THE USE OF ARTIFICIAL REEFS AND OPEN SEA BIO-FILTERS TO REDUCE THE ENVIRONMENTAL IMPACT OF MARICULTURE

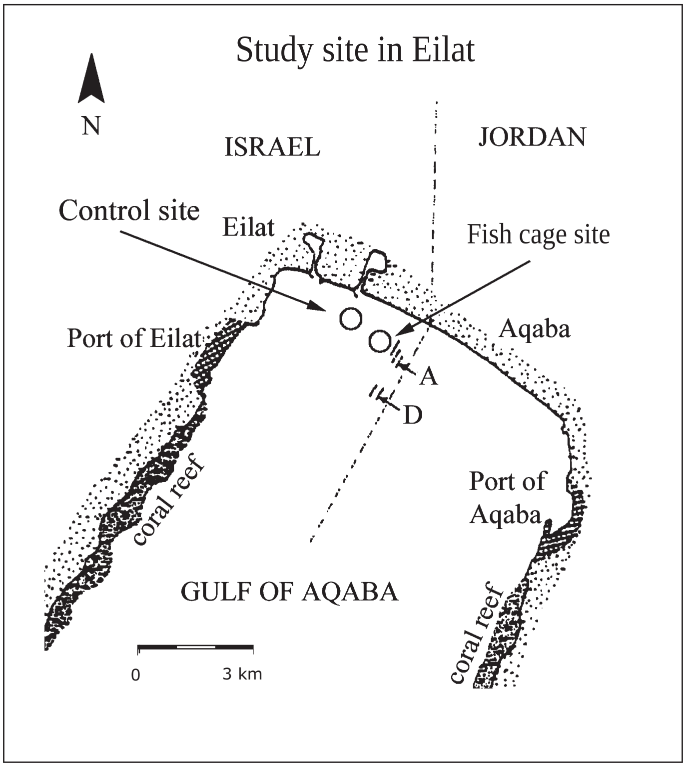

Fig. 1. Map of the study area

The seas were once considered a limitless source of food, yet recent studies have shown that the marine fisheries catch has decreased and is failing to meet the steadily increasing demand for seafood. In recent years, a growing proportion of this demand (≥ 30%) is supplied by the aquaculture industry, and especially by mariculture (marine aquaculture). However, many see the intense expansion of mariculture as a mixed blessing. Mariculture offers a viable alternative to many of the fishing traditions that have destroyed a variety of aquatic and marine habitats (through bottom trawling, dynamite fishing, overfishing, etc.) as well as to unemployed fishing fleets. Fish farms inevitably cause other environmental impacts. Indeed, one of the main factors that prevents the growth and expansion of the mariculture industry in many countries is the concern that it will lead to pollution and destruction of fragile aquatic environments.

Net pen fin fish mariculture, which is the main branch of mariculture, has grown and developed immensely over recent years. This open sea farming technique has several advantages over land-based aquaculture (there is no need to pump or aerate sea water, or use expensive coastal land). However, the main drawback of this open water technique is the environmental problem caused by its organic effluents released into the natural environment. This problem is worsening due to the fact that most net pen fish farms are located within protected bays and semi-enclosed coastal areas where the sea is relatively calm, therefore enabling smooth operation. However, such calm conditions also tend to reduce the exchange of water with the open sea, the result of which is the reduction of the dilution of the organic effluents.

An example of such a problem in Israel is the intensive pen fish aquaculture (map, Fig. 1) being carried out in two large fish farms by two commercial companies, Ardag (A) and Dag-Suf (D). The farms are situated several hundred meters off the northern coast of the Gulf of Eilat (Fig. 2) along the marine border with Jordan. The two fish farms produce about 2,500 metric tons annually of high quality fish, mainly gilthead sea-bream, *Sparus aurata*, and the European sea bass, *Dicentrarchus labrax*. The remains of the fish food and the fish secretions are released into the otherwise naturally oligotrophic (clear water which contains low levels of nutrients and organic matter) marine environment, as dissolved and particulate organic matter. These loadings can cause a variety of environmental problems such as sediment anoxia (low oxygen content), algal blooms and a reduced benthic (bottom) biodiversity.

The city of Eilat attracts many tourists from Israel and abroad due to its coral reef and clear water. However, the Eilat coral reserve (the only one in Israel) has severely deteriorated in recent years, and the variety and amount of marine organisms has decreased significantly. There are disputed claims that the deterioration of the coral reserve, which is situated approximately 7 km south-west of the farms, should be blamed on the organic loading from the fish farms (although other factors, such as damage inflicted by divers and glass-bottomed boats, sewage spills, spills from the

Fig. 2. Aerial view of a fish farm off the northern coast of Eilat

phosphate loading installations in ports in the area, nutrients seeping into the sea from the municipal ornamental vegetation water irrigation system, and natural phenomena, should be considered as additional alternative causes of the deterioration).

The environmental impact of fish cage mariculture is not unique to Israel. In Europe, as in other parts of the world, this is a rapidly-growing, highly lucrative industry, with the potential to have an adverse impact on the environment.

The original proposal to use artificial reefs and similar man-made structures to reduce environmental impact was developed into a pan-European research program within the framework of the European Union's 5th Research Program. The EU project (under the general section 'Quality of Life and Management of Living Resources') is entitled BIOFAQs (Biofiltration and Aquaculture), the goal of which is to evaluate hard substrate deployment performance within mariculture developments. There are 8 partner-research groups in this EU project, including the research group headed by Ehud Spanier of the Leon Recanati Institute for Maritime Studies (RIMS); NERC, the Centre for Coastal and Marine Sciences, Dunstaffnage Marine Laboratory (CCMS.DML) Oban, Scotland, UK; the National Center for Mariculture, Israel Oceanographic & Limnological Research (IOLR), Eilat, Israel; the Marine Biological Station, National Institute of Biology, Piran (NIB), Slovenia; the Institute of Marine Biology of Crete (IMBC), Greece; the Centre for the Economics and Management of Aquatic Resources (CEMARE), University of Portsmouth, Southsea UK; the University of Southampton (USOU), the School of Ocean and Earth Science, UK, and the Jozef Stefan Institute (JSI), Ljubljana, Slovenia.

This is a multidisciplinary research project dealing with a variety of aspects in an attempt to estimate and reduce the environmental impact of fish-cage aquaculture on a wide spectrum of issues, including community added value, the contribution to community social objectives and economic development, and scientific and technological prospects. Within the framework of this project scientists from Scotland, Britain, Slovenia, Greece and Israel, in diverse disciplines, such as marine biology, biological monitoring, productivity assessments, biofiltration, biogeochemistry, modelling, hydrodynamics, energy flow, stable isotope geochemistry, legal and regulatory comparison & analysis, and economic analysis, are collaborating with the aim of reaching sound scientific conclusions.

Special open sea bio-filters of similar design were deployed in the vicinity of fish farms and reference sites in four countries (Scotland, Slovenia, Greece and Israel) and studied using similar techniques.

Fig. 3. Schematic drawing of the 'cross-hatched' benthic artificial reef (Drawing: G. Spanier)

As the most promising results obtained so far were from the Israeli site in Eilat, where there are also benthic artificial reefs, an international workshop was held at the Inter-University Institute in Eilat in October 2002. Within the framework of the conference intense field activities in the area of the bio-filters and the artificial reefs took place. Members of BIOFAQS from all the partner countries participated in this ten-day workshop.

In Eilat, in March 1999, Ehud Spanier headed the RIMS group (Stephen Breitstein and Amir Yurman, of the RIMS diving workshop, graduate research assistants Anat Tsemel, Ayalon Roitemberg and Anat Shmueli, together with research technician Hadas Lubinevsky and a number of Ehud Spanier's research assistants), and in cooperation with the ILOR research group (Timor Katz and Noa Eden) headed by Dror Angel, deployed the two benthic 280x240x240 cm 'cross-hatch' artificial reefs made of porous polyethylene at a depth of 20 m (Fig. 3). One artificial reef was deployed below the fish farms cages (FF), and the other in a reference site (R) 500 m west of the fish farms.

Bony fish as well as macro-invertebrates that associated with the reefs were counted bi-monthly by divers' visual censuses complemented by video and still recordings.

In the framework of the EU FP-5 project BIOFAQs, four bio-filter arrays were deployed in June 2001 in each of the above sites. Each array consisted of 11 25x50 cm cylindrical bio-filter units (Fig.4) made of 25 mm NETLON plastic mesh. Eight horizontal bio-filters in each array, were arranged horizontally at a depth of 8 m, and an additional three bio-filter

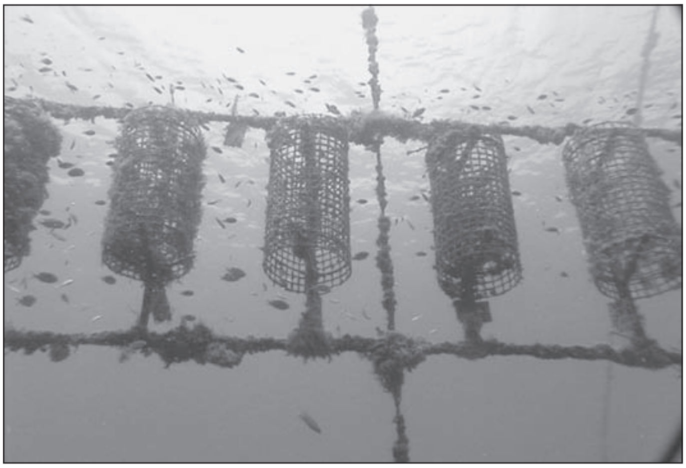

Fig. 4. View of horizontal array of bio-filters (Photo: S. Breitstein)

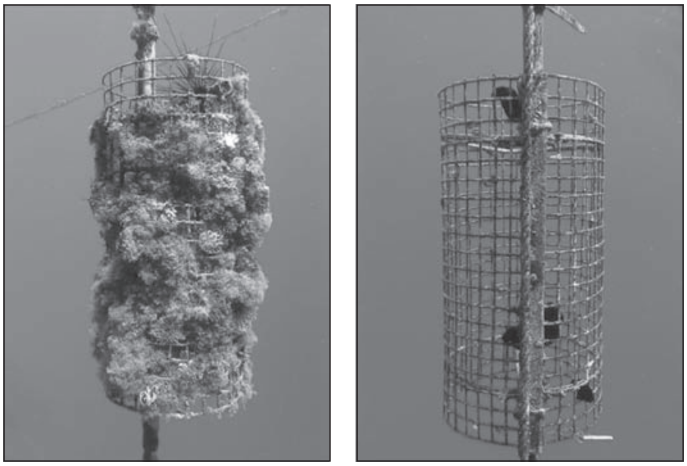

Fig. 6. Bio-filter from site FF (left) compared with one from site R (right), February 2002 (Photo: S. Breitstein)

units were installed vertically at depths of 6, 11 and 14 meters. Every two months, video and still photographs were taken of all the bio-filters. Random samples were taken from each horizontal array from one bio-filter and sub-samples were analyzed to determine the species composition of the bio-fouling, coverage and weight.

The results, so far, indicate that a variety of sessile organisms and fish - rapidly colonized both benthic reefs. Sponges, tunicates, bryozoans, polychaetes, gastropods and bivalves were the dominant sessile taxonomic groups. There were qualitative and quantitative differences in their appearance, depending on the site and the season. Stony corals (Fig. 5) appeared on both reefs, but in greater numbers and variety in site R. After one year, the number of fish species in site FF was 42 (with the cardinal fish, *Apogon flurieu* as the dominant species) compared to 31 in site R (most frequent species — another species of cardinal fish, *A. pseudotaeniatus*) while the number of specimens was 886:1185 respectively.

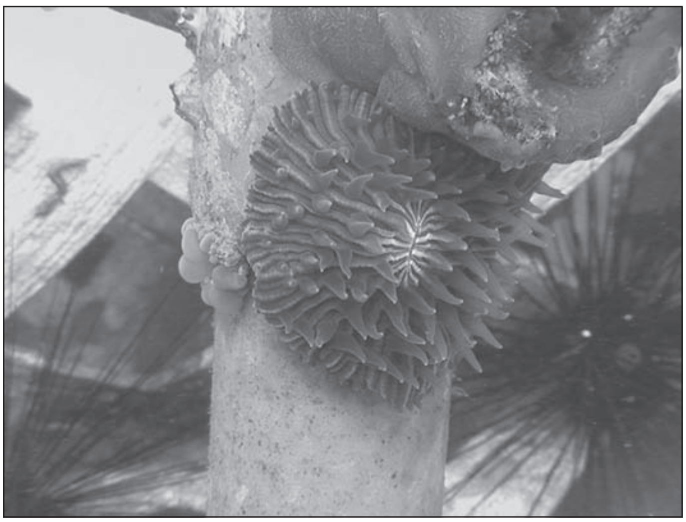

Fig. 5. Stony coral on the benthic artificial reef (Photo: S. Breitstein)

There was a subsequent process in the bio-fouling colonizing the bio-filters. Red algae, sponges, sea anemones, serpulid-polychaetes and bivalves were the dominant taxa. The number of species, coverage and biomass were significantly greater on bio-filters from site FF compared to those from site R (Fig. 6).

There is less than one year remaining until the completion of this stage of this three-year EU study. The conclusions to date, at least regarding fish, are that the benthic biodiversity increased due to the artificial reefs. Most sessile organisms colonizing the reefs and bio-filters are filtering organisms. The increase of bio-fouling on the bio-filters, in site FF compared to those from R, may indicate that these organisms have the potential, directly or through the food web, of utilizing the organic output from the fish cages. However, there may be an alternative explanation — the 'grazing effect'. Many wild fish were common around the bio-filters on both sites (Fig. 7). Yet, in site FF the wild fish have an alternative food source — the organic output from the cages. This artificial nutrition is lacking in site R and may cause greater grazing of the bio-fouling on the bio-filters.

Sonia Lojen, our colleague from the Department of Environmental Science, the Jozef Stefan Institute, Ljubljana, Slovenia, assisted in solving this question via stable isotope analyses of tissues of fouling organisms sent to her from our sites in Eilat. It was revealed that the organisms on the bio-filters were enriched in ^{15}N compared to those from the reference site. This strengthened the hypothesis that the fouling organisms at the bio-filters use the particulate organic matter and the remains of the fish food from the cages (Fig. 8). Moreover, Sonia Lojen, calculated that an estimated 61% of the food used by the organisms at the bio-filters is derived from the cages, indicating that bio-filters were effective. Thus, artificial reefs and bio-filters should be considered as a means to reduce the environmental impact of com-

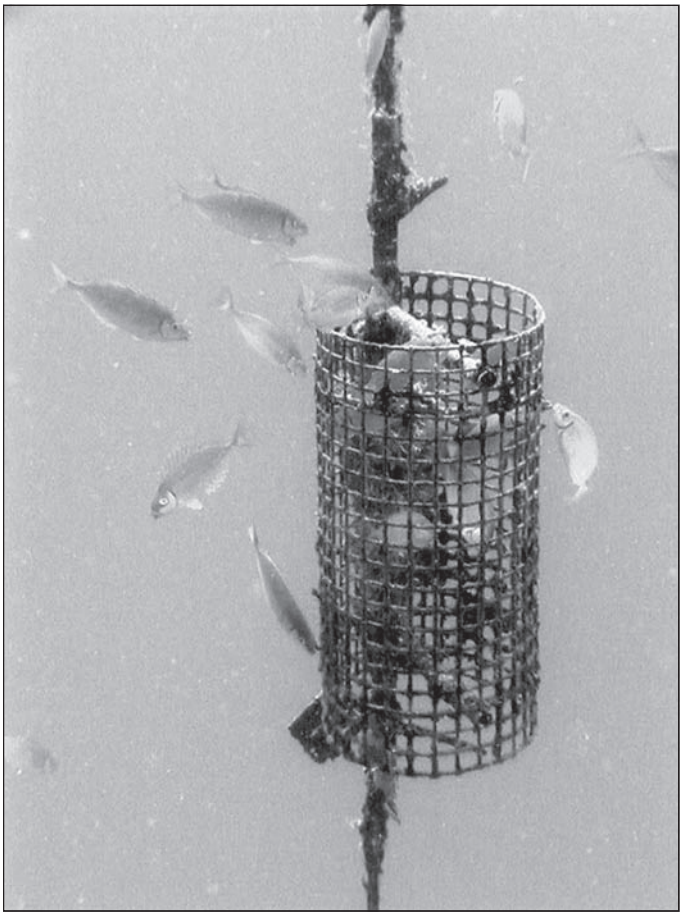

Fig. 7. Fish grazing on a bio-filter (Photo: S. Breitstein)

Fig. 8. Fish in a tube sponge on top of a bio-filter (Photo: S. Breitstein)

mercial fish farms on various marine habitats around the world.

Suggested reading:
"Crosshatch Artificial Reefs to Reduce Organic Enrichment by Commercial Net Cage Fish Farming in the Gulf of Eilat". CMS News Report No. 26, December 1999, pp. 14 -15)

Ehud Spanier

QUO VADIS ANATOLIA? THE COMPLEX TECTONIC REGIME OF CYPRUS ARC

The tectonic regime of Cyprus Arc is generally considered to be that of a collision zone between the northward moving African Plate and the southward moving Eurasia, a collision that is bound to close the eastern Mediterranean in the foreseeable geological future. The Arc is the location where the Tethyan lithospheric toe of Africa, in the easternmost Mediterranean, is being subducted northward under the Anatolian plate. Characteristic to this subduction process is the subsidence of the northern edge of Eratosthenes Seamount. A transect of 3 boreholes, that was drilled along the northern flank of the Seamount during ODP leg 160 in 1995, encountered evidence that the Seamount was affected by subaerial(?) erosion since the late Miocene, and that the most extensive erosion has affected the deepest part of the flank explored, which today is located at water depth of ca. 2500 m. This finding suggests that the presently deep part of the seamount had been near its summit in the late Miocene, and has subsided more than 3 km since then. It is reasonable to presume that the northwards subduction thrusted the northern flank of the seamount into its present structural configuration. Concurrently the Troodos Massif of southern Cyprus was uplifted by more than 4 km during that timespan. The converging motion of Africa towards Anatolia, the subsidence of Eratosthenes Seamount and the contemporaneous uplift of Troodos, should have led to the emplacement of Cyprus ophiolite on top of the continental lithosphere of Eratosthenes, therefore Cyprus Arc could have been considered a prime example of ongoing obduction of oceanic crust on top of a continental lithosphere.

However, numerous recently acquired GPS measurements show that Anatolia is not moving southwards to collide with Africa as expected, but it moves westwards, and the rate of displacement increases westwards and exceeds 30 mm/yr at the Aegean Basin, which is approximately 20 times faster than the rate of Africa-Anatolia collision. Consequently, the structural layout of the NE-trending eastern segment of Cyprus Arc, from Hecataeus Plateau to western Syria is transtensional. Earthquakes along Cyprus Arc and its surroundings show composite displacement patterns, most of the earthquakes show sinistral strike-slip offset, many are extensional, and compressional motions were encountered mainly along the central segment of Cyprus Arc. It is of interest to note that the region between southern Anatolia and Cyprus is characterized by predominantly extensional structural patterns, as indicated by a series of salt diapirs that were encountered in Cilicia Basin. Furthermore, during the early Pliocene, Mesaoria Plain in central Cyprus and Flor-