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Article in *Aquatic Toxicology* · September 1997

DOI: 10.1016/S0166-445X(97)00021-0

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Response of mussel *Brachidontes striatulus* to chlorination: an experimental study

S. Rajagopal^{a,*}, K.V.K. Nair^b, G. van der Velde^c, H.A. Jenner^d

^aDepartment of Zoology, University of Madras, Guindy Campus, Madras 600 025, India

^bWater and Steam Chemistry Laboratory (APCD, BARC), Indira Gandhi Centre for Atomic Research, Kalpakkam 603 102, India

^cDepartment of Ecology, Laboratory of Aquatic Ecology, Faculty of Science, University of Nijmegen, Toernooiveld, 6525 ED Nijmegen, The Netherlands

^dKEMA Environmental Research, P.O. Box 9035, 6800 ET Arnhem, The Netherlands

Accepted 14 January 1997

Abstract

Though the brackish-water mussel, *Brachidontes striatulus* (Hanley) (syn. *Modiolus striatulus*) is an important fouling animal in power station cooling circuits, there are no published studies on the tolerance of this species to chlorination. Mortality pattern as well as physiological behaviour (byssus thread production, foot activity index and filtration rate) of three different size groups (7, 18 and 25 mm shell length) of *B. striatulus*, were studied at different chlorine concentrations (0–5 mg l⁻¹). At 1 mg l⁻¹ chlorine residual, 7 mm size group mussels showed 100% mortality in 468 h (20 days) and 25 mm size group mussels in 570 h (24 days). At relatively high levels of chlorine residuals (5 mg l⁻¹), 100% mortality in 7 and 25 mm size groups took 102 and 156 h, respectively. The exposure time to chlorine required for 100% mortality of *B. striatulus* is much lower than that reported for some other common fouling mussels. Chlorine concentration significantly affected the mean time of death for all size groups of mussels. All size groups showed progressive reduction in physiological activities such as filtration rate, foot activity index and byssus thread production when chlorine residuals were increased from 0 to 1.5 mg l⁻¹. Reduction in physiological activities of mussels was strongly correlated with the concentration of chlorine. © 1997 Elsevier Science B.V.

Keywords: Power plant; Biofouling; Control measures; Chlorination; Mortality; *Brachidontes striatulus*; Physiological functions

1. Introduction

Biofouling in cooling water systems of coastal power plants is a well known

*Corresponding author. Department of Ecology, Laboratory of Aquatic Ecology, Faculty of Science, University of Nijmegen, Toernooiveld, 6525 ED Nijmegen, The Netherlands. Fax. (+31-24) 3652134.

problem (Mattice and Zittel, 1976; Khalanski and Bordet, 1980; Rajagopal, 1991). Sessile mussels are often a major fouling species in power plant cooling systems where their settlement and growth result in blockage of free flow of water in the conduits (Rajagopal et al., 1991) and clogging of condenser tubes (Holmes, 1970). To discourage settlement of mussels, chlorine is commonly used as it is both effective and economical (Lewis, 1985). However, owing to increasing concern about toxicity of chlorine by-products to aquatic life, several countries are making efforts to minimize chlorine residuals in the discharges (Post et al., 1985; Jenner, 1985; Fisher et al., 1991; Bidwell et al., 1995). A study of response of various mussel species to chlorine has great importance from the point of optimization of chlorine treatments in cooling systems (Lewis, 1985).

In tropical power stations, though larger mussels like *Perna viridis* (L.) and *P. indica* Kuriakose and Nair are conspicuous in terms of biomass, smaller mussels like *Brachidontes striatulus* (Hanley), *Modiolus modiolus* sensu auct. and *M. philippinarum* (Hanley) are numerically important (Morton, 1977; Rajagopal et al., 1991). *B. striatulus* was also reported to foul Visakhapatnam harbour and various docks of Calcutta (Morton, 1977). The objective of this study was to understand the lethal and sublethal effects of chlorine on different size groups of *B. striatulus*, a major foulant at Madras Atomic Power Station.

2. Materials and methods

2.1. Description of the study area

Madras Atomic Power Station (MAPS), situated at Kalpakkam (12°33'N & 80°11'E), about 65 km south of Madras, on the east coast of India, uses chlorine to control fouling in the seawater cooling conduits. *B. striatulus* is one of the major fouling species in the sub-seabed intake tunnel of MAPS (Rajagopal et al., 1991). In Kalpakkam coastal waters, *B. striatulus*, has two spawning periods in a year: one during April–May and the other in August–September (Rajagopal, 1991). The present study was carried out during the non-spawning period of mussels (15 October 1990–30 March 1991). *B. striatulus* grows to 7 mm shell length in a month and to 25 mm in a year.

2.2. Test animals

The response of *B. striatulus* to different chlorine concentrations was studied in the laboratory, using mussels collected from coastal waters near the MAPS intake area. In the laboratory, the mussels were left undisturbed in seawater (34.1 ± 0.4 ‰ salinity, 5.8 ± 0.5 mg l⁻¹ dissolved oxygen and 29.4 ± 0.6 °C temperature) for two days (48 h) to allow them to recover from the effects of stress. Animals were picked up from this stock for each experiment.

2.3. Mortality

Three size groups (shell length $\pm$ SD; 6.9 ± 0.2 , 18.9 ± 1.2 and 25.4 ± 1.9 mm) of mussels were tested for four different chlorine doses (1, 2, 3 and 5 mg l^{-1}). Seawater collected from the coastal waters was used for the experiment, after a day's storage. Factors which may change the response of mussels such as salinity, temperature, dissolved oxygen and flow rate were kept constant in each of the experimental treatments. Salinity was maintained between 33.8 and 34.3‰. Temperature and dissolved oxygen were maintained between 29.2 and 29.8°C and 5.1 and 6.5 mg l^{-1} , respectively. Moreover, in preliminary experiments similar mortality responses to chlorine were observed between fed (mixed algal culture) and starved mussels (Rajagopal, 1991; Rajagopal et al., 1995). Hence, the experimental mussels were not fed during the course of the experiment. The experiments were conducted in continuous once-through flow systems, following the procedures outlined by Rajagopal et al. (1995). Seawater was stored in a 150 l aquarium tank and chlorine solution prepared from bleaching powder was stored in a 2 l volumetric flask. Appropriate mixes of the two were used to maintain desired chlorine concentration in a 5 l glass beaker having an outlet at the 4.5 l mark, using a peristaltic pump (Buchler Instruments, Port Lee, N.J. USA, Model No. 73351). Mixing of the water was facilitated by the use of aerators. A continuous flow at a rate of 80 ml min^{-1} was maintained throughout the test. After 48 h of acclimation, six mussels [(6 mussels in each experiment) $\times$ (3 size groups) $\times$ (4 chlorine concentrations) = 72 mussels] were introduced into the experimental tanks containing seawater of known chlorine concentration. The levels of residual chlorine were monitored at subsequent 30 min intervals at the outlet. Residual chlorine measurements were done using the iodometric method (White, 1972). Since the death of the mussels is often not directly observable (Jensen, 1982), mussels failing to close their shell as a response to external stimuli, when removed from water, were considered dead (Wallis, 1975). The number of dead animals in each experiment was recorded along with their shell lengths and total weights for each observation time. The same experiment was repeated two (1 and 2 mg l^{-1}) to four times (3 and 5 mg l^{-1}) for each size group and chlorine concentration. Altogether 216 mussels were used for the mortality experiments [(12 experiments) $\times$ (6 mussels in each experiment) $\times$ (3 size groups) = 216 mussels].

2.4. Sublethal responses

Apart from this, filtration rate, foot activity index and byssus thread production of different size groups of mussels were also studied at six different chlorine doses (0, 0.25, 0.50, 0.75, 1.00 and 1.50 mg l^{-1}). Experiments were run exactly as detailed above with 10–15 mussels used in each treatment. The only difference was that the mussels were left for 24 h for foot activity index and byssus thread production and for 3 h for filtration rate studies.

Rate of filtration was measured following the method described by Coughlan (1969). The method is based on the absorption of neutral red by mussels from ambient water. The rate of filtration was calculated using the following equation

of Coughlan (1969):

$$m = \frac{M}{nt} \log \frac{C_0}{C_t}$$

where M is the volume of the test solution; n is number of animals used in the experiment; t is time (h); C_0 is the initial concentration of the dye; C_t is the concentration of the dye at time t ; m is the rate of filtration in ml h^{-1} per mussel.

For foot activity index, at every 10 min, a note was made of the number of mussels with the foot extended outside the shell (Holmes, 1970). No attempt was made to follow the foot activity of individual mussels. For each experiment, all foot activity readings were analyzed and a percentage foot activity index was calculated.

The rate of byssus thread production was determined following procedures outlined by Winkle (1970) and Allen et al. (1976). After acclimation (48 h), one mussel was placed in a 1 l glass beaker (outlet at 0.75 l mark) containing 0.75 l of seawater of known chlorine concentration ($n = 10\text{--}15$ per size group in each chlorine dose). Use of one mussel per container eliminated the need for coding mussels and avoided the problem of counting threads when mussels clump, which they invariably do. Byssus threads produced by mussels were counted after 24 h and expressed in threads per mussel per day (Winkle, 1970).

2.5. Statistical analysis

The differences in mortality of different size groups of *B. striatulus* at various chlorine doses were tested by analysis of covariance (ANCOVA). The sublethal responses of different size groups of mussels to various chlorine levels were analyzed using exponential regression and statistical tests of the correlation coefficients (Sokal and Rohlf, 1981). The differences in physiological activity between control (0 mg l^{-1} chlorine dose) and experimental mussels ($0.25, 0.50, 0.75, 1.00$ and 1.50 mg l^{-1} chlorine doses) were compared by Student's t -tests after Bonferroni corrections (Zar, 1984). The post-hoc differences between size groups in each chlorine dose were tested by one-way analysis of variance (ANOVA). All analyses were performed using a Statistical Analysis Systems package (SAS, 1985).

The data obtained on mortality of mussels at different chlorine doses were subjected to probit analysis, yielding the statistic LT_{50} (Litchfield and Wilcoxon, 1949).

Fig. 1. Cumulative mortality (%) of different size groups of mussel, *Brachidontes striatulus* at 1 mg l^{-1} ($n = 12$ mussels in each size group), 2 mg l^{-1} ($n = 12$ mussels in each size group), 3 mg l^{-1} ($n = 24$ mussels in each size group) and 5 mg l^{-1} ($n = 24$ mussels in each size group) chlorine concentrations. Mortality of *B. striatulus* was monitored at 6 h intervals. The criterion for mortality of mussels was shell valve gape with no response of exposed mantle tissues to external stimuli.

Fig. 2. Time required for 50% mortality (LT_{50}) of different size groups of *Brachidontes striatulus* at different chlorine concentrations (after probit and regression analysis). The correlation coefficient is significant to $P < 0.001$ in all cases.

3. Results

3.1. Mortality

The time required for 100% mortality of *B. striatulus* exposed to different chlorine levels is presented in Fig. 1. No mortality occurred in control tanks. The three size groups (7, 19 and 25 mm shell length) showed 100% mortality at significantly different exposure times between 1 and 3 mg l⁻¹ chlorine concentrations (mussel size effect: ANCOVA; $F_{(2,212)} = 20.33$, $P < 0.01$). At 1 mg l⁻¹ residual chlorine, 7 and 25 mm size group mussels took 468 and 570 h, respectively to achieve 100% mortality (ANCOVA; $P < 0.01$). However, at 5 mg l⁻¹, all size group mussels took identical exposure times to reach 100% mortality (ANCOVA; $P > 0.05$). Moreover, mean time to death was analyzed by ANCOVA for all four concentrations of chlorine (0–5 mg l⁻¹) and was found to be highly significant (chlorine dose effect: ANCOVA; $F_{(3,212)} = 837.09$, $P < 0.0001$). Comparison of means revealed that the exposure time for 100% mortality of all size groups decreased with increasing chlorine concentration (see Fig. 1).

Comparison of LT_{50} values of different size groups of mussels also shows that larger mussels are more resistant than smaller ones (Fig. 2). At 1 mg l⁻¹ chlorine concentration, mussels in 7 and 25 mm size group took 332 and 453 h respectively to achieve 50% mortality. At 3 mg l⁻¹, mussels in the 7 mm size group took 112 h to reach 50% mortality whereas those in the 25 mm size group took 165 h (see Fig. 2).

Table 1

Filtration rate, foot activity index and byssus thread production of different size groups of *Brachidontes striatulus* at different chlorine concentrations

Chlorine dose (mg l ⁻¹)	Rate of filtration (ml h ⁻¹ per mussel)			ANOVA		
	Size of the mussels (mm ± S.D)			df	F	P
	7.0 ± 0.6	18.5 ± 1.7	26.0 ± 2.3			
Control	19.2 ± 3.3	25.4 ± 3.6	30.2 ± 4.9	29	16.829	**
0.25	13.5 ± 2.9**	22.1 ± 4.0 ^{ns}	28.6 ± 3.9 ^{ns}	29	44.061	**
0.50	12.7 ± 3.0**	17.3 ± 3.2**	20.9 ± 3.2**	37	20.422	**
0.75	4.7 ± 1.7**	13.3 ± 2.9**	16.6 ± 2.5**	31	68.451	**
1.00	2.0 ± 1.0**	5.3 ± 1.9**	7.0 ± 2.1**	29	9.747	**
1.50	1.3 ± 0.6**	2.9 ± 1.2**	3.8 ± 1.5**	32	12.144	**
Chlorine dose (mg l ⁻¹)	Foot activity index (%)			ANOVA		
	Size of the mussels (mm ± S.D)			df	F	P
	6.2 ± 0.4	17.9 ± 2.1	25.2 ± 1.9			
Control	89.6 ± 10.6	75.1 ± 12.2	69.7 ± 8.6	29	9.457	**
0.25	67.4 ± 9.8**	65.4 ± 9.0 ^{ns}	61.9 ± 7.5*	29	0.988	ns
0.50	42.8 ± 7.4**	49.5 ± 6.2**	40.3 ± 6.1**	31	5.622	**
0.75	13.4 ± 3.6**	20.2 ± 5.1**	18.5 ± 3.0**	29	7.761	**
1.00	7.3 ± 2.2**	13.7 ± 4.2**	10.9 ± 3.1**	30	9.598	**
1.50	4.7 ± 1.5**	6.0 ± 2.8**	4.2 ± 2.4**	33	2.246	ns
Chlorine dose (mg l ⁻¹)	Byssus thread production (threads per mussel per day)			ANOVA		
	Size of the mussels (mm ± S.D)			df	F	P
	6.5 ± 0.9	17.8 ± 1.4	25.4 ± 1.5			
Control	89.5 ± 14.6	74.9 ± 9.8	62.9 ± 10.1	29	12.879	**
0.25	68.2 ± 8.7**	70.3 ± 9.0 ^{ns}	58.3 ± 9.9 ^{ns}	29	4.518	*
0.50	46.3 ± 9.8**	59.0 ± 8.2**	45.6 ± 7.4**	31	8.380	**
0.75	15.1 ± 5.6**	26.4 ± 6.3**	22.6 ± 5.1**	29	11.306	**
1.00	5.0 ± 3.0**	10.1 ± 5.0**	7.7 ± 3.8**	30	4.242	*
1.50	3.4 ± 1.9**	5.8 ± 2.0**	4.1 ± 1.8**	33	4.175	*

Data are expressed as mean ± SE ($n=10-15$). Differences between control and experimental mussels (0.25–1.50 mg l⁻¹ residual chlorine) were compared by student's *t*-tests after Bonferroni's adjustment^a for multiple pairwise comparisons. The *posteriori* differences between size groups in each chlorine dose were identified using one-way ANOVA. Significance levels are indicated by: * $P < 0.05$; ** $P < 0.01$; ^{ns} not significant. ^aBonferroni adjustments were carried out, taking into account, 5 tests per size group ($n=5$; $t < 3.0$ not significant; $3.00 < t < 3.5 = P < 0.05$; $t > 3.5 = P < 0.01$).

3.2. Filtration rate

Filtration rate of mussels at different chlorine levels showed a progressive decline as the chlorine concentration increased from 0 to 1.5 mg l⁻¹ (Table 1). For example,

the 7 mm size group showed a decrease of filtration rate from 19 ml h^{-1} per mussel in the control to 1 ml h^{-1} per mussel at 1.5 mg l^{-1} ($t = 17.590$, $df = 19$, $P < 0.01$), whereas the 26 mm size group mussels showed a decrease from 30 ml h^{-1} per mussel in the control to 4 ml h^{-1} per mussel at 1.5 mg l^{-1} residual chlorine ($t = 17.596$, $df = 20$, $P < 0.01$). There was a size-dependent variation in the filtration rate of mussels (ANOVA; control mussels; $df = 29$, $F = 16.829$, $P < 0.01$); with larger mussels showing higher filtration rates (Table 1).

3.3. Foot activity index

The maximum foot activity index (90%) was observed in control experiments with 6 mm size group mussels (Table 1). At increased concentrations of chlorine, the foot activity index of the 6 mm size group tended to decrease, reaching a very low level of 6% at 1.5 mg l^{-1} of residual chlorine ($t = 25.004$, $df = 18$, $P < 0.01$). A similar pattern was evident for other size groups of mussels as well. Moreover, significant size-dependent variation in foot activity index was observed (ANOVA; control mussels; $df = 29$, $F = 9.457$, $P < 0.01$), i.e. foot activity index decreasing with increasing size of the mussels.

3.4. Byssus thread production

As in the case of the filtration rate and foot activity index, a significant size-dependent variation was observed in the byssus thread production of mussels to different concentration of chlorine (control mussels, $df = 29$, $F = 12.879$, $P < 0.01$). The small mussels showed higher byssus production (Table 1). Furthermore, foot activity index and byssus production of mussels were strongly correlated to chlorine concentrations (7 mm size group; Spearman rank correlation test, $r = 0.88$, $P < 0.0001$).

Filtration rate, foot activity index and byssus production of mussels showed reduction with increasing concentrations of chlorine (Table 1). For 18 mm size group mussels, filtration rate showed a reduction of 6% ($t = 2.023$, $df = 18$, $P > 0.05$) and 92% ($t = 19.163$, $df = 20$, $P < 0.01$) at 0.25 and 1.5 mg l^{-1} , respectively. Similarly, at 1.5 mg l^{-1} , foot activity index and byssus production showed a reduction of 92% ($t = 21.736$, $df = 20$, $P < 0.01$) and 89% ($t = 19.913$, $df = 19$, $P < 0.01$) respectively, for the same size group of the mussels. At any given chlorine concentration, filtration rate, foot activity index and byssus production were lowest in young mussels. In all size groups, physiological activities of mussels showed a strong decrease at 0.75 mg l^{-1} residual chlorine; indicating that 0.75 is the chlorine level at which activities are critically affected in *B. striatulus*.

Fig. 3. Relationship between chlorine concentrations and physiological activities of different size groups of *Brachidontes striatulus* (each point represents mean value of 10–15 mussels). All regression parameters are significant at $P < 0.0001$.

Exponential regressions of the concentration of chlorine on the sublethal responses (filtration rate, foot activity index and byssus thread production) of different size groups of mussels are shown in Fig. 3. The sublethal responses of mussels are strongly correlated with different concentrations of chlorine ($0.96 < r < 0.99$; $P < 0.0001$).

4. Discussion

Continuous application of chlorine at low-levels (0.1 mg l^{-1} residual chlorine), is the most commonly used method of mussel control in cooling conduits of power stations (Jensen, 1982; Rajagopal, 1991). In India, recent studies have shown that continuous low-level chlorination ($0.1\text{--}0.5 \text{ mg l}^{-1}$) retards mussel settlement in the cooling systems of Madras Atomic Power Station (Rajagopal et al., 1996). Similarly, Bucaille and Kim (1976) observed that a chlorine level of 0.5 mg l^{-1} was enough to deter mussel settlement in a French power station. Work on larval *Dreissena polymorpha* (Pallas) (Benschoten et al., 1993) and *Mytilus edulis* L. (Lewis, 1985), has shown larval mortality occurring at residual chlorine levels as low as 0.1 mg l^{-1} . However, experiments with adult mussels have indicated that a treatment with higher concentrations (1 mg l^{-1} total residual chlorine) will eventually kill attached mussels in the cooling conduits of power stations (Jenner, 1985; Klerks and Fraleigh, 1991; Rajagopal et al., 1996). Moreover, for a complete kill, treatment times of 1 week (Jensen, 1982) to several months will be required, depending on water temperature (Lewis, 1985; Jenner and Janssen-Mommen, 1993). The present results show that the time to 100% mortality of *Brachidontes striatulus* was 24 days at 1 mg l^{-1} , 15 days at 2 mg l^{-1} and 10 days at 3 mg l^{-1} chlorine residuals (Table 2). The exposure time required for 100% mortality appears to be much lower than that reported for *Perna viridis* (Rajagopal et al., 1995), *Mytilus edulis* (James, 1967) and *Mytilopsis leucophaeta* (Conrad) (Rajagopal et al., 1994). However, no published results are available for *B. striatulus* to facilitate comparison with the present ones. Based on the results of this study, it seems that *B. striatulus* succumbs more easily to a given dose of chlorine, when compared to *P. viridis*, *M. edulis* and *M. leucophaeta*. The difference in tolerance among these species could be due to the different degree of their metabolic adaptations (Bayne et al., 1976). However, influence of other factors that may cause greater biocide resistance such as sex (Martin et al., 1993a), season (Jensen, 1982; Jenner, 1985) and reproductive differences (Martin et al., 1993b) cannot be discounted.

The most obvious feature of a bivalve is the protective shell. During periods of chlorination, mussels shut their valves (Khalanski and Bordet, 1980) and halt byssus production (Rajagopal et al., 1994). In doing so, they isolate their body tissues from changes in the external environment. Bayne et al. (1976) suggested that sensitive receptors on the mantle might be responsible for shell closure in mussels. The period they remained closed could last from 7 days (Jensen, 1982) to 35 days (Theede et al., 1969), with only short and intermittent periods of shell opening (Widdows, 1973; Kramer et al., 1989). Lewis (1985) noted that mussels, *M. edulis*

Table 2

A summary of selected data for chlorination of various mussel species in relation to power plant bio-fouling control

Species	TRC ^a (mg l ⁻¹)	Temperature (°C)	Duration (days)	Mortality (%)	Comments	Reference
<i>Dreissena polymorpha</i> (Pallas)	0.25	12–15	21	90	Flow-through	Jenner and Janssen-Mommen, 1993
	0.50	12–15	19	93		
	1.00	12–15	17	93		
	0.50	18–21	9	100	Flow-through	DeGirolamo et al., 1991
	0.50	17–27	9	100	Static	
	1.00	20–22	20	80	Static	
	2.50	20–22	13	100		Klerks and Fraleigh, 1991
	5.00	20–22	7	100		
	1.00	20	36	100	Flow-through	
<i>Mytilopsis leucophaeta</i> (Conrad)	2.50	20	23	100		Rajagopal et al., 1994
	5.00	20	15	100		
	10.00	20	7	100		
	1.00	—	39	100	Flow-through	
<i>Mytilus edulis</i> L.	10.00	—	7	100		James, 1967
	0.20	10	20	80	Flow-through	
	7.04	10	14	100		Jensen, 1982
	4.43	16.6	20	100	Flow-through	
	1.00	29–30	34	100	Flow-through	Lewis, 1985
<i>Perna viridis</i> (L.)	5.00	29–30	5	100	Flow-through	
<i>Perna indica</i> Kuria-kose & Nair	1.00	29–30	14	100	Flow-through	Rajagopal et al., 1995
	1.00	29–30	11	100	Flow-through	
<i>Modiolus modiolus</i> sensu auct.	1.00	29–30	24	100	Flow-through	Rajagopal, 1991 ^b
<i>Brachidontes striatulus</i> (Hanley) ^c	2.00	29–30	15	100	Flow-through	
	3.00	29–30	10	100	Flow-through	

^aTotal residual chlorine; ^bUnpublished data; ^c25 mm size group mussels

treated with chlorine residuals of 4.43 mg l⁻¹ for 49 h, were capable of making recovery within 30 min of exposure to ambient seawater. However, Jensen (1982) found that *M. edulis* failed to recover after a 24 h exposure to a chlorine residual of 8–40 mg l⁻¹. A review of the literature shows that at chlorine levels below

1.0 mg l⁻¹, mussels are able to open their valves to feed, although at a reduced rate (White, 1966; Rajagopal, 1991). However, at higher chlorine levels, they are forced to shut their valves and exist on stored food reserves and anaerobic respiration (Lewis, 1985) until energy resources are depleted or metabolic wastes reach a toxic level (Jensen, 1982). Higher chlorine residuals (i.e. 40 mg l⁻¹) may cause denaturation of cell membranes leading to lethal effects, particularly in the gills (Opresko, 1980), but at low residuals other physiological activities are affected (Rajagopal, 1997). Therefore, experiments were conducted to ascertain the effects of chlorine administered at low-levels (0.25–1.50 mg l⁻¹) on the physiological functions such as filtration rate, foot activity index and byssus thread production of *B. striatulus*. The present data clearly indicated that *B. striatulus* was able to sense the presence of chlorine at levels as low as 0.25 mg l⁻¹ and responded by reducing the filtration rate by 6% to 30% (Table 1). Since, chlorination is done on a continuous basis, mussels do not get an opportunity to compensate for the loss incurred owing to reduced food intake (Jensen, 1982). Under such circumstances, drastic decline of the growth rate could be expected (Lewis, 1985).

To make matters worse, production of byssus thread is also affected (Table 1). Moreover, a higher percentage reduction of byssus production was observed in young mussels at all chlorine levels (Fig. 3). It is well known that young mussels are more active than older mussels and have relatively high metabolic rates (Bayne et al., 1976). Therefore, under stress, juveniles might react more rapidly than larger mussels. Differences in filtration rate among different size groups of mussels are possibly due to the variations in the gill area as reported by Jones et al. (1992). Similarly, suppression of foot activity index and reduction of byssus strength in chlorinated *M. edulis* have been reported by White (1966) who observed that mussels chlorinated at 0.2 mg l⁻¹ residual level required 56% less force to detach than unchlorinated ones. Holmes (1970) also estimated that force required to detach *M. edulis* from a chlorinated cooling water system was 18–55% less than that for control mussels. Byssus inhibition by chlorine is thought to be mediated through interference in the biochemical machinery involved (Lewis, 1985). Holmes (1970) suggested that chlorine would interfere with the quinone tanning process, a vital step in the thread formation. However, further work is required to conclusively prove the mode of action of chlorine on byssus production.

Comparison of mortality data between young and adult *B. striatulus* shows that adult mussels are more resistant than young ones (Fig. 1). Therefore, it appears that when different age groups of *B. striatulus* are subjected to chlorine, it is the juveniles which are likely to get killed faster. The present chlorination regime at MAPS (low-dose continuous chlorination of 0.5 mg l⁻¹) was originally targeted against *P. viridis* (Rajagopal et al., 1991). From the present data, it is clear that *B. striatulus* is also likely to get eliminated at the above chlorine residuals, as it is more sensitive to chlorine than *P. viridis*.

5. Conclusions

1. The study showed that 100% mortality of *B. striatulus* could be achieved in 18 days at a chlorine concentration of 1 mg l^{-1} . The exposure time required for 100% mortality of *B. striatulus* is much lower than that reported for some other common fouling mussels.
2. Physiological functions of the mussels are affected by chlorine in a dose-dependent fashion.
3. The study showed 0.75 mg l^{-1} to be the threshold chlorine concentration at which some of the physiological functions are critically affected.
4. Where *P. viridis* and *B. striatulus* co-exist in large numbers such as in MAPS, chlorination regime targeted against the former will also eliminate the latter.

Acknowledgements

We express our sincere thanks to Dr. P. N. Murthy, Dr. P. K. Mathur and Shri. S. B. Kuppuraju for the facilities at plant site. Thanks are also due to Prof. Dr. J. M. van Groenendael and Dr. V. P. Venugopalan for useful discussions. We would also like to thank two anonymous referees for many helpful comments and suggestions on earlier versions of the manuscript. This research was supported by funding from Council of Scientific and Industrial Research, New Delhi, India.

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