

Table of Contents

Table of figures.....	2
Table of tables.....	2
1 Introduction.....	3
1.1 Filter feeders.....	3
1.1.1 Barnacles (<i>Semibalanus balanoides</i>).....	4
1.1.2 Blue mussels (<i>Mytilus edulis</i>).....	5
1.2 Predators.....	6
1.2.1 Sea Birds (<i>Somateria mollissima</i> , <i>Haematopus ostralegus</i> and <i>Larus</i> spp.).....	6
1.2.2 Crabs (<i>Carcinus maenas</i>) and seastars (<i>Asterias rubens</i>)	7
1.2.3 Dogwhelks (<i>Nucella lapillus</i>).....	8
1.3 Microorganisms.....	10
1.4 Biomarkers to detect pollutants.....	11
1.4.1 Biological response	12
1.4.2 Lysosomes	14
1.4.3 Metallothioneins (MTs).....	15
1.4.4 Use of bioindicators in Iceland.....	15
1.4.5 Use of bioindicators caused of industrial activities	18
1.4.6 Use of bioindicators at military places	18
1.5 Dumping sites – the Black box	19
1.5.1 Different ways of handling waste.....	19
1.5.2 Microbial processes.....	20
1.5.3 Dangerous materials	21
1.5.3.1 Arsenic (As).....	22
1.5.3.2 Cadmium (Cd).....	23
1.5.3.3 Chromium (Cr).....	24
1.5.3.4 Copper (Cu).....	24
1.5.3.5 Lead (Pb).....	25
1.5.3.6 Mercury (Hg).....	26
1.5.3.7 Zinc (Zn)	26
1.5.4 Measurements.....	28
1.5.5 Icelandic dumping sites, pollutants and control	30
1.5.5.1 Reykjavík	31
1.5.5.2 Akureyri.....	35
1.5.5.3 Húnaflói Bay	36
1.6 The aim of the study.....	39
2 Materials and methods	40
2.1 Choice of sample subject.....	40
2.2 Sampling.....	40
2.3 Quantification of metals and bacteria.....	41
3 Results.....	42
4 Discussion	44
5 Conclusions.....	51
References	52
Appendices	

Table of figures

Fig. 1 & 2. Open burning cistern at Draugagil	30
Fig. 3 & 4. Different types of waste: Wood, metal, plastics and asphalt at Draugagil	31
Fig. 5 & 6. Car tyres, wood, metal, plastics, electrical appliances at Draugagil	32
Fig. 7 & 8. Inert waste, refrigerator, fishing-net, hay bales, paint at Draugagil	32
Fig 9. Sampling sites: Draugagil (yellow point). Skúlahorn (red point) near the mole at Blönduós	36
Fig. 10. Sampling sites: Draugagil. Dogwhelks and microbial sampling site of leachate.....	37
Fig. 11. Sampling site: Skúlahorn. Dogwhelks collected near the mole	37
Fig. 12 & 13. Waste management: Garbage pushed down to fill Draugagil gully	37
Fig. 14 & 15. Sampling site: Draugagil. Microbial test. Brown leachate seeping from the dumping site	41
Fig. 16. Cadmium concentration in dogwhelk samples from Draugagil and Skúlahorn.....	44
Fig. 17. Copper concentration in dogwhelk samples from Draugagil and Skúlahorn.....	45
Fig. 18. Zinc concentration in dogwhelk samples from Draugagil and Skúlahorn	45

Table of tables

Table 1. Levels of metals in dogwhelks (mg per kg DW) in Ireland (Giltrap <i>et al.</i> , 2012).....	12
Table 2. Concentrations of metals in mussels and sediment in Iceland 1989 to 2010.....	17
Table 3. Worldwide production of heavy metals (Kelly & Matos, 2013).....	27
Table 4. Worldwide anthropogenic emission of heavy metals 1983 (Nriagu & Pacyna, 1988)	28
Table 5. Concentrations of different metals (mean \pm SD) in dogwhelks (Leung <i>et al.</i> , 2005).....	34
Table 6. Conductivity, pH, °C, bacteria number on PCA + HgCl ₂ in leachate (Markúsdóttir, 2011).....	35
Table 7. Levels of metals in sediment and water at Draugagil 1992 to 2012.....	39
Table 8. Physicochemical measurements on 23 th March 2012 in leachate	42
Table 9. Plate counts and coliform in samples collected on 23 th March 2012 in leachate	42
Table 10. Metal concentrations in <i>Nucella lapillus</i> at Draugagil and Skúlahorn 2012	43

Appendices

Appendix I: Blönduós. 4 chemical analysis 1992 to 2012
Appendix II: Report Analysis of waste water Draugagil, registered 2012-10-05
Appendix III: Matís ohf Analysis of leachate Draugagil, registered 02/10/2012
Appendix IV: Matís ohf Analysis of <i>Nucella lapillus</i> , registered 08/03/2012
Appendix V: Matís ohf Analysis of <i>Nucella lapillus</i> , registered 07/08/2012

1 Introduction

In the present study an attempt is made to explain a complex environmental situation at a rocky shore beneath a dumping site, in this particular case at Draugagil southern of the village of Blönduós in North Iceland.

Environments are based on their underlying geology and substrate-sediment type, size, and shape (Smith & Smith, 2009). In coastal environments, where the terrestrial and the marine environments meet, the marine erosion forms different intertidal habitats: emergent rocks and tidepools, where in the latter the environmental conditions for the marine organisms are more stable because they are nearly always submerged by water (Hunt & Scheibling, 1998). The shore communities are structured by the power of the waves, winter storms, ice scouring, freezing and thawing (Cusson, & Bourget, 2005). At the rocky shores a transitional zone is determined by daily, tidal and seasonal temperature fluctuations, desiccation and intensive solar radiation and gives rise to a diverse array of unique ecosystems (Ingólfsson, 2005; Smith & Smith, 2009).

1.1 Filter feeders

Biomagnification is an increase in concentration of a long-lived, mobile, soluble and biologically active pollutant from one item in a food chain to another (Wang & Rainbow, 2008). Bioconcentration occurs, when dissolved materials, that pass through the gills of marine animals, diffuse directly into the tissues of these animals, and concentrates in their fatty tissue. Bioaccumulation means bioconcentration as well as biomagnification (Baird & Cann, 2008). The oceanic primary production depends on marine microorganisms, taking up nutrients from the water column, which contain biologically important trace metals, such as zinc, as well as pollutants from natural sources and anthropogenic activities, for example cadmium (Lane & Morel, 2000). The metal accumulation in aquatic animals occurs when mussels and barnacles filter the water and feed on phytoplankton, as *Amphibalanus amphitrite* on the marine diatom *Thalassiosira weissflogii* does (Rainbow *et al.*, 2004).

At the top of the marine food web are carnivorous mammals such as toothed whales (Odontoceti), and in Icelandic waters harbour seals (*Phoca vitulina*) and grey seals (*Halichoerus grypus*), they feed on birds, which find their food on shore. To the food chain of the intertidal zone belong crabs and seastars, feeding on whelks, which are preying on mussels and barnacles (Smith & Smith, 2009).

1.1.1 Barnacles (*Semibalanus balanoides*)

Barnacles belong to the phylum Arthropoda, the class Maxillopoda, and to the order of the acorn barnacles (Sessilia). Adult barnacles are sessile crustaceans (Buchsbaum *et al.*, 1987). The common barnacle, rock barnacle or common rock barnacle *Semibalanus balanoides* belongs to the family Archaeobalanidae and the genus *Semibalanus*. Synonym for *S. balanoides* is *Balanus balanoides* (WoRMS, 2013b). The species *Balanus crenatus* belongs to the family Balanidae and the genus *Balanus*, like *B. balanus* and the purple acorn or striped barnacle *Amphibalanus amphitrite* do (Marine Life Information Network, 2013).

S. balanoides is distributed in the marine waters of northwest of Europe with a southern limit at Spain (Connell, 1961). The common rock barnacle occurs at the west and east coast of North America. *B. crenatus* is found offshore in the North Atlantic and the North Pacific Ocean (WoRMS, 2013a). *Amphibalanus amphitrite* is a worldwide distributed species in temperate and warm waters (Chan, 2012).

Shells of *S. balanoides* and *B. crenatus* are made of six calcareous plates. *B. crenatus* has a calcareous shell base, but *S. balanoides* has a membranous one. *B. crenatus* grows up to 25 mm in diameter, but *S. balanoides* only to 15 mm in diameter. Barnacles grow crouched to the substrate to withstand wave shock. The lifetime of *B. crenatus* is around one and a half year, but *S. balanoides* may live up to eight years (Castro & Huber, 2005).

Barnacles are cross fertilizing hermaphrodites using extended penis by mating (Kent *et al.*, 2003). All barnacles have typical crustacean planktonic larvae (nauplius) after hatching from the egg. Settling happens after passing through several stages swimming freely in the water column, then the last larval, non-feeding stage (cyprid stage) determines to attach its head end to solid surfaces. Before attaching cyprids explore appropriate sites by “walking” on the surface (Callow & Callow, 2002). The cyprids metamorphoses into a juvenile, often in neighbourhood to other barnacles of the same species (Buchsbaum *et al.*, 1987; Castro & Huber 2005). The habitat and the larval nutritional conditions determine the growth of juvenile barnacles (Thiyagarajan *et al.*, 2005). Cyprid larvae of *S. balanoides* settle more often in sheltered than in ice scour exposed places (Holm & Bourget, 1994). To withstand wave action adult barnacles are cemented to hard substrate, such as rocks, but they also attach to ships or the bodies of other animals like whales, mussels and crabs (Buchsbaum *et al.*, 1987). As epibionts on *Mytilus edulis* barnacles influence the growth of the mussels (Þórarinsdóttir *et al.*, 2007).

The desiccation tolerance of the species, interspecific competition and the risk of predation determine where the barnacles settle (Castro & Huber 2005). *S. balanoides* dominates the

intertidal zone of rocky shores in the boreo-arctic regions (Holm & Bourget, 1994). *B. crenatus* is a common species in the subtidal zone (Buschbaum & Saier, 2001).

Barnacles are suspension feeders, consuming plankton, when immersed in water. Exposed to air during low tide, barnacles are closed and seal in water to avoid desiccation (Castro & Huber 2005). When submerged, barnacles open their plates on the upper surface, extend the feathery feeding appendages (cirri) out of the shell, sweep them as the water and entrap organic fragments and small animals with these movements (Buchsbaum *et al.*, 1987).

1.1.2 Blue mussels (*Mytilus edulis*)

Mytilus edulis belongs to the phylum Mollusca, the class Bivalvia, the order Mytiloida, the family Mytilidae and the genus *Mytilus*. The authority is from Linnaeus, 1758. The species within the genus *Mytilus* include the blue mussel *Mytilus edulis*, the Mediterranean mussel *M. galloprovincialis*, the California mussel *M. californianus*, the bay mussel *M. trossulus* and Korean mussel *M. coruscus* (Gofas, 2012a; Gofas 2013a; Wilson *et al.*, 2011).

Mytilus edulis is widely distributed on the temperate to subarctic coasts of the northern hemisphere: in Europe blue mussels occur from the western shores of France to the White Sea, British Islands and Iceland. On the western coast of the Atlantic Ocean *M. edulis* is found from Canadian shores to North Carolina, in South America the Chilean mussel *M. edulis platensis* (synonym: *M. chilensis*) occurs on the shores of Argentina, the Falkland Islands, Chile and at the Kerguelen Islands in the Indian Ocean (Gofas, 2012; Gofas 2013a).

Mytilus spp. is a common inhabitant of the marine nearshore, blue mussels live attached to hard substrates (rocks, other mussels) and form dense mussel beds in the intertidal zone. *M. edulis* is an important component of coastal ecosystems, regulating biodiversity (Da Ros *et al.*, 2000; Quinn *et al.*, 2012).

The feeding method of *Mytilus* spp. is active filter feeding, they consume mainly dissolved organic matter, bacteria, phytoplankton and detritus. *Mytilus* spp. has separate sexes, the fertilization occurs inside the mantle cavity. Young mussels hatch as pelagic larvae, after the larval stadium they attach with byssal threads in big groups of high density in several layers on rocks at the shore, resulting in overcrowding and often death of the mussels which live in the lowest layers. Then the whole mussel bed is in danger to rip apart by the power of waves and tidal scours from the attachment to the ground (Bell & Gosline, 1996; Thorarinsdóttir & Gunnarsson, 2003). In the bay Húnaflói the settlement of *M. edulis* larvae has a maximum at the beginning of August, about 4 to 8 weeks after spawning (Jónasson *et al.*, 2010).

There is a large variability in the growth rate of *Mytilus edulis*, mainly caused by environmental

factors such as temperature, salinity, availability of food and intra- and interspecific competition for food and space, tidal exposure, parasitism and contaminants. These are also reasons for mortality of *Mytilus* populations, other reasons are dehydration, siltation, action of storms. However, the main factor for mortality of *Mytilus* spp. is predation. Growth can vary from 20 to 30 mm (in 15 to 20 years) to 60 to 80 mm (within 2 years), depending on the ecological as well as genetic factors (Gosselin & Qian, 1997).

1.2 Predators

Community structure is determined by the interactions between preys and their predators, which are organisms consuming other living organisms. The prey population is regulated by predation, and on the other hand the availability of a food source - a prey - influences the growth rate of the predator population (Smith & Smith, 2009).

An other interaction between preys and predators occurs, when migratory birds are distributing parasites, staying a short time at a marine coastal shore. Eider, oystercatcher and gulls are the final host in the life cycle of parasites (Trematoda), and they infect by feeding on molluscs containing sporocysts (Galaktionov *et al.* 2012).

1.2.1 Sea Birds (*Somateria mollissima*, *Haematopus ostralegus* and *Larus* spp.)

The common eider (*Somateria mollissima*) is a large marine duck which belongs to the genus of *Somateria*. It is one of the largest species of the subfamily Merginae, and measures up to 58 cm in length and weighs at average 2.2 kg. *S. mollissima* occurs in the northern coastal areas of Europe, North America, a coastal part of Siberia and the islands in the North Atlantic Ocean. For wintering eiders migrate to southern regions. Eiders reach an age of 10 to 20 years (Adriaens, 2013c).

Eiders breed in colonies at the shore in sheltered areas or on islands nearby. Eiders use their strong wings to dive in water 6 to 20 metres down to the bottom of the sea. There they rip mussels from the ground with their strong bill and swallow their food whole, crushing the shells of their prey in their large muscular gizzards. The food is molluscs, favourly *Mytilus edulis*, crustaceans and small fishes (Wilson *et al.*, 2011; Þórarinsdóttir *et al.*, 2007). In an investigation in spring 2007 to 2010 in the fjord Breiðafjörður in West Iceland, *S. mollissima* presents non-bivalve feeding preferences, mostly catching gastropods (*Buccinum undatum*), chitons (*Tonicella marmorea*) and crustaceans (*Hyas arenarius*) (Kristjánsson *et al.*, 2013). This duck species belongs to a more contaminated foodchain (Olafsdottir *et al.*, 1998).

The oystercatcher *Haematopus ostralegus* belongs to the bird family Haematopodidae.

Oystercatchers occur worldwide at all coasts except the polar region and some tropical coasts (Adriaens, 2013a). In the southwest of Iceland oystercatchers are also resident during winter, in other parts of the country they leave the island in autumn and return in spring to their breeding places. When staying the winter in Iceland, oystercatcher flocks are associated with *Mytilus edulis* beds. Oystercatchers live gregarious except during the breeding time. They reach an age of 10 years. *H. ostralegus* is a wader with long red legs, searching for food in the mud and between the stones at the shore. This black bird with white underneath picks up earthworms, mussels and snails with its strong long red bill. Oystercatchers use two different methods to open the shell of mussels and marine snails, and the bill shape varies according to its diet: they smash the shell to break it, or they hammer on it to crack the shell, always selecting relatively thin shelled prey (Le Rossignol *et al.*, 2011; Nagarajan *et al.*, 2006).

Gulls (*Larus* spp.) belong to the family Laridae. Gulls consume a lot of food which they reach from human activities, for example from waste sites, factory-, slaughterhouse- and sewage-outlets. In nature gulls feed on crustaceans, invertebrates, arthropods, echinoderms, small fishes and spoil the eggs of other birds. The European Herring gull (*Larus argentatus*) is a large gull breeding in Northern Europe (Adriaens, 2013b). *L. argentatus* migrates from the high North during winter, but some birds are permanent residents in Skandinavia. When wintering in cold regions the main diet is marine prey. The Herring gull prefers blue mussel (*Mytilus edulis*) and these gulls break the shell of the mussels by dropping them from height. Herring gulls, collected on the Reykjanes peninsula, are exposed to genotoxic pollution, as an investigation shows. The general DNA adduct level in the liver of herring gulls seems to be higher than the level in fish (Skarphedinsdottir *et al.*, 2010).

1.2.2 Crabs (*Carcinus maenas*) and seastars (*Asterias rubens*)

The European common shore – or green - crabs (*Carcinus maenas*) are native inhabitants of the European shores and coasts of North Africa. Green crabs are living in the littoral zone (Fransen & Türkay, 2013). Crabs feed on everything that is possible to catch and open with its claws: small crustaceans, bivalves, molluscs, polychaetes and worms. *C. maenas* preys on *Nucella lapillus*, and both are competitors for the same prey species, barnacles and *Mytilus edulis* (Castro & Huber, 2005). In the presence of crabs the foraging of dogwhelks is depressed (Quinn *et al.*, 2012).

The common seastar (*Asterias rubens* Linnaeus 1758) is an carnivorous inhabitant of the northeastern coast of the Atlantic Ocean, living as well solitary as gregarious on rock gravel and

sand (Mah & Hansson, 2013). *A. rubens* is a predator on attached and slow-moving animals. Seastars crawl with five arms over the marine ground, searching for small crustaceans, polychaete worms, enchinoderms, carrions, gastropodes, barnacles and bivalves. After opening the bivalve's shell with its tube feet, the seastar guzzles them in their shells by everting its stomach lobes into the mussel, secreting digestive enzymes and consumes their prey. *Asterias rubens* is sensitive to be exposed to air and sunshine, after one hour of increasing temperature the risk of desiccation is getting relevant for seastars. The lifespan of the common seastar is 5 to 7 years (Castro & Huber, 2005).

1.2.3 Dogwhelks (*Nucella lapillus*)

Dogwhelks (*Nucella lapillus* Linnaeus 1758) belong to the phylum Mollusca, the class Gastropoda, to the order Neogastropoda, to the family Muricidae and the genus *Nucella*. The family Muricidae includes two other purple dye snails: the banded murex (*Hexaplex trunculus*) (also known as *Murex trunculus*) and the (spiny) purple dye-murex *Bolinus brandaris* (originally called *Murex brandaris* by Linnaeus). From ancient time these murex snails were caught for human consumption, and a special interest was to harvest the distinctive purple-blue indigo dye, a mucus secreted by the hypobranchial gland (Vasconcelos *et al.*, 2008).

Synonyms by Linnaeus (1758) are *Buccinum lapillus* and *Thais lapillus* (Gofas, 2013b).

Today dogwhelks are distributed all over the rocky shores of Iceland, at least in the east of the island (Ingólfsson, 2009). 100 years ago this species did not live in the north and east, but according to the climate changes dogwhelks have been found in at 0 to 55 m depth at the southern, western and northwestern coast, especially in Húnaflói Bay (Óskarsson, 1962).

Nucella lapillus finds widely distributed in the North Atlantic Ocean. The relation between distribution of species and increasing temperatures offshore of Iceland shows that *N. lapillus* covers now the shores of the western and northwestern part of the country (Ingólfsson, 1996).

Dogwhelks have become common in the intertidal zone in Iceland (Leung *et al.*, 2005).

The maximum size of this marine snail is 25 to 50 mm. Food supply determines the shell colour: Dogwhelks feeding on mussels have a dark pigmented shell, while consuming barnacles results in a light shell colour (Crothers, 1974).

The sexes of dogwhelks are separate, but also self-fertilization is known. After mating the females lay eggs and fix them to the rocks. Dogwhelks have no planktonic dispersal stage and young snails emerge from the capsules (Crothers, 1985b; Matthiessen, 2013).

Dogwhelks can live up to 10 years, spending their lifetime in the same area in short distance from their place of birth, and crawling all their life within a 30 metres radius (Castel *et al.*, 1981;

Crothers, 1985a; Matthiessen, 2013). Observing adult animals Crothers (1985) found them after one year 30 cm far away from the first observed place. With an abundant food supply dogwhelks hardly move at all, only male adults show a little bit more activity at night (Crothers, 1985a).

Abiotic and biotic factors effect the predation rate of dogwhelks. Feeding is influenced for example by the weather, wave action, desiccation stress, the substratum, height on the shore, the presence of algae and physical disturbances. Dogwhelks show a varying feeding behaviour when the environmental conditions change (Hunt & Scheibling, 1998). They forage on barnacles and mussels (Rovero *et al.*, 1999). *N. lapillus* finds its prey by using olfaction, stimulated to feed by the smell of feeding conspecifics (Quinn *et al.*, 2012). The feeding process begins with a phase of inspection before penetration. Two different feeding strategies are used by adult dogwhelks: the bored hole method, when the predator bores a hole in the mussel shell, or the gape insertion method, when dogwhelks use their foot muscles to open the valves of the bivalve and then introduce the proboscis through a gap (Caro *et al.*, 2008). To penetrate through the gaping valves takes less time than to bore a hole. Larger dogwhelks from mussel-dominated shores prefer the gape insertion method to open the mussel's shell, that doubles their feeding rate, compared to boring a hole (Rovero *et al.*, 1999). When the tissue of the prey appears, dogwhelks use narcotization as well as chemical dissolution which they inject to weaken the closing muscles of the prey and to dissolve the calcareous layers of the shell. At the end dogwhelks digest the tissue inside the shell (Quinn *et al.*, 2012). Mussels are almost totally consumed (Rovero *et al.*, 1999).

The way dogwhelks handle their prey is effected by their dietary experience. Snails that are unexperienced of mussels, prefer the bored hole method. These dogwhelks are used to penetrate barnacles by opening the sutures between the skeletal plates. The radular activity of dogwhelks during boring the shells was less from musselcovered shores than from areas, where barnacles dominate (Rovero *et al.*, 1999).

In tidepools small mussels grow, forming dense beds. Small whelks feed on small mussels and the mussel recruitment is regulated by them, while larger dogwhelks can consume larger mussels (Hunt & Scheibling, 1998). Adult dogwhelks show an average consumption of between 15 and 40 mussels per year (Crothers, 1983).

1.3 Microorganisms

Bacterial growth, survival and metabolic activities differ according to environmental conditions, which may be extreme like low or high pH, salinity, temperature, pressure, radiation or desiccation and low supply of available, usable nutrients. The effects on microorganisms can be interactive with other parameters in the environment. Microorganisms can function at the whole range between extreme physiological tolerance limits of temperature, electric field, pH, hydrostatic pressure and salinity (Atlas & Bartha, 1993).

The adaptation to extreme environmental conditions is regulated by accommodated metabolic processes. Microorganisms need stability concerning their cell membrane and cell wall, therefore they regulate the components, the metabolisms and the conditions within their cells (Margesin & Schinner, 1994).

Temperature is limiting for growth, reproduction and survival of microorganisms. The optimal growth temperature for psychrophilic bacteria is below 16°C and they can divide at the lower temperature limit of 0°C. The tolerated range of temperatures for psychrotrophic bacteria range the upper growth limit at 40°C to freezing temperatures with an optimal growth temperature of 20 to 25°C. In nature cold-adapted microorganisms - psychrophilic and psychrotrophic - are distributed widely. They are able to grow at low temperatures, which results of a lot of physiological characteristics. The metabolic rates in cold-adapted bacteria is decreased, but their catalytic efficiencies are more effective than in mesophiles (Margesin & Schinner, 1994).

Without the availability of water bacteria die. Anaerobic conditions are the result of a water content of soils that limits the diffusion of air (Atlas & Bartha, 1993). Other parameters than extreme physical and chemical conditions are heavy metal contaminated environments (Nies, 2000).

Some trace metals in organisms like copper and zinc become strongly inhibitory, when low concentrated in microorganisms. When binding to the sulfhydryl (-SH) groups of essential proteins and enzymes, heavy metals have a toxic effect for microorganisms. An important role play the pH in soil and water and concentration of organic matter in the environment, because low pH causes mobilisation of heavy metals, while high pH reduces the toxicity of heavy metals. Organic matter reduces the toxicity of heavy metals by binding and chelating them (Atlas & Bartha, 1993).

Pollution of the marine environment results in locally high levels of heavy metals.

Microorganisms use different defence strategies against toxicity, which are a combination of

some responses like extracellular precipitation or complexing. The synthesis of metallothioneins, which bind and cut the toxic effect from heavy metals, belongs to the microbial response to extreme environmental conditions (Atlas & Bartha, 1993).

1.4 Biomarkers to detect pollutants

Measuring the pollution impact on the aquatic environment is a question of data collecting. The fundamentals of evaluation of the quantity and source of inputs to the marine environment is measured by the concentrations of the contaminants in marine organisms, in the water column and in sediments (Clark, 1992). Chemical analysis are complemented by evaluation of the biological responses in organisms, on different levels of biological organisation, so called biomarkers (Ericson *et al.*, 2002).

The behaviour after contaminants get into marine organisms is important because they modify and degradate there and they are on their way through the marine food web. Exposure to pollution can be as strong that effects of toxicity in the organisms occur. Data about sublethal responses by marine organisms are elevated by physiological, developmental or behavioural parameters (Clark, 1992).

Nucella lapillus is the most sensitive invertebrate species in detection and monitoring environmental contaminants such as the biocide tributyltin (TBT), an endocrine disrupting chemical that has been used extensively in antifouling paints since the 1960s (Callow & Callow, 2002; Matthiessen, 2013). When exposed to TBT dogwhelks react very sensitive. Imposex is characterized by formation of a penis in females and causes irreversible sterility of the female dogwhelk, when the developed vas deferens overgrows the genital papilla (Skarphéðinsdóttir *et al.*, 1996). These physiological changes are determining the degree of imposex and are measured (Jörundsdóttir *et al.*, 2005). *N. lapillus* exhibits imposex at concentrations of TBT below 1 ng/l (Callow & Callow, 2002), causing local population extinctions. In Iceland restrictions of the use of TBT have been implemented in 1990 (Jörundsdóttir *et al.*, 2005). In 2004 in autumn 50 dogwhelks at the shore of the former dumping site at Gufunes were analysed and the results show the trend of decreasing imposex in these animals (Jörundsdóttir *et al.*, 2005). Since 2008 TBT has worldwide to be completely removed from ship's hulls, but from anaerobic sediments TBT contamination is released over decades to the environment (Matthiessen, 2013).

In 2007 Giltrap *et al.* (2012) studied metal assimilation in dogwhelks at two coastal locations in Ireland: Dublin Bay and Dunmore East Harbour, which is a fishing place. Metal concentrations were analysed in whole tissues of 100 dogwhelks, after have been settled in cages at test locations for 18 weeks, shown in table 1 (Giltrap *et al.*, 2012).

Table 1. Levels of metals in dogwhelks (mg per kg DW) in Ireland (Giltrap *et al.*, 2012)

mg/kg tissue dryweight	As	Cd	Cr	Cu	Hg	Pb	Zn	Authors
Dunmore East Harbour	39.4	24.1	1.0	46.5	0.28	1.32	238	Giltrap <i>et al.</i> 2012
Dublin Bay	42.2	23.7	0.65	15.9	0.16	1.05	204	

Skarphéðinsdóttir *et al.* (1996) found out, that the season of the year is important to estimate the burden of TBT when sampling molluscs. At higher latitudes, for example in Iceland, dogwhelks show higher concentrations of TBT late in summer or early in autumn than in end of winter or spring (Skarphéðinsdóttir *et al.*, 1996). In winter while water temperature and phytoplankton levels are low, dogwhelks live aggregated under rocks and in clefts (Feare, 1970) and are not feeding for about five months. Cu, Cd and Zn concentrations decrease in *Mytilus edulis* throughout the season (Pellerin & Amiard, 2009). This indicates that dogwhelks as well as blue mussels depurate themselves every year (Skarphéðinsdóttir *et al.*, 1996).

1.4.1 Biological response

Metals are taken up and accumulated by all marine organisms, resulting in different body concentrations, depending on metal and species. Marine molluscs accumulate metals from seawater reaching tissue concentrations several orders of magnitude above the seawater levels. The levels of accumulated metals in molluscs depend on abiotic (for example water salinity) and biotic (age, sex, relative tissue composition) factors (Soto *et al.*, 1998).

For the cellular uptake of metals the chemical and physical forms of metals, for example organic and inorganic complexes, hydrated free ions or ion pairs, as a solid or dissolved, are important, though some forms are excluded from uptake in marine molluscs (Marigómez *et al.*, 2002).

For example the availability of metal ions differs with variations in temperature and pH (Marigómez *et al.*, 2002).

The metals are accumulated in two different ways: metabolically available and as stored detoxified metal (Rainbow, 2002). The general route of metals into aquatic molluscs is by uptake of metals bound to particles via food and by the cells of the digestive gland, where most of the accumulated metals are found. When metals are dissolved in water, aquatic molluscs take

metals in via their gills, binding metals to metallothionein and incorporating them into lysosomes. From there they are poured out into the blood plasma and via hemocytes excreted. In the digestive cells metals can be directly released to lysosomes. A third path of metals occurs in specific types of cells for different metals (Marigómez *et al.*, 2002).

The physicochemical form of the accumulated metal in the prey determines its assimilation by consumers from their prey, varying between prey, predator and metals because of the different digestive systems of the predators. Neogastropods show strong digestion and assimilation of Ag and Cd bound in prey (for example *M. edulis*). The metal accumulation patterns of *M. edulis* differ from other bivalves concerning the soluble and insoluble detoxification (Rainbow & Smith, 2010). Different metals can be found in different types of cells, changing with dietary concentration and with exposure time to the metal. In *M. edulis* the gills, the mantle and mainly the digestive gland contain cadmium, lead is found in extracellular deposits in the gills (Marigómez *et al.*, 2002).

Rainbow *et al.* (2004) show that differences in physiological metal accumulation patterns of mussels and barnacles result in extreme lack of insoluble detoxification, when barnacles are exposed to high levels of Ag and Cd. The major route of Ag and Cd uptake in barnacles is via plankton (Rainbow *et al.*, 2004) and detoxification of incoming metals are done by sequestering them into the insoluble form of metal-rich granules (Wang & Rainbow, 2008).

The shore crab *Carcinus maenas* shows a physiological response to decreased salinity by decreasing the apparent external epithelium permeability to water. The Cd and Zn dissolved uptake depends on the relationship between the changes in permeability and reduced salinity. *C. maenas* shows no difference in metal uptake between the crab has been collected from contaminated or uncontaminated sites (Wang & Rainbow, 2008).

The netted whelk *Nassarius reticulatus* (L.) is an marine prosobranch gastropod, found in the Atlantic Ocean, the Mediterranean and the Black Sea (Gofas, 2012b). *N. reticulatus* has been used as a bioindicator of tributyltin (TBT) in Europe. As an indicator for mercury contamination this species shows the highest concentrations of organic mercury in the tissue while feeding on carrion in the least contaminated areas. In a study by Coelho *et al.* (2006), organic mercury was detected in the range of 52% to 88% of total mercury in *N. reticulatus*, though no organic mercury was detected in the sediments. This is the result of biomagnification of mercury in *N. reticulatus* from its dietary in the trophic web (Coelho *et al.*, 2006). Pempkowiak *et al.* (1999) researched mussel and sediment samples from the Norwegian and the Baltic Sea and found that the concentrations of heavy metals in mussels and sediment correspond to each other according to the contamination of the sampling site (Pempkowiak *et al.*, 1999).

Metal analyses in biological monitoring programmes can use the whole organism of a mollusc or a part, for *M. edulis* this means to take the suspended particulate matter of the animal or either the soft tissues or the shell of it. The inner nacreous shell of *M. edulis* shows bioavailability of lead strongly correlated with the tissue concentration, when lead contamination is present. But other biophysical parameters such as the age and size of the mussel as well as the littoral zonation of the shore affect lead concentrations in *M. edulis* (Bourgoin, 1990). The size of mussels is directly associated to their age and is affecting the response of organisms to environmental stress. Reduction of oxygen and increased temperature affect older mussels more than younger ones and show different parameters in the cells and lysosomes of the digestive gland (Raftopoulou & Dimitriadis, 2012).

Effects of complex mixtures of low concentrated chemicals are determined by the Integrative Biological Response index. In an integrated biomarker approach the health of the mussels is checked and significant sublethal responses in *Mytilus edulis* are found though each chemical compound is very low concentrated in mussel tissues as well as in the water. Therefore this is the best way to monitor pollution in aquatic ecosystems (Brooks *et al.*, 2011).

1.4.2 Lysosomes

An important component of the endomembrane system in the eukaryotic cells are lysosomes, which are organelles, found in the cytoplasm of animal cells. These membranous-enclosed sacs contain active hydrolytic enzymes to digest food particles. In intracellular digestion the engulfed food particle in the food vacuoles has fused with lysosomes (Campbell *et al.*, 2008). Lysosomes participate in detoxification and excretion of pollutant (Da Ros *et al.*, 2007).

Many natural factors such as food availability, reproductive stress, changes in salinity and temperature and the tidal cycle affect molluscs as well as contaminants like heavy metals do (Lekube *et al.*, 2000; Marigómez & Baybay-Villacorta, 2003). High correlation is between high cadmium concentration in molluscs and high salinity (Apeti *et al.*, 2009). The chemical contaminants are particularly accumulated in the digestive cells of the digestive gland in the hepatopancreas by bivalve molluscs (Da Ros *et al.*, 2007). Lysosomes show response, when exposed to environmental stress: their content changes, the volume and size increases, and their number changes (Etxeberria *et al.*, 1995). The membranes destabilize and membrane permeability occurs (Krishnakumar *et al.*, 1994). The lysosomal response to exposure to contaminants can be measured and enlargement and membrane destabilisation are used as biomarkers (Marigómez *et al.*, 2006). Changes in lysosome content, volume density and the

labilisation period describe the tolerance of mussels to environmental stress (Izagirre & Marigómez, 2009).

1.4.3 Metallothioneins (MTs)

Detoxification of cells from heavy metal cations occurs by different mechanisms such as compartmentalization into lysosomes, accumulation in granules or membrane-bound vesicles. In the soluble phase metals are bound to metallothioneins and specific ligands (Viarengo *et al.*, 1993).

Metallothioneins are a type of metal-binding proteins and polypeptides, that have been used as marine biomarkers in bivalve molluscs in biological monitoring programmes such as OSPAR (Commissions of Oslo and Paris) and ICES (International Council for the Exploration of the Sea) because of the biological responses to contaminants from anthropogenic pollution (Atlas & Bartha, 1993; Leung *et al.*, 2005; Roesijadi, 1994). MTs are of low molecular weight, cysteine rich intracellular proteins without aromatic amino acid residues. MTs have a high affinity capacity for heavy metal cations, each molecule can contain 7 to 12 metal atoms (Baird *et al.*, 2006; Takahashi, 2012; Viarengo *et al.*, 1993). They regulate the concentration of free heavy metal ions in the cell and detoxify non-essential toxic metals. MTs bind essential metals such as Cu^{2+} , Zn^{2+} and toxic metal ions such as Cd^{2+} and Hg^{2+} (Leung & Furness, 1999; Viarengo *et al.*, 1993).

Various factors influence the level of MT induction in bivalves, some of them are natural properties, such as size and age, growth rate, nutritional and reproductive state, prey type, temperature and salinity. Anthropogenic factors, which affect MT induction, can be exposure to heavy metals and other pollutants. In *Nucella lapillus* the growth rate as well as the dietary metal uptake and the presence of other MT-inducing chemicals can lead to differences between the patterns of metals and MT distribution (Leung *et al.*, 2005).

1.4.4 Use of bioindicators in Iceland

In Iceland in 1971 the students and teachers of Marine Biology at the Department of Biology at the University of Iceland started to research the tidal biota in field investigations, at a shore near Reykjavík, away from sewage outlets and other visible anthropogenic impacts to the environment (Ingólfsson, 1999). In the same year the “Icelandic Group” (Sölumiðstöð hraðfrystihúsanna) needed the certification of low mercury contamination in fish for the export to Italy and bought a Coleman MAS 50 Mercury Analyzer for the detection of pollution in food by the Icelandic Fisheries Laboratories (Arnesen, 1976; Arnesen *et al.*, 1986).

For the construction of the canalisation in Reykjavík the impact of sewage outlets on the biota at the shore was measured in 1976 - for the first time in Iceland (Gunnarsson & Þórisson, 1976).

Gíslason (1980) discovered the anthropogenic impact of populated areas to the fauna of two thermal rivers in the districts Mosfellssveit and Ölfus (Gíslason, 1980).

Jónsson (1976) investigated the effect of unfiltered and uncleaned sewage to the macrofauna in the fjord Skerjafjörður. The results show that the number of species decreased towards the sewage outlets. Near the outlets a repetitive biota was found and *Mytilus edulis* was the dominant species on hard bottom there, the mussel density near the outlets was much more than in other places (Jónsson, 1976). The use of *Mytilus edulis* as an accumulator of metals in mussels to detect pollution in the sea around Iceland began in 1978 (Ólafsson, 1983; 1986). By accident polychlorinated biphenyl (PCB) was released into local canalisation in the Eastfjords, therefore Ólafsson and Jónsson (1988) researched blue mussels nearby, additionally old dumping sites, where PCB filled transformers were dumped, but they were not found again (Ólafsson & Jónsson, 1988).

An evaluation of water quality of the ocean around Iceland was performed 1991 and 1992.

Gadus morhua, *Limanda limanda*, *Clupea harengus* and *Mytilus edulis* were collected to analyse heavy metals, persistent organic pollutants such as dichlorodiphenyldichloroethylene (DDE), polychlorinated biphenyl (PCB) and hexachlorobenzene (HCB), radioactivity (^{137}Cs , ^{134}Cs), nutrients (Si, NO_3 , PO_4) and salinity in water, sediment and biota.

The concentration of metals in tissue depends on the natural amount of metals in the environment, effects from other natural environmental properties for example temperature and nutrients, but also physiological parameters and seasons and the impact of anthropogenic activities (Jóhannesson *et al.*, 1995; Leung *et al.*, 2005). The monitoring results (shown in table 2) are explained by geological conditions, where for example unusual high levels of copper may be caused of strong vertical currents at the Icelandic continental shelf, resulting in mussels generally accumulating more cadmium, copper and zinc around Iceland than elsewhere (Jóhannesson *et al.*, 1995; Leung *et al.*, 2005).

Table 2. Concentrations of metals in mussels and sediment in Iceland 1989 to 2010

mg metal/kg dryweight	As	Cd	Cu	Zn	Authors
<i>Mytilus edulis</i> Grímsey	14.4	3.64	7.19	314.58	Jörundsdóttir <i>et al.</i> , 2012
<i>M. edulis</i> Arnarfjörður		12.67	5.95	101.5	Gunnlaugsdóttir <i>et al.</i> , 2007
Sediment in Arnarfjörður		0.3	58.08	52.3	Gunnlaugsdóttir <i>et al.</i> , 2007
<i>M. edulis</i> 1989 to 1992	1.02 - 8.8	4.8-24.6	62 - 415		Jóhannesson <i>et al.</i> , 1995
Sediment	0.23 - 0.74	47 - 112	130 -240		Jóhannesson <i>et al.</i> , 1995

The Icelandic Fisheries Laboratories started 1986 to monitor annually the marine biosphere around Iceland to fulfill the OSPAR and AMAP (Arctic Monitoring Assessment Program) agreements by measuring metal concentrations and organochlorines in *Gadus morhua* and *Mytilus edulis* (Yngvadóttir & Halldórsdóttir, 1998). Nowadays the investigation is done by *Matis - Food Research, Innovation & Safety* and the collected data is submitted to the ICES databank (International Council for the Exploration of the Sea).

Fresh and frozen tissue of mussels contain 82.1% water, 10.4% protein, 3.4% carbohydrate, 2.5% fats and 1.2% minerals (Cu 0.3 mg, Fe 3.4 mg, Zn 9.3 mg per 100 g). By consuming 100 g of raw mussels the trace elements copper and zinc fulfill the human daily need by 33.33% for Cu and 103.33% for Zn (Matís, 2013). Therefore the in table 2 shown levels of the tissues of blue mussels from Grímsey, collected 2010 (Jörundsdóttir *et al.*, 2012) contain 2.3 fold of Cu and 3.3 fold of Zn than the general informations about the content of mussels accept as daily dose (Matís, 2013). Higher levels of Cd and Zn (Table 2) in the waters of midnorth of Iceland may be caused by small-scale and large-scale effects of the Icelandic Coastal Current, which transports water clockwise from the southwestern corner of Iceland to the area of the northern coast (Jóhannesson *et al.*, 1995; Leung *et al.*, 2005; Óskarsson *et al.*, 2009).

Because of increasing levels in 2007 an extra research was started to find the explanation for high cadmium levels in *M. edulis* (shown in table 2) from the fjord Arnarfjörður in the Westfjords.-The so called “general cadmium anomaly” of the Arctic Sea is considered to be caused by natural properties, but the accumulation of metals in sediment (shown in table 2) is not verified by the investigation 2007 (Gunnlaugsdóttir *et al.*, 2007). However, the increased cadmium levels in *M. edulis* are assumed to be of natural origin since “no anthropogenic source is known” (Jörundsdóttir *et al.*, 2012). During a study of concentration of metals in liver and kidney of young lambs in 1991 and 1992, samples from the same region showed the highest

concentration of cadmium compared to values from other parts of Iceland, though this area is far away from the impact of volcanic activities (Reykdal *et al.*, 2000).

1.4.5 Use of bioindicators caused of industrial activities

First in 1978 environmental researches on heavy metals, using blue mussels as bioindicator, began short before a ferro-silicon plant at Grundartangi in the fjord Hvalfjörður started.

Ólafsson (1983) mentions the advantages of using blue mussels as a bioindicator to assess environmental conditions. Samples of *Mytilus edulis* were collected from southwest Iceland to measure 9 heavy metals in mussel tissue. The results were, that the pollution from lead in gasoline and paint, and mercury pollution were observed in mussels from Reykjavík and its vicinity. Higher levels of mercury was evaluated in the fjord Hvalfjörður, and this result was considered to be caused by organic residues from the whaling station (Ólafsson, 1983).

In the operating licences of aluminium smelters in Iceland a periodic monitoring of the concentrations of various substances inside and outside the operating area is required. The environmental impact on the marine ecosystem, including the pollution in marine sediments and marine organisms, as well as the bioavailability of chemicals in blue mussels nearby have been checked regularly (Ingólfsson & Steinarsdóttir, 2002; Ingólfsson & Svavarsson, 1995; ISAL, 2002; Svavarsson, 2002).

1.4.6 Use of bioindicators at military places

The Civil Protection and Emergency Management in Iceland started a risk assessment of soil pollution and published the results, that the counties Borgarfjörður, Dalir, A-Skaftafellssýsla, the municipal Eskifjörður and the area of Hvalfjörður contains dangerous residues. Around the fjord Hvalfjörður are traces of the military occupation during World War II and later of the U.S. defense forces, but the area has not been studied to date, although naval mines have been found on beaches, and on the hill Heiðarfjall near Húsavík is a discarded military base that has not been cleaned yet. Another military base was on Stokksnes near the fjord Hornafjörður and PCB (polychlorinated biphenyl) contamination has been confirmed in an old garbage pile there (State Police Commissioner, 2012). The rough periwinkle (*Littorina saxatilis*) is a common inhabitant of the shores of Iceland since the last glacial period (Panova *et al.*, 2011) and has been found at water depth down to 62 metres (Ingólfsson, 1996; Óskarsson, 1962). The research of a point source of PCB at the former radar station at Stokksnes evaluated the ratio of PCB and DDE in the tissue of *Littorina saxatilis*. The results show a higher value in the vicinity of the former

dumping site than at other places (Ólafsdóttir, 2002; Bergur Sigurðsson, former local health inspectorate at Suðurnes, 21th of February 2012, personal communication).

In 2009 Lehtinen (2010) worked with earthworms (*Eisenia foetida*) to bioaccumulate the PCB mixture “Arochlor 1260” from the soil of the old NATO facilities in Keflavík. In her research Lehtinen measured the PCB concentration in earthworms and utilized them to bioremediate the PCB pollution on the area at Reykjanes peninsula, which had been ruled by NATO for decades (Lehtinen, 2010).

1.5 Dumping sites – the Black box

Waste management has become an important issue in Iceland, and at the Icelandic universities some final papers have been published about it. To mention particularly the landfill gas production and the leachate from old landfills as well as energy recycling instead of dumping organic byproducts from animals have been researched by graduates of environmental resources and engineering (Guðmundsdóttir, 2011; Júlíusson, 2011a; 2011b). Students of Natural Resource Sciences and of the Faculty of Education, Law and Social Sciences discuss the waste problem (Markúsdóttir, 2011; Sturluson, 2011). The handling of waste has become subject of folklife studies, to cover a topic on foodrecycling and foodsharing (Þorsteinsdóttir, 2012).

1.5.1 Different ways of handling waste

One basic concept related to waste management is the waste hierarchy: Most desirable is the reusing and recycling to avoid the forming of waste. In the case of forming unusable products, in Europe the incineration of waste with the aim of energy recovery is preferred (Umhverfisstofnun, 2010). In the ecosystem of landfills microorganisms are important participants in waste treatment as biodegraders of organic matter and they play an significant role in the nutrient cycle (Atlas & Bartha, 1993).

Decomposition of waste in municipal landfills occurs in three stages, where plastics, rubber and the synthetic waste are slow to degrade and only food and yard waste are biodegradable. In the first, the initial oxic stage, aerobic degradation takes place which means, that mainly organic compounds are hydrolysed and fermented, resulting in hydrogen, carbon dioxide and volatile fatty acids as reaction products (Jonsson *et al.*, 2003a; 2003b). This carbon dioxide acidifies the leachate which enables it to dissolve metals, that might be in the waste too (Baird & Cann, 2008). In the second, the anaerobic stage acetogenic microorganisms are active, transforming fatty acids and alcohols into hydrogen, carbon dioxide and acetic acid (Jonsson *et al.*, 2003a, 2003b). Now the leachate acidifies even more, and the concentration of heavy metals in the

leachate is very high. The biological oxygen demand (BOD) in the leachate is also very high at this stage (Baird & Cann, 2008).

In the third, the methanogenic stage the biodegradation intermediates are the substrates for methane production. Acetotrophic and hydrogenotrophic methanogens produce methane.

The final oxic degradation stage occurs after depleting the substrates in the methanogenic phase (Jonsson *et al.*, 2003a; 2003b). The pH rises to 7 or even 8 as the organic acids are consumed by bacteria, the heavy metals dissolve less with high pH, the concentration of heavy metals in the leachate drops, and the BOD decreases. The optimal conditions for biodegradation are the presence of appropriate microorganisms in a physical susceptible waste, and environmental conditions such as appropriate pH, temperature and oxygen level (Baird & Cann, 2008).

Landfill is the least preferable environmental option, not at least because of the large land use of landfills (Petursson, 2003). Another environmental impact of landfills is caused by leachates, when water is passing through the waste and transports organic and inorganic compounds, for example heavy metals, to the base of the landfill cell, where the liquid collects or is leaking out. The precipitation comes from rain, melted snow or the waste itself (Ward & Robinson, 2000). From 1950 to 2001 the average annual precipitation at Hjaltebakki and Blönduós has been measured approximately 450 mm (Anon., 2012) and the landfill together with the dumping site is estimated to be a 70,431 m² large area (Svavarsson, 2007; Registers Iceland, 2013), that means 0.450 x 70,431 m³ water running through an area at this size every year: 1 litre per second goes to the ground and to streaming waters, flowing into the sea, after it has been in contact with the dumping site and former landfill. Generally, most of the waste in Iceland, that is produced and not recycled, ends in landfills or in incineration. In former times much more waste was burned than buried in Iceland (Kamsma & Meyles, 2005).

1.5.2 Microbial processes

Human activity affects the quality of coastal waters by dumping of waste, releasing wastewater and municipal sewage. Inputs of terrestrial and freshwater microorganisms affect also the water quality. The natural bacteria flora reflects its environment and microorganisms are adapted to their habitats. Soil is a very competitive environment where physicochemical conditions can vary and soil is a rich source of bacteria, that recycle organic and nitrogenous compounds (Ward & Robinson, 2000).

In the marine environment filterfeeding sessile animals such as barnacles and blue mussels grow in coastal waters, and may be contaminated with sewage from urban area (Adams & Moss, 2008). Markúsdóttir (2011) evaluated the water quality at three marine environments in

Northern Iceland: Hvammstangi in Northwest Iceland, Ólafsfjörður in North and Reyðarfjörður in East Iceland. Her research reflects the anthropogenic impact of unfiltered sewage at Hvammstangi and Ólafsfjörður. In a sample of the seashore fauna, collected close to the sewage outlet at Hvammstangi in January 2011, surfactants in *Mytilus edulis* and *Semibalanus balanoides* were detected (Markúsdóttir, 2011).

The contamination with pathogenes and parasites influence the health of the animals and their response to stress by heavy metals and vice versa. Filter feeders such als *S. balanoides* and *M. edulis* live at risk to incorporate microorganisms with deleterious effect according to their pumping rate of water (Adams & Moss, 2008).

1.5.3 Dangerous materials

Heavy metals, non-biodegradable plastics and persistent synthetic chemicals belong to the pollutants, which are only transported in the environment from one place to the other, but stay in the environment. In a system some individual effects act synergistically when the combined effect of them is greater and/or different than their sum (Baird & Cann, 2008).

Persistant Organic Pollutants (POPs)

The largest volume of PCBs was produced until the 1970s and a wide range of industrial applications used PCBs, until the manufacturing, processing and importing of PCB was banned, because PCBs are highly resistant to degradation. PCBs pass up the food chain because they are lipophilic and bioaccumulate in cells. Uses of PCBs was in carbonless copy paper, inks, dyes, waxes, surface coatings, adhesives, pesticides, as lubricants for pumps and turbines, dielectrics in capacitors, heat exchange liquids, oil in transformers and hydraulic fluids in hydraulic equipment and tools (Borja *et al.*, 2005).

Many commercial used products in households, industry and medicine are made by polyvinylchloride (PVC) plastics, which are plasticised by phthalic acid diesters. Other types of plasticizers to improve the processing properties of the rigid polymer PVC are aliphatic carboxylic acid esters, polyesters, phosphates and epoxids (Mersiowsky *et al.*, 2001). Products with the mostly used PVC made flexible by phthalic acid diesters are toys, cosmetics, fragrances, paints, cable insulation, pesticide carriers, insect repellants, medical and packing materials (Jonsson *et al.*, 2003a; 2003b).

Goods are covered packing materials during transport and storage. The waste types are metallic and non-metallic wastes. Mixed metallic packaging are for example steel oil drums and aluminium cans. Non-metallic waste comes from glass, wood and plastic, paper and cardboard packaging, the latter made more than the majority of the waste amount in 1995 in Iceland. From

agriculture comes plastic waste such as pallets, films and foil, the fishing industry delivers bottles, bags, sacks, boxes, crates, tubs and barrels to the deposit sites. In packaging waste concentration levels of heavy metals are present (Kamsma & Meyles, 2005).

Under “normal” landfill conditions anaerobic bacteria generate organic acids from organic matter in the second stage, the pH drops, heavy metals become more soluble and the leachate contains high heavy-metal concentrations. This stage should be finished after six to twelve months. If the dumping site contains heavy metals, they will be leached into the environment (Baird & Cann, 2008). Dumping sites do contain organic matter together with heavy metals and cannot be described in stages like landfills (Bjarnadóttir *et al.*, 2008). Because of this facts, the most hazardous heavy metals are pointed out, to know what kind of danger we have to deal with.

The heavy metals arsenic (As), cadmium (Cd), chromium (Cr), lead (Pb), and mercury (Hg) belong to the ten most hazardous substances for the environment, because of their high toxicity, their extensive use, because of their abundance, and their continuance (WHO, 2010a). As they are not used equally all over the world, they all have been found only at some places at a toxic amount (Baird & Cann, 2008). The reasons of this toxicity are not always anthropogenic, in areas with “uncontaminated” soils derived from ultramafic rocks, plants can contain toxic amounts of chromium (Schachtschabel *et al.*, 1992).

Heavy metals occur as ores often together with other heavy metals. For example, the mineral smithsonite (ZnCO_3) can contain up to 5% of cadmium, and also other heavy metals. To get the zinc from this ore is a complicated process, because the ore must be heated to 1,200 to 1,400°C, and the evaporation temperature for zinc is 906°C. In this process cadmium must be recovered from airborne ashes, allowing part of it to escape into the environment as can be seen in the study of Nriagu & Pacyna (1988). The same problem occurs, when metals which are coated with heavy metals are recycled, or when heavy metal alloys are recycled. To recycle just zinc from coated iron, many processes are possible, but they all use materials such as Cl_2 , HCl , NaCN or NaOH (Römpf, 1966).

1.5.3.1 Arsenic (As)

Arsenic is a heavy metal and a metalloid with a density of 5.73 g/cm^3 and belongs to the 15. group of the periodic table together with nitrogen, phosphorus, antimony and bismut. The abundance of arsenic in the earth's crust is only about $5.5 \times 10^{-4} \%$. Arsenic occurs in many allotropes in metallic and non metallic forms and oxidation states of -III, 0, +III and +V. Grey crystals of the pure element occur (Der Brockhaus, 2003).

Arsenic has been used by poisoners for thousands of years. The most toxic arsenic compound is arsenic trioxide, 0.1 g can be a lethal dose for an adult (Römpp, 1966). The arsenic concentration in drinking water is a serious problem in many countries and in table 4 the limits for arsenic intake via drinking water per week are shown (WHO, 2010b).

Arsenic is mainly used for alloys for example for lead batteries of cars, for copper coolers in cars, in the woodpreservative “chromated copper arsenate” (CCA), glass production, and for semiconductor technology.

1.5.3.2 Cadmium (Cd)

Cadmium is a heavy metal with a density of 8.65 g/cm^3 . The chemical behaviour of cadmium and zinc is similar, both metals are in the 12. group of the periodic table together with mercury. Cadmium is found in the earth's crust only about $5 \times 10^{-5} \%$, so that the „natural“ concentration of cadmium is 0.5 ppm on average. In the case of cadmium there are no big changes of this value because it does not exist like many other metals in mines. It is almost entirely derived from zinc ore or zinc dust, usually by electrolysis, but also by distillation (Der Brockhaus, 2003).

Cadmium was used in large quantities in control-materials for nuclear fission, because it can slow down fast neutrons. It is used in bearing alloys because of its low friction coefficient, also used in electroplating, because a 0.008 mm thin layer is sufficient to prevent corrosion (Römpp, 1966). Car tyres exposure cadmium to air and soil (Schachtschabel *et al.*, 1992). Galvanised pipes, metal fittings and some types of solders contain cadmium, and Cd is used in alloys with low melting points, such as for electrical fuses (UNEP, 2010).

Some cadmium compounds are still used in paints, CdS is a yellow pigment, cadmium compounds are also used in some red and green colours. Cadmium is also used in some plastics for life extension and in all types of components in electrical equipment, such as optical sensors, semiconductors, laser devices and some sorts of solar cells (Der Brockhaus, 2003).

Cadmium accumulates mainly in the kidney and liver of all vertebrates. It is highly toxic to humans and causes damage to the kidneys, lungs - even fatal, osteoporosis (itai-itai disease in Japan in the past), and cancers of the lung, kidney and prostate gland (UNEP, 2010). The human exposure is most from food: the daily oral intake of cadmium is 10 to 35 μg (WHO, 2011). Tobacco smoke also contains significant amounts of cadmium (UNEP, 2010). The annual average for air shall not exceed 5 ng/m^3 (WHO, 2010c).

In Iceland the exposure of cadmium is most in young male persons, their average daily intake is $12.7 \mu\text{g}$. The average dietary intake by men in Iceland is $10.8 \mu\text{g}$ per day, woman take with food daily $7.9 \mu\text{g}$ cadmium in (Steingrímssdóttir *et al.*, 2002) and the human exposure is mostly from

imported goods (Reykdal *et al.*, 2000). Cadmium can accumulate in both animals and plants, especially vegetables and mushrooms with an exposure up to 4,000 mg cadmium/kg dryweight. If the cadmium concentration in fertilizers exceeds 10 mg/kg DW, it has growth inhibitory effects (Der Brockhaus, 2003). Phosphorus fertilizer contains at average 40 mg cadmium/kg P_2O_5 (Schachtschabel *et al.*, 1992).

1.5.3.3 Chromium (Cr)

Chromium is a heavy metal with a density of 7.18 to 7.20 g/cm³. It belongs to the 6. subgroup of the periodic table. The abundance of chromium in the earth's crust is about 0.02%. (Der Brockhaus, 2003).

Chromium hardly exists in pure form in nature, it is unsoluble and because of that not dangerous in this form. It can have oxidation states from +II to +VI, the common states are +III and +VI. 4 to 10 g of potassiumdichromate - $K_2Cr_2O_7$ with the Cr(III) ion – is lethal for human, however compounds with Cr(VI) ions are a 100 times more poisonous (Römpf 1966), they are even suspected to be carcinogen, whereas compounds with Cr(III) are essential for animals and humans, but not for plants (Schachtschabel *et al.*, 1992) and used as a nutrient. Cr(VI) ions are more soluble and more mobile than Cr(III) ions, for example the chromate ion can easily enter cells of organisms, where it can oxidize DNA and RNA bases (Baird & Cann, 2008).

It is used for making stainless steel, for electroplating, for corrosion protection, for all kinds of paint, for wood preservation with chromated copper arsenate (CCA) and for leather tanning (Schachtschabel *et al.*, 1992). When it is emitted during the production processes, chromium becomes a water pollutant and under hazardous waste sites it is the second most inorganic contaminant of groundwater (Baird & Cann, 2008).

1.5.3.4 Copper (Cu)

Copper is a heavy metal with a density of 8.96 g/cm³. It belongs to the 11. group of the periodic table. The abundance of copper in the earth's crust is about 0.005 % and it exists not rarely in pure form in nature, it is nearly insoluble and because of that not dangerous in that state. It is found in oxidation states from +I to +IV, most common is +II (Der Brockhaus, 2003).

Whereas copper is an essential trace element for humans, animals and some plants, the Cu^{2+} ion is highly toxic for microorganisms in soil and water, for some of them it is the most toxic element. Humans have to take up 2 mg of copper daily, their bodies contain in the range of 100 to 150 mg of copper, but higher doses are toxic (Der Brockhaus, 2003). Lethal dose of copper for the algae *Spirogyra* is a copper concentration of 0.001 ppm (Römpf, 1963).

Copper is used for making cables, pipes, sheet metal, electric and electronic equipment, for wood preservatives and alloys for example for making coins (Der Brockhaus, 2003).

1.5.3.5 Lead (Pb)

Lead is a heavy metal with a density of 11.35 g/cm^3 . The abundance in the earth's crust is about $1.8 \times 10^{-3}\%$. The element has been known for 2,500 years, and there are lead mines in many countries, mostly in China (Der Brockhaus, 2003).

Lead is used in large quantities for storage batteries, ammunition, fishing gear, boat keels, as protection against radiation in laboratory and for therapeutic purposes, in the coating of underground- and underwater cables, in some types of solders as additives in polyvinyl chloride (PVC), in some glass types and much more. Lead has been used as an additive in gasoline for many years, but in most countries it has been replaced by other pollutant materials such as methyl tert-butyl ether (MTBE), and lead in anti-rust paint has been replaced too in many cases (UNEP, 2008).

Lead is taken up by breathing or through digestion. When lead enters the human body, it is distributed in the brain, liver, kidneys and bones, it accumulates in teeth and bones and can be detected in the blood. Most toxic are organic compounds (tri-alkyl-lead, tetra-alkyl-lead). Both acute toxication from high doses and long-term toxication-effects from low doses of lead occur. Symptoms of lead-toxication are tremor, twitching, seizures, muscle soreness, fatigue, pain in the joints, weakness, lack of coordination and visual disturbances. Other effects are loss of appetite, weight loss, nausea, vomiting anorexia and abdominal pain. Hypertension occurs, and irritability, hallucinations, lack of motivation, little will of cooperation, headaches, sleep disturbances, confusion, coma may be effects of lead on the nervous system (WHO, 2010d). Children younger than 5 years old take up 4 to 5 times more lead compared to adults, as well as pregnant women are belonging to a risk group. Lead affects the nervous system, and if the level in young children reaches $50 \mu\text{g lead/l blood}$ or more, it can cause brain damage, behaviour problems, anemia, liver and kidney damage, developmental delay or disabilities and can in worst cases lead to death. Lead can affect male fertility and long term uptake of lead is under suspicion of causing cancer. WHO (2010d) states that the lead uptake in 2004 has led to the death of 143,000 people, and that lead has caused 0.6% of all disease cases in the world (WHO, 2010d). In surface water lead is bound to organic particles up to two years, and is also stable in soils. Soil erosion and uncontrolled waste disposal leads to the fact that lead is found in surface water (UNEP, 2008).

1.5.3.6 Mercury (Hg)

Mercury is a heavy metal with a density of 13.53 g/cm^3 . It belongs to the 12. group of the periodic table together with zinc and cadmium. The abundance of mercury in the earth's crust is only about $4 \times 10^{-5} \%$ (Der Brockhaus, 2003). Mercury is the only metal that is liquid with standard conditions for temperature and pressure, most volatile of all metals, and one of the rarest elements on earth. In the continental crust it occurs on an average of 0.02 ppm (Römpf, 1961). Mercury has been used in thermometers, manometers, sphygmomanometers, barometers, float valves, switches (for example car trunks), fluorescent lamps and many other devices, also batteries, paint and dental fillings (Barkay *et al.*, 2003). Because of its high toxicity it has been eliminated or been reduced in these products. It is also used in many industrial chemical processes.

Mercury vapour can easily cross the blood–brain barrier to the brain if inhaled, because it consists of uncharged atoms. This can cause serious brain damage, whereas liquid mercury itself is not that toxic, and most of it is excreted after it was swallowed. Mercury salts mainly damage kidney and liver and can also cause damage to the central nervous system, but less than the vapours of mercury do (Baird & Cann, 2008).

Methylmercury is even more toxic than all inorganic covalent compounds of Hg^{2+} , it is the most hazardous form of mercury. The reason is great intestinal absorbance, bioaccumulation in animal fat tissue and mobility of the compound (UNEP, 2013). It also causes brain damage in humans. In fish and humans methylmercury is the main part of the mercury contamination, it can be 80% of all the mercury in fish, and fish is the main source for methylmercury in humans (biomagnification). Big and old fish can contain more than 1 ppm methylmercury (Baird & Cann, 2008). Plankton takes up easier methylmercury, it can contain up to 10,000 times greater levels of mercury than those in the water around it (UNEP, 2013).

Methylmercury occurs either in the form of CH_3HgX , where X is Cl, OH and other molecules, or in the form of $(\text{CH}_3)_2\text{Hg}$, dimethylmercury, which is a very volatile liquid. All these compounds are formed by anaerobic bacteria and microorganisms on the ground of rivers and lakes, and more methylmercury than dimethylmercury is formed under acidic or neutral conditions in the water. In the U.S. it is recommended that methylmercury in fish in the human diet should be below 0.3 ppm (Baird & Cann, 2008).

1.5.3.7 Zinc (Zn)

Zinc is a heavy metal with a density of 7.14 g/cm^3 . It belongs to the 12. group of the periodic table of elements. The abundance of zinc in the earth's crust is about 0.012 % and it does not

exist in pure form in nature. The only oxidation state is +II. Because it is an activator for many enzymes, zinc is an essential trace element for humans, animals and some plants (Der Brockhaus, 2003). Humans have to take up 15 to 20 mg of zinc daily (WHO, 2011), nearly 200 enzymes are containing zinc. Because of its „metallic taste“ drinking-water that contains more zinc than 3mg/litre is not acceptable for humans (WHO, 2003). Solutions with concentrations of zinc more than 100 ppm are toxic for most plants (Römpp, 1966). There are not known many events of zinc poisoning, in the cases when it happened, the intake was 4 to 8 grammes (WHO, 2003). Zinc is used for making wires, pipes, sheet metal, for galvanising of metals, for batteries and for alloys for example for making coins (Der Brockhaus, 2003).

Copper has been used for more than 8,000 years, zinc and lead also for thousands of years. These amounts have been blown into the atmosphere and discharged into rivers, lakes and oceans, and as all these heavy metals are persistent, they still exist somewhere, either in the organisms, in the soil, in the aquatic ecosystems, in the atmosphere, whereas only a small fraction is transferred into sediments. But also this is not a one-way road, every year thousand of tons of heavy metals dissolve from the sea floor into marine ecosystems (UNEP, 2013). Data about levels from 1983 for the discharge of heavy metals to the environment are available for comparison (table 4). Since around 1983, emissions of heavy metals to the atmosphere and to aquatic ecosystems have been reduced from these levels (Der Brockhaus, 2003).

Table 3. Worldwide production of heavy metals and ratio of anthropogenic emissions to air and water (Kelly & Matos, 2013)

Heavy metal	Production 1900 [t]	Production 1983 [t]	Production 2011 [t]	Ratio of anthr. em. to air / production (1983)	Ratio of anthr. em. to water / production (1983)
As	6,170	31,9	34,700	37.6-80.3 %	37.6-219.4 %
Cd	14	17,600	22,200	17.6-68.4 %	11.9-96.6 %
Cr	16,500	2,540,000	7,180,000	0.3-2.1 %	1.8-9.4 %
Cu	495,000	7,610,000	16,100,000	0.3-0.7 %	0.5-1.2 %
Hg	3,150	6,230	2,010	14.6-99.5%	4.8-141.3 %
Pb	749,000	3,335,000	4,700,000	8.6-11.2 %	2.9-5.4 %
Zn	479,000	6,280,000	12,800,000	1.1-3.1 %	1.2-6.0 %

In table 4 the provisional tolerable weekly intake (PTWI) of arsenic, cadmium and lead are shown ($\mu\text{g/kg}$ body weight). The value for arsenic is withdrawn, and no new value is indicated instead because the risk of carcinogenicity. For oral intake of lead in drinking-water is 10 μg per

litre, for cadmium 3 µg per litre, copper 2 mg per litre and inorganic mercury 0.006 mg per litre (WHO, 2010b, 2010d, 2011).

Table 4. Worldwide anthropogenic emission of heavy metals 1983 (Nriagu & Pacyna, 1988)

Heavy Metal	Anthropogenic release into the atmosphere 1983 [t]	Anthropogenic release into aquatic ecosystems 1983 [t]	Fallout from the atmosphere into aquatic ecosystems 1983 [t]	PTWI µg/kg body weight
As	12,000-25,630	12,000-70,000	3,600-7,700	10
Cd	3,100-12,040	2,100-17,000	900-3,600	6
Cr	7,340-53,610	45,000-239,000	2,200-16,000	
Cu	19,860-50,870	35,000-90,000	6,000-15,000	
Hg	910-6,200	300-8,800	220-1,800	
Pb	288,700-376,000	97,000-180,000	87,000-113,000	25
Zn	70,250-193,500	77,000-375,000	21,000-58,000	

The main sources of emissions into aquatic ecosystems of the seven heavy metals investigated here, by human activities, include domestic wastewater and dumping of sewage sludge, “steam electric”, metal production and manufacturing, chemical industry and fallout from the atmosphere (Kelly & Matos, 2013). The amounts are shown in table 4. The ratio of anthropogenic release into air and water to the amount of production of heavy metals in 1983 is shown in table 3. The main sources of emissions into the atmosphere of the seven heavy metals investigated here, by human activities, are wood, coal and oil combustion, steel and iron manufacturing, metal production, and cement manufacturing. Only coal combustion and metal production applies to all of them, and another source, phosphate fertilizers, apply only for cadmium and copper (Kelly & Matos, 2013).

1.5.4 Measurements

Surface waters are a mixture of waters from different sources depending on precipitation, mineral weathering, vegetation and land use. The most important natural factors influencing water quality are geology and climate. Moving water dissolves material from the matrix rocks, the weathering reactions go faster at higher temperatures (Ward & Robinson, 2000).

The water quality is influenced by physical, chemical and biological processes, when receiving point sources of pollution, for example leachate from dumping sites (and landfills) or effluents from domestic sewage. These changes are affected by the water temperature, dissolved oxygen and the ability to transfer solid particles. Hazardous and toxic substances are adsorbed by sediments. In water dissolved material is moved as suspended load by water stream or deposite

on the ground as bed load, varying by the flow rate of water. The movement of these particles depends on convection, dispersion and reaction (Ward & Robinson, 2000). Indicator microorganisms are often clumped to suspended solids in surface water and the bacterial contamination level is reduced by dilution, sunlight, predation or thermal conditions (WHO, 2006). To detect contaminants in water the biological and chemical oxygen demand (BOD, COD), temperature, pH, water flow rate and conductivity are measured (Ward & Robinson, 2000).

The natural microbial community contains plenty of different bacteria species. Microbial detection of a single microorganism is based on isolation of the target bacteria from a sample. Bacteria form discrete colonies when deposited at discrete locations on a solid medium and the phenotypic characteristics get visible by cell reproduction, verifying the presence of the target bacteria in the sample. The ability of a particular microorganism to grow on a particular medium by utilizing specific inorganic nutrients such as mercury, is used to detect the specific - mercury resistant – bacteria. To differentiate the target bacteria from non target bacteria in the community its resistance to a certain heavy metal – for example mercury – is used (Atlas & Bartha, 1993). Measurement of microbial numbers, the quantitative approach to measure the microbial number support the elevation of changes in biomass and bacterial activity caused by increased nutrient availability. As long as environmental conditions such as temperature, oxygen concentration, nutrient availability remain constant, the quantitative approach of bacteria correlates with bacterial activity. Changes of the environmental conditions can cause changed cell size of microorganisms, for example increased biomass without increased number of bacteria (Atlas & Bartha, 1993).

During aerobic bioreduction the microbial number in leachate varies until the degraded waste material gets stable, as Hale Boothe *et al.* (2001) by an engineering test to determine the biodegradable status of a landfill found out. Air was injected to the landfill. In the beginning the microbial numbers in leachate were measured in the range of 3×10^2 to 10^4 ml⁻¹, after 5 months rising to the thousandfold, after 9 months treatment the bacterial number had decreased to be no longer detectable because of stability of the waste material (Hale Boothe *et al.*, 2001).

By plating procedure the targeted microorganisms are fed with all essential nutrients for growth and the cultures are incubated under favourable conditions for growth (Atlas & Bartha, 1993). The detection of mercury resistant bacteria is performed by the classical approach to place viable microbial cells onto medium including mercury.

1.5.5 Icelandic dumping sites, pollutants and control

In the period since 1970 uncontrolled open-pit burning in many open dumps - in short distance to urban areas - was the main treatment of waste, emitting smoke at relatively low incineration temperatures that leads to the production and emission of dioxins (Baird & Cann, 2008).



Fig. 1 & 2. Open burning cistern at Draugagil

In the 1990's burning-cisterns, made by high concrete walls to prevent waste to blow away (as shown on fig. 1 and 2 above), were built by many municipalities. In the best case the ash was covered with earth or something else, before the wind could blow the ash away. Around 2000 landfilling became more common (Kamsma & Meyles, 2005; Meyles, 2003). In 2003 the open-pit burning was discontinued (UN, 2011).

In Iceland the first Nature Conservation Act passed the Parliament 7th of April 1956. Both renewals in 1971 and 1996 took the view that waste dumping is a non legal action. The Nature Conservation Act contained an article about undesirable waste dumping until 1999. The principle of these articles was that "it is prohibited to collect garbage in heaps in public or besides roads. The person that runs a dumping site is obliged to leave the garbage dumps in a way so that the garbage neither blows away nor runs off" (Alpingi 2013b, 2013c, 2013d, 2013e). With the participation to the European Economic Area (EEA) in 1994 the European legislations about chemicals, pollution prevention and waste treatment have to be introduced to Icelandic law (Meyles & Schmidt, 2005). The Directive on the landfill of waste (Council of the European Union, 1999) was adopted to Icelandic law by the Act on Waste Management 55/2003 (Alpingi, 2013a), which says, that "it is forbidden to leave, transfer, distribute or store waste in a way that could cause damage, pollution or blemishes on the environment", but without any regulation how to treat the old dumping sites (Alpingi, 2013a).

1.5.5.1 Reykjavík

Before the local authorities of Reykjavík started in 1919 to bury waste collectively, the waste was buried beside the houses and dumped at the shore. Later on, it was decided to use sites in the vicinity of each part of the growing city, but in 1967 the Gufunes site was established and used for waste dumping the next 24 years. By opening this waste deposit no attention was paid to collecting the leachate or to seal the landfill gastight, care was only taken of visible problems such as to prevent drifting/blowing waste and reducing the emerge of birds, rats and minks (Hrólfssdóttir & Gunnarsson, 1993). Sixteen dumping sites from different periods are known in Reykjavík, but without any information on their contents, although all are located in urban areas. On top of some former dumping sites new buildings have been established without removing the old waste. Very little is known about the behaviour of the waste in the older Icelandic dumping sites and it is unclear how and when pollutants may pass into the environment (Ólafsdóttir & Steinarsdóttir, 2006). Records about the amount, the composition and the distribution of the waste do not exist (Meyles & Schmidt, 2005).



Fig. 3 & 4. Different types of waste: Wood, metal, plastics and asphalt at Draugagil

But it is possible to estimate the composition and the quantities of different categories of waste by studying the activities of households, industry and institutions from the years the waste was produced (Ólafsdóttir & Steinarsdóttir, 2006). The figures 3 to 8 show different compositions of waste at a dumping site.

At the dumping site at Gufunes the average waste was wrecked cars, oil drums, wood, concrete, scrap, soil and biodegradable garbage as well as transformers and other hazardous and infectious waste.



Fig. 5 & 6. Different types of waste: Car tyres, wood, metal, plastics, electrical appliances at Draugagil

The distribution of organic garbage from households and food industry over the area is very irregular like figure 8 shows. It is certain that at the dumping site at Gufunes biodegradable garbage together with inorganic waste was buried (Bjarnadóttir *et al.*, 2008). The former dumping site at Gufunes contains contaminants such as heavy metals, polychlorinated biphenyl (PCB) and polycyclic aromatic hydrocarbons (PAH) similar to the dumping site Geirsnef in the bay Elliðavogur, where old cars, batteries, and so on were disposed (Meyles & Schmidt, 2005). Both sites need further research (Ólafsdóttir & Steinarsdóttir, 2006).

The chemical composition of the disposal site is very inhomogenous not only because of different types of waste, but also because of different age, which means that the microbial activities and the gasification differ depending to the location of the waste (Bjarnadóttir *et al.*, 2008). Precipitation that falls on the dumping site has an easy access into the waste as the figures 3 to 8 show.



Fig. 7 & 8. Different types of waste: Inert waste, refrigerator, fishing-net, hay bales, paint at Draugagil

In drier areas there will be a delay in the outflow of contaminated leachate from the dumping site, because the downrunning water will first saturate the moisture of the dry waste with water and stimulate the decomposition process. The outwash of nutrients and inorganic substances such as salts and heavy metals appears later. Due to all these reasons it is not possible to generalize from single chemical analyses of the leachate about the concentration of contaminants inside the whole dumping site (Bjarnadóttir *et al.*, 2008).

Until 1991 the waste was unsorted and deposited in open waste sites at Grafarvogur and Ártúnshöfði (Hrólfsdóttir & Gunnarsson, 1993). Before the company “Efnamóttakan hf” was founded in the end of 1998, the responsibility for the disposal and recycling of hazardous waste was indeterminate. In the operation period from 1967 to 1991 the deposit at Gufunes never had an operating permission, so no institution was responsible for inspecting or advising on closing the dumping site (Bjarnadóttir *et al.*, 2008). 10 millions m³ of waste have been buried at Gufunes and after stopping to deposit waste at Gufunes, Hrólfsdóttir and Gunnarsson (1993) designed the leachate and gas treatment of a modern landfill (Hrólfsdóttir & Gunnarsson, 1993). In 2000 the company “Efnamóttakan hf”, which is run by the City of Reykjavík, got its operating permission for 2,500 tons of hazardous waste, additionally contagious waste, electric and electronic appliance, paper, plastics and car tyres (Umhverfisstofnun, 2004). Since that time this scrap is collected from all over the country and than mostly exported. At the refuse transfer station near the old dumping site at Gufunes municipal waste is sorted and pressed, and the solid, non-recyclable waste is transported to the landfill site at Álfsnes. Today the operating licence allows deposition of 120,000 tons annually at the landfill at Álfsnes near Reykjavík, serving more than 2/3 of all 321,000 inhabitants in Iceland, living in the capital area (Hollustuvernd ríkisins, 2001b).

At Álfsnes the leachate is discharged near the landfill into coastal water in Þerneyjarsund. The concentrations of cadmium, lead and mercury in the leachate are measured annually, and As, Cr, Cu, Fe, Ni and Zn every third year. Both Álfsnes and Gufunes have operating permissions, which include measurement of contaminant accumulation in the environment (Kamsma & Meyles, 2005), therefore the analysis of *Mytilus edulis* is at a four years intervals in consultation with the inspector and Environment Agency of Iceland performed (Hollustuvernd, 2001b). In 2002, 2005 and 2009 the concentrations of metals in blue mussels, placed in cages near the outlets of the leachate from the landfill at Álfsnes, and at a reference site in the fjord Hvalfjörður, were measured after ten weeks exposure to the outlets. The concentrations of arsenic, chromium, copper and zinc have been higher in 2009 than the years before (and measured by Jóhannesson *et al.* 1995), though the concentrations in leachate from landfill have

been stable. Einarsson (2011) explains levels of metals by changed conditions in measurement, that the mussels now have been closer to the outlet than before and proposes a more exact determination of the distance in the future (Einarsson, 2011).

At Gufunes the operator is obligated to measure every fourth year cadmium, lead and mercury in kelp and sand, where the leachate runs into the sea (Hollustuvernd, 2001a). In 2003 Svavarsson (2004) studied the number and composition of species on bottom and in kelp holdfasts in the waters near the old dumping site at Gufunes. The marine biota at Gufunes did not differ significantly compared with other sampling sites in the Reykjavík area (Svavarsson, 2004). In autumn 1992 and in summer 1993 dogwhelks were collected near Reykjavík harbour to study concentrations of metals related to their seasonal feeding and resting activities (Skarphéðinsdóttir *et al.*, 1996).

In August 1999 dogwhelks were collected for a study of metal exposure and toxicity from eight locations at Icelandic coasts. In the southwest of Iceland is the reference site Strandakirkja (ST). Vallarhús (VA) and Másbúðasund (MA) are both located near to little villages. At the time of sampling, the inhabitants in Sandgerði (SA) were 1,309 and 1,183 in the municipality Garður (GA). In Raufarhöfn (RA) in the northeast of Iceland lived 365 inhabitants. Grenivík (GR) is located in Eyjafjörður near Akureyri. The sample site in Reykjavík was at Gufunes (GU), 50 metres away from a wastewater outlet of the refuse transfer station. This sample of 9 dogwhelks (shell length 23 mm) showed the highest levels of TBT contamination compared to other study sites. The 9 dogwhelks at Gufunes removed metals in a higher rate (by excretion) than to store metals in their tissues, that means lower concentrations of MTs in dogwhelks at Gufunes. Leung *et al.* (2005) published only the overall means of the metal concentration (table 5 beneath), and the authors show the average value as a horizontal line at the figures 16, 17 and 18. For comparison in the present trial these figures for cadmium, copper and zinc, based on Leung *et al.* (2005), are used together with the results from Draugagil and Skúlahorn.

Table 5. Concentrations of different metals (mean \pm SD) in dogwhelks (Leung *et al.*, 2005)

μg metal per g soft body dryweight	Cadmium	Chromium	Copper	Zinc
Overall mean	8.66	192.8*	47.1	216.7

* The chromium values in the study seem to be 100 to 1,000 fold. This seems to be a mistake (Halldórsson, Halldór Palmar, Director of the University of Iceland's Research Centre in Sudurnes and co-author Leung *et al.*, 2005, 20th April 2013, personal communication).

1.5.5.2 Akureyri

The local former dumping site and landfill in the gully Glerádalur has been in use since 1960 (Sveinsdóttir, 2010). The operating area is 10794.0 m² large (Registers Iceland, 2013). Leachate from the dumping site runs into the brook Sigurðargilslækur, which flows into the river glacier Glerá. In 1987 Aðalsteinsdóttir (1987) investigated the biota of the river Glerá, that flows into the fjord Eyjafjörður after passing some anthropogenic inflows derived from activities at Akureyri. She found a microbial load of 10² colony forming per unit (cfu) per ml in the water of river Glerá (Aðalsteinsdóttir, 1987).

This leachate from Glerádalur has been a subject of study at the University of Akureyri since 1996 (Markúsdóttir, 2011). Sveinsdóttir (2010) evaluated the students reports as well as chemical analyses of the leachate performed by the National Energy Authority (Sveinsdóttir, 2010).

Markúsdóttir (2011) studied the anthropogenic impact on the microbiota of seashore and freshwater environments in Northern and Eastern Iceland by surfactant-degrader bioprospecting (Markúsdóttir, 2011). In summer 2010 samples from two sites near the dumping site and landfill in Glerádalur were taken. She found that the microbiota of the river Glerá is influenced by the leachate of the brook Sigurðargilslækur from the dumping site in the gully Glerádalur, both numbers of bacteria in river water and sediment, and also an increasing number of bacteria species downstream the river Glerá (Markúsdóttir, 2011). The results of the physicochemical measurement and bacteria count on Plate Count Agar (PCA) plates supplemented with 50 µM HgCl₂ in June 2010 from a flowing dumping site leachate sample in the brook Sigurðargilslækur are shown in table 6.

Table 6. Temperature, pH, conductivity and amount of bacteria on PCA + HgCl₂ in leachate and river water (Markúsdóttir, 2011)

	Temperature °C	pH	Conductivity µS cm ⁻¹	HgCl ₂ cfu
Brook Sigurðargilslækur	14	8.0	1,430.0	6.0×10 ⁴
Stagnant leachate pool 50 metres down stream	12	7.6	1,930.0	2.5×10 ⁴
River Glerá	5,1	7.3	33.5	2.0×10 ²

1.5.5.3 Húnaflói Bay

Blönduós lays at the mouth of the glacier river Blanda, which divides the village into two parts. At the shore at Blönduós in Húnaflói Bay, ocean currents are strong and water replacement is rapid, and at the coast north and south of Blönduós, impact from water erosion is visible. The water coming from the river Blanda flows to the south in Húnaflói Bay (Pétursson, 2006). At Blönduós the former local dumping site and old landfill is called “Draugagil”, placed south of the river mouth, and in a distance of 700 metres from the urban area (Fig. 9 and 10).

On 1 January 2013 the population of Blönduós and Húnavatnshreppur was 1,283 (0.4% of total inhabitants of Iceland), less than in the whole last century. The territory of both municipalities together is 5,830 km² (Statistics Iceland, 2013).

In the municipality Húnavatnshreppur is no disposal and all generated waste has been transferred to Draugagil until the new landfill at Stekkjarvík, located northern of Blönduós, started in 2011, designed for leachate and gas collecting.



*Fig 9. Sampling sites: Draugagil (yellow point).
Skúlahorn (red point) near the mole at Blönduós*

In former times the local slaughterhouse used land northern the village (Fig. 9 and 11) behind the mole of Blönduós as a waste site (Svavarsson, 2007). Nearby, at the shore in a little bay (200 m long) - beneath the hill Skúlahorn and the farmland Bakkakot - animal skulls have been found there.

Draugagil is circa 25 metres deep near the shore. A part of the old landfill belongs to the neighbour farm Hjaltabakki (Fig. 10).



Fig. 10 & 11. Sampling sites: Left Draugagil. Dogwhelks collected on shore (red point). Microbial sampling site of leachate is 70 metres above the shore (yellow point). Right Skúlahorn. Dogwhelks collected near the mole at Blönduós (red point)

From 1982 to 1991 the Blanda Power Plant, with an annual generation capacity of 910 GWh, and the associated infrastructure was built and the population reached a high of 1,767 persons in 1990. After the end of construction a decrease in population appeared and in 2010 454 persons (26% of the population 1990) had left the area since the Blanda Power Plant came online in 1991 (Statistics Iceland, 2013).



Fig. 12 & 13. Waste management: Garbage pushed down to fill Draugagil gully

In the period 1982 to 1991 waste in connection with construction of Blanda Power Plant was dumped at Draugagil like shown on fig.12 and fig 13, although some dumping elsewhere is suspected (Svavarsson, 2007). After these activities were finished, landfilling at Draugagil started in 1992 (Júlíusson, 2011b).

The waste management development at Húnaflói Bay was no uncommon/unusual case: As early as 1973 the waste problem was named at Blönduós (Ísberg, 1973), and discussed between the two neighbour villages at Húnaflói Bay - Blönduós and Skagaströnd - to buy collectively an open-pit for burning waste (Ísberg, 1974), but a year later it was announced, that the waste problem has been solved at Blönduós with the installation of cylinders to burn the waste (Ísberg, 1975). At Draugagil refrigerants, chlorinated compounds, mercury products, organic solvents, photographic materials, paints, pigments, petroleum products, cars, vehicle and other batteries, waste oil, developing chemicals and leftover oil-based paints were dumped down the gully (Fig. 12 and 13). Since 1991, household waste was collected by a special van, and 1992 the storage and pressing of cars at the dumping site started - without taking care of all fluids. The ash from incineration was dumped some steps aside down until the late 1990s (Halldórsson, Ívar Snorri, former lorry driver at Co-op at Blönduós, personal communication 2012).

In the annual "Húnavaka" Ingjaldsson (1977) wrote about waste management at Skagaströnd, where formerly all waste was dumped to the sea by the rocks at Höfði. In the 1970s the waste was buried at the site Spákonufellsmelar until 1976, when the burning-pit was built there (Ingjaldsson, 1977).

Farmers solved the waste problems differently by burning the household rubbish in open oil drums near the houses, without concerns of health risk and pollution by burning by low temperatures (Meyles, 2003). Additionally some places are known where in the past scrapie affected sheep flocks have been buried - with official permission (Svavarsson, 2007). A sewage plant, which treats the sewage only by mechanical cleaning, has its outlet near the mouth of the river Blanda and the sludge was deposited at Draugagil (Svavarsson, 2007). Another influx of contaminants is the pipe from the southern part of the village, where sewage from households flows untreated down to the sea (Ásgeirsdóttir, 2011), approximately 950 metres northern of the dumping site at Draugagil. Since the landfilling at Draugagil started 1992, chemical water analyses have been performed four times (1994, 2004, 2009, 2012) from the brook Draugagilslækur (table 7 beneath and Appendix I, II and III).

Table 7. Levels of metals in sediment and water at Draugagil 1992 to 2012

Date	Sample	As	Cd	Cr	Cu	Hg	Pb	Zn
6.04.1992	Sediment mg/100g		<0.005				<0.02	
6.04.1992	Sediment mg/100g		<0.005				<0.02	
14.11.1994	Water µg/litre		<20	<50	<50		<300	<200
8.12.2004	Water µg/litre		1.3	<1	<2	0.07		4.27
14.11.2009	Water µg/litre	<1	0.19	3.5	4.7	<0.02	<0.6	490
2.10.2012	Water µg/litre	<0.5	<0.05	<0.9	2.05± 0.84	<0.02	<0.5	213± 23

From the underground at Hjaltabakki some subterranean water source seeps to the sea (Hafstað, 1976). According to the local authorities at Blönduós, no leachate runs from Draugagil, so no regular analyses are available, despite such requirements in the operation permission (Júlíusson, 2011b; Umhverfisstofnun, 2005). In 2010 an investigation of landfill gas was performed from three test drills, resulting in maximum 13% of methane. Júlíusson (2011) supposes that something failed while filling the area at Draugagil. A low ratio of inert waste to low moisture may be the reason for the low concentration of methane at Draugagil (Júlíusson, 2011a).

1.6 The aim of the study

The aim of this study was to evaluate possible pollution from the dumping site at Draugagil by answering the question: Can chemical pollutants analysis in filterfeeder predators along with microbial testing detect marine pollution caused by leachate from a dumping site?

2 Materials and methods

1.7 Choice of sample subject

In the tidal zone - beneath dumping sites – blue mussels (*M. edulis*), barnacles (*S. balanoides*), dogwhelks (*N. lapillus*) and limpets (*Tectura tessulata*) settle in the clefts between the slippery rocks. The intention was to use *M. edulis* as an indicator of contamination, but all pre-investigations at the shore at Blönduós below the dumping sites showed no blue mussels of size big enough for laboratory analysis, as they only measured a few mm. *N. lapillus* preys on *Mytilus edulis* and the decision was taken to use the predators for metal determination according to Hunt & Scheibling (1998).

At Draugagil two different leachates emerge from the dumping site, run down to the rocky shore and seep to the sea: one brown coloured and the other with clear water and both were researched by microbial test.

The same elements were chosen for chemical determination as analysed in water samples from Draugagil (table 7). Information about the air temperature at Blönduós on sampling days and the precipitation two weeks before sampling was obtained from the website of the Icelandic Meteorological Office (Anon., 2012).

1.8 Sampling

A sample of *Nucella lapillus* was collected from the sampling site at the shore beneath the dumping site at Draugagil at ebbing tide before low tide at 7th of March 2012 and again 20th of March 2012 (UKHO, 2012).

The dogwhelks, found at 7th of March, filled only half a glass (approximately 50 snails). The second sampling was more successfully and 138 dogwhelks were collected, at a size of 34.6 mm and smaller. The dogwhelks collected in this investigation had mostly brownish and dark coloured shells. The samples were collected into plastic bags in glass bottles.

A second sample of *N. lapillus* was sampled from the site at the shore north of the mouth of the river Blanda (Skúlahorn). The snails were sampled at ebbing tide before low tide at 2nd of August 2012 into plastic bags in a glass bottle. All samples were sent immediately the sampling day to the laboratory at Matis ltd. in Reykjavík.

Samples of brown and clear leachate water and a sample of shore water were collected from the sampling site beneath the dumping site at Draugagil on 23th of March 2012 for microbial and physical analysis. (Fig. 14 and 15). The water samples were obtained from flowing water and

collected into sterile 800 ml glass bottles. During sampling the water temperature was measured with a thermometer. During transport to the laboratory of the University of Akureyri the samples were kept in an ice-cooled box before investigation after arrival.

Coordinates at sampling sites were set with a GPS (Model trex 10, Garmin).



Fig. 14 & 15. Sampling site: Draugagil. Microbial test. Brown leachate seeping from the dumping site

1.9 Quantification of metals and bacteria

After arrival at the laboratory at Matis ltd. the next day the dogwhelk samples were stored at - 20°C until processing. The tissues of *N. lapillus* were freeze-dried, milled and digested by acid and peroxide. The concentrations of As, Cd, Cr, Cu, Hg, Pb and Zn were determined by ICP-MS (Inductively Coupled Plasma Mass Spectrometry) with a Agilent 7500ce machine (Natasa Desnica, research scientist at Matis ltd., 8th of March 2012, personal communication). The reference sample was handled in the same way as *N. lapillus* before the concentrations of Cd, Cu and Zn were analysed (Natasa Desnica, research scientist at Matis ltd., 24th of September 2012, personal communication).

In the microbiology laboratory the water samples were diluted with Butterfield's buffer and placed directly on Plate Count Agar (PCA) (BD Difco) plates or PCA (BD Difco) plates supplemented with 50 µM HgCl₂. The plates with PCA and PCA+ HgCl₂ were incubated at 31°C without incident light. Bacteria colonies were estimated by direct count procedure. 10 ml of the sample were pipetted into test tubes with Durham tubes of double strength Lauryl Sulphate Tryptose (LST) broth (BD Difco) and 1 ml of the sample into single strength LST to detect gas production by bacteria. The LST glasses were incubated in a waterbath (approximately 35,5°C) without incident light. All samples were incubated for 64 up to 68 hours before checked for growth. At the laboratory conductivity was measured with the EC Meter (Model 1481-61, Cole-Parmer Instrument Co, Illinois) and also pH (Model 744, Metrohm).

3 Results

The physicochemical measurements on 23th of March 2012 in the leachate and shore water at Draugagil is shown in table 8 beneath:

Table 8. Physicochemical measurements on 23th March 2012 in leachate and shore water samples

Sampling site	T _{Air} (°C)	T _{Water} (°C)	Conductivity µS/cm	pH	Coordinates
Measured at	leachate	leachate	laboratory	laboratory	leachate
Brown leachate	11.8	7.7	796.5	7.27	N65°38,118' W020°03,676'
Clear leachate	10.4	4.7	715	8.16	N65°38,960' W020°18,527'
Shore water	9.8	3.0	1,347	7.95	
Draugagil dogwhelk site					N 65°38,960' W 020°18,527'
Skúlahorn dogwhelk site					N 65°40,334' W 020°17,728'

Bacteria growth on PCA + HgCl₂ was most from the brown leachate water taken beneath the dumping site at Draugagil, shown in table 9. Colony counts on PCA + HgCl₂ range between 25 cfu ml⁻¹ in the brown leachate water and 10 CFU ml⁻¹ in the clear leachate water. It is worth to mention that on the PCA + HgCl₂ plates cultivated with brown water 18 cfu ml⁻¹ were counted growing inside the agar. Colony counts on PCA + HgCl₂ showed 25 cfu ml⁻¹ in water from the shore beneath the dumping site at Draugagil (table 9).

Table 9. Plate counts and coliform in samples collected on 23th March 2012 in leachate and shore water

Sampling site	PCA (cfu/ml)	PCA + HgCl ₂ (cfu/ml)	Coliform (LST)*
Brown leachate	6×10 ²	25	cloudy
Clear leachate	4×10 ²	10	cloudy
Shore water	3×10 ²	25	cloudy

*no results for confirmation test

The water samples from both leachates and the seawater show bacteria colonies cultivated on PCA + HgCl₂ and from the water samples the Lauryl sulfate tryptose broth (LST) test for coliform was positive (10 ml sample on the Durham tubes of double strength lactose broth) (table 9). In all glasses of brown, clear leachate and shore water the samples in the single strength lactose broth and 10⁻¹ dilution appeared to be cloudy.

The measurement of metal concentrations in dogwhelks at the shore beneath the dumping site at Draugagil and the reference site at Skúlahorn is shown in the table 10 (Appendix IV and V).

Table 10. Metal concentrations (mg/kg tissue dryweight; 95% confidence interval (k=2)) of As, Cd, Cr, Cu, Hg, Pb, Zn in Nucella lapillus from Draugagil, collected 7th and 20th of March and Skúlahorn 2nd of August 2012

Metal	Draugagil [mg/kg dryweight]	Skúlahorn [mg/kg dryweight]	
Dry matter %	21.46%	21.61%	
Arsenic (As)	24.436		± 20%
Cadmium (Cd)	8.593	5.646	± 20%
Chromium (Cr)	0.873		± 0.02 mg/kg
Copper (Cu)	52.023	28.644	± 20%
Mercury (Hg)	0.125		± 20%
Lead (Pb)	0.058		± 20%
Zinc (Zn)	279.637	95.002	± 20%

4 Discussion

It is interesting to note that the cadmium contamination from both sites at Blönduós are higher than from sites “where relatively high population density and industries have resulted in considerable amounts of pollutants being released to the marine environment” (Leung *et al.*, 2005). The cadmium concentration in dogwhelks from the shores of Blönduós exceeds the levels of Cd in dogwhelks collected near the largest dumping site in Iceland, Gufunes (GU) in Reykjavík, shown here beneath in fig 16. The level of cadmium contamination at Draugagil shows similar values to the overall mean of the eight samples collected from the southwestern and northern coasts of Iceland (table 10).

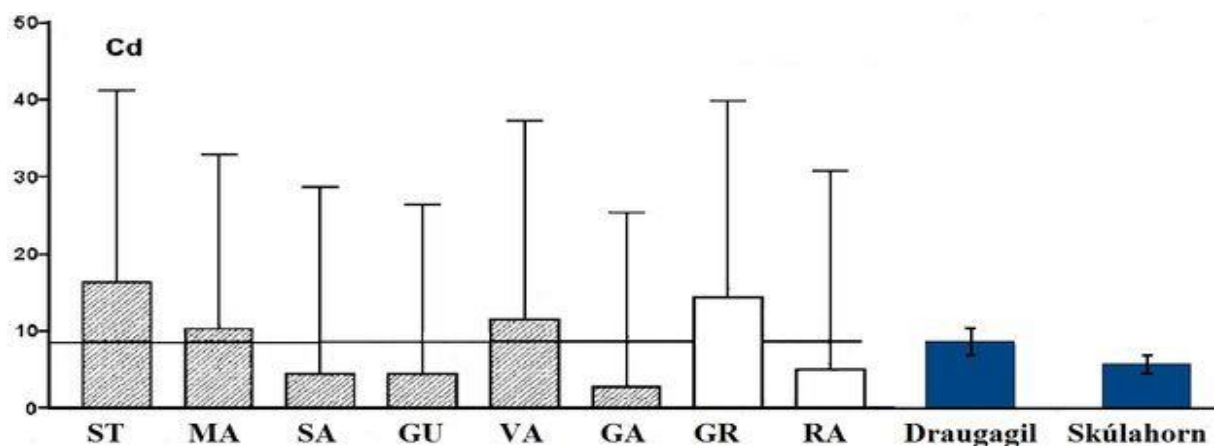


Fig. 16. Cadmium concentration (mg/kg DW) in dogwhelk samples from Draugagil and Skúlahorn (right, blue) compared to 6 dogwhelk samples at southwest (left, grey) and 2 at north (white) Iceland. The horizontal line over the first 8 samples is the overall mean of them: 8,66 (Table 5, Leung *et al.*, 2005)

In general, the metals cadmium, copper and zinc are more in *Nucella lapillus* from Draugagil than from Skúlahorn (Fig 16, fig. 17 and fig. 18). The cadmium contamination is 52% higher at Draugagil than at Skúlahorn, the level of copper at Draugagil exceeds values from Skúlahorn by 82% and the concentration of zinc in dogwhelks at Draugagil measures 194% more than at Skúlahorn, northern the mouth of the river Blanda (table 10).

The level of the copper contamination at Draugagil shows higher values compared to the overall mean of the eight samples collected from the southwestern and northern coast of Iceland (Fig. 17 and table 10). In detail the concentration of copper at both sites at Blönduós is higher than at some sites at the small fishing villages Sandgerði (SA) and Garður (GA) at the southwestern coast of Iceland, though the human population in these villages is similar to the number of inhabitants of Blönduós together with Húnavatnshreppur (1,277). The copper contamination is a few percents higher at Gufunes (GU) than at Draugagil.

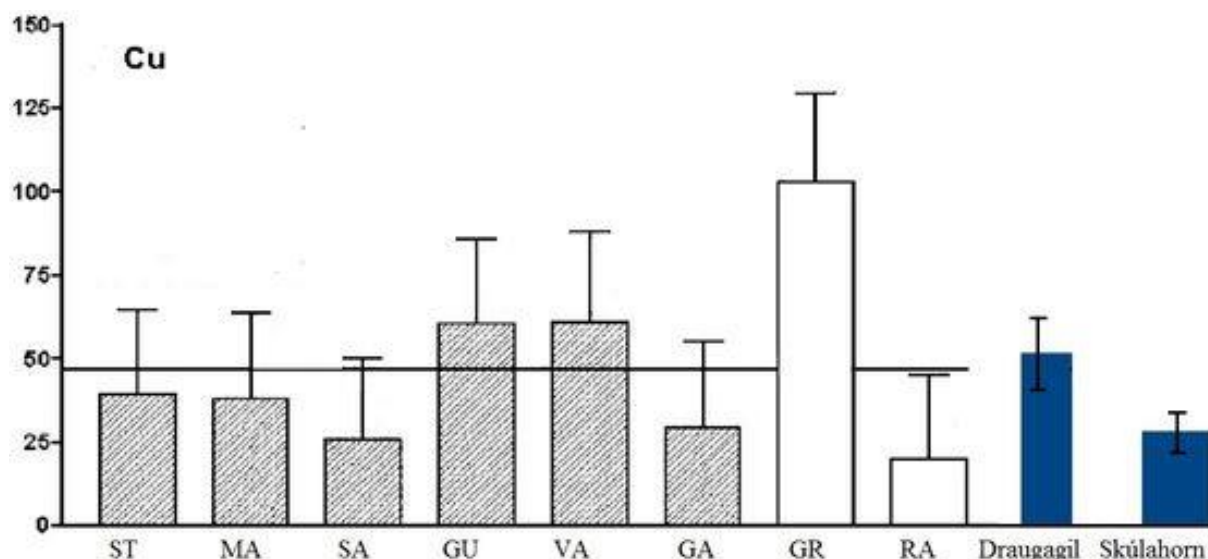


Fig. 17. Copper concentration (mg/kg DW) in dogwhelk samples from Draugagil and Skúlahorn (right, blue), compared to 6 dogwhelk samples at southwest (left, grey) and 2 at north (white) Iceland. The horizontal line over the first 8 samples is the overall mean of them: 47,1 (Table 5, Leung et al., 2005).

The level of the zinc contamination at Draugagil shows higher values compared to the overall mean of the eight samples collected from the southwestern and northern coasts of Iceland (Fig. 18 and table 10). To describe the concentration of Zn particularly, levels of seven samples are higher than the concentration of zinc at Skúlahorn, only the value at Garðskagi (GA) is an exception.

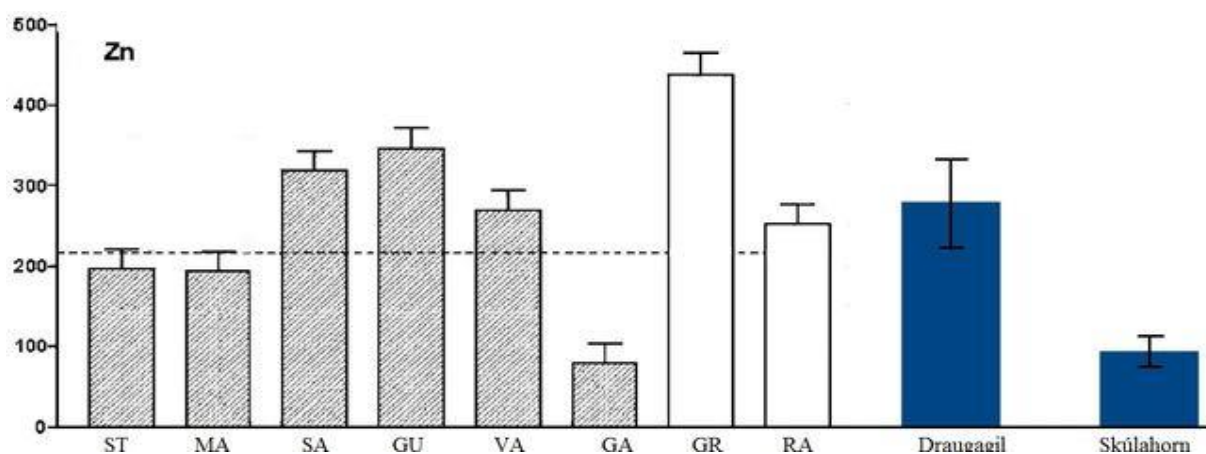


Fig. 18. Zinc concentration (mg/kg DW) of dogwhelk samples from Draugagil and Skúlahorn (right, blue), compared to 6 dogwhelk samples at southwest (left, grey) and 2 at north (white) Iceland. The horizontal line over the first 8 samples is the overall mean of them: 216,7 (Table 5, Leung et al., 2005)

In detail, the Draugagil sample has less concentration of Zn than the sampling sites near the small villages at the Icelandic southwest coast, and in Sandgerði (SA), though the sample at Draugagil (279.6 µg/g tissue dryweight) exceeds the overall mean of 8 samples in Iceland (216.7 µg/g tissue DW).

The levels of both cadmium and zinc suggest that the total level of metal concentration in dogwhelks is increased. Marine molluscs contain at average 10 to 50 mg zinc per kg wetweight (WHO, 2003) and the levels of the dogwhelks at Draugagil are within this range, holding 20.53 mg Zn/kg soft tissue wetweight (table 10).

No analyses of arsenic, chromium, lead and mercury or physicochemical, microbial measurements were made in dogwhelks at the sampling site in the little bay behind the mole of the harbour of Blönduós, at Skúlahorn. The study of the dumping site Draugagil is limited to chemical analyses of the metals, physicochemical measurements and microbiological tests. Biophysiological response of dogwhelks to contaminants and toxic effects are not evaluated. Only a few studies exist, where the concentrations of metals in tissue of *Nucella lapillus* are published, while most of the papers with dogwhelks as the subject investigate biophysiological response to environmental stress. Because of this lack of data the present thesis compares the chemical levels of metals to an Irish study from Giltrap *et al.* (2012).

Draugagil presents a higher chromium contamination (0.87 µg/g tissue DW, shown in table 10) than in the tissue of dogwhelks at Dublin Bay (0.65 µg/g tissue DW), but a lower level than at the other Irish site Dunmore East Harbour (1.0 µg/g tissue DW) and the concentrations of arsenic, lead and mercury are lower compared to levels in Ireland (table 1; Giltrap *et al.*, 2012). The higher concentrations of cadmium, copper and sink in marine biota are adverting to contamination from the dumping site at Draugagil. The measurements of temperature, pH and conductivity in the two brooks running from the dumping site down to the shore show differences between the brown leachate and the clear looking water in the so called Draugagilslækur, shown in table 8. The clear water, measured on behalf of the local authority of Blönduós 1st of October 2012 (Appendix 3), presents COD (less than 10 mg/l), a lower level of pH (7.25), but a higher level of conductivity (1,900 µS/cm) than the samples of clear water and brown leachate, measured in March 2012, did (table 8). In the leachate Sigurðargilslækur from the former dumping site at Glerádalur at Akureyri Markúsdóttir (2011) measured in June 2010 pH 8.0 and conductivity (1,430.0 µS/cm), shown in table 6.

The chemical analyses of the leachate Draugagilslækur (table 7, Appendix 1) show varying levels of zinc concentrations in the water between 1994 and 2012. Zinc levels around 640 µg/l, pH 8, COD 3,000 mg/l and BOD 180 mg/l can be indicators that the microbiological processes inside a controlled landfill are at the end stage of microbial degradation (Bjarnadóttir *et al.*, 2008).

The number of bacteria, counted in water from the dumping site (table 9), recalls the lower levels found by Hale Boothe *et al.* (2001) in the beginning of microbial degradation, where the

number of bacteria in leachate was determined in the range of 10^2 to 10^4 cfu. The only problem with these measurements is that the dumping site at Draugagil is no landfill in the sense of microbial degradation of organic matter (Figures 3 to 8).

The discrepancy of the levels of cadmium, chromium, copper and zinc in the soft tissue of dogwhelks collected beneath the dumping site (table 10), and chemical analyses of the leachate (table 7), which show low and tolerable levels of metal per litre, can be explained by the fact of bioaccumulation. The flow rate of the leachate has never been measured, though this measurement is required monthly – as well as pH, temperature and conductivity - by the operating permission (Umhverfisstofnun, 2005). Information about flow rate combined with chemical analyses would shed light on the amounts of the contaminants, which are transported by water from the dumping site to the environment, and which are accumulating in marine biota and sediment. The accumulation of the metals has happened though the chemical water analyses show low levels.

Ólafsdóttir and Steinarsdóttir (2006) suggest to estimate the composition and the quantities of different categories of waste by evaluating the local activities in the area from the period the waste was produced (Ólafsdóttir & Steinarsdóttir, 2006). The example of the composition of the dumping site at Gufunes describes the type of waste, that has been dumped at Draugagil, compared to figures 3 to 8. Additionally carries weight that a power plant including all necessary infrastructure (for example roads, power lines) was constructed in the area and the power plant is performing maintenance. The level of copper can be resulted by copper lines, dumped at Draugagil – an expensive natural resource, that is normally recovered and recycled. At the boom time at Blönduós some joineries were operating, for example impregnating timber with chromated copper arsenate (CCA) for the constructions. The declining population caused a large amount of waste. The level of chromium in the tissue of dogwhelks points to all cars, industrial equipment, household appliances and so on, that once had been with a silver coloured cover and chromium containing painting.

By pre-investigation in winter 2012 the rocks on the shore beneath the dumping site were covered with an immense number of blue mussels, but no individuals exceeded 10 mm. This indicates a lot of available organic matter beneath the dumping site, possibly coming by leachate with the effect of settlement of blue mussels there similar described by Jónsson (1976). Additionally, the small size of the mussels indicates decreased growth, possibly caused by physical, chemical and microbiological factors or by intra- and interspecific competition and by last not least, predators like migratory birds, crabs and dogwhelks. The shells of the dogwhelks,

collected in March 2012, were mostly dark coloured, which indicates that they feed predominantly on blue mussels and less on barnacles, found by Crothers 1974. At the first sampling time 7th of March less than fifty dogwhelks were found, which can be the result of the low temperature of the seawater (3°C, table 8), that they were still – somewhere else, but nearby – in winter aggregation, when not feeding for about five months and detoxifying themselves. The sampling of dogwhelks two weeks later, collected just before the migratory birds arrive in spring, yielded much more dogwhelks from the same area at the shore, that was depleted of dogwhelks two weeks before. While dogwhelks crawl only some centimetres a year (Castel *et al.*, 1981), the occurrence of 150 dogwhelks on the sampling site two weeks later is surprising. One possible reason may be that 7th of March the first “wave” of dogwhelks at this special feeding site were collected and may be two weeks later more dogwhelks of the same population, which had left their winter aggregation only a little bit later than the first group, were found. The appearance of these newcomers may be in opposite to the observations of Crothers (1985a), that dogwhelks move annually only up to 1 metre.

The collected dogwhelks were adult, shell length 34,5 mm and less, while the average shell length in the study by Leung *et al.* (2005) was 23 mm. Adult dogwhelks feed on 15 to 40 mussels a year (Crothers, 1983), the amount of consumed food depends among other things on the type of feeding strategy they use (Caro *et al.*, 2008). The sessile filter feeders at the sampling site were mostly only one winter old, and their metals level are unknown, no data is available about chemical analyses in blue mussels or barnacles in the Húnaflói Bay, especially not about such small individuals of these species.

Another question is whether 14 (or less) days exposure in the water column beneath the dumping site is sufficient to accumulate the metal concentrations, which were measured in their tissues. Or, the next question: whether possibly the sea water around contains increased levels of metals? Both *Nucella lapillus* and *Mytilus edulis* are common inhabitants of the tidal zone at Icelandic coasts (Ingólfsson, 2009), but for this study the described mobility of *N. lapillus* means uncertainty of the origin of the dogwhelks – and the measured levels of metals in their bodies. To solve this problem monitoring animals are placed in cages in front of expected exposure of contaminants like it is practised near industry or larger landfills in Iceland (Einarsson, 2011; ISAL, 2002).

All the spring and summer time dogwhelks are prey to eider, gulls and oystercatchers. In spite of exposure to predators and physical factors, in August the sampling site at Skúlahorn revealed a large number of dogwhelks under cover of *Fucus* spp., apparant meeting in feeding aggregations

at the rocky shore (Caro *et al.*, 2008; Feare, 1970; Hunt & Scheibling, 1998; Quinn *et al.*, 2012; Rovero *et al.*, 1999).

The concentrations of contaminants depend of the type of prey and their detoxification practices. *Mytilus edulis* and *Nucella lapillus* regulate the concentration of zinc by induction of MTs and detoxify, when bounded metals are excreted (Leung *et al.*, 2005). Seasonal differences can cause that the range between the contamination levels of dogwhelks collected in the end of winter and in late summer may be still more than it was indeed, because in winter blue mussels and dogwhelks do not feed and detoxify themselves, analog to Skarphéðinsdóttir *et al.* (1996).

The origin of the metals are natural and anthropogenic. The part of the metals, that comes from a natural source, can be of geochemical and volcanic origin. Gunnlaugsdóttir *et al.* (2007) reported, that the samples in the Westfjords contain higher contaminant levels in blue mussels, but not in sediment. Analog is the contamination of cadmium in blue mussels and their predators, the dogwhelks, at Blönduós at Húnaflói Bay not explained by direct volcanic impact, because these sampling sites are not located at the Icelandic volcanic zone. Gunnlaugsdóttir *et al.* (2007) validate, that the explanation for higher cadmium levels in blue mussels in this area is not found in cadmium levels in sediment.

One possible explanation is that aquatic transport of volcanic ash from the south of Iceland by the Icelandic current clockwise around the island. The very small amount of metals in the chemical water analyses (1994, 2004, 2009 and 2012) from the brook Draugagilslækur (Table 7) is not reflected by the values of metal concentration in dogwhelks collected at Draugagil in 2012 (Table 10). The discrepancy between low cadmium concentration in sediment and high levels in *Mytilus edulis* in the Westfjords contradict investigation in sediment and mussels (*Mya arenaria*) from Spitzbergen and the Baltic Sea (Pempkowiak *et al.*, 1999), which show the anthropogenic impact on geological environment and biota. The case of cadmium contamination, measured in blue mussels, in the Westfjords (Table 2) - in relation to the global amounts of cadmium production (Table 3) and worldwide distribution (Table 4) - brings up the question, whether the measured cadmium is transported by the currents similar to larvae in the ocean (Jónasson *et al.*, 2010; Óskarsson *et al.*, 2009).

Another explanation could be, that when there is low correlation between sediment and mussel concentrations of cadmium, that can be caused by high correlation between high cadmium concentration and high salinity (Apeti *et al.*, 2009; Giltrap *et al.*, 2012).

Kristján Jónasson (Project manager geology and curator of mineralogy and petrology at the Icelandic Institute of Natural History 6th of July 2012, personal communication) believes that the

environmental pollution at Draugagil is rather caused by anthropogenic impact. The significant differences in metal contamination between samples collected at Draugagil and samples at Skúlahorn exclude that it may be caused exclusively by airborne pollution, additionally the geochemical properties may be similar at both sites. Microbiological tests with mercury resistant bacteria indicate the presence of Hg resistant bacteria at the dumping site at Draugagil (table 9), but not as high levels as Markúsdóttir (2011) measured in leachate (table 7). It is understandable, that Ólafsdóttir and Steinarsdóttir (2006) in their regional survey of the dumping sites in Reykjavík call for the registration of former dumping sites, after they discovered waste deposits all around Reykjavík. The former dumping sites around Iceland are often located right there, where in former times open burning places were and later the municipalities got an operating licence to practice landfilling (Meyles, 2003). In that sense, the dumping sites are less visible, but anyhow, former dumping sites are still dispensing dangerous substances to the nature.

5 Conclusions

The results of metal measurements in dogwhelks show significant higher levels in dogwhelks from the shore beneath the dumping site at Draugagil than from the reference site.

The method to detect pollutants by microbial test can be targeted to particular metals by using contaminant specialised microorganisms.

Chemical pollutants analysis in marine biota along with microbial testing can detect marine pollution caused by leachate from a dumping site, but the method needs further development, preferably highlighting biological responses of the indicator organisms.

It is in the nature of a dumping site like these, that the mixture of organic matter with metals cause the discharge of undesirable and toxic substances. The uncontrolled metal transfer from the dumping site down to the shore leads to further accumulation in the marine ecosystem.

Metal exposure with cadmium, chromium, copper and zinc associated with the presence of mercury resistant bacteria in the leachate running from the dumping site at Draugagil calls for further investigations to limit the damage at the shoreline on both sides of the mouth of the river Blanda, also out of consideration for the importance of salmon angling in the rivers Blanda and Laxa á Ásum.

References

- Adams, M.R. & Moss, M.O. (2008).** *Food Microbiology*, 3rd ed. Cambridge: RSC Publishing.
- Adriaens, P. (2013a).** *Haematopus ostralegus* Linnaeus, 1758. Accessed through: World Register of Marine Species at <http://www.marinespecies.org/aphia.php?p=taxdetails&id=147436> on 2013-03-19.
- Adriaens, P. (2013b).** *Larus argentatus* Pontoppidan, 1763. Accessed through: World Register of Marine Species at <http://www.marinespecies.org/aphia.php?p=taxdetails&id=137138> on 2013-03-19.
- Adriaens, P. (2013c).** *Somateria mollissima* (Linnaeus, 1758). Accessed through: World Register of Marine Species at <http://www.marinespecies.org/aphia.php?p=taxdetails&id=137074> on 2013-03-19.
- Aðalsteinsdóttir, K. (1987).** Líf í ám og lækjum á Akureyri [Life in rivers and brooks at the town Akureyri in Northern Iceland]. *Fjölrit* **14**. Akureyri: Náttúrugripasafnið á Akureyri.
- Alþingi (2013a).** Lög um meðhöndlun úrgangs nr. 55/2003 [Act on Waste Management] 141th ed. Accessed 5th of May 2013 from Lagasafn <http://www.althingi.is/lagas/nuna/2003055.html>
- Alþingi (2013b).** Lög um náttúruvernd nr. 48/1956 [Nature Conservation Act].
- Alþingi (2013c).** Lög um náttúruvernd nr. 47/1971 [Nature Conservation Act] 120th ed. Accessed 5th of May 2013 from Lagasafn <http://www.althingi.is/lagas/120b/1971047.html>
- Alþingi (2013d).** Lög um náttúruvernd nr. 93/1996 [Nature Conservation Act] 123th ed. Accessed 5th of May 2013 from Lagasafn <http://www.althingi.is/lagas/123a/1996093.html>
- Alþingi (2013e).** Lög um náttúruvernd nr. 44/1999 [Nature Conservation Act] Accessed 5th of May 2013 from <http://www.althingi.is/altext/lagas/141a/1999044.html>
- Anon. (2012).** Veðurathuganir Meðaltalstöflur [Weather observations] Reykjavík: Icelandic Meteorological Office. Accessed 19th of Sept. 2012 from <http://www.vedur.is/vedur/vedurfar/medaltalstoflur/>
- Apeti, D.A., Lauenstein, G.G. & Riedel, G.F. (2009).** Cadmium distribution in coastal sediments and mollusks of the US. *Marine Pollution Bulletin* **58** (7), 1016-1024.

- Arnesen, G. (1974).** Sporefningarannsóknir Kvikasilfur í fiski [Research of trace elements. Mercury in fish] *Tæknitíðindi* **41** (20th of February 1974). Reykjavík: Icelandic Fisheries Laboratories.
- Arnesen, G., Árnadóttir, E., Guðmundsson, M. & Antonsson, H. (1986).** Snefilmálmur í íslenskum fiski og fiskafurðum [Trace metals in Icelandic fish and fish products] **9. Rit.** Reykjavík: Icelandic Fisheries Laboratories.
- Atlas, R.M. & Bartha, R. (1993).** *Microbial Ecology*, 3rd ed. San Francisco: *The Benjamin Cummings Publishing Inc.*
- Ásgeirsdóttir, B.R. (2011).** Blönduós lausn á fráveitumálum vestan Blöndu. [Blönduós sewer solution for western the river Blanda] B.Sc. thesis. School of Science and Engineering. Reykjavík: Reykjavik University.
- Baird, C. & Cann, M. (2008).** *Environmental chemistry*, 4th ed. New York: *W.H. Freeman and Company*.
- Baird, S.K., Kurz, T. & Brunk, U.T. (2006).** Metallothionein protects against oxidative stress-induced lysosomal destabilization. *Biochem. J.* **394**, 275–283.
- Barkay, T., Miller, S.M. & Summers, A.O. (2003).** Bacterial mercury resistance from atoms to ecosystems. *FEMS Microbiology Reviews* **27**, 355-384.
- Bell, E.C. & Gosline, J.M. (1996).** Mechanical design of mussel byssus: material yield enhances attachment strength. *The Journal of Experimental Biology* **199**, 1005-1017.
- Bjarnadóttir, H.J., Svavarsson, G., Steingrímsson, J.H. & Haltbakk, J. (2008).** *Urðunarstaður í Gufunesi* Mælingar og áhættumat vegna fyrirhugaðrar breytingar á landnotkun. [Landfill at Gufunes. Measurement and assessment of the proposed changes in land use] Project RU07GU. Reykjavík: City of Reykjavík.
- Borja, Á. (2005).** The European water framework directive: A challenge for nearshore, coastal and continental shelf research. *Continental Shelf Research* **25**, 1768-1783.
- Bourgoin, B.P. (1990).** *Mytilus edulis* shell as a bioindicator of lead pollution: considerations on bioavailability and variability. *Mar Ecol Prog Ser* **61**, 253-262.
- Brooks, S., Harman, C., Zaldibar, B., Izagirre, U., Glette, T., Marigómez, I. (2011).** Integrated biomarker assessment of the effects exerted by treated produced water from an onshore natural gas processing plant in the North Sea on the mussel *Mytilus edulis*. *Marine Pollution Bulletin* **62**, 327–339.
- Buchsbaum, R., Buchsbaum, M., Pearse, J. Pearse, V. (1987).** *Animals Without Backbones*, 3rd ed. Chicago: *The University of Chicago Press*.

- Buschbaum, C. & Saier, B. (2001).** Growth of the mussel *Mytilus edulis* L. in the Wadden Sea affected by tidal emergence and barnacle epibionts. *Journal of Sea Research* **45**, 27-36.
- Callow, M.E. & Callow, J.A. (2002).** Marine biofouling: a sticky problem. *Biologist* **49** (1), 1-5.
- Campbell, N.A., Reece, J.B., Urry, L.A., Cain, M.L., Wasserman, S.A., Minorsky, P.V. & Jackson, R.B. (2008).** *Biology*, 8th ed. San Francisco: *Pearson Benjamin Cummings*.
- Caro, A.U., Escobar, J., Bozinovic, F., Navarrete, S.A. & Castilla, J.C. (2008).** Phenotypic variability in byssus thread production of intertidal mussels induced by predators with different feeding strategies. *Mar Ecol Prog Ser* **372**, 127–134.
- Castel, S.L. & Emery, A.E.H. (1981).** *Nucella lapillus*: A possible model for the study of genetic variation in natural populations. *Genetica* **56** (1), 11-15. Abstract.
- Castro, P. & Huber, M.E. (2005).** *Marine Biology*, 5th ed. Boston: *McGrawHill*.
- Chan, B.K.K. (2012).** *Amphibalanus amphitrite* (Darwin, 1854). Accessed through: World Register of Marine Species at <http://www.marinespecies.org/aphia.php?p=taxdetails&id=421137> on 2013-03-19.
- Clark, R.B. (1992).** *Marine Pollution*, 3rd ed. Oxford: *Oxford University Press*.
- Coelho, J.P., Pimenta, J., Gomes, R., Barroso, C.M., Pereira, M.E., Pardal, M.A. & Duarte, A. (2006).** Can *Nassarius reticulatus* be used as a bioindicator for Hg contamination? Results from a longitudinal study of the Portuguese coastline. *Marine Pollution Bulletin* **52**, 674–680.
- Connell, J.H. (1961).** The Influence of Interspecific Competition and Other Factors on the Distribution of the Barnacle *Chthamalus Stellatus*. *Ecology* **42** (4), 710-723.
- Council of the European Union (1999).** Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste. *Official Journal L* **182** , 16/07/1999 P. 0001 – 0019. Accessed 5th of May 2013 from <http://eur-lex.europa.eu/en/index.htm>
- Crothers, J.H. (1983).** Some observations on shell-shape variation in North American populations of *Nucella lapillus* (L.). *Biological Journal of the Linnean Society* **19**, 237- 274.
- Crothers, J.H. (1974).** On Variation on the shell of *Nucella lapillus* (L). I. Pembrokeshire. *Field Studies* **4**, 39-60.
- Crothers, J.H. (1985a).** Dog-whelks. An Introduction to the Biology of *Nucella lapillus* (L). *Field Studies* **6**, 291-360.
- Crothers, J.H. (1985b).** Two different patterns of shell-shape variation in the dog-whelk *Nucella lapillus* (L.). *Biological Journal of the Linnean Society* **25**, 339-353.

- Cusson, M. & Bourget, E. (2005).** Small-scale variations in mussel (*Mytilus* spp.) dynamics and local production. *Journal of Sea Research* **53**, 255-268.
- Da Ros, L., Moschino, V., Guerzoni, S. & Halldórsson, H.P. (2007).** Lysosomal responses and methallothionein induction in the blue mussel *Mytilus edulis* from the south-west coast of Iceland. *Environmental International* **33**, 362-369.
- Da Ros, L., Nasci, C., Marigómez, I. & Soto, M. (2000).** Biomarkers and trace metals in the digestive gland of indigenous and transplanted mussels, *Mytilus galloprovincialis*, in Venice Lagoon, Italy. *Marine Environmental Research* **50**, 417-423.
- Der Brockhaus (2003).** *Der Brockhaus Naturwissenschaft und Technik* [Natural sciences and technics] III. Mannheim: Verlag Bibliographisches Institut & F.A. Brockhaus AG. Heidelberg: *Spektrum Akademischer Verlag GmbH*.
- Einarsson, Á. (2011).** Urðunarstaðurinn í Álfsnesi. Efnarannsóknir á sigvatni, grunnvatni, sjó og kræklingi árin 2009-2011. Drög. [The landfill at Álfsnes. Chemical Research in leachate, groundwater, blue mussels in the years 2009 to 2011. Draft] Reykjavík: Sorpa.
- Ericson, G., Skarphéðinsdóttir, H., Dalla Zuanna, L. & Svavarsson, J. (2002).** DNA adducts as indicators of genotoxic exposure in indigenous and transplanted mussels, *Mytilus edulis* L. from Icelandic coastal sites. *Mutation Research* **516**, 91-99.
- Ettxeberria, M., Cajaraville, M.E. & Marigomez, I. (1995).** Changes in Digestive Cell Lysosomal Structure in Mussels as Biomarkers of Environmental Stress in the Urdaibai Estuary (Biscay Coast, Iberian Peninsula). *Marine Pollution Bulletin* **30 (9)**, 599-603.
- Feare, C.J. (1970).** Aspects of the Ecology of an Exposed Shore Population of Dogwhelks *Nucella lapillus* L. *Oecologia* **5**, 1-18.
- Fransen, C. & Türkay, M. (2013).** *Carcinus maenas* (Linnaeus, 1758). Accessed through: World Register of Marine Species at <http://www.marinespecies.org/aphia.php?p=taxdetails&id=107381> on 2013-03-19.
- Galaktionov, K.V., Blasco-Costa, I. & Olson, P.D. (2012).** Life cycles, molecular phylogeny and historical biogeography of the 'pygmaeus' microphallids (*Digenea*: Microphallidae): widespread parasites of marine and coastal birds in the Holarctic. *Parasitology* **139 (10)**, 1346-1360.
- Giltrap, M., Macken, A., Davoren, M., McGovern, E., Foley, B., Larsen, M., White, J. & McHugh, B. (2012).** Utilising caging techniques to investigate metal assimilation in *Nucella lapillus*, *Mytilus edulis* and *Crassostrea gigas* at three Irish coastal locations. *Estuarine, Coastal and Shelf Science* xxx 1-10. (Article in press, corrected Proof. doi:10.1016/j.ecss.2011.11.040).

- Gíslason, G.M. (1980).** Áhrif mengunar á dýralíf í varmám [The effect of pollution on the fauna of two thermal rivers in Iceland] *Náttúrufræðingurinn* **50** (1), 35-45.
- Gofas, S. (2012a).** *Mytilus galloprovincialis* Lamarck, 1819. Accessed through: World Register of Marine Species at <http://www.marinespecies.org/aphia.php?p=taxdetails&id=140481> on 2013-03-19.
- Gofas, S. (2012b).** *Nassarius reticulatus* (Linnaeus, 1758). Accessed through: World Register of Marine Species at <http://www.marinespecies.org/aphia.php?p=taxdetails&id=140513> on 2013-05-04.
- Gofas, S. (2013a).** *Mytilus edulis* Linnaeus, 1758. Accessed through: World Register of Marine Species at <http://www.marinespecies.org/aphia.php?p=taxdetails&id=140480> on 2013-03-19.
- Gofas, S. (2013b).** *Nucella lapillus* (Linnaeus, 1758). Accessed through: World Register of Marine Species at <http://www.marinespecies.org/aphia.php?p=taxdetails&id=140403> on 2013-03-19.
- Gosselin, L.A. & Qian, P.J. (1997).** Juvenile mortality in benthic marine invertebrates. *Mar Ecol Prog Ser* **146**, 265-282.
- Guðmundsdóttir, S. (2011).** Sláturúrgangur í nýju ljósi. Samanburður á fjórum förgunar- og nýtingarleiddum [Offal in a new light. Comparison of four disposal and utilization methods] M.Sc. thesis. School of Engineering and Natural Sciences. Reykjavík: University of Iceland.
- Gunnarsson, K. & Þórisson, K. (1976).** Áhrif skolpmengunar á fjöruþörunga í nágrenni Reykjavíkur [Effects of sewage pollution on littoral algae in the vicinity of Reykjavík] *Fjölrit* **3**. Reykjavík: Marine Research Institute.
- Gunnlaugsdóttir, H., Auðunsson, G.A., Helgason, G.V., Jónsdóttir, R., Jónsdóttir, I., Ragnarsdóttir, Þ. & Rabieh, S. (2007).** Ólífræn snefilefni í lífverum við NV-land [Inorganic trace elements in biota at the northwestern coast of Iceland] *Report* **44-07**. Reykjavík: Matis - Food Research, Innovation & Safety.
- Hafstað, Þ.H. (1976).** Blönduós: neysluvatnsathugun [Blönduós: Research of drinking water] *Report* **OS-JKD-7610**. Reykjavík: National Energy Authority.
- Hale Boothe, D.D., Smith, M.C., Gattie, D.K. & Das, K.C. (2001).** Characterization of microbial populations in landfill leachate and bulk samples during aerobic bioreduction. *Advances in Environmental Research* **5** (3), 285-294.
- Hollustuvernd ríkisins (2001a).** Starfsleyfi fyrir móttöku-, flokkunar- og böggunarstöð Sorpeyðingar höfuðborgarsvæðisins b.s. Gufunesi, Reykjavík [Operating permit for

- receiving, sorting and refuse disposal of the capital area] Reykjavík: Environmental and Food Agency Iceland.
- Hollustuvernd ríkisins (2001b).** Starfsleyfi fyrir urðunarstað Sorpeyðingar höfuðborgarsvæðisins b.s. á Álfsnesi [Operating permit for the landfill of refuse disposal for the area of the capital] Reykjavík: Environmental and Food Agency Iceland.
- Holm, E.R. & Bourget, E. (1994).** Selection and population genetic structure of the barnacle *Semibalanus balanoides* in the northwest Atlantic and Gulf of St. Lawrence. *Mar Ecol Prog Ser* **113**, 247-256.
- Hrólfssdóttir, I.D. & Gunnarsson, S. (1993).** Sigvatn og þéttingar sorphauga Ástandsgreining Gufuneshauga [Leachate and gaskets of garbage heaps. State analysis of the heaps at Gufunes] B.Sc. thesis. School of Engineering and Natural Sciences. Reykjavík: University of Iceland.
- Hunt, H.L. & Scheibling, R.E. (1998).** Effects of whelk (*Nucella lapillus* (L.)) predation on mussel (*Mytilus trossulus* (Gould), *M. edulis* (L.)) assemblages in tidepools and on emergent rock on a wave-exposed rocky shore in Nova Scotia, Canada. *Journal of Experimental Marine Biology and Ecology* **226**, 87–113.
- Ingjaldsson, P.P. (1977).** Annáll Skagastrandar 1976. Sorpeyðingar. [Chronicle of Skagaströnd 1976. Refuse disposal] In: Ungmennasamband Austur-Húnavetninga. *Húnavaka*. 17th year. Prentverk Odds Björnssonar hf.
- Ingólfsson, A. (1996).** The distribution of intertidal macrofauna on the coasts of Iceland in relation to temperature. *Sarsia* **81**, 29-44.
- Ingólfsson, A. (1999).** The macrofauna of the tidal flats at Blikastaðir, southwestern Iceland, during a 27-year period. *Rit fiskideildar* **16**. 141-154.
- Ingólfsson, A. (2005).** Community structure and zonation patterns of rocky shores at high latitudes: an interocean comparison. *Journal of Biogeography* **32**, 169-182.
- Ingólfsson, A. (2009).** Predators on rocky shores in the northern Atlantic: Can the results of local experiments be generalized on a geographical scale? *Estuarine, Coastal and Shelf Science* **83**, 287–295.
- Ingólfsson, A. & Steinarsdóttir, M.B. (2002).** Rannsóknir á lífríki fjöru í Hraunsvík austan Straumsvíkur (Drög að lokaskýrslu) [Studies of the coastal biota at Hraunsvík eastern of Straumsvík (Draft of final report)] Institute of Biology. Reykjavík: University of Iceland.
- Ingólfsson, A. & Svavarsson, J. (1995).** Study of marine organisms round a cathode dumping site in Iceland. *The Science of the Total Environment* **163**, 61-92.

- Izagirre, U. & Marigómez, I. (2009).** Lysosomal enlargement and lysosomal membrane destabilisation in mussel digestive cells measured by an integrative index. *Environmental Pollution* **157**, 1544–1553.
- Ísberg, J. (1973).** Miklar framkvæmdir í vaxandi bæ. [Many projects in the growing town.] In: Ungmennasamband Austur-Húnavetninga. *Húnavaka*. 13th year. *Prentverk Odds Björnssonar hf.*
- Ísberg, J. (1974).** Fáum við heitt vatn? [Do we get hot water?] In: Ungmennasamband Austur-Húnavetninga. *Húnavaka*. 14th year. *Prentverk Odds Björnssonar hf.*
- Ísberg, J. (1975).** Frá Blönduóshreppi. [From Blönduós.] In: Ungmennasamband Austur-Húnavetninga. *Húnavaka*. 15th year. *Prentverk Odds Björnssonar hf.*
- ISAL (Icelandic Aluminium Company) (2002).** Mat á umhverfisáhrifum [Environmental impact assessment] Maí 2002. Reykjavík: *Hönnun hf.*
- Jonsson, S., Ejlertsson, J. & Svensson, B.H. (2003a).** Behaviour of mono- and diesters of o-phthalic acid in leachates released during digestion of municipal solid waste under landfill conditions. *Advances in Environmental Research* **7**, 429-440.
- Jonsson, S., Ejlertsson, J. & Svensson, B.H. (2003b).** Transformation of phthalates in young landfill cells. *Waste Management* **23**, 641-651.
- Jóhannesson, M., Ólafsson, J., Magnússon, S.M., Egilson, D., Sigurðsson, S., Auðunsson, G.A. & Einarsson, S. (1995).** Mengunarmælingar í sjó við Ísland, lokaskýrsla. 1995. [Pollution measurements of the sea around Iceland, final report]. Reykjavík: Ministry for the Environment and Natural Resources.
- Jónasson, J.P., Logemann, K., Marteinsdóttir, G., Jónasson, B. & Ólafsson, H. (2010).** Mat á umhverfisskilyrðum fyrir kræklingarækt við Norðurland – Forkönnun. [Evaluation of environmental conditions for blue mussel farming in the north of Iceland- pilot study.] Report Biopol 10-10 Desember 2010. Skagatrönd/Iceland: Biopol ehf. Marine Biotechnology Science. Reykjavík/Iceland: AVS R&D Fund of Ministry of Fisheries and Agriculture in Iceland. University of Iceland.
- Jónsson, E. (1976).** Mengunarransóknir í Skerjafirði – Áhrif frárennslis á botndýralíf. [Pollution research at Skerjafjörður - Impact of drainage on benthic biota] Reykjavík: Marine Research Institute.
- Júlíusson, A.G. (2011a).** Haugasrannsóknir á urðunarstöðum á Íslandi. [Landfill gas exploration in landfills in Iceland] M.Sc. thesis. Umhverfis- og byggingarverkfræðideild. Reykjavík, Iceland: University of Iceland.

- Júlíusson, A.G. (2011b).** Gagnagrunnur frá hauggasrannsóknnum á urðunarstöðum á Íslandi. [Data base for landfill gas exploration in landfills in Iceland] M.Sc. thesis. Umhverfis- og byggingarverkfræðideild. Reykjavík: University of Iceland.
- Jörundsdóttir, H., Desnica, N., Ragnarsdóttir, Þ. & Gunnlaugsdóttir, H. (2012).** Monitoring of the marine biosphere around Iceland 2010 and 2011/ Mengunarvöktun í lífríki sjávar við Ísland 2010 og 2011. Report no.28- 12. Reykjavík: *Matis - Food Research, Innovation & Safety*.
- Jörundsdóttir, K., Svavarsson, J. & Leung, K.M.Y. (2005).** Imposex levels in the dogwhelk *Nucella lapillus* (L.) - continuing improvement at high latitudes. *Marine Pollution Bulletin* **51**, 744-749.
- Kamsma, R.P.M. & Meyles, C.A. (2005).** Final report Pilot Study on Packaging and Packaging Waste of Iceland. Reykjavík: Environment and Food Agency of Iceland.
- Kelly, T.D. & Matos, G.R. (2013).** Historical statistics for mineral and material commodities in the United States: *U.S. Geological Survey Data Series* **140**. Accessed April 19th 2013 at <http://pubs.usgs.gov/ds/2005/140/>
- Kent, A., Hawkins, S.J. & Doncaster, P. (2003).** Population consequences of mutual attraction between settling and adult barnacles. *Journal of Animal Ecology* **72**, 941–952.
- Krishnakumar, P.K., Casillas, E. & Varanasi, U. (1994).** Effect 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.
- Kristjánsson, T. Ö., Jónsson, J.E. & Svavarsson, J. (2013).** Spring diet of common eiders (*Somateria mollissima*) in Breiðafjörður, West Iceland, indicates non-bivalve preferences. *Polar Biology* **36** (1), 51-59.
- Lane, T.W. & Morel, F.M.M. (2000).** A biological function for cadmium in marine diatoms. *PNAS* **97** (9), 4627-4631.
- Le Rossignol, A.P., Buckingham, S.G., Stephen E.G., Lea, S.E.G. & Nagarajan, R. (2011).** Breaking down the mussel (*Mytilus edulis*) shell: Which layers affect Oystercatchers' (*Haematopus ostralegus*) prey selection? *Journal of Experimental Marine Biology and Ecology* **405**, 87-92.
- Lehtinen, T. (2010).** Bioremediation trial on PCB polluted soils – A bench study in Iceland. M.Sc. thesis. Faculty of Earth Sciences. Reykjavík: University of Iceland.

- Lekube, X., Cajaraville, M.P. & Marigómez, I. (2000).** Use of polyclonal antibodies for the detection of changes induced by cadmium in lysosomes of aquatic organisms. *The Science of the Total Environment* **247**, 201-212.
- Leung, K.M.Y. & Furness, R.W. (1999).** Induction of Metallothionein in Dogwhelk *Nucella lapillus* during and after Exposure to Cadmium. *Ecotoxicology and Environmental Safety* **43**, 156-164.
- Leung, K.M.Y., Dewhurst, R.E., Halldórsson, H. & Svavarsson, J. (2005).** Metallothioneins and trace metals in the dogwhelk *Nucella lapillus* (L.) collected from Icelandic coasts. *Marine Pollution Bulletin* **51**, 729–737.
- Mah, C. & Hansson, H. (2013).** *Asterias rubens* Linnaeus, 1758. In: Mah, C.L. (2013). World Asteroidea database. Accessed through: World Register of Marine Species at <http://www.marinespecies.org/aphia.php?p=taxdetails&id=123776> on 2013-03-19.
- Margesin, R. & Schinner, F. (1994).** Properties of cold-adapted microorganisms and their potential role in biotechnology. *Journal of Biotechnology* **33**, 1-14.
- Marigomez, I., Soto, M., Cajaraville, M.P., Angulo, E. & Giamberini, L. (2002).** Cellular and Subcellular Distribution of Metals in Molluscs. *Microscopy Research and Technique* **56**, 358-392.
- Marigómez, I. & Baybay-Villacorta, L. (2003).** Pollutant-specific and general lysosomal responses in digestive cells of mussels exposed to model organic chemicals. *Aquatic Toxicology* **64**, 235-257.
- Marigómez, I., Soto, M., Cancio, I., Orbea, A., Garmendia, L. & Cajaraville, M.P. (2006).** Cell and tissue biomarkers in mussel, and histopathology in hake and anchovy from Bay of Biscay after the Prestige oil spill (Monitoring Campaign 2003). *Marine Pollution Bulletin* **53**, 287-304.
- Marine Life Information Network (2013).** Accessed 19th of March 2013 from <http://www.marlin.ac.uk>
- Markúsdóttir, M. (2011).** Anthropogenic impact on the microbiota of seashore and freshwater environments in Northern and Eastern Iceland: preliminary assessment and surfactant-degrader bioprospecting. M.Sc. thesis. Faculty of Natural Resource Sciences. Akureyri, Iceland: University of Akureyri.
- Matís (2013).** Hvað er í matnum. ÍSGEM Nutritional information for over 1100 types of food. Accessed 19th of April 2013 from <http://www.hvaderimatnum.is>.
- Matthiessen, P. (2013).** Detection, monitoring, and control of tributyltin – an almost complete success story. *Environmental Toxicology and Chemistry* **32 (3)**, 487-489.

- Mersiowsky, I., Weller, M. & Ejlertsson (2001).** Fate of plasticised PVC products under landfill conditions: a laboratory-scale landfill simulation reactor study. *Wat. Res.* **35 (13)**, 3063-3070.
- Meyles, C.A. (2003).** Förgun úrgangs 1970-2003. [Waste disposal 1970-2003]. Reykavík, Iceland: Fenur -The Icelandic Association of Waste Management.
- Meyles, C.A. & Schmidt, B. (2005).** Report on Soil Protection and Remediation of Contaminated Sites in Iceland. A preliminary study. Reykjavík: Environment and Food Agency of Iceland.
- Nagarajan, R., Lea, S.E.G. & Goss-Custard, J.D. (2006).** Seasonal variations in mussel, *Mytilus edulis* L. shell thickness and strength and their ecological implications. *Journal of Experimental Marine Biology and Ecology* **339**, 241-250.
- Nies, D.H. (2000).** Microbial heavy-metal resistance. *Appl Microbiol Biotechnol* **51**, 730-750.
- Nriagu, J. & Pacyna, J. (1988).** Quantitative assessment of worldwide contamination of air, water and soils by trace metals. *Nature* (**333**) 134-139.
- Ólafsdóttir, K., Skirnisson, K., Gylfadóttir, G. & Johannesson, T. (1998).** Seasonal fluctuations of organochlorine levels in the common eider (*Somateria mollissima*) in Iceland. *Environmental Pollution* **103**, 153-158.
- Ólafsdóttir, K. (4th of June 2002).** Rannsókn á PCB mengun í klettadoppum frá Stokksnesi samkvæmt beiðni dagsettri 16.5.2002 sbr. hjálagt ljósrit. [Study of PCB contamination in *Littorina saxatilis* from Stokksnes in accordance with the request dated 16/05/2002, attached photocopy] Department of Pharmacology and Toxicology. Reykjavík: University of Iceland.
- Ólafsdóttir, K.L. & Steinarsdóttir, S.S. (2006).** *Gamlir urðunarstaðir í Reykjavík*. [Old landfills in Reykjavík] UHR 3-2006. Department of Environment and Traffic. Reykjavík, Iceland: City of Reykjavík.
- Ólafsson, J. (1983).** Þungmálmar í kræklingi við suðvesturland. [Heavy metals in mussels at the southwestern coast of Iceland]. *Fjölrit* **10**. Reykjavík: Marine Research Institute.
- Ólafsson, J. (1986).** Trace metals in mussels (*Mytilus edulis*) from southwest Iceland. *Marine Biology* **90**, 223-229.
- Ólafsson, M. & Jónsson, G.S. (1988).** Mælingar á PCB mengun í krækling í Fáskrúðsfirði og Norðfirði [Measurement of PCB contamination in mussels in Fáskrúðsfjörður and Norðfjörður]. Reykjavík: Environmental and Food Agency Iceland. Icelandic Maritime Administration.

- Óskarsson, G.J., Gudmundsdottir, A. & Sigurdsson, T. (2009).** Variation in spatial distribution and migration of Icelandic summer-spawning herring. *ICES Journal of Marine Science*. **66**, 1762–1767.
- Óskarsson, I. (1962).** *Skeldýrafána Íslands*. II. Sæsniglar með skel (Gastropoda, Prosobranchia & Tectibranchia). [Shellfish fauna of Iceland. II. Sea snails with shell] Reykjavík: Prentsmiðjan Leiftur hf.
- Panova, M., Blakeslee, A.M.H., Miller, W., Mäkinen, T., Ruiz, G.M., Johannesson, K. & André, C. (2011).** Glacial History of the North Atlantic Marine Snail, *Littorina saxatilis*, Inferred from Distribution of Mitochondrial DNA Lineages. *PLoS ONE* **6** (3), e17511.
- Pellerin, J. & Amiard, J.-C. (2009).** Comparison of bioaccumulation of metals and induction of metallothioneins in two marine bivalves (*Mytilus edulis* and *Mya arenaria*). *Comparative Biochemistry and Physiology, Part C* **150**, 186–195.
- Pempkowiak, J., Sikora, A. & Biernacka, E. (1999).** Speciation of heavy metals in marine sediments vs their bioaccumulation by mussels. *Chemosphere* **39** (2), 313–321.
- Petursson, O. (2003).** Management of Contaminated Sites in Europe. Topic Report No. 13/1999. Copenhagen, Denmark: European Environmental Agency.
- Pétursson, H.G. (2006).** Hrun- og skriðuhætta úr bökkum og brekkum á nokkrum þéttbýlisstöðum. Unnið fyrir Ofanfljóðasjóð. [Risk of landslides from slopes at some municipalities. Prepared/Worked for Fond for Avalanches]. Research report NÍ-06016. Reykjavík, Akureyri/Iceland: The Icelandic Institute of Natural History.
- Quinn, B.K., Boudreau, M.R. & Hamilton, D.J. (2012).** Inter- and intraspecific interactions among green crabs (*Carcinus maenas*) and whelks (*Nucella lapillus*) foraging on blue mussels (*Mytilus edulis*). *Journal of Experimental Marine Biology and Ecology* **412**, 117–125.
- Raftopoulou, E.K. & Dimitriadis, V.K. (2012).** Aspects of the digestive gland cells of the mussel *Mytilus galloprovincialis*, in relation to lysosomal enzymes, lipofuscin presence and shell size: Contribution in the assessment of marine pollution biomarkers. *Marine Pollution Bulletin* **64**, 182–188.
- Rainbow, P.S. (2002).** Trace metal concentrations in aquatic invertebrates: why and so what? *Environ. Pollut.* **120**, 497–507.
- Rainbow, P.S., Ng, T.Y.T., Shi, D. & Wang, W.-X. (2004).** Acute dietary pre-exposure and trace metal bioavailability to the barnacle *Balanus amphitrite*. *J. Exp. Mar. Biol. Ecol.* **311**, 315–337.

- Rainbow, & Smith, B.D. (2010).** Trophic transfer of trace metals: Subcellular compartmentalisation in bivalve prey and comparative assimilation efficiencies of two invertebrate predators. *Journal of Experimental Marine Biology and Ecology* **390** (2), 143-148.
- Registers Iceland (2013).** Fasteignaskrá [Land Registry Database] Accessed 2nd of April 2013 from <http://www.skra.is/Fasteignaskra>
- Reykdal, Ó., Thorlacius, A., Auðunsson, G.A. & Steingrímssdóttir, L. (2000).** Selen, joð, flúor, járn, kopar, sink, mangan, kadmín, kvikasilfur og blý í landbúnaðarafurðum. [Selenium, iodine, fluorine, iron, copper, zinc, manganese, cadmium, mercury and lead in agricultural products] *Fjölrit Rala* **204**, 7-36.
- Roesijadi, G. (1994).** Metallothionein Induction as a Measure of Response to Metal Exposure in Aquatic Animals. Napa Conference on Genetic and Molecular Ecotoxicology held 12-15 October 1993 in Yountville, California. *Environ Health Perspect* **102** (12), 91-96.
- Rovero, F., Hughes, R.N. & Chelazzi, G. (1999).** Effect of experience on predatory behaviour of dogwhelks. *Animal Behaviour* **57**, 1241–1249.
- Römpp, H. (1966).** *Chemie-Lexikon*. [Chemistry Encyclopedia] 6th ed. Stuttgart: *Franckh'sche Verlagshandlung*.
- Schachtschabel, P., Blume, H.-P., Brümmer, G., Hartke, K.-H. & Schwertmann, U. (1992).** *Lehrbuch der Bodenkunde*. [Coursebook of pedology] 13th ed. Stuttgart: *Ferdinand Enke Verlag*.
- Skarphedinsdóttir, H. Hallgrímsson, G.T., Hansson, T., Hägerroth, P.-Å., Liewenborg, B., Tjärnlund, U., Åkerman, G., Baršienė, J. & Balk, L. (2010).** Genotoxicity in herring gulls (*Larus argentatus*) in Sweden and Iceland. *Mutation Research/Genetic Toxicology and Environmental Mutagenesis* **702** (1), 24-31. Abstract.
- Skarphéðinsdóttir, H., Ólafsdóttir, K., Svavarsson, J. & Johannesson, T. (1996).** Seasonal Fluctuations of Tributyltin (TBT) and Dibutyltin (DBT) in the Dogwhelk, *Nucella lapillus* (L.), and the Blue Mussel, *Mytilus edulis* L., in Icelandic Waters. *Marine Pollution Bulletin* **32** (4), 358-361.
- Smith, T.M. & Smith, R.L. (2009).** *Elements of Ecology*. 7th ed. San Francisco: *Pearson Benjamin Cummings*.
- Soto, M., Quincoces, I., Lekube, X. & Marigómez, I. (1998).** Autometallographed metal content in digestive cells of winkles: a cost-effective screening tool for monitoring Cu and Zn pollution. *Aquatic Toxicology* **40**, 123-140.

- State Police Commissioner (2012).** Áhættuskoðun almannavarna. [Civil Protection and Emergency Management]. Reykjavík: National Commissioner of the Icelandic Police (NCIP). Civil Protection Section.
- Statistics Iceland (2013).** Population. Accessed 19th of April 2013 from <http://www.statice.is/Statistics/Population>
- Steingrimsdóttir, L., Þorgeirsdóttir, H. & Ólafsdóttir, A.S. (2002).** Hvað borða Íslendingar? Rannsóknir Manneldisráðs Íslands V. [The Diet of Icelanders. Dietary Survey]. Reykjavík: The Icelandic Nutrition Council.
- Sturluson, H. (2011).** Rusl - Förgun þess hjá íslenskum sveitarfélögum. [Waste - Disposal by local municipalities in Iceland] B.Sc. thesis. Anthropology. Félagsvísindasvið Háskóla Íslands. Reykjavík: University of Iceland.
- Svavarsson, G. (2007).** Svæðisáætlun um meðhöndlun úrgangs 2007 – 2020. [Regional Programme about the treatment of waste 2007-2020]. Línuhönnun verkfræðistofa. Sauðárkrúkur, Iceland: Norðurá bs.
- Svavarsson, J. (2002).** Lífríki á klapparbotni neðansjávar í Hraunsvík. Drög að lokaskýrslu. [Life on the seabed underwater in Hraunsvík. Draft of final report]. Apríl 2002. Institute of Biology. Reykjavík: University of Iceland.
- Svavarsson, J. (2004).** Lífríki á botni neðansjávar út af Gufunesi. [Life on the seabed underwater in Hraunsvík. Draft of final report]. *Fjölrit* 70. Institute of Biology. Reykjavík: University of Iceland.
- Sveinsdóttir, K.S. (2010).** Áhrif urðunar á efnasamsetningu vatns í Glerárdal. [Effect of landfill on chemical composition of water in Glerárdalur valley]. B.Sc. thesis. Faculty of Natural Resource Sciences. Akureyri: University of Akureyri.
- Takahashi, S. (2012).** Molecular functions of metallothionein and its role in hematological malignancies. *Journal of Hematology & Oncology* 5:41, 1-8.
- Thiyagarajan, V., Hung, O.S., Chiu, J.M.Y., Wu, R.S.S. & Qian, P.Y. (2005).** Growth and survival of juvenile barnacle *Balanus amphitrite*: interactive effects of cyprid energy reserve and habitat. *Mar Ecol Prog Ser* 299, 229–237.
- Thorarinsdóttir, G.G. & Gunnarsson, K. (2003).** Reproductive cycles of *Mytilus edulis* L on the west and east coasts of Iceland. *Polar Research* 22 (2), 217-223.
- UKHO (2012).** United Kingdom Hydrographic Office. Accessed 6th of March 2012 from <http://easytide.ukho.gov.uk>

- Umhverfisstofnun (2004).** Landsáætlun um meðhöndlun úrgangs 2004-2016. [National waste treatment plan 2004-2016]. Report UST-2004:14. Reykjavík: Environment Agency of Iceland.
- Umhverfisstofnun (2005).** Starfsleyfi fyrir urðunarstað Blönduósbæjar við Draugagil. [Operating permission for landfill at Draugagil at Blönduós] Reykjavík: Environmental and Food Agency Iceland.
- Umhverfisstofnun (2010).** Landsáætlun um úrgang 2010-2022. [National Programme about waste (NPA) for Iceland 2010 - 2022]. Report UST-20. Reykjavík: Environmental and Food Agency of Iceland.
- UN (2011).** Chemicals. UN National report waste Iceland. New York: United Nations.
- UNEP (2008).** Draft final review of scientific information on lead. Version of November 2008. Geneva, Switzerland: United Nations Environment Programme Chemicals Branch. DTIE
- UNEP (2010).** Final review of scientific information on cadmium –Version of December 2010. Geneva, Switzerland: United Nations Environment Programme Chemicals Branch.
- UNEP (2013).** Global Mercury Assessment 2013, Sources, Emissions, Releases and Environmental Transport. Geneva, Switzerland: United Nations Environment Programme Chemicals Branch.
- Vasconcelos, P., Carvalho, S., Castro, M. & Gaspar, M.B. (2008).** The artisanal fishery for muricid gastropods (banded murex and purple dye murex) in the Ria Formosa lagoon (Algarve coast, southern Portugal). *Scientia Marina* **72** (2), 287-298.
- Viarengo, A., Canesi, L., Mazzucotelli, A. & Ponzano, E. (1993).** Cu, Zn and Cd content in different tissues of the Antarctic scallop *Adamussium colbecki*: role of metallothionein in heavy metal homeostasis and detoxication. *Mar Ecol Prog Ser* **95**, 163-168.
- Wang, W.-X. & Rainbow, P.S. (2008).** Comparative approaches to understand metal bioaccumulation in aquatic animals. *Comparative Biochemistry and Physiology Part C* **148**, 315–323.
- Ward, R.C. & Robinson, M. (2000).** *Principles of Hydrology*. 4th ed. Glasgow: McGrawHill.
- WHO (World Health Organisation) (2003).** Zinc in Drinking-water. In: Guidelines for drinking-water quality, 2nd ed. (2). Health criteria and other supporting information. Geneva, Switzerland: World Health Organization.
- WHO (World Health Organisation) (2006).** Microbial aspects. Guidelines for drinking-water quality. Geneva, Switzerland: World Health Organisation.
- WHO (World Health Organisation) (2010a).** Action is needed on chemicals of major public health concern. Geneva, Switzerland: World Health Organisation.

- WHO (World Health Organisation) (2010b).** Preventing disease through healthy environments. Exposure to arsenic: a major public health concern.
- WHO (World Health Organisation) (2010c).** Exposure to cadmium: a major public health concern. Geneva, Switzerland: World Health Organisation.
- WHO (World Health Organisation) (2010d).** Preventing disease through healthy environments. Exposure to lead: a major public health concern. Geneva, Switzerland: World Health Organization.
- WHO (World Health Organisation) (2011).** Chemical fact sheet. Guidelines for drinking-water quality. 4th ed. Geneva, Switzerland: World Health Organisation.
- Wilson, J.G., Galaktionov, K.V., Sukhotin, A.A., Skirnisson, K., Nikolaev, K.E., Ivanov, M.I., Bustnes, J.O., Saville, D.H. & Regel, K.V. (2011).** Factors influencing trematode parasite burdens in mussels (*Mytilus* spp) from the north Atlantic ocean across to the north Pacific. *Estuarine, Coastal and Shelf Science* **xxx**, 1-7.
(doi:10.1016/j.ecss.2011.10.005).
- WoRMS (2013a).** *Balanus crenatus* Bruguière, 1789. Accessed through: World Register of Marine Species at <http://www.marinespecies.org/aphia.php?p=taxdetails&id=106215> on 2013-03-19.
- WoRMS (2013b).** *Semibalanus balanoides* (Linnaeus, 1758). Accessed through: World Register of Marine Species at <http://www.marinespecies.org/aphia.php?p=taxdetails&id=106210> on 2013-03-19.
- Yngvadóttir, E. & Halldórsdóttir, H. (1998).** Mengunarvöktun í sjó við Ísland 1996 og 1997 Monitoring of the marine biosphere around Iceland 1996 and 1997. IFL report 20-98. Reykjavík: Icelandic Fisheries Laboratories.
- Þorsteinsdóttir, B.H. (2012).** “kíkja í ruslið” Af rusli og ruslurum í kapítalísku samfélagi. ["Check out the trash" About garbage and recyclers in capitalist society] B.Sc. thesis. Ethnology. School of Social Sciences. Reykjavík: University of Iceland.
- Þórarinsdóttir, G.G., Gunnarsson, V.I. & Theódórsson, B. (2007).** Kræklingarækt á Íslandi. [Cultivation of blue mussels in Iceland]. *Náttúrufræðingurinn* **76 (1–2)**, 63–69.