Marine pollution monitoring using mussels

P.K. Krishnakumar
Centre for Environment & Water, Research Institute, King Fahd University of Petroleum & Minerals, Dhahran 31261, Saudi Arabia, E-mail: kkumarpk@kfupm.edu.sa

Pollution is a major problem that has negative effects on all of the planet's ecosystems, including the oceans. In many parts of the region, economic development has been most active in coastal zones, putting enormous pressures on coastal ecosystems. Coastal and marine water pollution has increased throughout the world, mainly due to direct discharges from rivers, increased surface run-off and drainage from expanding port areas, oil spills and other contaminants from shipping, and domestic and industrial effluent. Most of the world's wastes- some 20 billion tones of it a year- end up in the sea, often without any preliminary processing.

The most widely accepted definition of marine pollution is the one devised by the United Nations Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP). This states that marine pollution is the:- "Introduction by man, directly or indirectly, of substances or energy into the marine environment (including estuaries) resulting in such deleterious effects as harm to living resources, hazards to human health, hindrance to marine activities including fishing, impairment of quality for use of sea water and reduction of amenities". There are many different types of toxic waste pollution and many of them cause various problems to marine life.

MAJOR SOURCES OF POLLUTION:

There are many different types of toxic waste pollution and many of them cause various problems to marine life. The major pollutants in the marine environment are given in Table 1.

In order to understand the impacts of the coastal pollutants, individual consideration of sources and types of pollutants are needed and therefore are discussed below:

1. Sewage pollution:

The most important primary feature of raw sewage from a disposal point of view is its 'oxygen demand'. The oxygen demand is the amount of oxygen that will be consumed by bacteria as they feed on and degrade the sewage waste. If the amount of oxygen required is similar to, or greater than, the amount of oxygen available then serious problems may arise. Sewage generally contains large amounts of nitrogen and phosphates, which can lead to phytoplankton blooms. Usually excessive nutrient discharge into the coastal waters will result in eutrphication. Red tides are caused by phytoplankton blooms, which deplete oxygen in coastal waters causing the mass death of aquatic organisms. In addition, the algae may produce toxins, which cause shellfish poisoning and present a serious health hazard to consumers. Red tides have become a major concern in several countries.

2. **Heavy metals:**

Among the critical pollutants, heavy metals and pesticides are more common in Asian waters. All natural metals occur in seawater in greater or lesser amounts. Some, such as iron, copper, cobalt and zinc are essential in small quantities for the healthy growth of marine organisms. Others, such as mercury, lead, tin and cadmium have no known biological role. All metals are toxic if present in excess but the most important marine contaminants are generally considered to be amongst the non-essential elements.

3. **Pesticides and other persistent organic chemicals:**

Pesticide usage has increased during the last three decades not only in the agriculture sector but also in the vector control programmes. Historically the chemicals that have provoked the greatest concern in terms of their effects on the marine environment are the chlorinated hydrocarbons. These chemicals include such well known substances as the pesticide DDT and the PCBs (used largely in electrical apparatus).

4. **Hydrocarbons:**

Oil pollution is a significant problem along major shipping routes and an increasing number of accidents have occurred in recent years. The total global production of crude oil is about 3 billion tonnes per year and approximately half of this is transported by sea. This means that on any given day there are approximately 8.25 million tonnes afloat around the oceans. According to one estimate, between 0.05 and 0.1 percent of the sea's surface is covered with an oil film at any one time. Recent, studies show that in many coastlines of the world, the tar ball concentrations have reached levels of kilograms per meter area of beach.

5. **Radioactivity:**

Radiation is another major toxic pollution source in the ocean but it is less well understood. The oceans contain appreciable amounts of radioactive materials, which derive from natural sources within the atmosphere and within the earth. Added to this natural radioactivity is a mixture of artificial radioactive substances deriving from atomic weapons testing, other military activities and peaceful uses of nuclear energy. Atmospheric and underwater tests of atomic weapons are a major source of radioactivity reaching the oceans. Other sources are now more important and include waste discharges from nuclear fuel reprocessing plants and nuclear power generating reactors, dumping of low level radioactive waste at sea and accidental discharges such as the unplanned return to earth of nuclear powered satellites and the loss of nuclear powered.

6. Thermal pollution:

Thermal pollution affects the ocean in a negative way. Increases in water temperature causes a change (lowering) of dissolved oxygen levels. This disrupts the body of water's ecological balance, resulting in the suffocation of some plant and animal species while encouraging the overgrowth of others. The overgrowth and suffocation causes a cascade reaction with other organisms that are dependant on the ones that don't survive and with organisms that now have to compete with the overgrowing organisms.

7. Solid wastes:

Solid waste takes the form of plastics, metal, paper, and glass thrown or washed into the ocean in mass quantities. Plastic, because of its strength, durability and buoyancy makes up the greater part of all debris found in the ocean and is by far the most harmful. Marine mammals, birds, turtles, fish, and crabs can often become entangled in plastic loops, strings and bands that can entangle them, wound them or prevent them from swimming.

BIOMAGNIFICATION:

Marine flora and fauna accumulate contaminants from the immediate environment (seawater or sediment) and this process is called bioaccumulation. Biomagnification is a phenomenon where levels of toxic pollutants (such as heavy metals and PCB's) increase as we move up the food chain (see Figure 1). This can also be called bioamplification. This happens because primary producers only absorb small amounts of toxins. Organisms tend not to get rid of the toxins within them, so it accumulates over the coarse of their life. When one organism eats many organisms which each contain some heavy metals, the metals accumulate even faster within it. But, then herbivores eat many primary producers, so they accumulate a higher concentration of toxins. And then consumers that eat the affected herbivores consumer even higher levels of toxins.

BIOACCUMULATION BY MUSSELS:

Bivalve molluscs such as oysters and mussels are filter feeders that accumulate contaminants directly from the water column or via ingestion of contaminants adsorbed to phytoplankton, detritus, and sediment particles. They are efficient bioaccumulators of heavy metals, polycyclic aromatic hydrocarbons (PAHs) and other organic compounds, and because they are sessile they may reflect local contaminant concentrations more accurately than more mobile crustacean or fin-fish species. Thus, shellfish serves as an important indicator of contaminated sediments and water quality and is frequently included as part of comprehensive environmental quality monitoring programs.

The green mussels (*Perna viridis*) are widely distributed in the Asian coastal waters, and recognized as commercially valuable seafood in this zone. Mussels are highly suitable for culture in the coastal areas. Being filter feeders, they occupy a low position in the food chain, making their exploitation a very economic utilization of the primary production available in coastal waters. Moreover, mussels have high protein content, averaging 67% of the body weight, which is comparable to the other food items of higher trophic levels and this underscores its importance as a source of inexpensive animal protein. It is for these reasons that mussels are an important part of Asian diet. If humans consume contaminated shellfish species either in large quantities or over a sustained period of time, there is a risk that both acute and chronic effects (such as chemical poisoning and long-term systemic effects) related to specific contaminants can occur. Hence, in order to protect public health, it is required to adopt appropriate surveillance measures regarding the presence of chemical contaminants in foodstuffs, especially mussels.

The stomach of bivalves is surrounded by a relatively large digestive gland. The digestive gland formed by a vast number of blind ending tubules, the digestive diverticula. This organ is involved in several functions including the extracellular and intracellular digestion of food, storage of lipids, glycogen and minerals; it is also the main site of nutrient absorption and plays a major role in detoxification. Recently, it is identified as a major site of accumulation of contaminants. Maximum tissue concentrations of contaminants are reported in the digestive gland compare to the other body parts in bivalves including mussels. Hence, it is recommended to remove the digestive gland before using bivalves of suspected contamination for human consumption. By allowing bivalves to remain in clean seawater for 24 hrs to depurate contaminants also will help to improve the shell fish quality.

MUSSEL WATCH:

Marine bivalves, such as clams, mussels and oysters are widely used in urban marine habitats to monitor levels of chemical contaminants. Mussels may hold one of the main keys to the monitoring of ocean pollutants. Because they concentrate chemicals from their surroundings making the chemical analyses simpler and less prone to error than that for water, they stay in a single location rather than swim around, and they are fairly resistant to chemical contamination and can be found living in areas where less hardy species may be absent (See Table 2). *Mussel watch* program is a study designed to systematically monitor environmental contaminants in the soft tissue of bivalves (mussel, oysters and clams) sampled from several locations within a region, country, continents or part of the globe. The main objective of the study is to assess and compare the environmental contamination within and between the study areas.

Blue mussels (*Mytilus edulis*) have been used extensively, in USA, UK, Europe, and elsewhere, as sentinel indicator species for monitoring exposure to chemical contaminants (Table 3). The green mussels (*Perna viridis*) have been used extensively in India, Singapore, Malaysia, Thailand and some other Asian countries for marine pollution monitoring.

INTERNATIONAL MUSSEL WATCH:

The genesis of the *International Mussel Watch Project* can easily be traced to the 1975 *Marine Pollution Bulletin* editorial where Professor Edward Goldberg of Scripps Institution of Oceanography called for a global marine monitoring program to serve as a "spring board for action" (Goldberg, 1975). In his editorial, Prof. Goldberg outlined a global scale monitoring program based on the sentinel organism concept that is capable of detecting trends in concentrations of several important marine contaminants. Since the mid-1970's, scientists of several countries have used bivalve filter-feeding mollusks to monitor for selected chemical contaminants in coastal marine waters. Such contamination of coastal waters might result in chemical changes that are deleterious, over the long term, to both the integrity of the coastal environment and to human health. Because of their sedentary habits and their ability to bioconcentrate the pollutants of interest, mussels and other bivalve species appear to be appropriate sentinel organisms. This approach to marine monitoring has been successfully applied in several national and regional programs in Europe, Taiwan, India, Canada and the United States and an extensive scientific literature has been generated from this works. The mussel watch approach has been adopted as one of several coastal environmental quality monitoring strategies by United Nations programs and the International Mussel Watch Project was created to build on this cumulative experience.

The International Oceanographic Commission (IOC), in collaboration with the United Nations Environment Program (UNEP) and the U.S. National Oceanographic and Atmospheric Administration (NOAA) have supported the creation of the International Mussel Watch Project and completed an initial monitoring program in the Latin America region, including central-South America and the wider Caribbean area including Mexico, in 1991-92 (Figure 2). The program has been directed by the International Mussel Watch Committee and coordinated and administered by the Project Secretariat office based at the Coastal Research Center of the Woods Hole Oceanographic Institution.

Another program, the Asia-Pacific mussel watch program (APMW), was started in 1994, under the umbrella of the International Mussel Watch-Asia Pacific Phase, a project that mainly involves coastal monitoring using sentinel organisms such as mussels and oysters as bioindicators in ascertaining the quality of coastal waters in the Asia-Pacific region. This program was completed successfully and subsequently several Asian countries started their own mussel watch programs.

BIOMARKER APPROACH IN MUSSEL WATCH:

The marine ecosystem is sensitive to exposure to toxic contaminants. Pollutants either individually or in combination may have sub-lethal effects at the cellular, organ and individual level, (e.g., causing changes in genetic, behavioural and reproductive activity). Key species have been identified as indicators of this sensitivity including the edible mussel and other bivalves. *Biomarkers* include a variety of measures of specific molecular, cellular and physiological responses of key species to contaminant exposure. A response is generally indicative of either contaminant exposure or poor health. The challenge is to integrate individual biomarker responses into a set of tools and indices capable of detecting and monitoring the degradation in health of a particular organism. It has been proposed Environmental Prognostics as a branch of systems biology that is specific to the reactions of organisms to both natural and anthroprogenic stress.

The biomarkers in mussels such as molecular and cellular responses to contaminant stress are recently started using to assess the coastal water quality. Biological responses at molecular and cellular levels include DNA break, lysosomal dysfunction, tissue pathology etc. Recently biomarkers (molecular and cellular responses, growth rate) are included and studied as part of mussel watch programs (Figure 3).

In recent years, the incorporation of biomarkers into research programs has helped to pinpoint needs for remediation in diverse aquatic ecosystems (e.g., Puget Sound, the Venice lagoon and the Black Sea). However, only recently have suites of biomarkers begun to be included in routine management protocols and their combination with chemical analyses used to link chemical exposure and biological response in situ. The widespread implementation of this approach has, so far, been limited, partly because complex analytical methods can make detailed studies of contaminated sites expensive and time-consuming but also by a lack of understanding of how biomarkers can be incorporated into legal instruments.

SUGGESTED REFERENCES:

Krishnakumar,P.K., P.K.Asokan and V.K.Pillai. 1990. Physiological and cellular responses to copper and mercury in the green mussel *Perna viridis*. **Aquat. Toxicol**. 18, 163 174.

Krishnakumar,P.K., V.K.Pillai and K.K.Valsala. 1990. Bioaccumulation of trace metals by marine flora and fauna near a caustic soda plant (Karwar, India). **Indian J. Fish**. 37, 129 137.

Krishnakumar,P.K., E. Casillas and U.Varanasi. 1994. Effects of environmental contaminants on the health of *Mytilus edulis* from Puget sound, Washington, USA. I. Cytochemical measures of lysosomal responses in the digestive cells using automatic image analysis. **Mar. Ecol. Prog. Ser.** 106, 249 261.

Krishnakumar,P.K., E. Casillas and U.Varanasi. 1995. Effects of environmental contaminants on the health of *Mytilus edulis* from Puget sound, Washington, USA. II. Cytochemical detection of subcellular changes in the digestive cells. **Mar. Biol.** 124, 251 - 259.

Krishnakumar,P.K, E.Casillas and U.Varanasi. 1997. Cytochemical responses in *Mytilus edulis* exposed to microencapsulated PAHs and PCBs. **Comp. Biochem. Physiol.** 118C, 11 - 18.

Krishnakumar,P.K., E.Casillas, R.G.Snider and U.Varanasi. 1999. Environmental contaminants and the prevalence of hemic neoplasia (leukemia) in the common mussel (*Mytilus edulis* complex) from Puget Sound, Washington, USA. **J. Invertebr. Pathol**. 73, 135 - 146.

A.N. Kagley, R.G. Snider, P.K. Krishnakumar and E. Casillas. 2003. Assessment of seasonal variability of cytochemical responses to contaminant exposure in the blue mussel *Mytilus edulis* (complex). ***Arch. Environ. Contam. Toxicol.*** 44, 43–52

Krishnakumar, P.K., Geetha Sasikumar, G. S. Bhat and P. K. Asokan (2006). Biomarkers of environmental contaminants in field population of green mussel (*Perna viridis*) from Karnataka–Kerala coast (South West coast of India), ***Ecotoxicol.*** 15: 347 - 352.

Geetha Sasikumar, Krishnakumar, P.K and G.S. Bhat (2006). Monitoring trace metal contaminants in green mussel, *Perna viridis* from the coastal waters of Karnataka, southwest coast of India. ***Arch. Environ. Contam. Toxicol.*** 51, 206 – 214.

Table 1: Marine pollutants of global concern

Pollutant	Description
Petroleum hydrocarbons	Crude oil and some of its refined products
Sewage	Effects of sewage pollution are generally local ones but sewage may contain some of the other toxic chemicals.
Halogenated hydrocarbons	Including compounds such as DDT and the PCBs together with their degradation and combustion products (e.g. polychlorinated dioxins and dibenzofurans)
Other organic compounds	Endocrine disrupting chemicals (also referred to as oestrogenic chemicals)
Metals	Particularly mercury, cadmium and lead
Radionuclides	Particularly caesium-137, strontium-90 and plutonium isotopes
Litter (Solid waste)	Particularly persistent plastics and including lost fishing nets

Table 2. Attributes of bivalves (mussels, oysters and clams) as sentinel organisms

- A correlation exists between the pollutant content of the organism and the average pollutant concentration in the surrounding habitat; contaminant concentration factors of many-fold (over seawater concentrations) are common.
- Bivalves are cosmopolitan, minimizing the inherent problems which arise when comparing data from markedly different species; this issue will be more important in tropical areas.
- Bivalves have reasonably high tolerance to many types of pollution and can exist in habitats contaminated within much of the known range of pollution.
- Bivalves are sedentary generally and better representative of the study area than mobile species.
- Bivalves often are abundant in relatively stable populations that can be sampled repeatedly throughout the study region.
- Many bivalve species are sufficiently long-lived to allow the sampling of more than one year-class, if desired.
- Bivalves are often of a reasonable size, providing adequate tissue for analysis.
- Bivalves are easy to sample and hardy enough to survive in the laboratory, allowing defecation before analysis (if desired) and laboratory studies of pollutant uptake.

- Several bivalve species tolerate a range of salinity and other environmental conditions, making them hardy enough to be transplanted to other areas for experimentation.
- Bivalves are generally metabolically passive to the contaminants in question and not alter the chemical after uptake; uptake by the organism provides an assessment of bioavailability from environmental compartments.
- Bivalves are commercially valuable seafood and a measure of chemical contamination is of public health interest.

Table 3. Concentration of Organic (ppb) and Metal (ppm) contaminants in whole tissue (dry weight) of *Mytilus edulis* collected from Puget Sound, Washington, during September 21–24, 1992 (Krishnakumar et al. 1999).

	Sites								
Contaminants	Eagle Harbor	Commencement Bay	Seacrest	Four Mile Rock	Sinclair Inlet	Oak Bay	Saltwater Park	Coupeville	Double Bluff
Polycyclic aromatic hydrocarbons									
Phenanthrene	9,000	330	110	150	24	14	17	20	15
Fluoranthene	15,000	2000	510	300	49	17	37	20	23
Benzo[a]pyrene	640	50	16	11	3	1	1	1	1
Total HMW PAHs[a]	64,000	5800	1600	1140	220	110	170	130	120
Chlorinated hydrocarbons									
Polychlorinated biphenyls[b]	400	400	500	200	180	60	140	50	50
Total DDTs[c]	21	29	28	10	15	11	9	11	11
Other pesticides[d]	16	33	22	17	11	10	17	12	11
Metals									
Arsenic	3.0	3.6	3.3	3.7	2.7	5.4	3.1	3.2	3.2
Cadmium	3.5	4.3	5.3	4.6	2.8	5.2	3.8	3.5	2.6
Mercury	0.64	0.23	0.66	0.13	0.20	0.19	0.39	0.05	0.37
Lead	0.94	12.0	1.4	1.5	0.95	0.55	0.55	0.86	0.41

[a] Σ Molecular weight PAHs includes the summed concentrations for the following organic compounds: naphthalene, acenaphthylene, acenapthene, fluorene, phenanthrene, anthracene, and 2-methylnaphthalene, fluoranthene, pyrene, benz[a]anthracene, chrysene, benzofluoranthenes, benzo[a]pyrene, indeno[1,2,3,-c,d]pyrene, dibenzo[a,h]anthracene, and benzo[g,h,i,]perylene.

[b] Poychlorinated biphenyls measured as Aroclor 1254.

[c] Total DDTs include the summed concentrations of the following compounds: DDT, DDE, and DDD.

[d] Pesticides include the summed concentrations of the following compounds: aldrin, chlordane, dieldrin, heptachlor, and lindane.

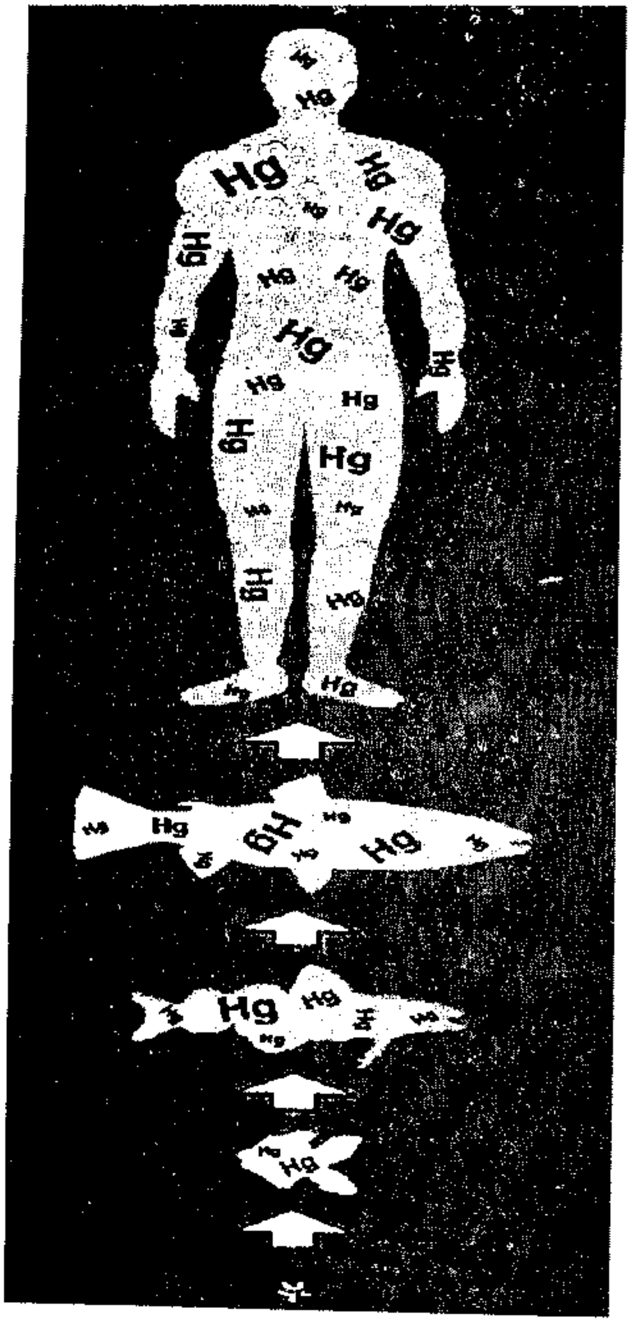

Figure 1. The biomagnification potential of mercury through marine food chain and human risk.

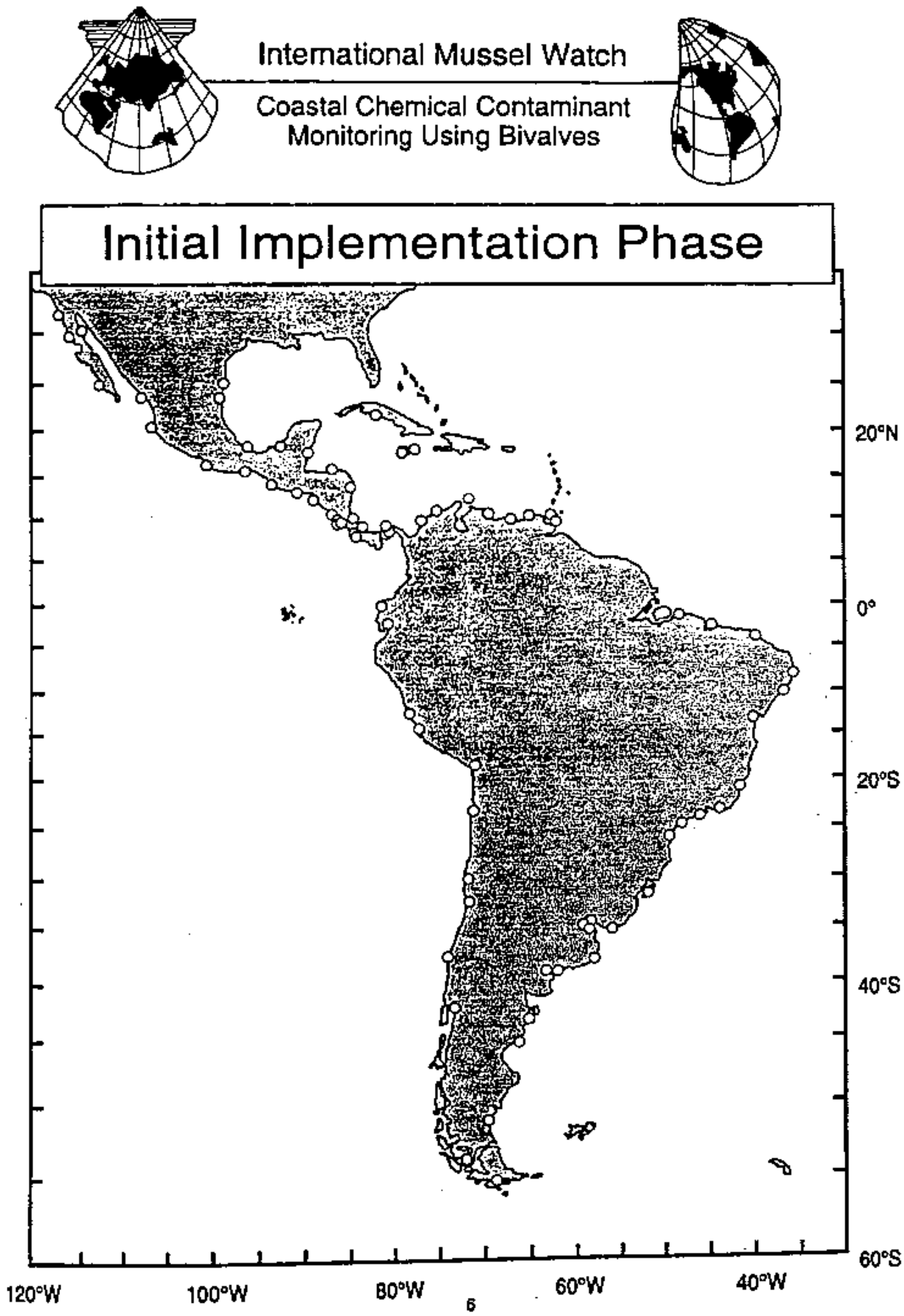

Figure 2. Mussel sampling locations along the coastal waters of American continent (North and South) for the first mussel watch study.

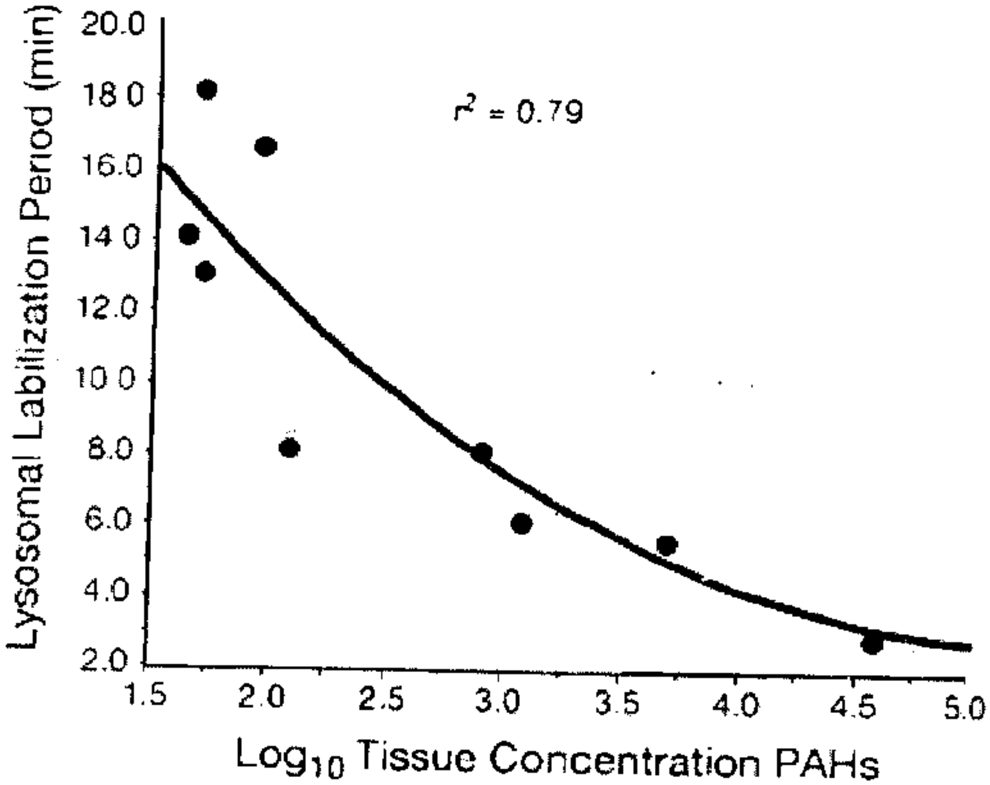

Figure 3. Relationship between lysosomal membrane stability (a biomarker) and tissue concentration of high molecular weight PAHs of mussels (*Mytilus edulis)* from urban-associated and reference sites in Puget Sound, USA (Krishnakumar et al. 1994).