Research Guru
Online Journal of Multidisciplinary Subjects (ISSN : 2349-266X)
UGC Approved Journal No. 63726
Impact Factor:3.021 website: www.researchguru.net
Volume-11,Issue-3,December-2017

Zooremediation: The new approach of bioremediation study – A Review

Dr. L.B. George, M.M. Nandotriya, Dr. H.N. Highland, Dr.K.R. Desai
Department of Zoology,BMTC & HG, School of Sciences,
Gujarat University, Navrangpura, Ahmedabad, Gujarat

INTRODUCTION

Vast number of pollutants and waste materials containing heavy metals are disposed into the environment per annum. Approximately 6 x 10^6 chemical compounds have been synthesized, with 1,000 new chemicals being synthesized annually. Almost 60,000 to 95,000 chemicals are in commercial use. According to Third World Network reports, more than one billion pounds (450 million kilograms) of toxins are released globally in air and water. The contaminants causing ecological problems leading to imbalance in nature is of global concern. The environmentalists around the world are trying to overcome it by several means. However, they are raising their voices at international platforms regarding the depletion of natural resources; little attention is given to their words and continues to use them without caring the adverse consequences. (McIntyre T, 2003)

Usually the contaminated sites are treated with traditional methods like physical, chemical and thermal processes resembling excavation and transportation. The bioremediation technology is cost effective, eco-friendly and alternative to conventional treatments, which rely on incinerations, volatilization or immobilization of the pollutants. The conventional treatment technologies simply transfer the pollutants, creating a new waste such as incineration residues and not eliminate the problem. (McIntyre T, 2003)

Bioremediation is an option that offers the possibility to destroy or render harmless various contaminants using natural biological activity. As such, it uses relatively low-cost, low-technology techniques, which generally have a high public acceptance and can often be carried out on site (Vidali M., 2001). Compared to other methods, bioremediation is a more promising and less expensive way for cleaning up contaminated soil and water. Bioremediation uses biological agents, mainly microorganisms, e.g. yeast, fungi or bacteria to clean up contaminated soil and water (Strong PJ and Burgess JE, 2008). Bioremediation, i.e. the use of living organisms to control or remediate polluted soils, is an emerging technology. It is defined as the elimination, attenuation or transformation of polluting or contaminating substances by the use of biological processes. Some tests make an exhaustive examination of the literature of bioremediation of organic and inorganic pollutants and another test takes a look at pertinent field application case histories (Flathman PE, D Jerger, JE Exner, 1993). Most bioremediation systems are run under aerobic conditions, but running a system under anaerobic conditions may permit microbial organisms to degrade otherwise recalcitrant molecules. Most important parameters for bioremediation of contaminated soil are (i) the nature of pollutants, (ii) the soil structure, pH, Moisture contents and hydrogeology, (iii) the nutritional state, microbial diversity of the site and (iv) Temperature and oxidation-reduction (Redox- Potential). In bioremediation processes, microorganisms use the contaminants as nutrient or energy sources (Tang CY, Criddle QS Fu CS, Leckie JO, 2007). Bioremediation activity through microbe is stimulated by supplementing nutrients (nitrogen and phosphorus), electron acceptors (oxygen), and substrates (methane, phenol, and toluene), or by introducing microorganisms with desired catalytic capabilities. Plant and soil microbes develop a rhizospheric zone (highly complex symbiotic and synergistic relationships) which is also used as a tool for accelerating the rate of degradation or to remove contaminants (Baldwin BR, Peacock AD, Park M, 2008).

Groundwater is one of the most vital sources of drinking water on earth. However, in the past few decades, it has been contaminated with petroleum hydrocarbons, which leaked from underground storage tanks. These organic compounds have caused serious public concern because benzene, toluene, ethyl benzene, and xylene (BTEX) are ubiquitous pollutants hazardous to human health (Lokhande PB, Patil1 VV, 2009). *In situ* bioremediation technology is a widely used technology that can clean up BTEX-contaminated sites, using indigenous microorganisms to enhance biodegradation of organic constituents in the subsurface. Bacteria have huge catabolic possibility for remediating wastes; however, the interactions between bacteria and pollutants are complex and suitable remediation does not always take place. Hence, molecular approaches are being applied to enhance bioremediation. The recent developments are taking place in bioremediation by utilizing rhizoremediation, protein engineering, metabolic engineering, whole-transcriptome profiling, and proteomics for the degradation of recalcitrant pollutants such as chlorinated aliphatic and polychlorinated biphenyl as well as for binding heavy metals (Thomas K Wood, 2008). Cell surface expression of specific proteins allows the engineered microorganisms to transport, bio accumulate and/or detoxify heavy metals as well as to degrade xenobiotic (Muhammad Arshad, Muhammad Saleem, Sarfraz Hussain, *2007)*.

OBJECTIVES OF THIS REVIEW

- Explore the current concepts of zoo remediation
- Provide an insight in to the role of various developed processes like zoo remediation and major controls that may be used for their management in degradation of inorganic and organic soil and water pollutants.
- Highlight the limitations and challenges associated with the various current processes of bioremediation.

DEVELOPMENT OF BIOREMEDIATION

Bioremediation techniques are divided into three categories; *in situ, ex situ* solid and *ex situ* slurry. With *in situ* techniques, the soil and associated ground water is treated in place without excavation, while it is excavated prior to treatment with *ex situ applications*. Selection of appropriate technology among the wide range of bioremediation strategies developed to treat contaminants depends on three basic principles *i.e.,* the amenability of the pollutant to biological transformation (Biochemistry), the accessibility of the contaminant to various organisms (Bioavailability) and the opportunity for optimization of biological activity (Bioactivity) (Dua M, Singh A, Sethunathan N, Johri AK, 2002). Simple hydrocarbons and petroleum fuels degradability decreases as molecular weight and degree of branching increase. Aromatic hydrocarbons one or two ring compounds degrade readily, higher molecular weight compounds less readily. Alcohols, esters, nitro benzenes and ethers degrade slowly, chlorinated hydrocarbons decreasing degradability within increasing chlorine substitution – highly chlorinated compounds like PCBs and chlorinated solvents do not appreciably degrade aerobically, Pesticides are not readily degraded. Few environmental conditions are required for the soil remediation (Table 1).

Table 1: Environmental factors and optimum condition for microbial activity for soil bioremediation.

Environmental Factor	Optimum condition	Condition required for microbial activity
Available soil moisture	25-85% water holding capacity	25-28% of water holding capacity
Oxygen	>0.2 mg/L DO, >10% air-filled pore space for aerobic degradation	Aerobic, minimum air-filled pore space of 10%
Redox potential	Eh>50 mill volts	-
Nutrients	C:N:P = 120:10:1 molar ratio	N and P for microbial growth
pH	6.5-8.0	5.5-8.5
Temperature	20-30˚C	15-45˚C
Contaminants	Hydrogen 5-10% of dry weight of soil	Not too toxic
Heavy metals	700 ppm	Total content 2000 ppm
Type of soil	-	Low clay or silt content

Phytoremediation:

Phytoremediation (from Ancient Greek *φυτο (phyto)*, meaning "plant", and Latin *remedium*, meaning "restoring balance") describes the treatment of environmental problems (bioremediation) through the use of plants that mitigate the environmental problem without the need to excavate the contaminant material and dispose of it elsewhere.

Phytoremediation consists of mitigating pollutant concentrations in contaminated soils, water, or air, with plants able to contain, degrade, or eliminate metals, pesticides, solvents, explosives, crude oil and its derivatives, and various other contaminants from the media that contain them (Hannink, N.; Rosser, S. J.; French, 2001).

Application

Phytoremediation may be applied wherever the soil or static water environment has become polluted or is suffering on going chronic pollution. Examples where phytoremediation has been used successfully include the restoration of abandoned metal-mine workings, reducing the impact of sites where polychlorinated biphenyls have been dumped during manufacture and mitigation of on-going coal mine discharges.

Phytoremediation refers to the natural ability of certain plants called hyper accumulators to bio accumulate, degrade, or render harmless contaminants in soils, water, or air. Contaminants such as metals, pesticides, solvents, explosives (Rupassara, S. I., Larson, R. A., Sims, G. K. & Marley, K.A., 2002) and crude oil and its derivatives, have been mitigated in phytoremediation projects worldwide. Many plants such as mustard plants, alpine pennycress, hemp, and pigweed have proven to be successful at hyper accumulating contaminants at toxic waste sites. (McIntyre T, 2003)

Phytoremediation is considered a clean and cost-effective and eco-friendly technology, as opposed to mechanical clean-up methods such as soil excavation or pumping polluted groundwater. Over the past 20 years, this technology has become increasingly popular and has been employed at sites with soils contaminated with lead, uranium, and arsenic. However, one major disadvantage of phytoremediation is that it requires a long-term commitment, as the process is dependent on plant growth, tolerance to toxicity, and bioaccumulation capacity. (Meagher, RB, 2000)

Limitations:

The main limitations for *in situ* phytoremediation are:

- Limited to the surface area and depth occupied by the roots.
- slow growth and low biomass require a long-term commitment
- with plant-based systems of remediation, it is not possible to completely prevent the leaching of contaminants into the groundwater (without the complete removal of the contaminated ground, which in itself does not resolve the problem of contamination)
- the survival of the plants is affected by the toxicity of the contaminated land and the general condition of the soil
- Bioaccumulation of contaminants, especially metals, into the plants which then pass into the food chain, from primary level consumers upwards or requires the safe disposal of the affected plant material.

Phycoremediation:

Phycoremediation, a type of bioremediation, can be defined in a broader sense as the use of macro algae or microalgae for the removal or biotransformation of pollutants including nutrients and xenobiotic from wastewater and CO_2 from waste air (Olguin, E.J., 2003).

The advantages of phycoremediation are:

- Ability of microalgae to tackle simultaneously more than one problem, a solution not capable by conventional chemical processes.
- Case specific as the process can be operated batch wise, semi- continuous or in continuous manner.
- Commercial benefits derived from the biomass and other extracted biochemicals.
- Compatible with existing operations.
- Cost effective as it saves power and a lot of chemicals.
- CO_2 sequestration – a solution for the threat of global warming (Muthukumaran, M., B.G. Raghavan, V.V. Subramanian and V.Sivasubramanian, 2005).

Mycoremediation:

Mycoremediation is a form of bioremediation in which fungi are used to decontaminate the area. The term *mycoremediation* refers specifically to the use of fungal mycelia in bioremediation.

One of the primary roles of fungi in the ecosystem is decomposition, which is performed by the mycelium. The mycelium secretes extracellular enzymes and acids that break down lignin and cellulose, the two main building blocks of plant fibre. These are organic compounds composed of long chains of carbon and hydrogen, structurally similar to many organic pollutants. The key to mycoremediation is determining the right fungal species to target a specific pollutant. Certain strains have been reported to successfully degrade the nerve gases VX and sarin (Singh, Harbhajan, 2006).

In one conducted experiment, a plot of soil contaminated with diesel oil was inoculated with mycelia of oyster mushrooms; traditional bioremediation techniques (bacteria) were used on control plots. After four weeks, more than 95% of many of the PAH (polycyclic aromatic hydrocarbons) had been reduced to non-toxic components in the mycelial-inoculated plots. It appears that the natural microbial community participates with the fungi to break down contaminants, eventually into carbon dioxide and water. Wood-degrading fungi are particularly effective in breaking down aromatic pollutants (toxic components of petroleum), as well as chlorinated compounds (certain persistent pesticides; Battelle, 2000).

Mycofiltration is a similar process, using fungal mycelia to filter toxic waste and microorganisms from water in soil.

Microbial biodegradation:

Interest in the microbial biodegradation of pollutants has intensified in recent years as humanity strives to find sustainable ways to clean up contaminated environments (Diaz E, 2008). These bioremediation and biotransformation methods endeavour to harness the astonishing, naturally occurring ability of microbial xenobiotic metabolism to degrade, transform or accumulate a huge range of compounds including hydrocarbons (e.g. oil), polychlorinated biphenyls (PCBs), polyaromatic hydrocarbons (PAHs), heterocyclic compounds (such as pyridine or quinolone), pharmaceutical substances, radionuclides and metals. Major methodological breakthroughs in recent years have enabled detailed genomic, met genomic, proteomic, bioinformatics and other high-throughput analyses of environmentally relevant microorganisms providing unprecedented insights into key biodegradative pathways and the ability of organisms to adapt to changing environmental conditions (Koukkou, 2011).

The elimination of a wide range of pollutants and wastes from the environment is an absolute requirement to promote a sustainable development of our society with low environmental impact. Biological processes play a major role in the removal of contaminants and they take advantage of the astonishing catabolic versatility of microorganisms to degrade or convert such compounds. New methodological breakthroughs in sequencing, genomics, proteomics, bioinformatics and imaging are producing vast amounts of information. In the field of Environmental microbiology, genome-based global studies open a new era providing unprecedented *in silico* views of metabolic and regulatory networks, as well as clues to the evolution of degradation pathways and to the molecular adaptation strategies to changing environmental conditions. Functional genomic and met genomic approaches are increasing our understanding of the relative importance of different pathways and regulatory networks to carbon flux in particular environments and for particular compounds and they will certainly accelerate the development of bioremediation technologies and biotransformation processes (McLeod MP and Eltis LD, 2008).

Zooremediation

The ability of animals to act in a bioremediative capacity is not widely known. Animals are rarely considered for bioremediation initiatives owing to ethical or human health concerns. Nonetheless, specific examples in the literature reveal that some animal species are effective remediators of heavy metals, microbial contaminants, hydrocarbons, nutrients and persistent organic pollutants, particularly in an aquatic environment. Recent examples include deploying pearl oysters to remove metals and nutrients from aquatic ecosystems and the harvest of fish to remove polychlorinated biphenyls (PCBs) from the Baltic. It is probable that many animal taxa will possess attributes amenable to bioremediation (Gifford, S. *et al*., 2005).

The use of animals for bioremediation can be achieved in three ways: pollutants can be extracted from an area by harvesting wild populations; through the introduction, culture, and harvest of animals – a form of aquaculture; and supplementation or maintenance of wild animal populations, which might lead to stabilization or degradation of pollutants. (Gifford, S. *et al*., 2005)

Zooremediation can be achieved by:

Zooextraction: The harvest and treatment of pollutant-containing animal biomass. The focus rests on animal species known to accumulate pollutants of interest.

Zoostabilization: The use of animals to inhibit pollutant migration. This involves the maintenance or supplementation of wild animal populations without the harvesting of animal biomass.

Zootransformation or zoodegradation: The use of animals to degrade organic pollutants to less toxic compounds. This involves the maintenance or supplementation of wild animal populations without the harvesting of animal biomass.

Animal metal-hyperaccumulator: Those animal species known to accumulate >100 mg/kg Cd, Cr, Co or Pb; or >1000 mg/kg Ni, Cu, Se, As or Al; or >10 000 mg/kg Zn or Mn. This field would probably be limited to invertebrates for ethical reasons (Gudimov, A.V., 2002)

Zooremediation of pollutants:

Zooextraction of nutrients and microorganisms

The cultivation and harvest of animals to remediate nutrient and pathogenic microorganism pollution in aquatic systems is the most common form of zooremediation. The practice has a long history in aquaculture, where polyculture can reduce nutrient and microorganism pollution from some monocultures. The most common group of animals used are bivalve molluscs, as demonstrated by the co-culture of salmon with mussels or oysters to reduce nutrient pollution from waste salmon feed (Neori, A. *et al*., 2004). Oysters reduced the levels of nitrogen and phosphorus in shrimp effluent by 72% and 86%, respectively (Jones, A.B. *et al*., 2001); similarly, turbidity and chlorophyll a concentrations in fish farm effluent were reduced by 68% and 79%, respectively (Shpigel, M. *et al*., 1997).

At an estuary level, the cultivation and harvest of pearl oysters (*Pinctada imbricata*, Figure (Fig.1)) can balance the nitrogen input of a sewage treatment plant. Gifford, S. *et al*., 2005 estimated that an annual harvest of 499 tonnes per year of pearl oyster material would balance the annual input of 3741 kg nitrogen entering the estuary from a small sewage treatment plant. Similarly, the deployment and harvest of shellfish has been proposed in Sweden (Haamer, J., 1996) and America (Rice, M.A., 2001), to mitigate anthropogenic nutrient input to coastal waters. Moreover, there has been recent interest regarding the use of sponges for bioremediation of aquatic microorganism pollution. Sponges have a renowned filtering capacity and in large communities filter the overlying water column in as little as 24 h (Reiswig, H.M., 1974), with high particle-retention rates and potential for economic gains through their use as bath sponges (Stabili L., *et al*., 2006) or the production of novel metabolites, for example, the cytotoxin latrunculin B for pharmaceutical use (Hadas, E. *et al*., 2005). A recent European study reported a successful trial of the marine sponge *Chondrilla nucula* (Fig.2) as an environmental remediator of bacteria. This study estimated that a 1 m^2 patch of this sponge can retain up to 7×10^{10} *E. coli* cells and filter 14 L of water per hour. A similar Chinese study investigated the potential of the marine sponge *Hymeniacidon perleve* (Fig.3) to remediate *E. coli* and *Vibrio anguillarum II*, with the sponges filtering up to 8×10^7 *E. coli* cells/h/gm. fresh sponge (Fu, W.T. *et al*., 2006). Recently, the successful use of polychaetes as environmental remediators of microbial pollution has also been reported, with *Sabella spallanzanii* (Fig.4) and *Branchiomma luctuosum* (Fig.5) demonstrating retention efficiencies of *Vibrio alginolyticus* of 70% and 98%, respectively (Licciano, M. *et al*., 2005). It has been estimated that a standing stock of 250000 worms (*Sabella spallanzanii*), with aging worms harvested and younger worms cultured, could be used to remediate the suspended-particulate waste matter.

Fig. 1 *Pinctada imbricata* Fig. 2 *Chondrilla nucula*

Fig. 3 *Hymeniacidon perleve* Fig. 4 *Sabella spallanzanii*

Fig. 5 *Branchiomma luctuosum*

- Zoostabilization or degradation of nutrients and microorganisms

Many filter-feeding animals act as benthic–pelagic couplers; they actively transfer energy and nutrients from the water column to the benthos. Newell, 1988 proposed that large-scale ecological changes in Chesapeake Bay (the largest estuary in the USA) due to eutrophication could be a result of overharvesting of oyster biomass. Newell calculated that the 1880 standing stock of oysters would have taken 3.6 days to filter the entire water column of the Bay, whereas in 1988 it would have taken 228 days. This finding has led to a concerted effort to re-establish oyster bars for ecological reasons in many areas of the USA (Coen, L.D. and Luckenbach, M.W., 2000), with the largest, the Chesapeake 2000 Agreement, committing various stakeholders to a tenfold increase in native oysters in the Chesapeake Bay by 2010, at a cost of US$100 million (Esher, D., 2002). Further examples of the potential for filter feeders to act as 'ecological engineers' include the zebra mussel (Fig.6) (*Dreissenia polymorpha*) and the Asiatic clam (Fig.7) (*Corbicula fluminea*). Between 1988 and 1989, following the introduction of the zebra mussel, turbidity in Lake Erie decreased markedly. Additionally, chlorophyll a concentrations reduced by 43%, and mean sechi disc transparencies (a measure of turbidity, assessed by lowering a patterned disc that lies on the end of a rope over the side of a boat and recording the depth at which the observer loses sight of the disc) increased by 1.24 m (Leach, J.H., 1993). Meanwhile, Phelps,1994 reported that following establishment of the Asiatic clam in the Potomac River estuary in the early 1980s, water quality improved substantially, with submerged aquatic vegetation that had been absent for 50 years reappearing; subsequent fish and bird surveys revealed large increases in their respective populations. Following reductions in clam biomass, water quality declined and fish, bird and aquatic vegetation populations contracted. Evidence such as this has supported recent calls for the deliberate introduction of exotic bivalve mollusc species to aquatic ecosystems (Gottlieb, S.J. and Schweighofer, M.E., 1996). However, to avoid the problems associated with the introduction of invasive species, the use of native species is generally preferable unless it is certain that exotic candidate species are non-invasive.

In addition to bivalve molluscs, zoostabilization of nutrient and microorganism pollution using polychaetes, sponges and a variety of filter feeding invertebrates is conceivable. Maintenance or supplementation of wild populations of these organisms could be used to manage nutrient or microbial pollution in aquatic ecosystems. Recognition of the importance of these ecosystem services might aid in the conservation of these communities (Ostroumov, S., 2005). However, research in this area remains poorly developed in comparison to oyster reef conservation and would profit from increased endeavours.

Fig.6 *Dreissenia polymorpha*

Fig.7 *Corbicula fluminea*

❖ Zooextraction of heavy metals

A recent review by Gifford *et al*., 2004 focusing on bivalve molluscs, identified species that satisfy the plant definition of a hyper accumulator for Cu (*Crassostrea virginica* (Fig.8) [2013 mg Cu/kg]), Pb (*Mytilus edulis* (Fig.9) [506 mg Pb/kg]), Cd (*Pinctada albina albino* (Fig.10) [108 mg Cd/kg]) and Al (*Crassostrea rhizophorae* (Fig.11) [2240 mg Al/kg]) and approached this status for Zn (*Crassostrea virginica* [9077 mg Zn/kg]). This phenomenon is well known, and many such animals are presently used in various large-scale environmental monitoring programs (O'Connor, T.P., 2002). Das and Jana, 2003 investigated the potential for the freshwater bivalve *Lamellidens marginalis* (Fig.12) as a biofilter of cadmium pollution in India, demonstrating a bio concentration factor (BCF – the ratio of concentration within the organism to the exposure concentration) for Cd of up to 347 and a dry weight Cd concentration >500 mg/kg (Das, S. and Jana, B., 2003).

Some metal-hyper accumulating animals offer non-food economic returns. Gifford *et al*., 2005 demonstrated that each tonne of pearl oyster harvested resulted in 703 g metals removed from an estuary on the east coast of Australia. However, this does not give an indication of the remediation potential of pearl oysters because the farm was located in a relatively pristine estuary. Gifford, 2006 investigated the uptake of Pb and Zn by pearl oysters under controlled laboratory conditions. Pearl oysters exposed to 90 mg/L of each metal accumulated 601 mg/kg and 209 mg/kg Pb as well as 4421 mg/kg and 54 mg/kg Zn in the soft tissue and shell, respectively.

A vast group of animals that is still unexplored as metal bioremediators that have the potential for non-food economic returns are the sponges. Sponges are exposed to many metal pollutants within aquatic ecosystems and, owing to their filtration capacity, they are known metal bio accumulators (Argali, R. *et al*., 1996) with a history of use as reliable biomonitors of marine pollution (Perez, T. *et al*., 2005). Indeed, the little work carried out on sponges indicates that they meet the definition of hyperaccumulators for Cd (*Halichondria panicea* (Fig.13) [271 mg Cd/kg]) (Cebrian, E. *et al*., 2003). These characteristics, combined with recent interest in sponges as a source of novel pharmaceuticals and bioactive compounds, indicate the possibility for a self-financing remediation program. Conceivably, other animals, such as bryozoans, polychaetes, and ascidians (which are known to accumulate (Kawakami, N. *et al.,* 2006), could be used as environmental remediators of metals and might also offer the potential for the farming of novel chemical compounds.

As with phytoremediation, there is a need for adequate treatment of harvested metal-laden animal biomass. One system that is presently in use is the recovery of Cd in waste scallop tissue: in scallops, only the muscle and the gonad are eaten, whereas the remainder of the organism preferentially accumulates natural sources of Cd from marine waters and thus is removed and discarded from the animal before sale (http://www.unirex-jp.com/engcadmium/engcadmium.htm). As such, there has been a need to develop systems to handle properly the estimated 400 000 tonnes of cadmium-contaminated scallop waste generated in Japan through scallop processing. The Cd is harvested from the scallop waste before being re-used in a nearby car battery plant, whereas the scallop tissue, now free of Cd, is used for fertilizer.

Fig. 8 *Crassostrea virginica*

Fig. 9 *Mytilus edulis*

Fig. 10 *Pinctada albina albino*

Fig. 11 *Crassostrea rhizophorae*

Fig. 12 *Lamellidens marginalis*

Fig. 13 *Halichondria panicea*

Zooextraction of organic pollutants

Although the deployment and harvest of animals that hyper accumulate organic pollutants is still undergoing trials, the use of pearl oysters (Gifford, S. *et al.*, 2004) and sponges is indicated by past studies. *Spongia officinalis* (Fig.14) is known to concentrate many organic contaminants, including polychlorinated biphenols (PCBs), to higher concentrations than bivalve molluscs, with a BCF of ~10^5 (Perez, T. *et al.*, 2003). Thus, substantial quantities of PCBs could potentially be removed from aquatic environments upon harvest of sponge tissue. Recently, fish have been proposed for zooextraction of PCBs and DDT (Mackenzie, B.R. *et al.*, 2004) : the authors propose that by not discarding fish waste, such as cod liver, overboard Baltic Sea fisheries could remove 31 kg per year of PCBs from the Baltic ecosystem. This amount compares with an annual influx of some 260 kg of PCBs; therefore, it would remove more from the ecosystem than all other alternative methods (such as degradation in the water column).

Zoostabilization and/or degradation of organic pollutants

Gudimov, 2002 reported that degradation of oil was accelerated 10–20 times in the presence of *Mytilus edulis*. Alternatively, the sponge *Spongia officinalis* can degrade the surfactant 1-(p-sulfophenyl) nonane to its main degradation products, 3-(p-sulfophenyl) propionic acid and p-sulfobenzoic acid, ten times more rapidly than marine bacteria (Perez, T. *et al.*, 2002) : the first evidence of pollutant degradation by a sponge. In addition, there is some evidence that this sponge can degrade the PCB CB138 (International Union of Pure and Applied Chemistry, IUPAC) (Perez, T. *et al.*, 2003). It is probable that many sponges are able to breakdown organic pollutants, particularly given their ability to produce and safely store many halogenated biomolecules within the cell. In addition, the differential accumulation of organic pollutants observed in the gastropod *Austrocochlea constricta* (Fig.15) (Walsh, K. *et al.*, 1995) could be used for zoostabilization: short-chain aliphatic hydrocarbons (C14–C18) accumulated in the soft tissue, whereas longer-chain aliphatic hydrocarbons (C20–C30) tended to accumulate in the shell. The authors proposed that those compounds that are more resistant to cellular degradation (longer chain) were isolated from metabolically active tissue and stored in the shell of the organism. As such, it is conceivable that certain contaminants could be remediated through isolation from trophic transfer through sequestration in the shell.

Fig. 14 *Spongia officinalis*

Fig. 15 *Austrocochlea constricta*

References:

McIntyre T, 2003. Phytoremediation of heavy metals from soils. Advance Biochemical Engineering Biotechnology, 78:97–123.

Vidali M., 2001. Bioremediation: An overview. Pure Applied Chemistry, 73:1163-1172.

Strong PJ and Burgess JE, 2008. Treatment methods for wine-related addistillery wastewaters: a review. Bioremediation Journal, 12: 70-87

Flathman PE, D Jerger, JE Exner, 1993. Bioremediation: Field Experience, Lewis, Boca Raton, FL. 6:14-19.

Tang CY, Criddle QS Fu CS, Leckie JO, 2007. Effect of flux (transmembrane pressure) and membranes properties on fouling and rejection of reverse osmosis and nanofiltration membranes treating perfluorooctane sulfonate containing waste water. Environmental Science and Technology, 41:2008-2014.

Baldwin BR, Peacock AD, Park M, Ogles DM, Istok JD, McKinley JP, Resch CT, White DC, 2008. Multilevel samplers as microcosms to assess microbial response tobiostimulation. Ground Water, 46: 295-304.

Lokhande PB, Patil1 VV, 2009. Mujawar Multivariate statistical study of seasonal variation of BTEX in the surface water of Savitri River, Journal Environmental Monitoring and Assessment, 157:55-61**.**

Thomas K Wood, 2008. Molecular approaches in bioremediation. Current Opinion in Biotechnology, *19: 572-578*.

Muhammad Arshad, Muhammad Saleem, Sarfraz Hussain, *2007***.** Perspectives of bacterial ACC deaminase in phytoremediation. Trends in Biotechnology, *25: 356-362*.

Dua M, Singh A, Sethunathan N, Johri AK, 2002. Biotechnology and bioremediation: successes and limitations. Applied Microbiology Biotechnology, 59(2-3):143-52.

Hannink, N.; Rosser, S. J.; French, C. E.; Basran, A.; Murray, J. A.; Nicklin, S.; Bruce, N. C. (2001), "Phytodetoxification of TNT by transgenic plants expressing a bacterial nitroreductase", *Nature Biotechnology* **19** (12): 1168–72

Rupassara, S. I.; Larson, R. A.; Sims, G. K. & Marley, K. A. (2002), "Degradation of Atrazine by Hornwort in Aquatic Systems", *Bioremediation Journal* **6** (3): 217–224

Meagher, RB (2000), "Phytoremediation of toxic elemental and organic pollutants", *Current Opinion in Plant Biology* **3** (2): 153–162

Olguin, E.J. 2003. Phycoremediation: key issues for cost-effective nutrient removal process. Biotechnol. Adv. 22 8 1-91.

Muthukumaran, M., B.G. Raghavan, V.V. Subramanian and V.Sivasubramanian 2005. Bioremediation of industrial effluent using microalgae. Indian Hydrobiology, 7(Supplement): 105 – 122

Singh, Harbhajan (2006). *Mycoremediation: fungal bioremediation*. New York: Wiley-Interscience.

Thomas, S.A. 2000. "Mushrooms: Higher Macrofungi to Clean Up the Environment", Battelle Environmental Issues, Fall 2000

Diaz E (editor). (2008). *Microbial Biodegradation: Genomics and Molecular Biology* (1st ed.). Caister Academic Press.

Koukkou, A-I (editor) (2011). *Microbial Bioremediation of Non-metals: Current Research*.

McLeod MP and Eltis LD (2008). "Genomic Insights Into the Aerobic Pathways for Degradation of Organic Pollutants". *Microbial Biodegradation: Genomics and Molecular Biology*. Caister Academic Press.

Gifford, S. et al. (2005) Quantification of in situ nutrient and heavy metal remediation by a small pearl oyster (Pinctada imbricata) farm at Port Stephens. Australia. Mar. Pollut. Bull. 50, 417–422

Gudimov, A.V. (2002) Zooremediation, a new biotechnology solution for shoreline protection and cleanup, In Proceedings of the 25th Arctic and Marine Oilspill Program, pp. 401–412

Neori, A. et al. (2004) Integrated aquaculture: rationale, evolution and state of the art emphasizing seaweed biofiltration in modern mariculture. Aquaculture 231, 361–391

Jones, A.B. et al. (2001) Integrated treatment of shrimp effluent by sedimentation, oyster filtration and macroalgal absorption: a laboratory scale study. Aquaculture 193, 155–178

Shpigel, M. et al. (1997) A biomechanical filter for treating fish pond effluents. Aquaculture 152, 103–117

Haamer, J. (1996) Improving water quality in a eutrophied fjord system with mussel farming. Ambio 25, 356–362

Rice, M.A. (2001) Environmental impacts of shellfish aquaculture: filter feeding to control eutrophication. In Marine Aquaculture and theEnvironment: A Meeting of Stakeholders in the Northeast (Tlusty, M., Bengtson, D., Halvorson, H.O., Oktay, S., Pearce, J. and Rheault, R.B., Jr, eds), pp. 77–86, Cape Cod Press

Reiswig, H.M. (1974) Water transport, respiration and energetics of three tropical marine sponges. J. Exp. Mar. Biol. Ecol. 14, 231– 249

Stabili, L. et al. (2006) Filtering activity of Spongia officinalis var adriatica (Schmidt) (Porifera, demospongiae) on bacterioplankton: Implications for bioremediation of polluted seawater. Water Res. 40, 3083–3090

Hadas, E. et al. (2005) Sea ranching of the marine sponge Negombata magnifica (Demospongiae, Latrunculiidae) as a first step for latrunculin B mass production. Aquaculture 244, 159–169

Fu, W.T. et al. (2006) Potential of the marine sponge Hymeniacidon perleve as a bioremediator of pathogenic bacteria in integrated aquaculture systems. Biotechnol. Bioeng. 93, 1112–1122

Licciano, M. et al. (2005) Clearance rates of Sabella spallanzii and Branchiomma luctuosum (Annelida: Polychaeta) on a pure culture of Vibrio alginolyticus. Water Res. 39, 4375–4384

Newell, R.I.E. (1988) Ecological changes in Chesepeake Bay: are they the result of overharvesting the American oyster, Crassostrea virginica? In Understanding the Estuary: Advances in Chesapeake Bay Research (Lynch, M.P. and Krome, E.C., eds), pp. 536–546, Chesapeake Research Consortium.

Coen, L.D. and Luckenbach, M.W. (2000) Developing success criteria goals for evaluating oyster reef restoration: ecological function or resource exploitation. Ecol. Eng. 15, 323–343

Esher, D. (2002) Recommendations on Suminoe oyster (Crassostrea ariakensis) aquaculture in Chesapeake Bay, Chesapeake Bay Program Federal Agencies Committee

Leach, J.H. (1993) Impacts of the zebra mussel (Dressena polymorpha) on water quality and fish spawning reefs in western Lake Erie. In Zebra

Mussels: Biology, Impacts, and Control (Nalepa, T.F. and Schloesser, D.W., eds), pp. 381–397, Lewis Publishers

Gottlieb, S.J. and Schweighofer, M.E. (1996) Oysters and the Chesapeake Bay ecosystem: a case for exotic species introduction? Estuaries 19, 639–650

Ostroumov, S. (2005) Some aspects of water filtering activity of filter feeders. Hydrobiologia 542, 275–286