Table 6 Some additional faunal components for coral reef aquaria

Niche	*Common name*	*Scientific name*
Detritus feeder	Anemone shrimp	*Periclimenea brevicarpalis*
	Shrimp	*P. pedersoni*
	Fiddler crab	*Uca* spp.
Algal feeder	Tiger cowrie	*Cypraea tigris*
	Money cowrie	*C. moneta*
	Starfish	*Patiria* spp.
Plankton feeders	Mandarin fish	*Synchiropus splendidus*
	Psychedelic fish	*S. picturatus*
	Midas blenny	*Escenius midas*

efficiently. Ahermatypic corals should be introduced first and placed in the darker regions of the tank since they feed on plankton. Once hermatypic corals are introduced appropriate blue light for at least 12 hours each day must be available, and strict water quality maintained (**Table 4**). Nitrate must not rise above $15\,mg\,l^{-1}$ and pH fall below 8.

Additional faunal components The living rock will introduce various invertebrates. Additional species must be selected carefully and on a scientific rather than an esthetic basis. The introduction of detritus and algal feeders will probably be essential and coral eaters must be avoided. Fish species require high protein diets which will necessitate further reductions of ammonia, nitrite, and nitrate from the aquarium. The species given in **Table 6** might be considered but there are many others. Selection will depend on the inhabitants.

See also

Corals and Human Disturbance. Coral Reefs. Coral Reef and other Tropical Fisheries. Mariculture Diseases and Health. Mariculture Overview.

Further Reading

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MARICULTURE OF MEDITERRANEAN SPECIES

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Basic Requirements

Obtaining Stock for Ongrowing

The starting point of any farming operation is the acquisition of stock for rearing; these may be spat for mollusks or alevins, fry or juveniles for fish.

From the wild For the Mediterranean mussel (*Mytilus galloprovincialis*), spat is always collected from the wild, from rocky shores or shallow harbors where they are abundant. Conditions are less favorable for oyster culture; the native (flat) oyster (*Ostrea edulis*) is captured only in the Adriatic and the other remnants of natural stocks are unable to support intensive culture. Spat from Japanese (cupped) oysters (*Crassostrea gigas*) has to be imported from the Atlantic coast. Clam culture utilizes both spat from Mediterranean species (*Tapes decussatus*) and a species originating in Japan (*Tapes philippinarum*) which has spread very rapidly, especially in the Adriatic.

Juvenile marine fish such as eels (*Anguilla anguilla*), mullets (*Mugil* sp.), gilthead sea bream (*Sparus aurata*) and sea bass (*Dicentrarchus labrax*) are traditionally captured in spring in the mouths of rivers or in traps or other places in protected lagoons in Italy; these form the basis of the valliculture of the northern Adriatic, a type of extensive fish culture. In practice, elvers and yellow eels are supplied mainly from fisheries in other Mediterranean lagoons, especially in France.

Bluefin tuna (*Thunnus thynnus*) for ongrowing are taken from the spring and summer fishery for juveniles weighing a few tens of kilograms by Spanish seine netters in the western Mediterranean and Croatians in the Adriatic.

Controlled reproduction in hatcheries The transition to intensive fish culture has been made possible by the control of reproduction in sea bass and sea bream (*see* **Mariculture Overview**). In 1999 around 100 hatcheries produced 209 million sea bass fry and 242 million gilthead sea bream fry; this represents respectively a doubling and a 50% increase on production in 1997. Hatcheries are very different from the structures used for ongrowing; France exports tens of millions of juveniles to all the Mediterranean countries.

Access to Technology

As an activity, aquaculture is becoming increasingly complex with regard to the technology associated with rearing as well as the interactions with the physical and socio-economic environment. It requires more specialized training than can be obtained in the traditional workplace. Management of a hatchery, monitoring of water quality, and genetic research are examples of the new requirements for training.

The transition to cage culture took place using cages designed and manufactured for salmonid culture. Manufacturing feed granules has developed only recently in countries such as Greece.

Feeding

Mollusk culture exploits the natural production of plankton and thus follows natural changes in productivity.

The extensive valliculture systems used in northern Italy in managed protected lagoons are based on natural production improved through control of the water (fish trapped in the channels communicating with the sea, overwintering in deep areas) and input of juveniles. Production remains low ($20\,kg\,ha^{-1}\,y^{-1}$).

Intensive fish culture in cages uses pelleted protein-rich diets where fishmeal comprises 60% of the dry weight. However, bluefin tuna only consume whole fish or fresh or frozen cephalopods during ongrowing. Their conversion rate is exceptionally poor, of the order of 15–20% depending on water temperature.

Transport

The aquaculture cycle requires dependable and rapid transport to take juveniles to ongrowing facilities and, especially, to move the final production output which is generally valuable and perishable to the consumer market, and must remain chilled at all times.

For isolated sites, particularly small islands, there is always the problem that the transport of feed and various items of equipment is expensive.

Manpower Requirements

Hatcheries require a specialized and motivated workforce, as the production cycle for fry must not be interrupted. Sea sites are becoming ever more highly mechanized, even in countries such as Turkey where labor is cheap, because the volumes to be handled are increasing continuously.

Capital

Mediterranean aquaculture requires heavy investment both for setting up and for operating. It is dependent on international capital. Scandinavian, British, and Japanese interests play a considerable part, alongside local entrepreneurs.

Distinctive aspects

Favorable

Sheltered waters There are numerous large areas of sheltered water around the Mediterranean, the shoreline having been submerged and straightened out by the rapid rise in sea level following the last glaciation, 12 000 years ago. Nowadays, many bays provide big expanses of water which are both deep and sheltered (Carthagena, Toulon, La Spezia, Gaete, Naples, Trieste, Thessaloniki, etc.). These waters are productive, but are threatened by pollution.

Channels between the islands of the Dalmatian archipelago or in the Aegean Sea or the large gulfs surrounding the Hellenic peninsular (Patras, Corinth, Thessaloniki, Argolis, Evvoia, etc.), and to the north of Entail are perfectly suited to the types of aquaculture systems that benefit from a rapid turnover of water.

Above all, the input of sediment from deltas or the effects of littoral erosion have led to the build-up of sand bars forming lido-type complexes of impounded lagoons where the waters experience strong variations in salinity and high productivity because of the movements through gaps in the barriers.

High demand from local markets The Latin countries of the north-west Mediterranean and Adriatic have a culinary tradition based on the consumption

of large quantities of seafood. Markets in Spain, Mediterranean France, and Italy pay high prices for the fresh products of mollusk culture and marine fish farming.

There is also the strong seasonal demand from more than 100 million tourists who travel around all the coasts and particularly the islands of the Mediterranean, except where there are political problems.

Unfavorable

Eutrophication, toxic blooms, bacterial pollution As elsewhere in the world, Mediterranean aquaculture cannot escape problems of disease. Nodovirus has hit fish in cages and two protozoans have decimated cultured stocks of the native oyster, *Ostrea edulis*.

Harmful blooms frequently affect lagoons where shellfish are cultured and the presence of serious pathogens (cholera, salmonella) has prohibited the use of certain zones for production.

Extreme temperatures In sheltered lagoons or enclosed waters (e.g., the Bougara Sea, Tunisia), temperatures may exceed 30°C in summer, causing harmful blooms which are prejudicial to the success of aquaculture. In the north-west Mediterranean and the northern Adriatic, the water temperature in the lagoons may drop to below + 5°C and ice may develop on the surface of the lagoons. In general, thermal conditions favor the eastern Mediterranean.

Competition for space (urbanization, tourism) Littoral space is under pressure from several users; tourism, navigation, and especially the extension of industrial and urban developments. Land bases are essential for mariculture. Lack of sites is further aggravated by complex regulations which are applied rigorously. Finally, the tendency to designate large areas of wetland and similar areas of sea for nature conservation removes significant areas from the expansion of aquaculture.

Dependence on fisheries When juvenile mollusks or fish for mariculture rearing are taken from the natural environment they are supplied by fisheries. This dependence is a major risk to the effective operation of the production process. In the absence of industrial pelagic fisheries there is no fishmeal production in the Mediterranean. In order to satisfy the demand linked to the expansion of fish culture, almost all components of the feed must be imported. This places production further under external control. Substitution of plant for animal protein in the diet is becoming necessary.

Cultural limits of the markets While the culture of Roman Catholic Christianity provides for a boosted local market, the Orthodox Christian culture is far less demanding in terms of seafood products. The Muslim countries of the southern coast and the Levantine Basin do not have the monetary resources nor, significantly, a dietary tradition adapted to the products of marine aquaculture. In contrast, the Mediterranean bluefin tuna achieves high prices on the Japanese sashimi market.

Production Systems

Mollusk Culture

The oyster reared everywhere (although sometimes in small quantities) is the cupped or Japanese oyster (*Crassostrea gigas*) introduced to Europe from Japan in the 1960s to replace the Portuguese oyster (*Crassostrea angulata*), stocks of which had been drastically reduced by disease. One single major center, the Etang de Thau, produces around 12 000 tonnes each year using spat taken from the Atlantic coast.

The native mussel (*Mytilus galloprovincialis*) is reared in small quantities around the Spanish coast (Ebro Delta, Mar Menor). In contrast, in Italy annual production is between 100 000 and 130 000 tonnes; the main sites are the Gulf of Taranto and the northern and mid-Adriatic, as well as several bays in the Tyrrhenean Sea (La Spezia, Gaete, and Naples). Along the French coast, only the Etang de Thau has a production of a few thousand tonnes. In Greece, the Gulf of Thessaloniki has a production of the same order.

For around 20 years, Japanese-type long lines have been installed in the open sea off Languedoc Rousillon in waters between 15 and 35 m deep. These structures resist the forces of the sea and production can reach tens of thousands of tonnes of mussels, but is strongly limited by storms and predation by sea bream.

Oysters and mussels are always cultured in suspension on ropes either in lagoons or in the sea. The spat of oyster is captured on the Atlantic coast on various substrates and is often attached with the help of quick-setting cement on the rearing bars, as this technique yields the best results. Other farmers leave the spat to develop on the mollusc shells where they have attached; the shells are placed in nets, spaced regularly, on the rearing ropes.

Mussel spat, collected from the wild, is placed in a tubular net, which is then attached to the rearing ropes. Mussels attach themselves to the artificial

substrate with the aid of their byssus. It is therefore necessary to detach and clean the mussels once or twice during their growth.

Clams are especially abundant around the Italian Adriatic coast. The Japanese species, introduced as hatchery-reared spat at the beginning of the 1980s to seed protected areas, has spread very rapidly and invaded neighboring sectors. The density of these mollusks can reach 4000 individuals per square meter and production is around 40 000 tonnes per annum. A large part of the production is exported to Spain.

Culture of Sea Bass and Gilthead Sea Bream

Control and management of the spawning of sea bass and sea bream has made it possible to respond to the demand for high quality aquatic products that cannot be supplied on a regular basis from fisheries based on wild stocks. This production is based on hatcheries (*see* **Mariculture Overview**). Broodstock can be held in cages or in earth ponds. In such ponds, control of the photoperiod and temperature allows fertilized eggs to be obtained through almost the whole year. Larvae are reared in the same way as those of other marine fish (*see* **Marine Fish Larvae**) although sea bass can be fed on *Artemia nauplii* from first feeding; this does away with the burden of rearing rotifers in these hatcheries. The trend is towards enlargement to bring about economies of scale; some hatcheries produce 20 million juveniles each year; those producing fewer than 1–2 million juveniles per year are unlikely to be profitable.

Water is generally recycled within the hatchery to save energy and to maintain the stability of physicochemical characteristics. The quality of the water available in the natural environment determines the suitability of a site for a hatchery.

Almost all ongrowing is carried out in sea cages. All Mediterranean countries have contributed to the development and there is a tendency to move further and further east. Cages have been installed in sheltered coastal waters, but the scarcity of such sites and progress in cage technology are encouraging the development of exposed sites in the open sea. Techniques used in this type of farming resemble those used in the cage farming of salmonids. (*see* **Salmonid Farming**) and identical cages are used. These have a diameter of up to 20 m and are up to 10 m deep. Dry granular feed is used and the conversion rate is continuously improving (between 1.3 and 2).

Growth rate is determined by water temperature; in Greece a sea bass reaches a weight of 300 g in 11 months, but would take twice as long to reach the same weight on the French coast. This demonstrates the advantage of the eastern Mediterranean.

Other species, for which larval rearing is more difficult, are reared on a small scale using different techniques. These include the dentex (*Dentex dentex*), common (Couch's) sea bream (*Pagrus pagrus*) produced in mesocosms in Greece, and the greater amberjack (*Seriola dumerilii*), ongrown in Spain. Diversification of species offers the potential for increasing markets; this is becoming true for the meagre (*Argyrosomos regius*) and the red drum (*Scianops ocellatus*), and many other trials are taking place.

Ongrowing Bluefin Tuna

Japanese attempts at rearing larval bluefin tuna have not yet produced economically viable results. Mediterranean aquaculture depends on juveniles or subadults captured in the spring fishery, which are transported in nets supported by rafts to large cages where they will be kept for a few months. The towage, which must be at speeds of between 1 and 2 knots, may take several weeks.

The fish are harvested at the end of autumn and beginning of winter, before periods of low temperature and bad weather. In general, the tuna double their weight after 6–7 months of ongrowing and their flesh acquires the color and quality which puts them in demand for the Japanese sashimi market.

Regionalization

During the last 20 years, regional specialization has developed progressively, based on a balance of favorable and unfavorable factors for each of the types of mariculture.

The development of Mediterranean aquaculture production has thus been subject to an evolutionary process which has taken account not only of the major factors previously described but also conditions peculiar to each nation. This has produced contrasting situations, as decribed below.

France and Spain – Relatively Low Level of Aquaculture Development

This is due to a coincidence of relatively high levels of aquaculture development on the Atlantic coasts of both countries (mussels and fish in Galicia, mussels and oysters in the Bay of Biscay and the English Channel) and large quantities of imports supplementing regional production. Aquaculture developments remain small in size and are very spread out. One exception, demonstrating the possibilities that

exist, is the success of the ongrowing of bluefin tuna in Spain in the Bay of Carthagena, from which 6000–7000 tonnes were sold in 1999–2000, for a revenue of over US $100 000 000.

The Size of the Italian Market

In the year 2000 only one third of the market was supplied by national production, in spite of rapid increases; production of sea bass (8800 tonnes) and gilthead sea bream (6200 tonnes) have both doubled from 1997. Italy absorbs almost all of the Maltese production (600 tonnes of sea bass and 1600 tonnes of sea bream in 2000); most of this comes from stock from eastern Mediterranean hatcheries.

The 40 000 tonnes of clams produced in the Adriatic saturate the market and the excess is exported to Spain. In spite of health problems, Italian mussel culture supports an annual market of 100 000–130 000 tonnes. In addition, the upper Adriatic has preserved the tradition of exploiting the valli and the lagoons.

In 2000 the Italian aquaculture market (by value) was supplied 40% by sea bass and sea bream (200 million lire), 33% by clams (165 million lire), and 27% by mussels (135 million lire).

The Dalmatian archipelago belonging to Croatia retains a sector of high quality traditional oyster culture. However, new possibilities have opened up with the transfer of technology and finance from Croatian emigrants to south Australia who have developed the ongrowing of bluefin tuna in the Ile de Kali, using the techniques they practiced in Port Lincoln. However, biological and logistic constraints are currently holding back development. Production from the Croatian businesses in 1999 and 2000 was limited to 1000 tonnes of small tuna (20–25 kg each); these receive relatively poor prices in Japan.

The Pioneering Front for Culture of Sea Bass and Sea Bream in the Eastern Mediterranean

This has reached Greece where production has gone from 1600 tonnes in 1990 to 6000 tonnes in 1992, 18 000 tonnes in 1996, 36 000 tonnes in 1998 and 56 000 tonnes in 2000. The movement then reached neighbouring Turkey, going from 1200 tonnes in 1992 to 3500 tonnes in 1994, reaching 12 500 tonnes in 1998 and 14 000 tonnes in 2000. Cyprus has also recently developed production which reached 1500 tonnes in 2000.

As part of this conquest of space, the first Greek seafish farms were installed between 1985 and 1995 in the west, in the Ionian islands and in Arcadia (center of the Peloponese). Then, via the Gulf of Corinth, they were joined from 1990 to 1995 by an active center in Argolis (east of the Peloponese). In addition, suitable sites for cages were found in the bays behind the barrier of the Isle of Evvoia. Finally, since 1990, developments have progressed to the Aegean around the archipelagos fringing the Peloponese. Between 1995 and 2000 Greek sites appear to have become saturated and mariculture has moved to the Turkish coast and the Anatolian bays of the Aegean coast.

Perspectives and Problems

Lack of sites

The area dedicated to intensive cage mariculture remains modest: the whole of the French marine fish culture, around 6000 tonnes annual production, occupies no more than 10 ha of sea and 5 ha of land.

Pollution Ascribed to Aquaculture

It is politically correct to speak of the pollution derived from intensive cage rearing. When this alleged pollution (from fish excreting mainly nitrogen and phosphorus) is ejected into oligotrophic open waters such as the Mediterranean it can be seen as a benefit rather than a nuisance. The FAO, elsewhere, has suggested that significant increases in fish catches occur in areas where human-derived wastes have increased in the Mediterranean.

Health Limits and Shellfish

Production of mussels fluctuates widely: pollution of coastal and lagoon waters (toxic plankton and bacterial pollution) regularly prevents their sale. Regular consumption of mussels could be dangerous as the species concentrates okadaic acid (a strong carcinogen) produced by toxic phytoplankton.

Marketing Problems

Overproduction of sea bass and gilthead sea bream has led to a periodic collapse in prices. This phenomenon appears to be due to lack of planning, organization, and commercial astuteness by the producers, as well as competition between countries operating within different economic frameworks (cost of manpower). The salmon market is characterized by identical examples. For bluefin tuna, dependence on a single, distant market (the sashimi market in Japan) makes ongrowing

a risky activity but very profitable in economic terms.

Conclusions

Traditional mollusk culture maintains its position but is encountering problems of limited availability of water. Transfer out to the open sea which is less polluted has been piloted in Languedoc (France) for two decades, but has demonstrated neither the suitability of the techniques nor their profitability, and production has stagnated.

The explosive growth of the production of marine fish in cages can be said to demonstrate the true revolution in Mediterranean mariculture. This is based entirely on species with a high commercial value. This type of rearing has expanded eastwards from the European Mediterranean countries but has not yet reached the southern shore.

Markets, particularly the huge European market of 360 million inhabitants, are not yet saturated. Diversification of the species produced may open up new markets. The expansion of cage-based mariculture has not yet finished, while progress in technology is unpredictable.

The major missing element in Mediterranean aquaculture is the rearing of penaeids, in spite of several sporadic but insignificant attempts at production in Southern Italy and Morocco.

See also

Mariculture Overview. Salmonid Farming.

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MARICULTURE OVERVIEW

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Introduction

Mariculture has been defined as the cultivation, management, and harvesting of marine organisms in their natural environment (including estuarine, brackish, coastal, and offshore waters) or in enclosures such as pens, tanks, or channels. The range of organisms cultured includes seaweeds, mollusks, crustaceans, fish and, a more recent development, echinoderms. As with all forms of aquaculture, operations range from extensive to highly intensive. At one extreme, extensive mariculture is simply based on the protection of the stock to improve survival rates of wild juveniles, with few or no nutrients supplied; at the other extreme, intensive mariculture may take place in an enclosed system where all nutrients are provided by the farmer and the environment is maintained through water filtration, sterilization and oxygenation, and the control of light and temperature regimes. Other forms of mariculture include ranching, in which juveniles (notably crustaceans and salmonids) produced in a hatchery are released into the marine environment where they feed and grow in the same way as their wild equivalents. Low survival rates in ranching are set against the reduced costs in comparison with those of a full-scale farming operation.

In this article the worldwide history of mariculture is reviewed, followed by a summary of its current status and opportunities and constraints for future development. More detailed information relating to major species groups (e.g., salmonids, marine fish, crustaceans, and bivalve mollusks) can be found in other articles, as can details of environmental impacts, fish health, and social and economic aspects of mariculture.