TABLE 12-2. Chronology of events, showing the detection of domoic acid (DA) in various marine animals used for human consumption and the physical oceanographic regime in which the event occurred (WBS = Western Boundary System; EBS = Eastern Boundary System).

Location	Year	Affected Species		*Pseudo-nitzschia* Species Implicated	Oceanographic Regime
		Common Name	Scientific Name		
Prince Edward Island, Canada	1987	Blue mussel	*Mytilus edulis*	*P. multiseries*	WBS, Shallow bay
Bay of Fundy, Canada	1988	Soft-shell clam Blue mussel Horse mussel Sea scallop	*Mya arenaria* *Mytilus edulis* *Volsella modiolus* *Placopecten magellanicus*	*P. pseudodelicatissima* or *P. calliantha*	WBS, Estuary
Washington and Oregon coasts, United States	1991	Razor clam Dungeness crab	*Siliqua patula* *Cancer magister*	*P. australis*	EBS, Upwelling
Monterey Bay, California, United States	1991	Northern anchovy	*Engraulis mordax*	Not directly linked	EBS, Upwelling, Bay
Pacific coast of the United States	1991 to 1993	Blue crab Rock crab Stone crab Spiny lobster	*Cancer spidus* *Cancer pagurus* *Menippe adina* *Palinurus elephas*	Not directly linked	EBS, Upwelling
Coastal New Zealand	1993 to 1997	Maori scallop Greenshell mussel Pacific oyster New Zealand cockle Chilean oyster Tuata surf clam	*Pecten novaezealandiae* *Perna canaliculus* *Crassostrea gigans* *Austrovenus stutchburyi* *Tiostrea chilensis* *Paphies subtriangulata*	*P. australis*, *P. pungens*	WBS, Upwelling
Galicia, NW Spain	1994	Mediterranean mussel	*Mytilus galloprovincialis*	*P. australis*	EBS, Upwelling
Georges, German and Browns Banks, Gulf of Maine	1995	Sea scallop	*Placopecten magellanicus*	*P. seriata* (likely)	WBS, Banks
Baja California peninsula, Mexico	1995	Pacific mackerel	*Scomber japonicus*	*Pseudo-nitzschia* spp.	EBS, Upwelling
Offshore Portugal	1996	Blue mussel Common cockle Peppery furrow shell clam Pullet carpet shell European oyster Razor clam Clam	*Mytilus edulis* *Cerastoderma edule* *Scrobicularia plana* *Venerupis pullastra* *Ostrea edulis* *Ensis* spp. *Ruditapes decussata*	*P. australis* (likely)	EBS, Upwelling
Chinhae Bay, South Korea	1998	Various shellfish	Not specified	*P. multiseries*	WBS, Shallow bay
Washington and Oregon coasts, United States	1991 to 2005	Razor clam	*Siliqua patula*	*P. pseudodelicatissima*, *P. australis*	EBS, Upwelling
Central coast, California, United States	1998	Northern anchovy	*Engraulis mordax*	*P. australis*	EBS, Upwelling
Offshore Scotland	1999 to 2000	King scallop	*Pecten maximus*	*P. australis*, *P. seriata*	EBS, Tidal, Downwelling
Offshore Ireland	1999	King scallop	*Pecten maximus*	*P. australis*	EBS, Tidal, Downwelling
Western Brittany, France	1999	Wedge shell clam	*Donax trunculus*	*P. multiseries*	EBS, Upwelling
Monterey Bay, California, United States	2000	Pacific mackerel Albacore tuna Northern anchovy Pacific sardine Market squid	*Scomber japonicus* *Thunnus alalunga* *Engraulis mordax* *Sardinops sagax* *Loligo opalescens*	*P. australis*	EBS, Upwelling

(*continued*)

TABLE 12-2. *(continued)*

Location	Year	Affected Species: Common Name	Affected Species: Scientific Name	*Pseudo-nitzschia* Species Implicated	Oceanographic Regime
Offshore Portugal	2000 to 2001	European sardine European anchovy Blue mussel Pacific sardine Common cockle Pullet carpet shell Clam Oyster Razor clam	*Sardina pilchardus* *Engraulis enchrasicolus* *Mytilus edulis* *Sardinops sagax* *Cerastoderma edule* *Venerupis pullastra* *Ruditapes decussate* *Crassostrea japonica* *Ensis* spp., *Solen* spp.	Not determined	EBS, Upwelling
Southern Gulf of St. Lawrence, Canada	2002	Blue mussel	*Mytilus edulis*	*P. seriata*	WBS, Deep estuary
Offshore Portugal	2002	Swimming crab	*Polybius henslowii*	Not directly linked	EBS, Upwelling
Offshore Portugal	2003	Common octopus Common cuttlefish	*Octopus vulgaris* *Sepia officinalis*	Not directly linked	EBS, Upwelling
Puget Sound, Washington, United States	2003	Blue mussel	*Mytilus edulis*	*P. australis*	Deep estuary
Southern California, United States	2003 to 2004	Red crab Pacific mackerel Jack mackerel Pacific sanddab Longspine combfish	*Pleuroncodes planipes* *Scomber japonicus* *Trachurus symmetricus* *Citharichthys sordidus* *Zaniolepis latipinnis*	*P. australis* and *P. multiseries*	EBS, Upwelling
Monterey Bay, California, United States	2003 to 2004	Rex sole Dover sole English sole Curlfin turbot	*Errex zachirus* *Microstomus pacifcus* *Pleuronectes vetulus* *Pleuronectes decurrens*	*P. australis* (likely)	EBS, Upwelling
Santa Cruz wharf, California, United States	2004	White croaker Staghorn sculpin	*Genyonemus lineatus* *Gymnocanthus tricuspis*	*P. australis* (likely)	EBS, Upwelling

The *Pseudo-nitzschia* species implicated may have been fed on either directly or indirectly by the animals. The table does not include marine zooplankton, birds, and mammals that have also been affected by DA. References are found in Bates *et al.* (1998) and Bates and Trainer (2006).

increase since the original 1987 ASP outbreak in eastern Canada. This is probably because toxigenic *Pseudo-nitzschia* species are ubiquitous, and more events are being detected as more countries establish regulatory programs to monitor for the presence of DA in food products from the sea.

OCEANOGRAPHY AND TOXIC DIATOM BLOOMS

Toxic blooms may arise under several different oceanographic settings, and the challenge is to tease out which controlling factors are most important. In spite of intense research on the biological and chemical influences on the bloom formation of HABs, the details of bloom initiation and termination and the species composition of a bloom remain elusive. Why does one species of diatom (e.g., toxic *Pseudo-nitzschia multiseries*) begin to grow and become dominant at a particular location and time? The given species must, of course, be present, but then certain biological factors (such as grazing by zooplankton and filter-feeding molluscs, infection by fungi and viruses, and inherent physiological properties) must also exert an important influence. In the case of *Pseudo-nitzschia* species, there is evidence that they are more lightly silicified than other coastal diatoms (Marchetti *et al.*, 2004) and may therefore have a competitive growth advantage at low silicon concentrations. Some work has indicated that toxigenic *Pseudo-nitzschia* species may also have unique capabilities to acquire trace metals such as iron and copper (e.g., Wells *et al.*, 2005), thereby giving them a competitive growth advantage over other phytoplankton.

Ocean circulation and seawater properties exert an additional important influence in the development of toxic diatom blooms; the details are largely unknown, but this is