A REVIEW OF PHYSIOLOGICAL EFFECTS OF TOXIC DINOFLAGELLATES ON BIVALVE MOLLUSCS

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ABSTRACT

The most common effect of red tide upon bivalves is a decrease in exposure to the environment either by reduced filtration, or increased periods of valve closure. The other physiological effects noted, such as changes in oxygen consumption and cardiac activity, may be associated with the former responses and may not be a direct effect of exposure to red tide organisms. Lastly, studies on *Mytilus* suggest that those animals most often exposed to red tide are more resistant than unexposed individuals of the same species.

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INTRODUCTION

While toxic dinoflagellates, the primary organisms responsible for "red tides", have been the focus of numerous studies, there has been relatively little attention paid to the effects of these organisms on bivalve molluscs, and many workers have assumed that red tide has little effect on these host organisms (Quayle, 1969; Prakash et al., 1971). Recent studies have shown, however, that shellfish are affected by these organisms and these effects are reviewed briefly here.

MORTALITY

There have been periodic reports in the literature of mass mortality of a variety of bivalves exposed to a variety of toxic dinoflagellates (table 1); however, the effects of the various red tide organisms are variable. For example, Sievers (1969) reported that *Crassostrea virginica* showed increased mortality when exposed to *Gymnodinium monilata*, but was unaffected by *G. breve*; similarly, Reish (1963) reported increased mortality of *Mytilus edulis* exposed to *Gonyalulax poleydra*, while Adams et al. (1968) reported no deaths for *Mytilus* exposed to *Protogonyaulax tamarensis*. In a laboratory study, there was 75% mortality in *Mytilus edulis* from Rhode Island and Spain upon exposure to *P. tamarensis*. These mussels had had no prior exposure to *P. tamarensis*. In contrast, there was no mortality in *Mytilus edulis* from Maine upon exposure to *P. tamarensis*. These mussels had had regular, prior exposure to the toxic dinoflagellate (Shumway & Cucci, 1987).

TABLE 1

Summary of physiological effects of red tides on bivalves. +: Increased response; 0: no response; - decreased response; 0-, 0+: partial decrease or increase.

SPECIES	EFFECT	DINOFLAGELLATES	REFERENCES
Mytilus edulis	Mortality +	*Gonoyaulax poleydra*	Reish, 1963
	Toxic -- no deaths	*G. tamarensis*	Adams et al., 1968
	Filtration		
	-	" "	Gilfillan & Hanson, 1975
	0	" "	Shumway et al.., 1985
	-	*Gyrodinium aureolum*	Widdows et al., 1979
	Valve Closure		
	0[1]	*Gonyaulax tamarensis*	Shumway & Cucci, 1987
	+[2]	" "	"
	Oxygen Consumption		
	0[1]	" "	"
	+[2]	" "	"
	Byssus Production -	" "	"
	Mucus Production +	" "	"
	Cardiac Activity 0 -	" "	Gainey & Shumway, 1988
	Neuronal Activity 0	10^{-4} M saxitoxin	Twarog & Yamaguchi, 1974
Mytilus californianus	Filtration 0	*Gonyaulax washing-tonensis*	Dupuy & Spares, 1968
Geukensia demissa	Filtration -	*Gonyaulax tamarensis*	Shumway et al., 1985
	Valve Closure +	" "	"
	Mucus Production +	" "	"
	Cardiac Activity 0 +	" "	"
	Neuronal Activity -	10^{-4} M saxitoxin	Twarog & Yamaguchi, 1974
Modiolus modiolus	Filtration 0	*Gonyaulax tamarensis*	Shumway & Cucci, 1987
	Valve Closure 0	" "	"
Choromytilus meridonalis	Mortality +	*Gonyaulax catenella* *G. grindeleyi*	Horstman, 1981
Brachiodontes recurvis	Valve Closure		
	+	*Gonyaulax monilata*	Sievers, 1969
	0	*Gymnodium breve*	"
	Byssus Production		
	-	*Gonyaulax monilata*	"
	0	*Gymnodinium breve*	"
Crassostrea virginica	Morality		
	+	*Gonyaulax monilata*	Sievers, 1969
	0	*Gymnodinium breve*	"
	Filtration		Ray & Aldrich, 1967
	-	*Gonyaulax monilata*	"
	0	*Gymnodinium breve*	"
	0-	*Gonyaulax tamarensis*	Shumway & Cucci, 1986
	Valve Closure		
	+	*Gonyaulax monilata*	Sievers, 1969
	0	*Gymnodinium breve*	"
	0-	*Gonyaulax tamarensis*	Shumway & Cucci, 1987
	Cardiac Activity 0	" "	Gainey & Shumway, 1986
	Neuronal Activity -	10^{-7} M saxitoxin	Twarog & Yamaguchi, 1974
Crassostrea gigas	Filtration -	*Gonyaulax washing-tonensis*	Dupuy & Spares, 1968
	Valve Closure +	" "	"
	"Clapping"	" "	"

TABLE 1 - Continued

SPECIES	EFFECT	DINOFLAGELLATES	REFERENCES
Ostrea edulis	Filtration 0	*Gonyaulax tamarensis*	Shumway & Cucci, 1987
	Valve Closure 0 +	" "	"
	Cardiac Activity 0 -	" "	Gainey & Shumway, 1988
Placopecten magellanicus	Filtration 0	*Gonyaulax tamarensis*	Shumway et al., 1985
	Valve Closure + "Clapping"	" "	"
	Oxygen Consumption -	"	"
	Mucus Production +	" "	"
	Cardiac Activity 0	" "	"
	Neuronal Activity 0	≤10^{-4} M saxitoxin	Twarog & Yamaguchi, 1974
Pecten irradians	Neuronal Activity -	10^{-4} M saxitoxin	Twarog & Yamaguchi, 1974
Mercenaria mercenaria	Filtration -	*Gonyaulax tamarensis*	Shumway & Cucci, 1987
	Valve Closure +	" "	"
	+	Gymnodinium sp.	Smith, 1958
	Cardiac Activity 0	*Gonyaulax tamarensis*	Gainey & Shumway, 1988
	Neuronal Activity 0 -	10^{-4} M saxitoxin	Twarog & Yamaguchi, 1974
Mercenaria campechiensis	Filtration -	*Gymnodinium monilata*	Ray & Aldrich, 1967
Mya arenaria	Filtration -	*Gonyaulax tamarensis*	Shumway & Cucci, 1987
	Valve Closure 0	" "	"
	Oxygen Consumption +	" "	Shumway et al., 1985
	Cardiac Activity 0	" "	Gainey & Shumway, 1988
	Neuronal Activity -	≥10-5 M saxitoxin	Twarog & Yamaguchi, 1974
Spisula soldissima	Filtration 0	*Gonyaulax tamarensis*	Shumway & Cucci, 1987
	Valve Closure 0	" "	"
	Oxygen Consumption -	" "	Shumway et al., 1985
	Cardiac Activity 0	" "	Gainey & Shumway, 1988
Arctica islandica	Filtration 0	*Gonyaulax tamarensis*	Shumway et al., 1985
	Valve Closure 0	" "	"
	Cardiac Activity 0	" "	Gainey & Shumway, 1988
Barnea (= *Cyrtopleura*) *costata*	Filtration -	*Gonyaulax monilata*	Ray & Aldrich, 1967
Donax variabilis	Filtration -	*Gonyaulax monilata*	Ray & Aldrich, 1967
Venus striatula	Mortality +	*Gonyaulax tamarensis*	Adams et al., 1968
Cerastoderma edule	Mortality +	*Gonyaulax tamarensis*	Adams et al., 1968
Macoma balthica	Mortality +	*Gonyaulax tamarensis*	Adams et al., 1968
Donax serra	Mortality +	*G. catenella* *G. grindeleyi*	Horstman, 1981

[1] *Mytilus* from Maine: prior exposure to *Gonyaulax*

[2] *Mytilus* from Rhode Island -- no prior exposure to *Gonyaulax*

SHELL VALVE CLOSURE

Perhaps the most widely reported effect of red tide organisms upon bivalve molluscs is isolation from the environment either by valve closure or reduced filtration. Increased valve closure has been reported for a number of bivalves (table 1). Differential valve closure has been reported in *Branchiodontes recurvis*, and *Crassostrea virginica*: valve closure increased in the presence of *Gymnodinium monilata* and was normal in the presence of *G. breve* (Sievers, 1969). Differential valve closure has also been reported in *Mytilus edulis*: *Mytilus edulis* from Rhode Island, which had no prior exposure to *Protogonyaulax tamarensis* showed increased valve closure upon exposure, while *Mytilus edulis* form Maine, which had prior exposure to *P. tamarensis*, showed no change in valve gape upon exposure (Shumway et al., 1985).

FILTRATION RATE

Reduced filtration rates have also been reported for a number of bivalves exposed to a variety of toxic diniflagellates. In general, those animals that showed increased valve closure also showed decreased filtration, e.g. *Geukensia demissa*, *Mytilus edulis* from Rhode Island (Shumway et al., 1985), *Crassostrea virginica* (Ray & Aldrich, 1967; Shumway & Cucci, 1986), *Mercenaria mercenaria* and *Crassostrea gigas* (Dupuy & Sparks, 1968), and *Mercenaria mercenaria* (Shumway & Cucci, 1987). Differential changes in filtration have been found in *Crassostrea virginica*: filtration was unaffected by *Gymnodinium breve*, and was inhibited by *G. monilata* (Ray & Aldrich, 1967).

MUCUS PRODUCTION

Increased mucus production has been noted in several species that also showed decreased filtrations rates and increased valve closure: *Mytilus edulis*, *Geukensia demissa*, although increased mucus production was also found in *Placopecten magellanicus*, which did not show decreased filtration (Shumway et al., 1986).

OXYGEN CONSUMPTION

Oxygen comsumption, after exposure to *Protogonyaulax tamarensis*, has been measured in four species of bivalves by Shumway et al. (1986), and the relationship between oxygen consumption and other physiological responses to red tide is not clear. For example, *Placopecten magellanicus* showed no change in filtration rate, but an increase in valve activity, yet showed a decrease in oxygen consumption. *Spisula solidissima* showed no change in filtration or valve activity, yet showed a decrease in oxygen consumption. *Mya arenaria* showed a decrease in filtration rate, yet an increase in oxygen consumption. *Mytilus edulis* from Rhode Island showed an increase in valve closure and an increase in oxygen consumption. Not surprisingly, *Mytilus* from Maine, which had prior exposure to *P. tamarensis* showed no change in oxygen consumption. The effects of red tide on oxygen consumption may be due to indirect effects, such as increased activity or repayment of an oxygen debt, although a direct effect on cellular

metabolism cannot be ruled out in species such as *Placopecten* or *Spisula* which either showed an increase, or no change, in activity yet had a decrease in oxygen consumption.

CARDIAC ACTIVITY

Cardiac activity was unaffected in most species studied by Gainey & Shumway (1988). In *Mytilus edulis*, 8 out of 17 animals showed cardiac arrhythmias upon exposure to *Protogonyaulax tamarensis*, while no arrhytthymias were found in 10 controls. In contrast, in *Geukensia demissa*, 3 out of 10 animals showed a transient increase in heart rate, which was not found in any of the 10 controls. In *Ostrea edulis*, 2 out of 9 animals exposed to *P. tamarensis* showed a significant decrease in rates, while there was no change in any of the 6 controls. Whether changes in cardiac activity are due to indirect effects associated with valve activity, with effects on nerves which regulate the heart, or on the heart muscle itself is unknown.

NEUROPHYSIOLOGICAL RESPONSES

The effects of red tide toxins on bivalve neurons have been investigated by Twarog & Yamaguchi (1972). They found a graded response that varied according to species. *Mytilus edulis*, *Placopecten magellanicus*, and *Mercenaria mercenaria* were unaffected by concentrations of saxitoxin (STX) less than or equal to 0.1 mM. *Mya arenaria* neurons were inhibited by 0.01 mM, while *Crassostrea virginica* neurons were inhibited by 0.1 µM STX. Twarog & Yamaguchi (1972) hypothesized that those animals that are most sensitive to STX either are not regularly exposed to the toxin or have a reduced filtration rate which would reduce accumulation of toxin. This hypothesis is at least partially borne out by the fact that *Mytilus edulis* rapidly accumulates toxin and is insensitive to STX, whereas the rate of accumulation in *Mya* is less (Shumway & Cucci, 1987).

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ADDENDUM

Since this manuscript was submitted for publication, several papers have been published and the reader is referred to these and the references therein:

GAINEY, L. F. & SHUMWAY, S. E., 1988. A compendium of the responses of bivalve molluscs to toxic dinoflagellates. — J. Shellfish Res., 7: 623-628.
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