RESEARCH ON THE REPRODUCTIVE BIOLOGY, GROWTH AND ARTIFICIAL SPAWNING OF NOBLE SCALLOP (Chlamys nobilis Reeve, 1852)

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ABSTRACT This paper is the abstract of the Ph.D. thesis of the author. The data used in the paper have been collected for many years. The reproductive biology, development, hatchery studies and growth-out of scallop by suspended culture method in the sea are concerned and discussed.

NGHIEN CÖU ÑAC ÑIEM SINH SAN, SINH TRÖÔNG VA KY THUAT SAN XUAT GIONG NHAN TAO ÑIEP QUAT (Chlamys nobilis Reeve, 1852)

Nguyen Thò Xuan Thu
Trung Tam Nghien Cöu Thuy San 3

TOM TAT Bao cao nay la tom tat Luan an Tien só cua tac gia. Cac so lieu söû dung trong bao cao ñöôc tap hôp trong nhieu nam. Nghien cöu ñac ñiem sinh hoc sinh san, qua trình phat trien, san xuat giong nhan tao va nuoi thöông pham Ñiep Quat ñöôc trình bay va thao luan trong bao cao.

INTRODUCTION

The bivalve mollusc Chlamys nobilis Reeve, 1852 commonly known as the noble scallop, belongs to the family Pectinidae, in the subclass Pteriomorpha or Amisomyaria. This species is rich in protein and other nutrients. The protein quality of the adductor muscle is equivalent to that of marine crabs (15%) and has great value for export.

C. nobilis is found mostly along the coasts of Binhthuan province in Central Vietnam, from Cana to Hamtan, at depths of 5-22 meters. The total exploited amount of C. nobilis for export represents a high proportion of all marine products produced in Binhthuan province. However, its harvest rate is not stable and has declined year by year, from 17,000 tons in 1986 to only about 100 tons in 1998. Even so, today it remains the most economically important product for export in Binhthuan. For this reason, knowledge of its biology is especially important.

Since 1985, there have been some studies on resource biology of the scallop Chlamys nobilis in Binhthuan coastal waters (Nguyen Trong Nho, 1993; Nguyen Huu Phung, 1991; Vo Si Tuan, 1994, 1995, 1997). In this study, knowledge on reproductive biology of the scallop, the growth of cultured scallops, and technical methods for hatchery production are concerned to maintain good yields and benefit of the economy. Moreover, human intervention to maintain steadily to increase numbers of C. nobilis is the best way to increase profits of this declining scallop resources.

The objectives of the research are to:

- Describe the reproduction and development of C. nobilis in order to understand its life cycle and its movements in nature.
- Study methods and techniques of hatchery production and growth of scallops.
- Experiment with the transfer of seeds of noble scallop in order to raise the scallops in other areas along the shores of Central Vietnam where the scallop is not naturally occurring. A goal of this research is to create more interest in raising scallops in this region and create more jobs for people in the coastal regions.

MATERIAL AND METHODS

For studies on reproductive biology: Studies on C. nobilis started in 1991. Twenty to thirty specimens of C. nobilis in various size groups (length from 20 to 90mm) were randomly collected monthly from the shallow region of Binhthuan coastal waters (108^0 N – $10,7^0$ E) by diving from April 1992 to November 1994. All scallops were measured for length and weight. Sex was determined based on the colour of the gonad. A piece of gonad was fixed in Bouin's fixative, dehydrated in ethyl alcohol, cleared in chloroform and embedded in paraffin. Tissues were sectioned (6 μm) and stained with hematoxylin and eosin. The stained preparations were classified into different developmental stages using a slight modification of the classification described for mussels and scallops (Mason, 1958; Seed, 1969). The gonad condition of noble scallop was classified into six stages based on a modification of the scheme described by Braley (1984) and Nash (1988). The gonad index was calculated using the formula GI = Weight of the gonad x 100/ Weight of the soft tissues of the animal. The histological and cytological study of the annual reproductive cycle allows the establishment of a series of stages in the development of the gonads and the prediction of the spawning season. A monthly sex ratio was calculated and the Chi-square test was applied to the samples to test whether the populations follow 1:1. For the study of fecundity, the number of eggs in the gonad per individual, per gram of body with shell and without shell, and per gram of ovary were calculated for absolute and relative fecundity of scallop. The first maturing age and size were calculated for the smallest size which had the gonad in stages III, IV and V occurring more than 50 % of total.

For study on growth of cultured scallop: The experiment was conducted in Vungro of Phuyen province (109^o4'N – 12^o7' W). One month old spats of scallops (mean height 1.5 $\pm$0.03 mm) were transferred from the laboratory to pearl nets (30x30x30 cm) suspended by floatation at 2-8m depths. Each month, 30 randomly chosen scallops were measured (with vernier calipers to 0.1mm accuracy) and weighed (with a beam balance of 0.01g accuracy). The shell height of scallops was defined as the maximum distance between dorsal and ventral margin. Mean height was used to calculate growth rate (G) by the formula:

$G= \{(\ln L_2 - \ln L_1)/(T_2 - T_1)\} \times 100$ (Ball and Jones, 1960)

The parameters of von Bertalanffy growth equations were calculated according to the Gulland & Holt plot method (Sparre & Venema 1992).

For study on hatchery seed production: C. nobilis broodstock of 50-60mm shell length was collected and transported to the laboratory and cultivated in 2 m^3 breeder tanks containing filtered sea water with salinity of 32 ‰, temperature of 27 ± 3^oC, and pH of 8. Continuous aeration was provided to maintain the oxygen level at more than 4 mg l^{-1} DO.

The seawater was replaced daily. The scallops were fed on unicellular algae such as Platymonas sp., Chlorella sp., and Chaetoceros muelleri. When the average gonadal index reached about 16%, spawning was induced by air exposure, thermal stimulation or through desiccation and flowing water. Fertilized eggs were kept at a density of 30 eggs per ml. The rearing density for larval cultivation ranged from 2-5 larvae per ml. Larvae were fed daily with a mixture of unicellular phytoplankton (Chaetoceros, Chlorella and Platymonas, Nanochloropsis). D-stage larvae were fed on 3000 cells ml^{-1} and the density of algae was gradually increased to 10,000 cells ml^{-1} for spats of 1mm length. During the early period of rearing, regular management procedures were followed with regard to feeding, exchange of water, observation of larval activity, removal of waste from the tank bottoms and counting numbers of larvae. In the late period, especially when collecting nets were placed in the tanks, the flowing water method was used to change water in the rearing tank. Spats attached to the collecting nets were maintained in the tanks until they reached 1mm shell length. To investigate the development of the larvae, 20-30 individuals from each spawning were measured and photographed using a compound microscope with attached camera.

RESULTS

1. Reproductive biology

This issue was published by Nguyen Thi Xuan Thu (1997a, 1999a). The summary is as follows:

1.1. Morphology and structure of gonad and the gonad condition of C. nobilis

C. nobilis is a separate sexual species. The shape of gonad is flabellate. The gonad is located next to the adductor muscle. Both male and female have the same shape and can be distinguished only by the colour of the gonad. In the maturing stage, white testis and orange ovary distinguish male from female. The gonad condition of the scallops was classified into six stages. Stage I is immature, II-III are maturing, IV is mature and V-VI are partially spent and spent conditions respectively. In stages I and II, testicular and ovarian regions cannot be distinguished. In stages IV and V, the gonad contains thickly packed follicles with free, active spermatozoa and mature pearl-shaped oocytes inside. The size of oocytes develops very quickly, from 25 to 80µ. The gonad increases considerably in volume and assumes a round form. In the partially spent and completely spent stages, the gonad retains some residual mature genital products, and is shrunken and flaccid with empty follicles. A few stray oocytes are in the follicles.

Hermaphroditic gonads were found with a small number of hermaphroditic individuals changing from female to male. Based on the observation of phenomena such as orange oocytes of female pale, white milk-like testis, and based on the hypothesis of Purchon (1968), the noble scallop may be a protandric hermaphrodite. However, more studies of its sexuality are needed to prove this hypothesis.

1.2. Reproductive cycle and spawning season

C. nobilis is able to spawn around the year but the spawning season occurs in two peaks, between March and April, and July and August each year. From September until February the observed occurrence of mature stage was low.

Temperature and food were two major factors related to spawning season of noble scallop. Due to the impact of strong upwelling in Ninhthuan - Binhthuan seawaters, there was variation of bottom water temperature with two maxima in April, May, and September, October and two minima in July, August and January, February. Gonadal development of C. nobilis related to the temperature variation and reproduction occurred when water temperature began increasing. The upwelling resulted in high diversity in species composition and number of phytoplankton in the sea zone. The peak of phytoplankton biomass appeared at the same time of the strongest upwelling period (July, August) in the year.

1.3. Sex ratio

The sex ratio fluctuated during the months in a year (Table 4). In most months the number of females was higher than that of males but this was not a consistent result. The average natural sex ratio of males to females for a year was 1/1.3.

The variation of sex ratio by size (Table 5) was:

- At size < 60mm: male/ female >1
- At size > 60mm: male/ female <1

1.4. Age and the first mature size

The first mature size was determined for the smallest group with 50% of individuals which have gonadal development at stages III, IV and V. The first mature size of a group was determined by graph at the point with 50% of mature individuals. The first mature size of C. nobilis was determined with shell height of 58mm corresponding with 1-year old C. nobilis. However, sometimes the first mature size could be observed with very small individuals (males of 42mm and females of 48mm)

1.5. Fecundity

Based on the volume method, the absolute and relative fecundity of 15 individuals with gonadal stage IV, 3 size groups (50-60mm, 61-80mm and over 80mm) were estimated. The result indicated that the absolute fecundity of C. nobilis increased with size, the relative fecundity decreased as increased size. The number of eggs per unit of gonad weight did not change with increase of size.

- For size group of 50-60mm, absolute fecundity ranged from 1.1 – 1.8 million eggs / female (average of 1.6 million eggs / female).

- For size group of 61-80mm, absolute fecundity ranged from 2.2 – 3.4 million eggs / female (average of 3 million eggs / female).

- For size group of 81-92mm, absolute fecundity ranged from 3.0 – 4.5 million eggs / female (average of 3.8 million eggs / female).

The average absolute fecundity for all 3 size groups was 2.8 million eggs / female. The average relative fecundity was 65.000 eggs / gram of wet weight (including shell) or 175.000 eggs/gram of somatic body (excluding shell) and 1million eggs/gram of gonadal weight

1.6. Reproductive activity, embryonic and larval development

Reproductive behavior of males and females of C. nobilis is similar and undertaken by contraction of adductor muscle. The muscles open and close the shells very fast and strongly. This activity produces pressure that extrudes eggs and sperm through genital openings. 5 minutes after spawning, eggs assume a spherical shape and have a diameter of about 40-60µm. Fertilization occurs in seawater. Fertilized eggs with a diameter of 60µm are surrounded by the fertilized membranella. The first polar body appears 20 minutes after fertilization; the second polar body appears after 5 minutes. The first cleavage occurs in 45 min., the second cleavage after 1h; morula within 5h after fertilization. Trochophore with size of 66 x 70 µm continuously moves rapidly 7h after fertilization. D-shaped veligers or straight-hinged stage with shells and circle of cilia in between appear 18-22h after fertilization. Veligers with size of 83x100 µm move quickly by the velum. Umbo stage is characterized by process of forming organs. These organs include: early umbones with size of 100 x 132 µm, which are characterized by the formation of the germ of the adductor muscle, intestine and a pair of transparent balance organ. In the mid umbone stage with size of 138 x 158 µm, the umbones become more prominent. At this stage, the mouth, oesophagus, stomach, intestine and digestive gland are well developed. The advanced umbones with eye spot appear 8 days after fertilization. After 9 days of fertilization, an active foot, a cement gland and a black eye spot develop, indicating the ending time of the swimming larval stage. The size of larvae is about 160x190 µm. 10-12 days after fertilization, the umbones were fully formed and the larvae were competent to metamorphose on properly placed spat collectors. The foot and cement glands were detached, the velum lost and body became twisted. The shells became distinctly coloured and firmly attached with byssus when the shells reached to 600-700 µm. The spats reached the length of 1mm after 20-25 days. The size of spats increased very fast:

Early spat stage: 250 x 175 μm (on day 12)
Mid spat stage: 450 x 400 μm.
Late spat stage: 700 x 700 μm (on day 18)

The shell length of straight-hinged veligers increased approximately 10.21μm day^{-1} until the pediveliger stage was reached and spats grew in length by 16.42μm day^{-1}. Growth in length increased to an average of 12.86μm day^{-1} for all larval stages.

1.7.Reproduction–recruitment and exploitation

Study on the relation between spawning season and exploitation season for molluscs generally and scallops particularly is necessary to determine a mean of sustainable exploitation, resource protection and long benefit maintenance. The relation between gonadosomatic index and fatness index of C. nobilis during the months in the year showed that fatness of C. nobilis increases with gonadal development and decreases after spawning. The correlation between nutrition value and size, age and gonadal mature stage was reflected in variation of biochemical composition in somatic body of C. nobilis as following:

- The composition of protein, lipid and minerals increased while water content decreased with increase of size and age of C. nobilis.
- Composition of protein, lipid increased from gonadal stages I – II to gonadal stage IV and decreased at gonadal stage V. In contrast, water content decreased from gonadal stages I – II to gonadal stage IV and increased at gonadal stage V.

Overall, the nutrition value of the large scallops was higher than the small one, and the nutrition value of the mature scallop was higher than immature one. The results showed that the best time in the year for exploitation of C. nobilis was the time when they had the highest fatness index. However, this time also is the spawning season of C. nobilis. To maintain the natural population and sustainable exploitation, the following factors must be considered in a plan for sustainable exploitation.

- 1-year old C. nobilis with the first mature size of shell height smaller than 60mm.
- Nutrition value is low for small size group and age of less than 1 year old (protein composition less than 10% for individuals with size smaller than 60mm and less than 1 year old)
- Absolute fecundity is rather high for females with the first spawning (1.1-1.8 millions eggs/female)

The major mean for sustainable exploitation is that scallops should be collected only at the size of 60 mm large. Individuals with size smaller than 60mm should be left as a resource for recruitment of the next years. By this way, the ecological balance between annual exploitation and recruitment ability of scallop natural population may be maintained.

2. Growth

2.1. Study on growth relation of natural C. nobilis

2.1.1. Correlation between length and height of shells

Correlation between shell length (SL) and shell height (SH) of C. nobilis varied with size groups, especially at larval stages. For swimming larval stage with size from 90-400μ, shell length was always higher than shell height. The ratio of SH/SL was 0.82. For spat stage with size from 400μ -1mm, shells developed very fast but shell length was still higher than shell height. The ratio of SH/SL was 0.97. For juvenile with size over 1mm, the ratio of SH/SL was always over 1. This fact means that shell height of C. nobilis is always higher than its shell length. This ratio decreased gradually with the increase of size. For every size group of C. nobilis, the relation between shell height and shell length is described by a linear equation in Table 1.

2.1.2. Correlation between length and weight

For small groups, the rate of growth of size was faster than that of weight. For size groups of over 60mm, C. nobilis began to increase in weight and the growth rate increased with the increase of size. Growth of somatic body weight was fast from size of 70mm onwards. This result suggests that exploitation of small size groups should be prohibited to avoid waste of resource of C. nobilis.

Table 1: Linear equation according to size groups of C. nobilis
(where y is height, x is length)

Size groups (mm)	Linear equation	Correlation coefficient ®	Number of individuals
0.1 – 0.4	y = 0.83 x – 0.002	0.96	195
0.41 - 1	y = 1.05 x – 0.056	0.93	46
1 – 10	y = 1.13 x + 0.61	0.97	166
11 – 30	y = 1.04 x + 2.11	0.97	203
31 – 50	y = 0.95 x + 4.88	0.88	195
51 – 70	y = 0.93 x + 7.46	0.81	93
71 - 90	y = 0.88 + 12.47	0.90	58

The general equation for all groups of C. nobilis is y= 1.05 x + 1.06 (R^2= 0.99)

Correlation equations were determined by Nguyen Thi Xuan Thu (1999b) as follows:

- The correlation between shell length and total weight

$$y = 0.0005\ x^{3.064}\ (R^2 = 0.95)$$

- The correlation between shell length and somatic body weight

$$y = 0.00003\ x^{3.16}\ (R^2 = 0.93)$$

- The correlation between shell length and adductor muscle weight

$$y = 0.00002\ x^{3.03}\ (R^2 = 0.90)$$

2.2. Growth relation of cultured scallops from artificial seed

Mature broodstocks with a size of 70-89mm harvested in Phanthiet bay were selected for artificial spawning. C. nobilis population grew from the artificial seed above so called F_1 generation. The mature broodstocks with size of 50-60mm from F_1 generation were selected to produce seed which grew out later on so called F_2 generation. The F_1 and F_2 seed of C. nobilis were reared separately in suspended cages in the seawater to determine their growth and development.

F_1 generation growth equation is described in Fig. 1.

The growth curve of F_1 generation showed that at the beginning of larval stage, C. nobilis larvae grew very fast, later on the growth rate decreased gradually. The monthly growth rate value during the first three months is 3.4 times higher than during the next three months, and 9 times higher than in the following three months. During the second year, the growth rate declined more slowly so that the differences were smaller between successive 3 month periods. The mean growth rate was 9.9 % $month^{-1}$ in the first year and 1.1 % $month^{-1}$ in the second year. By May 1997, after one year of culture, the scallops had an average shell height of 52.8±1.09mm s.d and in May 1998, after two years of culture, a height of 75.4±3.5mm s.d and a length of 71.2±4.6mm s.d were reached (Table 2).

The growth rate of F_2 generation was slower than that of F_1 generation. After one month of culture, length of F_1 seed was 2.5 times longer and its height was 2.6 times higher than those of F_2 seed. The average sizes of F_1 and F_2 of 1 year old M. crassicostata were 58.98 mm and 47.61 mm, respectively.

3. Artificial seed production technique

To produce artificial seed of C. nobilis, we studied some techniques including broodstocks, spawning, larval rearing and seed rearing techniques, and the affect of environmental factors on C. nobilis. The major issues were concerned by Nguyen Thi Xuan Thu (1997a, 1998a).

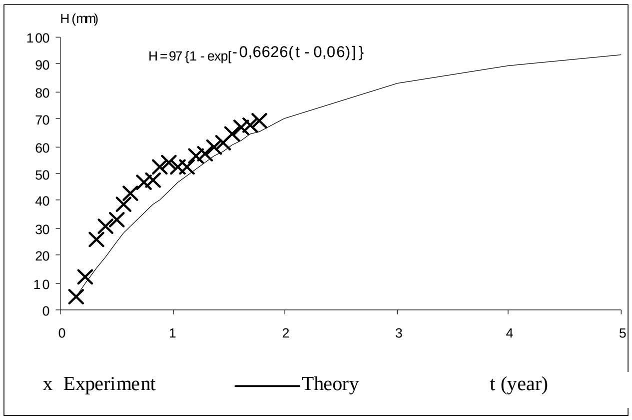

Fig 1: Von Bertalanffy growth curve of cultured C. nobilis in the first year

Table 2: Monthly changes in mean shell length, shell height and weight for scallops maintained in cages suspended at Vungro, Phuyen province of Vietnam

Time	Time from fertilized eggs	Growth in shell length	Growth in shell height	Growth in weight	n
7/5/1996	30	1.40 ± 0.03	1.48 ± 0.03		30
10/6/1996	64	3.87 ± 0.78	4.51 ± 0.95		30
12/7/1996	96	9.54 ± 2.46	11.80 ± 3.13		30
31/7/1996	115	13.97 ± 3.08	16.41 ± 3.45		30
29/8/1996	144	22.70 ± 2.97	26.12 ± 3.46	2.22 ± 0.78	30
16/10/1996	192	27.37 ± 3.27	31.30 ± 3.49	5.13 ± 1.57	30
25/11/1996	232	29.13 ± 2.78	33.27 ± 3.30	8.09 ± 1.77	30
20/12/1996	257	34.75 ± 3.79	38.67 ± 4.20	11.05 ± 7.39	12
10/1/1997	278	36.18 ± 5.21	40.58 ± 5.28	13.27 ± 4.13	20
23/2/1997	322	39.20 ± 6.59	43.40 ± 7.01	14.70 ± 4.13	15
22/3/1997	349	42.15 ± 7.63	47.20 ± 8.60	18.59 ± 5.21	13
10/4/1997	368	46.50 ± 2.65	51.75 ± 5.57	22.76 ± 5.62	16
10/5/1997	398	47.68 ± 5.05	52.78 ± 1.09	25.20 ± 2.35	18
10/6/1997	429	50.90 ± 2.25	53.67 ± 5.30	28.65 ± 3.56	15
10/7/1997	459	51.20 ± 2.40	55.84 ± 4.50	29.50 ± 3.40	15
10/8/1997	490	52.73 ± 2.89	56.87 ± 2.85	30.30 ± 4.44	10
10/9/1997	521	53.75 ± 3.08	57.32 ± 3.58	31.50 ± 7.38	20
10/10/1997	551	56.87 ± 3.38	61.33 ± 3.64	40.93 ± 6.38	16
10/11/1997	582	59.87 ± 4.31	62.87 ± 4.12	42.05 ± 6.86	24
10/12/1997	613	62.43 ± 4.38	65.71 ± 4.05	47.93 ± 9.39	14

3.1. Broodstock selection

Based on results related to the reproductive biology, selected criteria for C. nobilis broodstock were determined as below:

- Broodstocks were over 60 mm in length, healthy with unbroken shells.

- Gonadal development was at stages III or IV with gonadosomatic index over 16%.

The sex ratio was 1:2

3.2. Methods of stimulating egg spawning and sperm releasing in C. nobilis

Commonly used methods include the following:

- Air exposure stimulation: the breeders were exposed in the air from 20 –30 minutes. After that they were put into water again, then egg spawning and sperm releasing were stimulated by flowing water.

- Thermal stimulation: water temperature for spawning was increased 3-5^{0}C higher than normal water temperature.

- Light stimulation: C. nobilis broodstocks cultured in dark tank, were exposed under the sunlight on sunny days.

- Sex stimulation: sperm of male was used to stimulate egg spawning of female.

Among methods above, light stimulation method gave the best effect. The broodstock often spawn after 15-30 minutes of sunlight exposing. Other methods can give good results if selected broodstocks are in mature gonad stage.

3.3. Technique of larval rearing

Straight-hinger veligers were selected and quantified before transporting to rearing tank. Density of larvae was from 2-3/ml. Eating habit, activity and nutrition of larvae were recorded daily. 1/3 to 1/2 volume of rearing water was renewed daily. At spat stage, replacement of new water was done by flowing water method for 1 – 1.5 hours every day. Platymonas sp., Chaetoceros muelleri, Isochrysis galbana, Chlorella sp. and Nanocholoropsis were used for larval feeding. Use of specific algae depends on acceptance of larvae. Algal density for D-stage was 3000 cells/ml, after that the density increased gradually to 10,000 cells/ml for spats of 1mm. Amount of algae for feeding is based on amount of food in larval stomach, which was determined by microscope. Feeding was done twice a day after replacing new water to avoid loss of algae in rearing tank (Nguyen Thi Xuan Thu, Nguyen Bich Ngoc, 1998b). Size and density of larvae were determined every 2-3 days. Based on the observed larval growth rate, food and culture conditions were managed to maintain a normal development of larvae. At optimum culture conditions (temperature, salinity, density, water quality and food), larval eye spot appeared near center of shell on days 10 – 11 when larvae reached to size of 180 μm. D-shaped veliger larval stage was accomplished and followed by crawling stage. Spat collectors were prepared and placed into the settling tank as soon as larval eye spot appeared.

The effects of salinity and temperature on C. nobilis egg development, growth and survival of D-larvae to plantigrade stage as well as settling were studied (Nguyen Thi Xuan Thu, 1997a). The ecological range was determined as following:

Salinity:

- Fertilized eggs were able to develop into D-larvae from 20-40‰ with optimum range from 30-35 ‰

- D-larvae stages were able to survive to the Umbo stage when cultured in salinities from 21-36 ‰ with the best survival occurring between 30-33 ‰ (55-60%)

- The 1 month old seeds were able to develop in salinities from 25-35 ‰ with optimum range from 29-33 ‰

Temperature: C. nobilis larvae can develop normally in the temperature range from 25- 31 ^{0}C with the optimum range from 27-29^{0}C.

3.4. The result of C. nobilis hatchery seed production

Hatchery seed production of C. nobilis began in May 1992. For the first time at the experimental scale, survival rates from eggs to spat and from D-stage to spat were 1% and 1.7% respectively. 500,000 spats of 1-2mm were harvested. From 1992-1994, because of lack of unicellular algae for feeding M. crassicostata larvae, Chactoreros sp. and an artificial diet such as AP, BP...were used. This resulted in low survival and many experiments were not successful. In 1995, due to a cooperative study with Chinese experts, algae such as Chaetoceros muelleri, Platymonas sp., Isochrysis galbana were imported from China. Use of these algae increased the effectiveness of M. crassicostata larval rearing and resulted in a higher survival rate. In 1996 and 1997, the hatchery seed production was repeated to confirm stable ability of the technique. The experimental technique was developed at a production scale in the Binhthuan Fisheries Expansion Center. In addition, the techniques for C. nobilis hatchery seed production were used on oyster Pinctada martensii with very good results. From 1996 to 1999, 2-3 million seeds of P. martensii were supplied for Vietnam Pearl Company in Vanninh, Khanhhoa province each year according to their specifications to confirm stabilization of the technique. This technique can be applied for hatchery seed production of C. nobilis if enough suitable conditions are developed in the future.

The highest survival from D-stage to spat is 9.5%. The results of some experiments of C. nobilis seed production are shown in Table 3.

Table 3: C. nobilis log-book of experiments on hatchery seed production

Number	Time	Total egg ($x 10^6$)	Total D-stage ($x 10^6$)	Total Umbo ($x 10^6$)	Total spat ($x 10^6$)	Survival rate (%)	
						Egg-spat	D- spat
1	2/6-26/6/92	2	1.2	0.08	0.02	1	1.7
2	11/6-30/6/93	7.5	6	4	0.15	2	2.5
3	7/8-18/8/93	13	6.5	0	-	-	-
4	15/9-20/9/93	23.6	15	3.2	-	-	-
5	10/9-30/9/93	5	4.3	4	0.025	0.5	0.58
6	9/5-22/5/94	86	30	1	-	-	-
7	12/5-14/6/94	43	12	3	0.5	1.2	4.2
8	20/7-10/8/94	20	8	2	0.004	0.0002	0.0005
9	5/4-8/5/95	35	30	25	2.5	7.1	8.3
10	17/5-2/7/95	45	31.7	22.4	3	6.7	9.5
11	6/4-25/4/96	60	12	-	0.65	1.09	5.5
12	1/4-27/4/97	5	2	-	0.15	3	7.5

4. Experiment on suspended culture of C. nobilis from artificial seed and observation of reproductive ability of the scallop cultured in Vungro (Phuyen)

In Vungro, C. nobilis artificial seeds were hung in long lines at the depths of 6-8m, and with a density of 100-150 individuals/cage (35 x 35 cm). Cleaning of waste and fouling predators was done twice monthly. Growth and survival rates were recorded monthly (Nguyen Thi Xuan Thu, 1999b). After 19 months (from spat stage) and 20 months (from fertilized egg) of culture, C. nobilis average sizes were 62.43 $\pm$ 4.38 mm in length, 65.71$\pm$ 4.05 mm in height and 47.93$\pm$ 9.39g in weight. Average survival rate was 80%.

The size and age at maturity of cultured C. nobilis were small. For the F_1 generation, the first mature age was 8 months old corresponding with size of 34mm. For F_2 generation, the first mature age was 3 months old corresponding with size of 16mm. Spawning season concentrated from December of the year before to June of the next year. There were significant differences in mature ability and mature ratio between F_{1} - and F_2 generation. Fecundity of cultured M. crassicostata F_1 was lower than that of natural C. nobilis at the same size group (50-60mm). Absolute fecundity ranged from 227,138 – 1,646,513 (904,000 eggs/female in average). Relative fecundity ranged from 455,491 – 1,097,675 (825,797g/ovary weight in average).

Table 4: Sex ratio of the adult population of the scallop in Binhthuan waters, October 1993-October 1994

Month	Total no. of sample	Male		Female		Sex ratio
		No	%	No	%	
10/93	32	12	35.50	20	64.50	1:1.66
11	31	12	37.71	19	62.29	1:1.58
12	42	15	35.71	27	64.29	1:1.80
1/94	69	27	39.13	42	60.87	1:1.55
2	30	12	40.00	18	60.00	1:1.50
3	42	20	47.62	22	52.38	1:1.10
4	59	27	45.76	32	54.24	1:1.18
5	85	32	37.65	53	62.35	1:1.66
6	30	14	46.67	16	53.33	1:1.14
7	42	20	47.62	22	52.38	1:1.10
8	60	31	51.61	29	48.39	1:0.93
9	30	12	40.00	18	60.00	1:1.50
10/94	30	15	50.00	15	50.00	1:1.00
Total/average	**582**	249	42.93	333	57.07	1:1.34

Table 5: Sex ratio in size of the scallop in Binhthuan waters

Size groups (mm)	Total no. of sample	Male		Female		Ratio M:F
		No.	%	No.	%	
<50	72	40	55.56	32	44.44	1.25:1
51-60	75	41	54.67	34	45.33	1.2:1
61-70	157	64	40.76	93	59.24	1:1.45
71-80	154	57	37.01	97	62.99	1:1.7
81-90	66	23	34.85	43	65.16	1:1.87
>90	5	-	-	5		-
Total/ Average	529	225	43.53	304	57.47	1:1.35

DISCUSSION

Reproductive biology

The seasonal change in the gonad index and frequency of mature stage show clearly that spawning of scallop C. nobilis in Binhthuan province occurs around the year. Prior authors have noted this year-around pattern, but reported different time of spawning peaks. These researches suggest that the peak spawning times occur from May to August (Nguyen Trong Nho, 1986), from April to October with a peak in July (Nguyen Huu Phung, 1991) or with two peaks, between July-August and January–February (Vo Si Tuan, 1997). A zone of strong upwelling each year in Binhthuan causes variations in environmental factors such as food supply and temperature. Scallops need a minimum threshold temperature to start gamete differentiation and to succeed through gametogenesis (Sastry 1966, 1979; Thorarinsdottir 1992). In some years, gamete development may have started during a time of low sea temperature.

In this study the hermaphroditic gonads were found with a small number of hermaphroditic individuals changing from female to male. Nguyen Trong Nho (1986), Nguyen Huu Phung. (1991) found that C. nobilis is unisexual. They also reported that both sexes were equal in numbers and no sex changes were observed. This study shows that males predominate (55%) at size < 60mm, but larger scallops are 62%. The overall sex ratio is dominated by female 1:1.3. This, and the small proportion which is hermaphroditic, changing from male to female, may indicate that C. nobilis is a protandric hermaphrodite. However, more studies of its sexuality are needed to prove this condition.

Table 6: The absolute and relative fecundity of scallops in Binhthuan (means are given in parentheses)

Size groups (mm)	Absolute fecundity (Eggs/Ind.)	Relative fecundity		
		Eggs/ gam (with shell)	Eggs/gr. (without shell)	Eggs/gr. ovary
50-60	1.100.000 - 1.800.000 (1.600.000 ± 291.250)	49.100 - 81.100 (74.700 ± 6.473)	176.400 - 226.000 (217.200 ± 6.736)	978.000 - 1.298.600 (1.000.000 ± 143.480)
61-80	2.200.000 - 3.400.000 (3.000.000 ± 443.880)	35.000 - 70.000 (67.300 ± 12.026)	100.500 - 191.200 (184.000 ± 26.452)	995.700 - 1.145.700 (1.000.000 ± 70.370)
81-92	3.000.000 - 4.500.000 (3.800.000 ± 549.770)	45.000 - 52.000 (47.900 ± 23.420)	114.800 - 139.000 (122.500 ± 15.642)	1.043.900 - 1.146.000 (1.100.000 ± 42.197)
Average	2.800.000 ± 1.004.988	65.000 ± 30.021	175.000 ± 65.280	1.000.000 ± 145.818

The fecundity of C. nobilis has been studied by various authors. The fecundity of C. nobilis reported in this study is lower than in former studies. Fecundity ranged from 4.6 – 13.5 million eggs per individual with shell of 61-90 mm (Nguyen Trong Nho, 1986). Zhang Dan (1994) reported the fecundity of C. nobilis in Guang Dong of China about 2.5 million, 8-10 million and 18 million for one, two and four years old respectively.

Growth of C. nobilis

In general, the time to reach commercial size for the scallops depends on the species, location and culturing method (Thorarinsdottir, 1996).

Comparison of the shell growth of tropical scallops C. nobilis cultured in Vungro, Vietnam with that of the suspended culture in the temperature zone congener Chlamys islandica shows similar growth in spring and summer, with the maximum growth rate and differences in growth in the winter in Iceland. One year after settlement, the Iceland scallops reach an average height of 9.8 mm, while C. nobilis reaches an average height of 52.7 mm. The Iceland scallops required 4 years to reach market size (60-70mm) (Thorarinsdottir, 1994) while the C. nobilis required only 1.5 – 2 years. In comparison with other tropical scallops, the shell of Euvola (Pecten) ziczac in Venezuela generally attains about 46 mm in length after 7 months in suspended culture but in partly buried cages they attained 70-80mm in about 1.5 years (Ve'lez et all, 1995). Their growth rate was slightly higher than reported here for C. nobilis in Vungro.

Hatchery seed production of C. nobilis

Hatchery seed production of C. nobilis was established at the Wakayama Prefectural Sea-farming Center of Japan in 1973 (Tomori et al. 1992) and in Guang Dong of China in 1976 (Shan & Quo 1982). The mean survival rates of the spat in the rearing tanks were 2.7% in Japan and 6.3% in China.

This study has shown that hatching and rearing of C. nobilis larvae are possible and the survival rate is the same and lightly higher.

Culture of scallops in Vietnam is still in its experimental stage. Better rearing techniques and expansion of the growth-out culture need to be developed.

Prospect of developing C. nobilis in coastal waters of Southern Central Vietnam

Comparing to fish culture, C. nobilis culture technique is simpler, does not require an artificial food supply and does not pollute the environment. Moreover, reproduction of C. nobilis supplies more larvae which are used as food for zooplankton fed species, increases secondary production in seawater, resulting in increasing production of economic species. Because the natural stocks of C. nobilis have been declining and culturing techniques have only recently been developed, production has not met domestic and export requirements. Development of culture of C. nobilis and other molluscan species is the only way to utilize the abundant natural food resource in order to increase production and exploit effectively the advantages of the sea for the national economy. In near future, development of culture of C. nobilis will require the support of Government, the Ministry of Fishery as well as relevant offices and fishermen.

RECOMMENDATION

1. C. nobilis is a valuable export sea-product. However, due to the impact of human activity, both its average size and rate of harvest are declining. The scallop resource should be protected to maintain benefits. Over time exploitation in spawning season should not be prohibited, but harvesting of small individuals less than 60mm should be prohibited. This measure should be undertaken by managing indexes of exploitation and product consumption. Prohibiting consumption of products processed from small size individuals of C. nobilis would limit overfishing that is contributing to decline the natural population.

2. Along with natural resource protection, culture of C. nobilis from artificial seed should be expanded. Effective simple culture models for fishermen should be developed. To obtain good results, it is necessary to have synchronous coordination among managing offices, scientific offices and fishermen.

3. Based on hatchery seed production of C. nobilis, molluscan culture should be expanded by studying hatchery seed production technique for other economic bivalve species such as clams, mylitidea.

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