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Molluscs and echinoderms aquaculture: biological aspects, current status, technical progress and future perspectives for the most promising species in Italy

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Abstract

Shellfish aquaculture is a widespread activ-ity in the Italian peninsula. However, only two bivalve species are mainly cultured along the coastline of that country: the Mediterranean mussel Mytilus galloprovincialis and the Manila clam Venerupis philippinarum (Ruditapes philippinarum). By contrast, just a few other mollusc species of commercial inter-est are scarcely reared at a small-scale level.

After analysing the current status of Italian shellfish production, this paper reports and discusses the potential for culturing several different invertebrate species [i.e., the European flat oyster Ostrea (O.) edulis, the grooved carpet shell Venerupis (V.) decussata (Ruditapes decussatus), the razor clams Ensis (E.) minor and Solen (S.) marginatus, the cephalopod Octopus (O.) vulgaris, and the pur-ple sea urchin Paracentrotus (P.) lividus] in this country.

In addition, a detailed overview of the progress made in aquacultural techniques for these species in the Mediterranean basin is presented, highlighting the most relevant bot-tlenecks and the way forward to shift from the experimental to the aquaculture phase. Finally, an outlook of the main economic and environ-mental benefits arising from these shellfish culture practices is also given.

Introduction

Current status of the Italian shellfish aquaculture

The Italian shellfish production amounted to 181,455 t in 2008 (FAO Fisheries and Aquaculture Department, 2011), correspon-ding to 68% of the total Italian aquaculture pro-duction and ranking Italy in the 3rd position in Europe, after France and Spain (189,070 and 185,153 t, respectively). Similarly to what hap-pens to finfish production and unlike the two best shellfish producers in Europe, shellfish aquacultural practices are very scarcely diver-sified in Italy, since the only two species pre-dominantly cultured are the Mediterranean mussel (Mytilus galloprovincialis; 123,010 t) and the Manila clam [Venerupis (V.) philip-pinarum (Ruditapes philippinarum); 58,445 t]. Only sporadic activities of rearing can be listed for other species, currently at a small-scale aquaculture level, as in the case of the oysters

Crassostrea gigas and Ostrea (O.) edulis, and the grooved carpet shell Venerupis (V.) decus-sata (Ruditapes decussatus) or still as an exper-imental aquaculture example (Modiolus barba-tus).

About molluscs culture in Italy, old traditions coexists with modern intensive farming tech-niques (Prioli, 2004). Mussel culture covers a total surface of about 20,000 ha and is realised by 263 companies that give employment to 1,400 people (Prioli, 2008). The cycle is based on the recruitment of wild spat largely avail-able in many areas (namely, Apulia, Veneto and Emilia-Romagna regions) where the grow-out plants are located. The culture of Mytilus galloprovincialis is widely diffused along the coasts of the country (i.e., Sardinia and Sicily, but not Basilicata, Calabria and Tuscany), where different kind of rearing techniques are applied. The traditional ones (fixed systems) are mostly located in sheltered coastal and in lagoon areas (gulf of Trieste, gulf of Taranto, Veneto lagoon, etc.), while the new long-lines rearing systems (single long-line ventia and Trieste or multi ventia long-line in open sea and in partially or fully sheltered areas, respec-tively) have been more and more diffused in offshore farms. The single ventia plants have been spread for 20 years and currently repre-sent around 75% of total linear metres (2,000,000) of long-line quoted in Italy. The culture of the Manila clam started in Italy in the 1980s, when 200,000 juveniles from a North European hatchery were introduced in the Venice lagoon (southern basin) (Cesari and Pellizzato, 1985). Afterwards, this species was introduced in other areas of the Po river delta [Sacca di Goro (Ferrara), Sacca del Canarin-Porto Tolle (Rovigo) and Grado-Marano lagoon (Udine)].

Currently, the Venice lagoon is the most important production site for this bivalve, where 50% of the total Italian production is realised (Zentilin et al., 2008), followed by the area of the Po river delta in Emilia Romagna region (mainly Sacca di Goro) (28% of the total production) and in Veneto region (21%). The Grado-Marano lagoon very scarcely impacts on the total production (1%). Thanks to the optimal conditions found in North Adriatic areas, this species spreads spontaneously and now the farmers move from rearing practices to management of production areas in a more or less controlled way. Manila clam culture covers a surface of about 940,000 ha and gives employment to 4000 to 5000 people (Turolla, 2008). Similarly to mussel culture, the spat is mainly collected from the wild (95% of the total utilised), but a hatchery seed production is also realised. Only two hatcheries (i.e., ALMAR and TURBOT, this last producing 10 to 50 mil-lion of clam seeds year^{-1}) are currently operat-ing in Italy, while in Europe a total of 34 mol-lusc hatcheries were recently listed (Robert, 2009).

In agreement with the EU Regulations [CE Reg. 2073/2005 (European Commission, 2005) and CE Reg. 853/2004 (European Commission, 2004)] for the marketing of shellfish, 125 cen-tres for shellfish depuration and 320 centres for shellfish shipping (20 of which are located on boats in the service of equipment) are oper-ational in Italy (Prioli, 2008).

A third cultured species is the grooved car-pet shell V. decussata, amounting to about 100 t in 2008 (FAO Fisheries and Aquaculture Department, 2011). The interest for the culti-vation of that species has significantly increased in the last years due to its higher commercial value in comparison to that of the non-native species Manila clam. Also for oys-ters, despite their high market request, the amount produced is currently negligible, which puts Italy in the first position among the or to prevent the contamination by innovative rearing systems (Serratore, 2011).

The perspectives of traditional cultures for mussels currently are: 1) a positive trend towards the settlement of new production sites along the coastline of those Italian regions offering more favourable conditions for mussel growing; 2) a marked interest for finding new simplified rearing techniques. Also in the case of the clam culture, some priorities can be list-ed for promoting further development, such as: 1) an adequate management of the lagoons where this species is cultured. Indeed, during summer there are often anoxic crises and excessive growth of seaweed due to the pecu-liar condition of eutrophy; 2) a proper manage-ment of the nursery areas, appointed to the production of the seed which is mainly obtained (95%) from the wild (Turolla, 2008).

The high consumption of shellfish associat-ed with the seasonality of the national produc-tion (mainly in the case of mussels) and the lack of diversification of production typical of the Italian shellfish aquaculture generate large volumes of imported products, as shown in Table 1. In 2011, the importing of mussels – ranking the first position among the seafood consumed in Italy – dramatically increased of 58,300 t (+50% compared to 2010) (http://www.globefish.org/bivalves-june-2012.html), partly due to the current economic crisis that has pushed consumption towards products of lower commercial value.

To give impetus to the sector, some inter-ventions on traditional species and a greater diversification of farmed species are essential. As far as the first aspect is concerned, appro-priate business strategies need to be adopted in order to maintain the functional product price and to create new market niches through appropriate techniques of processing and of storage (freezing) of the product.

At a national and regional level, some research has recently been carried out to stim-ulate the culture of new species of molluscs. Most of the results are documented in grey lit-erature and in final reports written in Italian language, and have had a very scarce impact on the international literature. althoguh much research has been carried out since the 1990s, no significant progress has been made in the Italian aquaculture landscape. As a matter of fact, for the cultured species it barely changed over the last 20 years. The main issues tackled in the studies of mollusc species which are deemed as promising for Italian aquaculture are summarised in Table 2.

In the following chapters, a detailed analysis of the most promising species for diversifica-tion of Italian shellfish culture is reported. Precisely, our attention will focus on some species that are supposed to change the land- scape of Italian aquaculture in: i) the short term, as rearing techniques are already estab-lished (cf. the oyster O. edulis and the grooved carpet shell V. decussata); or in ii) the medi-um-long term, as much research has been done or is going to develop the different phas-es of the breeding cycle [cf. the razor clams Ensis (E.) minor and Solen (S.) marginatus, and the common octopus Octopus (O.) vul-garis].

Lastly, the state of the art of the purple sea urchin Paracentrotus lividus is also given. Indeed, because of its significant marketing potential, the aquacultural activities of this species is undergoing a noteworthy improve-ment and its gonad quality is currently under-taken in many European regions.

Perspectives of Italian shellfish aquaculture

European flat oyster

Distribution, habitat and exploitation

The European flat oyster O. edulis (Linnaeus, 1758) belongs to the Ostreidae family (Rafinesque, 1815) and is native of Europe. This species naturally lives in a region going from the Norwegian fjords to Morocco (North eastern Atlantic coasts) and in the Mediterranean Sea (Jaziri, 1990) up to the Black Sea coasts (Alcaraz and Dominguez, 1985). It is also found in South-Africa, North-eastern America (from Maine to Rhode Island), Canada, Nova Scotia, New Brunswick and British Columbia, probably imported from population whose ancestors were from the Netherlands (Vercaemer et al., 2006).

Ostrea edulis is a typical filter feeder, filter-ing phytoplankton, copepod larvae, protozoans and detritus as food. Being a sessile organism, it lives fixed to a hard substrate and its feeding entirely depends on the resources naturally present in the surrounding environment. As a matter of fact, food is pumped in with the sea-water and removed by the gills (Laing et al., 2005), filtering even up to 25 l h^1 depending on animal size and temperature (Korringa, 1952). This species is typical of coastland, estuarine and marine environments and sheltered areas, preferring hard substrates as rocks or artificial structures but also muddy sand, muddy gravel with shells, and hard silt. It lives in brackish and marine seawater, having an optimum of salinity rounding between 17 and 26 PSU (Blanco et al., 1951) up to 40 metres deep.

Ostrea edulis is similar to other species of oysters widely cultivated in many regions of the world, like the Pacific cupped oyster Crassostrea gigas (Thunberg, 1793). This latter, however, has a more elongated, distorted and irregular shell and, above all, is characterised by a different sexuality. Oysters are prey of sev-eral organisms, including fish, crabs, snails, starfish and flatworms but also of boring sponges, seaworms, molluscs, pea crabs and fouling in general, that can be cause irritation problems or compete for food. With regard to disease, the protist Bonamia ostrae is one of the most dangerous pathogens: in 1920 it caused massive mortality events among flat oyster populations (Mirella da Silva et al., 2005). These populations were then reintro-duced in Europe where the disease was trans-ferred to other established populations.

Reproduction

The European flat oyster is a protandric her-maphrodite (Mirella da Silva et al., 2005) and shows an alternation of sexuality within one spawning season: early in the reproductive period it is male, but when it reaches the sex-ual maturity can alternate between the female and male stages for the rest of its life (Laing et al., 2005). Males are mature after about one year of age when they release sperms into the water depending on temperature values (with a minimum of 14 to 16 °C) (Walne, 1979). Females collect sperms by using their feeding and respiration system (Laing et al., 2005).

The oogenesis can produce up to 1 million eggs per spawning event, releasing them from the gonad and retaining them in the mantle cavity where they can be fertilised by external-ly released sperms (i.e., larviparous species). After an incubation period of about 8 to 10 days larvae develop a formed shell, a digestive sys-tem and the ciliated swimming and feeding organ (i.e., the velum) reaching about 160 m in size. At this point, they are released into the open water where they live at pelagic stage (8 to 10 days), feeding on phytoplankton for 2 to 3 weeks before settlement (Korringa, 1941, 1952; Laing et al., 2005). The amount of larvae released into the seawater is correlated to the parent size, which ranges between 1.1 and 1.5 millions for oyster from 4 to 7 years old (Walne, 1979).

By contrast, Crassostrea gigas inverts its sex after one spawning season and releases its gametes (eggs or sperms) into the environ-ment at one time or in small amounts over a long period (i.e., oviparous species). Thus, fer-tilisation occurs externally and the resulting larvae develop in the seawater.

Therefore, during the larval stage life is typ-ically planktonic and, as metamorphosis pro-gresses, oyster moves with an extensible foot in search of a suitable substrate. Once the oys-ter finds it, it attaches itself by a byssus forma-tion and then by cementation (with a physio-logical and morphological metamorphosis last-ing 3 to 4 days) and starts its sessile life as juvenile, thus becoming spat (Laing et al., 2005). From this event, the growth is quite quick for about 18 months, then it stabilises remaining constant at about 20 g of fresh weight per year and finally slows down after 5 years (Laing et al., 2005). Depending on the environmental conditions, these bivalves can achieve the marketable size of 7 cm in shell length in 4 to 5 years and live in natural beds up to 20 years growing up to 20 cm of size.

Aquacultural activities

Oyster spat can be obtained by both wild stocks and hatchery production. Like in other bivalves, sexual maturation and subsequent reproduction is obtained by modifying the tem-perature of the water (i.e., increasing it) and by administering the phytoplankton ad libi-tum, thus imitating the natural reproductive cycle. Compared to the conditioning of other species, the fertilisation of O. edulis speci-mens is more difficult due to a lower larval sur-vival rate, so that a period of incubation is nec-essary. In general, spat is cultured using tradi-tional techniques for bivalves at nursery stages and, when it reaches the size of 5-6 mm, it can be moved to open water to grow up.

On the contrary, natural spat harvesting is based on the employment of collectors. Some examples are mussel shells sown in density of about 30 to 60 m^3 ha^{-1} (the Netherlands), or tubular nets containing mussel shells (about 600) suspended under steel frames in shallow waters (France). Recently, PVC dishes are used in intertidal areas. Therefore, seed can be transferred to the growing or fattening area. Yet, this is not always necessary for the seed-ing area can also become the growing and fat-tening area in some facilities. Breeding meth-ods are generally categorised into on-bottom and off-bottom, each of them having its advan-tages and disadvantages. Thus, it should be better to choose the most suitable method for the selected site and for the specific financial possibility. On-bottom techniques require that oysters are seeded directly in subtidal or inter-tidal grounds with a stable, non-shifting bot-tom (Quayle, 1980), at a density of about 50-100 kg ha^{-1}. Seeding is generally carried out in the period between May and June, when mol-luscs are about 1 cm long (1 year old), and at that time they reach the marketable size. Traditionally, cotton nets or steel frames are used to preserve the culture from predators. The on-bottom method certainly is the sim-plest and cheapest one, but mortality, stock loss caused by predation and siltation events are highest, and even harvesting is difficult.

On the other hand, off-bottom techniques allow oysters to be cultured in suspension. This method is certainly more expensive than the first one and requires more maintenance, but it is compensated by the rapid growth and high quality of the cultured oysters. The tech-nique consists of using floating structures, rafts, long-line systems, suspended ropes, lanterns or plastic baskets pending from a raft/rope, where oysters are located in. Product is thinned out as it grows. Harvesting should be programmed when oysters are in their best conditions, with full and creamy meat. From on-bottom cultures, molluscs can be dredged or handily collected, whereas in the off-bottom ones they can be handily-picked. Finally, before marketed, they are temporarily stored in clean water and subjected to depuration procedures as all other bivalve molluscs.

Rearing in Europe

In Europe, several rearing experiments with this species have been carried out in the last decades. In particular, much attention has been paid to both survival and growth of exper-imental batches of hatchery-reared O. edulis larvae and spat (Davis and Calabrese, 1969; Laing and Millican, 1986; Spencer et al., 1986; Utting, 1988; Beiras and Pérez Camacho, 1994; Beiras et al., 1994; Berntsson et al., 1997; Rodstrom and Jonsson, 2000), and to the bio-chemical composition of larvae fed on different food regimes (Ferreiro et al., 1990; Millican and Helm, 1994).

On the other hand, a few studies have been conducted on its reproduction (Mann, 1979; Wilson and Simons, 1985; Ieropoli et al., 2005), while many growth trials were tested in differ-ent European countries like Ireland (Wilson, 1987), Germany (Pogoda et al., 2011), Croatia (Zrn i et al., 2007), Malta (Agius et al., 1978), Turkey (Yildiz et al., 2011), Spain (González and González, 1985; Pérez Camacho and Roman, 1985; Cano and Rocamora, 1996), and most of all Italy (Pellizzato and Da Ros, 1985; Lubrano Lavadera et al., 1999; Pellizzato et al., 2005; Pais et al., 2007, 2012; Carlucci et al., 2010). Nevertheless, commercial farming activities of this species are still scarce in Italy. The Pacific cupped oyster Crassostrea gigas is preferred for aquacultural purposes although in recent years this industry has experienced high mortality rates of up to 80% due to Type 1 Ostreid Herpes Virus (OsHV-1) (EFSA, 2010).

Grooved carpet shell

Distribution, habitat and exploitation

The grooved carpet shell V. decussata (Linnaeus, 1758) is a bivalve belonging to the Veneridae family (Rafinesque, 1815). This species is found all through the Mediterranean Sea, but it is widely distributed along the west-ern Atlantic coasts from Norway to Congo and also in the northern part of the Red Sea where it migrated from the Suez Canal.

This species typically lives buried in sandy and silt-muddy bottom, inhabiting the areas near and below the mean sea level (intertidal zone and subtidal zone, respectively), and buried 15 to 20 cm into the sediment. Moreover, it continuously filters surrounding water through its two siphons protruded from the substrate, picking up organic particles and phytoplanktonic cells as nourishment to allow gas exchange between oxygen and carbon dioxide that occur with breathing. Overall, clams bear quite well the variations of chemi-cal and physical variables of water, such as temperature, salinity, dissolved oxygen, turbid-ity, typical of lagoon environments or estuarine areas where they live. As a consequence, their favourite sites are generally located away from areas with high hydrodynamic, and from windy areas where the substrate where they are buried can be destabilised. Nevertheless, it is important the presence of a slight and a con-stant current that allows good water exchange and the constant flow of food. For this reason, clams can live on a variety of substrates although a mixture of sand, silt and granules is the most suitable composition which allows a good oxygenation and a comfortable softness of the bottom. It is important to emphasize that other filter feeders species (e.g. Bivalves, Hydroids, Bryozoans, Serpulids, etc.), can com-pete with a clam population for food availabili-ty. At the same time, another form of competi-tion can take place during the recruitment, depending on the availability of suitable sub-strates (Paesanti and Pellizzato, 2000; FAO, 2004).

In Europe, the harvesting of V. decussata mainly occurs in countries like Spain and France, but also in Italy, especially in Sardinia, where the semi-extensive culture of the allochthonous species Ruditapes (R.) philip-pinarum has been banned by the Regional Government in order to protect the native Mediterranean carpet clam (Chessa et al., 2005; Pais et al., 2006).

Reproduction

Even though occasional cases of hermaphro-ditism can be observed (Delgado and Pérez Camacho, 2002) especially in juvenile forms (Lucas, 1975), this clam is strictly gonochoris-tic and the reproduction takes place externally in the aqueous medium, mainly in summer when temperature is higher and food is abun-dant. Resulting larvae are freely floating for 10 to 15 days until they settle as spat (about 0.5 mm in length) and continue their growth to adult form once they found a suitable sub-strate.

Like most of other marine bivalves, V. decus-sata is characterised by a cyclical pattern of reproduction, which can be divided into differ-ent phases: gametogenesis and vitellogenesis, spawning and fertilisation, larval development and growth. Each species evolved a number of adaptive strategies (genetic or not) to coordi-nate these events with the environment in order to maximise the reproductive process (Newell et al., 1982). In this regard, numerous studies show that gametogenic cycle in marine invertebrates is strictly conditioned by the interaction between exogenous factors (i.e., temperature, salinity, light, availability of food, parasitic infestations) as well as by internal factors (Rodríguez-Moscoso and Arnaiz, 1998). Temperature is certainly one of the most important factors influencing the reproductive cycle (Sastry, 1975), defining both the starting point and the rate of gonadal development, whereas food availability can determine the extension of the reproductive process (Lubet, 1959). Exogenous and internal factors are sub-ject to natural seasonal fluctuations and their variability is closely related to the energy avail-able for growth and reproduction. In particular, clam reproduction requires abundant energy for providing a suitable gonadic development so that the success directly depends on ingest-ed food or on previously stored reserves (Delgado and Pérez Camacho, 2005). In gener-al, when food is abundant, reserves accumulated before and after gametogenesis (i.e., glyco-gen, lipid and protein) are utilised to produce gametes when metabolic demand is high (Bayne, 1976). As a consequence, gametogen-esis can differ from location to location depending on the geographic area considered: for example, in adult clams from southern Europe the cycle generally starts in March, gonads become ripe in May-June and spawn-ing occurs in summer, following a phase of inactivity in winter (Shafee and Daoudi, 1991).

Aquacultural activities

Until a few decades ago, the management of this species was exclusively related to the availability of natural seed. However, nowa-days the manipulation of its gonadal cycle is a quite common practice. In fact, artificial spawning techniques and larval rearing pro-grams have been recently developed. These methods are applied in highly specialised sys-tems – the hatcheries – where breeders (pre-viously selected from natural beds on the basis of their appearance, size and shape) are stocked into tanks for 30 to 40 days at 20°C of temperature, and richly fed with phytoplank-tonic algae. In order to guarantee the continu-ous availability of this nourishment for breed-ers and future larvae, hatcheries have to pos-sess algal culture systems.

The specimens selected are abundantly fed to maximise their gonadic maturation until they are ready to reproduction. At this phase, the release of gametes is induced by a thermal shock of the water of about 10°C (from 18 to 28°C), repeated for one or more cycles of about 30 min each. Generally, males emit before females and fertilisation occurs in small con-tainers. The eggs obtained are counted, fil-tered and placed into little aquariums (about 10 L in volume), where veliger larvae appear after 8 days. Subsequently, they are filtered through a 100 m mesh, daily fed with phyto-plankton for the first week and then every 2 days. At the pediveliger stage, clams have a diameter of about 180 to 220 m, they already have the foot but the velum is still present. Indeed, they spend most of their time swim-ming and sometimes they are fixed on the con-tainer surfaces. After about 3 weeks, the meta-morphosis process is completed and the spat stage is reached (about 250 m in size). The lit-tle mollusc can be now reared in greenhouses, fed with phytoplankton or with pumping envi-ronmental water into inland tanks, where they are placed inside small containers having a rigid mesh as bottom (i.e., nursery).

From this stage onwards, methods of farm-ing may be different depending on the features of the hatchery (e.g. standing water, constant water flow, downwelling and upwelling forced water flow). As said above, spat can be obtained both from natural populations in the vernal period (digging them with sand by a small rank and riddling it to retain the seed) and from hatcheries. When a size of about 1 mm is reached, a new phase of rearing can start using a controlled system: the so-called pre-fattening. Clams grow up to about 10 to 15 mm in 2 to 4 months and it would be conven-ient to complete their weaning period outside, pumping natural seawater or brackish water since their maintenance into the hatchery is quite difficult for both management and for economic reasons. Once they have reached this size – which vary from the preferences and the possibilities of the farmer – molluscs can be transferred to the ground (with a densi-ty of about 5000 individuals per m^{-2}) or in spe-cial facilities that allow their growth in suspen-sion, such as net bags (pôches) or stacked bas-kets (at lower density). Moreover, if they are sown directly on the substrate, it is advisable to protect the seed from predation by plastic nets. In this way, clams are able to attain a size of 20 to 25 mm in about 2 months. At this phase, management regards only the prepara-tion and maintenance of breeding substrate (i.e., cleaning and removal of algae or preda-tors) or the control of the suspension systems (i.e., attachment and clearing of encrusting organisms or fouling).

The last procedure of the production cycle is fattening, i.e., when carpet shells grow in the bottom within the sediment. In this way, mol-luscs live following their natural pattern, filter-ing water and then feeding until they achieve the commercial size of at least 25 mm in length. According to the environmental condi-tions and breeding, the fattening stage can be completed in a period of 12 to 28 months. After reaching the commercial size, clams can be gathered in different ways depending on the type of farming. When and where it is possible, fishermen manually collect the bivalves by walking using a rake equipped with an appro-priate net, whose mesh is sized to hold the molluscs and allow the escape of the sediment. Alternatively, the harvest can be made from boats (with oars or engines) furnished with an extended rake.

Rearing in Europe

During the last decades, clam aquaculture has conspicuously developed in Europe and particularly in Italy where, after its introduc-tion into the northern Adriatic lagoons, the Pacific carpet clam V. philippinarum (Adams and Reeve, 1850) has been intensively exploit ed due to its rapid growth and propagation (Paesanti and Pellizzato, 2000). On the con-trary, farming activities of the grooved carpet shell Ruditapes (R.) decussatus are still limited at present, although intensive research on the rearing of this species has been carried out throughout the continent. In particular, several studies have been conducted both on gameto-genesis (Xie and Burnell, 1994; Rodríguez-Moscoso and Arnaiz, 1998; Ojea et al., 2004; Serdar and Lok, 2009) and reproductive cycle (Breber, 1980; Beninger and Lucas, 1984; Laruelle et al., 1994; Urrutia et al., 1999; Delgado and Pérez Camacho, 2003, 2007) of this species.

Much research has been carried out also on broodstock conditioning (Ojea et al., 2008; Matias et al., 2009) and on diets for R. decussa-tus larvae (Pérez Camacho et al., 1994; Matias et al., 2011) and seed (Albentosa et al., 1996a, 1996b, 1996c, 1997, 1999; Lamela et al., 1996; Jara-Jara et al., 1997; Fernández-Reiriz et al., 1998, 1999; Pérez Camacho et al., 1998, 2007; Enes and Borges, 2003) in controlled condi-tions. Furthermore, a number of successful tri-als have demonstrated the feasibility of rear-ing this bivalve in different European coun-tries (Walne, 1976; Breber, 1985; Pastore et al., 1996) using different culture techniques in the sea as well as in coastal lagoons (Chessa et al., 1998, 2005; Pais et al., 2006; Serdar et al., 2007).

Razor clams

Only two genera of razor clams are commer-cially exploited in Europe: genus Ensis (E. arcuatus, E. minor, and E. siliqua), belonging to the Pharidae family; and genus Solen (S. marginatus), belonging to the Solenidae fami-ly. The razor clams have a high and increasing commercial value due to the high prices reached in European and international mar-kets (Barón et al., 2004). Spain, Italy, France, Portugal and the Netherlands are considered as the most important countries involved in this market. In 2004, the import value of the razor clam market within the EU25 was 550 million € (BIM, 2005). The world landings of these species are low compared with other tra-ditional shellfish species (i.e., oysters, scal-lops, or clams), and the fishing pressure on wild populations is increasing. Signs of severe exploitation of natural stocks are documented (Gaspar et al., 1998; Tuck et al., 2000; Fahy and Gaffney, 2001) also in Italy, where razor clams (E. minor and S. marginatus, a less valuable species) are widely distributed, and the quan-tity harvested from the wild is decreasing. This species is of interest for aquaculture both for improving natural stocks and for producing food. The aquaculture potential of E. arcuatus and S. marginatus has been recently assessed by a number of specific trials carried out main-ly in Spain, a country importing large quantity of this seafood (47% of the European importa-tion value, according to data obtained from Eurostat information database). The experi-ments carried out on the production of razor clam species diffused in Spain, using hatchery and semi-intensive aquaculture techniques, are deeply summarised in a recently published report (Guerra Diaz et al., 2011).

Despite interest in razor clam aquaculture, little is known about its growth and reproduc-tion, even though the studies of the cultivation of 3 razor clams (S. marginatus, E. siliqua and E. arcuatus) date back to 1990. Available litera-ture is scarce and mainly represented by docu-ments for internal use (reports, manuscripts or PhD thesis), or by posters and short presen-tations documented as short abstracts in inter-national or, more often, national meetings. The availability of these last documents is reduced also for the use of native languages other than English. Some documents are in form of grey literature, thus reducing the pos-sibility for exchanging results among researchers. Currently, no information is avail-able about the aquaculture potential of E. minor, which is located exclusively in the Mediterranean sea basin.

Reproduction, larval and post-larval rearing

In S. marginatus the spawning takes place in a few weeks during spring, in E. minor in March-April in the southern Adriatic sea, while in E. siliqua there is only one spawning period (May-June) (Guerra Diaz et al., 2011). The increase of seawater temperature during broodstock conditioning helps the maturation process in most of the species, except for E. arcuatus that is conditioned to ripeness at low temperature. In some species (S. marginatus, E. siliqua), the ripe adult can be successfully induced to spawn using thermal shock (Loosanoff and Davies, 1963; Martinez-Patiño et al., 2007; da Costa and Martinez-Patiño, 2009), while in E. arcuatus the change of water levels by simulating tides is the only effective method (da Costa et al., 2008).

The management of eggs for fecundation and of larvae during rearing can be carried out according to the same protocol utilised for other bivalve species. Larval culture duration is very short in S. marginatus (8 days), due to the high levels of stored reserves in eggs (da Costa et al., 2011b), and a larval survival rang-ing from 28 to 81% (53% on average) was recently achieved by da Costa and Martinez-Patiño (2009) in specimens obtained from adults spawned in hatchery by induction. As a consequence of the large size of eggs and the short length of the larval stage, a different pat-tern in the use of gross biochemical and fatty acid reserves during larval development com-pared to other razor clams and bivalve species was recently found (da Costa et al., 2011b). A dramatic reduction in survival was obtained by the same authors in 1-month-old spats (8.6%), the bottleneck phase resulting at the post-lar-vae age corresponding to 1 mm in length (15 to 22 day from settlement). Using seed 1.3 mm in length, da Costa and Martinez-Patiño (2009) achieved better survival when the rearing was done without substrate than when 2 types of sand were utilised. In E. arcuatus, recently da

Costa et al. (2011a) achieved the settlement of larvae on day 20, a survival from egg to newly settled postlarvae ranging between 4.8 and 24.8% (14.35% on average), and a very low (4.8%) survival from settlement (day 20) to 3-month-old spat (15.5 mm in length).

Grow-out

The effect of substrate (fine-grain sand or coarse sand, 150 to 600 or 300 to 1200 m grain diameter, respectively) in comparison to the absence of substrate was tested by da Costa et al. (2011a) in seed culture of E. arcuatus (3.76 mm in length) in nursery during a experiment lasting 30 days. No differences among treat-ments resulted for length, while the fine sand induced a lower weight and the absence of substrate a lower survival. Substrate and stock-ing density influenced the E. arcuatus juve-niles performance (length and survival), that resulted the worst at high density (36 g per a 5 l bottle) and with fine sand as substratum (vs coarse sand). The on-growing in cage buried in sand, in natural environment, from the ini-tial size of 60 to 80 mm highlighted high mor-tality and high sensitivity to changes in salini-ty. For those reasons, the choice of the site is highly affecting juveniles grow-out and per-formance.

Da Costa and Martinez-Patiño (2009) in S. marginatus broodstock from the wild managed spawning induction and fecundation, larval and spat rearing in hatchery, and assessed growth performance of juveniles produced in hatchery when transferred to natural beds. Two-year-old razor clams showed a survival ranging from 50 to 83% and after 2 to 3 years from seeding they reached the commercial size (80 mm). Since some of those specimens were utilised as broodstock, the culture cycle of S. marginatus was closed. In this species, a greater tolerance for salinity variations was found in comparison to E. arcuatus.

In experimental condition, E. arcuatus reached a length ranging from 90 to 100 mm (da Costa et al., 2011a) after two years of culti-vation, while S. marginatus reached the com-mercial size only after 3 years (da Costa and Martinez-Patiño, 2009). In E. minor, Froglia (1975) found that the size of 100 mm was reached in 2-year-old individuals. After 2 years, the growth is reduced as a consequence of the gametogenic activity both in E. arcuatus and in S. marginatus.

Critical points

Among the limiting factors for aquaculture of razor clams, the followings can be listed: short reproduction period, requirement of sub-strate and, for the on-growing phase, appropri-ate seed holding systems, low survival times in absence of soft substrate, difficulties for checking growth due to burying behaviour, need for appropriate substrate. At the moment, postlarval and seed survival obtained is very low for S. marginatus, and mainly for E. arcua-tus. For S. marginatus, low survival during the on-growing of juveniles has been also achieved. The information related to larval and postlarval nutrition and their influence on growth and survival presently is very scarce. In addition to these aspects which constitute a major bottleneck for the reproduction manage-ment, the requirement of an appropriate sub-strate for the culture process can also be envis-aged as an obstacle for promoting the develop-ment of culture in hatchery. Therefore, further investigations on the specific requirements at different stages of the development for the diverse species could improve the results and the potential for culture of razor clams.

Octopus

Statistics

The benthic octopuses of the family Octopodidae (Order: Octopodida, Leach, 1818) are one of the most familiar groups amongst the cephalopods. In this family, there are over 200 species, which range in size from pygmy taxa mature at <1 g (e.g., O. wolfi) to giant forms exceeding 100 kg (e.g., Enteroctopus dofleini). These species inhabit all marine habitats from tropical intertidal reefs to polar latitudes and in the deep sea to nearly 4000 m (Villanueva and Norman, 2008). Only a few cephalopods are commercially fished on a large scale (Kreuzer, 1984): squid (genus Loligo) is by far the main species, representing 73% of cephalopod world catches; cuttlefish (genus Sepia) is the second with 15%; and octopus the third with 8.8%. Octopus vulgaris (Cuvier, 1797; order Octopoda, suborder Incirrata) is one of the most important species in terms of commercial value and landings. Thirty-one per cent of the total production is put out by Mexico (11,855 t), which is the world leader, followed by Portugal (9,965 t; 27%), Spain (5,792 t; 16%) and Italy (3,018 t; 8%) (FAO, 2010).

Potential for aquaculture

Octopus vulgaris presents many characteris-tics: easy adaptation to captivity due to their benthic mode of life, reclusive behaviour, and low swimming activity; high growth rates (Aguado-Giménez and García García, 2002; Iglesias et al., 2006, 2007) (between 3 and 15% body weight day^{-1}); high food conversion rates (incorporating 40 to 60% of ingested food into tissue) (Mangold and Boletzky, 1973); high fecundity (producing from 100 to 500 thousand eggs per female) with well developed hatch-lings compared to other molluscs; high market size and price (García García et al., 2004) in areas where cephalopod consumption is high; and a non-geographically limited request by the markets (Berger, 2010).

The life cycle of this octopus species was carried out for the first time in captivity by Iglesias et al. (2002) using Artemia and zoeae of spider crab (Maja squinado) as live feed. The authors obtained a survival of 31.5% day^{-1} post-hatching, a weight of 0.5 to 0.6 kg in 6-month-old animals and of 1.6 kg in 8-month-old animals (Iglesias et al., 2002).

Reproduction

Octopuses are dioecious. Octopus vulgaris, as other benthic octopuses (O. mimus), pro-duces numerous small eggs (2.7 mm in length) that hatch into planktonic, free-swim-ming hatchlings (1.2 mg) very different in their morphology, physiology, ecology and behaviour compared to the adult stage. Other octopuses (i.e., O. maya, O. bimaculoides), by contrast, produce relatively few, large eggs resulting in better developed hatchlings with a benthic habit that resembles the adult (Villanueva and Norman, 2008). They readily mate in captivity and easily spawn, and females reared to the sexual maturity can pro-duce viable spawns (Iglesias et al., 2000, 2004). No further information is available about reproduction in captivity. However, reproduction is not considered as a limiting factor for this species and Iglesias et al. (2000) recommend a correct feeding of broodstock before mating and a correct management of females after eggs deposition. The optimal water conditions for broodstock (maintained at a 1:1 ratio of males and females or 1:3 ratio, according to Iglesias et al., 2007) are temperature ranging from 13 to 20°C and salinity around 32-35 PSU. Normally rectangular tanks (5 to 10 m^3), maintained with low light to obtain spawning as swiftly as possible, have been utilised (Iglesias et al., 2000; De Wolf et al., 2011) and a diet based on frozen crus-taceans (80%), fish (15%) and bivalve mol-luscs (5%) seemed to be favourable to obtain highly viable spawns (Iglesias et al., 2002). Males show a copulatory activity and egg depo-sition occurs on the walls and on the roof of den where the broodstock move. The eggs, cared for by the females, hatch after 34 days at 20±1°C, in the Mediterranean area (Villanueva, 1995), while more time is taken for hatching in captivity as the results obtained by Iglesias et al. (2000) showed.

Currently, the rearing of paralarvae is not possible, and the impossibility of obtaining benthic juveniles on a commercial scale in cap-tivity (Navarro and Villanueva, 2000, 2003; Iglesias et al., 2004, 2007) forces farmers to catch the juveniles that will be utilised in industrial on-growing from the wild. This behaviour is highly objectionable from an eth-ical point of view because it potentially increases fishing pressure on octopus stocks.

Larval rearing and feeding

Many rearing systems have been experi-mented, different for tank colour, size and shape, larval and prey densities and environ-mental factors (light, water flow and tempera-ture), resulting in different survival of paralar-vae. However, the phase of paralarvae rearing is considered inadequately explored and sur-vival of paralarvae older than 50 days post-hatch in captivity conditions is very rare, and referred only by Iglesias et al. (2002, 2004) that reared octopus until 8 months by Artemia and zoeae. In Italy, De Wolf et al. (2011) carried out many trials fom 2003 to 2007. They produced eggs and paralarvae in captivity and reared juveniles that reached the age of 160 days, by using standard aquaculture procedures for feeding (based on Artemia and rotifers as live prey) and rearing paralarvae. Currently, the most recognised opinion is that nutritional aspects are the most important factors influ-encing the performance and mortality of par-alarvae (Iglesias et al., 2007). For feeding par-alarvae different prey were experimented: Palaemon serrifer zoeae (Itami et al., 1963), Artemia (Imamura, 1990), Artemia enriched with Nannochloropsis sp. (Hamazaki et al., 1991) or Tetraselmis suecica or Chlorella sp., Liocarcinus depurator and Pagurus prideaux (Villanueva, 1994, 1995; Villanueva et al., 1995, 1996), Artemia with spider crab Maja brachy-dactyla zoeae (Moxica et al., 2002; Iglesias et al., 2004), Artemia supplemented with cope-pods or juvenile mysids. Rotifer Brachionus plicatilis too was recently tested (De Wolf et al., 2011). The survival rate largely varied with prey (species, strain, size, culture technique) and with trial, usually resulting very low after 1 or 2 months from hatching: 8.3% (Moxica et al., 2002) and 0.8 to 9% (Villanueva, 1994, 1995; Villanueva et al., 1995, 1996), respective-ly. As regards to live prey, spider crab was pre-ferred and induced better performance, proba-bly for its high content in the essential fatty acids (EFA), particularly in arachidonic acids (ARA) (Iglesias et al., 2007). A mix of Artemia, inert diet (Navarro and Villanueva, 2000), and millicapsules (Villanueva et al., 2002; Navarro and Villanueva, 2003) was also tested, thus obtaining reduced growth performance and a survival limited to first month.

Even though much research was carried out on this topic, high mortality and scarce growth performance have been obtained. At the moment, the high diversity of the experimen-tal protocol of the trials and the lack of stan-dardised methodologies do not let find the most effective diet for adequately feeding paralarvae. The low performance of this stage of culture can be also due to inappropriate tech-niques utilised during rearing. An inadequate size of tanks and the hydrodynamic behaviour of water can be responsible for mortality or damages in paralarvae arms and mantle (Rasmussen and McLean, 2004). In large vol-ume tanks, higher survival and longevity was obtained by De Wolf et al. (2011) and better growth by Sanchez et al. (2011), the larger vol-umes mitigating the fluctuations in water tem-perature and in other water parameters. A drastic reduction of survival (4 to 0.6%) was noticed when density increased from 3 to 15 ind. L^{-1} (De Wolf et al., 2011). The negative effect of high density could be explained by the releasing of paralysing substances or by the competition for space during prey location and capture. Useful information was obtained about the nutritional requirements of paralar-vae by the comparison of the chemical profiles of mature ovaries, eggs at different develop-mental stages, fresh hatchlings and wild juve-niles with the chemical profiles of paralarvae cultured for one month with different live nat-ural prey and with those of the prey adminis-tered (Navarro and Villanueva, 2000, 2003; Villanueva et al., 2002, 2004, 2009; Villanueva and Bustamante, 2006). Special attention was paid to polyunsaturated fatty acids (PUFA), especially docosahexaenoic (DHA), DHA/ eicosapentaenoic **(**EPA) ratio, phospholipids, cholesterol, to some essential amino acids (lysine, leucine and arginine representing about 50% of the total essential amino acids of paralarvae), mineral (copper) and vitamins (Vitamin A, but especially Vitamin E; Villanueva et al., 2009). The requirement of Vitamin E, which is higher than for other marine molluscs and fish larvae, is probably due to the high percentage of PUFA in paralar-val and juvenile cephalopods, that consequent-ly need of a strong antioxidant system.

Grow-out

The on-growing of octopus started in Galicia in the mid-1990s with wild sub-adults 750 g in weight. The first findings on on-growing experimental trials date at the end of the last century and have been obtained in Spain (Iglesias et al., 1997, 2000), Portugal (Sendao et al., 1998) and Italy (Cagnetta and Sublimi, 2000).

Rearing parameters

Much information on the behaviour of octo-pus, which can be usefully used for an appro-priate design of tanks and equipment for rear-ing, is obtained by observing octopus in labora-tory or directly in nature.

Even though octopus shows a rapid and easy adaptation to life in captivity (Iglesias et al., 2000) in different kinds of containers [aquar-ia, cylindrical-conical containers, raceways, floating cages and also benthic cages, as recently showed by Estefanell et al. (2012)], the habit to attach to any surface can be a problem for handling the specimen main-tained in captivity, also as a consequence of their tendency to escape from containers. To counteract the aggressive behaviour and to respect the natural habits of octopuses that prefer dark sites, inside tanks or floating cages, shelters should be put in adequate num-ber. The feeding habits and the utilisation in captivity of live food or dead whole marine organisms need frequently cleaned tanks or the utilisation of self-cleaning tanks (Vaz-Pires et al., 2004).

About water quality parameters, octopus shows a very low tolerance to low concentra-tions of salts, normally living in a range fluctu-ating from 35 to around 27 g L^{-1} (Boletzky and Hanlon, 1983). For on-growing, the tempera-ture should be kept between 10 and 20°C, and better performances are achieved at the higher temperatures in this range. Temperature above 23°C can be responsible for high mortal-ity, so that rearing in the Mediterranean area can be critical in summer months. This param-eter affects the most important zootechnical parameters (growth, food conversion and ingestion).

The results obtained by Cerezo Valverde et al. (2003) highlighted that ammonia excretion is very important in this species compared to finfish, such as sea bass or sea bream. Thus, checking this parameter during rearing is fun-damental. The same can be said for oxygen (Cerezo Valverde and García García, 2004), mainly in post-prandial period (from 6 to 16 hours after the meal ingestion), due to high consumption found in octopus. At a tempera-ture of 17 to 20°C, the optimum oxygen satura-tion resulted ranging from 100 to 65%, subop-timal saturation from 65 to 35%, dangerous below 35%, and lethal below 11% of saturation (Cerezo Valverde and García García, 2005). Octopus vulgaris showed a great resistance to hypoxia, similarly to other cephalopod species. The resistance to low oxygen levels was higher in small sized octopuses and at low tempera-ture, this parameter playing an important role by increasing the lethal oxygen value. Given the relevant changes produced in the most suitable oxygen levels, temperature variations are highly critical for octopus. For this reason the utilisation of benthic cages could reduce the abrupt changes of environmental parame-ters associated with rearing in floating cages (Estefanell et al., 2012). Males and females showed a different behaviour, the latter having greater oxygen consumption, conversely to what the same authors previously found on immature males and females (Cerezo Valverde and García García, 2004).

The separation according to sex improved culture yield, as the non-fertilised females con-tinued to grow to commercial size without interferences due to the stopping of feeding during eggs care. The rearing performance of female can be further improved by using high light intensity in order to delay the sexual mat-uration and to achieve a greater somatic growth (Iglesias et al., 2002), because egg for-mation generates higher metabolic require-ments during sexual maturation of females (O'Dor and Wells, 1978). In other experiments, differences in growth and food intake between males and female were not found (Aguado-Gimenéz and García Garcia, 2002).

In relation to the hierarchical behaviour of octopus, the influence of rearing density has been studied. Domingues et al. (2010) tested growth and survival during on-growing of octo-pus at 3 densities (4 vs 8 vs 15 kg m^{-3}) in an experiment lasting 70 days. No differences were found for growth, but a lower survival characterised the highest density group. Even though the groups showed similar feeding rates, the food conversion rates were lower in medium and high density octopuses, probably for their more stressing and uncomfortable condition. Previously, Otero et al. (1999) tested 10 and 20 kg m^{-3} as stocking density, suggest-ing a density no higher than 10 kg m^{-3} to obtain the best growth performance. A modula-tion of density in relation to water temperature (higher density at lower temperature) and to culture system (higher in cage than in tank) should be considered.

Feeding

Lee (1994) studied the feeding behaviour of cephalopods and highlighted the importance of visual stimuli, chemical and textural proper-ties of food, and nutritional quality of the diet, this last affecting the ingestion. Octopuses prefer live food, giving better performance with mixed diet than with monodiet. Cagnetta and Sublimi (2000) obtained a better growth when crabs were used in comparison to a diet based on squid or fish, even though squid sim-plify the management of tank for cleaning, due to reduced waste. In a recent paper, Estefanell et al. (2012) showed how feeding octopused on monodiet based on bogue (Boops boops) dis-carded from fish farms produced high growth (1.8 to 1.9% day^{-1}) and high survival (91 to 97%), and the best biomass increment (178 to 212%) and food conversion rates (2.3 to 2.6) ever recorded for O. vulgaris under industrial rearing conditions The species can be easily adapted to dead food (Boucaud-Camou and Boucher-Rodoni, 1983) and to commercial dehydrated foods, as pelleted diets (Lee, 1994), that can be appreciated and ingested in rela-tion to the specific texture characteristics. Different digestibility for lipids (46%) and pro-teins (96%) justifies the nutritional superiori-ty of food poorer in lipids and richer in protein that is the main source of energy in octopus (Lee, 1994; O'Dor et al., 1983). The knowledge of aminoacid composition of food could be essential for evaluating the adequacy of pro-tein to satisfy energetic requirements. Crabs are also preferred to fish for specific pre-inges-tional (size, shape, texture, flavour) and/or post-ingestional stimuli (digestibility, assimi-lation or energetic benefit) that this food can generate (Lee, 1994). The high variability of natural food tested in trials referred in differ-ent papers is responsible for the large differ-ences found in documented growth responses and for non-consistent results (Aguado-Giménez and García García, 2002).

Even if research on artificial diets for cephalopods started 2 decades ago (in the early 1990s), the lack of an appropriate artificial diet for nutritional requirements of octopus still represents a limiting factor for its fattening phase.

Quality

The shelf life of octopus is very short, even at low positive temperatures, due to high pro-tein deterioration which is responsible for an increase in nitrogen released during storage. Hurtado et al. (1999) reported a shelf life last-ing 6 to 7 days after catch at 2.5°C and Barbosa and Vaz-Pires (2003) found a shelf life of 10 days at 0°C. Different methods and different parameters have been tested for monitoring quality and quality evolution during the shelf life, based on physical, chemical, and microbi-ological analysis. A sensorial scheme based on the Quality Index Method was developed by Barbosa and Vaz-Pirez (2003). In their trail, the authors found that the rejection of octopus kept in crushed ice occurs at day 8. Several attempts were carried out to increase the shelf life by an appropriate treatment (high pres-sure, heat combined to high pressure, gamma radiation) and to improve the textural proper-ties inducing the softening of meat (Hurtado et al., 2001a, 2001b, 2001c; Sinanoglou et al., 2007). Recently, Mendes et al. (2011) tested the active packaging based on soluble CO_2 sta-bilisation (SGS) methodology to obtain ready-to-eat products. Even though no extension of shelf life was obtained, the bacteriostatic effect allowed an effective extension of the period of use by date. Besides the short shelf life, octopus shows other peculiarity as regards its quality, for example the high solubility of fibrillar protein, responsible for a considerable leaching when processing in water is per-formed, reducing nutritive value and affecting sensorial characteristics.

The edible portion of octopus is very high, compared to fish or crustaceans (80 to 85 vs 40 to 75 vs 40 to 45%) (Kreuzer, 1984). Also, its composition presents very low content in fat (0.54 to 0.94%, according to the season), where the total polyunsaturated fatty acids (PUFAn-3) range between 42 and 47% (Ozogul et al., 2008), and EPA and DHA repre-sent a high percentage of total fatty acids (Zlatanos et al., 2006; Ozogul et al., 2008).

Critical points

The high market request in the Mediterranean, Latin America and Asian coun-tries, the declining landings by fishery, the fea-tures of subadults and adults constitute excel-lent starting points for proposing octopus as a new candidate for aquaculture. Currently, the production from aquaculture is constantly increasing, even though it is still scarce (30 t).

Some reviews summarising useful informa-tion for the different steps of the octopus cycle in aquaculture conditions are available. Unfortunately, the results achieved until now are not conclusive and some bottlenecks reduce the feasibility of farming this species in a manner completely independent from the wild.

The high mortality in the paralarvae stage (Iglesias et al., 2006) and the inexistence of adequate artificial feeds for paralarvae and subadults (Domingues et al., 2005, 2006, 2007; Rosas et al., 2007; García et al., 2011) currently are the two major bottlenecks for the commer-cial aquaculture of this species (García García and García García, 2011). Evaluating the eco-nomic viability of O. vulgaris on-growing, García García et al. (2004) found that juveniles represented around 41% of total costs. Even though that incidence is highly variable depending on catches, the on-growing activity is now retained a high risk business with low profits. The success of paralarval rearing in order to achieve economic and environmental sustainability for octopus aquaculture is essential.

The management of this species in captivity (i.e., during the different steps of the culture until slaughtering) should take into account that, like other cephalopods, O. vulgaris has some behavioural characteristics (Mather, 2008) which highlight the needs for the animal welfare consideration. In UK, Canada and Australia an appropriate legislation is already at stake (Berger, 2010).

Purple sea urchin

Distribution, habitat and exploitation

The purple sea urchin Paracentrotus lividus (Echinodermata: Echinoidea) is widely distrib-uted in the Mediterranean sea and along the North-eastern Atlantic coast, from Scotland and Ireland to southern Morocco (Boudouresque and Verlaque, 2001). This sea urchin lives on rocky substrates and in sea-grass meadows, from shallow waters down to about 20 m depth. It is a species of commercial importance, with a high market demand for its roe, particularly in the Mediterranean basin (Régis et al., 1986) and more recently in other European non-Mediterranean areas (Byrne, 1990; Barnes and Crook, 2001). In the last decades, its populations have shown a wide scale decline in many European countries due to overfishing (Boudouresque and Verlaque, 2001). In Italy, the harvesting of P. lividus is a widespread activity mainly exerted in southern regions (Tortonese, 1965; Guidetti et al., 2004; Gianguzza et al., 2006; Pais et al., 2007) and, despite the fishery of this species being regu-lated by a number of decrees (i.e., fishing peri-ods, minimum size of harvestable individuals and quantity per day per fisherman), the harvesting of P. lividus is intensively practised, particularly due to high tourism demand. For this reason, shallow rocky reef populations of P.

lividus are mainly exploited by both autho-rised fishermen and poachers equipped with SCUBA, but also by occasional collectors throughout the year (Pais et al., 2012).

Reproduction

In general, Paracentrotus lividus biology has been well studied, and much research has been carried out to determine all the phases of the reproductive cycle from many European countries (Byrne, 1990; Lozano et al., 1995; Spirlet et al., 1998b; Sanchez-Espana et al., 2004; Pais et al., 2006). This Echinoid has external fertilisation and gametes are released in the water. The development of the embryo is quite fast and is a multi-phase process.

In controlled conditions, adult sea urchins are taken out from the rearing seawater (18 to 20°C) in order to obtain gametes. To do so, 0.5 to 1 mL (according to the specimen size) of a 5×10^{-1} M KCl solution are injected inside the mouth using a syringe. Afterwards, sea urchins are gently rotated putting them upside down on glass beakers containing sterilised and ultra-filtered (Millipore filters 0.22 m) (Millipore Co., Billerica, MA, USA) seawater and the gonadal products (orange-red eggs from females and white emulsion from males) are emitted from the genital pores. After cleav-age, the larval period can last differently, and metamorphosis may be delayed due to environ-mental features. In fact, the ciliary movement of the larvae can be negatively affected by sev-eral factors and, consequently, may influence their feeding ability. Generally, however, the echinopluteus stage is reached within 48 hours and if the echinoplutei are properly fed, they can undergo the metamorphosis within 3 weeks (Yokota et al., 2002). Subsequently, the newly formed juveniles can settle in the sub-strate and their benthic phase begin.

Aquacultural activities

In case of severe depletion of Paracentrotus lividus wild stocks, aquacultural practices could represent a valid alternative to fishing (Fernandez and Pergent, 1998). Actually, as several recent studies demonstrated the possi-bility of improving cultivated edible sea urchin gonadal quality (Spirlet et al., 2000; Shpigel et al., 2005), local and tourism roe market demand could be supplied by industrial appli-cations of similar techniques. Furthermore, the optimisation of P. lividus gametogenesis (Shpigel et al., 2004; Luis et al., 2005), if aimed at obtaining fertilised eggs, larvae and juve-niles, could be useful to test restocking practises in the most severely exploited areas.

As dsccribed above, P. lividus artificial reproduction is a very easy practice. In con-trast, the subsequent rearing phases are to some extent more difficult to carry out. Post-metamorphic juveniles can be fed using differ-ent algal species (Cellario and Fenaux, 1990; Grosjean et al., 1996, 1998) until their mean individual size reaches 3 to 5 mm. However, since the growth of the juveniles is not homo-geneous, sea urchins are graded regularly, and those with a diameter larger than 5 mm are transferred into pre-growing nurseries. Subsequently, the subadults (i.e., specimens whose size exceeds 10 mm, but it is below the minimum marketable size of 40 to 50 mm) are positioned in rearing baskets with all sides made out of mesh. These rearing baskets are suspended in tanks to allow a good seawater circulation around and inside them, and an effective removal of solid wastes produced by the sea urchins. In general, during the growing phase sea urchins are fed ad libitum with fresh algae (or, in alternative, with artificial diets) twice a week. The cleaning of the bas-kets and tanks is regularly done and dead spec-imens are daily removed. Furthermore, sorting of sea urchins is done to divide the batches into different size classes. During the entire production cycle, a photoperiod of 12h/12h light/dark is usually used.

Rearing in Europe

In the past decades, several studies carried out in Europe have pointed out the possibility of successfully rearing this Echinoid. Indeed, much research has been done to reproduce the entire life cycle of Paracentrotus lividus, since aquaculture techniques have the potential for production of this species for both human con-sumption and for its use as model in research in developmental biology. Therefore, a number of studies have been conducted on the feeding preferences of juvenile and adult sea urchins and, begin them herbivorous, they have focused on the use of several algal species (Le Gall, 1989; Frantzis and Grémare, 1992; Boudouresque et al., 1996; Lemée et al., 1996; Grosjean et al., 1996, 1998; Cook and Kelly, 2007a; Cook et al., 2007). On the other hand, the use of different artificial diets has been tested in trials aimed to improve gonadal qual-ity and somatic growth of the sea urchins (Fernandez, 1997; Basuyaux and Blin, 1998; Fernandez and Pergent, 1998; Spirlet et al., 1998a, 2001; Fernandez and Boudouresque, 2000; Pantazis, 2009; Fabbrocini et al., 2011). In addition, a number of polyculture systems have been tried out in small-scale rearing experiments in order to enhance the production performances of P. lividus (Schuenhoff et al., 2003; Cook and Kelly, 2007b, 2009).

At present, however, despite all the above mentioned farming experiences, no rearing activities of commercial importance are pres-ent in Europe. The only exception is represent-ed by the Dunmanus Seafood Ltd. (Durrus, Ireland), in which hatchery-reared juveniles of this species are grown to market size mainly by ranching and are then seeded to rock pools or sub-tidal areas (Kelly and Chamberlain, 2010).

Conclusions

Shellfish culture can be regarded as a posi-tive example of aquaculture activity. In partic-ular, bivalve culture can be looked at as a para-digmatic example of sustainable economy safeguarding the environment. Indeed, it is at a low trophic level, it does not require the pro-vision of feed input, it can help to reduce the level of water eutrophication, and it is suitable for integrated forms of aquaculture [i.e., inte-grated multi-trophic aquaculture (IMTA)].

Nevertheless, we cannot hide or leave out some criticism on this activity, such as the environmental consequences due to the translocation of non native species which in turn are vectors of coastwise introduction of non-indigenous species (protists, algae, macroalgae, invertebrates, etc.), the impact generated on benthic communities (when the intensiveness of the culture is very high), or due the tools utilised for harvesting (as in the case of burrowing species).

The two sides of the same coin dictate more careful choices than those made in the past. These new choices should favour the cultiva-tion of native species and avoiding the translo-cation of seed, juveniles and adults. This approach can be an economic driver, stimulat-ing the development of a complete production chain, enhancing the creation of hatchery for spat production and reducing the potential dependence from other countries for seed sup-ply. Although significant improvements could be achieved through specific actions on the species traditionally cultured, the way forward for the future is the culture of new species. The above survey, focused on the perspectives offered by some mollusc native species and the echinoderm Paracentrotus lividus, shows that we can make a virtue of necessity. This can be done thanks to research and experimentations carried out primarily in other countries that insist on the Mediterranean, but also in Italy where the transition from the experimental

trials to the effective culture could be immedi-ate for some species (i.e., flat oyster and grooved carpet shell), or less immediate but certainly feasible for other species (i.e., razor clams, octopus and purple sea urchin) for which we are still in a more or less advanced development of the whole culture process.

Therefore, if we move from theory to prac-tice, enormous economic and environmental benefits can be achieved through the creation of new activities, the demand for new jobs, an expanded product offer for the market and, simultaneously, a reduced impact on natural resources that the traditional fishery for shell-fish species of commercial importance notori-ously produces.

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Table 1. Quantity of different species of molluscs imported in Italy in 2008 (FAO, 2011).

Commodity	Quantity (t)
Frozen	
Squids (Ommastrephes sagittatus, Loligo spp.)	65,518
Octopus	50,945
Squids (Illex spp.)	21,399
Cuttlefishes	19,230
Squids nei°	8271
Cuttlefishes (Sepia officinalis, Rossia macrosoma, Sepiola rondeleti)	163
Live, fresh or chilled# (prepared or preserved)	
Mussel meat (prepared or preserved, not in airtight containers)	9279
Molluscs nei (prepared or preserved)	7627
Oysters nei	5550
Cuttlefishes and squids nei	4755
Octopus	2764
Squids nei	2760
Squids (Ommastrephes sagittatus, Loligo spp.)	1576
Other aquatic invertebrates (prepared or preserved)	1406
Cuttlefishes (other than live, fresh or chilled)	1026
European flat oyster (shucked or not)	740
Squids (other than live, fresh or chilled)	739
Octopus (dried, salted or in brine)	438
Mussel meat (prepared or preserved, in airtight containers)	373
Squids (dried, salted or in brine)	110
Total	204,669

°Not elsewhere identified, according to FAO. #Live, fresh or chilled, unless otherwise specified in brackets.

Table 2. Topics studied about several mollusc species and considered as promising for Italian aquaculture.

Scientific name	Common name	Topics	Country	References
Bolinus brandaris	Purple dye murex	Larval rearing,	Spain,	Ramón and Flos (2001)
		semi-intensive rearing	Portugal	Vasconcelos et al. (2012)
Callista chione	Smooth venus clam	Larval rearing,	Spain	Perez-Larruscain et al. (2011)
		diet and gonadal development		Martínez-Pita et al. (2011)
Donax trunculus	Wedge shell	Larval rearing under different conditions	Spain	Ruíz-Azcona et al. (1996)
		in hatchery diet and lipid composition		Martínez-Pita et al. (2012)
		of broodstock managed in hatchery		
Haliotis tuberculata	Abalone	Juvenile rearing	Spain	Viera et al. (2011)
Hexaplex trunculus	Banded murex	Hatchling and juveniles	Portugal	Vasconcelos et al. (2004)
			Tunisia	Lahbib et al. (2008)
Modiolus barbatus	Bearded horse mussel	Genetics	Italy	Libertini et al. (1996)
		Artificial reproduction	Italy	Turolla et al. (2002),
		Rearing	Italy	Barile et al. (2011)
				Turolla (1998), Rossi et al. (1998), Pellizzato et al. (1998), Prioli et al. (1998), Turolla and Rossi (1999), Rossi (2011)
Pholas dactylus	Common piddock	Artificial reproduction	Italy	Rossi (2011)
Venus verrucosa	Warty venus	Artificial reproduction	Italy	Piccinetti (2011), Rossi (2011)