Common octopus aquaculture in Tenerife (Canary Islands, Spain): outlook and challenges

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The common octopus *Octopus vulgaris* is a good candidate for aquaculture because it meets many of the criteria for intensive aquaculture, such as having a short life cycle and rapid growth (Iglesias *et al*. 2000), ready adaptation to captive conditions (Boyle and Rodhouse 2005), high feed efficiency, high reproductive rate (Mangold and Boletzky 1973) and elevated nutritional value and market price.

Octopus culture is currently limited to on-growing of sub-adult individuals captured from the wild (Prato *et al*. 2010), although great effort has recently been made to rear *O. vulgaris* paralarvae. High mortality rates and poor paralarval growth resulting from nutritional imbalances have been identified as the main bottlenecks for aquaculture of this species (Navarro and Villanueva 2000). Because of high metabolic rate, rapid growth and limited nutritional reserves, octopus paralarvae must find enough energetic substrates with essential nutrients at early life stages.

At present, only limited information regarding the nutritional requirements of octopus paralarvae is available. This information is necessary to develop feeds, including different types of live prey, enriched *Artemia* and inert commercial diets.

The aim of this article is to summarize the state-of-the-art knowledge of common octopus paralarvae culture, identifying current bottlenecks and emphasising relevant research areas being developed to overcome existing problems, and to promote the high potential of common octopus commercial production at facilities of the Oceanographic Centre of the Canary Islands (COC). The COC is part of the Spanish Institute of Oceanography, which has an Experimental Marine Culture Unit that has been exclusively dedicated to aquaculture research since 1980.

FIGURE 1. *General view of facilities of the Oceanographic Institute of the Canary Islands (COC).*

Facilities

Experimental facilities (Fig. 1) include hatchery, nursery, on-growing area and rearing tanks, allowing the conduct of large-scale experiments and investigation of species at different stages of development. In addition, fully equipped laboratories make it possible to undertake studies in nutrition, physiology, histology, reproductive performance, feeding behavior and genetics of marine fish and cephalopods. Research on common octopus aquaculture began in 2000 and, since then, multiple research projects have been funded and scientific articles and national and international congress communications have been presented. This has resulted in a body of knowledge and expertise on paralarvae culture and a direct acquaintance with related problems, including the high mortalities and the pace of developmental events connected to the quality and quantity of food (Fig. 2).

Systems for Octopus Paralarvae Culture

A standardized protocol for common octopus rearing has not yet been developed, giving rise to high variability in the zootechnical conditions used in previous studies undertaken at the COC and other facilities. In experimental facilities of the COC, the first approach to optimizing paralarval culture conditions (12L:12D photoperiod, 21.0 ± 0.7 ºC water temperature and 36.8 ± 0.1 PSU salinity) was carried out in 100-L tanks (Fig. 3). Usually the duration of these experiments was 15 days and samples were collected for biometry, survival and/or biochemical composition determination.

TOP LEFT, FIGURE 2. *Culture facilities at Oceanographic Centre of the Canary Islands (COC).*

TOP RIGHT, FIGURE 3. *Tanks (100 L) for rearing common octopus paralarvae.*

BOTTOM LEFT, FIGURE 4. Artemia *culture tanks.*

BOTTOM RIGHT, FIGURE 5. Grapsus adscensionis *culture tanks.*

The best paralarvae performance has been achieved in tanks of 500-1,000 L (De Wolf *et al*. 2011, Sánchez *et al*. 2011). A second line of work has applied the best results obtained from 100-L tanks to 500-L tanks, because larger volumes allow better growth and longer-term experiments, until settlement in the best case.

Rearing of octopus paralarvae is currently being carried out at the COC using flow-through systems with filtration consisting of three inline mesh filters and ultraviolet disinfection. Tanks are under a light regime of 150-200 lux with 6500 K normal white fluorescent light, and a photoperiod of 12L:12D in black tanks. To improve survival, paralarvae density has been reduced to 3-5 individuals/L with moderate (lateral) aeration.

Paralarval Nutrition

Artemia enrichment. Poor performance, inconsistent growth and a lack of settlement has been obtained when *Artemia* is used as prey for octopus paralarvae. These adverse results could be explained by an imbalanced nutrient profile that does not meet paralarvae needs, and a relatively small size (0.45 mm total length) of *Artemia* nauplii that is not suitable for paralarvae greater than 15 days old.

Paralarvae feeding experiments with *Artemia* have been undertaken recently using *Artemia* juveniles (1.5-2 mm long) with phytoplankton (Iglesias *et al*. 2006). New *Artemia* enrichment protocols are being developed based on the use of liposomes to enhance dietary lipid components (Fig. 4).

Inert diets. An artificial microdiet eliminates costs related to logistics, management and cultivation of live prey, while allowing better control of the feed nutritional content. However, preliminary experiences using microdiets were not promising, probably related to acceptability, palatability, floating/sinking, loss of nutrients and/or manufacturing processes (Domingues *et al*. 2001). Current research focuses on the development of inert diets using different raw materials and binding agents that produces a water-stable diet, reduces waste and improves management efficiency.

Alternative Live Prey Species. Decapod crustacean larvae are probably one of the main natural prey of planktonic common octopus paralarvae (Roura *et al*. 2010) and most successful long-term rearing trials in the laboratory have been obtained when crustacean larvae are the primary prey (Villanueva and Norman 2008), resulting in the best survival and settlement rates (Iglesias *et al*. 2007). Decapod larvae have several advantages compared to other live prey, including good acceptability and appropriate nutrient profile. However, several problems have arisen from its use, such as the need for a parallel culture, infeasibility at commercial scale and increased culture cost.

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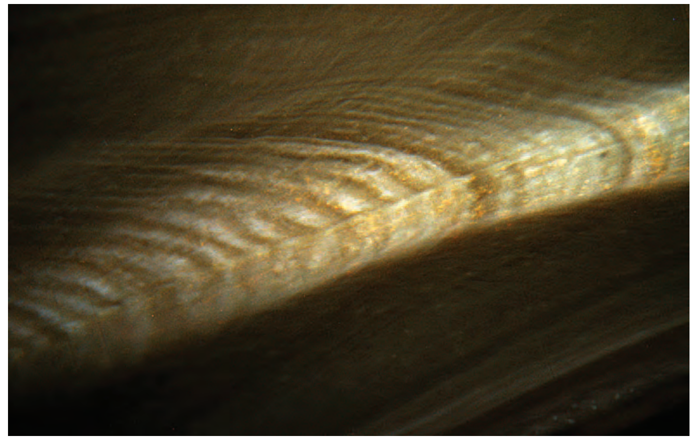

LEFT, FIGURE 6. *Offshore octopus cage used in pilot study in the Canary Islands.* RIGHT, FIGURE 7. *Daily increments and two stress checks (darker increments to the right) in a sagittal section of* Octopus vulgaris *beak (200x).*

The most successful studies have used decapod crustacean zoeae ranging from 0.01 to 1 zoea/mL (Iglesias *et al*. 2002), with a size representing 50-100 percent of paralarvae mantle length (Villanueva 1994) and large (>100-L) tanks (De Wolf *et al*. 2011).

Based on the search for appropriate logistical (accessibility and low cost) and zootechnical methodology (high fertility rate and easy rearing in captivity), new benthic prey have been tested recently, emphasizing mysids (*Gastrosaccus roscoffensis*), grass shrimp zoea (*Palaemon elegans*), eggs and zoea of the pandalid shrimp (*Pleisonika narval*), sea urchin larvae (*Diadema* aff. *antillarum*) and rock crab zoea (*Grapsus adcensionis*) (Fig. 5).

Best results have been obtained with rock crab zoea, with 2.5 percent survival at 77 days of culture and one 10-g juvenile of 223 days old. Specific growth (5 percent) was less than values previously reported (7-9 percent) by Iglesias *et al*. (2004) but similar to those reported by De Wolf *et al*. (2011).

Lipid Metabolism. Poor growth and high mortality observed during the planktonic stage of common octopus rearing seems to be associated with a nutritional imbalance in the lipid profile (Navarro and Villanueva 2000, 2003, Villanueva *et al*. 2004, Iglesias *et al*. 2007, Seixas *et al*. 2010). Therefore, it is essential to determine the metabolic needs of paralarvae for the success of commercial-scale octopus aquaculture. Assays are presently being performed using ^{14}C-labelled fatty acids. In addition, similar research activities are being conducted with the main prey items (*Artemia* and *G. adscensionis*) used in octopus paralarvae culture.

Stress Biomarkers

Cultured paralarvae have a high sensitivity to handling, which may cause massive mortalities. Therefore, it is necessary to define and establish biomarkers that can help to further explore the requirements for successful rearing of these organisms. Biomarkers for the detection and quantification of stress are being selected to improve the rearing conditions of common octopus.

Grow-out in Sea Cages

Commercial-scale aquaculture of common octopus is currently restricted to grow-out of wild juveniles in cages. The lack of sheltered sea areas in the Canary Archipelago forced the design of a rearing system to meet the demanding conditions of the offshore environment. A pilot offshore cage platform with a capacity of 1.5 t was designed for the implementation of experimental trials (Fig. 6). Individuals were fed a diet of minced low-value fish and kept at a maximum density of 18 kg/m^3. Grow-out tests in these cages resulted in good growth, survival and easy handling.

Fisheries Management

Age validation in common octopus beaks. As with other harvested species, age and growth determination is critical to understanding common octopus life history and to model the dynamics of wild populations for sustainable management. The identification and interpretation of growth increments in calcified structures can be used for exploited species of cephalopods (Fig. 7). Validation studies of the periodic deposition in hard structures of common octopus are as yet incomplete without known-age individuals; daily deposition has been confirmed only in some sizes (Canali *et al*. 2011). Laboratory experiments of chemical and environmental marking in wild specimens of all sizes have been conducted to confirm the daily deposition of beak increments across the age range of the species. It has also been used to age individuals of known age from paralarvae to adult.

Beaks as stress biomarkers. The study of beak increment validation has highlighted the value of this structure as life recorders by observing environmental or biological stress marks (checks or stress increments) in the microstructure of beak sagittal sections, making it possible to detect stressful events during the lifetime of the animal. Therefore, stress marks in the beak microstructure could be a tool to assess stress related to handling and other events.

Animal Welfare

The European Directive 2010/63/EU for the protection of animals used for experimentation and other scientific purposes includes, for the first time, breeding of and experimenting with cephalopods in aquaculture research, inasmuch as there is scientific evidence of their ability to experience pain, suffering, distress and lasting harm. This directive promotes the identification and development of suitable methods of anaesthesia, analgesia and euthanasia. All experimental planning and design of culture facilities at the COC, including those involving octopus, are undertaken according to the baseline described in the directive. Thus, in the quest for new methods to avoid pain and suffering in cephalopods, one of the research lines is to optimize the anaesthesia and euthanasia methodology employed in common octopus by testing different anaesthetics, such as cold water, clove oil, $MgCl_2$ or ethanol (Perales-Raya *et al*. 2010).

Future Goals

- Identification of factors affecting the spawning quality (mainly female conditions and water temperature) to reduce the high variability among spawns.
- Improvement of knowledge on digestive physiology, absorption and nutrient metabolism to design suitable diets.
- Better understanding of behavior and physiology of wild paralarvae to better adapt the culture conditions and diet design.
- Study the physiological mechanisms related to stress and select biomarkers to detect and quantify stress in paralarvae.
- Perform beak analysis in paralarvae and identify the most stressful events across the paralarval stage to understand the causes of low survival of octopus paralarvae and the reasons for prevention of the settlement stage in captivity.

Notes

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