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Bioindicators of Marine Contaminations at the Frontier of Environmental Monitoring and Environmental Genomics

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Abstract

Oceans provide major resources for rapidly increasing population worldwide. Ocean sustainability thus constitutes a major issue for human health, as well as economic and ecological perspectives. Indicators of oceanic contamination have been selected in order to identify, but also further prevent impact of human activities on marine ecosystems. However while some bioindicating species appear consensual, others are typically representatives of restricted marine areas and/or restricted range of marine contaminants. We here attempt a review of marine species used as bioindicators/ biomarkers of major human activities focusing on the requirement to integrate modern metagenomics approaches of marine ecosystems in order to define consensual, pertinent, ubiquitous bioindicators of marine health.

Keywords: Biomarkers; Bioindicators; Oceans; Ecotoxicology; Omics Sciences; Epigenetics

Introduction

Coastal Areas support increasing population worldwide, for whom marine ecosystems constitute either directly or indirectly, principal economic resources. For instance, over two billion people worldwide rely on seafood consumption and sea products for their diet [1]. Alternatively, the ocean appears as a promising reservoir for novel pharmaceuticals [2], but simultaneously, novel energetic and mining resources [3-5]. However, oceanic ecosystems are today suffering from past but also novel, rapidly diversifying modern human activities. Indeed, this common reservoir suffers from environmental pressure exerted by humans on the marine ecosystems itself, such as of shore petroleum production, sea transport or fishing [6] but also, more recently exploitation of deep sea metallic nodules [5], marine aquaculture [7], rocket launching activities and installation of offshore wind mills fields, but also, indirectly from the exploitation of nearby terrestrial ecosystems by tourism, agriculture and industry, (including mining) [8-10]. Even exponentially increasing marine aquaculture (that is today expected to supplement natural stocks of seafood and which relies on availability of uncontaminated water), actively impacts marine ecosystems, through the release from marine farms, of antimicrobials, food supplements, nutrients, and disease controlling substances [7] (in final EMIDA MOLTRAQ project's report). While most contaminations are concentrated in coastal zones, mainly affecting pelagic and benthic food webs of the continental shelf [11], long-range transport of contaminants through large distances has been described in the literature [12]. The sustainability of these marine resources and their derivative activities thus appears today as a major common preoccupation worldwide [1,13].

Pollutants affecting marine ecosystems include a wide range of synthetic organic chemicals, (Substances of particular concern are chlorobiphenyls, chlorinated dioxins, pesticides and some industrial solvents); diverse heavy metals and alloys with principal focus on mercury or chromium VI; but also, alternatively, toxins and pathogenic species; pharmaceuticals and personal care products; plastic materials; and more recently, genetically modified organisms [14]. Contaminants tend to accumulate through marine food webs, biomagnified in a greater extent than through their continental counterparts due, among other, to their higher complexity and compartment level. Their final accumulation in fish tissues is of major public concern [15,16]. Indeed, since the widely discussed Minamata case [17], end-level human consumption of contaminated marine products evolves novel interrogations, while reported impacts on human health increases and diversifies. Effects on human health include today, among other, neurologic disorders, endocrine-disrupting functions, developmental problems [18] but also, human reproduction, neurobehavioral development, liver function, birth weight, immune response, and tumorigenesis [19]. Additionally, in given cases, microorganisms have been reported that are able to degrade, sometimes only partially, given molecules through complex pathways, sometimes liberating metabolic intermediates with higher toxicity than the originally released environmental contaminant [20]. Unfortunately, association with deleterious effects of specific compounds is very difficult and follow up of this extending diversity and complexity of environmental contaminants, requires integrated approaches.

Discussion

Environmental monitoring requires rapid, efficient and cost-effective methods for detecting pollutants at risk to accumulate in marine food webs and to impact human health. However, toxicity level for a given compound is not restricted to the chemical property of a substance or to its concentration, but rather relies on its bioavailability which is highly dependent on environmental conditions [21]. For instance, levels of clay particles, dissolved or particulate carbonates, silicates, sulfides and organic matters are acting as complexing factors for most metals but also given organic contaminants. Additionally, metal toxicity is highly related to their redox level [22], the latter being itself influenced, among other, by microbial metabolism of metals, that may be used for given microbial groups, as alternative electron receptors in anaerobic respiration processes. Among available methods, the use of bioindicators and biomarkers of marine contamination is an interesting tool to assess deleterious effects of environmental contaminants in marine ecosystems, as it is clearly correlated with levels of bioavailable contaminants. Thus, several inventories of marine biotest methods have already been compiled and their interest reviewed [23-26]. Indeed, both marine microflora, (among others foraminifers [27,28], diatoms [29], dinoflagellate cyst [30] but also macrofauna have been mined for relevant bioindicator species and used in biomonitoring of environmental contaminations [31]: Among macrofaunal organisms, literature reports communities and individual species of copepods [32,33], bivalves [34,35], echinoderms [36,37], sponges [38,39], anemones [40], crustaceans [41,42], insects [43], fishes [44,45] and even birds [46]. Some examples are summarized in Table 1 that illustrates the extreme diversity of bioindicator organisms and the lack of consensus at international scale.

Table 1: Illustration of the diversity of bioindicators used for environmental monitoring in marine areas.

Species	Environment	Contaminant	Reference
Bacteria *Vibrio fischeri* *Vibrio sp.*	*in vitro* *mediterranean laguna*	wide range of chemicals pathogens	[47,48]
Phytoplancton	Taipei		[49]
Green algae *Ulva lactuca* *Ulva rigida* Brown algae *Lobophora variegata*	Hong Kong tropical waters	metals Hg, Cu, Cd, Zn, Ni, Cr Cd, Co, Cr, Ni, Zn	[49-51]
Foraminifera	marine, benthic	heavy metals	[27,28,52]
Sponges *Spongia officinalis* *Haliclona tenuiramosa*	Indian Gulf	Polychlorobiphenyl Fe, Mn, Ni, Cu, As, Co, Cd	[53,54]
Cnidaria *Aurelia aurita* (ephyra) *Anemona viridis* *Actinia equina* *Nematostella vectensis*	water column sessile sessile estuarine sediments	SDS, Cd(NO3)2 Cd, Zn Cd, Zn CdCl2	[55,56]
Annelida *Arenicola marina* *Hediste diversicolor*	sediment, coasts, ports	PAHs, Pb, Pharmaceuticals pharmaceuticals	[57,58]

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Bivalves *Mytilus edulis* *Mytilus galloprovincialis* *Crassostrea gigas* *Crassostrea virginica* *Crassostrea corteziensis* *Mytella strigata* *Pinctada radiata* *Venus verrucosa*	coast Arabian Gulf Mauritania	Cd, Hg Cu, Cr, Ni, Zn, Fe, Mn, 137Cs Zn>Fe,Cu>Mn>Ni>Pb>Cr>Cd Zn>Fe,Cu>Mn>Ni>Pb>Cr>Cd metals Cd, Cu, Fe, Mn, Zn Hg, Cu, Cd, Zn, Ni, Cr	[35,50,59-68]
Macoma balthica *Tapes philipinarum* *Perna viridis* *Anadara granosa* *Soletellina acuminata* Gastropoda *Trivia monacha* *Trivia arctica* *Hinia reticulata* *Nucella lapillus* *Donax trunculus*	estuaries Hong Kong Malaysia Mangroves North Atlantic North Atlantic Mauritania	PCB As, Cd, Cr, Cu, Pb, Se, Zn PAH Tributyltin Tributyltin Tributyltin Tributyltin Cd, Cu, Fe, Mn, Zn	
Amphipoda *Corophium volutator* *Echinogammarus pirloti* *Gammarus locusta* *Gammarus zaddachi* *Gammarus salinus* Branchiopoda *Artemia salina* Ostracoda *Cypris sp.* *Cyprideis torosa* *Leptocythere psammophila* Decapoda *Palaemon elegans* *Litopenaeus vannemei* Cirripedia *Balanus amphitrite* *Fistulobalanus dentivarians* *Elminis modestus*	Mediterranean coast, marine and estuarine sediments in vitro	Cu, Zn, Cd Zn, Cu, Cd $CuSO_4$, $PbSO_4$, $ZnSO_4$, $NiSO_4$ Cu, Zn, Cr, Pb, Al, Si, Fe, Ca, Mg, Na, Mn, Ba, Sr, S, Cl, oil, industrial waste water Zn, Cu, Cd Zn>Mn>Cu>Pb>Ni>Cr>Cd Zn, Cu, Cd	[60,69-76]
Insecta *Halobates micans*	surface of open ocean, Atlantic	Cd	[43]
Echinodermata *Paracentrotus lividus* *(premature)*	Iberian coast	Cu, Cd, Pb, Hg Fe, Zn	[36]
Fish Thunnus thynnus Katsuwonus	**offshore, Japanese coastal waters,** **wetland**	Organochlorines Polybrominate biphenyl ethers	[45]

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pelamis *Oreochromis niloticus* *Mullus barbatus* *Serranus hepatus* *Serranus cabrilla* *Zoarces viviparus*	Mediterranean Mediterranean Mediterranean	Zn, Cu, Cr, Mn PAH, PCB PAH, PCB PAH, PCB As, Hg, Pb, Ti	[57-59]
Birds *Sterna sp.* *Larus sp.* *Fulmarus glacialis*	estuaries, oceans North Pacific	Pb, Hg, Cd Pb, Hg, Cd plastic pollution	[46,77,78]

Further, bioindicators may be classified into two groups: Biomarkers on one hand, and sentinel species on the other [79,80], biomarkers being generally defined on taxa considered as sentinel organisms:

A. Distinctively, biomarkers of marine contamination require (bio) chemical analysis, such as the concentration of a given tracer or pollutant in a given tissue or measure of a given biological marker in it [26], using a wide range of chemical, molecular, but also physiological approaches (among other: biochemical assays, enzyme linked immuno-sorbent assays (ELISA), spectrophotometric, fluorometric measurement, differential pulsed polarography, liquid chromatography, atomic absorption spectrometry and more recently transcriptomics and metabolomics). Classical biomarkers include for instance, cytochrome P4501A activity, DNA integrity, acetylcholinesterase activity or metallothionein induction. Biomarkers assess, at an infra-organism level (i.e; they address a tissue, a cell type etc…), a physiologic, genetic, molecular, or morphologic response [80]. Biomarkers may be considered as anticipative as they can enlighten a toxic effect earlier than a lethal effect observed at a population level, and affecting whole organisms

B. Sentinel species [81] trace the occurrence level of selected species at the population level. Choice of sentinel species is based on previously demonstrated correlation between the contamination level of a given pollutant and the species occurrence and or behaviour.

C. Additionally one may distinguish the toxicological approaches performed under laboratory conditions (rather relevant for biomarkers) from environmental impact studies performed in the field that are often based on numeration of sentinel species.

Microbial Bioindicators

Historically, defined microbial species were used as bioindicators of water quality to assess risks of microbiological contamination by pathogens and guidelines were for long defined in the three water-related areas (drinking water, wastewater but also (marine) recreational water) by measuring indicator bacteria [82,83]. Further, bacterial indicators were then derived, among which *Vibrio* species, to monitor microbial status of marine environments. For instance, comparative heath status and level of contamination by terrestrial sewages of three laguna ecosystems of the French Mediterranean coast were monitored through the search for *Vibrio* species that were here used as bioindicators of risks of environmental contamination by pathogenic bacteria [84]. Similarly, number of microbial bioindicator species were defined to monitor ranges of environmental pollutants in the water column, at the water-sediment interface or within the sediment. Indeed, as microbes constitute key actors of the end loop of most biogeochemical cycles (i.e. carbon , nitrogen phosphorous cycles etc..), their role is vital for the health of the aquatic ecosystem and modification of their population or activity can indeed anticipate further impacts noticeable only lately on food webs. Microbial indicators were thus generalized to assess environmental changes. For instance, Benthic diatoms, among numerous others, have been used as markers of marine eutrophication in coastal ecosystems [85].

Beyond microbial natural species, microbes present the advantage to evolve rather rapidly to adapt to adverse condition, to degrade novel compounds [20] and to be genetically modifiable through mutagenesis and recombinant DNA technology. These, advantages were thus used for the development of recombined biosensors for numerous environmental contaminants (both metallic and organic) and number of bioluminescent biosensors especially have been constructed [25,86-88].

Finally today, as molecular tools and their associated computing methods develop, comparative diversity analysis of marine microbial communities constitutes as a whole, a promising indicator of impacts of human activities on marine ecosystems. Diversity loss can indeed for long be easily monitored using whole community DNA-based molecular approaches. Originally, Denaturation Gradient Gel Electrophoresis (DGGE) of community amplified 16S or 18S sequences [89] and derived DNA pattern analysis tools (based on Random Amplification of 16S-23S Intergenic Spacers (RISA), Single Strand Conformation Polymorphism of community amplified 16S rDNA sequences (SSCP) and all derivative methods) appeared useful tools for ecologoical monitoring. More recently, metabarcoding (https://www.embl.de/tara-oceans/start/) [90,91], further, marine

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ecological (meta)genomics which have been defined as the application of genomic sciences to attempt to understand the structure and function of marine ecosystems [90], and its derivative, comparative metagenomics have started to emerge in marine ecotoxicological approaches to assess environmental impacts [92]. As Marine ecological (meta) genomics evolves, associated computer based analysis of such data could evolve rarefaction curves that would indeed be informative of impacts at an ecosystemic scale. Further, the -omic based analysis of the metabolic behaviours of microbial communities and identification of mechanisms that microbes use to respond to environmental changes and to adapt to man-made pressures may be used for environmental monitoring purposes: Microbial biodiversity at itself starts to be used to evolve response-specific functional indices tentatively integrating evolution of complex interactions between microbial communities. These were based on species ecological preferenda and autoecology, especially in order to allow the discernment of the stressing factor involved in the ecosystem perturbation [85]. Such indexes are informative as they attempt to integrate the evolution of the microbial community as a whole and combined to modern omics, should open novel environmental monitoring area

Molluscs

Molluscs species are interesting bioindicators considering their ability to filter large volumes of sea water and thus to accumulate trace contaminants. As sessile species presenting increased longevity, they constitute interesting bioindicators in long term impact studies in given habitats [93,94]. Among molluscs, mussels and oysters have been particularly used as bioindicators in many countries for marine pollution monitoring [95,96]. According to physico-chemical properties of pollutants (especially their solubility in sea water and complexing affinity to organics or minerals), either filtrating species such as the blue mussel (*Mytilus edulis*), [95,96] or conversely, scavengers such as the Manila clam (*Ruditapes philippinarum*) are used [97,98]. However, for the latter, accumulation of a number of anthropogenic compounds in clam's tissues suggests that these species may present mechanisms that allow them to cope with the toxic effects of contaminants and thus question their use as bioindicators.

Alternatively, some authors have used animal behaviour to estimate effects of a range of contaminants in various marine conditions. For instance Redmond et al. [99] used mussels (*Mytilus edulis*) valve opening and shell movements to assess toxicity of dispersed crude oil (DCO); further, changes in patterns of movement and social interaction in the gilthead seabream, *Sparus aurata*, were linked to several biomarkers following exposure to phenanthrene, a common PAH in petroleum products [100]. (Additional examples of use animal behaviour or social interactions as bioindicator can be found in [101,102].

Fishes

In Europe, the EC Water Framework Directive (WFD), requires from its member states to ensure, among others, a satisfactory ecological and chemical status of their coastal and marine waters which is defined on a basis of an a priority list of hazardous chemicals and substances with associated standard values based on concentrations found in certain marine organisms, and notably in fishes. Length and cost of chemical determinations lack of anticipation of potential pollution risks by other substances have been underlined and stress tests and bioindicators of fish health have been evolved for a range of species. Fish species used as bioindicators include, among others,: *Thunnus thynnus, Katsuwonus pelamis, Oreochromis niloticus, Mullus barbatus, Serranus hepatus, Serranus cabrilla, Zoarces viviparus* [45,103-105](Table 1). Biomarkers have also been derived from a set of fish species to assess various marine contaminants [105]. However, most classic ecotoxicologic test species are currently reconsidered due to the lack of genomic sequences that could allow development of cheap and rapid PCR based ecotoxicological kits based on long known tissue specific responses of target species.

Definition and main properties of performant bioindicators

Conversely to terrestrial conditions for which consensual model exists that use for instance rats as reference species for toxicity assessments, no consensus has yet been reached for marine biomonitoring and often, marine species have been used in biomonitoring independently of what should constitute the basic properties of a bioindicator [48] that we have to remain here:

Indeed, to be relevant and reliable, bioindicators, have to present given characteristics:

A. They should appear/ or disappear or react concomitantly with the contaminant itself, and behave in a quantitative manner (i.e; the measured bioindicator population level or intensity of the biomarker response have to be proportional to the bioavailable contaminant)

B. Anticipative as they require to be particularly sensitive to toxic compounds. Resistant species do not constitute proper bioindicators or sources for biomarkers.

C. Integrative as they may collect and cumulate over a period of time the impact of ranges of diverse environmental contaminants but also their potential interactions

D. Able to distinguish impacts from xenobiotic compounds from natural ecological stresses

E. They are required to present a wide geographical range. Site specific species are not suitable as they do not allow inter site comparisons. For instance The clam *Ruditapes*

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decussatus and the mussel *Mytilus edulis* that both present a worldwide distribution constitute interesting bioindicators. However they do not occur in all marine environments

F. They are easy to sample and to measure

G. Cost efficient as they aim at avoiding numerous instant measures of potentially toxic substances

H. For legal purposes they need to have been previously referenced as suitable for ecological impact studies

Revisiting the biomarker and bioindicator concepts in the light of modern -omic sciences

While pre-millennium ecotoxicological studies concentrated on the description of biomarkers and bioindicators, basing their choice on preliminary often biased knowledge, modern -omics enlighten the requirement to revisit previous concepts, while extending the description of biological diversity far beyond the known isolable, cultivable, and identifiable species, and extending the list of potential genes and function potentially used as biomarkers. Conversely, long used consensual biomarkers/bioindicators have lost interest while failing to provide available complete and full annotated genomic sequences. This is the case of *Mytilus edulis* for which a group of researchers interested in the use of bivalves as a research model for environmental and biomedical purposes, lately decided to join efforts to produce and assemble sequences from Sanger and NSG methods to elucidate genomic sequence,. The project was initiated in 2010 only (http://www.openmytilusconsortium.org/) and seems today still ongoing, as only the mitochondrial sequences and cDNA libraries of *M. edulis* [107] and *M. galloprovincialis* [108], respectively, seem available. Late sequence availability indeed reordered interest for previously consensual bioindicator species and their associated biomarker. For instance, availability of the fish *Danio rerio* genomic sequence [109] paved the way for the set-up of quantitative PCR based ecotoxicological tests [110]. Indeed, the genomic tools for ecotoxicogenomics have now been reviewed [111], Miracle & Ankley (2005) with a particular emphasis on fish testing that are emerging in this field, such as that of the effects of 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) exposure on zebrafish caudal fin regeneration. Soon sequence characteristics (such as sequence length of given marine species [112] appeared itself a base for environmental impact studies. Genomes may also be the base for further metabolomics approaches that now emerge as novel ways to assess impact of pollutants on the complete metabolism of species whose sequence is available –such as in the case of *Ruditapes philippinarum* [113].

Novel trends are also integrating epigenics as novel tools to assess organismal response to environmental stressors [106,114]: indeed, Epigenetic mechanisms in an ecotoxicogical context is a new concept and has not yet been considered to be integrated into current environmental regulatory practices [115]. Epigenetic biomarkers have been demonstrated in humans, mice and zebrafish [116-118]. While some newer studies have focused on bivalves and other marine invertebrates, epigenetic responses appears as next-generation pollution biomonitoring [106,114]. Epigenetic techniques can provide the link from environmental stressor to detectable biomarker responses and ultimately the goal of linking these omic responses to physiological changes that can be tied to classical ecotoxicological endpoints.

Conversely, lack of available genomic sequences for classically used bioindicator species such as those species long used by the US EPA and other environmental regulatory agencies for marine toxicity studies including the mysid shrimp, *Americamysis bahia* [119], the sheepshead minnow, *Cyprinodon variegatus* [120] the inland silverside, *Menidia beryllina* [121], the sea urchin *Arbacia punctulata* [122], and the red macroalgae *Champia parvula* [123], clearly slow down the development of functional molecular biomarkers from these classic ecotoxicological workhorses. With the passing of legislation such as REACH in the EU, the use of whole organism toxicity studies will steadily decrease while the demand for non-lethal ecotoxicological studies will increase. Biomarker and bioindicator studies are excellent candidates to fill this gap. Although classical ecotoxicogical endpoints (mortality, growth, and reproduction) are still used in regulatory decision making, we anticipate the use of biomarker and bioindicator information in regulatory frameworks becoming more practical and needed.

Conclusion

Legal issues are solved for terrestrial ecosystems. However, consensual international definition of marine biomarkers and bioindicators remains under discussion [48,124]. Classic bioindicator species and their derived biomarkers remain thus often not fully consensual and vary from country to country requiring final common approval. Finally, Environmental Protection Agencies appear extremely slow in adapting new technologies into their policy making decisions and still relies on classical toxicological endpoints such as mortality, growth, and reproductive output. We here want to underline the necessity to revisit biomarkers in bioindicator species in the light of novel omics data. New techniques and technologies provide understanding in organismal omic response to stressors (chemical or environmental) and warrant more attention and integration into regulatory policies [93-124].

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References

1. FAO (1999) The State of World Fisheries and Aquaculture 1998. FAO, Rome, Italy.
2. http://www.pharma-sea.eu/
3. Kato Y, Fujinaga K, Nakamura K, Takaya Y, Kitamura K, et al. (2011) Deep-sea mud in the Pacific Ocean as a potential resource for rare-earth elements. Nat Geosci 4: 535-539.
4. Momber AW, Plagemann P, Stenzel V (2016) The adhesion of corrosion protection coating systems for offshore wind power constructions after three years under offshore exposure. International Journal of Adhesion & Adhesives 65(2016): 96-101
5. Ingole BS, Goltekar R, Gonsalves S, Ansari ZA (2005) Recovery of deep-sea meiofauna after artificial disturbance in the Central Indian Basin. Marine georesources & geotechnology 23(4): 253-266.
6. Guerra-García JM, García-Gómez JC (2004) Crustachan Assemblages and Sediment Pollution in an Exceptional Case Study: A Harbour with Two Opposing Entrances. Crustaceana 77(3): 353-370
7. www.moltraq.wordpress.com
8. Boening DW (1999) An evaluation of bivalves as biomonitors of heavy metals pollution in marine waters. Environmental monitoring and assessment 55(3): 459-470.
9. Viaroli, P, Bartoli, M, Giordani, G, Austoni M, Zaldivar JM (2005) Biochemical processes in coastal lagoons: from chemical reactions to ecosystem functions and properties. Indicators of stress in the marine benthos. IOC worshop report No 195: 27-30.
10. Warwick R (2005) Taxonomic distincness as an indicator of stress in the marine macrobenthos. Indicators of stress in the marine benthos, IOC worshop report No. 195, pp. 10-11.
11. Bélanger D (2009) Utilisation de la faune macrobenthique comme bioindicateur de la qualité de l'environnement marin côtier (Doctoral dissertation, Université de Sherbrooke), Canada.
12. Knap AH (1990) Proceedings of the NATO Advanced Research Workshop on the Long-Range Atmospheric Transport of Natural and Contaminant Substances from Continent to Ocean and Continent to Continent. 10-17 January 1988, Volume: 267, NATO Science Series C: Mathematical and Physical Sciences, St. George's, Bermuda.
13. UNESCO (1996) A Strategic Plan for the Assessment and Prediction of the Health of the Ocean: A Module of the Global Ocean Observing System. IOC/INF-1044, Paris: UNESCO, France.
14. Knap A, Dewailly E, Furgal C, Galvin J, Baden D, et al. (2002) Indicators of ocean health and human health: developing a research and monitoring framework. Environmental Health Perspectives 110(9): 839-845.
15. Falandysz J, Kannan K, Tanabe S, Tatsukawa R (1994) Organochlorine pesticides and polychlorinated biphenyls in cod-liver oils: North Atlantic, Norwegian Sea, North Sea and Baltic Sea. Ambio 23(4:) 288-293.
16. Boon JP, Sleiderink HM, Helle MS, Dekker M, van Schanke A (1998) The use of a microsomal in vitro assay to study phase I biotransformation of chlorobornanes (Toxaphene®) in marine mammals and birds: possible consequences of biotransformation for bioaccumulation and genotoxicity. Comparative Biochemistry and Physiology Part C: Pharmacology, Toxicology and Endocrinology 121(1): 385-403.
17. Harada M (1995) Minamata disease: methylmercury poisoning in Japan caused by environmental pollution. Crit Rev Toxicol 5(1): 1-24.
18. Heindel JJ, Collman GW, Suk WA (1998) Endocrine disruptors: extrapolation from wildlife to human effects. In: Kendall R, Dickerson R, Giesy J, Suk W (Eds.), Principles and Processes for Evaluating Endocrine Disruption in Wildlife, Society of Environmental Toxicology and Chemistry Press, Pensacola, Florida, USA, pp. 335-347.
19. Dewailly É, Mulvad G, Pedersen HS, Ayotte P, Demers A, Weber JP, Hansen JC (1999) Concentration of organochlorines in human brain, liver, and adipose tissue autopsy samples from Greenland. Environ Health Perspect. 107(10): 823-828.
20. Topp E, Vallaeys T, Soulas G (1997) Pesticides, Microbial degradation and effects on microorganisms. In Soil Microbiology (eds Van Elsas, J.D, Trevors, J.T, Wellington, E.M.H.) Marcel Dekker, New-York pp. 547-575.
21. Geffard O (2001) Toxicité potentielle des sédiments marins et estuariens contaminés: Evaluation chimique et biologique, biodisponibilité des contaminants sédimentaires (Doctoral dissertation, Bordeaux 1).
22. DeLaune R.D, Patrick, W H, NGuo T (1998) The redox-pH chemistry of chromium in water and sediment. Metals in surface waters 241-255.
23. Nendza M (2002) Inventory of marine biotest methods for the evaluation of dredged material and sediments. Chemosphere 48: 865-883
24. Chapman PM, Wang F (2001) Assessing sediment contamination in estuaries. Environmental Toxicology and Chemistry. 20(1): 3-22.
25. Van Beelen P (2003) A review on the application of microbial toxicity tests for deriving sediment quality guideline. S Chemosphere 53 (8): 795-808.
26. Sarkar A, Ray D, Shrivastava AN, Sarker S (2006) Molecular Biomarkers: Their significance and application in marine pollution monitoring. Ecotoxicology 15(4) : 333-340.
27. Alve E, Bernhard JM (1995) Vertical migratory response of benthic foraminifera to controlled oxygen concentrations in an experimental mesocosm. Oceanographic Literature Review 9(42): 771.
28. Yanko V, Arnold AJ, Parker WC (1999) Effects of marine pollution on benthic foraminifera. In Modern foraminifera: 217-235.
29. Cooper SR, Brush GS (1991) Long-Term History of Chespeake Bay Anoxia. Science, 254(5034): 992-996.
30. Willard DA, Cronin, T. M, Verardo S (2003) Late-Holocene climate and ecosystem history from Chesapeake Bay sediment cores, USA. The Holocene 13(2): 201-214.
31. Ruiz JM, Barreiro R, González JJ (2005) Biomonitoring organotin pollution with gastropods and mussels. Marine Ecology Progress Series 287: 169-176.
32. Lampadariou N, Austen MC, Robertson N, Vlachonis G (1997) Analysis of meiobenthic community structure in relation to pollution and disturbance in Iraklion harbour, Greece. Oceanographic Literature Review 44(10): 1206-1206.
33. Lee MR, Correa JA, Castilla JC (2001) An assessment of the potential use of the nematode to copepod ratio in the monitoring of metals pollution. The Chanaral case. Marine Pollution Bulletin 42(8): 696-701.
34. Cossa D (1989) A review of the Mytilus spp. as a quantitative indicator of cadmium and mercury contamination in coastal waters. Oceanologica Acta 12: 417–432.
35. Hiss E, Heyvang, I, Geffard O, X De Montaudouin (1999) A comparison between oyster (*Crassostrea gigas*) and sea urchin (*Paracentrotus*

How to cite this article: Tatiana V, Sophia P K, Eymeric F, Benjamin L M, Jehan H L, Abraham J S. Bioindicators of Marine Contaminations at the Frontier of Environmental Monitoring and Environmental Genomics. Adv Biotech & Micro. 2017; 4(1): 555629. DOI: 10.19080/AIBM.2017.04.555629.

lividus) larval bioassays for toxicological studies. Water research 33(7): 1706-1718.

36. Fernández N, Beiras R (2001) Combined toxicity of dissolved mercury with copper, lead and cadmium on embryogenesis and early larval growth of the *Paracentrotus lividus* sea-urchin. Ecotoxicology, 10(5): 263-271.

37. Beiras R, Bellas J, Fernández N, Lorenzo JI, Cobelo-Garcıa A (2003) Assessment of coastal marine pollution in Galicia (NW Iberian Peninsula); metal concentrations in seawater, sediments and mussels (*Mytilus galloprovincialis*) versus embryo–larval bioassays using *Paracentrotus lividus* and *Ciona intestinalis*. Marine environmental research 56(4): 531-533.

38. Perez T, Wafo E, Fourt M, Vacelet J (2003) Marine sponges as biomonitor of polychlorobiphenyl contamination: concentration and fate of 24 congeners. Environmental science &technology 37(10): 2152-2158.

39. Thierry Perez, Jean Vacelet, Pierre Rebouillon (2003) In situ comparative study of several Mediterranean sponges as potential biomonitors of heavy metals. Bollettino dei musei e degliistitutibiologicidell'Universita di Genova 68: 517-525.

40. Harland AD, Bryan GW, Brown BE (1990) Zinc and cadmium absorption in the symbiotic anemone *Anemonia viridis* and the non-symbiotic anemone *Actinia equina*. Journal of the Marine Biological Association of the United Kingdom 70(04): 789-802.

41. Rainbow PS, White S L (1989) Comparative strategies of heavy metal accumulation by crustaceans: zinc, copper and cadmium in a decapod, an amphipod and a barnacle. Hydrobiologia 174(3): 245-262.

42. Clason B, Duquesne S, Liess M, Schulz R, Zauke GP (2003) Bioaccumulation of trace metals in the Antarctic amphipod Paramoera walkeri (Stebbing, 1906): comparison of two-compartment and hyperbolic toxicokinetic models. Aquatic Toxicology 65(2): 117-140.

43. Schulz-Baldes M (1989) The sea-skater *Halobates micans*: an open ocean bioindicator for cadmium distribution in Atlantic surface waters. Marine Biology 102(2): 211-215.

44. Kress WJ, Heyer W R, Acevedo P, Coddington J, Cole D, Erwin T L, Weitzman MJ (1998) Amazonian biodiversity: assessing conservation priorities with taxonomic data. Biodiversity and Conservation, 7(12): 1577-1587.

45. Ueno D, Iwata H, Tanabe S, Ikeda K, Koyama J, et al. (2002) Specific accumulation of persistent organo chlorines in bluefin tuna collected from Japanese coastal waters. Marine pollution bulletin 45(1): 254-261.

46. Burger J, Gochfeld M (2004) Metal levels in eggs of common terns (*Sterna hirundo*) in New Jersey: temporal trends from 1971 to 2002. Environmental Research 94(3): 336-343.

47. Monfort P, Cantet F, Vallaeys T (2010) Dynamique des bactéries pathogènes dans les écosystèmes naturels: de l'observation locale à la modélisation régionale. Bulletin de veille scientifique de l'AFSSET 10: 56-60.

48. Parvez S, Venkataraman C, Mukherji S (2006) A review on advantages of implementing luminescence inhibition test (*Vibrio fischeri*) for acute toxicity prediction of chemicals. Environment international 32(2): 265-268.

49. Wu JT (1984) Phytoplankton as bioindicator for water quality in Taipei. Bot Bull Academia Sinica 25: 205-214.

50. Ho YB (1990) Metals in *Ulva Lactuca* in Hong Kong Intertidal Waters. Bulletin of Marine Science. 47(1): 79-85.

51. Locatelli C (2003) Heavy metal determinations in algae, mussels and clams. Their possible employment for assessing the sea water quality criteria. J Phys IV France 107: 785-788.

52. Metian M, Warnau M (2008) The Tropical Brown Alga *Lobophora variegata* (Lamouroux) omersley: Prospective Bioindicator for Ag Contamination in Tropical Coastal Waters. Bulletin of Environmental Contamination and Toxicology 81(5): 455-458.

53. Frontalini F, Coccioni R (2011) Benthic foraminifera as bioindicators of pollution: a review of Italian research over the last three decades. Revue de micropaléontologie 54(2): 115-127.

54. Berthet B, Mouneyrac C, Pérez T, Amiard-Triquet C (2005) Metallothionein concentration in sponges (*Spongia officinalis*) as a biomarker of metal contamination. Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology 141(3): 306-313.

55. Rao VJ, Srikanth K, Pallela R, Gnaneshwar Rao T (2009) The use of marine sponge, *Haliclona tenuiramosa* as bioindicator to monitor heavy metal pollution in the coasts of Gulf of Mannar, India. Environ Monit Assess 156(1-4): 451-459.

56. Faimali M, Garaventa F, Piazza V, Costa E, Greco G, et al. (2014) Ephyra jellyfish as a new model for ecotoxicological bioassays. Mar Environ Res 93: 93-101.

57. Harter VL, Mattews RA (2005) Acute and chronic toxicity test methods for *Nematostella vectensis* Stephenson. Bull Environ Contam Toxicol 74(5): 830-836.

58. Ramos-Gómez J, Martins M, Raimundo J, Vale C, Martín-Díaz ML, et al. (2011) Validation of *Arenicola marina* in field toxicity bioassays using benthic cages: biomarkers as tools for assessing sediment quality. Marine pollution bulletin 62(7): 1538-1549.

59. Maranho LA, Baena-Nogueras RM, Lara-Martín PA, DelValls TA, Martín-Díaz ML, et al. (2014) Bioavailability, oxidative stress, neurotoxicity and genotoxicity of pharmaceuticals bound to marine sediments. The use of the polychaete *Hediste diversicolor* as bioindicator species. Environ Res 134: 353-365.

60. Catsiki VA, Florou H (2006) Study on the behavior of the heavy metals Cu, Cr, Ni, Zn, Fe, Mn and 137 Cs in an estuarine ecosystem using *Mytilus galloprovincialis* as a bioindicator species: the case of Thermaikos gulf, Greece. Journal of Environmental Radioactivity 86(1): 31-44.

61. Ruelas-Inzunza JR, Páez-Osuna F (2000) Comparative bioavailability of trace metals using three filter-feeder organisms in a subtropical coastal environment (Southeast Gulf of California) Environ Pollut 107(3): 437-444.

62. Al-Madfa H, Abdel-Moati MAR, Al-Gimaly FH (1998) *Pinctada radiata* (Pearl Oyster): a bioindicator for metal pollution monitoring in the Qatari waters (Arabian Gulf) Bull Environ Contam Toxicol 60(2): 245-251.

63. Romeo M, Gnassia-Barelli M (1988) *Donax trunculus* and *Venus verrucosa* as bioindicators of trace metal concentrations in Mauritanian coastal waters. Marine biology 99(2): 223-227.

64. Tanabe S, Tatsukawa R, Phillips DJ (1987) Mussels as bioindicators of PCB pollution: A case study on uptake and release of PCB isomers and congeners in green-lipped mussels (*Perna viridis*) in Hong Kong waters. Environ Pollut 47(1): 41-62.

65. Yusof A, Yanta N, Wood A (2004) The use of bivalves as bio-indicators in the assessment of marine pollution along a coastal area. Journal of Radio analytical and Nuclear Chemistry 259(1): 119-127.

66. Zuloaga O, Prieto A, Usobiaga A, Sarkar SK, Chatterjee M, et al. (2009) Polycyclic aromatic hydrocarbons in intertidal marine bivalves of Sunderban mangrove wetland, India: an approach to bioindicator species. Water, air, and soil pollution 201(1-4): 305.

67. Stroben E, Schulte-Oehlmann U, Fioroni P, Oehlmann J (1995) A comparative method for easy assessment of coastal TBT pollution by the degree of imposex in prosobranch species. Haliotis Paris 24: 1-12.

68. Stroben E, Oehlmann J, Fioroni P (1992) The morphological expression of imposex in *Hinia reticulata* (Gastropoda: Buccinidae): a potential indicator of tributultin pollution. Marine Biology 113(4): 625-636.

How to cite this article: Tatiana V, Sophia P K, Eymeric F, Benjamin L M, Jehan H L, Abraham J S. Bioindicators of Marine Contaminations at the Frontier of Environmental Monitoring and Environmental Genomics. Adv Biotech & Micro. 2017; 4(1): 555629.DOI: 10.19080/AIBM.2017.04.555629.

69. Stroben E, Oehlmann J, Fioroni P (1992) *Hinia reticulata* and *Nucella lapillus*. Comparison of two gastropod tributyltin bioindicators. Marine Biology 114(2): 289-296.

70. Bat L, Raffaelli D, Marr IL (1998) The accumulation of copper, zinc and cadmium by the amphipod *Corophium volutator* (Pallas) Journal of Experimental Marine Biology and Ecology 223(2): 167-184.

71. Rainbow PS, White SL (1990) Comparative accumulation of cobalt by three crustaceans: a decapod, an amphipod and a barnacle. Aquatic Toxicology 16(2): 113-126.

72. Clason B, Zauke GP (2000) Bioaccumulation of trace metals in marine and estuarine amphipods: evaluation and verification of toxicokinetic models. Canadian Journal of Fisheries and Aquatic Sciences 57(7): 1410-1422.

73. MacRae TH, Pandey AS (1991) Effects of metals on early life stages of the brine shrimp, *Artemia*: a developmental toxicity assay. Arch Environ Contam Toxicol 20(2): 247-252.

74. Ruiz F, Abad M, Bodergat AM, Carbonel P, Rodríguez-Lázaro J, et al. (2005) Marine and brackish-water ostracods as sentinels of anthropogenic impacts. Earth-Science Reviews 72(1): 89-111.

75. Wu JP, Chen HC (2005) Metallothionein induction and heavy metal accumulation in white shrimp *Litopenaeus vannamei* exposed to cadmium and zinc. Comp Biochem Physiol C Toxicol Pharmacol 140(3-4): 383-394.

76. Morillo J, Usero J, El Bakouri H (2008) Biomonitoring of heavy metals in the coastal waters of two industrialized bays in southern Spain using the barnacle *Balanus Amphitrite*. Chemical Speciation & Bioavailability, 20(4): 227-237.

77. O'Brien P, Rainbow PS, Nugegoda D (1990) The effect of the chelating agent EDTA on the rate of uptake of zinc by *Palaemon elegans* (Crustacea: Decapoda) Marine environmental research 30(2): 155-159.

78. Avery-Gomm S, O'Hara PD, Kleine L, Bowes V, Wilson LK, et al. (2012) Northern fulmars as biological monitors of trends of plastic pollution in the eastern North Pacific. Mar Pollut Bull 64(9): 1776-1781.

79. Roméo M, Bennani N, Gnassia-Barelli M, Lafaurie M, Girard JP (2000) Cadmium and copper display different responses towards oxidative stress in the kidney of the sea bass *Dicentrarchus labrax*. Aquat Toxicol 48(2-3): 185-194.

80. Rinderhagen M, Ritterhoff J, Zauke GP (2000) Crustaceans as bioindicators. In Biomonitoring of Polluted Water-Reviews on Actual Topics. Environmental Research Forum 9: 161-194.

81. Markert BA, Breure AM, Zechmeister HG (2003) Definitions, strategies and principles for bioindicator/biomonitoring of the environment. Bioindicators and biomonitors: principles, concepts and applications, in: [Eds.] Markert BA, Breure AM, Zechmeiter HG, Oxford: Elsevier Science Limited, USA, pp. 3-39.

82. Kaiser J (2001) Bioindicators and Biomarkers of Environmental Pollution and Risk Assessment. In: Jamil K (Ed.), Sciences publishers inc, USA, p. 204.

83. Berg G (1978) The indicator system. In Indictors of Viruses in Water and Food. In: Berg G (Ed.), Ann Arbor Science Publishers, Ann Arbor, MI, USA, pp. 1-13.

84. World Health Organization (WHO) (2001) Water Quality: Guidelines, Standards and Health. In: Lorna Fewtrell and Jamie Bartram (Eds.), IWA Publishing, London, UK.

85. Desrosiers C, Leflaive , Eulin A, Ten-Hage L (2013) Bioindicators in marine waters: Benthic diatoms as a tool to assess water quality from eutrophic to oligotrophic coastal ecosystems. Ecological Indicators: 32: 25-34.

86. Corbisier P, Thiry E, Diels L (1996) Bacterial biosensors for the toxicity assessment of solid wastes. Environ Toxicol Water Qual 11(3): 171 -177

87. Bundy JG, Wardell JL, Campbell CD, Killham K, Paton GI (1997) Application of bioluminescence-based microbial biosensors to the ecotoxicity assessment of organotins. Lett Appl Microbiol 25: 353-358.

88. SF D'Souza (2001) Review Microbial biosensors. Biosensors & Bioelectronics 16: 337-353.

89. Vallaeys T, Topp E, Muyzer G, Macheret V, Laguerre G, et al. (1997) Evaluation of denaturing gradient gel electrophoresis in the detection of 16S rDNA sequence variation in rhizobia and methanotrophs. FEMS Microbiology Ecology 24: 279-285.

90. Samuel Dupont, Karen Wilson, Mathias Obst, Helen Sköld, Hiroaki Nakano, et al. (2007) Marine ecological genomics: when genomics meets marine ecology. Mar Ecol Prog Ser 332: 257-273.

91. Magalie Castelin, Niels Van Steenkiste, Scott Gilmore, Eric Pante, Rick Harbo, et al. (2015) Use of integrative taxonomy and DNA barcoding for characterization of ecological processes structuring marine benthic community assemblages in British Columbia. 6th International Barcode of Life Conference, Aug 2015, Guelph, Canada. 58(5): 204. Scientific abstracts from the 6th International Barcode of Life Conference / Resumes scientifiques du 6e congres international " Barcode of Life " .

92. Delmont T.O. and Eren A.M. 2016. Linking comparative genomics and environmental distribution patterns of microbial populations through metagenomics, DOI: http://dx.doi.org/10.1101/058750.

93. Espinosa F, Guerra-García JM, García-Gómez JC (2007) Sewage pollution and exinction risk: an endangered limpet as bioindicator? Biodiversity and conservation 16: 377-397.

94. Huang H, Wu JY, Wu JH (2007) Heavy metal monitoring using bivalved shellfish from Zhejiang coastal waters, East China Sea. Environmental monitoring and assessment 129: 315-320.

95. Panfoli I, Burlando B, Viarengo A (2000) Effects of heavy metals on phospholipase C in gill and digestive gland of the marine mussel *Mytilus galloprovincialis* Lam. Comparative Biochemistry and Physiology Part B: Biochemistry and Molecular Biology 127(3): 391-397.

96. Ji J, Choi HJ, Ahn IY (2006) Evaluation of Manila clam as a sentinel species for metalpollution monitoring in estuarine tidal flats of Korea: Effects of size, sex, and spawning on baseline accumulation. Mar Pollut Bull 52(4): 447-453.

97. Li C, Sun H, Chen A, Ning X, Wu H, et al. (2010) Identification and characterization of an intracellular Cu, Zn-superoxide dismutase (icCu/Zn-SOD) gene from clam *Venerupis philippinarum*. Fish Shellfish Immunol 28(3): 499-503.

98. Zhang Y, Wang Q, Ji Y, Zhang Q, Wu H, Xie J, et al. (2014) Identification and mRNA expression of two17hydroxysteroid dehydrogenase genes in the marine mussel *Mytilus galloprovincialis* following exposure to endocrine disrupting chemicals. Environ Toxicol Pharmacol 37: 1243-1255.

99. Redmond KJ, Berry M, Pampanin DM, Andersen OK (2017) Valve gape behaviour of mussels (*Mytilus edulis*) exposed to disperse crude oil as an environmental monitoring endpoint. Marine Pollution Bulletin 117(1): 330-339.

100. Correia AD, Gonçalves R, Scholze M, Ferreira M, Henriques MAR (2007) Biochemical and behavioral responses in gilthead seabream (*Sparus aurata*) to phenanthrene. Journal of Experimental Marine Biology and Ecology 347: 109-122.

101. Baltz DM, Chesney EJ, Tarr MA, Kolok AS, Bradley MJ (2005) Toxicity and Sublethal Effects of Methanol on Swimming Performance of Juvenile *Florida Pompano.* Transactions of the American Fisheries Society 134(3): 730-740

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102. Silva C, Oliveira C, Gravato C, Almeidae JR (2013) Behaviour and biomarkers as tools to assess the acute toxicity of benzo(a)pyrene in the common prawn *Palaemon serratus.* Marine Environmental Research 90: 39-46.

103. Schladot JD, Backhaus F, Ostapczuk P, Emons H (1997) Eel-pout (*Zoarces Viviparus L.*) as a marine bioindicator. Chemosphere 34(9-10): 2133-2142.

104. Burgeot T, Bocquéné G, Porte C, Dimeet J, Santella RM, et al. (1996) Bioindicators of pollutant exposure in the northwestern Mediterranean Sea. Marine ecology progress series 131(1): 125-141.

105. Birungi Z, Masola B, Zaranyika MF, Naigaga I, Marshall B, et al. (2007) Active biomonitoring of trace heavy metals using fish (*Oreochromis niloticus*) as bioindicator species: The case of Nakivubo wetland along Lake Victoria. Physics and Chemistry of the Earth, Parts A/B/C 32(15): 1350-1358.

106. Gonzalez-Romero RV, Suarez-Ulloa J, Rodriguez-Casariego D, Garcia-Souto G, Diaz A, et al. (2017) Effects of Florida Red Tides on histone variant expression and DNA methylation in the Eastern oyster Crassostrea virginica. Aquatic Toxicology 186: 196-204.

107. Boore, J. L, Medina, M, & Rosenberg, L. A. (2004) Complete sequences of the highly rearranged molluscan mitochondrial genomes of the scaphopod *Graptacme eborea* and the bivalve *Mytilus edulis*. Molecular Biology and Evolution, 21(8): 1492-1503.

108. Mizi A, Zouros E, Moschonas N, Rodakis GC (2005) The complete maternal and paternal mitochondrial genomes of the Mediterranean mussel *Mytilus galloprovincialis*: implications for the doubly uniparental inheritance mode of mtDNA. Molecular Biology and Evolution 22(4): 952-967.

109. Howe K, Clark MD, Torroja CF, Torrance J, Berthelot C, et al. (2013) The zebrafish reference genome sequence and its relationship to the human genome. Nature 496(7446): 498-503.

110. Dambal VY, Selvan KP, Lite C, Barathi S, Santosh W (2017) Developmental toxicity and induction of vitellogenin in embryo-larval stages of zebrafish (*Danio rerio*) exposed to methyl Paraben. Ecotoxicology and Environmental Safety 141: 113-118.

111. Wilson JG (1994) The role of bioindicators in estuarine management. Estuaries 17(1): 94-101.

112. Dixon DR, LRJ Dixon, PL Pascoe, JT Wilson (2001) Chromosomal and nuclear characteristics of deep-sea hydrothermal-vent organisms: correlates of increased growth rate. Marine Biology 139: 251-255.

113. Ji C, Cao L, Li F (2015) Toxicological evaluation of two pedigrees of clam *Ruditapes philippinarum* as bioindicators of heavy metal contaminants using metabolomics. Environ Toxicol Pharmacol 39(2): 545-554.

114. Suarez-Ulloa V, Gonzalez-Romero R, Eirin-Lopez JM (2015) Environmental epigenetics: A promising venue for developing next-generation pollution biomonitoring tools in marine invertebrates. Marine Pollution Bulletin 98: 5-13.

115. Vandegehuchte MB, Janssen CR (2014) Epigenetics in an ecotoxicological context. Mutation Research - Genetic Toxicology and Environmental Mutagenesis 764-765: 36-45.

116. Hou L, Wang D, Baccarelli A (2011) Environmental chemicals and microRNAs. Mutation Research/Fundamental and Molecular Mechanisms of Mutagenesis 714(1-2): 105-112.

117. Ho SM, Johnson A, Tarapore P, Janakiram V, Zhang X, et al. (2012) Environmental Epigenetics and Its Implication on Disease Risk and Health Outcomes. ILAR Journal 53: 289-305.

118. Williams TD, Mirbahai L, Chipman JK (2014) The toxicological application of transcriptomics and epigenomics in zebrafish and other teleosts. Briefings in Functional Genomics 13(2): 157-171.

119. Hirano M, Ishibashi H, Matsumura N, Nagao Y, Watanabe N, et al. (2004) Acute toxicity responses of two crustaceans, *Americamysis bahia* and *Daphnia magna*, to endocrine disrupters. Journal of health science 50(1): 97-100.

120. Heitmuller PT, Hollister TA, Parrish PR (1981) Acute toxicity of 54 industrial chemicals to sheepshead minnows (*Cyprinodon variegatus*) Bulletin of environmental contamination and toxicology 27(1): 596-604.

121. Hemmer MJ, Middaugh DP, Comparetta V (1992) Comparative acute sensitivity of larval topsmelt, *Atherinops affinis*, and inland silverside, *Menidia beryllina*, to 11 chemicals. Environmental toxicology and chemistry 11(3): 401-408.

122. Nacci D, Jackim E, Walsh R (1986) Comparative evaluation of three rapid marine toxicity tests: sea urchin early embryo growth test, sea urchin sperm cell toxicity test and Microtox. Environmental Toxicology and Chemistry 5(6): 521-525.

123. Thursby GB, Steele RL (1984) Toxicity of arsenite and arsenate to the marine macroalga *Menidia beryllina* (Rhodophyta) Environmental Toxicology and Chemistry 3(3): 391-397.

124. Sammarco PW, Hallock P, Lang JC, LeGore RS (2007) Roundtable discussion groups summary papers: environmental bio-indicators in coral reef ecosystems: the need to align research, monitoring, and Environmental Regulation. Journal of Environmental Bioindicators 2(1): 35-46.

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