ISSN: 0001-5113 AADRAY	ACTA ADRIAT. 34 (1/2): 77 - 87, 1994	UDC: 639.42 Original scientific paper

The impact of hydrographic conditions on the possibilities of rearing the Mediterranean mussel (*Mytilus galloprovincialis*, Lamarc) in the Rijeka dubrovačka estuary

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The paper discusses the results of research into the hydrographic conditions (temperature, salinity, oxygen, pH and transparency) of the Rijeka dubrovačka estuary and the impact of these conditions on the season and intensity of spat settlement, as well as growth to marketable size, mortality, and the index of condition of adult mussels.

Due to constant fresh water inflows the area has low salinity values at surface (often lower than 20 x 10^{-3}) and less pronounced temperature variations than those characteristic for the Adriatic coast. Best mussel settlement was recorded at 1 m depth (1406 ind/100 cm^2) in spring, and relatively fast growth and low mortality rate of adults were recorded. At 3 m depth mussels needed 4 months to reach marketable size. The quality of mussels was excellent with the highest values of index of condition (Baird's 74.62%, and Hopkins' 17.76%).

INTRODUCTION

A number of studies on the biology and ecology of mussels, the possibilities of commercial cultivation, and the improvement of the rearing mussel technology, have been conducted in numerous bays and estuaries on the eastern coast of the Adriatic Sea. The following publications concern the coast of Istrian peninsula (NIKOLIĆ and STOJNIĆ, 1963; HRS-BRENKO, 1967, 1971 a, b, 1973 a, b, 1980, 1983; HRS-BRENKO and FILIĆ, 1973; HRS-BRENKO *et al.*, 1986; BOHAČ *et al.*, 1984), the Krka River estuary (MARGUŠ, 1983, 1985; MARGUŠ and TESKEREDŽIĆ, 1986; MARGUŠ *et al.*, 1988), the Bay of Mali Ston (MOROVIĆ and ŠIMUNOVIĆ, 1969; ŠIMUNOVIĆ, 1981) and the Boka Kotorska Bay (STJEPČEVIĆ, 1974; HRS-BRENKO, 1983).

The Rijeka dubrovačka estuary has never been investigated, and the initiative for this study was VALLE *et al.* (1898) publication which indicates this area as a fish and molluscs rearing site, as well as more recently occasional mentions that this locality could be a convenient one for shellfishery.

This paper presents the results of one-year comparative research of the hydrographic conditions and some phases of the life-cycle (attachment of spat, growth, mortality and index of condition of adults) of the Mediterranean mussel (*Mytilus galloprovincialis*, Lmk.) in the Rijeka dubrovačka estuary.

GEOGRAPHIC LOCATION AND RESEARCH METHODS

The Rijeka dubrovačka estuary is situated northwest from Dubrovnik (South Adriatic Sea) (Fig. 1). The estuary is 5.3 km in length, and averages 300 m in width. Actually, it is subsided valley of the river which bears the same name. In the innermost part of the estuary, there is a strong karstic spring (capacity of 3-5 $m^3 s^{-1}$) and a brook of a varying yield. The coast of the estuary is cut into the flysch layers and separated from its hinterland by a steep limestone barrier. The depth of the outer part of the estuary ranges from 20 m (offshore the Sustjepan village) to 33 m (in the mouth), and gradually decreases towards the inner part to only 5 meters depth. The inner part of the estuary narrows towards the spring and into a 2-3 m depth river bed flanked by a wide zone of alluvial sediments on either bank. Permanent and alternating landward and seaward air currents are typical for this area. The strong northern wind ("bura") causes the outward going sea current.

The hydrographic data (temperature, salinity, oxygen, pH, transparency) were recorded twice a month from May 1984 until May 1985. Temperature, salinity, oxygen and pH were checked by a probe (HORIBA water checker, model U-7) from the surface, 0.5 m, and every meter to 4 m depth. The transparency was measured by the Secchi disk (30 cm in diameter).

Several seed collectors (25 mm in diameter, and 4 m long nylon rope) were used for larval attachment. A weight secured the ropes to hang vertically in the sea water. The collecting ropes were taken out of the water after two, and again after four months, from July 1984 to October 1985. The section (20 cm) of the rope was cut off as a sample, at 0.5 m, and at every one meter from the surface down to the sea bottom (4m).

The experimental mussels (30-50 mm and 43.6 mm in mean length) originating from the Bistrina rearing place (the Bay of Mali Ston), were suspended in nylon nettings on the support pillars of the existing yachting marina, in May 1984.

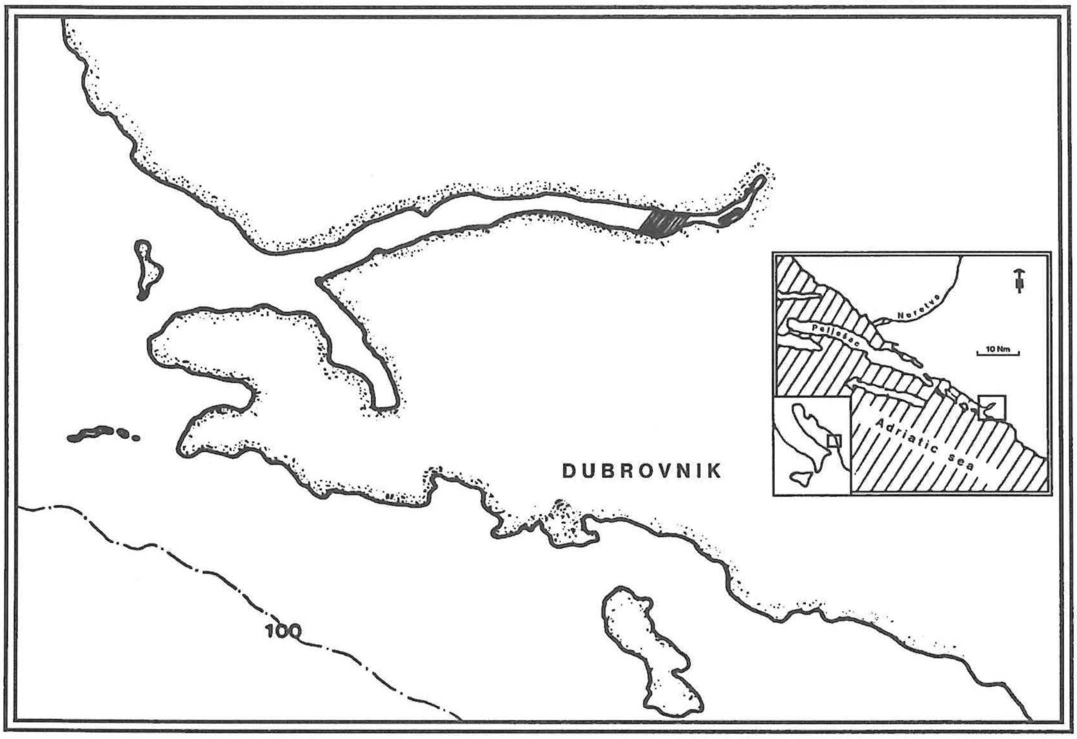

Fig. 1. Study area (The Rijeka Dubrovačka estuary)

The nylon nettings (stocking-shaped) ("pergolar") 60-70 cm in length filled with mussels were used to monitor the growth, mortality, index of condition and the percentage of organic matter in the flesh and shells. The nettings were suspended at 1 m and 3 m depth.

The growth rates of 50 mussels was monitored every month until they reached marketable size (60 mm) using a vernier caliper. The mortality of mussels was recorded by the count of dead individuals in the plastic fishing racks suspended at the depth of 1 m and 3 m, respectively.

To calculate the index of condition, BAIRD (1958) and HOPKINS (MANN, 1978) methods were used.

The percentage of the organic matter in the flesh, as well as in the shells was derived from the weight difference between the dry flesh and the ash which remained after incineration of the samples at the temperature of 550 °C over the period of 24 hours.

RESULTS

The hydrographic parameters (temperature, salinity, oxygen, pH and transparency), particulary with regard to the upper layers of the sea water, are largely dependent on the continuous fresh-water inflow of the spring. The water temperature increased from January, and reached highest values in summer at 0, 2 and 4 m depth (Fig. 2). More fluctuations were observed at surface layer. The rapid warming of the deeper sea water layers started somehow later than surface ones in spring, when the vertical stratification was established. Due to fresh water inflows, during summer and autumn, inverse stratification was formed (colder surface than deeper layers). The isothermy was observed in winter months.

In July and September 1984 and March 1985 extremly low salinities (about 5 x 10^3) were recorded at surface. In the deeper layers the salinity was always higher, with less prominent variations (Fig. 3).

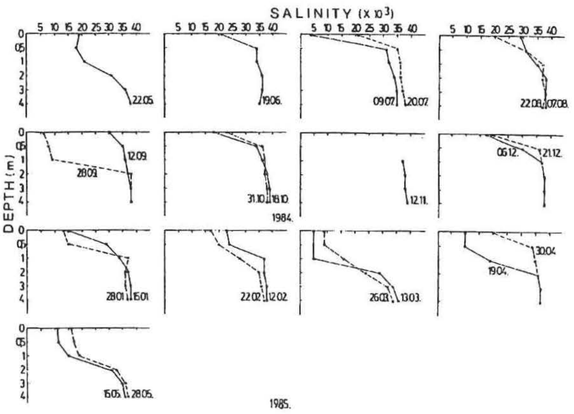

Fig. 3. Salinity (x 10^3) changes from 0 to 4 m depth in 1984 and 1985 (Data missing on November 12 is due to technical difficulties)

During these investigations, the dissolved oxygen reached its lowest mean value (7.6 mg O_2 l^{-1}) at 4 m depth in July, whereas the highest one (12.3 mg O_2 l^{-1}) at 3 m depth in February (Fig. 4).

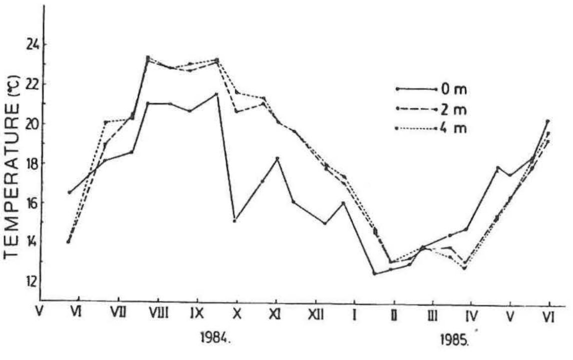

Fig. 2. Temperature (°C) changes at 0, 2 and 4 m depth from May 1984 to May 1985

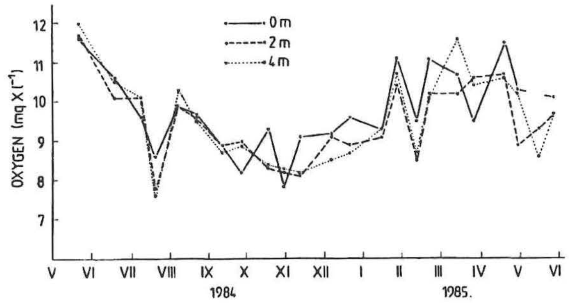

Fig. 4. Dissolved oxygen (O_2 l^{-1}) at 0, 2 and 4 m depth from May 1984 to May 1985 (Data missing on May 15 is due to technical difficulties)

Throughout the investigations, a maximum pH 8.4 was recorded at 4 m depth at the end of May, in August 1984 and end of January 1985, whereas a minimum even 7.5 at the surface in March 1985 (Fig. 5). The variations of pH values in the surface layers were more pronounced than those in the deeper layers.

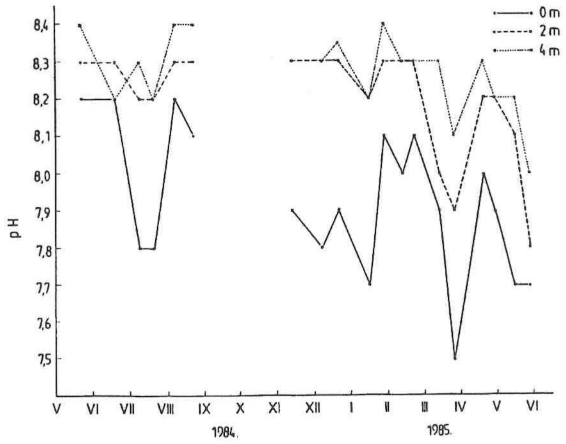

Fig. 5. pH changes at 0, 2 and 4 m depth from May 1984 to May 1985 (Data missing on September 12 and 28, October 18 and 31 is due to technical difficulties)

The sea water transparency in the Rijeka dubrovačka estuary ranged from 2.5 to 4.5 (at the bottom), with the calculated annual mean 3.8 m (Table 1).

The results indicate only one settlement season of mussel spat, occurring between February and June 1985. The number of attached individuals on the rope increased from the surface (19/100 cm^2) with maximum at 1 m (1406/100 cm^2), then followed a decrease toward 4 m depth (266/100 cm^2). Only three mussel juveniles between 0.5 and 2 m depth were observed on the collector analyzed in October 1985 (Fig. 6).

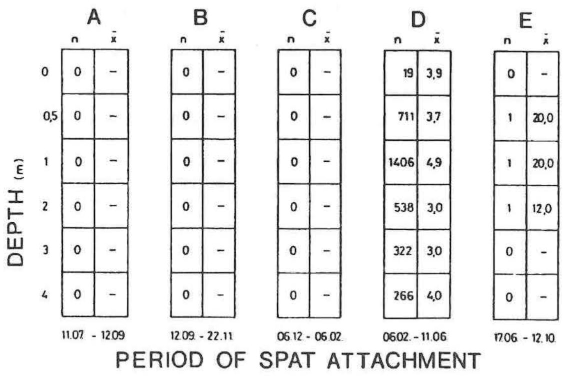

Fig. 6. Attachment of juvenile mussels on A - E collectors (n = number of individuals / 100 cm^2; $\bar{x}$ = mean length of an individual) between the 0 and 4 m depth from July 1984 to October 1985

Mussels at 1 m depth reached the mean length of 64.5 mm in March 1985 (the end of the testing period). They were already marketable size ($\bar{x}$ = 62.1 mm) in January. The highest monthly increase in length (5.5 mm) was recorded in August, and the mean daily increase 0.17 mm in July and August 1984 (Table 2; Fig. 7). At 3 m depth mussels reached the marketable size ($\bar{x}$ = 61.8 mm) even in September 1984. At the end of experiment, in March, mussels were about 71.1 mm in mean length.

Table 1. Water transparency (m) in the Rijeka dubrovačka estuary from May 1984 to May 1985

1984.			
DATE	TRANSPARENCY (m)	DATE	TRANSPARENCY (m)
22/05	4.5	12/11	4.0
19/06	3.0	06/12	4.0
09/07	4.5	21/12	4.5
20/07	3.5		
07/08	2.5		
22/08	2.5		
12/09	4.0		
28/09	2.5		
18/10	2.5		
31/10	4.5		

1985.	
DATE	TRANSPARENCY (m)
15/01	4.0
28/01	4.5
12/02	4.5
22/02	3.5
13/03	2.5
26/03	4.5
19/04	4.5
30/04	4.5
15/05	4.5
28/05	3.5

Table 2. Mean monthly increase in length (mm), height (mm), width (mm) and weight (g) of mussels in Rijeka dubrovačka estuary from May 1984 to March 1985

Date	Mean length (mm)	Mean height (mm)	Mean width (mm)	Length increase (mm)	Height increase (mm)	Width increase (mm)	Mean weight (g)
			1 m depth				
24/05/1984.	43.6 ± 5.1	24.1 ± 2.7	15.2 ± 1.9	-	-	-	7.3
19/06/1984.	47.9 ± 5.6	25.5 ± 2.6	16.6 ± 1.9	4.3	1.4	1.4	9.1
20/07/1984.	51.4 ± 4.9	26.9 ± 2.4	18.5 ± 2.0	3.5	1.4	1.9	11.9
22/08/1984.	56.9 ± 5.1	29.4 ± 2.5	20.9 ± 1.8	5.5	2.5	2.4	17.1
28/09/1984.	58.3 ± 4.2	29.0 ± 2.7	21.7 ± 1.6	1.4	-	0.8	18.8
31/10/1984.	57.5 ± 7.0	28.8 ± 2.3	22.5 ± 2.4	-	-	0.8	18.9
06/12/1984.	59.3 ± 6.1	30.1 ± 2.8	23.2 ± 2.1	1.8	1.3	0.7	21.1
15/01/1985.	62.1 ± 6.1	30.9 ± 3.2	24.9 ± 2.1	2.8	0.8	1.7	22.0
22/02/1985.	63.8 ± 5.6	31.8 ± 3.0	25.0 ± 2.1	1.7	0.9	0.1	24.7
26/03/1985.	64.5 ± 4.9	31.7 ± 1.7	25.7 ± 2.0	0.7	-	0.7	23.8
			3 m depth				
24/05/1984.	43.6 ± 5.1	24.1 ± 2.7	15.2 ± 1.9	-	-	-	7.3
19/06/1984.	47.8 ± 5.9	25.8 ± 2.9	16.5 ± 1.9	4.2	1.7	1.3	8.6
20/07/1984.	49.7 ± 6.3	26.6 ± 3.0	17.6 ± 2.4	1.9	0.8	1.1	11.0
22/08/1984.	59.0 ± 4.3	30.1 ± 2.5	21.2 ± 1.7	9.3	3.5	3.6	18.2
28/09/1984.	61.8 ± 7.4	31.8 ± 2.8	22.6 ± 2.7	2.8	1.7	1.4	22.3
31/10/1984.	61.8 ± 6.6	32.2 ± 3.0	22.4 ± 2.3	-	0.4	-	21.9
06/12/1984.	61.7 ± 6.3	31.3 ± 2.6	22.9 ± 2.7	-	-	0.5	21.8
15/01/1985.	64.7 ± 6.1	33.3 ± 2.3	24.0 ± 2.4	3.0	2.0	1.1	24.0
22/02/1985.	68.6 ± 5.9	34.4 ± 3.2	25.4 ± 2.6	3.9	1.1	1.4	26.2
26/03/1985.	71.1 ± 6.1	36.0 ± 2.8	26.4 ± 2.3	2.5	1.6	1.0	30.1

Maximum monthly increase 9.3 mm with an mean daily growth rate of 0.28 mm was recorded in August (Table 2; Fig. 7).

The highest increase of mussels in weight was 5.2 g at 1 m, and 7.2 g at 3 m depth in August 1984 (Fig. 8).

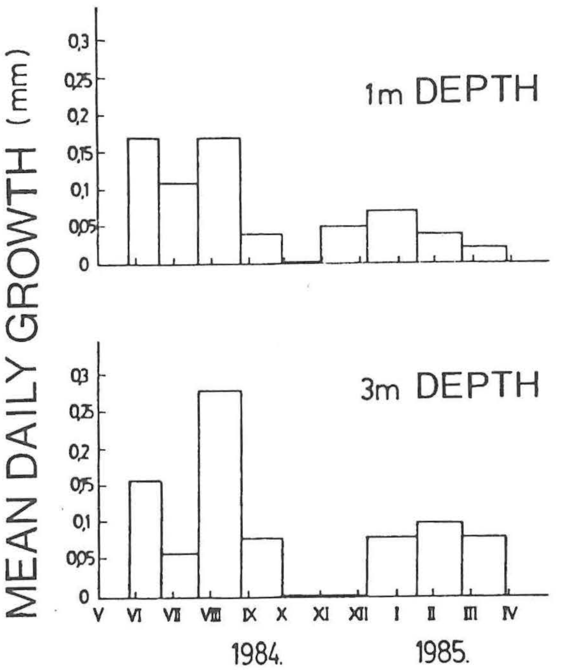

Fig. 7. Daily mean increase in length (mm) of mussels at 1 and 3 m depth, respectively, from May 1984 to March 1985

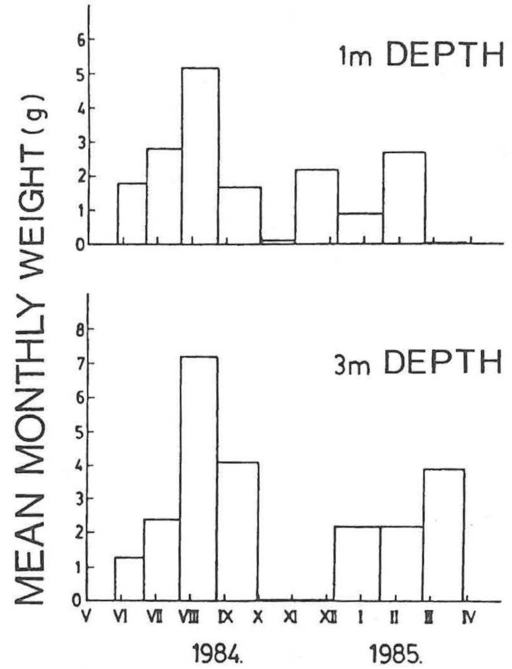

Fig. 8. Monthly mean increase in weight (g) of mussels at 1 and 3 m depth, respectively, from May 1984 to March 1985

The mortality of experimental mussels was insignificant; the highest one was 2.96% at 3 m, and 2.10% at 1 m depth in January 1985 (Fig. 9). The total mortality throughout the sampling period was somewhat lower at the 1 m layer (8.00%) than at 3 m depth (13.33%).

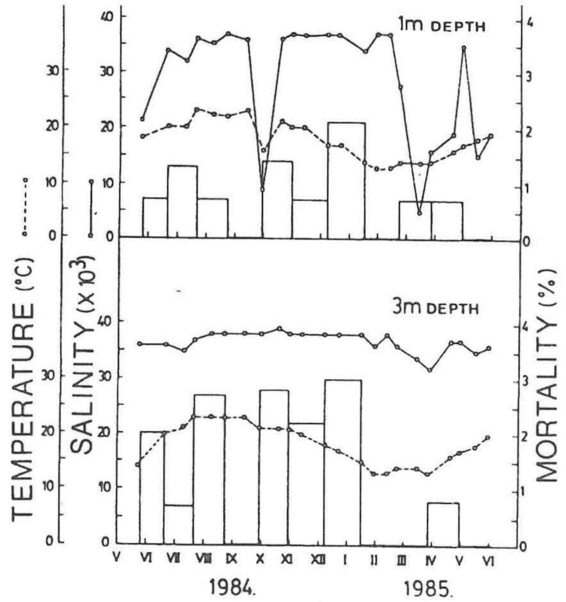

Fig. 9. The impacts of salinity (x 10^3) and temperature (°C) changes on the mortality of mussels (%) recorded at 1 and 3 m depth, respectively, from May 1984 to May 1985

The highest value of the Baird's volumetric index of condition 74.62 at 1 m and 72.30 at 3 m depth was recorded in September 1984 at both sampling depths (Fig. 10). The highest value of the Hopkins' gravimetric index of condition 17.76 at the 1 m and 16.21 at the bottom layers was recorded in August (Fig. 10).

The water content in the mussel flesh ranged from 73.44% in July to 89.50% in February at 3 m depth. Mussels at 1 m depth had almost the same amount of content throughout the investigation except in June. The amount of organic matter in the flesh was as usual in an inverse ratio with the amount of water (7.42% in February and 22.66% in July). The largest percentage of ash (4.17%) was recorded in May, and the smallest one (1.83%) at 1 m in September (Fig. 11). The amount of water in shells varied between 0.36% and 0.87%, the

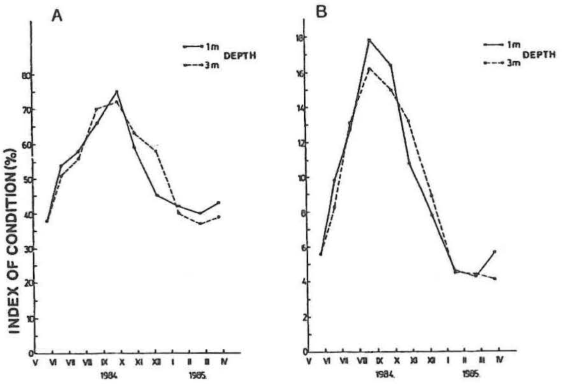

Fig. 10. Indexes of condition of mussels according to Baird (A) and Hopkins (B) from May 1984 to March 1985.

organic matter ranged from 3.57% to 4.35% and the amount of ash between 94.84% and 95.99% at both sampling depths (Fig. 11).

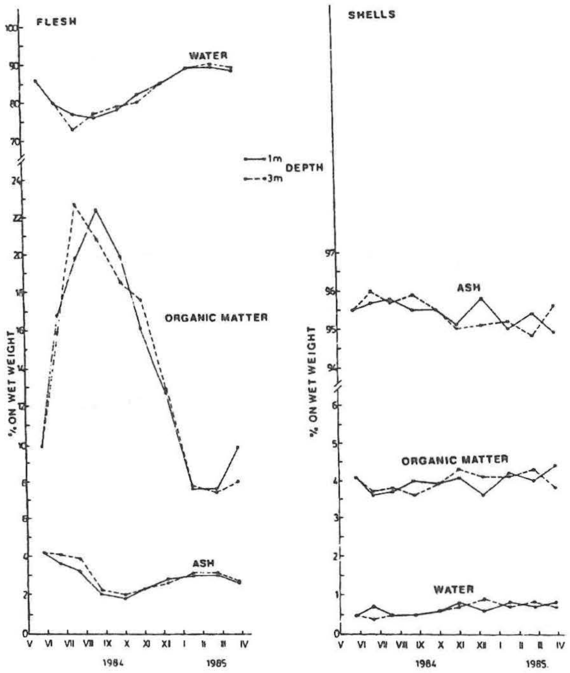

Fig. 11. Changes of the content of water, organic matter and ash in the flesh and shells of mussels from May 1984 to March 1985.

DISCUSSION AND CONCLUSIONS

Hydrographic data indicated that Rijeka dubrovačka estuary is a typical estuary area. Thus, due to strong influence of the spring on entire Rijeka dubrovačka estuary, the surface layers are cooler then deeper ones during summer and autumn, and warmer in winter and spring months. In addition, the river spring influences the significant fluctuations of salinity at the upper layers of the estuary.

Content of dissolved oxygen as well as pH values did not reach critical level for mussel survival in the inner part of the estuary.

The transparency of the water column also depends on the fresh-water inflow and the amount of organic detritus, which is distributed as suspended particles, increases with the increased intensity of the inflow. During less intensive inflow, the sea water becomes more transparent, and due to shallow water the sea bottom is often visible.

Only one year observations cannot determine accurately the length of the settlement season and the intensity of spat attachment. Therefore the investigations are neccesary to be continued.

Intensive mussel settlement occurring only in spring 1985 (February to June) is also characteristic in some areas of the northern Adriatic sea (HRS-BRENKO, 1973 a; 1980). In some parts of the Krka River estuary and Boka Kotorska Bay there were recorded two settlements of various intensity, one in spring and another one in autumn (MARGUŠ and TESKEREDŽIĆ, 1986; STJEPČEVIĆ, 1974).

The length of the settlement season depends on the successful reproduction, larval development in the plankton and environmental conditions (HRS-BRENKO, 1989; 1990). In the Rijeka dubrovačka estuary convenient range of sea water temperatures (higher than 12 °C and lower than 22 °C), and probably accompanied with enough available food enable the normal gametogenesis, unrollment spawning and larval development of mussels. According to BAYNE (1964) mature mussel larvae are geonegative, swim near the surface, where usualy attach themselves on hard support. However, in the Rijeka dubrovačka estuary, the highest amount of the attached spat was recorded at one meter below the surface. It seems that strong fresh-water inflow which could significantly decrease surface temperature (often below 20 °C) is responsible for more intensive mussel settlement in deeper water (at 1 m in 1985) than at surface.

Attached individuals (1406/100 cm^2) indicate that the Rijeka dubrovačka estuary belongs to the category of areas with high intensity of mussel recruitments. At Vela Draga Bay (the Northern Adriatic Sea), the number of mussels attached on experimentall glass plates ranged from 7 to 425 per 100 cm^2 and 585 individuals per 100 cm^2 on the rocky shores around Rovinj (HRS-BRENKO, 1973 a; 1980). In the Krka river estuary a maximum of 5249 individuals per 125 cm^2 was counted on suspended ropes (MARGUŠ and TESKEREDŽIĆ, 1986). In the Boka Kotorska Bay STJEPČEVIĆ (1974) recorded 5000 mussels per 1 m of the rope. Covering only a part of the settlement season (winter months), HRS-BRENKO (1983) recorded 58 juveniles per 100 cm^2 on the rope collector in Tivat Bay.

The suitable temperature regime of the estuary, as well as the enough available food, probably caused a rapid growth of mussels to the marketable size.

In the Mediterranean, and also in other areas, where the temperature variations are considerable seasonal variations in the intensity of mussel growth are characteristic with the maximum rate increase in summer (BOHLE, 1972; INCZE *et al.*, 1978; VALLI, 1980). In the Rijeka dubrovačka estuary, the peak of the growth was in the warmest parts of the year.

Some authors (PAUL, 1942; REMANE and SCHLIEPER, 1971; JAMIESON *et al.*, 1975) suggested that the growth of mussels *Mytilus edulis* and *M. californianus* was slower, also in considerably low salinity water. In this case the growth rate is probably possible due to eurihaline properties of mussel species. It seems that less intensive mussel growth in the surface layers of the Rijeka dubrovačka estuary is not only due to low salinity, but also to a high number of fauling organisms which compete for food. Thus at the depth of 3 m where salinity is considerably higher, the number of fauling organisms is less abundant, the growth of mussels was better and they reached marketable size in four months (61.8

mm), while the mussels suspended at 1 m depth needed almost twice as long to reach the same size.

The Rijeka dubrovačka estuary may be considered as the very favourable area for mussel rearing. The maximum daily mean growth of the experimental mussels was 0.28 mm recorded at 3 m depth. In the areas of northern Adriatic these values were considerably lower (0.083 mm in Lim Channel, 0.052 mm in Pomer Bay and 0.127 mm in delta of river Po) (HRS-BRENKO and FILIĆ, 1973; CECCHERELLI and BARBONI, 1983). In Krka estuary, MARGUŠ (1983) reported the growth of 0.277 mm, and STJEPČEVIĆ (1974) 0.170 mm for Boka Kotorska Bay.

The gravimetric and volumetric index of conditions agree with the water temperature variations, and mussel's reproductive activity. The maximum values were recorded in the summer and autumn when mussels become sexually inactive, and intensively accumulate nutrients in their flesh. After the spawning (loosing the organic matter by ejecting reproductive cells) the values of the both indexes decrease abruptly in the end of autumn. During winter months indexes were low until late spring.

The impact of changed salinity on seasonal variations of the index of conditions has not been observed. Thus at 1 m depth (salinity below 10 x 10^3) they do not differ significantly from the index values recorded at 3 m depth where salinity is much more stable.

The calculated maximum values of the both indexes were much higher (17.76 Hopkin's and 74.62 Baird's) than those reffered in other parts of the Adriatic (HRS-BRENKO, 1967, 1973; BOHAČ *et al.*, 1984; MARGUŠ, 1985). According to MARGUŠ (1985), Hopkin's index of condition ranged between 4.63 and 14.22% in the Krka estuary.

The extremely high values of both indexes recorded in the Rijeka dubrovačka estuary are probably the consequence of transfering the mussels from Bistrina (the Bay of Mali Ston) to an ecologically more favourable environment for them, or even the result of a shock due to the change. A similar situation was reported by MARGUŠ (1983) for the Krka estuary.

The analysis of the seasonal variations of the index of condition have not shown any significant difference from one sampling depth to another. The slower drop in the index value at 3 m depth than at the 1 m in autumn may be attributed to a higher amount of the phytoplankton in this layer.

The mortality in general was low. At 1 m depth (8.00%) lower than at 3 m depth (13.33%). This may be due to a higher turbidity which tends to occur in deeper layers.

According to SEED (1969), only extreme values of salinity and temperature or an excessive turbidity may cause a high mortality of mussels under natural conditions. According to MAURIN (1976), FISCHER (1948) and VERWEY (1952) *Mytilus edulis* is capable of surviving in brakish waters even at 4 - 6 x 10^3. This statement was also supported as to *M. galloprovincialis* (HRS-BRENKO, 1967).

It seems that temporary decreases in salinity at the surface layer of the Rijeka dubrovačka estuary and a larger number of fauling organisms on the racks did not affect much the survival of the mussels.

ACKNOWLEDGEMENTS

This work has been suported by the Board for Scientific Research of Croatia and Hotel Tourist Enterprise of Dubrovnik.

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Accepted: August 29, 1994

Utjecaj hidrografskih faktora na mogućnosti uzgoja Mediteranske dagnje (*Mytilus galloprovincialis*, Lamarck) u estuariju Rijeke dubrovačke

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KRATKI SADRŽAJ

Estuarij Rijeke dubrovačke spominje se u prošlosti kao poznato ribolovno područje, a Valli *i sur.* (1898) ga navode kao uzgajalište riba i školjaka. U cilju ispitivanja mogućnosti revitalizacije uzgoja školjkaša na ovom području, tijekom 1984/85. god. provedena su istraživanja nekih faza životnog ciklusa mediteranske dagnje (*Mytilus galloprovincialis*, Lmk.).

U radu se iznose rezultati istraživanja hidrografskih faktora (temperatura, salinitet, kisik, pH i prozirnost) i njihov utjecaj na vrijeme i intenzitet prihvata mlađi po dubinama, te rast, mortalitet i indeks kondicije odraslih dagnji.

Dagnje veličine 30-50 mm, u pletenicama i kašetama, postavljene su na stupove nosače vezova marine u gornjem dijelu estuarija Rijeke dubrovačke.

Jak utjecaj izvora Rijeke dubrovačke karakterizira cijeli estuarij. Slatka voda uzrokuje manju amplitudu kolebanja temperature tijekom godine od one karakteristične za priobalne vode Jadrana, dok su godišnja kolebanja saliniteta značajno izražena u površinskom sloju do 2 m dubine.

Prihvat mlađi dagnje izražen je tijekom proljeća s maksimumom od 1406 jedinki na 100 cm^2 kolektora na 1 m dubine, što ovaj lokalitet ubraja među područja s najvišim intenzitetom obnavljanja populacija dagnji na jadranskoj obali.

Rast dagnji je ubrzan u toplijem dijelu godine i povećava se s dubinom vodenog stupca. Maksimum dnevnog prirasta od 0.28 mm zabilježen je na 3 m dubine, što je vjerojatno posljedica veće količine planktonske hrane u tom sloju vode. Dagnje na ovoj dubini dosegle su tržišnu veličinu ($\bar{x}$=61.8 mm) u roku od četiri mjeseca od početka pokusa, dok je onima u površinskom sloju (1 m dubine) za to bilo potrebno skoro dvostruko više vremena.

Vrijednosti indeksa kondicije pokusnih školjkaša podudaraju se s varijacijama temperature, s maksimumima u najtoplijem dijelu godine, a izračunate vrijednosti su znatno više od vrijednosti dobivenih na drugim lokalitetima na jadranskoj obali.

Analiza dobivenih rezultata o preživljavanju dagnji pokazuje relativno zanemariv mortalitet (8.00% na 1 m, odnosno 13.33% na 3 m dubine) pokusnih školjkaša u istraživanom periodu.