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Hatchery production of European lobster (*Homarus gammarus*, L.): broodstock management and effects of different holding systems on larval survival

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ABSTRACT

The biometry of wild berried females was collected during an entire reproductive season at the South-Wexford Lobster Co-op hatchery in Nethertown, Ireland. Second degree regressions between total body weight (TW, g) and carapace length (CL, mm) ($TW=CL^2$ -36.675CL+1793.2, $R^2=0.9022$) and number of "weaned" larvae and carapace length (Larvae number=$1.217CL^2$–21.777CL-5281.1, $R^2=0.743$) were observed. Afterwards, berried females were divided according to two variables: 1. holding system: recirculating system (Rs) *vs* barrel (Bar); 2. CL size: <101 mm (A), 101-120 mm (B), >120 mm (C). The total weight of larvae (212.5 *vs* 92.4 g) and their numbers (7788 *vs* 5679) were significantly higher for the largest females than for the smaller sizes ($P<0.01$). The maximum survival rate of larvae (77.86%) was noted for initial stocking density <1000 individuals/hopper, but the optimal stocking density for management purposes in the hatchery is higher (2001-3000 individuals/hopper).

Key words: European lobster, Hatchery, Hens, Holding system, Larvae.

RIASSUNTO

PRODUZIONE DI LARVE DI ASTICE EUROPEO (*HOMARUS GAMMARUS*, L.) IN AVANNOTTERIA: GESTIONE DEI RIPRODUTTORI ED EFFETTI DI SISTEMI DIVERSI DI ALLEVAMENTO SULLA SOPRAVVIVENZA LARVALE

Si sono raccolte le biometrie di riproduttrici selvatiche di astice europeo durante un'intera stagione riproduttiva presso la South-Wexford Lobster Co-op hatchery in Nethertown, (Irlanda). Si sono ottenute regressioni di 2° grado tra peso corporeo totale (TW, g) e lunghezza del carapace (CL, mm) ($TW=CL^2$ –36,675CL+1793,2, $R^2=0,9022$) e numero di larve "svezzate" e lunghezza del carapace materno (Larvae

nr.=1,217CL²–21,777 CL–5281,1, R²=0,743). Successivamente le riproduttrici si sono suddivise in funzione di 2 variabili: il sistema di allevamento: sistema a ricircolo (Rs) vs "barili" (Bar); 2. lunghezza del carapace: <101 mm (A), 101-120 mm (B), >120 mm (C). Il peso totale delle larve prodotte da riproduttrice (212,5 vs 92,4 g) ed il loro numero (7788 vs 5679) è risultato significativamente maggiore per le femmine C rispetto quelle di taglia minore (P<0,01). La massima sopravvivenza percentuale delle larve (77,86%) si è ottenuta con densità iniziali di stoccaggio delle larve <1000 individui/ cassetta, ma la densità ottimale, ai fini gestionali dell'impianto, sono maggiori (2001-3000 individui/cassetta).

Parole chiave: *Astice europeo, Avannotteria, Riproduttrici, Sistemi d'allevamento, Larve.*

Introduction

The life cycle of the European lobster (*Homarus gammarus*, L. 1758) is relatively long and animals generally have slow growth rates (Lee and Wickins, 2002). Lobsters have a pluriannual reproductive cycle, spawning every two to three years or longer (Aiken and Waddy, 1986). Usually individuals are sexually mature when they reach a cephalothorax length (CL) equal to 85 mm (Aiken and Waddy, 1980). The wild stocks of the species along many coasts of Europe are progressively declining due to over fishing (Tully *et al*., 2001). Several factors may be responsible for the decline, including: 1) increased number of fishing-boats, and their capacity; 2) larger number of pots used per boat; 3) increased efficiency of pots (due to improved design); and 4) longer fishing season (Tully, 2004.). Different tools have been proposed to counteract this decline: V-notching of females, increase of the minimum landing size, decrease of the catch effort, delimitation of no fishing areas and reduction of the fishing season (Tully *et al.*, 2001). Another approach is the production of juveniles for release, which incorporates the management of broodstock ("berried hens") in a hatchery (Lee and Wickins, 2002). In different European countries (Norway, United Kingdom, France, Ireland, Italy) specific programs based on this approach have been carried out (Van Der Meeren *et al*., 1990; Latrouite and Lorec, 1991; Beard and Wickins, 1992; Scovacricchi *et al*., 1999). The larval rearing of the species is the "bottleneck" of lobster production (47% survival from stage I to IV; Browne and Mercier, 1998) which could benefit from further research for a successful farming system (Lee and Wickins, 2002). Furthermore, stock enhancement programs are mainly based on two different strategies to release cultured juveniles: large numbers (>5000 per release) of small (stage IV or V) lobsters or small numbers of larger animals (≥stage VII) reared for longer times in hatcheries (Browne, 1999; Beal *et al*., 2002). Restocking coastal marine waters requires at least 8-10 years for this species (Tully, 2004), and constant efforts to increase species production.

The present research was performed to obtain preliminary data on the management of berried females (hens) and their larvae in the hatchery. The main biometry and reproductive performances of wild-caught berried females were measured. Different berried female holding systems (recirculating system vs barrels) and female carapace length classes (<101mm, 101-120 mm, >120 mm) were tested. Final survival rates of hatchery-reared lobster larvae (at stage IV) were measured taking into consideration initial stocking density and maternal holding system.

Material and methods

Facilities

Reproductive data were collected during a whole reproductive season at the South-Wexford Lobster Co-op hatchery (Nether-

town, Carne, Co. Wexford, Ireland), from April to September 2005.

Wild berried females were randomly distributed in two farming systems: barrels (Bar) *vs* recirculating water system (Rs). The barrel sector of the hatchery had 12 aerated barrels (50 L capacity), with a daily water change of each unit. The recirculating water system (10% daily water change) was composed of 36 small tanks (25 L), each of them with adjustable outlets (Figure 1).

Larvae were automatically collected in small larvae baskets every two hours and then transferred to the larval-room. Both these sectors had a normal day length but inverted photoperiod. Larvae were reared in 27 cylindrical conical plastic hoppers (60 L), through stage IV (approximately two weeks), when they were transferred to the juvenile growth systems. The operative conditions of the "hopper" sector are reported in Table 1.

Two systems were adopted to rear juveniles, both based on small individual cells, to avoid cannibalism and to reduce time for growing: stand system *vs* stack system. In the stand system there were 48 trays (l * w * h=0.36 * 1.08 * 0.07 m) each divided in 216 triangular cells (18 cm^2), 60 mm deep (water depth) (Figure 2). The bottom was a 2 mm mesh netting that allowed water flow and prevented animal movements. Six of these trays were placed within each of 8 shallow tanks (l * w * h=2.4 * 1.2 * 0.150 m). Water was recirculated to these tanks from an outside reservoir (24 m^3 capacity), which was replenished with new seawater every 2 to 3 days. Water flow to the individual juvenile lobster cells was enhanced by the use of a tidal siphon placed at the outlet of each

Figure 1. Recirculating system (Rs) of the lobster hatchery.

Table 1. Operative conditions adopted for the larval stage rearing of European lobster (*Homarus gammarus*) in hatchery.

Period of sampling		June-September
Photoperiod		Natural
Temperature °C	average ± SD	18.80 ± 1.05
Larvae /hopper	n.	500-6800
Artemia/hopper	g/day	4.0
Cysts of Artemia /larvae	mg/day	0.58 – 8.00
Naupli of Artemia fed/larvae/day	n	110-1500

shallow tank, which caused the water level to rise and fall periodically (approx every 5 minutes). The total capacity of the stand system was around 10,000 animals.

The stack system was composed of trays (l * w * h=45 * 45 * 4.5 cm), containing 100 cells (l * w * h=4.3 * 4.3 * 4.5 cm). Ten trays were stacked in a column, and submerged in a larger tank (l * w * h=1 * 1 * 0.5 m), with air inlet on the bottom (Figure 3). Sixteen of these columns assured a final capacity of 16,000 specimens. Once juveniles had reached a minimum stage of VI, they were released in the sea, using a pipe system similar to that described by Lee and Wickins (2002).

The temperature in the different sectors of the hatchery was recorded daily and it ranged between 13.7 and 15.9°C for broodstock; it was 18.8±1.0°C for larvae in the hopper sector and 13.6±1.0°C for juveniles.

Animals

Fifty-eight wild hens were caught between April and September and their total body weight (TW, g) and CL (mm) were measured. Berried hens did not feed during the incubation period, except up to a few days before their release to the sea, when fresh segments of fish were supplied to them.

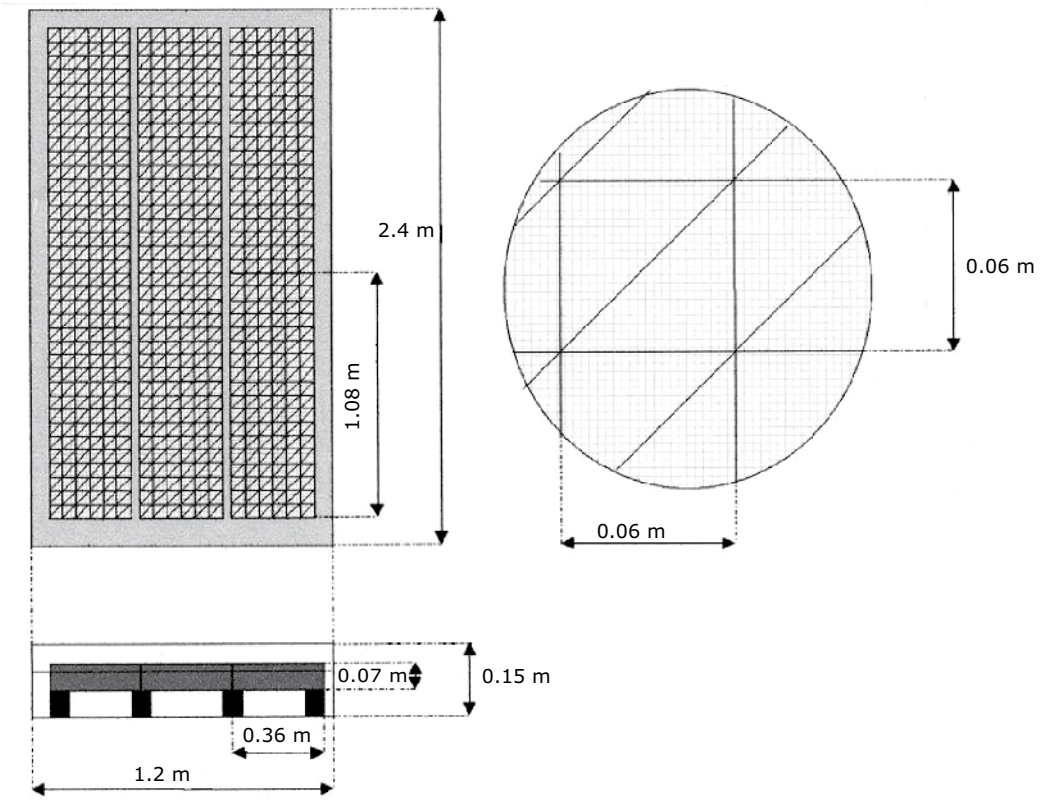
After hatching, larvae were collected in the concentrators every two hours and then transferred to the hoppers (in the larval-room). Once they reached stage IV, all specimens were collected with a small aquarium net, weighed, counted and transferred to the trays. We estimated the number of larvae of each female by dividing total weights of several batches of larvae by their number and applying the average value of all these batches to the total weight of larvae. On the contrary, all larvae that reached stage IV were individually counted and survival rates, up to this stage, were obtained. Larvae in the hoppers were fed every two days 1.5 x 10^6 metanaupli of Artemia plus unicellular algae (*Tetraselmis, Isochrysis sp*.; approximatly 50-150x10^6 cells/L).

From stage IV on, it was not possible to keep the different batches of larvae separated according to mother CL, as a sufficient volume of water was not available in the hatchery for the hatching synchrony of lots of larvae. Consequently stocks of larvae were reared according to the maternal rearing system and initial stocking density in the hoppers: <1000, 1001-2000, 2001-3000, 3001-4000, 4001-5000, >5000 specimens/hopper.

Statistical analysis

General equations, and their R^2 were computed for: 1.) Female total weight as a function of their CL; 2.) Number of larvae as a function of female CL.

Figure 2. Stand system of the lobster hatchery.



Hens were divided according to two variables: 1.) holding system: recirculating system (Rs) *vs* barrels (Bar); 2.) CL class: <101mm (A), 101-120 mm (B), >120 mm (C). Consequently 6 treatments were considered: ARs, BRs, CRs, ABar, BBar and CBar. The biological data and reproductive performances of the female lobsters were submitted to 2- way ANOVA and the comparison between adjusted means was made using a L.S.D. test (Snedecor and Cochran, 1980).

Larval survival rates in the hoppers were submitted to analysis of variance for the maternal rearing system (Rs *vs* Bar) and initial stocking density in the hoppers: <1000, 1001-2000, 2001-3000, 3001-4000, 4001-5000, >5000 specimens/hopper. Data were covariated for number of *Artemia* cysts fed and the significantly different adjusted means were tested with "t" test (Snedecor and Cochran, 1980).

Results and discussion

The general equation to estimate the female TW in function of their CL was a second degree equation, graphically represented in Figure 4:

$TW=0.2665CL^2/-36.675CL+1793.2$,

$R^2=0.9022$

In addition, a second degree equation was obtained for female CL and the number

Figure 3. Stack system used for lobster larvi.

of larvae produced; this graphic is reported in Figure 5:

Larvae (Number)=1.2171CL^2– 21.777 CL –6281.12, R^2=0.743.

After grouping wild berried females according to the experimental factors, their CL was significantly different (P<0.01), as expected, in function of the size classes: 93.4 mm (A), 108.7 mm (B) and 130.6 mm (C) (Table 2). Also, total body weights were significantly different: A 691.6 g *vs* B 966.5 *vs* C 1571.5 (P<0.01; Table 2). The female weight loss, when it was possible to measure (37 df), was higher for C group: 113.8 g *vs* 42.8 g (Table 2). Time needed by larvae to hatch was shorter for B-females (11.42 days), and longer for C-females (15.15 days), but this variable was only the final part of the long "incubation" phase of the berried females (Table 2, P<0.01). Nevertheless there was a farming system effect: in Barrels the average time for hatching was significantly

Figure 4. Weight of berried females (g) in function of their carapace length (CL).

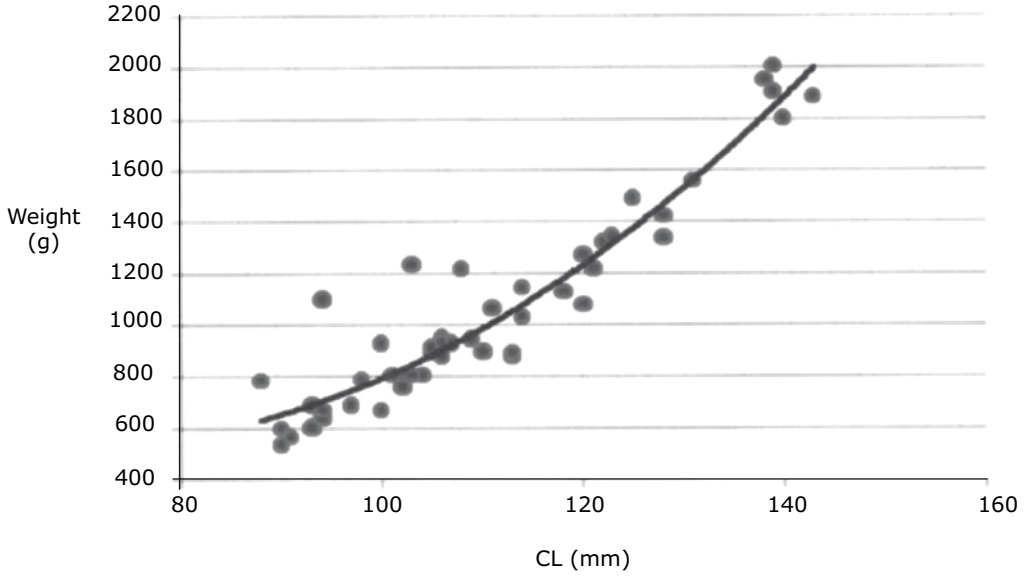
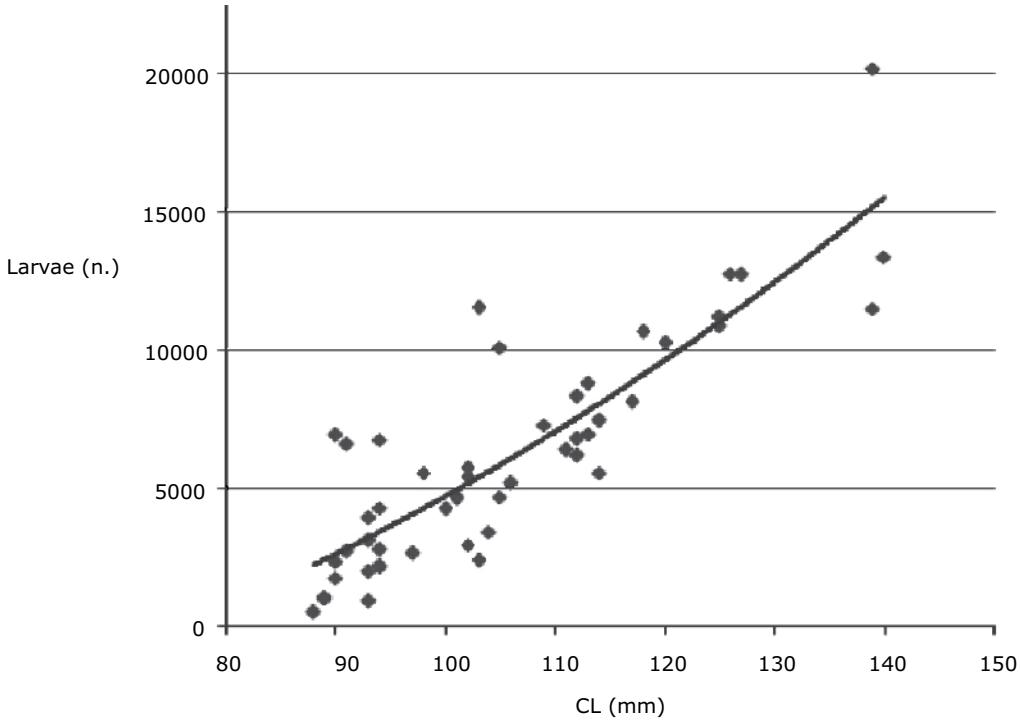


Figure 5. Number of hatched larvae (stage I) in function of maternal carapace length (CL).



shorter (2.70 days) than in the Recirculating System (Bar: 11.63 *vs* Rs: 14.33 days, P<0.05, Table 2).

Data concerning the production of larvae are reported in Table 3. The total number of larvae produced was ~317,000: 68,406 from A group, 125,691 from B and 123,594 from C. The average number of larvae produced was significantly lower for the younger females: 5771 (A) and 5587 (B) *vs* 7788 (C) (P<0.01). There was no effect of the holding system, although a slight trend to a lower number for Bar (5293) than Rs (6722) (Table 3). The total weight of hatched larvae was significantly greater for the older females: 212.5 g (C) *vs* 92.4 g (A and B) (P<0.01), but not for any farming system. The average weight of larvae was significantly affected by farming system: 17.96 mg (Bar) *vs* 16.42 mg (Rs) (P<0.05), but not by mother size: 18.33 mg (C), 16.78 mg (A) and 16.62 mg (B) (Table 3).

The twenty-three females reared in the recirculating system released 174,406 larvae, from June 5th to August 26th , 2005 (Table 3). These larvae were placed in 70 hoppers, with density ranging between 560 larvae/hopper (~11 larvae/L) and 6586 larvae/hopper (~150 larvae/L). The average survival rate of larvae (at stage IV) was 32.69% (Table 3).

Table 2. Main biometry measured on berried females of European Lobster (*Homarus gammarus*) stocked in hatchery.

		Hen size class			Hen holding system		
Biological Data		A	B	C	Rs	Bar	SEM (54 df)
N. of farmed hens		19	26	13	27	31	-
CL	mm	93.4^{A}	108.7^{B}	130.6^{C}	108.7	108.9	5.86
Weight	g	691.9^{A}	965.4^{B}	1571.5^{C}	1077.4	1008.2	139.69
[1]Weight loss	"	34.5^{a}	51.2^{a}	113.8^{b}	63.0	54.0	39.99*
[2]Time to hatch	days	13.45^{a}	11.42^{b}	15.15^{a}	14.33^{b}	11.63^{a}	4.20
Average weight loss/average time required to hatch	g/days	2.54^{a}	4.02^{a}	6.83^{b}	4.31	3.97	1.99*

Means, within the same row not sharing a common superscript letter are significantly different (a,b,c: P<0.05; A, B, C: P<0.01).

[1] Weight loss: (TW_i – TW_f) , where TW_i is the total body weight at the entry in the hatchery and TW_f is the total body weight at release in the sea.

[2] Days necessary for egg hatching, after the female placement in the hatchery.

**df (degree of freedom)=37.*

Table 3. Main reproductive performance of berried female of European Lobster (*Homarus gammarus*) stocked in the hatchery.

		Hen size class			Hen holding system		
Biological Data		A	B	C	Rs	Bar	SEM (47 df)
Hens	n.	15	23	13	23	28	-
Hatched larvae (stage Ist):							
Number		68,406	125,691	123,594	174,406	143,285	-
N./hen		5771^{b}	5587^{b}	7788^{a}	6722	5293	2817.98
Total weight	g	79.5^{B}	105.3^{B}	212.5^{A}	126.0	106.7	51.22
Average weight	mg	16.78	16.62	18.33	16.42^{b}	17.96^{a}	2.51
Larvae (stage IVth):							
Hoppers	n.				70	59	-
Number					57,011	41,426	-
Survival	%				32.69	28.91	-

Means, within the same row, not sharing a common superscript letter are significantly different: P<0.05; P<0.01. df: degree of freedom.

7 berried hens were discharged having lost their eggs.

The twenty-eight hens in the barrels system released, from June the 12th to September the 4th 2005, 143,285 larvae (Table 3), placed in 59 hoppers, with a density ranging between 516 larvae/hopper (~10 larvae/L) and 6621 larvae/hopper (~132 larvae/L). The overall final survival rate, at stage IV, was 28.91% (Table 3). Time necessary to reach stage IV was around 12 days. The total number of larvae that reached stage IV was 98,437.

A significant decrease of larvae survival rates was observed according to the increase of larvae stocking density. In fact there were the maximum survival rates (>70%) for larval initial stocking density <1000 specimens/hopper; intermediate survivals (~50%) when initial stocking density ranged between 1001-3000, and the lowest survivals (<40%) when larvae were stocked at initial stocking density >3000 individuals/hopper (P<0.01; Table 4). No difference was observed for the different farming system previously adopted for hens, but only a higher survival rate for Bar than Rs, at larval stocking density ranging between 2001-3000: 57.76 *vs* 33.74% (P<0.01, Table 4).

The berried females in this research weighed less and had higher fecundity compared to those of the same size (CL) studied by Scovacricchi *et al*. (1999). In fact, a 120 mm CL female, according to our equations, should weigh 1229.8 g and should produce 9631 larvae stage I (Table 5). On the contrary, for the same size hens, Scovacricchi *et al.* (1999) estimates a production of 4886 larvae stage I and 1450 g TW. With a 100 mm CL female we get: TW=790 g and nr. of larvae: 4712 (Table 5), while Scovacricchi *et al.* (1999) obtained: BW=937 g and 1860 larvae stage I. Tully *et al.* (2001), instead, fit an equation as function of female CL, to estimate the number of eggs produced: Egg (#)=0.025 $CL^{2.804}$ (R^2 =0.571) (Table 5). The values obtained using this equation are higher than ours, but it could be expected, being the dependent variable the number of eggs and not the number of larvae. The loss of eggs from spawning to hatching according to Talbot and Helluy (1995) ranges between 30 and 50%. Adopting these figures, the differences between the two equations become very small (Table 5). According to Talbot *et al.* (1984), there would not be a direct correlation between maternal CL and number of larvae produced. There could be small females producing many eggs, and vice versa big females carrying a low number of eggs. A low number of eggs, and therefore of developing larvae, carried by a female could be explained by both extrinsic and intrinsic factors. The first is the stress due to other

Table 4. Survival rates from stage I to stage IV larvae of European lobster (*Homarus gammarus*) in function of the initial stocking density and maternal farming system (adjusted means for n. of *Artemia* cysts administered).

Classes of density	<1000	1001-2000	2001-3000	3001-4000	4001-5000	>5000	B	SD^2
-	77.86^A	50.01^B	43.96^B	26.67^C	28.23^C	17.98^C	0.027	318.973
Maternal Rs	74.39^A	56.49^B	33.74^C	28.80^C	22.05^C	17.28^C	0.027	318.973
Maternal Bar	85.62^A	56.97^B	57.56^B	24.13^C	33.11^C	23.28^C		

Means not sharing a common superscript letter are significantly different (P<0.01).

Table 5. Comparison between the equations estimating the number of eggs or larvae in function of maternal carapace length (CL).

CL (mm)	[1] N. eggs = 0.025 $X^{2.804}$	[2] N. larvae (=70% eggs)	[3] N. larvae (=50% eggs)	[4] N. larvae= 1.2171X^2– 21.77 X + - 5281.1
80	5422.56	3795.79	2711.28	766.18
100	10,137.71	7096.39	5068.86	4712.20
120	16,903.02	11,832.11	8451.51	9631.90
130	21,156.18	14,809.33	10,578.09	12,456.88

[1] Tully (2004).

[2] Data obtained multiplying n. eggs x 0.7 (according to Talbot and Helluy, 1995).

[3] Data obtained multiplying n. eggs x 0.5 (according to Talbot and Helluy, 1995).

[4] Present research.

specimens (in the wild) or handling in the hatchery during spawning stage; the second an abnormal behaviour during the egg release, or poor husbandry practices, or anomalies in the generation of the hairs for the egg adherence. According to Talbot *et al*. (1984), this variability in the number of eggs produced could also be due to the biodiversity of natural stocks.

For the production of stage I larvae, the only significant difference between the two farming systems of berried females was the time for larvae "weaning," which was 2.7 days shorter for the barrel system. Also in this case an extrinsic factor - stress by daily handling of the barrels (by operators) - could explain this difference.

The water temperature recorded in this reproductive cycle was lower, on some days by at least 5°C, compared to the temperature reported by Scovacricchi *et al*. (1999). This seems to affect positively the final result of this phase. In fact, the number of larvae produced from each female was greater for the same size of female in the present setting than in other ones. The larval rearing phase (stage I-IV), on the contrary, had similar temperatures to those adopted by Scovacricchi *et al*. (1999) and was equal in the average time to metamorphosis for stage IV, being 12 days.

The general survival rate from stage I to stage IV was satisfactory although lower than 47%, as reported by Browne and Mercer (1998), but with less variability compared to other authors: 30% *vs* 5-41% by Scovacricchi *et al*. (1999) or 5-30% by Burton (1993). Survival rate from stage IV to juveniles to release (stage VI), instead, was lower: ~11%, but close to the lower values obtained by Scovacricchi *et al.* (1999): 11.6-28%.

The highest survival rates in function of the stocking density were obtained with less than 1000 larvae/hopper, but for the best management of the hatchery larval sector it is necessary to consider not only the total number of "weaned" larvae, but also the cost of the structures and labour, as well. Consequently, we suggest an initial stocking density ranging between 2001-3000 (2500 on average=40 stage I larvae/liter).

A practical technical problem that occurred was the synchrony of larval hatching due to the natural reproductive cycle of the species. In fact facilities were underused in certain periods due to low numbers of available berried females and hoppers used (therefore used with low density), while in other

periods there was an overexploitation of facilities. Finally, from a management point of view of the hatchery, it would be better to choose bigger females than smaller ones. For example, using our second equation, to produce 500000 larvae it would be sufficient to handle 41 hens with 130 mm CL, instead of 113 specimens with 100 mm CL, with a direct savings on the total price of purchase of berried females. An hypothesis of 15 minutes of work for each female (larvae collection, clean barrels, etc.) means a further savings of 18 hours of work each day.

Conclusions

The management of berried females and rearing the first stages of *H. gammarus* (larvae through phase VI) are the basis for producing fair amounts of larvae to restock suitable coastal marine areas. The number of "weaned" larvae can be estimated by hen carapace length (Larvae number=$1.2171CL^2$–$21.777CL$–5281.12, R^2 =0.743.). The bigger (and older) the hens, the higher the number and the heavier the weight of the larvae produced. Hens reared in a recirculating system are less stressed (days for hatching 14.33 *vs* 11.63). Special care must be taken for larvae stocking density. If limited surface is available in the hatchery, 2001-3000 individuals/hopper can be optimal; if surface is not a limiting factor, larval stocking density can be lower (<1000 sp/hopper), but costs can increase greatly.

This work is dedicated to the unforgettable memory of Prof. Domenico Lanari, a great man and a great researcher.

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