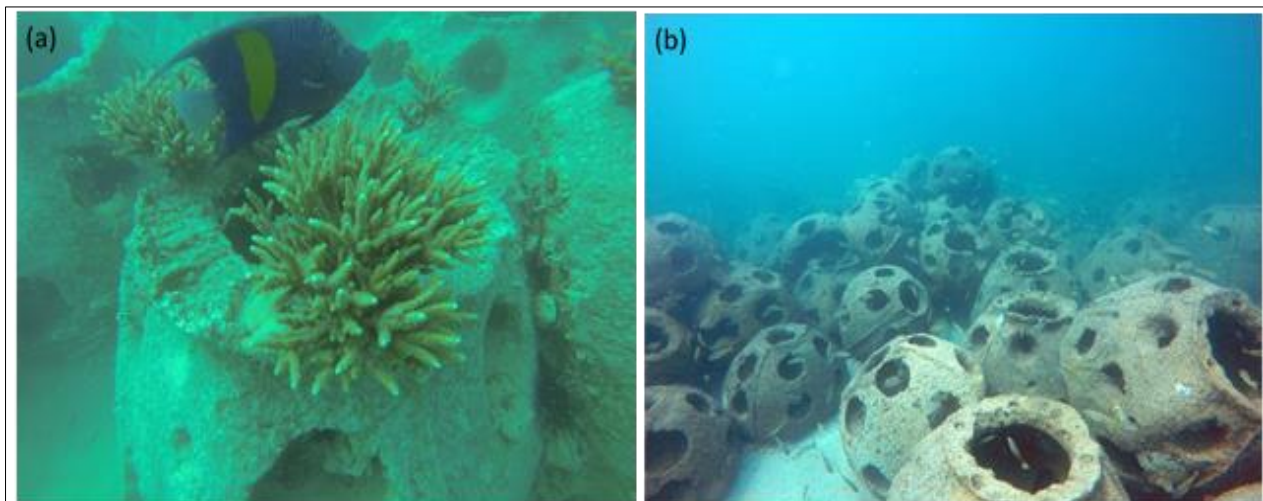


Figure 5 (a) Coral transplantation on reefballs in Al Yasat Island and (b) fish congregation at reefballs

4.4. Marine Protected Areas (MPA)

In many parts of the world, large areas of the oceans and seas are being set aside as marine protected areas (MPAs) to buffer the direct impact of disturbances on the critical habitats to ensure the ecosystem services they provide. Where nursery grounds are degraded, restoration of the coastal habitats will enhance the carrying capacity and will be an

indispensable tool in ensuring the success of stock enhancement programs. Growing awareness of this issue has led to a worldwide interest in establishing marine protected areas (MPA's) as a tool to protect the marine biodiversity and preserving the full functioning of this ecosystem in providing goods and services for the present and future generations [43]. Currently, Abu Dhabi has five major marine protected areas - the Marawah Marine Biosphere Reserve which covers a territory of 4,255 km², the Al Yasat Marine Protected Area, which covers a territory of 2,046 km², Saadiyat Marine National Park which covers a territory of 59 km², Ras Ghanadah which covers a territory of 55 km², and Mangrove Marine National Park which covers a territory of 19 km². The main objectives of the marine protected areas in Abu Dhabi are to conserve the natural habitats and wild aquatic species. The waters surrounding Abu Al Abyad Island are in the process of being declared a MPA.

5. Conclusion and Recommendations

Recoveries of exploited marine species in estuarine and coastal regions were enabled by reduced or banned exploitation; habitat protection, especially the breeding and feeding grounds and by pollution controls and that most often these measures were successful when implemented in combination. The UAE is also proactively responding to this looming crisis by reducing fishing efforts, regulating gear and mesh size, declaring no take areas through MPA's to rejuvenate the natural stocks and implementing the closed season during the breeding period.

For the success of the stock enhancement programmes in the UAE, it is highly recommended that the stock enhancement programme should be targeted at local species which are facing high commercial fishing pressures. Conservation and rebuilding plans needs to be tailor made for specific species/areas and implemented, focusing specifically on some of the critically declining stocks like the spangled emperor (*Lethinus nebulosus*), white-spotted rabbit fish (*Siganus canaliculatus*) and orange spotted grouper (*Epinephelus coioides*). Enhancement and conservation of declining fish stocks will be successful over the long term only when the degraded nursery grounds and spawning habitats are rehabilitated. The ecological carrying capacity must be taken into consideration while deciding on the magnitude of releases to accommodate both the hatchery releases and natural recruitment. It is therefore suggested to further increase the efforts made in restoration of the degraded coastal habitats to enhance the carrying capacity. Establishment of an optimal release size that would maximize the survival of the released fish is critical. Reducing the post release mortalities is a key goal that needs further detailed investigations. Therefore, it is imperative to carry out trials to evaluate fish size at release, release season, release habitat and release magnitude should be standardized for each species. The genetic structure of the wild stocks targeted for enhancement should be clearly identified and managed according to the objectives of the enhancement program. Hatcheries in UAE producing fingerlings of local fish species should focus on producing fingerlings having the same levels of genetic diversity and fitness when compared to wild stock.

A stronger coordination between the fishing, aquaculture and conservation communities is required to be mandatorily enforced by the regulatory authorities, as well as providing sufficient funding to support such an initiative. Existing commercial aquaculture hatcheries should support these initiatives by earmarking certain percentage of the fingerling production for the restocking programme.

Compliance with ethical standards

Acknowledgments

The authors would like to thank the AMSC technical staff for their constant effort and enthusiastic cooperation.

Disclosure of conflict of interest

The authors declare no conflict of interest.

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