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Phycotoxin-Related Shellfish Poisoning: Bivalve Molluscs Are Not The Only Vectors

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ABSTRACT: The continuing increase in numbers of toxic algal species coupled with increased incidences of blooms of these species presents a constant threat to public health worldwide. Traditionally, only filter-feeding molluscs that concentrate these toxic algae are considered in monitoring programs for paralytic (PSP), diarrhetic (DSP), neurotoxic (NSP), and amnesic (ASP) shellfish poisons; however, increasing attention is being paid to higher-order consumers such as carnivorous gastropods and crustaceans. This review summarizes data on accumulation of phycotoxins by "non-target" species frequently consumed by humans, and stresses the importance of including such species in routine monitoring programs, especially in regions where nontraditional species are being harvested.

KEY WORDS: phycotoxins, shellfish, molluscs, crustaceans, PSP, NSP, ASP, DSP, public health.

I. INTRODUCTION

Accumulation of phycotoxins by filter-feeding shellfish is a well-known global phenomenon. Whereas bivalve molluscs are unquestionably the most serious vectors of shellfish toxins, including paralytic (PSP), diarrhetic (DSP), amnesic (ASP), and neurotoxic (NSP) shellfish poisoning (see Shumway, 1990; Figure 1), other vectors also warrant serious concern. Many species of carnivorous and scavenging gastropods and crustaceans are popular domestic and commercial food items throughout the world. World landings of gastropods (including abalones, winkles, conchs, whelks, etc.) were 74,690 metric tons (MT) in 1990 (FAO, 1992) with Atlantic catches greater than 22,000 MT in 1991 (Stamatopolous, 1993; Figure 2). World landings of crabs (1,137,676 MT) and lobsters (208,692 MT) continue to rise, with Atlantic landings contributing over 358,000 MT (FAO, 1992; Stamatopolous, 1993). This article summarizes the role of crustaceans and gastropod molluscs as vectors of tetrodotoxin (TTX) and phycotoxin-related shellfish poisoning and discusses the

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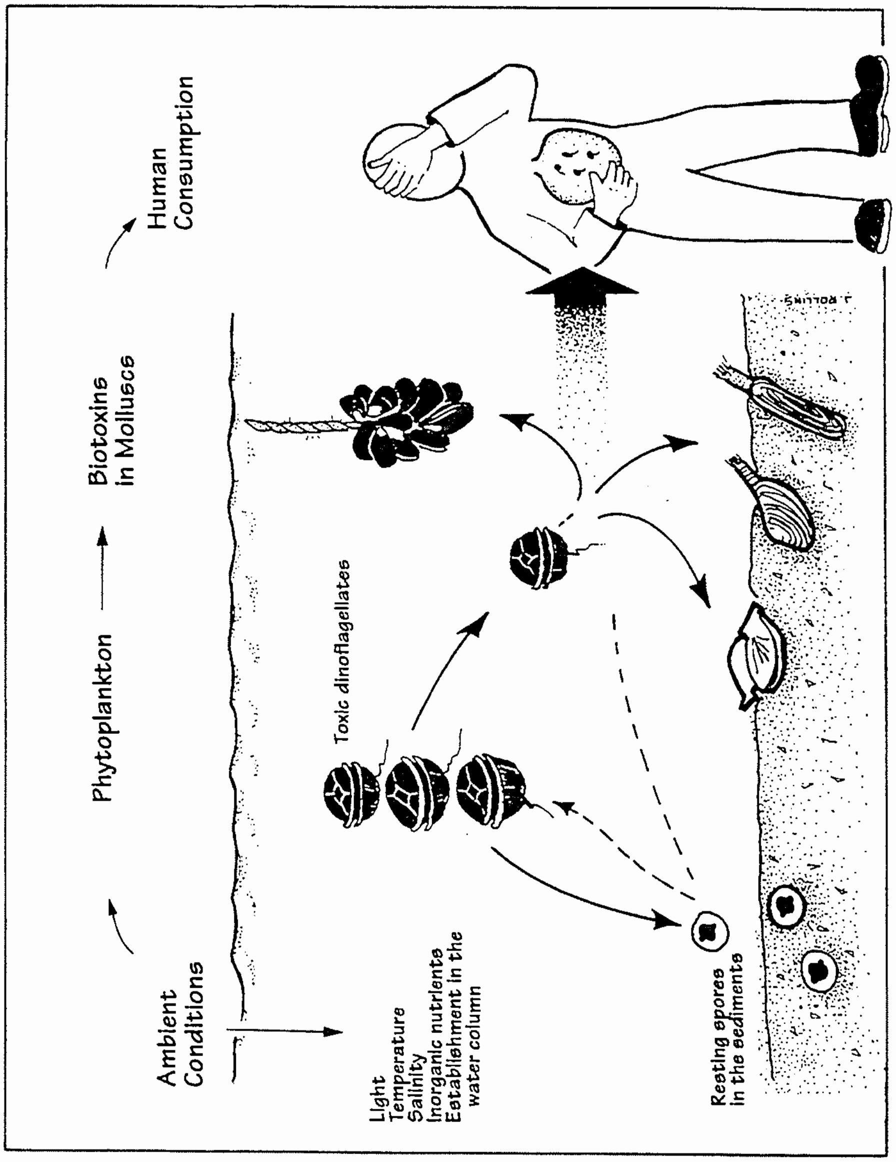


FIGURE 1. Diagrammatic representation of proliferation of algal blooms, the subsequent accumulation of phycotoxins by filter-feeding shellfish, and human illnesses resulting from consumption of contaminated shellfish.

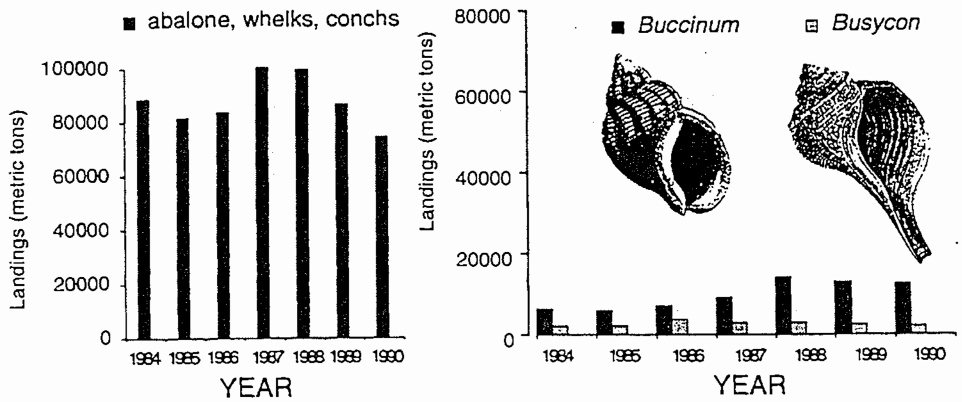


FIGURE 2. World landings of abalone, whelks, and conchs (left) and specifically (right) the carnivorous gastropods *Buccinum* and *Busycon* for the period 1984 to 1990 (FAO, 1992).

need for increased surveillance worldwide to protect public health and ensure quality seafood products.

A. GASTROPODS

Whelks and other species of carnivorous snails prey on other molluscs, predominantly filter-feeding bivalves such as scallops, mussels, and clams. The importance of *Lunatia* (=*Euspira*) *heros* as a predator of the surfclam (*Spisula solidissima*) is well known (Belding, 1910; Ropes et al., 1969; Franz, 1977). The gastropods feed "by boring a beautifully countersunk hole by means of a rasping tongue" (Belding, 1910), at the umbo (directly over the digestive gland) and sucking out the contents of the bivalve shell. Thus, the snails accumulate any toxins present in the prey organism. Members of the Buccinidae (e.g., *Buccinum undatum*) are not equipped for such boring and attack live prey by manipulating the prey with the foot and placing the lip of the whelk's shell between the valves, thus preventing valve closure while the proboscis extracts the soft tissues from the bivalve (Nielsen, 1975; Himmelman and Hamel, 1993; Figure 3A,B). Shimek (1984) reported bivalve molluscs to be the primary prey item of six species of *Neptunea*. Other species of gastropods (e.g., *Nassarius*) (Figure 3C) are scavengers and can also accumulate significant amounts of phycotoxins. Given that many bivalve molluscs concentrate toxins in the digestive gland, predators can accumulate significant amounts of toxin in only one meal. It has also been suggested (Worms et al., 1993) that moonsnails may accumulate paralytic shellfish toxins over time by ingesting small amounts continuously. In regions where bivalves such as scallops (*Placopecten magellanicus*) and surfclams (*Spisula solidissima*) harbor paralytic shellfish toxins throughout the year (e.g., White et al., 1993a,b; Figure 4) secondary intoxication of gastropods poses an extra threat to consumers and an added problem for fisheries health managers.

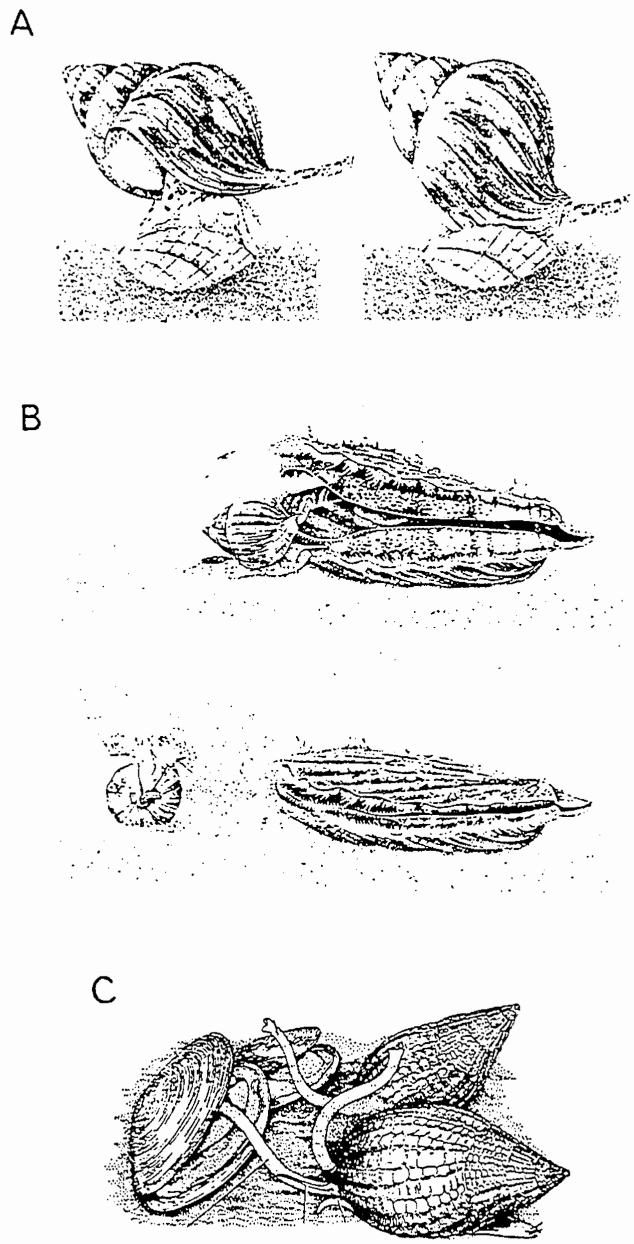


FIGURE 3. (A) The carnivorous prosobranch *Buccinum undatum* attacking a cockle, *Cardium edule* and (B) attacking a scallop *Pecten maximus* (after Nielsen, 1975). (C) The scavenging prosobranch, *Nassarius reticulatus* eating dead bivalves (*Tellina crassa* (after Fretter and Graham, 1962).

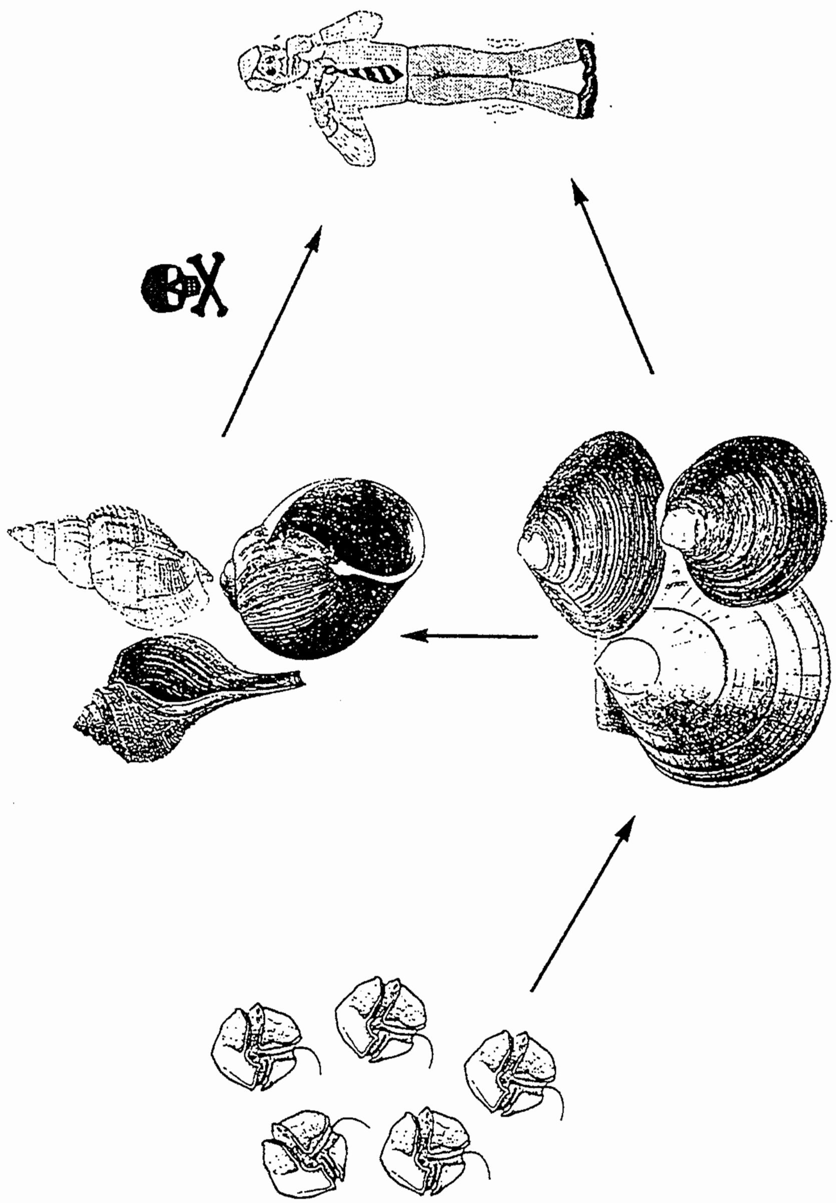


FIGURE 4. Pathways of human intoxication with paralytic shellfish toxins via both filter-feeding bivalve molluscs and carnivorous and scavenging gastropod molluscs.

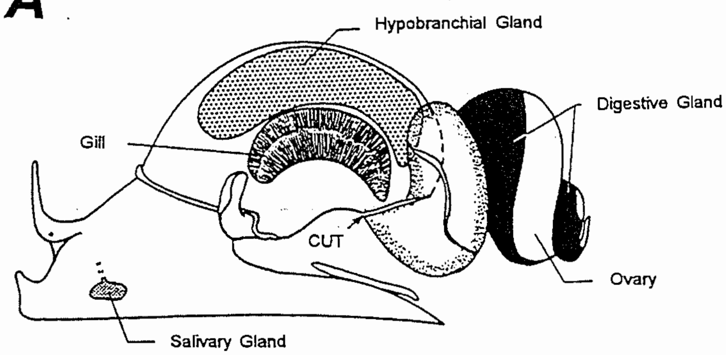
As in bivalves, toxins in gastropods are usually concentrated in the digestive gland and muscular portions are usually toxin-free (Caddy and Chandler, 1968; Figure 5A,B). Marked exceptions to this are the lined moon snail, *Natica lineata*, and the moon snail, *Euspira (=Polinices) heros*, which concentrate tetrodotoxin and paralytic shellfish toxins, respectively, in the muscle tissue (Figure 5C). The variability of toxicity between individual animals from the same region is very high (±47% for *Euspira (=Polinices) heros*, White et al., 1993a; Figure 6), due in part to the sporadic nature of feeding and the fact that the snails are mobile. A further complication is the fact that many gastropods (e.g., *Polinices, Busycon, Buccinum*) tend to release toxins very slowly once acquired (Worms et al., 1993; Shumway, unpublished).

A summary of phycotoxins and tetrodotoxins (TTX) associated with gastropod molluscs is given in Table 1. At least four species of snails have been responsible for human fatalities and many others have been implicated in illnesses (Figure 7). Whereas the majority of these outbreaks have been the result of paralytic shellfish toxins, at least one report exists of human fatalities from snails secondarily toxified with tetrodotoxin, and at least six species of gastropods are now known to be vectors of TTX (see Table 1). The source is still not clear and the suggestion has been made that bacteria may play a significant role in toxin production (see Hwang et al., 1990).

In addition to scavenging and predatory gastropods, toxins have been detected in a few grazing gastropods, albeit at low levels. Four species of grazing snails (*Turbo marmorata*, *T. argyrostoma*, *Tectus pyramis*, and *T. nilotica maxima*) had measurable levels of PSP toxins, and it is believed that the toxins originated in the macro alga, *Jania* sp. (see references in Table 1). A closely related species of turban, *Turbo cornutus*, accounted for 12,646 MT landed in Japan in 1990 (FAO, 1992; Figure 8). Two individual slipper limpets, *Crepidula fornicata*, had toxin levels of 46 and 58 µg STX equiv/100 g (White et al. 1993b). It is presumed that these snails ingested either cysts of *Alexandrium tamarense* or cells that were settling out of the water column after the bloom. An abalone, *Haliotis tuberculata*, was reported to contain 0.78 ng/g meat, but the source of toxin is not clear (Martinez et al. 1993). The common periwinkle (*Littorina littorea*) is a herbivore and usually toxin-free; however, very low levels of PSP-toxins have been reported in this species, and certification is necessary for shipment of snails between North America and the European market (J. Hurst, personal communication).

Other molluscan species have also been reported to contain various toxins. Sommer and Meyer (1937) reported trace levels of PSP toxins in one chiton (*Mopalia muscosa*) and a limpet (*Acmaea pelta*). Halstead (1965) reported *Murex brandaris* as a transvector of dinoflagellate poisons and there is a report of toxic squid (*Loligo* sp.) at Carigara Bay, Philippines, that resulted in 16 illnesses and 1 death (Estudillo and Gonzales, 1984). The source of toxin in these squid is not known; however, it is possible that the squid acquired the toxins by feeding on contaminated filter-feeding fish (Figure 9). Given that squid landings (*Loligo* sp.) of 26,574 MT were reported from the Philippines in 1990 (FAO, 1992; Figure 10), the potential presence of toxins should be considered. Hashimoto (1979) and Yasumoto and Kanno (1976) reported occurrence of ciguatera-like poisoning from ingestion of a turban shell, *Turbo argyrostoma*. Isolated toxins resembled ciguatoxin, scaritoxin, and maitotoxin,

A

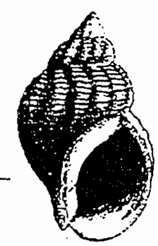


B

Buccinum (Georges Bank)

Digestive gland	7784
All other tissue	>40

(μgSTX equiv 100 g tissue^{-1})



C

Euspira (Georges Bank)

Digestive gland	2880
All other tissue	2690

(μgSTX equiv 100 g tissue^{-1})

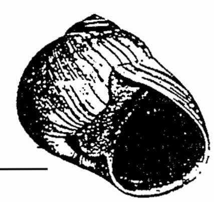


FIGURE 5. (A) Diagrammatic representation of the whelk *Buccinum undatum* demonstrating differentiation of digestive gland and muscular portions of the snail (after Caddy and Chandler, 1965). (B) Comparison of toxicity (µg STX equiv/100 g tissue) of digestive gland (marked in black) and "all other tissue" between two carnivorous whelks, *Buccinum undatum* and *Euspira heros,* from Georges Bank. (Snails collected 7.16.91; see also White et al., 1993a,b).

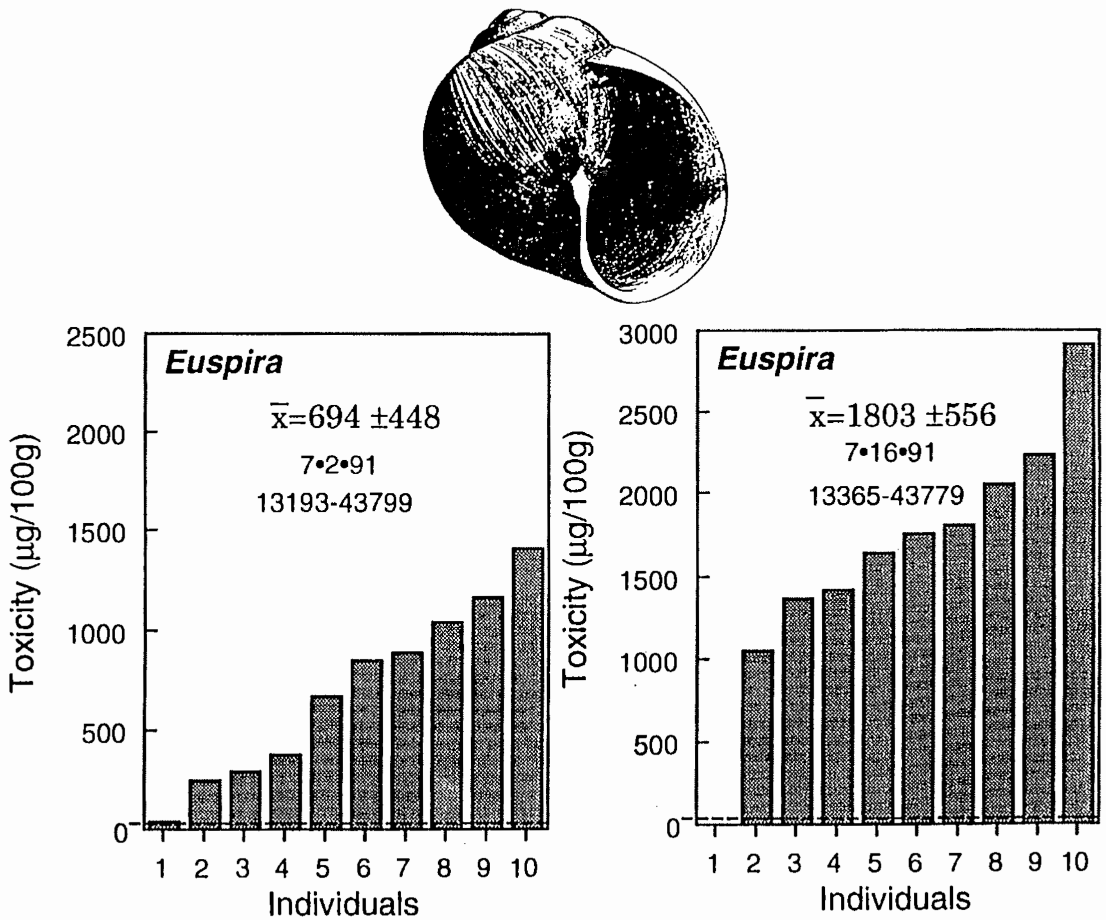


FIGURE 6. Toxin levels of individual snails (*Euspira*) collected from Georges Bank. Mean toxin level (µg STX equiv/100 g tissue), standard deviation, date of collection, and Loran C coordinates of the collection site (after White et al., 1993a).

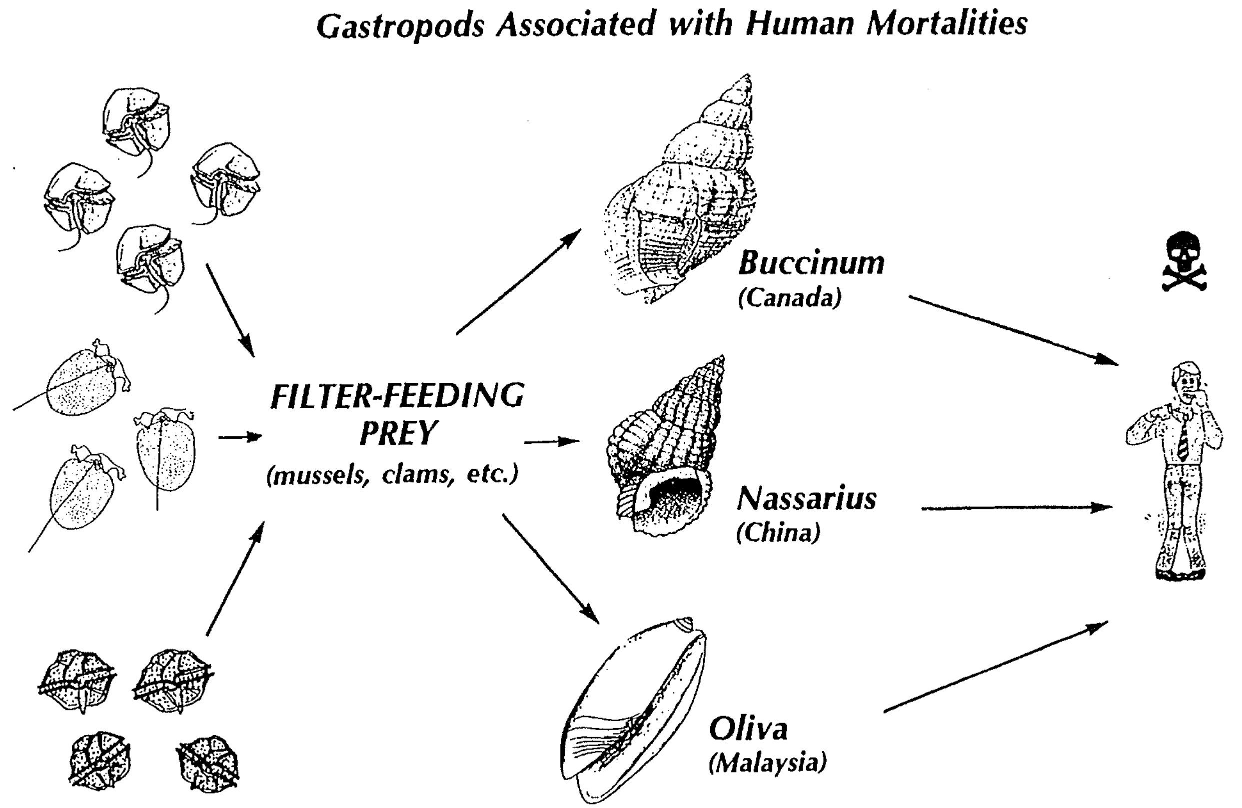


FIGURE 7. Generalized pathways of lethal human intoxications of shellfish poisoning involving gastropod molluscs. (See text and Table 1 for specific references.)

TABLE 1
A Summary of Phycotoxins and Tetrodotoxins (TTX) Associated with Gastropod Molluscs. Maximum Recorded Values are Given. Species Names are as Given in Original Publications

Gastropod species[a]	Toxin Source[b]	Toxin Level[c]	Notes	Location	Ref.
Littorina sitkana	*Gonyaulax tamarensis*	Trace	Whole snails	Washington	MacDonald (1970)
Littorina littorea *Polinices heros*	Probably *A. tamarense*	72 1450	2 cases of PSP; victims ate both species of snail	Massachusetts	Tufts et al. (1975); Tufts (1979)
Littorina littorea	*Alexandrium tamarense*	37	Whole snails	New Brunswick, Canada	Matter (1993)
Thais lapillus	*G. tamarensis*	34		Maine	Goggins (1961)
Buccinum undatum	*G. tamarensis*	Whole body: 608 digestive gland: 1600	12 cases of PSP 4 deaths	Quebec Quebec	Medcof (1972); Prakash et al. (1971)
	G. excavata	Not given	Snail mortalities	Faroe Islands	Mortensen (1985)
	G. tamarensis	1096 MU 100 g^{-1}	Fed toxic mussels in laboratory	Great Britain	Ingham et al. (1968)
Turbo marmorata *Turbo argyrostoma* *Tectus pyramis* *Tectus nilotica maxima*	*Jania* sp.	4.2 MU g^{-1} 20 MU g^{-1} 19 MU g^{-1} 5 MU g^{-1}	All grazers	Japan	Yasumoto and Kotaki (1977, 1983); Kotaki et al. (1981, 1983); Kanno et al. (1976)
Zidona angulata	*A. excavatum*	Not given	One mild case of PSP	Argentina	Elbusto et al. (1991)
Haliotis tuberculata *Littorina* sp. *Patella* sp.	*Gymnodinium catenatum* (?)	0.78 ng/g meat None detected None detected	All browsers; tests for DSP negative in all species	Spain	Martinez et al. (1993)
Oliva vidua fulminans	*Pyrodinium bahamense*	2525 MU 100 g^{-1}	5 human fatalities; 8 cases of PSP	Malaysia	Sang and Ming (1984); Ming and Wong (1989); Kan et al. (1986)
Polinices duplicata *Thais haemastoma*	*Gonyaulax monilata*	Not given	Snail mortalities	Texas	Wardle et al. (1974)
Tekuyong	*Pyrodinium bahamense*	71–876 MU 100 g^{-1}		Borneo	Jaafar and Sburamaniam (1984); Jaafar et al. (1989)

Lunatia heros	*A. tamarense*	247		Gulf of St. Lawrence, Canada	Worms et al. (1993)
Lambis lambis	*Pyrodinium bahamense*	ND–175 MU 100 g^{-1} very toxic	Several cases of PSP	Sabah, Malaysia	Sang and Ming (1984) Ming and Wong (1989)
Nassarius sp.	Probably *A. catenella*	9	Scavengers	Washington	Beitler (1992)
Buccinum undatum	*A. tamarense*	3337	Illnesses and deaths	Gulf of Maine, USA	White et al. (1993);
Euspira heros		2922			Prakash et al. (1971);
Neptunea decemcostata		1060	Steamed; ≈3000–4000 raw		Hurst (unpublished);
Crepidula fornicata		46–58			Bond (1975)
Colus stimpsoni		Toxic			
Thais lapillus		Toxic			
Polinices lewisii	*G. acatenella*	176–600	Not specified	British Columbia	Quayle (1969); Matter (1993)
Thais lamellosa	*A. catenella*	Positive	Whole snails	Washington	MacDonald (1970)
T. lima		180	Whole snails		
Thais sp.		23	GTX 2 + 3 only		Beitler (1992)
Neptunea spp.	*A. catenella*	200–250	Whole individuals	Alaska	Matter (1993)
Argobuccinum sp.	*A. catenella*	5629	Stomach	Chile	Uribe (1995)
		92	Muscle		
Adelamelon ancilla		Toxic			
Trophon sp.		Toxic			
Concholepas concholepas		Toxic			
Busycon spp.	*A. tamarense*	50–500	Not specified	Quebec	Matter (1993)
Nassarius sp.	*Prorocentrum minimum*	1820–1890 MU 100 g^{-1}	Many human fatalities	Zhengjiang and Fuziang, China	Chen and Gu (1993)

TABLE 1 (continued)

A Summary of Phycotoxins and Tetrodotoxins (TTX) Associated with Gastropod Molluscs. Maximum Recorded Values are Given. Species Names are as Given in Original Publications

Gastropod species[a]	Toxin Source[b]	Toxin Level[c]	Notes	Location	Ref.
Zeuxis siquijorensis	Tetrodotoxin	3.4 MU g^{-1}	Edible parts	Japan	Narita et al. (1984)
Niotha clathrata	Tetrodotoxin	35 MU g^{-1}	Edible parts	Japan	Jeon et al. (1984)
Natica lineata	Tetrodotoxin Anhydrotetrodotoxin	12 MU g^{-1} 720 MU g^{-1}	Digestive gland Muscle	Taiwan	Hwang et al. (1990)
Rapana rapiformis *Rapana venosa venosa*	Tetrodotoxin	140 MU g^{-1} 13 MU g^{-1}	Digestive gland Digestive gland	Taiwan	Hwang et al. (1991)
Charonia sauliae *Babylonia japonica*	Tetrodotoxin from starfish and pufferfish	1950 MU g^{-1} 180 MU g^{-1}	Illnesses and deaths	Japan	Shiomi et al. (1984); Noguchi et al. (1981a), 1992); Narita et al.
(1981);					
Tutufa lissostoma		700 MU g^{-1}	Digestive glands/ toxic year round	Japan	Yasumoto et al. (1981); Noguchi et al. (1984)

[a] *Euspira heros = Lunatia heros = Polinices heros; Thais = Nucella.*

[b] *Alexandrium tamarense (=Gonyaulax tamarensis = Protogonyaulax tamarensis = Gonyaulax excavata); A. catenella (=Gonyaulax catenella = Protogonyaulax catenella); G. monilata (=Alexandrium monilata); all taxonomic names are as in original publications.*

[c] *Unless otherwise specified, toxin level is given in μg STX equiv/100 g tissue.*

and it was suggested that the epiphytic dinoflagellate *Gambierdiscus toxicus* found on benthic algae (major food source of turbans) was a toxin source. This appears to be the only record of ciguatera-like toxins in gastropods, but may only be the result of no one having looked for it.

There are no records of diarrhetic or amnesic shellfish toxins in gastropods; however, it is known that digestive glands of scallops (*P. magellanicus*) contain domoic acid (Hurst, unpublished) and diarrhetic shellfish toxins (J. Marr, personal communication) and there is every reason to believe that these toxins may be transferred to predatory snails.

B. CRUSTACEA (LOBSTERS, CRABS AND SHRIMP)

Detectable phycotoxins in crustaceans are generally limited to those accumulated in the hepatopancreas or "green-gland" (see Table 2). Once intoxicated, most crustaceans remain so for extended periods of time (Noguchi et al., 1983; Desbiens and Cembella, 1995). Because usually only the meat of crustaceans is consumed, transfer of phycotoxins to higher trophic levels is then uncommon; however, it is not unknown and should not be ignored. In many regions the green-gland, or tomalley as it is known in lobsters, is considered a delicacy and is often spread on toast or included in soups. In other regions, small crabs are included in soups whereby all toxins present are made available to the consumer. In addition, Wright (1993) has demonstrated that some toxins may be transferred to crab meat after cooking in boiling water.

The primary source of toxins in lobsters (*Homarus americanus*) is clearly consumption of bivalve molluscs, especially scallops, *P. magellanicus,* which remain highly toxic throughout the year in many areas. Sherman and Hurst (unpublished, AOAC mouse bioassay) showed that lobsters readily accumulate PSP toxins in the hepatopancreas after consuming toxic scallops. They demonstrated considerable individual variation in PSP levels between individual lobsters and no correlation between toxicity and sex or size of lobsters. No detectable levels of toxins were noted in the lobster meat. Field studies in the Gulf of Maine (Hurst, unpublished) and the Bay of Gaspe (Desbiens and Cembella, 1995) demonstrated consistently high levels of PSP toxins in lobster hepatopancreas with maximum recorded values of >1600 μg STX equiv/100 g. Cooking significantly reduced, but did not eliminate, the toxicity and also reduced the variance in toxicity between individual lobsters. Low levels of toxin were recorded in stomachs and no toxins were detected in muscle tissue (Hurst, unpublished). Using the more sensitive HPLC techniques, Desbiens and Cembella (1995) were able to demonstrate low but detectable levels of PSP toxins in the lobster meat.

Lobster hepatopancreas or "tomalley" is considered a delicacy by many and the question is often asked, "How dangerous is lobster tomalley?". Given the paucity of human volunteers for toxicity studies, estimates of PSP-toxin sensitivity have been calculated from residues of meals eaten by people known to have been affected. The only generalization that can be made is that children seem to be more sensitive than adults. It has been shown that as little as 120 to 180 μg of STX can induce moderate symptoms in adults and as little as 400 to 1060 μg of STX may cause death in adults, although the lethal level is probably closer to 10,000 μg (Acres and Gray, 1978;

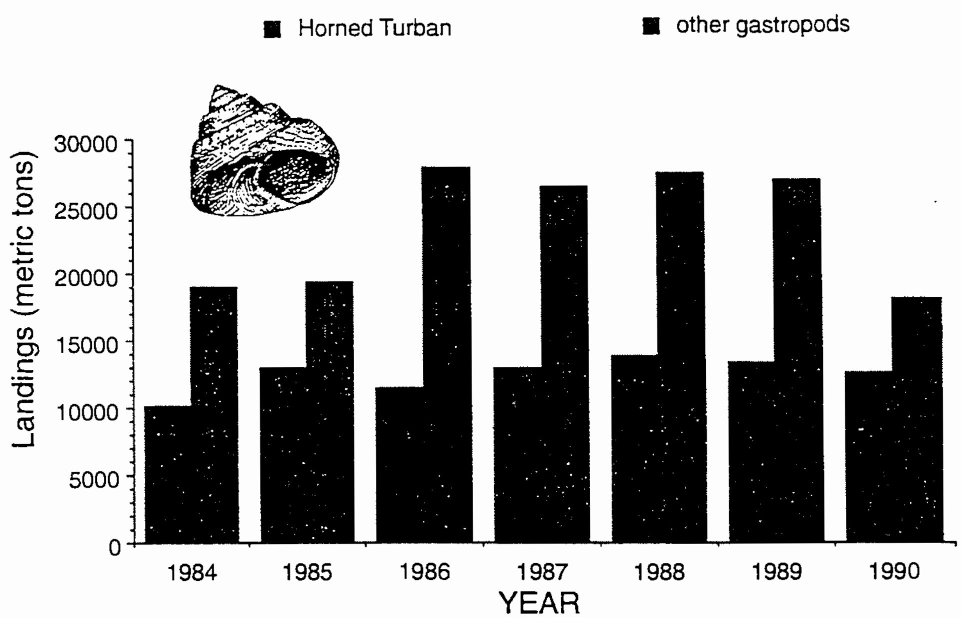


FIGURE 8. World landings of gastropods and specifically horned turbans for the period 1984 to 1990. (FAO, 1992.)

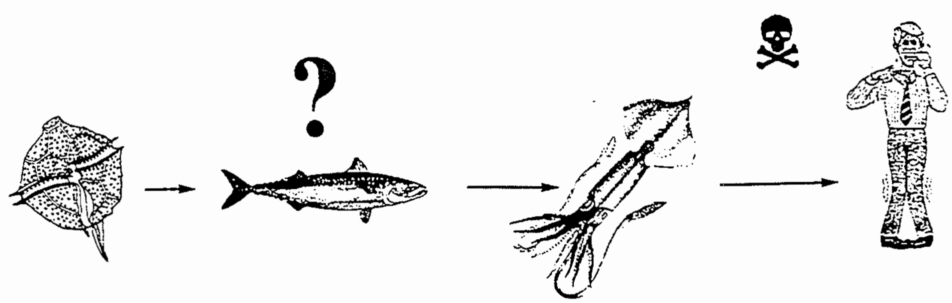


FIGURE 9. Possible pathway of lethal human intoxication with paralytic shellfish poisons from consumption of squid.

Krogh, 1983; Langeland et al., 1984; McFarren et al., 1960; Prakash et al., 1971; Valenti et al., 1979). Assume a "worst-case" scenario with toxicity of lobster hepatopancreas of 3000 μg STX/equiv/100 g. When cooked, this tomalley will have a toxicity of approximately 1000 μg STX equiv/100 g (Desbiens and Cembella, 1995; Lawrence et al., 1994; Hurst, unpublished). The tomalley from a 1.25 lb (500 to 600 g) lobster

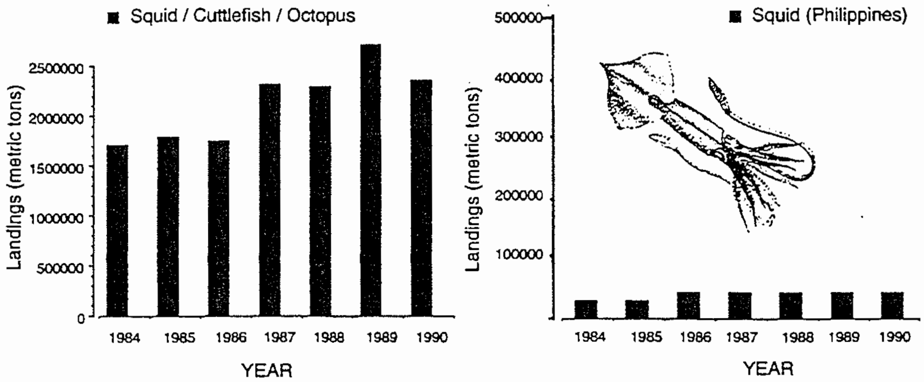


FIGURE 10. World landings of squid, cuttlefish, and octopus (left) and squid in the Philippines for the period 1984 to 1990. (FAO, 1992.)

weighs approximately 25 g raw and 15 g cooked. Therefore, potential toxin consumption from the tomalley of one lobster could be approximately 150 µg. Illnesses have been reported after consumption of 144 to 1660 µg STX equiv per person (see references above), and fatal intoxications have been reported after a calculated consumption of 456 to 12400 µg STX equiv per person, that is, a person with high sensitivity to PSP toxins could become ill or die from only one serving. The real health risk is unclear, and, to date, there have no reports of illnesses linked to PSP toxins and lobster tomalley.

Like lobsters, some species of crabs (e.g., *Cancer* spp.) also prey on toxic bivalves and store accumulated toxins in the hepatopancreas (see Foxall et al., 1979; Table 2). Toxicity in other crabs remains a complicated picture. Garth and Alcala (1977) reported highly toxic crabs (*Demania alcalai, Lophozozymus pictor, Atergatis floridus,* and *Zosimus aeneus;* Figure 11). In these species, toxicity is probably attained through consumption of the macroalgae *Jania.* They also listed several mildly toxic species (*Etisus splendidus, Atergatis dilitatus, A. integerrimus, Carpilius convexus, Eriphia sebana,* and *Daldorfia horrida*); however, in neither case did they list the toxin responsible. *Demania splendida* and *Lophozozymus pictor* have been responsible for several human fatalities (Garth and Alcala, 1977). Sources of toxin(s) are not always known (see Table 2), and it is possible that, in some species, the toxicity is an inherent part of the animals' biology. Xanthid crabs (*Atergatis floridus*), in addition to containing STX and neoSTX, are the first arthropods reported to contain tetrodotoxin (Noguchi et al. 1983, 1984). The fact remains, however, that crabs contain paralytic shellfish toxins, TTX, and sometimes both!

Horseshoe crabs, although not true crabs, are included here because they are responsible for sporadic food poisonings in Thailand and landings are significant (Figure 12). The unlaid eggs are especially prized, although other parts of the animals are also eaten. Both saxitoxin and its derivatives and tetrodotoxin have been isolated from the edible horseshoe crab, *Carcinoscorpius rotundicauda,* in Thailand and have been responsible for human illnesses (Fusetani et al., 1982, 1983; Kungsuwan et al., 1987a,b; Saitanu et al., 1987). Saitanu et al. (1987) also reported toxicity (TTX)

TABLE 2

A Summary of Phycotoxins and Tetrodotoxins Associated with Crustaceans. Maximum Recorded Values are Given. Species Names Are as Given in Original Publications

Crustacean species	Toxin source[a]	Toxin level[b,c]	Notes	Location	Ref.
Crabs					
Actaeodes tomentosus	*Jania* sp. (?)	5.9 MU g^{-1}	Human illnesses and mortalities	Japan	Yasumoto et al. (1981, 1983); Hashimoto et al. (1967); Inoue et al. (1968); Kotaki et al. (1983); Noguchi et al. (1969; 1983a,b); Mote et al. (1970)
Atergatis floridus		9000 MU g^{-1}			
Eriphia scabricula		120 MU g^{-1}			
Neoxanthias impressus		10 MU g^{-1}			
Percnon planissimum		7.4 MU g^{-1}			
Pilumnus vespertilio		6.1 MU g^{-1}			
Platypodia granulosa		5000 MU g^{-1}			
Schizophrys aspera		2.3 MU g^{-1}			
Thalamita sp.		80 MU g^{-1}			
Zosimus aeneus		16500 MU g^{-1}	Highly variable	Ishigaki Island	Koyama et al. (1983); Konosu et al. (1970)
		2000 MU g^{-1}	Appendages		
		800 MU g^{-1}	Cephalothorax		
		1260 MU g^{-1}	Whole body (calculated)		
Portunus pelagicus	*Pyrodinium bahamense*	175 MU 100 g^{-1}	Whole crab	Sabah, Malaysia	Sang and Ming (1984)
		288 MU g^{-1}	Gills		
		328 MU g^{-1}	Guts		
		ND	Flesh		
Cancer magister	*Gonyaulax catenella*	72	Viscera	Washington	Washington Dept. Soc. Health Services (1980)
Cancer irroratus	*Gonyaulax tamarensis*	242	Hepatopancreas	Laboratory study; fed toxic clams	Foxall et al. (1979)
Cancer productus	*Gonyaulax catenella*	285	Viscera	Washington	Jonas Davies and Liston (1985)
		ND-27	Muscle		
Cancer borealis	*Gonyaulax tamarensis*	56	Not specified	Maine	Goggins (1961)
Cancer magister stone crab	*Pseudonitzschia*	485 ppm DA[c]	Viscera	Pacific Coast, USA	Villac et al. (1993); Anonymous (1992); DFO (1992); Wekell et al. (1995)
	P. delicatissima	176 ppm	Gut		
	Others ?	105 ppm	Body meat		

Fabia subquadrata	*Gonyaulax catenella*	32	Whole crabs; commensal in butterclams	Washington	MacDonald (1970)
Pagurus sp.	*Gonyaulax catenella*	35	Whole crabs	Washington	MacDonald (1970)
Pugettia producta	*Gonyaulax catenella*	146 1710 48	Eggs Viscera Muscle	Maine	Goggins (1961)
Hemigrapsus oregonensis *Hemigrapsus nudus*	*Gonyaulax catenella*	32 44	Not specified Whole bodies, legs and carapace removed	Washington	Jonas-Davies and Liston (1985); Barber et al. (1988); MacDonald (1970)
Emerita analoga	*Gonyaulax* sp.	>60 mg[d] 250 mg 10 mg	Filter-feeder; whole crab Viscera Muscles	California	Sommer (1932)
Crab	*Pyrodinium bahamense*	339 MU 100 g^{-1}	Not specified	Brunei Darussalam	Jaafar and Subramaniam
Lophozozymus pictor	Unknown	18.9 MU g^{-1} 0.3 MU g^{-1}	Homogenized crabs Moult	Australia	Llewellyn and Endean (1989)
Thalamita stimpsoni	Unknown	4.9 MU g^{-1}	Whole crabs	Australia	Llewellyn and Endean (1987)
Atergatis floridus	Tetrodotoxin	Not specified	STX/neoSTX also present; first record of TTX in arthropod	Japan	Noguchi et al. (1984); Noguchi et al. (1983)
Mangrove crabs	*Pyrodinium bahamense*	239 MU 100 g^{-1} 175 MU 100 g^{-1} ND	Guts Gills Flesh	Sabah, Malaysia	Sang and Ming (1984)

TABLE 2 (continued)

A Summary of Phycotoxins and Tetrodotoxins Associated with Crustaceans. Maximum Recorded Values are Given. Species Names Are as Given in Original Publications

Crustacean species	Toxin source[a]	Toxin level[b,c]	Notes	Location	Ref.
LOBSTERS					
Panulirus versicolor	*Pyrodinium bahamense*	175 MU 100 g^{-1} 175 MU 100 g^{-1} ND MU 100 g^{-1}	Whole lobster Body only Tail only	Sabah, Malaysia	Sang and Ming (1984)
Panulirus longipes	*Pyrodinium bahamense*	211 MU 100 g^{-1} 177 MU 100 g^{-1} ND	Whole lobster Head and legs Tail only	Sabah, Malaysia	Sang and Ming (1984)
Homarus americanus	*Gonyaulax tamarensis*	60 3 21	Hepatopancreas Tail muscle Appendage muscle	Laboratory study; fed toxic clams	Foxall et al. (1979)
Homarus americanus	*Alexandrium tamarense*	429 110	Hepatopancreas (raw) Hepatopancreas (cooked); lobsters fed toxic scallops in laboratory	Gulf of Maine	Sherman (unpublished)
		124 64	Hepatopancreas (raw) Hepatopancreas (cooked); mean values (n=20)	Nova Scotia	Watson-Wright et al. (1991)
Homarus americanus	*Alexandrium tamarense*	1654 540 ND	Hepatopancreas (raw) Hepatopancreas (cooked) Muscle	Cutler, Maine	Hurst (unpublished)
Homarus americanus	*Alexandrium tamarense*	1512 961 69	Hepatopancreas (bioassay) Hepatopancreas (HPLC) Meat (HPLC)	Bay of Gaspe, Canada	Desbiens and Cembella (1995)
Homarus americanus	*Alexandrium tamarense*	275–3200 ND	Hepatopancreas Tail muscle	Laboratory study; fed toxic scallop viscera	Haya et al. (1992)
Spiny lobster	*Pseudonitzschia* *P. delicatissima* Others ?	12 ppm DA[d]	Gut	Pacific Coast, USA	DFO (1992); Villac et al. (1993); Anon. (1992)

SHRIMP					
Penacidae	*Pyrodinium bahamense*	175 MU 100 g^{-1}	Frozen tails for export	Sabah, Malaysia	Sang and Ming (1984)
		268 MU 100 g^{-1}	Body only		
Penaeid prawn	*Pyrodinium bahamense*	190 MU 100 g^{-1}	Not specified	Brunei Darussalam	Jaafar and Subramaniam (1984)
HORSESHOE CRAB					
Carcinoscorpius rotundicauda	Unknown (resembles STX)	25 MU 100 g^{-1}	Exoskeleton, muscle	Thailand	Fusetanl et al. (1982)
		65 MU 100 g^{-1}	Eggs		
		75 MU 100 g^{-1}	Hepatopancreas		
		10 MU 100 g^{-1}	Stomach and contents		
		85 MU 100 g^{-1}	Gills		
		50 MU 100 g^{-1}	Coelomic fluid		
		35 MU 100 g^{-1}	Tail		
	Tetrodotoxin	16 MU g^{-1}	Eggs; some STX/ neoSTX also present; human illnesses	Gulf of Thai	Kungsuwan et al. (1987)
	Tetrodotoxin	65 MU g^{-1}	Hepatopancreas	Thailand	Saitanu et al. (1987)

[a] *Alexandrium tamarense* (=*Gonyaulax tamarensis* = *Protogonyaulax tamarensis*); *A. catenella* (=*Gonyaulax catenella* = *Protogonyaulax catenella*); *Pseudonitzschia* (=*Nitzschia*). All taxonomic names are as in original publications.

[b] *Unless otherwise specified, toxin level is given in μg STX equiv/100 g tissue.*

[c] *Note: domoic acid concentrations.*

[d] *Average lethal dose (to mice) of extracts.*

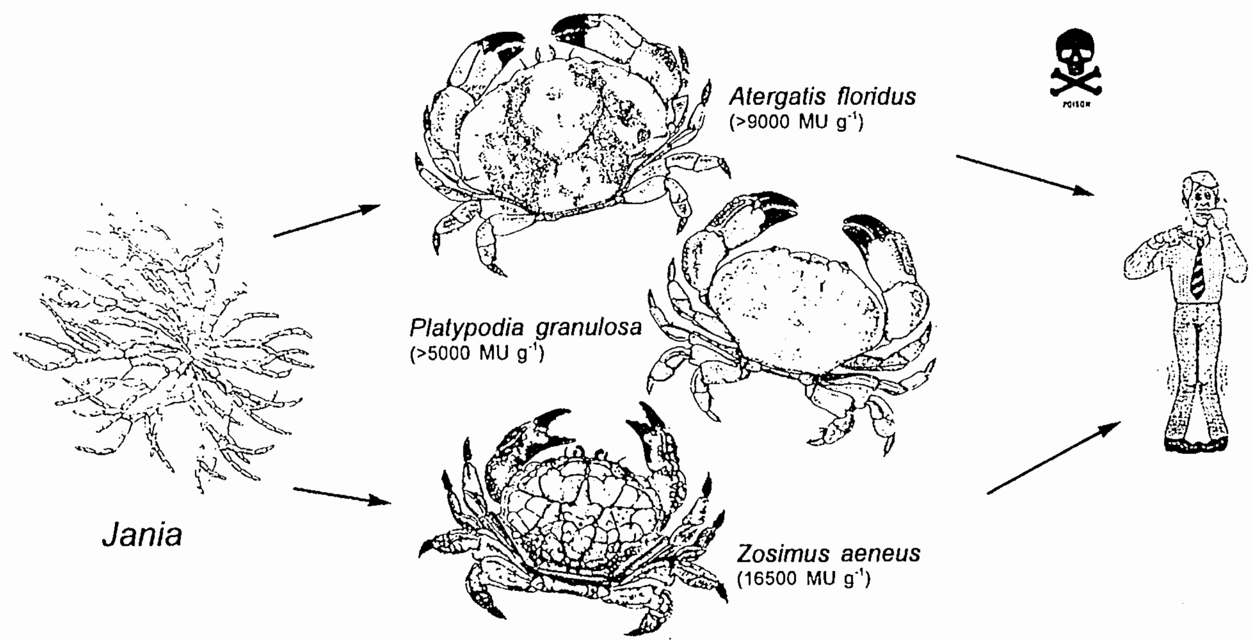


FIGURE 11. Pathways of lethal human intoxications of shellfish poisoning resulting from consumption of various species of crabs. (See Table 2 for specific references.)

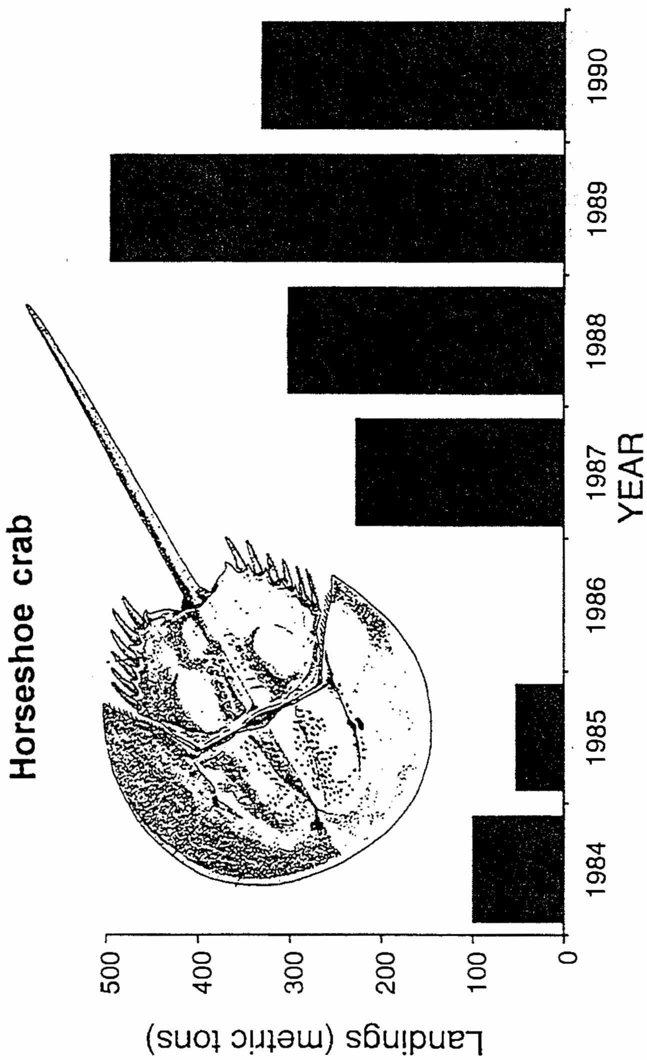


FIGURE 12. World landings of horseshoe crabs for the period 1984 to 1990. (FAO, 1992.)

in another horseshoe crab, *Tachypleus gigas,* in Thailand. Poisonings due to ingestion of horseshoe crab eggs have been reported since 1933 (Smith, 1933; Banner and Stephens, 1966; Trishnananda et al., 1966). Toxicity has been reported in all tissues of the horseshoe crabs and regional, seasonal, and sexual variation is high. Finally, barnacles (*Balanus balanoides* and *B. cariosus*; Figure 13) have also been reported to accumulate paralytic shellfish toxins at levels >50 µg 100 g STX equiv/100 g (Quayle, 1969; Hurst, unpublished), which in turn serve as a source of toxins for *Thais* spp. (Figure 14).

Recent studies in affected regions indicate that other toxins, including domoic acid, are accumulated (>20 ppm) in the hepatopancreas of carnivorous and scavenging crabs (e.g., Dungeness crabs, *Cancer magister*) (Wright, 1992). Crabs, normally marketed whole, are currently marketed only after removal of the hepatopancreas. The source has not been identified, but is undoubtedly contaminated molluscs (Figure 15). Domoic acid levels up to 160 µg/g were reported in razor clams (*Siliqua patula*) on the Washington and Oregon coasts in the fall of 1991. Toxins are stored in muscle tissues and are not readily eliminated. Storage seems to be for periods in excess of at least 1 year (Gilgan et al., 1990). The US Food and Drug Administration (USFDA) has recently established a quarantine level of 30 ppm domoic acid in cooked viscera from Dungeness crabs (Health Hazard Evaluation Board, Center for Food Safety and Applied Nutrition Report #2937, October 5, 1993).

Domoic acid is also known to persist in the digestive glands of scallops (*P. magellanicus*) for extended periods (months/years??) (Gilgan et al. 1990; Hurst, unpublished). Other species of bivalves can also serve as vectors of domoic acid (e.g., mussels) (*Mytilus edulis*) and clams (*Mya arenaria*); however, the toxins are quickly eliminated in these species (Novaczek et al., 1991; Madhyastha et al., 1991) and thus the mussels and clams do not serve as a steady source of toxins for secondary consumers as do razor clams and other species. Given the expanding distribution of various shellfish toxins and especially of domoic acid, the importance of monitoring species to maintain safe public health standards becomes a necessity.

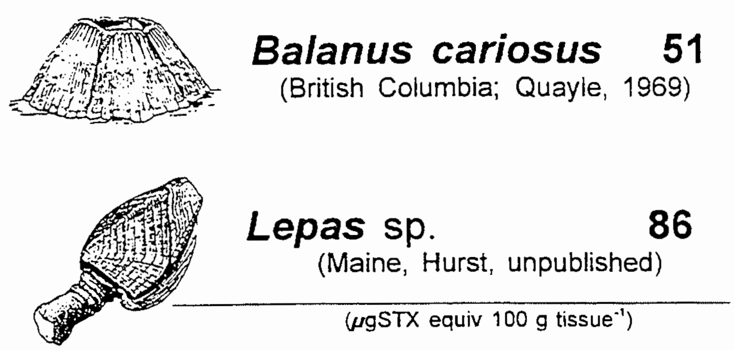


FIGURE 13. Levels of paralytic shellfish toxicity in two species of barnacles (µg STX equiv/100 g tissue) from Canada (*Balanus*) and the Gulf of Maine (*Lepas*).

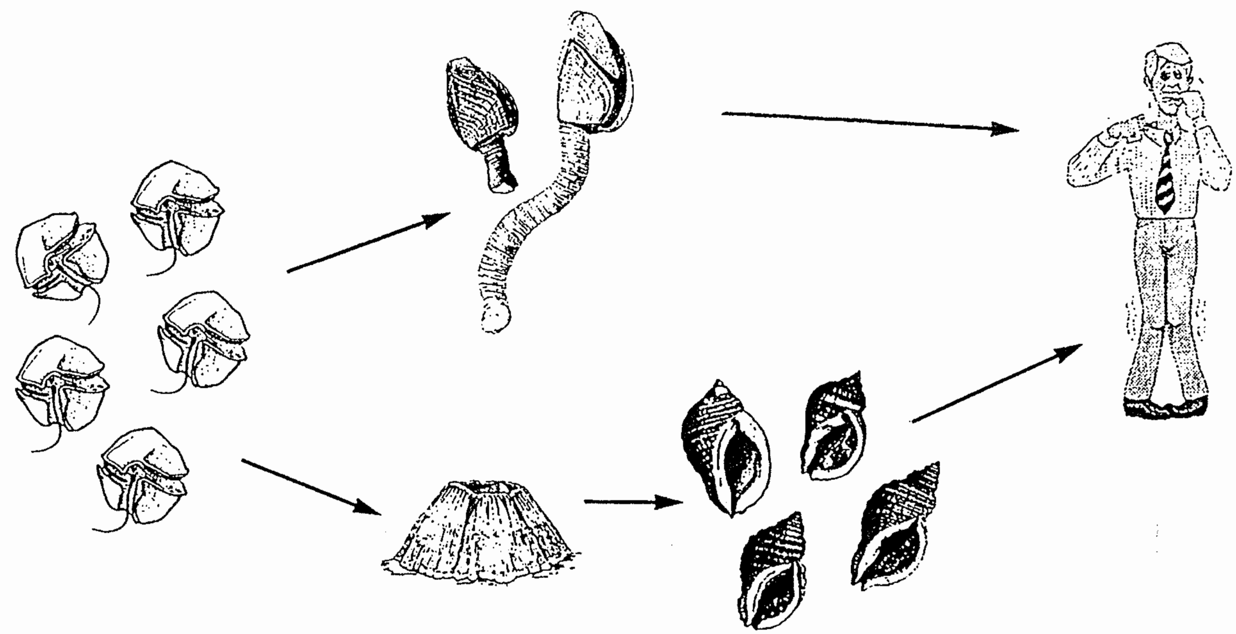


FIGURE 14. Possible pathways of human intoxication with paralytic shellfish poisons via consumption of gooseneck barnacles or carnivorous snails.

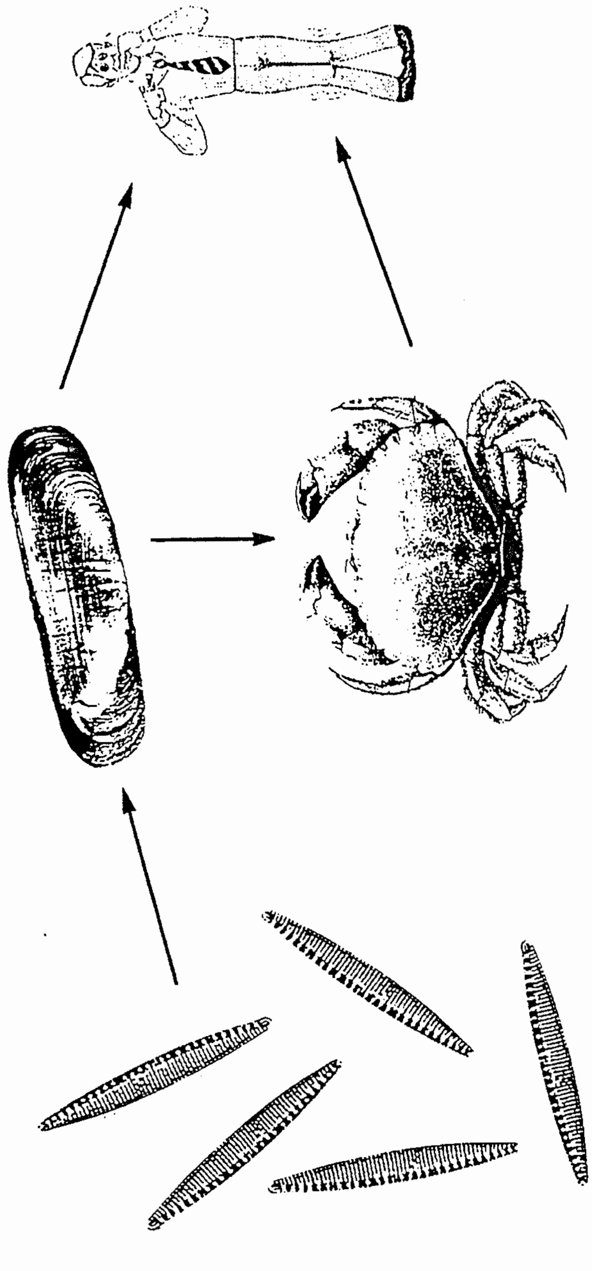


FIGURE 15. Pathways of human intoxication with domoic acid or other shellfish poisons via consumption of primary consumers (filter-feeding bivalve molluscs) or secondary consumers (predatory or scavenging crabs).

II. SUMMARY AND CONCLUSIONS

While the threat to public health posed by toxic gastropods and crustaceans does not approach the magnitude of toxic bivalve molluscs, the threat is nevertheless serious and cannot be ignored. There seems little question that there is currently a global speading and increase in frequency of harmful and toxic phytoplankton blooms. These blooms are no longer limited to the dinoflagellates and the list of highly toxic forms is growing. From a public health standpoint, the most significant new threat must be domoic acid.

It is no longer sufficient to monitor only filter-feeding bivalve molluscs for PSP toxins. There are currently no records of diarrhetic shellfish toxins in gastropods or crustaceans. Undoubtedly, this is only because no one has looked for them. Incidence of new and highly potent toxins and their prolonged retention by the bivalve molluscs that serve as prey items for predatory and scavenging crustaceans (crabs and lobsters) and gastropods, demands that these organisms be included in shellfish surveillance programs and closure notices. This is especially important in regions where prey organisms (e.g., scallops and surfclams) often remain toxic throughout the year.

Maine was the first state to initiate inclusion of gastropods in PSP-related closures (J. Hurst, personal communication). In North America, regulating agencies in California and Oregon still do not include carnivorous gastropods in PSP closures, even though moon snails, whelks, turban snails, tritons, and other species of predatory marine snails are recreationally harvested for consumption in these three states (Matter, 1993). Washington State began including carnivorous gastropods (moon shails) in PSP advisory notices in Spring 1994, but they still do not monitor them for toxins. Their PSP Hotline states "closures include clams, mussels, oysters, and scallops and their predators such as moon snails" (Ken Chew, personal communication).

While comprehensive monitoring programs exist in many countries, other areas are not so fortunate and must rely on local folklore to ensure public safety. Reports of poisonings in developed countries with established monitoring programs are scarce these days, most outbreaks being attributed to visitors and picnickers; however, in developing countries, shellfish poisonings are still responsible for considerable morbidity and economic hardship. The worldwide increase in frequency of harmful algal blooms makes increased public education essential, especially in underdeveloped countries and regions where immigrant populations are likely to utilize shellfish species not commonly used by natives. Multilingual informative leaflets, posters, radio and television announcements, and school programs can all be used as effective means of alerting both residents and visitors to the dangers of shellfish poisoning. Special care should be taken not to alarm people unduly or to enter into scare tactics. Bad publicity can be just as dangerous as the toxic shellfish!

Shellfish-mediated poisonings or intoxications are a continuing problem worldwide. As dangers of environmental contaminants become more alarming, there must be an acute awareness of the potential dangers of "non-target" species such as gastropods and crabs, and increased efforts must be made to protect public health and ensure quality seafood products.

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