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Tub gurnard *Chelidonichthys lucerna* L.: a new fish species suitable for farming? First answers evaluating the growth of juveniles reared at different stocking densities, welfare and fillet quality

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Abstract

A trial was conducted to evaluate the growth performance and survival of *Chelidonichthys lucerna*. A total of 13 352 180-days old juveniles (5.5 ± 2 g; 5 ± 1 cm) were reared at two different densities (A-EXP = 68 fish m^{-3}; B-FFA = 15 fish m^{-3}) in eight tanks (four tanks per group) for 360 days. The welfare status and meat quality of fish were evaluated for the A-EXP and B-FFA groups in comparison with wild-caught fishery gurnard (C-WID). The survival rate was high for both A-EXP (79%) and B-FFA (93.5%). B-FFA fish had the highest specific growth rate (1.16 vs. 1.07; $P < 0.05$), and were heavier than A-EXP fish (321 ± 40 g vs .239 ± 44 g; $P < 0.01$). Rearing conditions did not affect blood metabolites, except for glucose concentrations, which were higher in C-WID ($P < 0.05$). The meat quality traits showed that reared groups were fatter (2.8–3.2%) than C-WID (0.94%); total n-3 fatty acids (19.02–19.26%) were lower in reared groups than C-WID (29.99%); and EPA + DHA were similar in all groups (15.1–16.61% vs. 27.99%). Despite the good growth and survival, the final mean weight was below that requested by the market (400–500 g). Future research efforts should focus on reducing the feed conversion rate (3:1).

Keywords: tub gurnard, stocking density, growth performance, welfare, fillet quality

Introduction

In aquaculture, the need to diversify the number of reared species has been emphasized in the last 2 decades (Avault 1993; Suquet, Divanach, Hussenot, Coves & Fauvel 2009). The main advantages of fish domestication are that the growth and reproduction of new species may be regulated to produce large numbers of specimens in sustainable systems, in accordance with the most recent practices (Lorenzen, Beveridge & Mangel 2012). For example, knowledge about the size reached at sexual maturity of fish stocks is important to elucidate the spawning rates of captive stocks (Vallisneri, Montanini & Stagioni 2012). In some cases, aquatic species that are threatened by over-fishing or pollution may be supported by aquaculture practices, resulting in species conservation and/or an increase in fish product availability. For example, in Italy, national fishing activities do not meet the demand for seafood; consequently, it is necessary to import fish from abroad, which amounts to about 923 000 t $year^{-1}$ (ISMEA 2010).

Among the most appreciated fish species coming from fisheries is tub gurnard, *Chelidonichthys lucerna* Linnaeus, 1758. This species was previously classified as *Trigla lucerna*, and belongs to the Triglidae family. This fish is one of the most common species of gurnards, and is of great commercial importance to European fishing nations that border the Atlantic and Mediterranean Sea, where eight species of gurnards are caught (Hureau

1986). According to FAO fishery statistics (FAO 2011), European gurnard catches (70–80% tub gurnard) amount to about 10 000 t year^{-1} (Spain 4000–5000 t; Britain 1400–1500 t; France 1500 t; Italy 1500 t; Portugal 500 t).

Wild tub gurnard shows opportunistic foraging behaviour, mainly preying on epibenthic and nectobenthic organisms. Diet composition is considered to reflect the biological community (termed biocenoesis) typical of the area (Serena, Voliani & Auteri 1998; Colloca, Ardizzone & Gravina 1994; Morte, Redon & Sanz-Brau 1997; Stagioni, Montanini & Vallisneri 2012). Tub gurnard is often found free-swimming at depths of between 10 and 150 m in areas with soft or mixed seabeds (Riedl 1991). In the North-Central Adriatic Sea, maturity of 50% of the population is reached at a size of 22.1 cm and 24.3 cm forked length for males and females respectively (Vallisneri *et al.* 2012). In general, males reach sexual maturity at smaller sizes than females. This phenomenon is usually attributed to the fact that reaching a larger size at maturity has selective advantages for females, as they produce larger eggs with higher survival rates, as well as having higher fecundity and access to the best spawning sites. Size differences may also be attributed to certain ecological conditions, particularly temperature, that stimulate sexual maturation (Uckun Ilhan & Togulga 2007), as well as the aquaculture methods used in reared stock. This species is highly valued for its taste and white flesh, and it has a high market price, particularly if fish are heavier than 0.4 kg (Melotti, Barbaro, Roncarati, Mordenti & Gennari 2000).

Several studies have provided reports about the reproduction and distribution of gurnard in natural waters, as well as their feeding habits and habitat preferences (Caragitsou & Papaconstantinou 1994; Boudaya, Neifar, Rizzo, Badalucco, Bouain & Fiorentino 2008; Lopez-Lopez, Preciado, Velasco, Olaso & Gutiérrez-Zabala 2011). Despite the abundance and importance of gurnard as an economic resource, knowledge about their basic biology, stock composition and population dynamics remains limited (Olim & Borges 2006; Marriott, Latchford & McCarthy 2010). For instance, there is still no optimized rearing system of gurnards in Italian seas (Colloca, Cardinale & Ardizzone 2003; Vallisneri, Montanini, Stagioni & Tommasini 2009; Montanini, Stagioni & Vallisneri 2010; Vallisneri, Montanini & Stagioni 2010; Vallisneri *et al.* 2012); however, some studies have reared tub gurnard to assess the larval phase, sea ranching and genetic characterization (Melotti *et al.* 2000; Dulčić, Grubišić, Katavić & Skakelja 2001; D'Andrea, Roncarati, Melotti, Scarano & Pilla 2012).

To understand the potential utility of rearing tub gurnard for long timeframes under aquaculture conditions, a 1-year ongoing trial was conducted to compare the growth performance and survival rate of juveniles reared at two different stocking densities and two different facilities (experimental hatchery vs. a fish farm). The welfare status and final meat quality of fish were evaluated. In addition, the blood metabolites, and proximate and fatty acid composition of fillets from the two cultured groups were compared with those of wild fishery specimens captured in the mid-Adriatic sea.

Materials and methods

Fish and experimental design of the rearing trials

All procedures involving animals were conducted in accordance with the Italian law on experimental animals, and were approved by the Camerino University Animal Experimental Committee.

For the trial, 180-day old juveniles of *C. lucerna* (mean body weight 5.5 ± 2 g, mean length 5 ± 1 cm) were selected from a group of weaned larvae, which had been obtained by the induced spawning of wild broodstocks captured in the mid-Adriatic sea. The larvae were then acclimated to captive conditions at our experimental hatchery (San Benedetto del Tronto, Italy).

In total, 13 352 juveniles were subdivided into two groups subject to different initial stocking densities and water supply systems. The first group (A-EXP) was reared at a high density (68 fish m^{-3}) in tanks operated as part of an open circuit, located inside in the experimental hatchery. The second group (B-FFA) was transferred to a south Adriatic fish farm company, and reared at a low density (15 fish m^{-3}) in outdoor tanks supplied with ground saltwater, at 16–23°C. Although the weight increases in this species under farmed conditions has not been previously documented, the initial number of juveniles was selected based on the expectation of final loads of 12 kg m^{-3} and 3.5 kg m^{-3} in the A-EXP and B-FFA groups respectively.

The A-EXP group consisted of four 16 m^3 tanks, which were located inside an experimental

hatchery situated on 100 m from the coast of San Benedetto del Tronto. The tanks operated in an open cycle circuit, obtaining seawater through a sub-sand PVC pipeline system running 3 m below the sand of the shoreline. This pipeline system transported and filtered water by gravity, to fill a 100 m^3 storage tank located near the outdoor area of the facility. The storage tank was connected to two pumps that supplied the hatchery sectors with 15 L sec^{-1} water flow. The B-FFA group consisted of four 150 m^3 outdoor concrete tanks that were supplied with seawater drawn from underground, at temperature ranging between 16 and 23°C. These tanks were covered with bird nets to avoid the predation of fish by birds, and to protect them from excessive solar radiation in summer.

The trial was initiated in May for both groups, and spanned a 360-day period. The main farming parameters adopted in the experimental design of the trial are reported in Table 1. All fish were provided with the same feeding programme, which comprised a commercial crumbled feed (Feed 1) for marine fingerlings of different sizes at a daily ratio of 4% of fish body weight, until an average weight of 30 g was reached. The daily ratio was then decreased to 2% body weight. When fish reached 100 g body weight, an extruded feed (Feed 2) for fattening of marine fish was administered at a daily ratio of 1.5% body weight. The feed was supplied to each tank using an automatic feeder for 14 h day^{-1}, over a period of 6 days per week. The proximate composition and fatty acid profile of the two feeds are reported in Table 2.

Every 60 days, 30 fish from each group were individually weighed to the nearest 0.1 g using electronic balance scales (Mettler 5000, Mettler Toledo International, Novate Milanese, Italy), and total body length (from the most anterior extremity - mouth closed – to the caudal rays squeezed to give the maximum length measurement) was measured to the nearest millimetre using an ictiometer.

The tank bottoms were cleaned once a week and once every 2 weeks for the A-EXP and B-FFA groups respectively. When the feed was placed into the feeder each day, tanks were inspected for dead specimens, which were immediately removed. After 3 months of fattening, the two groups were graded.

The water in all the tanks (A-EXP, B-FFA) was monitored when fish were sampled from the two groups. Dissolved oxygen, temperature, salinity and pH were measured using a portable electronic device (YSI mod. 55 and 60). At the same time, 500 cc of water was collected for laboratory-based determination of total ammonia nitrogen (TAN), nitrite-nitrogen (NO2-N), nitrate-nitrogen (NO3-N) and phosphates, using a spectrophotometer (Hach mod-2005, Hach Company, Loveland, USA) according to APHA (1995).

At the end of the trial, the main biomorphometric parameters recorded in both groups were used to calculate the condition index [KI = (weight fish/length^{-3}) × 100], perivisceral fat index [PFI = (perivisceral fat/body weight) × 100], viscerosomatic index [VSI = (weight viscera/whole body weight) × 100] and hepatosomatic index [HSI = (liver weight/body weight) × 100]. The specific growth rate was

Table 1 Main parameters of the trials

	A-EXP	B-FFA
Age of fingerlings (days)	180	180
Initial weight (g) (mean ± SD) (n = 500)	5.5 ± 2	5.5 ± 2
Initial stocking density (no. fish m^{-3})	68	15
Replicates (no. basins per group)	4	4
Blood sampling (no. fish per basin per group)	10	10
Fattening period (days)	360	360
Water flow (L s^{-1} t^{-1})	15	10
Expected final density (kg m^{-3})	12	3.5

Table 2 Proximate analysis, energy content and fatty acids (mean ± SD) of feeds administered to A-EXP and B-FFA tub gurnards at the start until 30 g mean body weight (Feed 1) and until harvesting (Feed 2). The main ingredients were fish meal, soybean meal, fish oil, cereal grain products and vitamin-mineral premix

	Feed 1	Feed 2
Moisture (%)	6.63 ± 1.1	6.28 ± 0.6
Protein (g kg^{-1})	525.4 ± 4	430.7 ± 3
Lipid (g kg^{-1})	174.5 ± 4	200.4 ± 5
N-free extract (g kg^{-1})	12.99 ± 0.8	243.6 ± 6
Ash (g kg^{-1})	10.39 ± 0.9	62.5 ± 9
Metabolizable energy (kcal kg^{-1})	415.87 ± 0.04	444.01 ± 0.05
Fatty acids (% of total fatty acids):		
Total saturated	33.83 ± 1.20	29.33 ± 1.29
Total monounsaturated	25.34 ± 1.15	25.66 ± 1.16
Total n6	9.05 ± 1.06	10.51 ± 0.05
Total n3	25.82 ± 1.32	19.51 ± 1.64
n3/n6	2.85 ± 0.02	1.86 ± 0.02

calculated using the formula $100 \times [(\ln(w_t) - \ln(w_i))/t)]$, where $\ln(w_t)$ and $\ln(w_i)$ are the natural logarithms of weight at time t and initial weight respectively, whereas t is the time interval in days. The final stocking density (kg m^{-3}), survival rate (%) and food conversion rate were also evaluated.

Determination of blood metabolites of farmed and wild tub gurnards

Blood sampling of A-EXP and B-FFA groups was performed after 300 days of the trial (10 fish per tank per group), and repeated during the last week of the trial. In parallel, blood samples were collected from five wild tub gurnards (C-WID) caught by professional fishermen with hooks and longlines in the marine area in front of the harbour of San Benedetto del Tronto. C-WID blood sampling and live body weight measurements were directly performed on the boat during favourable sea and weather days immediately after the measurements of A-EXP and B-FFA fish. When collecting blood samples, we caught one fish at a time to minimize the effects of stress on physiological conditions (Barton & Iwama 1991).

Blood (1–2 cc per fish) was collected by heart puncture using a heparinized syringe. The blood was centrifuged at 1000 *g* for 20 min to separate the plasma, which was then frozen at −20°C and stored for the subsequent assays. The following plasma parameters were determined spectrophotometrically (Bergmeyer 1974): glucose (glucose oxidase and 4-aminoantipyrine (GOD-PAP) Trinder method); total cholesterol (Cholesterol oxidase and peroxidase (CHOD-POD) Trinder method); triglycerids (glycerol-3-phosphate oxidase (GPO) colorimetric method); total protein (Biurete colorimetric method); lactate dehydrogenase (LDH) (UV optimized Scandinavian Committee on Enzymes (SCE) method); transaminases, such as aspartate aminotransferase (AST) and alanine aminotransferase (ALT) (UV optimized International Federation of Clinical Chemistry and Laboratory Medicine (IFCC) method); and creatine kinase (CK) (UV method).

Proximate and fatty acid composition of the fillet

At the end of the growing trial, five tub gurnards were randomly selected from each group (A-EXP; B-FFA), and sampled to analyse meat quality. The main traits were compared against those of the wild tub gurnards (C-WID) caught by fishermen in the Adriatic Sea and subjected to blood sampling.

A portion of about 50 g of skinless dorsal left muscle from each fish was collected, homogenized and submitted to proximate analysis (moisture, protein, lipid and ash content). The percentage of moisture was determined in duplicate, according to the Association of Official Analytical Chemists procedure (AOAC 1990). Proteins were determined using the standard Kjeldahl copper catalyst method (AOAC 1990). Ash content was determined using the procedure described by the AOAC (AOAC 1990). Total lipids were measured using the procedure described by Bligh and Dyer (1959). After the determination of total lipids, fatty acids were converted to methyl esters, following the method described by Christopherson and Glass (1969). The separation of fatty acids was carried out using a GC 3800 gas chromatograph (Varian Strumentazione, Cernusco sul Naviglio, Italy) with a WP-4 Shimadzu integration system (Shimadzu Corporation, Tokyo, Japan), which was equipped with a Supelco SP^{TM} – 2340 capillary column (30 m × 0.25 mm i.d.; 0.25 μm film thickness; Supelco, Bellefonte, Pennsylvania, USA) and a flame ionisation detector. The operating conditions of the gas chromatograph were as follows: oven temperature was maintained at 170°C for 15 min, increased to 190°C at a rate of 1°C min^{-1}, then increased to 220°C at a rate of 5°C min^{-1} and kept at this temperature for 17 min. The temperature of the injector was 270°C, while that of the detector was 300°C. Helium was used as the carrier gas at a constant flow of 1.7 mL min^{-1}. The identification of individual fatty acids was accomplished by comparing the retention times to fatty methyl esters of standard mixtures (37 FAME Mix and C22:5 n3, Supelco).

Statistical analysis

At the end of the trial, Statistica software (version 6) was used to calculate the relationship between body length and weight based on the following equation (Froese 2006): $\log W = \log(a) + b \log(TL)$, where W is the total body weight of the fish (g), TL is the total length (cm), a is the intercept on the *Y*-axis of the regression curve and b is the regression coefficient.

Analysis of variance (ANOVA) using the SAS General Model procedure was conducted to detect differences among the A-EXP and B-FFA specimens with respect to (1) the water chemical parameters

(TAN, N-NO2, N-NO3), (2) the final results of growth performances and indices between the two groups and (3) the proximate and fatty acid composition of meat. ANOVA was also performed to show differences among the A-EXP, B-FFA and C-WID fish with respect to blood metabolites. The means were separated using a Student Newmann–Keuls test (SAS Institute 1988). Differences were considered significant at $P < 0.01$ and $P < 0.05$.

Results

Rearing trials

Table 3 shows the length-weight relationship parameters for the two captive reared groups of tub gurnard. Table 4 presents the live body weight, length, somatic indices and main productivity results. Fish reared at a low stocking density (B-FFA = 321 ± 40 g) were significantly heavier ($P < 0.01$) than those raised at a high stocking density (A-EXP = 239 ± 44 g), whereas body length was not affected by fish density (A-EXP = 27.3 ± 6.3 cm; B-FFA = 32 ± 4 cm). The condition index K did not differ between A-EXP and B-FFA (1.3 vs. 1). The hepatosomatic index ranged from 2.35 (A-EXP) to 2.41 (B-FFA), with no obvious differences. The viscerosomatic index was significantly higher ($P < 0.05$) in A-EXP (11.03) than in B-FFA (7.95) gurnards. Similar differences ($P < 0.05$) were observed for the specific growth rate, with B-FFA performing higher than A-EXP fish (1.16 vs. 1.07). The feed conversion ratio was the same in both groups of tub gurnard (3:1). The final stocking density was higher in the A-EXP group (12.8 kg m^{-3}) compared to the B-FFA (4.5 kg m^{-3}). The survival rate was significantly higher in the B-FFA group (93.5%) than in the A-EXP group (79%). High mortality was recorded during the first months in the A-EXP group.

Figure 1 presents water quality data, including the trend in mean values for temperature, salinity, pH, total ammonia nitrogen, nitrites and nitrates. Oxygen levels remained at about 90% saturation in both groups at all times throughout the trial. Water temperature and salinity showed the highest fluctuations in A-EXP tanks (ranging between 15.1 and 24.5°C and 24.4 and 34.3 g L^{-1} respectively), particularly during the initial period of the trial (summer). TAN levels were significantly higher in A-EXP (0.95 mg L^{-1}) than in B-FFA (0.37 mg L^{-1}) tanks on day 60 of the trial; however, these values remained low in both groups for the remainder of the trial.

Table 3 Length-weight relationships of *C. lucerna* reared in the two groups (A-EXP and B-FFA)

	Length (cm)	Weight (g)	A	B	R^2
A-EXP	3.1–27.3	3.4–239	0.0027	3.02	0.89
B-FFA	3.1–32	3.4–321	0.0050	3.3	0.76

Table 4 Morpho-biometric parameters, somatic indices and productive results obtained at the end of the trial. Different letters on the same line show significant differences (a, b = $P < 0.05$; A, B = $P < 0.01$) between the two reared groups (A-EXP and B-FFA)

		A-EXP	B-FFA
Final body weight	G	239 ± 44 B	321 ± 40 A
Final total length	Cm	27.3 ± 6.3	32 ± 4
K index		1.3 ± 0.5	1 ± 0.3
HSI		2.35 ± 1.2	2.41 ± 0.6
VSI		11.03 ± 0.7 a	7.95 ± 2.2 b
Specific growth rate	%	1.07 ± 0.03 b	1.16 ± 0.02 a
Survival rate	%	79 ± 2 A	93.5 ± 2 B
Food conversion rate	Kg/kg	3:1	3:1
Final density	Kg m^{-3}	12.8	4.5

HSI, Hepatosomatic index; VSI, Viscerosomatic index.

Determination of blood metabolites of farmed and wild tub gurnards

Table 5 presents the blood parameter data determined at 300 and 360 days of the trial in the two farmed groups (A-EXP, B-FFA) and wild-caught fish (C-WID). There was no difference in mean triglyceride values among A-EXP, B-FFA or C-WID groups. The maximum total cholesterol value was recorded in A-EXP on day 360 (232 mg 100 mL^{-1}), whereas the lowest value was recorded in C-WID on day 300 (146 mg 100 mL^{-1}). The glucose values of wild fish were lower than farmed fish, which were similar to each other. The levels of total protein, transaminases (AST and ALT), alkaline phosphatase, LDH and CK showed no significant differences among the three groups.

Proximate and fatty acids composition of the fillet

Table 6 presents the proximate composition and energy content of fillet, which was evaluated at the end of trial in A-EXP, B-FFA and C-WID tub

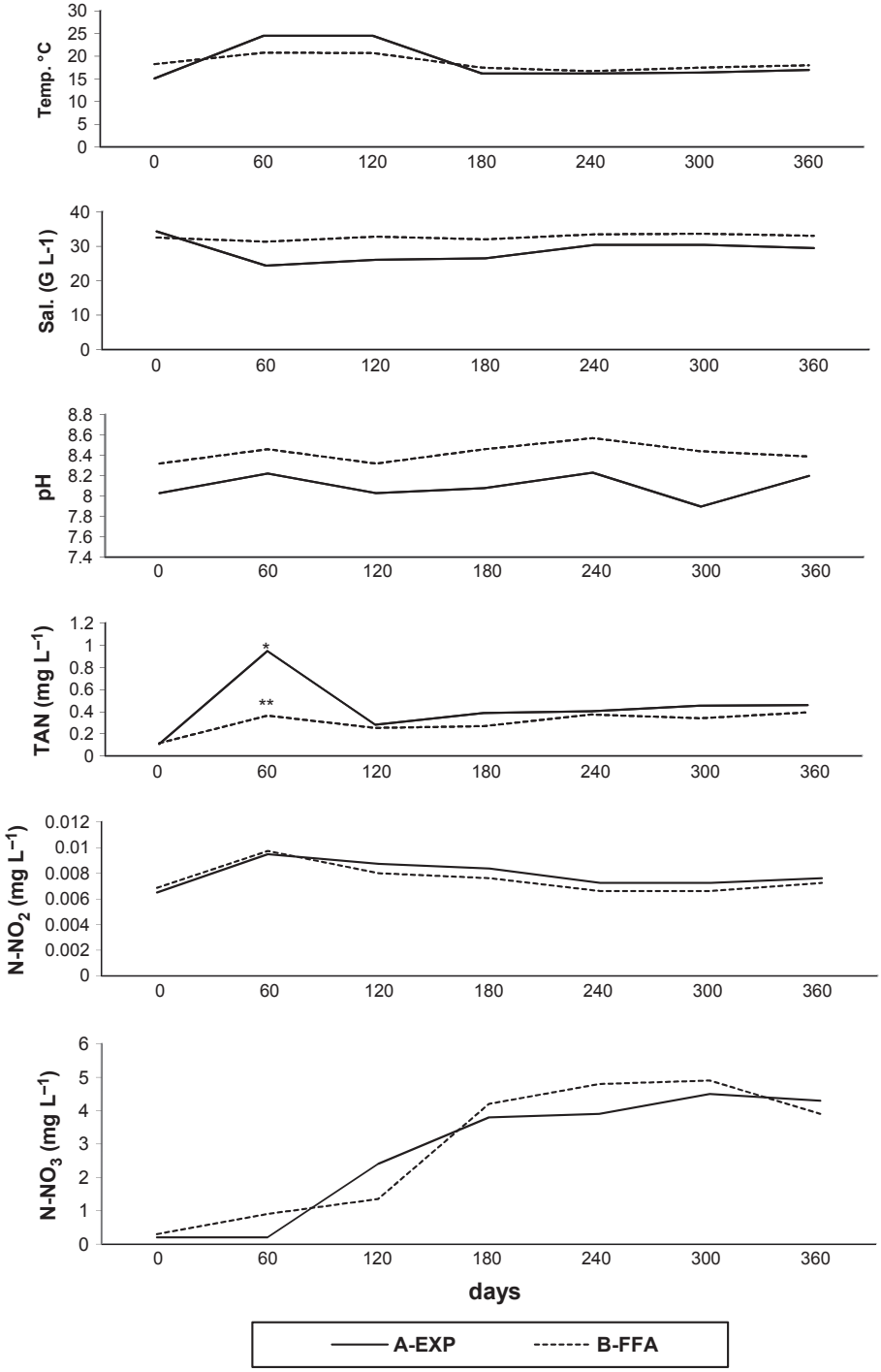

Figure 1 Trend in water temperatures, salinity, pH, total ammonia nitrogen (TAN), nitrites (N-NO2) and nitrates (N-NO3) measured for two groups (A-EXP and B-FFA) of reared tub gurnard. The asterisks show significant differences ($P < 0.05$).

gurnard. Major differences were observed in the most important quality traits between the two cultured groups and the wild specimens, except for protein, which ranged from 19.15% to 19.84%. A-EXP and B-FFA exhibited the highest lipid content (2.8–3.2%) compared to C-WID (0.94%).

Table 5 Blood parameters (mean ± SD) determined at 300 and 360 days of trials. T (°C) indicates water temperature (°C) at the blood sampling times of reared (A-EXP and B-FFA) and wild (C-WID) specimens of tub gurnard. Different letters on the same line show significant differences (a, b = $P < 0.05$) between the groups

	A-EXP	B-FFA	C-WID
300 d – Temperature (°C)	T = 16	T = 17	T = 14
Mean body weight (g)	175 ± 20	280 ± 26	1240 ± 520
Mean total length (cm)	23 ± 2	25 ± 1	44 ± 3
360 days – Temperature (°C)	T = 18°C	T = 18.3°C	T = 17°C
Mean body weight (g)	230 ± 40	320 ± 35	1450 ± 430
Mean total length (cm)	26 ± 3	31 ± 2	47 ± 2
Triglycerides (g L^{-1}):			
300 days	1.87 ± 0.85	1.49.3 ± 0.63	1.34 ± 0.83
360 days	1.96 ± 0.45	1.87 ± 0.64	1.12 ± 0.54
Total cholesterol (g L^{-1}):			
300 days	1.65 ± 0.37	1.82 ± 0.52	1.25 ± 0.72
360 days	2.32 ± 0.63	1.96 ± 0.29	1.46 ± 0.66
Glucose (g L^{-1}):			
300 days	0.98 ± 0.27 a	0.95 ± 0.16 a	0.58 ± 0.19 b
360 days	1.23 ± 0.18 a	1.05 ± 0.13 a	0.79 ± 0.10 b
Total protein (g L^{-1}):			
300 days	2.6 ± 0.4	2.7 ± 0.5	3.2 ± 1
360 days	2.8 ± 0.6	2.9 ± 0.5	3.1 ± 0.6
LDH (U L^{-1}):			
300 days	58 ± 22	48 ± 6	37 ± 11
360 days	51 ± 19	44 ± 11	32 ± 9
ALP (U L^{-1}):			
300 days	60.4 ± 18	45.0 ± 23	49 ± 13
360 days	45 ± 21	52 ± 18	32 ± 15
CK (U L^{-1}):			
300 days	59.8 ± 9	67.9 ± 19	53.5 ± 34
360 days	49.4 ± 21	54.3 ± 21	48.1 ± 14
AST (U L^{-1}):			
300 days	87.9 ± 14	99.6 ± 20	43.6 ± 37
360 days	83.4 ± 16	85.9 ± 12	83 ± 26
ALT (U L^{-1}):			
300 days	86.9 ± 17	79.2 ± 12	41.2 ± 21
360 days	83.5 ± 19	80.4 ± 13	54 ± 15

Similarly, high differences were observed for moisture (A-EXP = 75.98%; B-FFA = 73.30% vs. C-WID = 78.92%) and ash (A-EXP = 2%; B-FFA = 1.99% vs. C-WID = 2.69%) content.

Figure 2 shows the most important categories of fatty acids of the fillets. The proportion of total saturated fatty acids (SFA), total monounsaturated fatty acids (MUFA) and total n-3 and n-6 fatty acids was similar between the fillets of the two cultured groups, but differed compared to the wild fish. The fillets of farmed fish had a similar proportion of SFA, MUFA, n-3 and n-6 polyunsaturated fatty acids (PUFA). Wild fish had a higher proportion of SFA (35.01% vs. 31.24 and 31.94%) and n-3 PUFA (29.99 vs. 19–19.26%), and a lower proportion of MUFA, than farmed fish. The main n-3 PUFA were eicosapentaenoic acid (EPA) and docosaenoic acid (DHA), for which the proportion was higher in captured fish (27.99 vs. 15.1–16.61%). A similar MUFA and total n-6 content was obtained.

Table 6 Proximate composition of fillet of cultured tub gurnards in the two reared groups (A-EXP; B-FFA) at the end of the trial, and for wild fish (C-WID). Different letters on the same line show significant differences (a, b = $P < 0.05$) between the groups

	A-EXP	B-FFA	C-WID
Moisture (g kg^{-1})	759.8 ± 3 b	733.0 ± 5 b	789.2 ± 5 a
Protein (g kg^{-1})	191.5 ± 2	198.4 ± 6	192.2 ± 2
Lipids (g kg^{-1})	32.3 ± 4 a	28.2 ± 5 a	9.4 ± 3 b
Ash (g kg^{-1})	20.0 ± 1 b	19.9 ± 2 b	26.9 ± 3 a

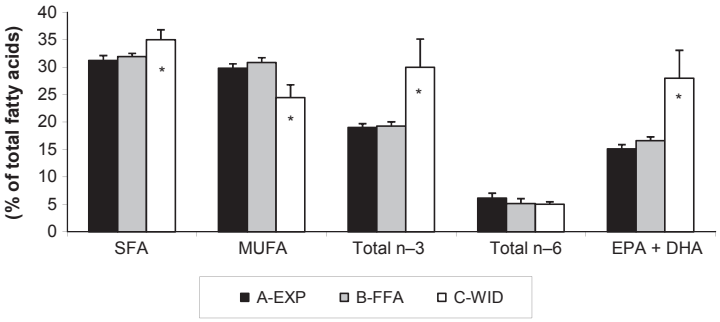

Figure 2 Fatty acids of tub gurnards reared in the two groups (A-EXP and B-FFA) at the end of the trial and for wild fish (C-WID). The asterisks show significant differences ($P < 0.05$).

Discussion

The main result of this study emphasizes the possibility of captive rearing *C. lucerna* juveniles, which is supported by the final average weight and survival rates of rearing this species at different stocking densities. Certainly, the densities tested in our study were significantly lower than those adopted for sea bass and sea bream; however, the number of juveniles introduced per volume was significantly different between the two groups. The expected final density results were reached for A-EXP (12 kg m^{-3}) and B-FFA (3.5 kg m^{-3}), and exceeded expectations at the low stocking density. As significant differences in final mean weight (which was higher at the low rearing density) were obtained between the two rearing groups, it is likely that tub gurnard farming is affected by stocking density. However, no clear effect of stocking density on survival rate was observed until after the first 3 months of the trial, because mortality was initially very high in both groups.

The reasons for mortality were assumed to arise for different reasons. In the A-EXP group, mortality appeared to be influenced by major changes in water quality, particularly with respect to increased water temperatures and reduced salinity. In fact, the first months of growth occurred during summer, with the highest temperatures being recorded in the open circuit water inlet system of the A-EXP group. In the Mediterranean Sea, this species naturally occurs at sea depths of 10–150 m, where temperatures usually remain below 20°C, even in summer. A relationship amongst size, depth and season has been shown in the North-Central Adriatic Sea (Vallisneri, Stagioni, Montanini & Tommasini 2011; Vallisneri *et al.* 2012); in fact, according to the published literature, juveniles aggregate in shallow waters adjacent to the coast during summer, probably because of high food abundance (particularly crustacean *Philocheras* spp.) (Froglia 1976; Colloca *et al.* 1994; Boudaya *et al.* 2008). In our study, the total body length of reared gurnards remained consistently lower than that of captured fish, and slightly shorter than the wild adult males of *C. lucerna* collected by Vallisneri *et al.* (2012). Therefore, high water temperatures, along with changes in water quality (such as fluctuations in salinity and TAN) may have caused considerable stress to the study animals, resulting in higher mortality during summer. This observation was supported by the recorded decline in mortality from October onwards, when temperatures ranged from about 20 to 16°C.

B-FFA gurnards also exhibited similar high mortality to A-EXP during the first months of the trial. The stocking density of this group was low, with the tanks being supplied with groundwater that was not characterized by any significant fluctuations in salinity or temperature, along with very low values of nitrogen and phosphorous compounds. However, larger gurnards attacked smaller fish, with cannibalistic behaviour also being observed. A similar situation has been reported for other fish species (including European eel, sea bass, sole, catfish), when reduced density appears to serve as a stressful factor, causing chronic stress and decreased feeding activity, leading to mortality. It has been shown that specimens consume less food when stocked at low density, because the motivation to maintain a territory is stronger than the motivation to eat the provided feed (Degani & Levanon 1983; Doyle & Talbot 1986; Baras 1998). For this reason, we decided to perform a grading after the initial 3 months of rearing. After

this initial 3-month period, the tendency for cannibalism disappeared, possibly due to specimens growing larger, with the body weight and growth rate becoming the highest in this low-density rearing group (B-FFA). In *C. lucerna*, cannibalism may be accidental because tub gurnard has a large mouth, and some prey may reach the stomach accidentally. Alternatively, cannibalism may be a population survival mechanism when resources are scarce in the environment, with it serving as an important recruitment control factor.

In relation with somatic indices, the heaviest fish showed the lowest incidence of visceral parts. In fact, we observed that meat yield increased with increasing weight, due to the large size of the head in smaller specimens, which may reach 25% of the total weight and progressively declines with increasing weight. The food conversion rates of the two groups were similar, and not very favourable; however, a commercial feed for euryhaline fish species was used, which might not be sufficient for the nutrient requirements of tub gurnard.

The haematochemical values in the advanced phase of the trial (300 and 360 days) were similar for the two captive reared groups and the wild-caught fish. The obtained haematological values for *C. lucerna* were similar to that of the majority of fish species reared under captive conditions. External factors, such as water quality, diet and culture conditions, may affect some blood values (Burtis & Ashwood 1996). For example, the monitored parameters remained within normal physiological limits, when the minimum and maximum levels reported for the main euryhaline fish species are used as a reference (Kavadias, Castritsi-Catharios & Dessypiris 2003; Lemarie′, Dosdat, Cove's, Dutto, Grasset & Person-Le 2004; Roncarati, Dees, Mordenti, Angellotti & Melotti 2006). Significant differences in glucose were observed between the two reared groups and wild-caught specimens; however, captured specimens exhibited noticeable differences in average size, ranging between 600 and 1800 g. Besides, the different method of capturing reared and wild specimens might have also influenced the different values that were observed. Glucose is an indicator of stress (Pottinger, Yeomans & Carrick 1999), but it is also influenced by other factors, such as temperature, fish size (Hemre & Sandnes 1999) and diet. In comparison, total protein may serve as an indicator of liver condition (Rehulka 2003). It is possible that significant differences were not observed in protein levels due to high variability in the enzyme intragroups, such as AST and ALT, which are involved in structural liver alterations (Burtis & Ashwood 1996). In addition, no general effects of crowding were detected in energy metabolites, such as tryglicerides and cholesterol, which are considered as important diagnostic tools, along with other enzymes.

Fillet quality was evaluated at the end of the growing trial with respect to proximate and fatty acid composition, comparing the blood parameters of captive reared tub gurnard with wild-caught fish from the Adriatic. This comparison was performed despite the considerable difference in size between the cultured and captured specimens. The fishery technique used by the fishermen (hook and longline) participating in our study does target large specimens. Although the farmed gurnards were fatter than the wild ones, the lipid content of farmed fish was below 3.5%; hence, this species may continue to be included among the leaner fish.

The general fatty acid profiles were similar for the two-farmed gurnards, but they differed compared to the wild gurnards. The reared fish contained lower proportions of SFA and total n-3 PUFA compared to the specimens captured in the Adriatic Sea, reflecting the fatty acid profile of the administered feeds. This difference in composition is also due to the feeding habits of wild gurnards, with the gastric content of most specimens indicating a diet dominated by fish and crustaceans rich in DHA. Our data support that of Zlatanos and Sagredos (2006), who observed that tub gurnard also contained more than 1 g total n-3-fatty acids per 100 g fresh fish. In the open sea, the trophic spectrum of tub gurnard is very wide. This diet is characterized by a high degree of biodiversity, and is correlated with changes in feeding habits during growth. As tub gurnard grow, its diet changes, both in terms of prey size and type of prey, a fact that has also been attributed to its bathymetric migratory behaviour (Colloca *et al.* 1994; Morte *et al.* 1997; Stagioni *et al.* 2012; Vallisneri *et al.* 2012). Smaller individuals feed on benthic Crustacea, Amphipoda and Decapoda Natantia. As they grow larger, *C. lucerna* increasingly prey on decapods (mainly Portunidae and Crangonidae) and teleosts (Froglia 1976; Stagioni, Mazzoni, Montanini & Vallisneri 2007; Montanini, Stagioni & Vallisneri 2008; Vallisneri *et al.* 2012).

In the open sea of the Adriatic, tub gurnard reach a "critical size," which coincides with the

start of sexual maturity. This transition probably depends on the predator changing its energy requirements and dietary protein levels, which influence fish size at first maturity, in relation to fish size (Al Hafedh 1999). The age at first maturity is 2–3 years in Italian waters (Bombace & Lucchetti 2011). In our trial, the sexual maturity was not reached; however, in the North-Central Adriatic Sea, sexual maturity is assumed to be reached at 1–2 years, due to the rapid growth of these fish. The current study presented the first investigation of growth performance of tub gurnard in captivity. This fish is one of the most widespread species in the Mediterranean Sea, representing an important portion of annual fishery catches (ISMEA 2010).

This study evaluated the potential domestication of *C. lucerna* by focusing on the responses of this species to a certain rearing technique, in which the environmental conditions were monitored and feed was provided in relation to growth size, using the most important farmed fish species as references. The initial average weight of juveniles (5.5 g) selected for growing phase was adequate to achieve good performances after 1 year (250–350 g); however, the final mean weight did not reach the market size primarily requested by Mediterranean consumers (400–500 g). It is likely that this species may reach a marketable size within 18–20 months of captive rearing, which is of more economic value than the size obtained in our study. Future research efforts should focus on reducing the feed conversion rate.

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