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Aquaculture of *Octopus* species: present status, problems and perspectives

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Abstract
The aquaculture of *Octopus* species is currently an active field of research around the world, but economic viability is not yet achieved. Here, the current state of knowledge with respect to *Octopus* water quality and nutritional requirements, reproduction, juvenile and adult stages in culture systems, which comes mainly from just one species, *Octopus vulgaris* (Cuvier, 1797), is reviewed. Some critical considerations are addressed and new research lines are proposed.

Keywords: Paralarvae, Ongrowing, Animal welfare

Introduction

Octopuses (Order: Octopodida, Leach, 1818) are marine, cephalopod molluscs, easily identified by their eight arms. They inhabit all marine habitats ranging from tropical reefs to polar latitudes, where they are ecologically important species, being voracious, purely carnivorous predators and an important prey item, providing a good resource of protein for fish and marine mammals as well. Their life-history is characterised by short life-spans, rapid growth, reaching relatively large body sizes (average 2-3 kg) compared to other invertebrates, early maturity and little overlap in generations (Boyle and Rodhouse, 2005). Although some wholly pelagic families exist, the majority of octopuses (more than 200 species) have a benthic or bottom-dwelling life-style, belonging to just one family, the Octopodidae (Orbigny 1940), (Norman and Hochberg, 2005). It is these benthic octopuses that have probably been exploited in coastal areas around the world for more than 2 000 years, being caught by traps, hocks, spears or pots and can be considered the most traditional of all cephalopod resources. They are a very healthy food item, mainly constituted by water, protein, low fat and high proportions of polyunsaturated fatty acids (Vaz-Pires and Barbosa, 2004). Most exploited species are of the genus *Octopus* and often support artisanal, subsistence fisheries, but they are also fished recreationally as well as supporting large industrial fisheries (Roper et al. 1984), where fishing effort increased substantially over the past 50 years (Fig 1). This increase was partly due to an increased market demand and the high prices that are paid for these species, especially *Octopus vulgaris* (Boyle and Rodhouse, 2005).

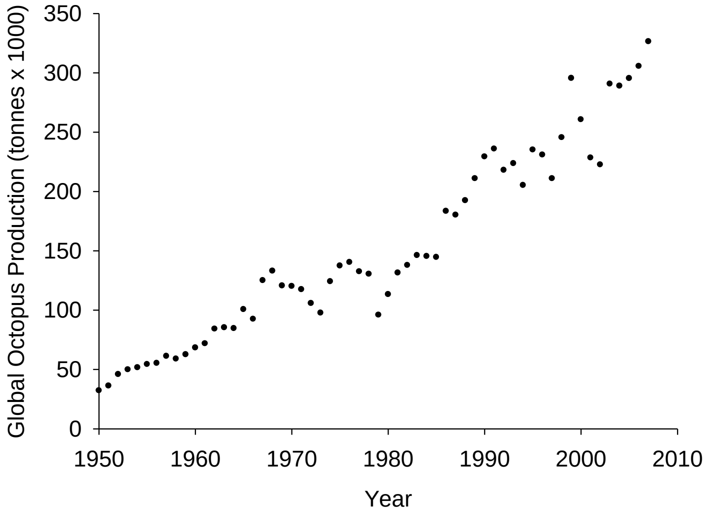

Fig 1 Global *Octopus* production from 1950 – 2007 (FAO 2009a)

Even though Octopuses are part of many traditional dishes, their consideration for aquaculture for human consumption is a very recent development. Research was initiated by northern Mediterranean countries, where the marine farming industry suffers relative market saturation for some species like sea bream (*Dicentrarchus labrax*) and sea bass (*Sparus aurata*), and the need to diversify this sector has been identified. In the 90s this led to many trial cultures with new species of which *Octopus vulgaris*, the common octopus in the Mediterranean was one of them (Vaz-Pires, 2004).

A few active research groups around the world now look at the aquaculture potential of octopuses for example *Octopus maya* and *Octopus bimaculoides* in Mexico (Rosas, 2007; Solorzano et al., 2009), *Octopus ocellatus* and *O. vulgaris* in

Japan, (even though the taxonomic status of *O. vulgaris* outside the Mediterranean and central Atlantic is unclear), (Segawa and Nomoto, 2002; Okumara et al., 2005) and *Octopus mimus* in Peru (Baltazar et al. 2000). However, to date there is no industrial aquaculture of *Octopus spp.,* defined has the rearing from hatchling through to the complete life-cycle. Only in Galicia (North-Spain) small sized *O. vulgaris* are bought from local fisherman, fattened for 3-4 months on by-catch fish, crabs and molluscs in offshore floating cages, and then sold at a higher price (Table 1).

Table 1 Global production of *Octopus spp*. from Aquaculture (FAO 2009a)

Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Quantity (tonnes)	0	3	32	32	28	15	14	8	12	16	11	27
Value (USD)	0	12	128	128	112	62	56	32	48	64	44	108

Aquaculture of *Octopus spp.*

General Overview

The principle characteristics that favoured *Octopus vulgaris* to be considered for aquaculture in the first place were the following: (1) easy adaptation to captivity, which is probably due to their benthic mode of life, reclusive behaviour, and low swimming activity (2) fast growth (between 3 and 15% body weight/day), (3) high food conversion rates, incorporating 40-60% of ingested food into tissue (Mangold and Boletzky, 1973), (4) high fecundity, producing from 100- 500 thousand eggs per female with well developed hatchlings compared to other molluscs and (5) the size and price of its market in the Mediterranean, Latin America and Asia, where cephalopod consumption is high (Table 2), (Iglesias et al., 2007).

Table 2 Top 10 cephalopod consuming countries in terms of total and per capita consumption in 2003 (FAO 2009b)

Country	**Quantity (tonnes/yr)**	**Country**	**Quantity (kg/capita/yr)**
Japan	745054	Korea	8
China	721712	Japan	5
Korea	397550	New Zealand	4
Italy	209122	Spain	4
Spain	188572	Cyprus	3
Thailand	131981	Greece	3
Mexico	86367	Italy	3
USA	80400	Portugal	3
Indonesia	65084	Malta	2
Peru	57918	Mauritius	2

Advantageous was also that rearing trials could build on experience gained in research carried out to evaluate the culture potential of *Octopus spp.* for supplying biomedical research needs (i.e. Forsythe and Hanlon, 1988) and that its biology is the most well known. Similar characteristics are valid for other octopus species, however fecundity is lower in some species as benthic octopuses either produce numerous small eggs that hatch into planktonic, free-swimming hatchlings with distinct differences in their morphology, physiology, ecology and behaviour compared to the conspecific adult such as *O. vulgaris* and *O. mimus* or relatively few, large eggs resulting in better developed hatchlings with a benthic habit that resembles the adult (i.e. *O. maya, O. bimaculoides*), (Villanueva and Norman, 2008). For the planktonic hatchlings the term paralarvae has been chosen as the transformation to the immature adult stage, when settling to the bottom and becoming benthic, is less dramatic as in other marine animals (Young and Harman, 1988). Whereas the rearing of paralarvae is not yet possible on a commercial scale, the rearing of benthic hatchlings is more successful, however here low fecundity and lack of artificial feeds are limiting economic viability (Iglesias et al., 2007; Solorzano et al., 2009).

Water requirements

The most important water quality parameters are temperature, salinity, pH, dissolved oxygen concentration, ammonia (NH_3), nitrite (NO_2^-) and nitrate (NO_3^-); the former two are likely to fluctuate in offshore culture whereas the latter parameters are more likely to cause problems in tank rearing systems (Vaz-Pires, 2004).

Octopuses are strictly marine animals with very low tolerance to low salinity; therefore proximity to freshwater inflow needs to be considered when planning an offshore installation. High salinities are clearly preferred and it should not drop below 30 ppt (Chapela et al., 2006). They are ammonotelic, with two thirds of nitrogen excreted in this form, mainly through the gills, the rest being urea with a little uric acid (Wells and Clarke, 1996), which means that the toxic ammonia and its products nitrite and nitrate need to be monitored and kept to low levels in rearing tanks (Vaz-Pires et al., 2004).

The most important factor influencing development and growth of *Octopus* is temperature (Mangold and Boletzky, 1973). Higher temperatures accelerate all aspects of reproductive biology and growth, thus lowering rearing temperature can be used for example to obtain paralarvae for a longer time period (Forsythe and Hanlon, 1988; Villanueva, 1995). At temperatures above 23°C mortality was observed in ongrowing trials with *O. vulgaris* (Aguado and García García, 2002; García García et al., 2009) and optimum temperatures between 16-21 °C for growth and food intake were suggested. This temperature range is much lower than naturally occurring temperatures in the Mediterranean (12-29°C), which would limit culture to months outside summer. However, in these studies individuals above 500g body weight were used and Miliou et al. (2005) extended the culture temperature to 25°C for smaller individuals in a study looking at the combined effects of temperature and body weight on growth and protein utilization in *O. vulgaris*. They found that maximum response for specific and absolute growth rate, feed efficiency, protein and energy retention efficiency decreased with increasing size, being 25 °C for 50-150 g octopus and 15°C for animals of 200-600 g. Only absolute feeding rate was independent of body weight and reached a maximum at 21.88°C. It was therefore suggested that closed recirculation systems with temperature control as opposed to offshore installations should be considered to increase economic viability. García

García et al. (2009) on the other hand suggested that submerged cages might be a solution to consider in future studies to overcome to problem of high temperatures in summer.

Dissolved oxygen is essential for animal respiration and depends on temperature, decreasing with increasing temperature. Oxygen consumption increases after feeding (called the specific dynamic action or SDA) and with increasing body weight and temperature (Segawa and Nomota, 2002). Cerezo Valverde and García García (2004) found a peak SDA 6-16 h whereas Petza et al., (2006) 1 h after feeding *O. vulgaris*. Based on the responses of *Octopus* to reduced dissolved oxygen Cerezo Valverde and García García (2005) established optimum oxygen saturation levels for temperatures between 17-20 °C that should be maintained, between 100% and 65% (ventilatory rate and oxygen consumption were constant). Suboptimal saturation level were established between 65% and 35% (ventilatory rate increased being energetically costly, but oxygen consumption was constant), dangerous below 35% (ventilatory rate as well as oxygen consumption changed) and lethal at saturation levels below 11% for the same temperature range. Interestingly resistance to lethal saturation levels was higher at low temperatures and in smaller animals.

Reproduction

Octopuses are dioceous, mate individually and both male and female generally die after their first breeding event. They readily mate in captivity and spawns are easily obtained, for example spawning was observed in 100% of the impregnated *O. vulgaris* females, by Iglesias et al. (2000). Female octopuses must guard their eggs throughout embryonic development, during which they stop feeding and continuously ventilate the egg mass with water flushes from the funnel. *Octopus* females that have been reared to sexual maturity produced viable spawns (i.e. Iglesias et al., 2004) and *O. maya* has been cultured for five generations in the laboratory (Hanlon and Forsythe, 1985). Information about reproducing stocks are difficult to obtain, as often only reported at conferences, but it can be concluded that reproduction is not a limiting factor for the viability of *Octopus* culture and some recommendations have been given such as to separate females once they have deposited eggs and to include crabs into the diet of the reproducing stock to obtain good quality spawns (Iglesias et al., 2000).

Paralarvae

As the rearing of paralarvae is not yet possible, industrial ongrowing of juvenile *O. vulgaris* caught from the wild is carried out in the north of Spain. However, the acquisition of juveniles from the wild renders the entire operation environmentally unsustainable, potentially increasing fishing pressure on *Octopus* stocks that are only managed poorly already, with cascading effects on ecosystems. In addition García García (2004) evaluated the economic viability of *O. vulgaris* ongrowing and found that juveniles represented around 41% of total costs. As these costs are also highly variable depending on catches, it was concluded that ongrowing is currently a high risk business with low profits. In order to achieve economic and environmental sustainability, a lot of research is directed towards paralarval rearing, but survival and growth is still poor.

There is no standardized system for paralarval rearing so far, which makes studies difficult to compare and evaluate. Different research groups have used different rearing systems with respect to tank colour, size and shape, larval and prey densities and environmental factors, such as light, water flow and temperature (Table 3), all of which could influence survival and the need to establish a standardized rearing system is clear.

However, in 2005 a meeting of scientists representing the most active research groups in this field concluded that the nutritional aspect is the most important factor influencing paralarval mortality, making research on nutritional requirements of highest priority (Iglesias et al., 2007). *Artemia* is the only prey easily available in large quantities for commercial aquaculture, but it has been shown to be suitable for the first two weeks of rearing only, leading to 100% mortality after this, despite various enrichments applied. In table 3 the multitude of different crustacean zoeae and some formulated diets that have been administered with varying success, are shown. A research group at the Institut de Ciències del Mar (CSIC) in Barcelona looked for the first time at the nutritional requirements of *O. vulgaris* paralarvae with regard to lipids, fatty acids, amino acids, essential and non-essential elements and Vitamin A and E. This was achieved by establishing “natural” profiles of those parameters by analysing mature ovaries, eggs at different developmental stages, fresh hatchlings and wild juveniles and comparing those to the ones in paralarvae cultured for one

Table 3 Comparison of survival achieved in *Octopus* paralarvae rearing trials using different methods and prey items, ordered from most to least successful

Species	**Prey species and density offered**	**Tank volume (L)**	**Paralarval density (individual/L)**	**Water System**	**Photo-period**	**Temper-ature (°C)**	**Algae added to tank**	**Best survival recorded, settlement**	**Reference**
O. vulgaris	*Artemia* (0.05-0.1/ml) and *Maja squinado* (0.01-0.1/ml)	1000	2	np	24 hL	22.5	*Chlorella sp*., Isochrysis galbana and Chaetoceros sp.	31.5% at day 40, settlement from day 40, life-cycle completed	Iglesias et al., 2004
"	*Liocarcinus depurator, Pagurus prideaux* (0.1-03 zoeae/ml) and ovaries from *Carcinus maenas* (Other food briefly trialled: mysidacean shrimp were too fast, *Euphausia sp* and *Leptomysis sp*. were rejected)	50	13	Flow rate 120l/h	24 hL	19-23	No	8.9 % at settlement at day 47, 0.8% at day 60	Villanueva, 1995
"	*Artemia* (0.2-0.5/ml) and *Maja squinado* (0.5-1.0/ml), frozen mysids (from day 40, 8-12g)	30	20-25	Tank with upwelling system	12 hL	21.1-22-2	No	3.4% at day 60, settlement from day 52	Carrasco et al., 2003, 2006
O. joubini	Wild zooplankton, zoea of penaeid shrimp, mysidacean shrimp (Vitamines added to tank)	np	500 larvae in total		np	24	No	10 % at day 7, 5 individuals became benthic at day 23, of which one survived until day 124	Fosythe and Toll, 1991
O. vulgaris	*Artemia* nauplii and metanauplii (0.1/ml) and zoeae of *Maja squinado* (0.3-0.6/ml)	9000	1	Closed system, opened for 5h/day from day 15 at flow rate of 0.9 m3/h	24 hL	25	*Isochrysis galbana,Tetraselmis suecica* and *Chaetoceros sp.*	to day 56, settlement n.a.	Moxica et al., 2002
"	Small and large type *Artemia* with and without fish flakes supplement (*Ammodytes personatus*)	4500	2.4	Closed, opened from day 5, exchange 100%/day	10 hL	24-26.9	*Chlorella sp*.	10% at day 42, settlement n.a. Best survival with "large type" *Artemia* and fish flakes	Kurihara et al., 2006
"	Enriched *Artemia,* supplemented with copepods *Acartia tonsa*, juvenile M*etamysidopsis elongata atlantica* and *Callinectes sapidus* crab zoeae	100	5 – 30	Closed (recirculation)	10 hL	20-+1	*Tetraselmis* and *Isochrysis*	39% at day 40, settlement n.a.Best survival using *A. tonsa* with *Artemia.* Mortality caused by damage to arms from constant friction against walls.	Iglesias et al., 2007

"	"large type" (from Quinghai Province in China) and "small type" *Artemia* nauplii (from Utah State of USA) (2/ml and 2.3/l depending on tank size) supplemented with fish flakes *Ammodytes personatus*	500 and 4000	3	Closed, opened from day 5, 100%/day	natural	21.2-24.8	*Chlorella sp*.	45.9 % at day 32, settlement n.a. Best survival in large tank with "large type" *Artemia*, fish flakes improved DHA content	Okumara et al., 2005
"	Enriched *Artemia* nauplii (4-7/ml) with and without essential amino acids added to rearing tanks	25	48	Semi-closed system with flow of 80l/h	24 hL	19.2-21.1	No	12.5% at day 30, settlement n.a.	Villanueva et al., 2004
"	*Artemia* and pellets with 6% moisture	25 and 70	16 and 9	Semi-closed system with flow of 120l/h	24 hL	20-22.5	No	6.7 % at day 30, settlement n.a. Paralarvae were observed to feed on pelleted diet	Navarro and Villanueva, 2000
"	Rotifers (2/ml), fish eggs (1/ml), micropellets, wild copepods (0.2/ml), *Artemia* nauplii and metanauplii (0.5/ml), *Palaemon serratus* zoeae*, Carincus maenas* (0.5/ml) and *Necora puber* (0.5/ml)	100 and 2000	10	np	24 hL	18-20	*Isochrysis galbana* and *Tetraselmis suecica*	Survived to day 32, settlement n.a. Best results with *Artemia*, on other diets paralarvae survived no longer than 8 days	Iglesias et al 2000
"	*Artemia* nauplii (10/ml) supplemented with formulated millicapsules (84-91 % moisture)	25	32	Semi-closed system with flow of 20l/h	24 hL	19.4-22.5	No	4.6% at day 30, settlement n.a Millicapsules were captured and ingested, resulted in better growth but lower survival	Villanueva et al., 2002
"	*Aremia*, Grapsus grapsus (0.015/ml) and *Plagusia depressa* zoeae	100	25	Open 25%/ day	natural	21.5-22.5	No	27% at day 28, settlement n.a. Best survival with *G. grapsus* zoeae	Iglesias et al., 2007
O. mimus	Artemia nauplii (0.5/ml)	200	50	water flow 1.5l/ min	np	21-22	*Chaetoceros sp*., Isocrysis sp. and *Dunaliella sp.*	10% at day 5,maximum survival to day 17	Baltazar et al., 2000
O. vulgaris	*Artemia, Moina salina, Maja squinada* and *Palaemon serratus* zoeae, eggs and larvae of fish (*Solea senegalensis*), pellets	50 and 200	np	open circuit and 10% daily exchange	np	21-22	No	To day 10	Morote et al., 2006

Note: np, not provided; n.a., not achieved; hL, hours light month. These parameters were also analysed in the prey used during the one month of culture and related to the cultured paralarvae. It was concluded that paralarvae require food rich in polyunsaturated fatty acids (PUFA), especially docosahexaenoic (DHA), phospholipids, cholesterol and moderate content of neutral lipids; the essential amino acids lysine, leucine and arginine play a relevant role in nutrition and paralarvae have a remarkable requirement of copper. Vitamin A content was not much different to other marine animals, but vitamin E content was relatively high, which was expected as a strong antioxidant system was assumed, because of the high amount of PUFAs in *Octopus*, which are more susceptible to oxidation at their unsaturated site than saturated lipids. Therefore, the unsuitability of *Artemia* as sole food was primarily related to its low PUFA content, where the amount of eicosapentaenoic acid (EPA) is low and DHA basically absent, its high content of neutral lipids, especially triacylglycerol (TAG), which was clearly reflected in the lipid profile of cultured paralarvae and its low copper content. However their amino acid profile was similar to the one of *Octopus* paralarvae, except for maybe histidine, and they may also provide sufficient tocopherol, even though *Artemia* fed paralarvae had gamma-tocopherol, which was absent in wild juveniles (Navarro and Villanueva, 2000, 2003; Villanueva et al., 2002, 2004, 2009; Villanueva and Bustamente, 2006). Crab zoeae generally matched biochemical requirements more closely, however obtaining decapod zoeae from parallel cultures are difficult beyond the experimental scale and more research is needed to find and culture alternative prey and develop suitable formulated diets. Viable co-feeding techniques and specific enrichments for Artemia are also an option (Iglesias et al., 2007). Seixas et al. (2008) recently suggested, based on biochemical analysis of Artemia and different microalgae that the algae *R. lens* might be a suitable enrichment. *R. lens* has not yet been used and future experiments could lead to interesting results.

Juveniles

Octopuses for experiments as well as industrial ongrowing are normally captured using pots or traps with relatively low environmental impact and survival is high using these methods (Cagnetta and Sublimi, 2000). Mortality is equally low during transport if appropriate methods as described by Iglesias et al. (2000) are used. Whether ongrowing is carried out in tanks or floating cages, it is agreed that shelters must be provided in equal numbers or in excess to the octopuses held. Not only do shelters reduce aggressive behaviour and increase growth rates, they are also important taking animal welfare into account as *Octopus* prefer dark places and actively search for and modify shelters, also called “homes” or “dens” in nature (Iglesias et al., 2000; Moltschaniwskyj et al., 2007). Aggressive behaviour and cannibalism is often encountered in ongrowing trials and has been related to high stocking densities, large differences in size between individuals and the quality of food supplied, meaning that food leading to poor growth also induced this aggressive behaviour indicating a deficiency of some nutrients (Rey-Méndez et al., 2001; García García and Cerezo Valverde, 2006). It has therefore been suggested that animals should be divided into similar sized groups, a separation which might has to be repeated after some time as variability in octopus growth is naturally high, and that the initial density should not be greater then 10 kg/m3 (Iglesias et al. 2000). However the optimal stocking density is still open to debate, as it will vary with other parameters such as tank size, water quality and temperature and higher as well as lower initial densities have been used. Clearly low densities should be preferred as octopuses are by nature solitary animals that have been observed to be more stressed and uncomfortable at high densities using more energy in activities of territorial confrontations and less for biomass production (Domingues et al., 2008).

The best results so far for *Octopus* growth have been obtained using crabs as food source, which is also an important prey in nature along with molluscs and fish. *Octopus* selectively ingest high-quality parts of their food, rejecting parts such as shell, carapace, bone and cartilage that are less digestible or nutritious. These unconsumed parts currently contribute most to organic pollution from cage culture (Mazón et al., 2007) and solutions for their removal need to be found. Protein is the primary and almost exclusive source for energy in octopods, lipids are only used for cell membrane structure, cholesterol and steroid hormones, but carbohydrates can be metabolised via an arginine phosphate-octopus pathway during short bursts of anaerobic respiration (Lee, 1994; Wells and Clarke, 1996). Despite high food conversion efficiencies, their high protein and energy requirement, is clearly environmentally problematic as marine protein is used to produce a smaller quantity of octopus higher up the food chain (Boyle and Rodhouse, 2005), however this issue is rarely addressed. Lower growth rates are achieved in *Octopus* fed on a monodiet of high lipid containing by-catch fish species such as *Sardina pilchardus* (49.7% lipid content in dry matter), *Boops boops* (29.1%), *Scomber colias, Engraulis encrasicolus* (18.4%) as opposed to low lipid monodiets of squid *Loligo vulgaris* (6.4%) or crab *Carcinus mediterraneus* (2.9-5.1%), which is generally explained by low lipid digestibility of Octopus and it has been suggested that lipids obstruct the absorption of amino acids (Pham and Isidro, 2009; Petza et al., 2006; Miliou et al., 2005; García García and Aguado Giménez, 2002). As crabs are not available as by-catch in some areas such as the Mediterranean or the Azores, García García and Cerezo Valverde (2006) experimented diets including different percentages (from 0-100%) of crab (*Carcinus mediterraneus*) and bogue (*Boops boops*) and obtained best growth at a 1:1 ratio, however, from an economic point of view a ratio of 1:3 was more favourable, as marketable size was reached only 15 days later, a longer time that was compensated by cost reduction using less crab in the diet. They suggested that, similar to what was observed in paralarvae, copper, which is found in the respiratory pigment haemocyanin of cephalopod and crustacean blood, might be a deficient nutrient. Feeding low-value natural prey in *Octopus* culture could be used for marketing this species as "biologically produced " or the like (Vaz-Pires et al., 2004), however cost considerations are currently driving research to find commercial pelleted foods, which might also reduce the use of protein. To day all formulated dry or moist diets that have been trialled in *O. maya* and *O. vulgaris* rearing, led to either negative, no or much lower growth compared to a crab diet (Aguila et al., 2007; Domingues et al., 2007; Rosas et al., 2007). However it is promising that these diets were accepted and ingested by the animals. It has been found that granulated or semi-moist feeds such as those used for fish are not suitable for O*ctopus* as they disintegrate before being consumed or fall apart during the animal handling and suitable "gummy" like texture can be achieved by agglutinating the feed components with alginate or gelatin, of which gelatin has been found to be digested better (Cerezo Valverde et al., 2008; Quintana et al., 2008; Rosas et al. 2008).

Disease problems are rarely encountered in *Octopus* culture, however increased infections of the natural pathogen *Aggregata octopina* (Protozoa: Apicomplexa) could become a limiting factor in intensive culture and more research is needed (Gestal et al., 2007).

Ethical considerations

So far animal welfare considerations that need to be addressed, when maintaining animals in captivity, have only marginally been touched. Octopuses have a well developed nervous system, display advanced behaviour, are able to learn, evaluating both visual and tactile cues to base actions upon their consideration, are very likely able to feel pain, which might be extended to include psychological suffering and they probably have a primary consciousness (Mather, 2008). This suggests that welfare legislations for these animals are needed. However *Octopus spp.* are not included in welfare guidelines in most countries and such legislation is only in place in the UK, Canada, Australia and for some research institutes in certain states in the USA (Moltschaniwskyj et al., 2007). Research looking at appropriate culture conditions for animal well-being, which might include behavioural enrichment, is needed to develop appropriate standards, especially if commercial aquaculture is to be carried out in future.

Conclusions

Economic viability is not yet achieved, but there is "no reason not to believe that the aquacultural rearing of octopus will be of great economic potential" as soon as artificial diets and the necessary technology for rearing systems have been developed, all of whose research is promising (García García, 2004). In the case of *Octopus vulgaris* it will be particularly important to achieve better survival of paralarvae in the future. It can positively be noted that all rearing trials are currently carried out with endemic species of the respective countries, which is likely to remain so in order to avoid the risk of potentially adverse effects deriving from introduced species. However, other environmental, ecological and ethical concerns remain and new research lines looking into organic pollution from octopus culture, whether the ecological inefficiency of their high protein requirement is acceptable and their welfare, also including pathologies, in culture conditions are needed.

References

Aguado, F., García García, B., 2002. Growth and food intake models in *Octopus vulgaris*, Cuvier (1797): influence of body weight, temperature, sex and diet. Aquaculture International 10, 361– 377.

Aguila, J., Cuzon, G., Pascual, C., Domingues, P.M., Gaxiola, G., Sánchez, A., Maldonado, T., Rosas, C., 2007. The effects of fish hydrolysate (CPSP) level on Octopus maya (Vossand Solis) diet: Digestive enzyme activity, blood metabolites, and energy balance. Aquaculture 273, 641–655.

Baltazar, P., Rodríguez, P., Rivera, W., Valdivieso, V., 2000. Cultivo experimental de O*ctopus mimus*, Gould 1852 en perú. Revista Peruana de Biología 7, 151–160.

Boyle, P.R., Rodhouse, P.G., 2005. Cephalopods: ecology and fisheries. Oxford, Blackwell Science.

Cagnetta, P., Sublimi, A., 2000. Productive performance of the common octopus (*Octopus vulgaris* C.) when fed on a monodiet. Recent Advances in Mediterranean Aquaculture Finfish Species Diversification. Cahiers Options Méditerranéennes 47, 331–336.

Carrasco, J.F., Arronte, J.C., Rodríguez, C., 2006. Paralarval rearing of the common octopus, Octopus vulgaris (Cuvier). Aquaculture Research 37, 1601–1605.

Carrasco, J.F., Rodríguez, C., Rodríguez, M., 2003. Cultivo intensivo de paralarvas de pulpo (Octopus vulgaris, Cuvier) utilizando como base de la alimentación zoeas vivas de crustáceos. Libro de Resúmenes. IX Congreso Nacional de Acuicultura, Mayo 2003, Cádiz, Spain, pp. 255–256.

Cerezo Valverde, J., García García, B., 2004. Influence of body weight and temperature on post-prandial oxygen consumption of common octopus (Octopus vulgaris). Aquaculture 233, 599–613.

Cerezo Valverde, J., García García, B., 2005. Suitable dissolved oxygen for common octopus (Octopus vulgaris, cuvier, 1797) at different weights and temperatures: analysis of respiratory behaviour. Aquaculture 244, 303-314.

Cerezo Valverde, J., Hernández, M., Aguado-Giménez, F., García García, B., 2008. Growth, feed efficiency and condition of common octopus (*Octopus vulgaris*) fed on two formulated moist diets. Aquaculture 275, 266–273.

Chapela, A., Gonzalez, A.F., Dawe, E. G., Rocha, F.J., Guerra, A., 2006. Growth of common octopus (*Octopus vulgaris*) in cages suspended from rafts. Scientia Marina 70, 121-129.

Domingues, P., Garcia, S., Garrido, D., 2008. Effects of three culture densities on growth and survival of *Octopus vulgaris* (Cuvier, 1797) Aquaculture International

FAO, 2009a. Global Production Statistics, 1950 - 2007. Available from internet: http://www.fao.org/fishery/statistics/global-production. Accessed: 08 November 2009.

FAO, 2009b. FAO Fisheries Circulars no. 821. Fish and Fishery products - World Apparent Consumption Statistics based on Food Balance Sheets (1961-). Available from internet: http://www.fao.org/fishery/statistics/global-consumption/en. Accessed: 08 November 2009.

Forsythe, J.W, Hanlon, R.T., 1988. Effect of temperature on laboratory growth, reproduction and life span of *Octopus bimaculoides*. Marine Biology 98, 369-379.

García García, B., Aguado Giménez, F., 2002. Influence of diet on ongrowing and nutrient utilization in the common octopus (*Octopus vulgaris*). Aquaculture 211, 171 – 182.

García García, B., Cerezo Valverde, J., 2006. Optimal proportions of crabs and fish in diet for common octopus (Octopus vulgaris) ongrowing. Aquaculture 253, 502–511.

García García, B., Cerezo Valverde, J., Aguado Giménez, F., García García, J., Hernández, M.D., 2009. Growth and mortality of common octopus Octopus vulgaris reared at different stocking densities in Mediterranean offshore cages. Aquaculture Research 40, 1202-1212.

García García, J., Rodrquez, L.M. and García García, B., 2004. Cost analysis of octopus ongrowing installation in Galicia. Spanish Journal of Agricultural Research 2, 531-537.

Gestal, C., Guerra, A., and Pascual, S. 2007. Aggregata octopiana (Protista: Apicomplexa): a dangerous pathogen during commercial *Octopus vulgaris* ongrowing. – ICES Journal of Marine Science, 64, 1743 – 1748.

Iglesias, J., Otero, J.J., Moxica, C., Fuentes, L., Sánchez, F.J., 2004. The completed life cycle of the octopus (*Octopus vulgaris*, Cuvier) under culture conditions: paralarval rearing using Artemia and zoeae, and first data on juvenile growth up to 8 months of age. Aquaculture International 12, 481–487.

Iglesias, J., Sánchez, F.J., Bersano, J.G.F., Carrasco, J.F., Dhont, J., Fuentes, L., Linares, F., Munoz, J.L., Okumura, S., Roo, J., van der Meeren, T., Vidal, E.A.G., Villanueva, R., 2007. Rearing of Octopus vulgaris paralarvae: present status, bottlenecks and trends. Aquaculture 266, 115.

Iglesias, J., Sánchez, F.J., Otero, J.J., Moxica, C., 2000. Culture of octopus (*Octopus vulgaris*, Cuvier). Present knowledge, problems and perspectives. Cahiers Options Méditerranéennes 47, 313–321.

Kurihara, A., Okumura, S., Iwamoto, A., Takeuchi, T. 2006. Feeding pacific sand eel enhances DhA level in common octopus paralarvae. Aquaculture Science 54, 413–420.

Lee, P.G., 1994. Nutrition of cephalopods: fuelling the system. Marine and Freshwater Behaviour and Physiology 25, 35–51.

Mangold, K., Boletzky von, S., 1973. New Data on Reproductive Biology and Growth of *Octopus vulgaris.* Marine Biology 19, 7-12.

Mather, J.A., 2008. Cephalopod consciousness: Behavioural evidence. Consciousness and Cognition 17, 37–48

Mazón, M.J., Piedecausa, M.A., Hernández, M.D., García García, B., 2007. Evaluation of environmental nitrogen and phosphorus contributions as a result of intensive ongrowing of common octopus (Octopus vulgaris). Aquaculture 266, 226 – 235.

Miliou, H., Fintikaki, M., Kountouris, T., Verriopoulos, G., 2005. Combined effects of temperature and body weight on growth and protein utilization of the common octopus, *Octopus vulgaris*. Aquaculture 249, 245– 256.

Moltschaniwskyj, N.A., Hall, K., Lipinski, M.R., Marian, J.E.A.R., Nishiguchi, M., Sakai, M., Shulman, D.J., Sinclair B., Sinn D.L., Staudinger, M., Van Gelderen, R., Villanueva, R., Warnke , K., 2007. Ethical and welfare considerations when using cephalopods as experimental animals. Reviews in Fish Biology and Fisheries 17, 455–476.

Morote, E., Rodríguez, M., Mancera, J.M., Moyano, F.J., Muñoz, J.l. 2005. Las enzimas digestivas como indicadores del estado nutricional en paralarvas de pulpo *Octopus vulgaris* cuvier, 1797. Boletín del Instituto Español de Oceanografía 21, 177–186.

Moxica, C., Linares, F., Otero, J.J., Iglesias, J., Sánchez, F.J., 2002. Cultivo intensivo de pararlarvas de pulpo, Octopus vulgaris Cuvier, 1797, en tanques de 9 m3. Boletín del Instituto Español de Oceanografía 18 (1–4), 31–36.

Navarro, J.C., Villanueva, R., 2000. Lipid and fatty acid composition of early stages of cephalopods: an approach to their lipid Requirements. Aquaculture, 183,161 – 177.

Navarro, J.C., Villanueva, R., 2003. The fatty acid composition of Octopus vulgaris paralarvae reared with live and inert food: deviation from their natural fatty acid profile. Aquaculture 219, 613–631.

Norman, M.D., Hochberg, F.G., 2005. The current state of Octopus taxonomy. Phuket Marine Biological Center Research Bulletin 66, 127–154.

Okumura, S., Kurihara, A., Iwamoto, A., Takeuchi, T., 2005. Improved survival and growth in Octopus vulgaris paralarvae by feeding large type Artemia and Pacific sand eel, Ammodytes personatus. Aquaculture 244, 144–157.

Petza, D.,Katsanevakis, S., Verriopoulos, G., 2006. Experimental evaluation of the energy balance in *Octopus vulgaris,* fed ad libitumon a high-lipid diet. Marine Biology 148, 827–832.

Pham, C.K., Isidro, E., 2009. Growth and mortality of common octopus (*Octopus vulgaris*) fed a monospecific fish diet. Journal of Shellfish Research 28, 617–623.

Quintana, D., Domingues, P., García, S., 2008. Effect of two artificial wet diets agglutinated with gelatin on feed and growth performance of common octopus (*Octopus vulgaris*) sub-adults. Aquaculture 280, 161–164.

Rey-Méndez, M., Tuñón, E.G., Amor, R., 2001. Estudio comparativa del tipo de jaula y disposición de refugios sobre la mortalidad en el engorde industrial del pulpo (Octopus vulgaris, Cuvier. 1797).IX congreso latinamericano sobre ciencias del mar, Resumen Ampliado.

Roper, C.F.E., Sweeney, M.J., Nauen, C.E., FAO 1984 species catalogue. Vol. 3. Cephalopods of the world. An annotated and illustrated catalogue of species of interest to fisheries. FAO Fisheries Synopsis, 125.

Rosas, C., 2007. The effects of fish hydrolysate (CPSP) level on Octopus maya (Voss and Solis) diet: Digestive enzyme activity, blood metabolites, and energy balance. Aquaculture 273, 641 – 655.

Rosas, C., Cuzon, G., Pascual, C., Gaxiola, G., Chay, Lòpez, N., Maldonado, T., Domingues, P.M., 2007. Energy balance of Octopus maya fed crab or an artificial diet. Marine Biology 152, 371–381.

Rosas, C., Tut, J., Baeza, J., Sánchez, A., Sosa, V., Pascual, C., Arena, L., Domingues, P.M., Cuzon, G., 2008. Effect of type of binder on growth, digestibility and energy balance of Octopus maya. Aquaculture 275, 291–298.

Segawa, S., Nomoto, A., 2002. Laboratory growth, feeding, oxygen consumption and ammonia excretion of Octopus ocellatus. Bulletin of Marine Science 71, 801–813,

Seixas, P., Rey-Méndez, M., Valente, L.M.P., Otero, A., 2008. Producing juvenile Artemia as prey for *Octopus vulgaris* paralarvae with different microalgal species of controlled biochemical composition. Aquaculture 283, 83–91.

Solorzano, Y., Viana, M.T., López, L.Mc, Correa, J.G.,True, C.C., Rosas, C., 2009. Response of newly hatched *Octopus bimaculoides* fed enriched *Artemia salina*: Growth performance, ontogeny of the digestive enzyme and tissue amino acid content. Aquaculture 289, 84–90.

Vaz-Pires, P., Barbosa, A., 2004. Sensory, microbiological, physical and nutritional properties of iced whole common octopus (*Octopus vulgaris*). Lebensmittel-Wissenschaft und Technologie 37, 105–114.

Vaz-Pires, P., Seixas, P., Barbosa, A., 2004. Aquaculture potential of the common octopus (*Octopus vulgaris Cuvier*, 1797): a review. Aquaculture 238 (1–4), 221–238.

Villanueva, R., 1994. Decapod crab zoeae as food for rearing cephalopod paralarvae. Aquaculture 128, 143–152.

Villanueva, R., 1995. Experimental rearing and growth of planktonic *Octopus vulgaris* from hatching to settlement. Canadian Journal of Fisheries and Aquatic Sciences 52, 2639–2650.

Villanueva, R., Bustamante, p. 2006. Composition in essential and non-essential elements of early stages of cephalopods and dietary effects on the elemental profiles of *Octopus vulgaris* paralarvae. Aquaculture 261, 225–240.

Villanueva, R., Escudero, J.M., Deulofeu, R., Bozzano, A., Casoliva, C., 2009. Vitamin A and E content in early stages of cephalopods and their dietary effects in *Octopus vulgaris* paralarvae. Aquaculture 286, 277-282.

Villanueva, R., Koueta, N., Riba, J., Boucaud-camou, E., 2002. Growth and proteolytic activity of *Octopus vulgaris* paralarvae with different food rations during first-feeding, using Artemia nauplii and compound diets. Aquaculture 205, 269–286.

Villanueva, R., Norman, M.D., 2008. Biology of the planktonic stages of benthic octopuses. Oceanography and Marine Biology: An Annual Review, 46, 105-202.

Villanueva, R., Riba, J., Ruiz-capillas, C., González, A.V., Baeta, M. 2004. Amino acid composition of early stages of cephalopods and effect of amino acid dietary treatments on *Octopus vulgaris* paralarvae. Aquaculture 242, 455–478.

Wells, MJ, Clarke, A., 1996. Energetics, the cost of living and reproducing for an individual cephalopod. Phil Trans R Soc Lond B 351, 1083–1104.

Young, R.E., Harman, R.F., 1988. “larva”, “paralarva” and “subadult” in cephalopod terminology. Malacologia 29, 201–207.