Available online at www.sciencedirect.com
ScienceDirect
Harmful Algae 6 (2007) 218–231
HARMFUL ALGAE
www.elsevier.com/locate/hal

Toxicity of *Dinophysis* spp. in relation to population density and environmental conditions on the Swedish west coast

Odd Lindahl *, Bengt Lundve, Marie Johansen

The Royal Swedish Society of Sciences, Kristineberg Marine Research Station, SE 450 34 Fiskebäckskil, Sweden

Received 29 April 2006; received in revised form 14 May 2006; accepted 28 August 2006

Abstract

The aim of this study in the field was to investigate whether there are differences between the outer archipelago (Gullmar Fjord) and a semi-enclosed fjord system (Koljö Fjord) in occurrences of *D. acuta* and *D. acuminata* as well as in their content of diarrheic shellfish toxin (DST) per cell. When all data pairs of cell toxicity of *D. acuminata* and the corresponding number of cells l^{-1} from the two sites were tested in a regression analysis, a statistically significant negative correlation became evident and was apparent as a straight line on a log–log plot ($p < 0.0001$). Obviously, there was an overall inverse relationship between the population density of *D. acuminata* and the toxin content per cell. Plotted on a linear scale, all data-pairs of cell toxicity and cell number made up a parabolic curve. On this curve the data-pairs could be separated into three groups: (i) *D. acuminata* occurring in numbers of fewer than approximately 100 cells l^{-1}, and with a toxin content per cell above 5 ρg cell^{-1}; (ii) cell numbers between 100 and approximately 250 cells l^{-1} with a cell toxin content from 5 to 2 ρg cell^{-1}; (iii) when the population became greater than 250 cells l^{-1}, the toxicity, with few exceptions, was less than 2 ρg cell^{-1}. By applying this subdivision, some clear patterns of the distribution of the differently toxic *D. acuminata* became evident. When comparing the cell toxicity of the two sites, it was obvious that the *D. acuminata* cells from all depths from the Gullmar Fjord as a mean were significantly more toxic compared to the Koljö Fjord samples. The results have demonstrated that approximately 100 high-toxicity cells in a low-density population at surface may lead to the same accumulation of DST in a mussel as the ingestion of 1500 low-toxicity cells from a high-density pycnocline population.

Keywords: *Dinophysis*; Cell toxicity; Population density; Cell signalling; Diarrheic shellfish poisoning (DSP)

1. Introduction

Diarrheic shellfish poisoning (DSP) is a major problem for the shellfish industry around the world (Lee et al., 1989; Haamer et al., 1990; Dahl and Johannessen, 2001; Pavela-Vrancic et al., 2002; Morono et al., 2003). On the Swedish west coast the toxic dinoflagellate genus *Dinophysis* is the main contributor of the mussel toxins DST (diarrheic shellfish toxins) (Godhe et al., 2002). The problem with toxic mussels has been highlighted in several studies during the last few decades, however, knowledge about the phenomena is still sparse, and the ability to forecast the occurrence of *Dinophysis* and the toxin content in the shellfish has not been fully developed.

Dinophysis spp. occurs in coastal waters all over the world (Hallegraeff et al., 2003), including Scandinavia (Edebo et al., 1988; Belgrano et al., 1999; Andersen et al., 1996; Aune et al., 1996; Godhe et al., 2002,). They vary in the content of toxin per cell and their ability to produce different kinds of toxins of different poisonouness (Tables 1 and 2). Diarrheic shellfish

* Corresponding author.
E-mail address: odd.lindahl@kmf.gu.se (O. Lindahl).

1568-9883/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.hal.2006.08.007

Table 1
Summary of reported toxicity per cell (ρg cell^{-1}) of *D. acuminata*

Country	Area	OA cell^{-1}	DTX-1 cell^{-1}	DTX-2 cell^{-1}	Reference
Denmark	Coastal	0–40			Andersen et al. (1996)
	The Wadden sea	0.3			Andersen et al. (1996)
	Limfjord	6.1			Andersen et al. (1996)
	East coast of Jutland	5.3			Andersen et al. (1996)
Canada	Gulf of St. Lawrence	25.5			Cembella (1989)
France	Le Havre	1.6			Lee et al. (1989)
Japan	Tokyo Bay J	Trace			Lee et al. (1989)
Spain	Rio de Pontevedra	1–37		0.3–0.6 ?	Blanco et al. (1995)
Sweden	Gullmar Fjord	9.1	0		Johansson et al. (1996)
	Gullmar Fjord	0.04	0.02		Yasumoto (unpublished)
	Gullmar Fjord	0–17			Present paper
	Koljö Fjord	0–2.6			Present paper

poisoning (DSP) causes abdominal cramps, diarrhea, nausea, and vomiting (Daranas et al., 2001). The first incident of illness was reported in the Netherlands in the 1960s, and the toxic substance was first isolated from the black sponge *Halicondria okadai* (Hallegraeff et al., 2003). There are three kinds of DSP toxins: the okadaic acid (OA) group, the pectenotoxin-group, and the yessotoxin group. In Sweden the okadaic acid has previously been the most commonly observed DST toxin (Edebo et al., 1988). The OA group also includes DTX-1 and DTX-2 and several derivatives (Quilliam, 2003). These compounds are lipid-soluble long-chain-linked polyether rings and are accumulated in the hepatopancreas of the blue mussel (*Mytilus edulis*) (Yasumoto et al., 1985; Hallegraeff et al., 2003).

There are several species of DST-producing *Dinophysis*: for example, *D. acuta*, *D. acuminata*, *D. norvegica*, *D rotundata*, *D. caudata*, *D. fortii*, *D. sacculus*, and *D. dens* (Hallegraeff et al., 2003; Graneli et al., 1997). In Sweden *D. acuta* and *D. acuminata* have been reported to cause most of the DST toxicity (Godhe et al., 2002). *D. acuminata* has in many countries in northern Europe been reported to produce OA (Carmody et al., 1996), while *D. acuta* has been reported to produce OA, DTX-1, or DTX-2 (Tables 1 and 2). In Sweden *D. acuta* has been observed to cause OA in mussels in the outer archipelago, while the co-occurrence of DTX-1 in mussels and algae was observed in confined fjord areas (Svensson, 2003a,b).

In the review of Maestrini (1998) it was concluded that little is known about the taxonomy of *Dinophysis* spp. and about how they thrive and survive in the pelagic. Further, it was concluded that knowledge is especially limited concerning whether the species have several life stages, exactly what they take from the sea in order to live and grow, and to what extent dense, vertically patchy populations result from active or passive concentration, from growth, or from a mixture of both processes. It is generally clear that at times of greatest cell density, cells of *Dinophysis* can be

Table 2
Summary of reported toxicity per cell (ρg cell^{-1}) of *D. acuta*

Country	Area	OA cell^{-1}	DTX-1 cell^{-1}	DTX-2 cell^{-1}	Reference
Spain	Vigo	9.4			Lee et al. (1989)
Norway	Sogndal	4	4.2		Lee et al. (1989)
Sweden	Gullmar Fjord	20			Riisgaard (1991), Edler and Hageltorn (1990)
Sweden	Kulefjord	100–160			Haamer et al. (1990)
Sweden	Gullmar Fjord	0	6.6		Johansson et al. (1996)
Sweden	Gullmar Fjord	0.52	0.01	1.57	Yasumoto (unpublished)
Ireland	Southwest coast	58		78	Kevin et al. (1998)
Spain	Ria de Pontevedra	0.6–94		0.4–169 ?	Blanco et al. (1995)
Portugal	Northwest coast			Detected	Vale and Sampayo (2000)
Ireland	Bantry Bay			Detected	Draisci et al. (1998)
	Gullmar Fjord		Detected		Present paper
	Koljö Fjord		0.4–7.8		Present paper