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Marine Science Review – 385

Blooms and biotoxins

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<u>In this review:</u>

A. Recent articles – no abstract
B. Recent articles with abstracts

O/A denotes an open access article or journal

A. Recent articles – no abstract

Samimi Namin, K., Risk, M.J., Hoeksema, B.W., Zohari, Z., and Rezai, H. **Coral mortality and serpulid infestations associated with red tide, in the Persian Gulf.** *Coral Reefs* 29(2): 509, 2010.

B. Recent articles with abstracts

Hu, C., Li, D., Chen, C., Ge, J., Muller-Karger, F.E., Liu, J., Yu, F., and He, M.-X. **On the recurrent *Ulva prolifera* blooms in the Yellow Sea and East China Sea.** *Journal of Geophysical Research* 115(C5): art. C05017, 2010.

Notes: A massive bloom of the green macroalgae *Ulva prolifera* (previously known as *Enteromorpha prolifera*) occurred in June 2008 in the Yellow Sea (YS), resulting in perhaps the largest "green tide" event in history. Using a novel index (Floating Algae Index) and multiresolution remote sensing data from MODIS and Landsat, we show that *U. prolifera* patches appeared nearly every year between April and July 2000-2009 in the YS and/or East China Sea (ECS), which all originated from the nearshore Subei Bank. A finite volume numerical circulation model, driven by realistic forcing and boundary conditions, confirmed this finding. Analysis of meteorological/environmental data and information related to local aquaculture activities strongly supports the hypothesis that the recurrent *U. prolifera* in the YS and ECS resulted from aquaculture of the seaweed *Porphyra yezoensis* (or *nori*) conducted along the 200 km shoreline of the Subei Bank north of the Changjiang (Yangtze) River mouth. Given the continuous growth in aquaculture efforts in the region, similar macroalgae bloom events, such as the summer 2008 event, are likely to occur in the future, particularly between May and July. This was confirmed by the 2009 bloom event in the same regions and the same period. The profit of the local *P. yezoensis* aquaculture industry (~16,000 Ha in 2007) is estimated as U.S. $53 million, yet the cost to manage the impact of the summer 2008 *U. prolifera* bloom exceeded U.S. $100 million. Therefore, better strategies are required to balance the economic benefit of seaweed aquaculture and the costs of environmental impacts.

Rasher, D.B. and Hay, M.E. **Chemically rich seaweeds poison corals when not controlled by herbivores.** *Proceedings of the National Academy of Sciences [USA]* 107(21): 9683-9888, 2010. O/A

Notes: Coral reefs are in dramatic global decline, with seaweeds commonly replacing corals. It is unclear, however, whether seaweeds harm corals directly or colonize opportunistically following their decline and then suppress coral recruitment. In the Caribbean and tropical Pacific, we show that, when protected from herbivores, ~40 to 70% of common seaweeds cause bleaching and death of coral tissue when in direct contact. For seaweeds that harmed coral tissues, their lipid-soluble extracts also produced rapid bleaching. Coral bleaching and mortality was limited to areas of direct contact with seaweeds or their extracts. These patterns suggest that allelopathic seaweed-coral interactions can be important on reefs lacking herbivore control of seaweeds, and that these interactions involve lipid-soluble metabolites transferred via direct contact. Seaweeds were rapidly consumed when placed on a Pacific reef protected from fishing but were left intact or consumed at slower rates on an adjacent fished reef, indicating that herbivory will suppress seaweeds and lower frequency of allelopathic damage to corals if reefs retain intact food webs. With continued removal of herbivores from coral reefs, seaweeds are becoming more common. This occurrence will lead to increasing frequency of seaweed-coral contacts, increasing allelopathic suppression of remaining corals, and continuing decline of reef corals.

Hallegraeff, G.M. **Ocean climate change, phytoplankton community responses, and harmful algal blooms: A formidable predictive challenge.** *Journal of Phycology* 46(2): 220-235, 2010.

Notes: Prediction of the impact of global climate change on marine HABs is fraught with difficulties. However, we can learn important lessons from the fossil record of dinoflagellate cysts; long-term monitoring programs, such as the Continuous Plankton Recorder surveys; and short-term phytoplankton community responses to El Nino Southern Oscillation (ENSO) and North Atlantic Oscillation (NAO) episodes. Increasing temperature, enhanced surface stratification, alteration of ocean currents, intensification or weakening of local nutrient upwelling, stimulation of photosynthesis by elevated CO_2, reduced calcification through ocean acidification ("the other CO_2 problem"), and heavy precipitation and storm events causing changes in land runoff and micronutrient availability may all produce contradictory species- or even strain-specific responses. Complex factor interactions exist, and simulated ecophysiological laboratory experiments rarely allow for sufficient acclimation and rarely take into account physiological plasticity and genetic strain diversity. We can expect: (i) range expansion of warm-water species at the expense of cold-water species, which are driven poleward; (ii) species-specific changes in the abundance and seasonal window of growth of HAB taxa; (iii) earlier timing of peak production of some phytoplankton; and (iv) secondary effects for marine food webs, notably when individual zooplankton and fish grazers are differentially impacted ("match-mismatch") by climate change. Some species of harmful algae (e.g., toxic dinoflagellates benefitting from land runoff and/or water column stratification, tropical benthic dinoflagellates responding to increased water temperatures and coral reef disturbance) may become more successful, while others may diminish in areas currently impacted. Our limited understanding of marine ecosystem responses to multifactorial physicochemical climate drivers as well as our poor knowledge of the potential of marine microalgae to adapt genetically and phenotypically to the unprecedented pace of current climate change are emphasized. The greatest problems for human society will be caused by being unprepared for significant range expansions or the increase of algal biotoxin problems in currently poorly monitored areas, thus calling for increased vigilance in seafood-biotoxin and HAB monitoring programs. Changes in phytoplankton communities provide a sensitive early warning for climate-driven perturbations to marine ecosystems.

Nam, D.-H., Adams, D.H., Flewelling, L.J., and Basu, N. **Neurochemical alterations in lemon shark (*Negaprion brevirostris*) brains in association with brevetoxin exposure.** *Aquatic Toxicology* 99(3): 351-359, 2010.

Notes: Brevetoxins are persistent, bioaccumulative, lipophilic polyether neurotoxins synthesized by *Karenia brevis* , a harmful algal bloom (HAB) dinoflagellate. Although some marine organisms accumulate potentially harmful levels of brevetoxins, little is known about neurotoxic effects in wild populations. Here, tissue (i.e., liver, kidney, muscle, intestine, gill, brain) brevetoxin levels (as ng PbTx-3 eq/g) and four neurochemical biomarkers (monoamine oxidase, MAO; cholinesterase, ChE; muscarinic cholinergic receptor, mAChR; N-methyl-d-aspartic acid receptor, NMDAR) were compared between eleven lemon sharks collected during a *K. brevis* bloom and eighteen lemon sharks not exposed to a bloom (controls) in a case-control manner. Brevetoxin levels in tissues were significantly higher in HAB-exposed sharks when compared to controls, and tissue levels (e.g., 277-3112 ng/g in livers, 429-2833 ng/g in gills) in HAB-exposed sharks were comparable to levels detected in a shark (e.g., 1223 ng/g in liver, 930 ng/g in gill) that died presumably of toxin exposure. Further, there were significant correlations between brain brevetoxin levels and ChE activity ($r = -0.41$; $p < 0.05$), MAO activity ($r = -0.37$; $p < 0.05$), mAChR levels ($r = 0.55$; $p < 0.01$), and NMDAR levels ($r = -0.49$; $p < 0.01$). There were no relationships between neurochemical biomarkers and metals (total mercury, methylmercury, selenium). Overall, these results in tissues from free-ranging lemon sharks indicate that ecologically relevant exposures to brevetoxins may cause significant changes in brain neurochemistry. As disruptions to neurochemistry precede structural and functional damage to the nervous system, these results suggest that relevant exposures to HABs may be causing sub-clinical effects in lemon sharks and raise further questions about the ecological and physiological impacts of HABs on marine biota.

Levin, M., Joshi, D., Draghi, A., Gulland, F.M., Jessup, D., and De Guise, S. **Immunomodulatory effects upon in vitro exposure of California sea lion and southern sea otter peripheral blood leukocytes to domoic acid.** *Journal of Wildlife Diseases* 46(2): 541-550, 2010.

Notes: During red tide bloom events, the marine diatom *Pseudo-nitzschia* produces the toxin domoic acid (DA), which has been associated with stranding and mortality events involving California sea lions (*Zalophus californianus*) and southern sea otters (*Enhydra lutris*). In addition to these well-documented DA-induced neurotoxic events, there is increasing concern that DA may exert chronic effects, such as immunomodulation, which may potentially increase an individual's susceptibility to a number of opportunistic infections following nonlethal exposure. We investigated the effects of DA on innate (phagocytosis and respiratory burst) and adaptive (mitogen-induced lymphocyte proliferation) immune functions with the use of peripheral blood leukocytes collected from healthy California sea lions and southern sea otters upon in vitro exposure to 0 (unexposed control), 0.0001, 0.001, 0.01, 0.1, 1.0, 10, and 100 μM DA. Domoic acid did not significantly modulate phagocytosis or respiratory burst in either species. For California sea lions, DA significantly increased ConA-induced T-lymphocyte proliferation upon exposure to DA concentrations ranging from 0.0001 to 10 μM, resulting in a nonlinear dose-response curve. There was no effect on lymphocyte proliferation at the highest concentration of DA tested. No effects on lymphocyte proliferation were observed in southern sea otters. Importantly, the in vitro DA concentrations affecting T-cell proliferation were within or below the range of DA in serum measured in free-ranging California sea lions following natural exposure, suggesting a risk for immunomodulation in free-ranging animals. Understanding the risk for immunomodulation upon DA exposure will contribute in the health assessment and management of California sea lions and southern sea otters, as well as guide veterinarians and wildlife rehabilitators in caring for and treating afflicted animals.

Pitcher, G.C., Figueiras, F.G., Hickey, B.M., and Moita, M.T. **The physical oceanography of upwelling systems and the development of harmful algal blooms.** *Progress in Oceanography* 85(1-2): 5-32, 2010.

Notes: The upwelling systems of the eastern boundaries of the world's oceans are susceptible to harmful algal blooms (HABs) because they are highly productive, nutrient-rich environments, prone to high-biomass blooms. This review identifies those aspects of the physical environment important in the development of HABs in upwelling systems through description and comparison of bloom events in the Benguela, California and Iberia systems. HAB development is dictated by the influence of wind stress on the surface boundary layer through a combination of its influence on surface mixed-layer characteristics and shelf circulation patterns. The timing of HABs is controlled by windstress fluctuations and buoyancy inputs at the seasonal, event and interannual scales. Within this temporal framework, various mesoscale features that interrupt typical upwelling circulation patterns, determine the spatial distribution of HABs. The inner shelf in particular provides a mosaic of shifting habitats, some of which favour HABs. Changes in coastline configuration and orientation, and bottom topography are important in determining the distribution of HABs through their influence on water stratification and retention. A spectrum of coastline configurations, including headlands, capes, peninsulas, Rías, bays and estuaries, representing systems of increasing isolation from the open coast and consequent increasing retention times, are assessed in terms of their vulnerability to HABs.

Trainer, V.L., Pitcher, G.C., Reguera, B., and Smayda, T.J. **The distribution and impacts of harmful algal bloom species in eastern boundary upwelling systems.** *Progress in Oceanography* 85(1-2): 33-52, 2010.

Notes: Comparison of harmful algal bloom (HAB) species in eastern boundary upwelling systems, specifically species composition, bloom densities, toxin concentrations and impacts are likely to contribute to understanding these phenomena. We identify and describe HABs in the California, Canary, Benguela and Humboldt Current systems, including those that can cause the poisoning syndromes in humans called paralytic shellfish poisoning (PSP), diarrhetic shellfish poisoning (DSP), and amnesic shellfish poisoning (ASP), as well as yessotoxins, ichthyotoxins, and high-biomass blooms resulting in hypoxia and anoxia. Such comparisons will allow identification of parameters, some unique to upwelling systems and others not, that contribute to the development of these harmful blooms.

Pearson, L., Mihali, T., Moffitt, M., Kellmann, R., and Neilan, B. **On the chemistry, toxicology and genetics of the cyanobacterial toxins, microcystin, nodularin, saxitoxin and cylindrospermopsin.** *Marine Drugs* 8(5): 1650-1680, 2010. **O/A**

Notes: The cyanobacteria or "blue-green algae", as they are commonly termed, comprise a diverse group of oxygenic photosynthetic bacteria that inhabit a wide range of aquatic and terrestrial environments, and display incredible morphological diversity. Many aquatic, bloom-forming species of cyanobacteria are capable of producing biologically active secondary metabolites, which are highly toxic to humans and other animals. From a toxicological viewpoint, the cyanotoxins span four major classes: the neurotoxins, hepatotoxins, cytotoxins, and dermatoxins (irritant toxins). However, structurally they are quite diverse. Over the past decade, the biosynthesis pathways of the four major cyanotoxins: microcystin, nodularin, saxitoxin and cylindrospermopsin, have been genetically and biochemically elucidated. This review provides an overview of these biosynthesis pathways and additionally summarizes the chemistry and toxicology of these remarkable secondary metabolites.

Ramos, V. and Vasconcelos, V. **Palytoxin and analogs: biological and ecological effects.** *Marine Drugs* 8(7): 2021-2037, 2010. **O/A**

Notes: Palytoxin (PTX) is a potent marine toxin that was originally found in soft corals from tropical areas of the Pacific Ocean. Soon after, its occurrence was observed in numerous other marine organisms from the same ecological region. More recently, several analogs of PTX were discovered, remarkably all from species of the dinoflagellate genus *Ostreopsis*. Since these dinoflagellates are also found in other tropical and even in temperate regions, the formerly unsuspected broad distribution of these toxins was revealed. Toxicological studies with these compounds shows repeatedly low LD_{50} values in different mammals, revealing an acute toxic effect on several organs, as demonstrated by different routes of exposure. Bioassays tested for some marine invertebrates and evidences from environmental populations exposed to the toxins also give indications of the high impact that these compounds may have on natural food webs. The recognition of its wide distribution coupled with the poisoning effects that these toxins can have on animals and especially on humans have concerned the scientific community. In this paper, we review the current knowledge on the effects of PTX and its analogs on different organisms, exposing the impact that these toxins may have in coastal ecosystems.

Wiese, M., D'Agostino, P.M., Mihali, T.K., Moffitt, M.C., and Neilan, B.A. **Neurotoxic alkaloids: saxitoxin and its analogs.** *Marine Drugs* 8(7): 2185-2211, 2010. **O/A**

Notes: Saxitoxin (STX) and its 57 analogs are a broad group of natural neurotoxic alkaloids, commonly known as the paralytic shellfish toxins (PSTs). PSTs are the causative agents of paralytic shellfish poisoning (PSP) and are mostly associated with marine dinoflagellates (eukaryotes) and freshwater cyanobacteria (prokaryotes), which form extensive blooms around the world. PST producing dinoflagellates belong to the genera *Alexandrium*, *Gymnodinium* and *Pyrodinium* whilst production has been identified in several cyanobacterial genera including *Anabaena*, *Cylindrospermopsis*, *Aphanizomenon Planktothrix* and *Lyngbya*. STX and its analogs can be structurally classified into several classes such as non-sulfated, mono-sulfated, di-sulfated, decarbamoylated and the recently discovered hydrophobic analogs – each with varying levels of toxicity. Biotransformation of the PSTs into other PST analogs has been identified within marine invertebrates, humans and bacteria. An improved understanding of PST transformation into less toxic analogs and degradation, both chemically or enzymatically, will be important for the development of methods for the detoxification of contaminated water supplies and of shellfish destined for consumption. Some PSTs also have demonstrated pharmaceutical potential as a long-term anesthetic in the treatment of anal fissures and for chronic tension-type headache. The recent elucidation of the saxitoxin biosynthetic gene cluster in cyanobacteria and the identification of new PST analogs will present opportunities to further explore the pharmaceutical potential of these intriguing alkaloids.

Dyson, K. and Huppert, D.D. **Regional economic impacts of razor clam beach closures due to harmful algal blooms (HABs) on the Pacific coast of Washington.** *Harmful Algae* 9(3): 264-271, 2010.

Notes: Visitor spending in the recreational razor clam fishery positively impacts the coastal economies of Grays Harbor and Pacific counties in Washington State. Since 1991 the fishery has frequently closed due to harmful algal blooms (HABs). These events reduce or eliminate recreational clam-related visitor spending. We develop an economic impact model, based on recreationists' spending, to estimate the economic impacts of these closures. To estimate visitor expenditure patterns, questionnaires were distributed in April of 2008 to an on-site sample of clammers at four beaches on Washington's Pacific coast: Mocrocks, Copalis, Twin Harbors, and Long Beach. Based upon responses from 240 parties, the average expenditure per party ranged from $268.77 at Mocrocks beach to $412.67 at Long Beach. Overall expenditures for the 2007-2008 season were estimated at $24.4 million. A regional input-output model was used to estimate that the fishery had the local economic impact of supporting 404 full-time equivalent jobs and $12.6 million in labor income. To estimate negative impacts of HAB closures, expected visitor expenditures are adjusted to account for visitors' stated intentions when razor clamming is unavailable. For a full year closure of all four beaches, the estimated negative economic impact is a loss of support from the razor clam fishery impacting 339 full-time equivalent jobs and $10.6 million of labor income in the two counties. Further, impacts were calculated for beach closures ranging from a single (2-5 days) season opening to a full year, for individual beaches and combinations of beaches. As expected, the closing of a single opening at one beach had the smallest economic impacts, while whole season closures at multiple beaches had the largest impact.

May, S.P., Burkholder, J.M., Shumway, S.E., Hegaret, H., Wikfors, G.H., and Frank, D. **Effects of the toxic dinoflagellate *Alexandrium monilatum* on survival, grazing and behavioral response of three ecologically important bivalve molluscs.** *Harmful Algae* 9(3): 281-293, 2010.

Notes: Little is known about interactions between shellfish and the toxic dinoflagellate *Alexandrium monilatum*. Toxic strains produce endotoxins with hemolytic and neurotoxic properties, and have been linked to fish and invertebrate kills. We experimentally assessed the survival, grazing and behavioral responses of three shellfish species to *A. monilatum*. Grazing studies were conducted with two size classes of *Crassostrea virginica*, *Mercenaria mercenaria*, and *Perna viridis*. These species inhabit areas where blooms of *A. monilatum* occur. Clearance rates of each species were depressed when exposed to toxic *A. monilatum* alone or with nontoxic *Pavlova* sp., in comparison to control animals fed only nontoxic algae. Exposure to toxic *A. monilatum* also caused shellfish to decrease shell valve gape. Intact cells of *A. monilatum* were found within shellfish feces, but the cells did not re-establish growing populations following gut passage. Survival of larval *M. mercenaria* and *C. virginica* was also tested when exposed to *A. monilatum* cells. Survival was significantly lower for larvae exposed to sonicated *A. monilatum*, in comparison to control larvae tested with nontoxic *A. tamarense*. Overall, the data indicate that blooms of *A. monilatum* can adversely affect some shellfish species by reducing valve gape and clearance rate, and by inducing larval mortality.

Lefebvre, K.A., Robertson, A., Frame, E.R., Colegrove, K.M., Nance, S., Baugh, K.A., Wiedenhoft, H., and Gulland, F.M.D. **Clinical signs and histopathology associated with domoic acid poisoning in northern fur seals (*Callorhinus ursinus*) and comparison of toxin detection methods.** *Harmful Algae* 9(4): 374-383, 2010.

Notes: Between July 2005 and March 2009, 33 northern fur seals (*Callorhinus ursinus*) were collected after stranding along the central California coast between Sonoma and San Luis Obispo counties. Of these, 26 were collected live and could be observed for signs of neuroexcitotoxicity. Approximately half exhibited the classic clinical signs of domoic acid (DA) toxicosis including muscle twitches and ataxia, to seizures and coma, and had lesions in the central nervous system and heart. Several biological fluids were collected for DA analysis including aqueous humor, serum, stomach contents, feces, urine, abdominal fluid, amniotic fluid and milk. Four analytical methods were employed including receptor binding assay (RBA), enzyme-linked immunosorbent assay (ELISA), high performance liquid chromatography (HPLC-UV) and ultra performance liquid chromatography-tandem mass spectrometry (UPLC-MS/MS). The DA concentrations determined by each method were positively correlated. Domoic acid was detected in 83% of fecal samples collected from northern fur seals in the present study and in one animal was calculated to contain up to 18.6 μg DA/g. Interestingly, DA was detected and confirmed in the aqueous humor of the only animal this sample-type was collected from, suggesting that this may prove to be a useful diagnostic body fluid for algal toxin detection in marine mammal mortality events. These data document for the first time that northern fur seals are impacted by DA-producing harmful algal blooms along the California coast.

Rhodes, L., Smith, K., Selwood, A., McNabb, P., van Ginkel, R., Holland, P., and Munday, R. **Production of pinnatoxins by a peridinoid dinoflagellate isolated from Northland, New Zealand.** *Harmful Algae* 9(4): 384-389, 2010.

Notes: A peridinoid dinoflagellate was newly identified as the producer of pinnatoxins E (0 - 3.7 pg $cell^{-1}$) and F (0.3 - 20.1 pg $cell^{-1}$), as determined by LC-MS analysis of extracts of eight strains of the organism. The cyst-forming, thecate dinoflagellate was isolated from surface sediments associated with eel grass beds and mangroves in Rangaunu Harbour, Northland, New Zealand. Extracts of mass cultures of the dinoflagellate were tested for toxicity in mice by intraperitoneal injection, gavage and voluntary consumption. The LD_{50} values were 1.33, 2.33 and 5.95 mg/kg respectively.

Hattenrath, T.K., Anderson, D.M., and Gobler, C.J. **The influence of anthropogenic nitrogen loading and meteorological conditions on the dynamics and toxicity of *Alexandrium fundyense* blooms in a New York (USA) estuary.** *Harmful Algae* 9(4): 402-412, 2010.

Notes: The goal of this two-year study was to explore the role of nutrients and climatic conditions in promoting reoccurring *Alexandrium fundyense* blooms in the Northport-Huntington Bay complex, NY, USA. A bloom in 2007 was short and small (3 weeks, 10^3 cells L^{-1} maximal density) compared to 2008 when the *A. fundyense* bloom, which persisted for 6 weeks, achieved cell densities $>10^6$ cells L^{-1} and water column saxitoxin concentrations $>2.4 \times 10^4$ pmol STX eq. L^{-1}. During the 2008 bloom, both deployed mussels (used as indicator species) and wild soft shell clams became highly toxic (1400 and 600 μg STX eq./100 g shellfish tissue, respectively) resulting in the closure of shellfish beds. The densities of benthic *A. fundyense* cysts at the onset of this bloom were four orders of magnitude lower than levels needed to account for observed cell densities, indicating *in situ* growth of vegetative cells was responsible for elevated bloom densities. Experimental enrichment of bloom water with nitrogenous compounds, particularly ammonium, significantly increased *A. fundyense* densities and particulate saxitoxin concentrations relative to unamended control treatments. The $\delta^{15}N$ signatures (12-23‰) of particulate organic matter (POM) during blooms were similar to those of sewage (10-30‰) and both toxin and *A. fundyense* densities were significantly correlated with POM $\delta^{15}N$ ($p<0.001$). These findings suggest *A. fundyense* growth was supported by a source of wastewater such as the sewage treatment plant which discharges into Northport Harbor. Warmer than average atmospheric temperatures in the late winter and spring of 2008 and a cooler May contributed to an extended period of water column temperatures optimal for *A. fundyense* growth (12-20 ºC), and thus may have also contributed toward the larger and longer bloom in 2008. Together this evidence suggests sewage-derived N loading and above average spring temperatures can promote intense and toxic *A. fundyense* blooms in estuaries.

Hall, A. J. and Frame, E. **Evidence of domoic acid exposure in harbour seals from Scotland: A potential factor in the decline in abundance?** *Harmful Algae* 9(5): 489-493, 2010.

Notes: The exposure of marine mammals to the toxins associated with harmful algae can be lethal. Domoic acid (DA) is a biotoxin produced by the *Pseudo-nitzschia* group of diatoms many of which are now a common component of the Scottish phytoplankton community (Stobo *et al.*, 2008). DA is a potent excitatory neurotoxin that has caused large-scale mortality of marine mammals. We found harbour seals (*Phoca vitulina*) in Scotland are exposed to DA. Low levels, likely from recent exposure, were measured in the faeces and urine of live captured adult animals (using a direct competitive enzyme linked immunosorbent assay) and exposure was highest during August-September 2008 (7/32 of the faecal (22%) and 11/29 (38%) of the urine samples were positive). Median concentrations in positive faeces and urine were 25 ng/g and 6 ng/ml respectively. One positive pregnant female was subsequently found dead with 10 ng/ml DA in her amniotic fluid but the contribution of DA exposure to the cause of death could not be established. However, the highest levels in the study were found in anonymous faecal samples collected in September 2009 on the east coast of Scotland (up to 397 ng/g). Further studies are urgently needed to determine the importance of DA exposure to the population dynamics of Scottish harbour seals in light of the recently reported major population declines.

Pezzolesi, L., Cucchiari, E., Guerrini, F., Pasteris, A., Galletti, P., Tagliavini, E., Totti, C., and Pistocchi, R. **Toxicity evaluation of *Fibrocapsa japonica* from the Northern Adriatic Sea through a chemical and toxicological approach.** *Harmful Algae* 9(5): 504-514, 2010.

Notes: Since the 1990s red-tide blooms of *Fibrocapsa japonica* have frequently been observed in European waters; despite their recurrence also in the Adriatic coastal areas, they have never been conclusively linked to ichthyotoxic events. Since the toxicity of *F. japonica* is still under debate and its effects differ among the strains, in this study all the compounds previously postulated as involved in the toxic mechanism, such as brevetoxins, fatty acids and ROS, were screened for Adriatic strains. Whole algal extracts were analyzed for brevetoxin PbTx-2, which was not found, and for a qualitative and quantitative analysis of fatty acids. The fatty acid profile evidenced the presence of PUFAs, with considerable amounts of 18:4n-3, 20:4n-6, and 20:5n-3, as already found in different strains, but with a lower amount of arachidonic acid (20:4n-6). None of the PUFAs was released in the extracellular medium. Different toxicological assays (*Vibrio fischeri*, *Artemia* sp., haemolysis of fish erythrocytes) were performed using algal cellular, extracellular or subcellular samples as well as fractions of the algal extract, in order to identify the toxic compounds. The tested cultures were found to inhibit *V. fischeri* bioluminescence, to affect *Artemia* nauplii viability and to have haemolytic effects comparable to those previously observed in different strains. The solid phase extraction (SPE) of the Adriatic *F. japonica* extracts resulted in a high concentration of PUFAs in two main fractions, which caused mortality in *Artemia* nauplii and inhibition of *V. fischeri* bioluminescence. Fish (*Dicentrarchus labrax*) assays were also performed, reporting mortality after long exposure times and the cause of fish death was investigated. A significant increase of H_2O_2 in the tanks where sea basses were exposed to *F. japonica* was obtained, indicating that the presence of fish stimulates H_2O_2 production by algal cells and leading to the hypothesis of H_2O_2 involvement in *F. japonica* toxicity. The presence of oxidative stress in the exposed fish was confirmed by the increased malondialdehyde concentration in their gills. Overall these results indicate that since *F. japonica* cells can easily cling to fish gills, due to their high polysaccharide production, it is presumable that high PUFA amounts are released in loco, as a result of cell breakage, and that exert their toxicity together with ROS. This study shows that the Adriatic strains of *F. japonica* can be harmful to higher level organisms. Nevertheless a high cell density and a long lasting bloom are necessary to cause severe damage to fish gills or death for crustaceans.

Etheridge, S.M. **Paralytic shellfish poisoning: Seafood safety and human health perspectives.** *Toxicon* 56(2): 108-122, 2010.

Notes: Paralytic shellfish poisoning (PSP) is the foodborne illness associated with the consumption of seafood products contaminated with the neurotoxins known collectively as saxitoxins (STXs). This family of neurotoxins binds to voltage-gated sodium channels, thereby attenuating action potentials by preventing the passage of sodium ions across the membrane. Symptoms include tingling, numbness, headaches, weakness and difficulty breathing. Medical treatment is to provide respiratory support, without which the prognosis can be fatal. To protect human health, seafood harvesting bans are in effect when toxins exceed a safe action level (typically 80 μg STX eq 100^{-1} tissue). Though worldwide fatalities have occurred, successful management and monitoring programs have minimized PSP cases and associated deaths. Much is known about the toxin sources, primarily certain dinoflagellate species, and there is extensive information on toxin transfer to traditional vectors – filter-feeding molluscan bivalves. Non-traditional vectors, such as puffer fish and lobster, may also pose a risk. Rapid and reliable detection methods are critical for toxin monitoring in a wide range of matrices, and these methods must be appropriately validated for regulatory purposes. This paper highlights PSP seafood safety concerns, documented human cases, applied detection methods as well as monitoring and management strategies for preventing PSP-contaminated seafood products from entering the food supply.

Dickey, R.W. and Plakas, S.M. **Ciguatera: A public health perspective.** *Toxicon* 56(2): 123-136, 2010.

Notes: Ciguatera fish poisoning is a seafood-borne illness caused by consumption of fish that have accumulated lipid-soluble ciguatoxins. In the United States, ciguatera is responsible for the highest reported incidence of food-borne illness outbreaks attributed to finfish, and it is reported to hold this distinction globally. Ciguatoxins traverse the marine food web from primary producers, *Gambierdiscus* spp., to commonly consumed fish in tropical and subtropical regions of the world. Ciguatoxins comprise 12 known congeners among Caribbean and tropical Atlantic fish and 29 reported congeners among Pacific fish. Expanding trade in fisheries from ciguatera-endemic regions contributes to wider distribution and increasing frequency of disease among seafood consumers in non-endemic regions. Ciguatoxins produce a complex array of gastrointestinal, neurological and cardiological symptoms. Treatment options are very limited and supportive in nature. Information derived from the study of ciguatera outbreaks has improved clinical recognition, confirmation, and timely treatment. Such studies are equally important for the differentiation of ciguatoxin profiles in fish from one region to the next, the determination of toxicity thresholds in humans, and the formulation of safety limits. Analytical information from case and outbreak investigations was used to derive Pacific and Caribbean ciguatoxin threshold contamination rates for adverse effects in seafood consumers. To these threshold estimates 10-fold safety factors were applied to address individual human risk factors; uncertainty in the amount of fish consumed; and analytical accuracy. The studies may serve as the basis for industry and consumer advisory levels of 0.10 ppb C-CTX-1 equivalent toxicity in fish from the tropical Atlantic, Gulf of Mexico, Caribbean, and 0.01 ppb P-CTX-1 equivalent toxicity in fish from Pacific regions.

Plakas, S.M. and Dickey, R.W. **Advances in monitoring and toxicity assessment of brevetoxins in molluscan shellfish.** *Toxicon* 56(2): 137-149, 2010.

Notes: Herein, we describe advancements in monitoring of brevetoxins in molluscan shellfish, with respect to exposure management and control of neurotoxic shellfish poisoning (NSP). Current knowledge of the fate of brevetoxins in molluscan shellfish, and the toxic potency of brevetoxin metabolites, is presented. We review rapid assays for measuring composite brevetoxins, and methodology for measuring constituent brevetoxins, in contaminated shellfish. The applicability of in vitro methods for estimating brevetoxin burden and composite toxicity in shellfish is assessed. Specific and measurable biomarkers of brevetoxin exposure and toxicity in shellfish, and of human intoxication, are described. Their utility in regulatory monitoring of toxic shellfish and in clinical diagnosis of NSP is evaluated.

Deeds, J.R. and Schwartz, M.D. **Human risk associated with palytoxin exposure.** *Toxicon* 56(2): 150-162, 2010.

Notes: Palytoxin (PTX) was first isolated from the zoanthid *Palythoa toxica*. Evaluation of PTX toxicity using various animal models determined that PTX was extremely potent through intravenous, intraperitoneal, and intratracheal exposure. PTX was less potent by direct intragastric exposure. PTX also caused significant, non-lethal effects through dermal and ocular exposure. PTX and PTX-like compounds have now been found in additional zoanthid species, red alga, a sea anemone, and several dinoflagellates. PTXs are found throughout certain reef associated food webs, including in fish and crabs responsible for human illness and death. Many of the organisms found to contain PTXs in the environment are also sold in the home aquarium trade, and recent evidence suggests poisonings have occurred through exposure to these organisms. Due to co-occurrence with other seafood toxins, such as ciguatoxins, saxitoxins, and tetrodotoxin, it has been difficult to assess the true risk of PTX poisoning through seafood consumption in humans, but limited cases have been well documented, some involving human fatalities. Recent evidence also suggests that humans are negatively impacted through PTX exposure by inhalation and dermal routes. Continued research into the distribution and occurrence of PTX and PTX-like compounds both in seafood and marine organisms sold in the aquarium trade appears warranted.

Tubaro, A., Dell'Ovo, V., Sosa, S., and Florio, C. **Yessotoxins: A toxicological overview.** *Toxicon* 56(2): 163-172, 2010.

Notes: Yessotoxins (YTXs) are polyciclic ether compounds produced by phytoplanktonic dinoflagellates and accumulated in filter feeding shellfish. These toxins can be ingested by humans through contaminated seafood consumption. Initially, YTXs were classified as Diarrhetic Shellfish (DS) toxins but the biological activity of these compounds, which lack of diarrheogenic effects, differs from that of diarrheic toxins. Thus, YTXs have been recently classified as a separate group of algal toxins. Yessotoxin (YTX), homoyessotoxin and 45-hydroxy-homoyessotoxin are lethal after intraperitoneal injection to mice but not after single or repeated oral administration. The target organ seems to be the cardiac muscle cells, where these toxins induce light and electron microscopy ultrastructural changes not only after intraperitoneal injection, but also after oral exposure. On the other hand, di-desulfo-yessotoxin affects liver and pancreas, where it induces fatty degeneration. The mechanisms at the basis of the cardiac effects of YTX and homoyessotoxins are still not completely understood. No short term and chronic toxicity data are available as well as pharmacokinetic studies are lacking. Nevertheless, YTX is known to exert different in vitro activities, such as changes of intracellular calcium and cyclic AMP levels, alteration of cytoskeletal and adhesion molecules, caspases activation and opening of the permeability transition pore of mitochondria. This review reports the current knowledge on the in vivo toxicity and in vitro effects of these toxins.

Furey, A., O'Doherty, S., O'Callaghan, K., Lehane, M., and James, K.J. **Azaspiracid poisoning (AZP) toxins in shellfish: Toxicological and health considerations.** *Toxicon* 56(2): 173-190, 2010.

Notes: It has been almost a decade since a previously unknown human toxic syndrome, azaspiracid poisoning (AZP), emerged as the cause of severe gastrointestinal illness in humans after the consumption of mussels (*Mytilus edulis*). Structural studies indicated that these toxins, azaspiracids, were of a new unprecedented class containing novel structural features. It is now known that the prevalent azaspiracids in mussels are AZA1, AZA2 and AZA3, which differ from each other in their degree of methylation. Several hydroxylated and carboxylated analogues of the main azaspiracids have also been identified, presumed to be metabolites of the main toxins. Since its first discovery in Irish mussels, the development of facile sensitive and selective LC-MS/MS methods has resulted in the discovery of AZA in other countries and in other species. Mice studies indicate that this toxin class can cause serious tissue injury, especially to the small intestine, and chronic exposure may increase the likelihood of the development of lung tumours. Studies also show that tissue recovery is very slow following exposure. These observations suggest that AZA is more dangerous than the other known classes of shellfish toxins. Consequently, in order to protect human consumers, proper risk assessment and regulatory control of shellfish and other affected species is of the utmost importance.

Dominguez, H.J., Paz, B., Daranas, A.H., Norte, M., Franco, J.M., and Fernández, J.J. **Dinoflagellate polyether within the yessotoxin, pectenotoxin and okadaic acid toxin groups: Characterization, analysis and human health implications.** *Toxicon* 56(2): 191-217, 2010.

Notes: Diarrhetic Shellfish Poisoning (DSP) is a specific type of food poisoning, characterized by severe gastrointestinal illness due to the ingestion of filter feeding bivalves contaminated with a specific suite of toxins. It is known that the problem is worldwide and three chemically different groups of toxins have been historically associated with DSP syndrome: okadaic acid (OA) and dinophysistoxins (DTXs), pectenotoxins (PTXs) and yessotoxins (YTXs). PTXs and YTXs have been considered as DSP toxins because they can be detected with the bioassays used for the toxins of the okadaic acid group, but diarrhegenic effects have only been proven for OA and DTXs. Whereas, some PTXs causes liver necrosis and YTXs damages cardiac muscle after intraperitoneal injection into mice. On the other hand, azaspiracids (AZAs) have never been included in the DSP group, but they cause diarrhoea in humans. This review summarizes the origin, characterization, structure, activity, mechanism of action, clinical symptoms, method for analysis, potential risk, regulation and perspectives of DSP and associated toxins produced by marine dinoflagellates.

Lefebvre, K.A. and Robertson, A. **Domoic acid and human exposure risks: A review.** *Toxicon* 56(2): 218-230, 2010.

Notes: Domoic acid is a potent neurotoxin that is naturally produced by several diatom species of the genus *Pseudo-nitzschia*. The toxin acts as a glutamate agonist and is excitotoxic in the vertebrate central nervous system and other glutamate receptor-rich organs. Human exposure to domoic acid occurs via the consumption of contaminated shellfish that have accumulated the toxin while filter feeding on toxigenic phytoplankton during blooms. The first reported human domoic acid poisoning event occurred in Canada in 1987 during which clinical signs of acute toxicity such as gastrointestinal distress, confusion, disorientation, memory loss, coma and death were observed. The illness was named amnesic shellfish poisoning (ASP) and due to effective seafood monitoring programs there have been no documented ASP cases since 1987. However, domoic acid poisoning has a significant effect on marine wildlife and multiple poisoning events have occurred in marine birds and mammals over the last few decades. Currently, domoic acid producing diatom blooms are thought to be increasing in frequency world wide, posing an increasing threat to wildlife and human health. Of particular concern are the potential impacts of long-term low-level exposure in "at risk" human populations. The impacts of repetitive low-level domoic acid exposure are currently unknown. This review provides a basic description of the mechanism of action of domoic acid as well as a synthesis of information pertaining to domoic acid exposure routes, toxin susceptibility, and the importance of effective monitoring programs. The importance of investigating the potential human health impacts of long-term low-level domoic acid exposure in "at risk" human populations is also discussed.