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RESEARCH ARTICLE

The floating upwelling system (FLUPSY) for breeding of *Venerupis decussata* (Linnaeus, 1758) juveniles in a coastal lagoon in Sardinia (Italy)

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Abstract

1 - In recent years, interest in farming the grooved carpet shell *Venerupis decussata* (Linnaeus, 1758) in Sardinian lagoons has greatly increased due to a decrease in clam populations. Aquaculturists around the world have developed a variety of different clam farming systems, notably for the Manila clam, *Venerupis philippinarum* (Adams & Reeve, 1850).

2 - The aim was to test the aquaculture of *V. decussata* using the FLoating UPwelling SYstem (FLUPSY) to evaluate their growth rate over two seasons: spring 2011 (from 10 March, 2011, to 21 May, 2011), and autumn 2011 (from 18 October, 2011, to 28 December, 2011). The study was carried out in the Tortolì coastal lagoon, Eastern Sardinia (Italy; latitude 39°56' N, longitude 9°41' E).

3 - *V. decussata* juveniles with mean shell lengths of 10.88±0.91 mm in spring and 8.95 ± 0.75 mm in autumn, mean shell thicknesses of 5.21±0.54 mm in spring and 3.36 ± 0.27 mm in autumn, and mean total weight of 0.33±0.09 g in spring and 0.1 2± 0.03 g in autumn, were bred following FLUPSY. To compare this with the aquaculture of these *V. decussata* juveniles under natural conditions, a control group was transplanted to a separate area in the lagoon. The shell length, shell thickness and total weight were measured fortnightly and monthly from the FLUPSY and natural farming, respectively. Temperature, salinity, pH, dissolved oxygen and chlorophyll a were monitored monthly using a multiparameter probe.

4 - At the end of the seasons, *V. decussata* showed the mean spring parameters of shell length 19.60 ± 1.11 mm, shell thickness 9.99 ± 0.54 mm and total weight 1.87 ± 0.23 g, and the mean autumn parameters of shell length 15.87 ± 1.34 mm, shell thickness 6.70 ± 0.69 mm and total weight 0.79 ± 0.20 g. Comparisons with the natural control system showed significant improvements for FLUPSY.

5 - The use of the FLUPSY appears to be useful for the breeding of *V. decussata* juveniles, particularly during the spring season.

Keywords: *Venerupis decussata*, growth rate, coastal lagoon, FLUPSY, juveniles.

Introduction

Mediterranean aquaculture still focuses mainly on mollusc production (53.9%), and from 1995 to 1999, the total mollusc production grew by 3.9% a year (Chessa *et al.*, 2005). This was mainly because the rapid growth rate of the Manila clam *Venerupis philippinarum* led to it replacing the aquaculture of the grooved carpet shell *Venerupis decussata*, which is the natural European species (Mann, 1979; Breber, 1985; Varadi *et al.*, 2001). *V. philippinarum* aquaculture has more recently become widespread for breeding purposes in France, Spain, England and Ireland. In the 1980's, *V. philippinarum* was introduced into Italy, where it rapidly propagated in natural beds and was intensively exploited (Turolla, 2008; Paesanti and Pellizzato, 1994; Sorokin and Giovanardi, 1995). From 1988 to 1993, the Italian production of *V. philippinarum* increased greatly, from 19,370 tons to 21,700 tons, and in 1997 it represented 73% of the total European production (Geri *et al.*, 1996). This is now one of the most important monospecific products of Italian fisheries (Orel *et al.*, 1998).

The grooved carpet shell *V. decussata* is a common infaunal bivalve that is native to Europe, and it occurs along the Atlantic coast, from the British Isles to Morocco and Senegal, and into the Mediterranean (Tebble, 1966). The suitability of many European coastal lagoons, especially in France, England, Portugal, Spain and Italy, has allowed the development of fisheries and mollusc farming (Vincenzi *et al.*, 2006; Parisi *et al.*, 2012).

In the past, *V. decussata* were traditionally collected from coastal areas of the Mediterranean and from the Atlantic coast of France, Spain and Portugal, but this level of harvesting ceased to satisfy the expanding markets. Aquaculturists around the world thus developed a variety of different clam-farming systems, particularly for *V. philippinarum*, although *V. decussata* can also be obtained from European hatcheries. Between 1984 and 2010, the total aquaculture production of *V. decussata* varied from 4,445 tons to 2,052 tons, with most of this production in Portugal, France and Spain (FAO Fishery Statistics, 2010).

Currently in Sardinia, the ever-growing demand for a quality product for both the local market and the tourist trade has demonstrated the need to enhance and increase these aquacultural activities (Saba, 2011). Indeed, simple harvesting from the wild is not sufficient to meet the increasing demand for these products, which in some cases has even resulted in the overexploitation of the natural resources. Newly grown seed stock from European hatcheries can provide a good tool for the restocking of lagoons and for the future growth of the *V. decussata* operations. The aim of the present study was to determine the growth performance of *V. decussata* over two seasons (spring and autumn of 2011) in a Sardinian coastal lagoon when they are grown naturally and using what is known as the FLoating UPwelling SYstem (FLUPSY).

Materials and methods

This study was carried out in Tortolì Lagoon, in Sardinia (Italy; Fig. 1), over two different seasons: spring 2011, from 10 March, 2011, to 21 May, 2011; and autumn 2011, from 18 October, 2011, to 28 December, 2011.

Tortolì lagoon is a typical Mediterranean coastal lagoon of 250 ha on the East of Sardinia (latitude 39°56' N, longitude 9°41' E). It is classified as a eutrophic lagoon, where water exchange occurs by tidal exchange and wind through its two mouths to the sea. The average depth of the lagoon is 1.5 m, with a maximum depth of about 4.0 m. In 2010, the filter-feeding bivalve production was about 13 tons, including the harvesting of *V. decussata*.

FLUPSY is a nursery system that promotes the growth of juvenile clams, and a system was set up in the middle of the lagoon (Fig. 2). Shellfish aquaculturists use water welling to provide an intensive, controlled nursery system, which force feeds nutrient-rich water to the juveniles (Jones *et al.*, 1993). FLUPSY is a system that creates an upwelling current that passes through cubical bins (area, 1 m^2), which allow the water to flow up through the screened bottoms. The bins are located on either side of a central channel that is an integral part of a floating

Figure 1. Study site. Left: Position of Tortolì in Sardinia, Italy. Right: Tortolì lagoon, eastern Sardinia (latitude 39°56' N, longitude 9°41' E).

platform. The water current through the bins is provided by a sealed electric motor at the channel exit that turns a propeller.

The floating system requires a protected site that has warmer temperatures and productive water (heavy blooms are neither necessary nor desirable, as too much algae will clog the screens of the bins and restrict the water flow to the clams) (Jones *et al.*, 1993).

The temperature, salinity, dissolved oxygen and chlorophyll a were monitored monthly using an Ocean Seven 316 Plus CTD multiparameter probe.

Sixteen experimental stations were chosen: 14 in the lagoon, and two close to the FLUPSY. The hydrological variables were measured for the whole year (2011) for the 14 lagoon stations, and also for the two FLUPSY stations during the experimental period.

The *V. decussata* juveniles used in this trial were provided by European hatcheries. In spring, 300,000 specimens with mean shell length of 10.88 ± 0.91 mm, mean shell thickness of 5.21 ± 0.54 mm, and mean total weight of 0.33 ± 0.09 g were grown in three bins (100,000/ bin) of the FLUPSY. In autumn, 300,000 specimens with mean shell length of 8.95±0.75 mm, mean shell thickness of 3.36±0.27 mm, and mean total weight of 0.12 ± 0.03 g, were also grown in three bins (100,000/ bin) of the FLUPSY.

To assess the growth performance using FLUPSY, a control *V. decussata* group was seeded in the lagoon under natural substrate conditions. A total area of 3 m^2 was cleared of natural predators and divided into three sub-areas, each of 1 m^2. These areas were seeded with *V. decussata* juveniles (250/m^2) and then covered with flexible netting, to protect them from predators.

Samples of *V. decussata* were collected every two weeks with FLUPSY (100 specimens × 3 replicates: spring, t_0 to t_5; autumn, t_0 to t_6) and monthly for the control natural system (30 × 3 replicates; spring, t_0, t_2, t_4, t_5; autumn, t_0, t_1, t_3, t_5). The mean

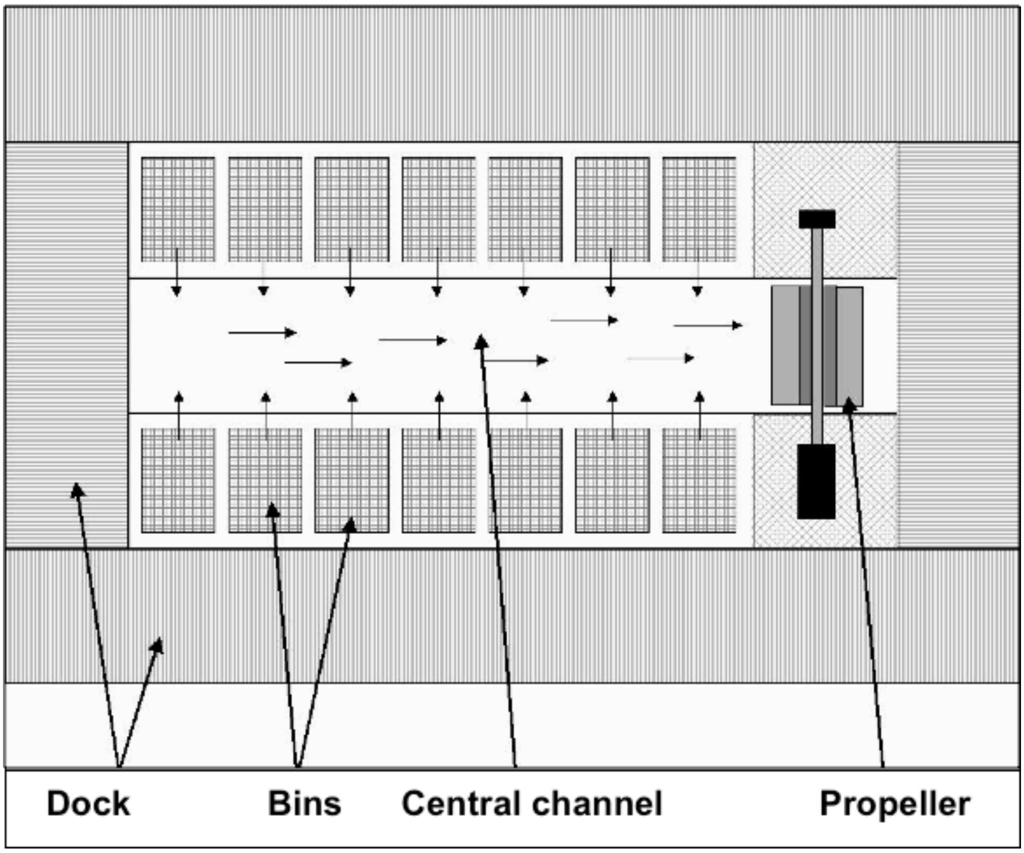

Figure 2. The FLUPSY model for aquaculture of *V. decussata* (modified from Doiron, 2008).

shell length, shell thickness and total weight were measured for each kind of farming.

The shell length and shell thickness were measured using digital callipers, to an accuracy of 0.01 mm, and the total weight was determined using a precision electronic balance, to an accuracy of 0.01 g. The *V. decussata* samples for these measures were replaced in their respective aquaculture systems afterwards.

The growth rates per day were calculated for the two seasons for each measured datapoint for FLUPSY, as: shell length per day, shell thickness per day and total weight per day.

The growth of the *V. decussata* under FLUPSY over the two seasons for the three biometric measurements taken in the same period were compared to the *V. decussata* growth under the natural control system.

Two-way analysis of variance and T-tests on the least-squares means were used with the data to assess the effects of 'growth system' and 'season', using the SAS software system.

Results

The environmental conditions of Tortolì Lagoon for 2011 are reported in Table 1. The mean parameters showed the typical Mediterranean trends, with the higher temperatures measured in June (26.80 ± 1.44 °C), and low temperatures in December (11.58 ± 1.62 °C). The salinity ranged from 28.21 ± 3.22 ppt in November 2011 at the lowest, to 35.73 ± 0.85 ppt in August 2011.

Table 1 - Mean monthly hydrological variables measured for Tortolì lagoon for 2011. [a]Spring period: 10 March, 2011, to 21 May, 2011; [b]autumn period: 18 October, 2011, to 28 December, 2011.

Month	**Mean temperature** (°C)	**Mean salinity** (ppt)	**Mean dissolved oxygen** (mg/l)	**Mean chlorophyll *a*** (µg/l)
January	13.31 ±0.96	34.49 ±1.10	7.02 ±0.28	1.80 ±1.45
February	13.51 ±0.41	32.42 ±1.77	8.93 ±0.24	2.15 ±0.91
March[a]	**13.86 ±0.74**	**32.59 ±1.52**	**7.03 ±0.49**	**3.89 ±1.63**
April	**16.80 ±0.39**	**31.71 ±1.88**	**7.16 ±0.32**	**2.40 ±0.73**
May	**22.54 ±1.09**	**35.20 ±0.87**	**5.62 ±0.51**	**1.17 ±0.68**
June	26.80 ±1.44	35.62 ±0.71	5.67 ±0.31	1.80 ±0.73
July	25.97 ±0.25	33.35 ±1.21	4.95 ±0.34	2.75 ±1.05
August	26.48 ±0.41	35.73 ±0.85	4.72 ±0.34	2.90 ±1.32
September	23.98 ±0.70	33.41 ±1.33	5.00 ±0.17	5.63 ±2.04
October[b]	**20.22 ±0.38**	**35.04 ±1.18**	**5.68 ±0.26**	**1.64 ±0.89**
November	**16.61 ±0.81**	**28.21 ±3.22**	**7.26 ±0.92**	**4.96 ±2.63**
December	**11.58 ±1.62**	**30.98 ±2.25**	**7.50 ±0.63**	**0.79 ±0.55**

The dissolved oxygen reached the highest values in February (8.93 ± 0.24 mg/l). The seasonal variations in chlorophyll a reached their maximum in September (5.63 ± 2.04 µg/l) and minimum in December (0.79 ± 0.55 µg/l).

The mean growth parameters of the *V. decussata* under the control natural system and FLUPSY for both spring and autumn are reported in Table 2.

By the end of the spring season, the shell length, shell thickness and total weight reached 19.60 ± 1.11 mm, 9.99 ± 0.54 mm and 1.87 ± 0.23 g, respectively. The increases in these parameters were relatively consistent over the first 6 weeks of the spring season (Table 2, t_0-t_3), and then they reached their highest values over the final 4 weeks (Table 2, t_3-t_5), when the temperature increased.

The growth performance of *V. decussata* observed with FLUPSY in autumn saw the shell length, shell thickness and total weight reach 15.87±1.34 mm, 6.70±0.69 mm and 0.79 ± 0.20 g, respectively. All of these parameters showed the same increasing trend, with the exception of a slow period for growth during the early stages (Table 2, t_1, t_2), which was followed by the highest increases (Table 2, t_2, t_3).

The growth rates per day recorded for *V. decussata* during the spring and autumn periods are reported in Table 3. In spring, the daily increases were lowest at the beginning of the season, starting with rates for the shell length, shell thickness and total weight of 32.53 µm/day, 24.74 µm/day and 4.33 mg/day, respectively (Table 3, t_1). These increased in the later warmer period, to 238.92 µm/day, 115.29 µm/day and 51.57 mg/day, respectively (Table 3, t_5).

The *V. decussata* growth rates per day in autumn were at their lowest at the end of the season, with the onset of winter. For the rates for shell length, shell thickness and total weight increases, these started from 168.26 µm/day, 68.40 µm/day and 8.95 mg/day, respectively (Table 3, t_1), and slowed to 14.20 µm/day, 11.56 µm/day and 3.19 mg/day, respectively (Table 3, t_6). Thus, the *V. decussata* daily growth rates recorded in autumn showed an opposite trend to the spring season.

Table 2 - Aquaculture growth characteristics of *V. decussata* according to the natural system (control) and FLUPSY during spring and autumn of 2011. [a]Seeded at low density: 250/m^2; [b]FLUPSY, FLoating UPwelling System, seeded at high density: 100,000/m^2 bin; c10 March, 2011, to 21 May, 2011; d18 October, 2011, to 28 December, 2011; *significantly different versus control (natural system): P <0.001.

Sample period	Mean shell length (mm)		Mean shell thickness (mm)		Mean total weight (g)	
	Natural system[a]	FLUPSY[b]	Natural system[a]	FLUPSY[b]	Natural system[a]	FLUPSY[b]
Spring[c]						
t_0	10.88 ±0.91		5.21 ±0.54		0.33 ±0.09	
t_1		11.50 ±0.89		5.68 ±0.53		0.41 ±0.09
t_2	11.61 ±0.95	12.82 ±1.20*	5.68 ±0.54	6.49 ±0.70*	0.41 ±0.10	0.57 ±0.15*
t_3		14.17 ±1.86		7.28 ±0.97		0.78 ±0.25
t_4	14.99 ±1.98	16.73 ±1.02*	7.36 ±0.90	8.61 ±0.61*	0.80 ±0.26	1.25 ±0.20*
t_5	18.67 ±3.53	19.60 ±1.11*	8.82 ±1.43	9.99 ±0.54*	1.46 ±0.72	1.87 ±0.23*
Autumn[d]						
t_0	8.95 ±0.75		3.36 ±0.27		0.12 ±0.03	
t_1	10.54 ±1.32	11.65 ±0.80*	4.00 ±0.55	4.46 ±0.36*	0.19 ±0.07	0.26 ±0.06*
t_2		12.23 ±0.93		4.87 ±0.48		0.33 ±0.08
t_3	10.86 ±1.94	14.30 ±1.01*	7.57 ±1.22	5.76 ±0.48*	0.23 ±0.11	0.54 ±0.12*
t_4		15.11 ±1.22		6.24 ±0.59		0.66 ±0.17
t_5	12.40 ±2.02	15.50 ±1.04*	4.86 ±0.85	6.40 ±0.55*	0.33 ±0.15	0.71 ±0.15*
t_6		15.87 ±1.34		6.70 ±0.69		0.79 ±0.20

The comparisons of these growth performances of *V. decussata* farmed according to the natural control system and FLUPSY are also reported in Table 2 for both spring and autumn. FLUPSY showed consistently higher values then the natural farming system, with the biometric parameters for both seasons showing significant differences between the two farming systems (P <0.001). Also, overall for both farming systems, the shell length, shell thickness and total weight of the spring group were significantly higher than for the autumn group (P <0.001).

Discussion and conclusion

According to several studies, temperature and food availability have direct influences on the growth of bivalve molluscs (Jara-Jara *et al.*, 1997, Sastry, 1979; Maître-Allain, 1982; Beninger and Lucas, 1984; Body *et al.*, 1986; Laing *et al.*, 1987). In the present study, the lagoon water temperature was considered optimal (both in spring and in autumn) for *V. decussata* aquaculturing, as indicated by Laing *et al.* (1987), who reported that the greatest growth-rate coefficients for *V. decussata* juveniles occurs from 12 °C to 20 °C. For the nourishment consideration, although the values of chlorophyll a can explain the low levels of growth rate during the autumn, they do not explain the performances recorded during spring, as the growth rate increased in this season. The good performances recorded in spring were probably influenced by the 'seston', the living and non-living material in the water, the concentrations of which were not determined in the present study (Walne, 1972; Griffiths and Griffiths, 1987; Hoffman, 1983; Delgado and Pérez-Camacho, 2007). Furthermore, the increase in temperature speeds up most of their physiological processes, including their clearing and ingestion rates, as well as their respiration and growth.

These juveniles of *V. decussata* in Tortolì Lagoon showed better growth performances during spring because this season is more suitable for farming clam spat. Indeed, spring plantings benefit from the more suitable water conditions (temperature

Table 3 - Aquaculture growth rates of *V. decussata* according to FLUPSY during spring and autumn of 2011. [a]For baseline values, see Table 2; FLUPSY, FLoating UPwelling System; [b]10 March, 2011, to 21 May, 2011; [c]18 October, 2011, to 28 December, 2011.

Sampling period	**Mean growth rates under FLUPSY[a]**		
	Shell length (µm/day)	**Shell thickness** (µm/day)	**Total weight** (mg/day)
Spring[b]			
t_1	32.53	24.74	4.33
t_2	94.38	57.73	11.89
t_3	90.06	52.37	13.54
t_4	213.37	111.09	39.06
t_5	238.92	115.29	51.57
Autumn[c]			
t_1	168.26	68.40	8.95
t_2	48.57	34.57	5.53
t_3	138.03	59.13	13.81
t_4	57.93	34.12	9.06
t_5	28.22	11.52	3.16
t_6	14.20	11.56	3.19

and food) that promote faster growth. The comparisons between the growth rates of *V. decussata* juveniles in the FLUPSY bins (at high density) and the juveniles seeded in the natural system (at low density) showed significantly higher rates for FLUPSY. These differences were consistent for both spring and autumn, and for the growth performances for shell length, shell thickness and total weight. These differences might be due to factors like the water flow conditions and the nutrient availability. For the FLUPSY bins, it is possible to regulate the water flow and the nutrient concentration, allowing these juveniles to feed continuously in an environment free of predators, where the water flow can be regulated as needed. On the other hand, these conditions cannot be controlled in the natural environment, where clam growth rates are more influenced by the fluctuating weather conditions and predation. FLUPSY aquaculture therefore appears to overcome what was always considered a limitation factor for clam growth rates: the aquaculture density. Indeed, according to Jara-Jara *et al.* (1997), high aquaculture densities appear to result in decreased growth rates in the different clam bins, which was probably due to the increase in the culture density, which involves higher competition for food.

The culture densities applied for the present study were 33 kg/m^2 in spring and 11 kg/m^2 in autumn. These densities are considerably higher than the 2.5 kg/m^2 usually used for extensive aquacultures, and they are also higher than the final biomass of 5.5 kg/m^2 that was obtained by Jara-Jara *et al.* (1997) (Perez-Camacho and Cuña, 1987; Cerviño *et al.*, 1993; Robert *et al.*, 1993; Pech *et al.*, 1993).

The advantages seen for FLUPSY are probably related to the adjustable up-welling water flow pattern and the high food flux. Another important benefit is certainly represented by the lack of predators. Moreover, the management of juveniles using FLUPSY aquaculture presents some other advantages, such as the simple and rapid cleaning of the bins, and the fast removal or collection of the *V. decussata* juveniles. Furthermore, these juveniles will not suffer the typical and natural movements produced in systems of suspended aquaculture. The high densities used and the positive increases in weight using the trays without any substrate reinforces the advantages of this type of system for the growing of clams on an industrial scale.

However, there are also disadvantages of FLUPSY, such as the relatively high start-up costs and the cost management, related in particular to the reduction of fouling organisms and the need for the constant rearrangement of the juveniles on the container bottoms. Indeed, especially during the early weeks of culture, clams juveniles tend to form dense conglomerates that are held together by byssus threads, and these clusters can cause the water to pass through preferential channels, resulting in oxygen loss where the water flow is impeded. This needs to be absolutely avoided, as this oxygen loss where there is little or no water flow can cause the death of the clams.

In conclusion, the present study shows how the use of FLUPSY is of specific interest for the breeding of *V. decussata* juveniles with a shell length of 5 mm to 8 mm. Indeed, FLUPSY provides good environmental conditions, such that after 3 months the *V. decussata* juveniles can reach the size of 15 mm to 20 mm, at which stage it is possible to seed them in the natural substrate of the lagoon until they reach the required commercial size.

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