ECOLOGIA BALKANICA

2018, Vol. 10, Issue 1 June 2018 pp. 57-84

Synopsis

Mussels in Ecotoxicological Studies - Are They Better Indicators for Water Pollution Than Fish?

***Vesela S. Yancheva*[1], *Stela G. Stoyanova*[2*], *Elenka S. Georgieva*[2], *Iliana G. Velcheva*[1]**

1 - University of Plovdiv, Faculty of Biology, Department of Ecology and Environmental Conservation, Tzar Assen Str. 24, Plovdiv, 4000, BULGARIA
2 - University of Plovdiv, Faculty of Biology, Department of Developmental Biology, Tzar Assen Str. 24, Plovdiv, 4000, BULGARIA
*Corresponding author: stela.st@abv.bg

Abstract. EU Member states are required to apply the EU Water Framework and its Daughter Directives in order to achieve Good Environmental Status (GES) for all 11 qualitative descriptors by 2015 in all water bodies for a list of priority and specific pollutants. Therefore, environmental indicators and biological-effect techniques have to be carefully selected for the management of chemicals in the aquatic environment and for developing an integrated framework. The most commonly applied biological-effect tools are measures of the biochemical and physiological state of selected organisms, such as mussels or fish. The present article provides basic information on the EU Water Directive, the essence of biomarkers, and outlines why mussels may be the better choice of indicators in toxicological research and monitoring programs in order to study the impact of contaminants in water ecosystems.

Key words: mussels, contamination, water, indicators.

Water contamination as a global issue

Water is the key resource required to sustain life on this planet and it is important to both society and ecosystems (PAUL, 2017). In addition, freshwater is the most important resource for mankind, crosscutting all social, economic and environmental activities. It is a condition for life on the Earth, an enabling or limiting factor for any social and technological development, a possible source of welfare or misery, cooperation or conflict (BOUWER, 2002). As stated by LOMSADZE *et al.* (2017) we depend on a reliable, clean supply of drinking water to sustain our health. We also need water for agriculture, energy production, recreation and manufacturing. However, many of these uses put pressure on water resources. Therefore, in recent years, water contamination has been considered as a global issue (CUI *et al.*, 2011; YUAN *et al.*, 2011). Studies conducted in Arabian Gulf (NASER, 2013); Argentina (MARCOVECCHIO, 2004); Bangladesh (RAHMAN *et al.*, 2012); Chile (TAPIA *et al.*, 2009); China (WANG *et al.*, 2005; QIAO-QIAO *et al.*, 2007; YI *et al.*, 2011; LI *et al.*, 2013; ZHANG *et al.*, 2013); Croatia (KLOBUČAR *et al.*, 2008); Egypt (RASHED, 2001a); Ethiopia (YOHANNES *et al.*, 2013); France (SHINN *et al.*, 2009); India (SANKAR *et al.*, 2006; SIVAPERUMAL *et al.*, 2007; RAJESHKUMAR *et al.*, 2013; AROCKIA

http://eb.bio.uni-plovdiv.bg

Union of Scientists in Bulgaria – Plovdiv
University of Plovdiv Publishing House

VASANTHI *et al.*, 2013); Malaysia (TAWEEL *et al.*, 2013); Norway (NÆS *et al.*, 1999; BERGE *et al.*, 2011); Pakistan (SHAHBAZ *et al.*, 2013); Serbia (SUBOTIĆ *et al.*, 2013); Slovenia (TOLLEFSEN *et al.*, 2006; MILAČIČ *et al.*, 2017); Spain (OLMEDO *et al.*, 2013); Sudan (PRAGST *et al.*, 2017); Tailand (PEEBUA *et al.*, 2006); Turkey (TÜRKMEN *et al.*, 2005; GÖRÜR *et al.*, 2012); Zimbabwe (BIRUNGI *et al.*, 2007) and even Arctic regions (SONNE *et al.*, 2009) show that contamination is an ecological problem worldwide, suggesting that it could be affecting the aquatic organisms and having a considerable impact on the health of water ecosystems. Thus, the scientific community suggests that urgent actions and strategies need to be taken to prevent and control the pollution.

One of the dangerous types of water pollution is with heavy metals (As, Cu, Cd, Hg, Pb, Zn) (MOISEENKO & KUDRYAVTSEVA, 2001; SHAH *et al.*, 2009; CARRASCO *et al.*, 2011; PAUL & SINHA, 2013; AVKOPASHVILI *et al.*, 2017); persistent organic pollutants (POPs) (HYLLAND *et al.*, 2006; 2008), pesticides (DEVAULT *et al.*, 2009; LOOS *et al.*, 2009; YADAV *et al.*, 2010); crude oil (OLSEN *et al.*, 2007; HOLTH *et al.*, 2009; HOLTH *et al.*, 2011; BALK *et al.*, 2011; VESTHEIM *et al.*, 2012) and plastics (ANDRADY, 2011; LÖHR *et al.*, 2017). Furthermore, it has been reported that in recent decades the level of foreign compounds in aquatic ecosystems such as heavy metals, pesticides and other persistent organic pollutants has increased alarmingly as a result of domestic, industrial and agricultural effluents (SEKABIRA *et al.*, 2010; LUSHCHAK, 2011; ONDARZA *et al.*, 2011; PEREIRA *et al.*, 2013; JÖRUNDSDÓTTIR *et al.*, 2014).

Heavy metals are toxic, non-biodegradable and persistent environmental contaminants (HAS-SCHÖN *et al.*, 2008). Large quantities of heavy metals have been released into aquatic systems, both fresh and marine worldwide due to a global rapid population growth and intensive domestic activities, as well as expanding industrial and agricultural production (SREBOTNJAK *et al.*, 2012; ISLAM *et al.*, 2014). Thus, they have severely deteriorated the aquatic ecosystems because of their toxicity, abundance, persistence, and subsequent bioaccumulation and biomagnification (ALI *et al.*, 2013).

POPs include many different contaminant groups such as polyaromatic hydrocarbons (PAHs), organochlorine pesticides (OCPs), including dichlorodiphenyltrichloroethane (DDT), polybrominated diphenyl ethers (PBDEs) used as flame-retardants, and industrial organochlorines (OCs) such as polychlorinated biphenyls (PCBs) (CIESIELSKI *et al.*, 2017). Since most POPs are lipophilic they accumulate in the lipid-rich tissues of living organisms, and thereby biomagnify in the food web (LETCHER *et al.*, 2010). Under this consideration, the United States Environmental Protection Agency (USEPA) classified 16 of them as priority pollutants (QIAO *et al.*, 2006).

Pesticides have been widely applied to protect agricultural crops since the 1940s, and since then, their use has increased steadily (GRUNG *et al.*, 2015). The organochlorine pesticides (OCPs) became the dominant pesticides after the Second World War. With the publishing of "Silent Spring" by Rachel Carson in 1962, a wider audience was warned of the environmental effects of the widespread use of pesticides. Since 1970s, after evidence of their toxicity, persistence and bioaccumulation in environmental matrices OCPs production, usage and disposal have been regulated or prohibited in most of the developed countries (JAN *et al.*, 2009; MARIN-MORALES *et al.*, 2013). In this sense, organophosphorous pesticides (OPs) in many cases replaced organochlorine pesticides (OCs) in agriculture. Even though they have a short-term degradation and fewer residues, OPs unfortunately lack target specificity and can also cause severe, long lasting population effects on aquatic non-target species (FULTON & KEY, 2001; SUN *et al.*, 2011).

Crude oil consists of variety proportions of hydrocarbons such as alkanes, aromatics and PAHs, asphaltene and resins, as well as non-hydrocarbons namely sulphur, nitrogen, oxygen and traces of metals, particularly copper, iron, nickel and vanadium (BRANDT, 2006; SAKTHIPRIYA *et al.*, 2015; WILBERFORCE, 2016). At present, the petroleum industry has entered into a period of modernization and transition. Due to this industrial development, pollution of seawater by crude oil has been increased and creating a serious issues (BAO *et al.*, 2014). As a result, each year enormous quantities of crude oil are disposed into the environment, either deliberate or accident during crude oil production and transportation. Between 1.7 and 8.8 million metric tons of crude oil are estimated being released in the water environment each year (NRC, 1985), of which >90% as deliberate waste disposal, directly related to human activities (NDIMELE, 2010). According to EFFENDI *et al.* (2017) oil spills often bring devastated effects on the aquatic organisms and consequently ruin the aquatic ecosystem homeostasis. LENNUK *et al.* (2015) state that the impact of oil toxicity on various ecosystem elements have been increasingly reported since 1960s and the majority of studies have focused on the oil spill effects on organisms such as plankton, fish, birds and marine mammals. In addition, oil spills incidences all over the world occasionally occur and one of the most devastating ones are linked with the explosion of Deepwater Horizon (WEISBERG *et al.*, 2017) and Exxon Valdez (LINDEBERG *et al.*, 2017).

Last but not least, worldwide there is a growing concern about the risks and possible adverse effects of (micro) plastics because since the 1950s the amount of plastics in the marine environment has increased dramatically (JAMBECK *et al.*, 2015; UNEP, 2016). Furthermore, substantial quantities of microplastics are already present in the global marine ecosystem (ANDRADY, 2011; DESFORGES *et al.*, 2014), from the tropics to the poles, including in Arctic sea ice and numerous studies have already showed the negative effects of microplastics on marine biota (LUSHER *et al.*, 2013; LUSHER, 2015; ROMEO *et al.*, 2015).

Legislation in the field of water conservation

According to VETHAAK *et al.* (2015) many maritime countries in Europe have implemented marine environmental monitoring programs, which include the measurement of chemical contaminants and related biological effects. Moreover, the European Union (EU) has, over the last twenty years, developed its water policies so that now there is significant European legislation covering marine waters, as well as the lakes and rivers that ultimately flow into our coastal ecosystems.

To maintain the water at an adequate quality for humans and to preserve natural ecosystems and biodiversity, it is necessary to sustainably use, protect and manage the water resources. In the countries of the European Union (EU), national water agencies, which follow EU policy and the requirements of the EU Water Framework and its Daughter Directives (DIRECTIVE 2000/60/EC; DIRECTIVE 2008/105/EC; DIRECTIVE 2008/56/EC; EUROPEAN COMMUNITIES ENVIRONMENTAL OBJECTIVES 272/2009; EUROPEAN COMMUNITIES TECHNICAL REPORT, 2010), implement regular water monitoring with the aim to control and prevent pollution (MILAČIČ *et al.*, 2017).

Recently, the Water Framework Directive (WFD, DIRECTIVE 2000/60/EC) of the European Union specified monitoring programs required to assess the achievement of good chemical and ecological status for all water bodies by 2015 for a list of specific pollutants (SANCHEZ & PORCHER, 2009). This list currently stands at 41 pollutants (33 priority substances (PSs) and 8 other pollutants) given in Annex I of DIRECTIVE 2008/105/EC; furthermore, the European Commission (EC) proposed recently to include 15 additional PSs on this existing list (BESSE *et al.*, 2012).

More recently, the European Union has implemented the Marine Strategy Framework Directive (MSFD, Directive 2008/56/EC). At its heart is the concept of "good environmental status" (GES) for all European waters and the provision of a framework for the protection and preservation of the marine environment, the prevention of its deterioration, and, where practicable, the restoration of that environment in areas where it has been adversely affected (Vethaak *et al.*, 2015). In addition, the MSFD is a wide-ranging framework directive with the overall objective of maintaining GES in the seas of Europe by 2020 (Lyons *et al.*, 2010).

GES will be assessed on a regional basis. The Regional Sea Conventions (OSPAR Commission, Helsinki Commission (HELCOM), Barcelona Convention (In 1975, 16 Mediterranean countries and the European Community adopted the Mediterranean Action Plan (MAP), the first-ever Regional Seas Program under UNEP's umbrella) and the Black Sea Commission), which aim to protect the marine environment, were required to support the implementation of the MSFD (Vethaak *et al.*, 2015). According to Lyons *et al.* (2010) the Joint Research Centre (JCR) and the International Council for the Exploration of the Sea (ICES) were also commissioned to facilitate the preparation of scientific bases for criteria and to propose methodological standards in relation to 8 of the GES descriptors during the course of 2009.

As stated by Besse *et al.* (2012) the application of the WFD for the surveillance of chemical contamination of surface waters involves two main objectives: (1) to assess the chemical status of the water bodies, by determining whether contamination levels are compliant with the regulatory Environmental Quality Standards (EQSs); and, (2) to assess the temporal trends of the contamination in the different environmental compartments of aquatic ecosystems. EQSs are defined as "the concentration of a particular pollutant or group of pollutants in *water, sediment or biota,* which should not be exceeded in order to protect human health and the environment". In addition, the assessment of chemical status under WFD is undertaken in fresh, transitional and coastal waters using EQS, which are derived from toxicological information and used to set acceptable limits for individual priority contaminants (Lyons *et al.*, 2010).

Choice of bioindicator species – fish or mussels

The use of living organisms in the study of environmental quality is widely accepted (Stamenković *et al.*, 2013). However, according to Sherman (1994) selecting indicators can be challenging, given the variety of ecosystem characteristics they are intended to track. Furthermore, according to Besse *et al.* (2012) there are currently two different strategies for chemical biomonitoring (i.e. monitoring contamination in biota) that can be adopted: *passive or active.* Passive approaches rely on indigenous organisms, while active approaches rely on transplanted (or caged) individuals from a reference site (see Schøyen *et al.*, 2017).

In the review of Rees *et al.* (2008) it is explained the ideal indicator should be: (i) capable of conveying information that is responsive and meaningful to decision-making (directly tied to management questions and linked to thresholds for appropriate action relative to designated ecosystem goals); (ii) linked to a conceptual stressor–response framework (with the ability to communicate potential cause–effect relationships); (iii) capable of measuring change or its absence with confidence (robust to influences of confounding environmental factors); (iv) highly sensitive and anticipatory (early warning of potential problems); (v) applicable over a variety of spatial scales and conditions (to support global as well as local comparisons); (vi) desirable operationally (easy to measure, reproducible with minimum measurement error, cost-effective); (vii) integrative (serves multiple indicator purposes); (viii) non-destructive (measurement does not cause ecosystem damage); (ix) easy to understand and communicate (non-specialists need to act on findings); (x) scientifically and legally defensible (robust to peer review and wider challenge).

CAIRNS *et al.* (1993) encapsulated the issue of single vs. multiple indicators by noting that "... everything is an indicator of something but nothing is an indicator of everything" in a review of ecosystem health indicators. UNESCO identified three classes of ecosystem indicators (slightly modified): (i) ecological indicators: to characterize and monitor change in the state of various physical, chemical, and biological aspects of the environment relative to defined quality targets with thresholds for management action (see also FISHER, 2001); (ii) socio-economic indicators: to measure whether environmental quality is sufficient to maintain human health, human uses of resources, and favorable public perception (see also CAIRNS *et al.*, 1993); (iii) governance indicators: to monitor the progress and effectiveness of management and enforcement practices towards meeting environmental policy targets. As stated by REES *et al.* (2008) until recently, *ecological indicators* have received most attention.

According to WFD, fish represent one of the key elements to evaluate the rivers ecological status (SCARDI *et al.*, 2008; HERMOSO *et al.*, 2010).

BESSE *et al.* (2012) explain that fish are ideal organisms for checking compliance against biota EQSs, since the protection objectives targeted are human health and/or high-level predators. Hence, out of the 3 biota EQSs defined under Directive 2008/105/EC and the 8 biota EQSs given in the EC proposal to revise this Directive, 10 are based exclusively on a fish matrix. However, BESSE *et al.* (2012) state that if fish are the test organisms of choice for checking compliance with biota EQSs, they have several characteristics that limit their use for active biomonitoring, while macroinvertebrates represent a good compromise in terms of feasibility and fulfilling the objectives of the WFD. In addition, the authors add that fish carry disadvantages for long-term trend analysis on contamination patterns, as they are known to strongly metabolize certain contaminants, and that makes them less valuable as indicators for some PSs. For example, fish strongly metabolize PAHs, limiting in this way their relevance as reliable indicators of PAH pollution; indeed, it is only possible to estimate recent exposure to PAH indirectly by determining biliary concentrations of PAH metabolites (VAN DER OOST *et al.*, 1994). Furthermore, caging is generally unsuitable for fish species and the use of fish for active biomonitoring purposes remains difficult to achieve because in logistical terms, the size of these organisms requires large caging systems that are difficult to handle in the field; and, fish are easily stressed, especially in caging-experiment conditions (which limit their mobility), which risk introducing bias in the responses obtained (OIKARI, 2006).

YANCHEVA *et al.* (2015, 2016a) describe in reviews why in ecotoxicology fish have become the major vertebrate model. Indeed, a tremendous body of information has been accumulated (STEINBERG *et al.*, 1995; BRAUNBECK *et al.*, 1998; MOISEENKO, 2005; RAISUDDIN & LEE, 2008; MURTHY *et al.*, 2013; CZÉDLI *et al.*, 2014). Fish are among the group of aquatic organisms, which represent the largest and most diverse group of vertebrates. They are present virtually in all environments and many species have been found to be susceptible to environmental pollutants (VAN DER OOST *et al.*, 2003). A number of characteristics make fish excellent experimental models for toxicological research, especially for the contaminants which are likely to exert their impact on aquatic systems (LAW, 2003; DE LA TORRE *et al.*, 2010). According to DE LA TORRE *et al.* (2005) monitoring sentinel fish species is widely used to assess the degree of accumulation of pollutants and the effects on health status. In addition, fish have been found to be good indicators of water contamination in aquatic systems because they occupy different trophic levels; they are of different sizes and ages and in comparison with invertebrates, are also more sensitive to many toxicants (DALLINGER *et al.*, 1987; POWERS, 1989; BARAK & MASON, 1990; WESTER *et al.*, 1991; BURGER *et al.*, 2002) Fish respond to environmental toxic changes with adapting of their metabolite functions (MISHRA & SHUKLA, 2003). They are also preferred in toxicological research because of their well-developed osmoregulatory, endocrine, nervous, and immune systems compared to invertebrates (SONG *et al.*, 2012). In addition, the studies of PÉREZ CID *et al.* (2001); FISK *et al.* (2001); RASHED (2001b); MONDON *et al.* (2001); MANSOUR & SIDKY (2002); USERO *et al.* (2004); MENDIL & ULUÖZLÜ (2007); ÖZTÜRK *et al.* (2009); SOUNDERAJAN *et al.* (2010); ROWAN (2013) show that fish may absorb toxicants directly from the surrounding water and sediments (waterborne exposure), or ingest them through contaminated food in the food chain (dietary exposure), enabling the assessment of pollutant transfer through the tropic web.

The pollutants are accumulated through different organs of the fish because of the affinity between them. In this process, many of them are concentrated at different levels in different organs of the fish body (RAO & PADMAJA, 2000). Therefore, in teleost fish, the gills, liver, kidney and muscles are the tissues most frequently utilized in toxicological studies because they are metabolically active tissues and accumulate toxicants at higher levels (HEIER *et al.*, 2009; JOVIČIĆ *et al.*, 2014).

In their review BESSE *et al.* (2012) present information about different national and international project involving fish as a test organism. The authors provide data about the French ''Plan National PCB'', which is a public health-oriented program deployed between 2008–2010. It was designed to step up the monitoring of contamination in aquatic environment and fish products, in order to adopt appropriate risk-management measures. Dioxins, furans, dioxin-like PCBs and indicator PCBs, as well as total Hg were investigated within this program. The project framework included sampling schemes on several fish species across more than 300 sites (around 100 sites a year). The fish species were selected for their PCB bioaccumulation profiles, their national geographical distribution profiles, and their history of use as human food. Another program is the ''Flemish Eel Pollutant Monitoring Network'', which was launched in 1994 in Belgium by the Research Institute for Nature and Forest (Inbo). This monitoring network, public-health oriented, aimed at monitoring the dispersion of pollutants in Flanders for continental waters using European eel (*Anguilla anguilla*). Over a 10-year period, around 360 sites (streams, rivers, canals, ponds and lakes) across Belgium were sampled for environmental analysis of PCB, OCPs and heavy-metal pollution.

To monitor the health of water ecosystems, other sentinel organisms such as mussels (bivalves) have been identified as suitable candidates to indicate the levels of contaminants and their effects in the aquatic environment and as such, they have been proposed to be suitable "biomonitors" of pollution (NAIMO, 1995; BESADA *et al.*, 2011).

Their filtering habits, low metabolism and ability to bioaccumulate pollutants make them an excellent choice to assess their bioavailability and effects (BAYNE, 1989; FOSSATO *et al.*, 1989; WIDDOWS & DONKIN, 1992). Mussels are also sessile, sedentary, long-lived and easy to collect, have a reasonable size for chemical analyses, they are worldwide distributed and present across a very wide geographical areas (basically the entire range of North Atlantic, Baltic, and Mediterranean coastal areas, see THAIN *et al.* (2008)), particularly abundant in coastal and estuarine waters and often found in large amounts (FARRINGTON *et al.*, 1983; GOLDBERG, 1980; 1986; BOLOGNESI *et al.*, 2006; BELLOTTO & MIEKELEY, 2007; CHANDURVELAN *et al.*, 2015).

The U.S. Environmental Protection Agency (EPA) classifies mussels as biomonitors because they react to changes in the surrounding environment. Additionally, since mussels are filter feeders, they bioaccumulate heavy metals and POPs and other contaminants in their bodies and shells (RAINBOW, 1993; CAPPELLO *et al.*, 2013). In comparison to fish and crustaceans, bivalves have a very low level of activity of enzymatic systems capable of metabolizing POPs. Therefore, bivalves are widely used as bioindicators of organic pollution in freshwater, marine and estuarine ecosystems because they are known to provide a time integrated indication of environmental contamination, as well as reliable information on the potential impact of seafood consumption on human health (TURJA *et al.*, 2013).

To monitor the nature and extent of coastal pollution, a Mussel Watch Programme (MWP) was developed by GOLDBERG (1975; 1986) in an attempt to quantify the levels of pollutants in coastal systems. BESSE *et al.* (2012) describe in their review that in marine waters, the NOAA "Mussel Watch" represents the oldest, continuous running contaminant-monitoring program in US coastal and Great Lakes waters. This project has been running since 1986, but the original "US Mussel Watch" program was initiated in 1975 as shown above. The program covers 300 coastal sites and monitors over 100 organic and inorganic contaminants (PAHs, PCBs, DDTs, TBT, OCPs and toxic trace elements) in sediment and biota tissue. It is based on yearly collection and analysis of oysters and mussels. Since there is no species of mussel or oyster common to all coastal regions, a variety of species are collected (*Mytilus* species, *Crassostrea virginica* and *Dreissena* species) in order to gain a national perspective (BESSE *et al.*, 2012).

As stated by BESADA *et al.* (2011) the use of mussels to monitor coastal pollution is now widely accepted and supported by many international organizations (see APETI *et al.*, 2010; MARUYA *et al.*, 2014; MELWANI *et al.*, 2014; SCHÖNE & KRAUSE JR., 2016; BEYER *et al.*, 2017). According to SCHØYEN *et al.* *(2017)* most commonly the mussel watch studies involve collection of samples from natural blue mussel populations, but the adoption of an active biomonitoring alternative by using transplanted blue mussels has gained considerable popularity in ecotoxicology research and monitoring.

Mytilus sp. have been widely used since the 90s, and have been shown to be one of the most successful model organisms for time-integrated responses to complex mixtures of pollutants (UNEP/RAMOGE, 1999). Furthermore, the blue mussels such as *Mytilus edulis* and *Mytilus galloprovincialis* are widely used as sentinels in coastal pollution monitoring (mussel watch) programs, mainly because their biological characteristics make them very suitable as bioindicators for assessing the quality status of coastal waters (ZATTA *et al.*, 1992; HAGGER *et al.*, 2008; WEPENER & DEGGER, 2012; SPARKS *et al.*, 2014; ROUANE-HACENE *et al.*, 2015; FARRINGTON *et al.*, 2016).

In this sense, in France, Ifremer (French research institute for exploration of the sea) has been running the "RNO" network (National observatory network on marine environment quality) since 1974 and since re-named "ROCCH" – National chemical contamination network. This approach is based on monitoring natural populations of three bivalve mollusks – one oyster species (*Crassostrea gigas*) and two mussel species (*Mytilus edulis* and *Mytilus galloprovincialis*) in order to ensure national-scale coverage. About 50 chemical contaminants (PAHs, PCBs, OPs and metals) are currently being monitored at 80 sampling sites around the French coastline. Organisms that have spent at least 6 months seeded in the zone are sampled semi-annually for metal pollutants and annually for organic pollutants (BESSE *et al.*, 2012). In addition, in 1996, Ifremer developed RINBIO ("Re´seau Inte´grateurs Biologiques") as a methodology built around caging marine mussels (*Mytilus galloprovincialis*). Indeed, using transplanted organisms made it possible to compensate for the scarcity of wild-mussel colonies in certain sections of the French Mediterranean coastline as explained by BESSE *et al.* (2012). The authors also mention the recent "Projet Mytilos" initiative, based on the same structural principle as RINBIO, was developed to study heavy-metal contamination (Cd, Hg, Ni and Pb) in caged mussels (*Mitilus galloprovincialis*) at over 120 sites spanning the entire Mediterranean Basin. Another monitoring program in which mollusks were used is the National Water-Quality Assessment (NAWQA) program in the USA, which was launched in 1993 by the United States Geological Survey (USGS) to monitor spatial and temporal trends of contamination for a selection of micropollutants (PAHs, OPs, PCBs, dioxins and metals). This monitoring program encompasses several species: (1) a bivalve mollusk (*Corbicula fluminea*); (2) three insect genus (*Trichoptera, Chironomidae, Plecoptera*); (3) six fish species; and, (4) vascular plants (*Potamogeton sp.* and *Elodea sp.*). Chemical analysis in resident biota was integrated as part of the first cycle of assessments (1993–2001), but was dropped from the second cycle due to the high costs involved and to data-interpretation difficulties (see BESSE *et al.*, 2012).

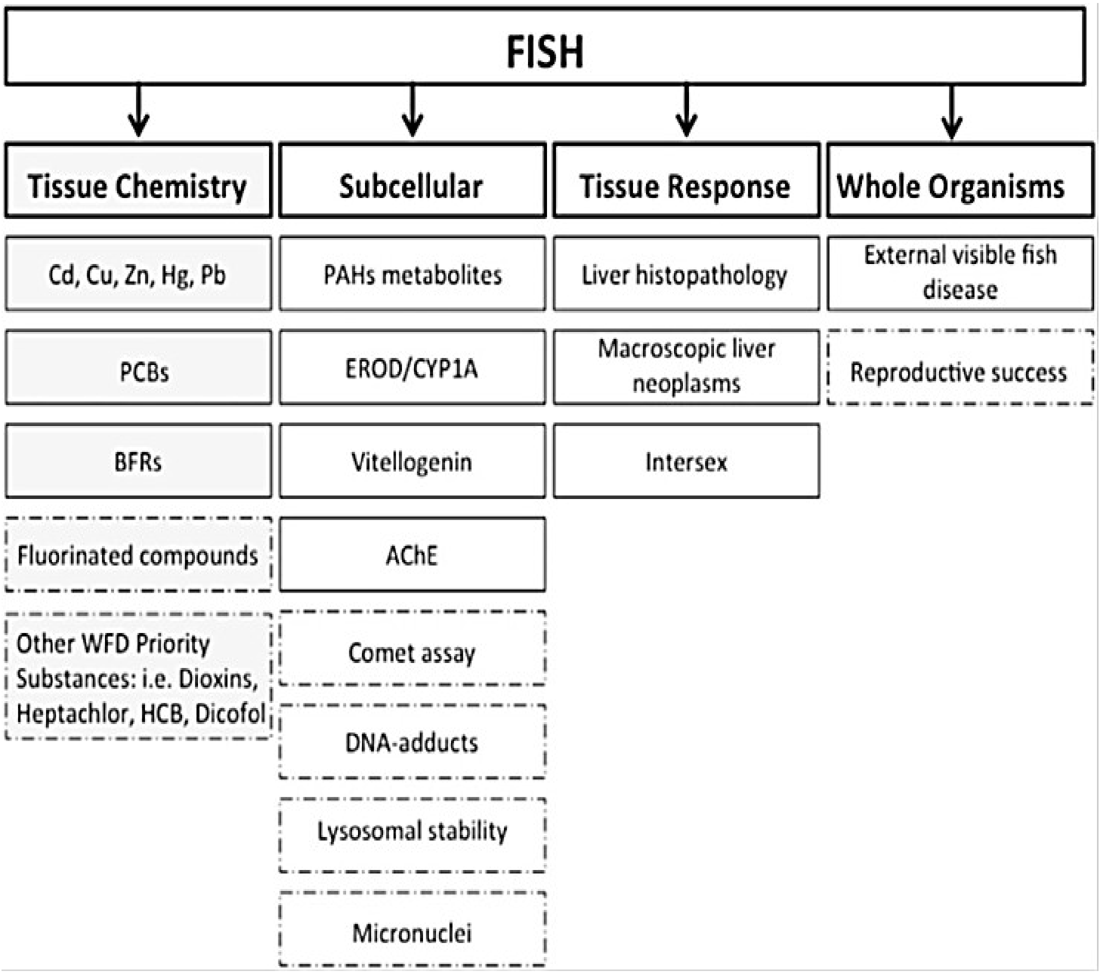

Fig. 1. Determinants and measurements included in the fish component of the ICES/ OSPAR integrated monitoring framework. *Legend:* solid lines - core methods; broken lines - additional methods; PCBs - polychlorinated biphenyls; BFRs - brominated flame retardants; AChE - acetylcholinesterase; WFD - Water Framework Directive, WFD - priority substances are required in biota under DIRECTIVE 39/2013/EU (see THAIN *et al.* (2008) and VETHAAK *et al.* (2015)).

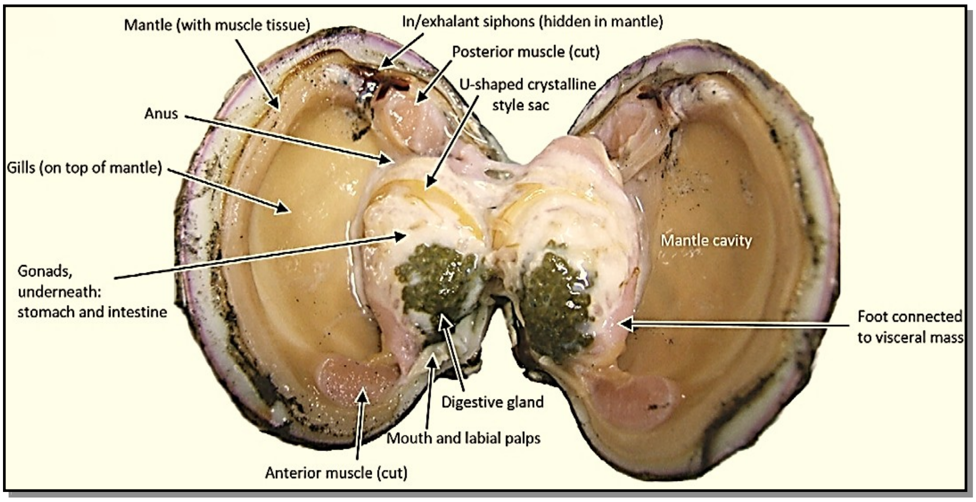

Fig. 2. Overall bivalve anatomy (after SCHÖNE & KRAUSE JR., 2016).

However, other freshwater bivalves such as zebra mussel (*Dreissena polymorpha*) can be used as a freshwater substitute of *Mytilus* sp. (LEPOM *et al.*, 2012) and has already been successfully used in ecotoxicological studies and monitoring programs (CAMUSSO *et al.*, 1994; JOHNS & TIMMERMAN, 1998; DE LAFONTAINE *et al.*, 2000; GUERLET *et al.*, 2007; BINELLI *et al.*, 2010; FARIA *et al.*, 2010; YANCHEVA *et al.*, 2016c; d; 2017).

It is important to outline that the organisms used to cover all three main trophic levels in monitoring programs are – bryophytes, macroinvertebrates, and fish. Furthermore, the most commonly applied species are *Fontinalis antipyretica* for bryophyte species, invasive bivalves *Dreissena polymorpha* and *Corbicula fluminea* for invertebrate species, and *Cyprinus carpio for* fish species (see BESSE *et al.*, 2012).

According to BINELLI *et al.* (2015) one of the fundamentals in the ecotoxicological studies is the need of data comparison. In their study the authors showed the advantages of *Dreissena polymorpha* application in biomonitoring, as well as for the evaluation of adverse effects induced by several pollutants, using both *in vitro* and *in vivo* experiments. Since Directive 2013/39/EU establishes EQS for biota because it has been demonstrated that pollutants bioaccumulate in aquatic organisms, BENITO *et al.* (2017) evaluated bioaccumulation of inorganic elements in the soft tissues of zebra mussels in order to assess the usefulness of this species as a bioindicator of contaminant presence in superficial waters along the Ebro River Basin (Spain). The authors concluded that *Dreissena polymorpha* not only supplies information about current water quality but also acts as a witness of past water quality by bioconcentrating toxic elements present in the environment and providing relevant results about historical water contamination. BESSE *et al.* (2012) explain that in Switzerland, the International Commission for the Protection of the Waters of Lake Geneva (CIPEL), established in 1962, has monitored trends of contamination in biota, notably fish, for 30 years, with the dual purpose of public health and the environment. For example, in 2004, organic micro-pollutants (mercury, PCBs and organotins) and trace metals in aquatic ecosystems and biota (fish and mussels) of Lake Geneva were investigated. Metals and organotins were monitored in *Dreissena polymorpha*, as were mercury and PCBs in several fish species (*Perca fluviatilis, Lota lota, Coregonus sp*. and *Salvelinus alpinus*).

Although, zebra mussels is a harmful and among the top 100 most dangerous invasive species in aquatic habitats, its pervasiveness means that it can be also used as a bioindicator to assess current and past presence of elements in water. Moreover, according to BESSE *et al.* (2012) for active strategies, the use of invasive species should be avoided, meaning that the use of zebra mussels and Asian clams (*Anodonta*) (which are among the most widely-used species) should be limited to sites that these species have already colonized. However, MERSCH *et al.* (1996) and BOURGEAULT *et al.* (2010) successfully used zebra mussels in caging experiments dealing with the effects of different pollutants.

Lastly, the most commonly used bivalve tissues in toxicological studies are gills and digestive gland (Fig. 2) because they play major part in the process of bioaccumulation of toxicants. Thus, they are used in biomarker analyses to the study the subsequent negative effects.

Choice of biomarkers in integrated monitoring

Biomarkers are defined as responses to any exposure evidenced in histological, physiological, biochemical, genetic and behavioral modification (FOSSI & MARSILI, 1997; FOSSI, 1998). Furthermore, as stated by VIARENGO & CANESI (1991) the effects of pollutants on living organisms can be evaluated at different levels of organization (molecular, cellular, individual, population and community.

More recent, VAN DER OOST *et al.* (2003) defined biomarkers as biological indicators from an exposure to a stressor responding in various ways. PICADO *et al.* (2007) add that biomarkers, which act as early warning signals of the presence of potentially toxic xenobiotics, are useful tools for assessing either exposure to, or the effects of these compounds providing information about the toxicant bioavailability.

A range of techniques (Fig. 1 and 3) has been developed to quantify or indicate the effects of pollutants on aquatic organisms from cellular to community levels (ICES, 2004). In addition, THAIN *et al.* (2008) explains that the most widely used biological-effect tools are measures of the biochemical and/or physiological state of selected organisms, such as mussels or fish.

According to HYLLAND *et al.* (2006) over the past decade there has been evidence of effects at low exposure levels. The authors state that many chemicals are metabolized or cause effects at very low levels (e.g. endocrine disrupting substances, PAHs and OPs). Therefore, descriptor 8 in MSFD defines that “concentrations of contaminants are at levels not giving rise to pollution effects” (Table 1).

According to MARIA *et al.* (2009) connections must be established between external levels of exposure, internal levels of tissue contamination and early adverse effects and determining the extent and severity of such contamination only by the result of water chemical analysis is insufficient and often overestimates the proportion and duration of exposure to the toxic agent. Therefore, integration of chemical analyses with biomarker responses in organisms has been recommended for monitoring anthropogenic activities (HYLLAND *et al.*, 2008). According to BAYNE (1986) good interpretation of the data can be obtained by studying the effects of pollutants in individuals, with the aim of understanding and eventually predicting the possible consequences at higher levels.

In the past 25 years, numerous biomarkers have been developed with the objective to apply them for environmental biomonitoring and risk assessment programs (NRC, 1987; HINTON *et al.*, 1992; HINTON, 1994; SCHMITT *et al.*, 2007; PANDEY *et al.*, 2008; ARDESHIR *et al.*, 2017). PINTO *et al.* (2009) suggest that the biomonitoring process should include analyses at different levels of biological organization, from sub-cellular and cellular analysis of tissues and organs, to the of population and community levels. Therefore, studies using biomarkers are essential to complement environmental monitoring in order to control pollution effects on the animals that inhabit the water bodies (AU, 2004).

The usefulness of any biological-effect method will depend on how well it is able to separate anthropogenic stressors from the influence of environmental or host-related processes (LYONS *et al.*, 2010). According to HYLLAND *et al.* (1998) it is well established that there are seasonal variations, most commonly coordinated with reproduction, for most biomarkers in temperate organisms. Furthermore, according to HYLLAND *et al.* (2006) the methods must be able to separate between effects from contaminants and natural variation or the effects from other environmental factors. For example, KAMMANN *et al.* (2005) found that certain biomarkers such as hepatic EROD activity in fish are influenced by a number of non-contaminant related factors including ambient water temperature and stage of sexual development. As explained by HYLLAND *et al.* (2006) European flounder (*Platichthys flesus*), which is a common test species in monitoring programs in Europe and numerous toxicology studies, shows natural variability through a year (HYLLAND *et al.*, 1998); response to individual contaminants (BEYER *et al.*, 1996); combination of contaminants (SANDVIK *et al.*, 1997) or response in caging experiments (BEYER *et al.*, 1996). On the other hand, there is enough evidence for already established cause-and-effect relationships between the presence of contaminants and biological-effect responses in the organisms. A good example here would be tributyltin (TBT)-induced imposex in dogwhelk as THAIN *et al.* (2008) explain. Once population effects that could be directly related to concentrations of organotins in the marine environment were observed (GIBBS & BRYAN, 1996), management actions were taken to reduce TBT emissions and introduce international policies through the EU and International Maritime Organisation (IMO), which has resulted in a decrease in the prevalence and severity of imposex (BIRCHENOUGH *et al.*, 2002).

WHO (1993) state that biomarkers have been classified into three separate categories that correspond to three major parameters necessary to conduct ecological risk assessments. To perform such an accurate ecological risk assessment, ecological effects, as well as exposure and susceptibility to contaminants must be well-characterized following identification or formulation of a problem. In each of these processes, well-defined biological indicators can be used in certain cases to help make inexpensive predictions regarding the bioavailability (exposure), mechanism of action (effect) and uncertainty of response (susceptibility) elicited by various anthropogenic substances (SCHLENK, 1999). According to VETHAAK *et al.* (2015) the concept of a background level of response (residual noise of the measurement found from responses of animals in relatively clean waters) is applicable to all effects measurements. Assessment criteria analogous to the Environmental Assessment Criteria (EAC) (i.e. representing levels of response below which unacceptable responses at higher, e.g. organism or population, levels of biological organization would not be expected) are applicable for some biological effects measurements, and these have been termed *"biomarkers of effect"*. In other cases, the link to higher level effects is less clear, and these measurements have been termed *"biomarkers of exposure"*, in that they indicate that exposure to hazardous substances has occurred.

Biological effects measurements and chemical methods have been selected for the *biota matrix (separated as fish, mussels and gastropods)* using different criteria – general designs for integrated monitoring of fish are presented in Fig. 1 and of mussels in Fig. 3.

Table 1. Qualitative descriptors for determining Good Environmental Status as defined in Annex I of the MSFD (see Lyons *et al.*, 2010).

1. Biological diversity is maintained. The quality and occurrence of habitats and the distribution and abundance of species are in line with prevailing physiographic, geographic and climatic conditions.
2. Non-indigenous species introduced by human activities are at levels that do not adversely alter ecosystems.
3. Populations of all commercially exploited fish and shellfish are within safe biological limits exhibiting a population age and size distribution that is indicative of a healthy stock.
4. All elements of the marine food webs, to the extent that they are known, occur at normal abundance and diversity and levels capable of ensuring the long-term abundance of the species and the retention of their full reproductive capacity.
5. Human-induced eutrophication is minimized, especially adverse effects, such as losses in biodiversity, ecosystem degradation, harmful algae blooms and oxygen deficiency in bottom waters.
6. Sea-floor integrity is at a level that ensures that the structure and functions of the ecosystem are safeguarded and benthic ecosystems, in particular, are not adversely affected.
7. Permanent alteration of hydrographical conditions does not adversely affect marine ecosystems.
8. Concentrations of contaminants are at levels not giving rise to pollution effects.
9. Contaminants in fish and other seafood for human consumption do not exceed levels established by Community legislation or other relevant standards.
10. Properties and quantities of marine litter do not cause harm to the coastal and marine environment.
11. Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment.

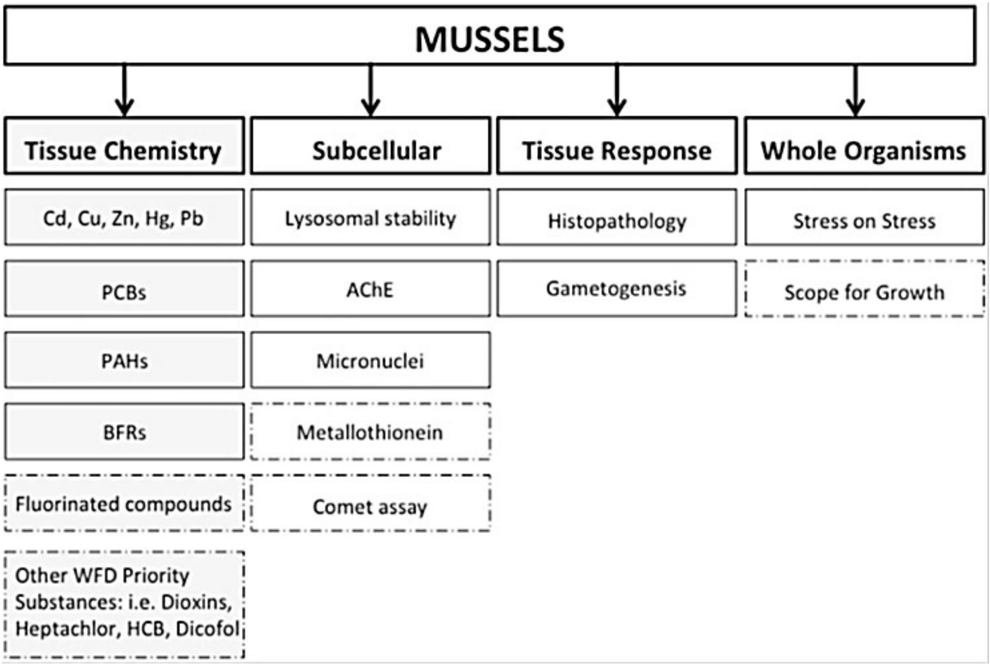

Fig. 3. Determinants and measurements included in the mussel component of the ICES/ OSPAR integrated monitoring framework. *Legend:* solid lines - core methods; broken lines - additional methods; PCBs - polychlorinated biphenyls; PAH - polycyclic aromatic hydrocarbon; BFRs - brominated flame retardants; AChE - acetylcholinesterase. WFD - Water Framework Directive. WFD priority substances are required in biota under Directive 39/2013/EU (see Thain *et al.* (2008); Vethaak *et al.* (2015)).

Table 2. OSPAR status of biological-effect techniques for invertebrates and fish (JAMP) (see THAIN *et al.*, 2008).

Method	In JAMP	CEMP category	Rec. by WGBEC	QC
Mussels				
Whole sediment bioassays	Yes	II	Yes	B
Sediment pore water bioassays	Yes	II	Yes	B
Sediment seawater elutriates	Yes	II	-	-
Water bioassays	Yes	II	Yes	B
In vivo bioassays	No	-	Yes	B (some)
In vitro bioassays	No	-	Yes	-
Lysosomal stability	No	-	Yes	B-a
Multidrug resistance (MXR/MDR)	No	-	Yes	-
Scope for growth	No	-	Yes	B-a
AChE	No	-	Yes	-
Metallothionein (MT)	No	-	Yes	B-a
Histopathology	No	-	Yes	-
Imposex/Intersex in gastropods	Yes	I (M)	Yes	Q
Benthic community analysis	Yes	-	Yes	B
Fish				
AChE in muscle	No	-	Yes	-
Lysosomal stability	Yes	II	Yes	B-a
Externally visible diseases	Yes	I (V)	Yes	B-a
Reproductive success (eelpout)	Yes	II	Yes	B-a
Metallothionein (MT)	Yes	II	Yes	B-a
ALA-D	Yes	II	Yes	B-a
Oxidative stress	Yes	II	-	-
CYP1A-EROD	Yes	II	Yes	Yes
DNA adducts	Yes	II	Yes	B-a
PAH metabolites	Yes	II	Yes	Q
Liver neoplasia/hyperplasia	Yes	I (V)	Yes	B
Liver nodules	Yes	I (V)	Yes	B
Liver pathology	Yes	I (V)	Yes	B
Vitellogenin in cod	No	-	Yes	Yes
Vitellogenin in flounder	No	-	Yes	-
Intersex in male flounder	No	-	Yes	B-a

CEMP category: II, method suitable for marine monitoring purposes; I, method suitable and analytical-quality control (AQC) is available; M, mandatory method in place, with AQC and assessment criteria established. Quality control: V, voluntary method in place, with AQC but conducted voluntarily. Recommendations for inclusion by WGBEC (ICES, 2007a) and information on existence of quality control [QC: B, Biological Effects Quality Assurance in Monitoring Programmes; B-a, available online (BEQUALM, 2009); Q, Quality Assurance of Information for Marine Environmental Monitoring in Europe (QUASIMEME, 1992).

WGBEC (ICES, 2007a) has reviewed the status of biological-effect techniques regularly and recommended in its reports those techniques for fish and invertebrates that are in the research phase, look promising, and require development and analytical-quality control, or are available for use and take-up in national and international monitoring programs. Some of the recommended methods have been included in OSPAR guidelines for contaminant-specific or general monitoring (JAMP, 1998a; b) and have, after a process of quality assurance, been included in CEMP (JAMP/CEMP, Joint Assessment Monitoring Programme/Co-ordinated Environmental Monitoring Programme). The updated list (Table 2) includes information on the current position of each technique relative to these guidelines.

Conclusions

In summary, in 2006 Working Group on Biological Effects of Contaminants (WGBEC; ICES, 2006) made a preliminary proposal, endorsed by Workshop on Integrated Monitoring of Contaminants and their Effects in Coastal and Open-Sea Areas (WKIMON) for combining methods in a program of integrated chemical- and biological-effect monitoring that contains three ecosystem components: water, sediment, and biota, restricted so far to *fish, bivalves, and gastropods* (THAIN *et al.*, 2008). Moreover. according to Directive 2008/105/ EC Member States are now required to check compliance with EQSs and to monitor the contamination trends for PSs, and they are strongly recommended to use integrating matrices, e.g., *biota* in order to meet these objectives for bioaccumulative substances (BESSE *et al.*, 2012). Overall, we can conclude that it is especially important to choose fish as a test species when the research concerns human health, but mussels are also commercial products in terms of aquaculture and are consumed extensively in some areas of the world. From our case studies (GEORGIEVA *et al.*, 2014a; b; 2015; 2016; YANCHEVA *et al.*, 2014a; b; 2016b; 2017) we can confirm that mussels are easier to collect on the field compared to fish, but fish are particularly sensitive to contamination, which is essential in the field of ecotoxicology. Therefore, we would recommend that both, fish and mussels are used in monitoring programs on water contamination, along with combined biomarkers which can be applied on vertebrates and invertebrates for better results.

Acknowledgements

This paper is supported by the NPD-Plovdiv University under Grant No SP17-BF003 "Integrated biomarkers for priority toxic substances in aquatic ecosystems by using zebra mussel (*Dressena polymorpha* Pallas, 1771) as bioindicator".

References

ALI Z., R.N. MALIK, A. QADIR. 2013. Heavy metals distribution and risk assessment in soils affected by tannery effluents. - *Chemistry and Ecology*, 29: 676-692. [DOI].

ANDRADY L. 2011. Microplastics in the marine environment. - *Marine Pollution Bulletin*, 62(8): 1596-1605. [DOI].

APETI D.A., G.G. LAUENSTEIN, J.D. CHRISTENSEN, K. KIMBROUGH, W.E. JOHNSON, M. KENNEDY, K.G. GRANT. 2010. A historical assessment of coastal contamination in Birch Harbor, Maine based on the analysis of mussels collected in the 1940s and the Mussel Watch Program. - *Marine Pollution Bulletin*, 60(5): 732-742. [DOI].

ARDESHIR R.A., A. MOVAHEDINIA, S. RASTG. 2017. Fish liver biomarkers for heavy metal pollution: a review article. - *American Journals of Toxicology*, 2: 1-8

Arockia Vasanthi L., P. Revathi, J. Mini, N. Munuswamya. 2013. Integrated use of histological and ultrastructural biomarkers in *Mugil cephalus* for assessing heavy metal pollution in Ennore estuary, Chennai. - *Chemosphere*, 91: 1156-1164. [DOI].

Au D.W.T. 2004. The application of histo-cytopathological biomarkers in marine pollution monitoring: a review. - *Marine Pollution Bulletin*, 48(9-10): 817-834. [DOI].

Avkopashvili G., M. Avkopashvili, A. Gongadze, M. Tsulukidze, E. Shengelia. 2017. Determination of Cu, Zn and Cd in soil, water and food products in the vicinity of RMG gold and copper mine, Kazreti, Georgia. - *Annals of Agrarian Science*, 15: 269-272. [DOI].

Balk L., K. Hylland, T. Hansson, M.H.G. Berntssen, J. Beyer, G. Jonsson, A. Melbye, M. Grung B.E. Torstensen, J.F. Børseth, H. Skarphedinsdottir, J. Klungsøyr. 2011. Biomarkers in natural fish populations indicate adverse biological effects of offshore oil production. - *PLoS ONE*, 6(5): e19735. [DOI].

Bao M., Y. Pi, L. Wang, P. Sun, Y. Lia, L. Cao. 2014. Lipopeptide biosurfactant production bacteria Acinetobacter sp. D3-2 and its biodegradation of crude oil. - *Environmental Science: Processes & Impacts*, 16(4): 897-903. [DOI].

Barak N.A., C.F. Mason. 1990. Mercury, cadmium and lead concentrations in five species of freshwater fish from eastern England. - *Science of the Total Environment*, 92: 257-263. [DOI].

Bayne B.L. 1989. Measuring the biological effects of pollution: the mussel watch approach. - *Water Science & Technology*, 21: 1089-1100. [DOI].

Bellotto V.R., N. Miekele. 2007. Trace metals in mussel shells and corresponding soft tissue samples: a validation experiment for the use of *Perna perna* shells in pollution monitoring. - *Analytical and Bioanalytical Chemistry*, 389(3): 769-776. [DOI].

Benito M., R. Mosteo, E. Rubio, D. La Plante, M.P. Ormad, P. Goñi. 2017. Bioaccumulation of inorganic elements in *Dreissena polymorpha* from the Ebro River, Spain: Could Zebra mussels be used as a bioindicator of the impact of human activities? - *River Research and Applications*, 33(5): 718-728. [DOI].

Berge J.A., K. Hylland, M. Schlabach, A. Ruus. 2011. Accumulation of polychlorinated dibenzo-p-dioxins and furans in Atlantic cod (*Gadus morhua*) - cage experiments in a Norwegian Fjord. - *Journal of Toxicology and Environmental Health, Part A*, 74: 455-465. [DOI].

Besada V., J.M. Andrade, F. Schultze, J. Gonzalez. 2011. Monitoring of metals in wild mussels (*Mytilus galloprovincialis*) from the Spanish North-Atlantic coast. - *Continental Shelf Research*, 31(5): 457-465. [DOI].

Besse J.-P., O. Geffard, M. Coquery. 2012. Relevance and applicability of active biomonitoring in continental waters under the Water Framework Directive. - *Trends in Analytical Chemistry*, 36: 113-127. [DOI].

Bequalm. 2009. *Biological Effects Quality Assurance in Monitoring Programmes*. Available at: [bequalm.org]. Accessed: 10.05.2018.

Beyer J., M. Sandvik, K. Hylland, E. Fjeld, E. Egaas, E. Aas, J.U. Skåre, A. Gokssyr. 1996. Contaminant accumulation and biomarker responses in flounder (*Platichthys flesus* L.) and Atlantic cod (*Gadus morhua* L.) exposed by caging to polluted sediments in Storfjorden, Norway. - *Aquatic Toxicology*, 36: 75-98. [DOI].

Beyer J., N.W. Green, S. Brooks, I.J. Allan, A. Ruus, T. Gomes, I.L.N. Bråte, M. Schøyen. 2017. Blue mussels (*Mytilus* *edulis* spp.) as sentinel organisms in coastal pollution monitoring: A review. - *Marine Environmental Research*, 130: 338-365. [DOI].

BINELLI A., D. COGNI, M. PAROLINI, A. PROVINI. 2010. Multi-biomarker approach to investigate the state of contamination of the R. Lambro/R. Po confluence (Italy) by zebra mussel (*Dreissena polymorpha*). - *Chemosphere*, 79(5): 518-528. [DOI].

BINELLI A., C. DELLA TORRE, S. MAGNI, M. PAROLINI. 2015. Does zebra mussel (*Dreissena polymorpha*) represent the freshwater counterpart of *Mytilus* in ecotoxicological studies? A critical review. - *Environmental Pollution*, 196: 386-403. [DOI].

BIRCHENOUGH A.C., S.M. EVANS, C. MOSS, R. WELCH. 2002. Re-colonisation and recovery of populations of dogwhelks *Nucella lapillus* (L.) on shores formerly subject to severe TBT contamination. - *Marine Pollution Bulletin*, 44: 652-659. [DOI].

BIRUNGI Z., B. MASOLA, M.F. ZARANYIKA, I. NAIGAGA, B. MARSHALL. 2007. Active biomonitoring of trace heavy metals using fish (*Oreochromis niloticus*) as bioindicator species: The case of Nakivubo wetland along Lake Victoria. - *Physics and Chemistry of the Earth*, 32: 1350-1358. [DOI].

BOLOGNESI C., E. PERRONE, P. ROGGIERI, A. SCIUTTO. 2006. Bioindicators in monitoring long term genotoxic impact of oil spill: Haven case study. - *Marine Environmental Research*, 62(1): 287-291. [DOI].

BOURGEAULT A., C. GOURLAY-FRANCÉ, F. VINCENT-HUBERT, F. PALAIS, A. GEFFARD, S. BIAGIANTI-RISBOURG, S. PAIN-DEVIN, M.H. TUSSEAU-VUILLEMIN. 2010. Lessons from a transplantation of zebra mussels into a small urban river: An integrated ecotoxicological assessment. - *Environmental Toxicology*, 25(5): 468-478. [DOI].

BOUWER H. 2002. Integrated water management for the 21st century. Problems and solutions. - *Journal of Irrigation and Drainage Engineering*, 128: 193-202. [DOI].

BRANDT R., N. MERKL, R. SCHULTZE-KRAFT, C. INFANTE, G. BROLL. 2006. Potential of vetiver (*Vetiveria zizanioides*) for the use in phytoremediation of petroleum hydrocarbon-contaminated soils in Venezuela. - *International Journal of Phytoremediation*, 8(4): 273-284. [DOI].

BRAUNBECK T., B. STREIT, D.E. HINTON (Eds.). 1998. *Fish Ecotoxicology*. Vol. 86. Birkhäuser Basel. Switzerland, 398 p. [DOI].

BURGER J., K.F. GAINES, C.S. BORING, W.L. STEPHENS, J. SNODGRASS, C. DIXON, M. MCMAHON, S. SHUKLA, T. SHUKLA, M. GOCHFELD. 2002. Metal levels in fish from the Savannah River: potential hazards to fish and other receptors. - *Environmental Research*, 89(1): 85-97. [DOI].

CAIRNS J., P.V. MCCORMICK, B.R. NIEDERLEHNER. 1993. A proposed framework for developing indicators of ecosystem health. - *Hydrobiologia*, 263: 1-44.

CAMUSSO M., R. BALESTRINI, F. MURIANO, M. MARIANI. 1994. Use of freshwater mussel *Dreissena polymorpha* to assess trace metal pollution in the lower River Po (Italy). - *Chemosphere*, 29(4): 729-745. [DOI].

CAPPELLO T., M. MAISANO, A. D'AGATA, A. NATALOTTO, A. MAUCERI, S. FASULO. 2013. Effects of environmental pollution in caged mussels (*Mytilus galloprovincialis*). - *Marine Environmental Research*, 91: 52-60. [DOI].

CARRASCO L., L. BENEJAM, J. BENITO, J.M. BAYONA, S. DIEZ. 2011. Methylmercury levels and bioaccumulation in the aquatic food web of a highly mercury-contaminated reservoir. - *Environment International*, 37: 1213-1218, [DOI].

CHANDURVELAN R., I.D. MARSDEN, C.N. GLOVER, S. GAW. 2015. Assessment of a mussel as a metal bioindicator of coastal contamination: relationships between metal bioaccumulation and multiple biomarker responses. - *Science of the Total Environment*, 511: 663-675. [DOI].

CIESIELSKI T.M., I.T. HANSEN, J. BYTINGSVIK, M. HANSEN, E. LIE, J. AARS, B.M. JENSSEN, B. STYRISHAVE. 2017. Relationships between POPs, biometrics and circulating steroids in male polar bears (*Ursus maritimus*) from Svalbard. - *Environmental Pollution*, 230: 598-608. [DOI].

CUI B.S., Q.J. ZHANG, K.J. ZHANG, X.H. LIU, H.G. ZHANG. 2011. Analyzing trophic transfer of heavy metals for food webs in the newly-formed wetlands of the Yellow River Delta, China. - *Environmental Pollution*, 159(5): 1297-1306. [DOI].

CZÉDLI H., L. CSEDREKI, A.G. SZÍKI, G. JOLÁNKAI, B. PATAKI, C. HANCZ, L. ANTAL, S.A. NAGY. 2014. Investigation of the bioaccumulation of copper in fish. - *Fresenius Environmental Bulletin*, 23(7): 1547-1552.

DALLINGER R., F. PROSI, H. SEGNER, H. BACK. 1987. Contaminated food and uptake of heavy metals by fish: a review and a proposal for further research. - *Oecologia*, 73(1): 91-98. [DOI].

DE LA TORRE F.R., L. FERRARI, A. SALIBIÁN. 2005. Biomarkers of a native fish species (*Cnesterodon decemmaculatus*) application to the water toxicity assessment of a peri-urban polluted river of Argentina. - *Chemosphere*, 59(4): 577-583. [DOI].

DE LA TORRE C., T. PETOCHI, I. CORSI, M.M. DINARDO, D. BARONI, L. ALCARO, S. FOCARDI, A. TURSI, G. MARINO, A. FRIGERIC, E. AMATO. 2010. DNA damage, severe organ lesions and high muscle levels of As and Hg in two benthic fish species from a chemical warfare agent dumping site in the Mediterranean Sea. - *Science of the Total Environment*, 408(9): 2136-2145. [DOI].

DE LAFONTAINE Y., F. GAGNÉ, C. BLAISE, G. COSTAN, P. GAGNON, H.M. CHAN. 2000. Biomarkers in zebra mussels (*Dreissena polymorpha*) for the assessment and monitoring of water quality of the St Lawrence River (Canada). - *Aquatic Toxicology*, 50: 51-71. [DOI].

DESFORGES J.P.W., M. GALBRAITH, N. DANGERFIELD, P.S. ROSS. 2014. Widespread distribution of microplastics in subsurface seawater in the NE Pacific Ocean. - *Marine Pollution Bulletin*, 79(1): 94-99. [DOI].

DEVAULT D.A., M. GÉRINO, C. LAPLANCHE, F. JULIEN, P. WINTERTON, G. MERLINA, F. DELMAS, LIM P., J.M. SÁNCHEZ-PÉREZ, E. PINELLI. 2009. Herbicide accumulation and evolution in reservoir sediments. - *Science of Total Environment*, 407: 2659-2665. [DOI].

DIRECTIVE 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy (Water Framework Directive). - *Official Journal of the European Communities*, L 327, 22.12.2000, p. 1–73. Available at: [eur-lex.europa.eu].

DIRECTIVE 2008/105/EC of the European Parliament and of the Council of 16 December 2008 on environmental quality standards in the field of water policy, amending and subsequently repealing Council Directives 82/176/EEC, 83/513/EEC, 84/156/EEC, 84/491/EEC, 86/280/EEC and amending Directive 2000/60/EC of the European Parliament and of the Council. - *Official Journal of the European Communities*, L 348, 24.12.2008, p. 84–97. Available at: [eur-lex.europa.eu].

DIRECTIVE 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Framework Directive). - *Official Journal* *of the European Communities*, L 164, 25.6.2008, p. 19–40. Available at: [eur-lex.europa.eu].

EFFENDI H., A. MUNAWAROH, I.P. AYU. 2017. Crude oil spilled water treatment with *Vetiveria zizanioides* in floating wetland. - *Egyptian Journal of Aquatic Research*, 43(3): 185-193. [DOI].

EUROPEAN COMMUNITIES ENVIRONMENTAL OBJECTIVES (SURFACE WATERS). 2009. Regulations S.I. No. 272/2009. Available at: [irishstatutebook.ie].

EUROPEAN COMMUNITIES TECHNICAL REPORT 2010-041. 2010. Common Implementation Strategy for the Water Framework Directive (2000/60/EC), Guidance Document No. 25 on chemical monitoring of sediment and biota under the Water Framework Directive. Available at: [circabc.europa.eu].

FARIA M., D. HUERTAS, D.X. SOTO, J.O. GRIMALT, J. CATALAN, M.C. RIVA, C. BARATA. 2010. Contaminant accumulation and multi-biomarker responses in field collected zebra mussels (*Dreissena polymorpha*) and crayfish (*Procambarus clarkii*), to evaluate toxicological effects of industrial hazardous dumps in the Ebro river (NE Spain). - *Chemosphere*, 78(3): 232-240. [DOI].

FARRINGTON J.W., E.D. GOLDBERG, R.W. RISEBROUGH, J.H. MARTIN, V.T. BOWEN. 1983. U.S. mussel watch 1976-1978: an overview of the trace-metal, DDE, PCB, hydrocarbon and artificial radionuclide data. - *Environmental Science & Technology*, 17: 490-496. [DOI].

FARRINGTON J.W., B.W. TRIPP, S. TANABE, A. SUBRAMANIAN, J.L. SERICANO, T.L. WADE, A.H. KNAP. 2016. Edward D. Goldberg's proposal of "The Mussel Watch": reflections after 40 years. - *Marine Pollution Bulletin*, 110: 501-510. [DOI].

FISHER W.S. 2001. Indicators for human and ecological risk assessment: a US EPA perspective. - *Human and Ecological Risk Assessment*, 7: 961-970.

FISK A.T., K.A. HOBSON, R.J. NORSTROM. 2001. Influence of chemical and biological factors on trophic transfer of persistent organic pollutants in the Northwater Polynya marine food web. - *Environmental Science and Technology*, 35(4): 732-738. [DOI].

FOSSATO V.U., G. CAMPESAN, L. CRABOLEDDA, G. STOCCO. 1989. Trends in chlorinated hydrocarbons and heavy metals in organisms from the Gulf of Venice. - *Archivio di Oceanographia e Limnologia*, 21: 179-190.

FOSSI M.C. 1998. Biomarkers as diagnostic and prognostic tools for wildlife risk assessment: integrating endocrine-disrupting chemicals. - *Toxicology and Industrial Health*, 14(1-2): 291-309. [DOI].

FOSSI M.C., L. MARSILI. 1997. The use of non-destructive biomarkers in the study of marine mammals. - *Biomarkers*, 2(4): 205-216. [DOI].

FULTON M.H., P.B. KEY. 2001. Acetylcholinesterase inhibition in estuarine fish and invertebrates as an indicator of organophosphorus insecticide exposure and effects. - *Environmental Toxicology and Chemistry*, 20: 37-45.

GEORGIEVA E., I. VELCHEVA, V. YANCHEVA, S. STOYANOVA. 2014a. Trace metal effects on gill epithelium of common carp, *Cyprinus carpio* L. (Cyprinidae). - *Acta Zoologica Bulgarica*, 66(2): 277-282.

GEORGIEVA E., S. STOYANOVA, I. VELCHEVA, T. VASILEVA, V. BIVOLARSKI, I. ILIEV, V. YANCHEVA. 2014b. Metal effects on histological and biochemical parameters of common rudd (*Scardinius erythrophthalmus* L.). - *Archives of Polish Fisheries*, 22: 197-206. [DOI].

GEORGIEVA E., V. YANCHEVA, I. VELCHEVA, M. BECHEVA, S. STOYANOVA. 2015. Histological alterations under metal exposure in gills of European perch (*Perca fluviatilis* L.) from Topolnitsa Reservoir (Bulgaria). - *Archives of Biological Sciences*, 67(2): 729-737. [DOI].

GEORGIEVA E., V. YANCHEVA, I. VELCHEVA, I. ILIEV, T. VASILEVA, V. BIVOLARSKI, M. BECHEVA, S. STOYANOVA. 2016. Histological and biochemical changes in common carp (*Cyprinus carpio* L.) liver under metal exposure. - *North-Western Journal of Zoology*, 12(2): 261-270.

GIBBS P. E., G. W. BRYAN. 1996. Reproductive failure in the dogwhelk *Nucella lapillus* associated with imposex caused by tributyltin pollution: a review. – In: CHAMP M. A., P. F. SELIGMAN (Eds). *Organotin: Environmental fate effects*. Chapman and Hall, London, pp. 259–284.

GOLDBERG E.D. 1975. The mussel watch: a first step in global marine monitoring. - *Marine Pollution Bulletin*, 6: 111-132. [DOI].

GOLDBERG E.D. 1980. *The International Mussel Watch*. Washington, D.C., National Academy of Sciences, 89 p.

GOLDBERG E.D. 1986. The mussel watch concept. - *Environmental Monitoring and Assessment*, 7: 91-103. [DOI].

GÖRÜR F.K., R. KESER, N. AKCAY, S. DIZMAN. 2012. RADIOACTIVITY AND HEAVY METAL CONCENTRATIONS OF SOME COMMERCIAL FISH SPECIES CONSUMED IN THE BLACK SEA REGION OF TURKEY. - *CHEMOSPHERE*, 87: 356-361. [DOI].

GRUNG M., Y. LIN, H. ZHANG, A.O. STEEN, J. HUANG, G. ZHANG, T. LARSSEN. 2015. Pesticide levels and environmental risk in aquatic environments in China - a review. - *Environment International*, 81: 87-97. [DOI].

GUERLET E., K. LEDY, A. MEYER, L. GIAMBERINI. 2007. Towards a validation of a cellular biomarker suite in native and transplanted zebra mussels: a 2-year integrative field study of seasonal and pollution induced variations. - *Aquatic Toxicology*, 81: 377-388. [DOI].

HAGGER J.A., M.B. JONES, D. LOWE, D.R.P. LEONARD, R. OWEN, T.S. GALLOWAY. 2008. Application of biomarkers for improving risk assessments of chemicals under the Water Framework Directive: a case study. - *Marine Pollution Bulletin*, 56: 1111-1118. [DOI].

HAS-SCHÖN E., I. BOGUT, V. RAJKOVIĆ, S. BOGUT, M. ČAČIĆ, J. HORVATIĆ. 2008. Heavy metal distribution in tissues of six fish species included in human diet, inhabiting freshwaters of the Nature Park "Hutovo Blato" (Bosnia and Herzegovina). - *Archives of Environmental Contamination and Toxicology*, 54(1): 75-83. [DOI].

HEIER L.S., I.B. LIEN, A.E. STROMSENG, M. LJONES, B.O. ROSSELAND, K.E. TOLLEFSEN, B. SALBU. 2009. Speciation of lead, copper, zinc and antimony in water draining a shooting range - Time dependent metal accumulation and biomarker responses in brown trout (*Salmo trutta* L.). - *Science of the Total Environment*, 407(13): 4047-4055. [DOI].

HERMOSO V., M. CLAVERO, F. BLANCO-GARRIDO, J. PRENDA. 2010. Assessing the ecological status in species-poor systems: A fish-based index for Mediterranean Rivers (Guadiana River, SW Spain). - *Ecological Indicators*, 10(6): 1152-1161. [DOI].

HINTON D.E., P.C. BAUMANN, G.R. GARDNER, W.E. HAWKINS, J.D. HENDRICKS, R.A. MURCHELANO, M.S. OKIHIRO. 1992. Biomarkers; biochemical, physiological, and histological markers of anthropogenic stress. - In: HUGGETT R.J., R.A. KIMERLE, P.M. MEHRLE, H.L. BERGMAN (Eds.): *Histopathologic biomarkers*. Boca Raton. Lewis Publishers, pp. 155-209.

HINTON D.E. 1994. Cells, cellular responses, and their markers on chronic toxicity of fishes. - In: MALINS D.C., G.K. OSTRANDER (Eds.): *Aquatic Toxicology: molecular, biochemical, and cellular perspectives*. Boca Raton. Lewis Publishers, pp. 207-239.

HOLTH T.F., B.A. BEYLICH, H. SKARPHÉDINSDÓTTIR, B. LIEWENBORG, M. GRUNG, K. HYLLAND. 2009. Genotoxicity of environmentally relevant concentrations of watersoluble oil components in Cod (*Gadus morhua*). - *Environmental Science & Technology*, 43(9): 3329-3334. [DOI].

HOLTH T.F., J. BECKIUS, I. ZORITA, M.P. CAJARAVILLE, K. HYLLAND. 2011. Assessment of lysosomal membrane stability and peroxisome proliferation in the head kidney of Atlantic cod (*Gadus morhua*) following long-term exposure to produced water components. - *Marine Environmental Research*, 72: 127-134. [DOI].

HYLLAND K., T. NISSEN-LIE, P.G. CHRISTENSEN, M. SANDVIK. 1998. Natural modulation of hepatic metallothionein and cytochrome P4501A in flounder, *Platichthys flesus* L. - *Marine Environmental Research*, 46(1-5): 51-55. [DOI].

HYLLAND K. 2006. Biological effects in the management of chemicals in the marine environment. – *Marine Pollution Bulletin*, 53: 614-619. [DOI].

HYLLAND K., O.Ø. ASPHOLM, J.A. KNUTSEN, A. RUUS. 2006. Biomarkers in fish from dioxin-contaminated fjords. - *Biomarkers*, 11(2): 97-117. [DOI].

HYLLAND K., K.-E. TOLLEFSEN, A. RUUS, G. JONSSON , R.C. SUNDT, S. SANNI, T.I. RØE UTVIK, S. JOHNSEN, I. NILSSEN, L. PINTURIER, L. BALK, J. BARSIENE, I. MARIGÒMEZ, S.W. FEIST, J.F. BØRSETH. 2008. Water column monitoring near oil installations in the North Sea 2001–2004. - *Marine Pollution Bulletin*, 56: 414-429. [DOI].

ICES. 2004. Report of the Working Group on Biological Effects of Contaminants (WGBEC).

ICES. 2006. Report of the Working Group on Biological Effects of Contaminants (WGBEC).

ICES. 2007a. Report of the Working Group on Biological Effects of Contaminants (WBGEC).

ICES. 2007b. Report from the ICES/OSPAR Workshop on Integrated Monitoring of Contaminants and their Effects in Coastal and Open-Sea Areas (WKIMON).

ISLAM M.S., S. HAN, S. MASUNAGA. 2014 Assessment of trace metal contamination in water and sediment of some rivers in Bangladesh. - *Journal of Water and Environment Technology*, 12: 109-121.

JAMBECK J.R., R. GEYER, C. WILCOX, T.R. SIEGLER, M. PERRYMAN, A. ANDRADY, R. NARAYAN, K.L. LAW. 2015. Marine pollution. Plastic waste inputs from land into the ocean. - *Science*, 347: 768-771. [DOI].

JAMP. 1998a. JAMP guidelines for general biological effects monitoring. Joint Assessment and Monitoring Programme. Oslo and Paris Commissions. 38 p.

JAMP. 1998b. JAMP guidelines for contaminant-specific biological effects monitoring. Joint Assessment and Monitoring Programme. Oslo and Paris Commissions. 38 p.

JAN M.R., J. SHAH, M.A. KHAWAJA, K. GUL. 2009. DDT residue in soil and water in and around abandoned DDT manufacturing factory. - *Environmental Monitoring and Assessment*, 155: 31-38. [DOI].

JOHNS C., B.E. TIMMERMAN. 1998. Total cadmium, copper, and zinc in two Dreissenid mussels, *Dreissena polymorpha* and *Dreissena bugensis*, at the Outflow of Lake Ontario. - *Journal of Great Lakes Research*, 24(1): 55-64, [DOI].

JÖRUNDSDÓTTIR H., T.I. HALLDORSSON, H. GUNNLAUGSDOTTIR. 2014. PFAAs in fish and other seafood products from Icelandic waters. - *Journal of Environmental and Public Health*, pp. 6, [DOI].

JOVIČIĆ K., D.M. NIKOLIĆ, Ž. VIŠNJIĆ-JEFTIĆ, V. DIKANOVIĆ, S. SKORIĆ, S.M. STEFANOVIĆ, M. LENHARDT, A. HEGEDIŠ, J. KRPO-ĆETKOVIĆ, I. JARIĆ. 2014. Mapping differential elemental accumulation in fish tissues: assessment of metal and trace element concentrations in Wels catfish (*Silurus glanis*) from the Danube River by ICP-MS. - *Environmental Science and Pollution Research*, 22(5): 3820-3827, [DOI].

KAMMANN U., T. LANG, M. VOBACH, W. WOSNIOK. 2005. Ethoxyresorufin-Odeethylase (EROD) activity in dab

(*Limanda limanda*) as biomarker for marine monitoring. - *Environmental Science and Pollution Research*, 12(3), 140-145.

KLOBUČAR G.I.V., A. ŠTAMBUK, K. HYLLAND, M. PAVLICA. 2008. Detection of DNA damage in haemocytes of *Mytilus galloprovincialis* in the coastal ecosystems of Kaštela and Trogir bays, Croatia. - *Science of the Total Environment*, 405(1-3): 330-337. [DOI].

LAW J.M. 2003. Issues related to the use of fish models in toxicologic pathology: session introduction. - *Toxicological Pathology*, 31: 49-52. [DOI].

LENNUK L., J. KOTTA, K. TAITS, K. TEEVEER. 2015. The short-term effects of crude oil on the survival of different size-classes of cladoceran *Daphnia magna* (Straus, 1820). - *Oceanologia*, 57: 71-77, [DOI].

LEPOM P., U. IRMER, J. WELLMITZ. 2012. Mercury levels and trends (1993–2009) in bream (*Abramis brama* L.) and zebra mussels (*Dreissena polymorpha*) from German surface waters. - *Chemosphere*, 86: 202-211. [DOI].

LETCHER R.J., J.O. BUSTNES, R. DIETZ, B.M. JENSSEN, E.H. JORGENSEN, C. SONNE, J. VERREAULT, VIJAYAN M.M., G.G. GABRIELSEN. 2010. Exposure and effects assessment of persistent organohalogen contaminants in arctic wildlife and fish. - *Science of the Total Environment*, 408: 2995-3043. [DOI].

LI G., B. HU, J. BI, Q. LENG, C. XIAO, Z. YANG. 2013. Heavy metals distribution and contamination in surface sediments of the coastal Shandong Peninsula (Yellow Sea). - *Marine Pollution Bulletin*, 76(1-2): 420-426. [DOI].

LINDEBERG M.R., J. MASELKO, R.A. HEINTZ, C.J. FUGATE, L. HOLLAND. 2017. Conditions of persistent oil on beaches in Prince William Sound 26 years after the Exxon Valdez spill. - *Deep Sea research part II: Topical studies in Oceanography*. In Press, Corrected Proof. [DOI]

LÖHR A., H. SAVELLI, R. BEUNEN, M. KALZ, A. RAGAS, F. VAN BELLEGHEM. 2017. Solutions for global marine litter pollution. - *Current Opinion in Environmental Sustainability*, 28: 90-99. [DOI].

LOMSADZE Z., K. MAKHARADZE, M. TSITSKISHVILI, R. PIRTSKHALAVA. 2017. Water resources of Kakheti and ecological problems. - *Annals of Agrarian Science*, 15: 204-208. [DOI].

LOOS R., B.M. GAWLIK, G. LOCORO, E. RIMAVICIUTE, S. CONTINI, G. BIDOGLIO. 2009. EU-wide survey of polar organic persistent pollutants in European river waters. - *Environmental Pollution*, 157: 561-568. [DOI].

LUSHCHAK V.I. 2011. Environmentally induced oxidative stress in aquatic animals. - *Aquatic Toxicology*, 101(1): 13-30. [DOI].

LUSHER A., M. MCHUGH, R.C. THOMPSON. 2013. Occurrence of microplastics in the gastrointestinal tract of pelagic and demersal fish from the English Channel. - *Marine Pollution Bulletin*, 67: 94-99. [DOI].

LUSHER A. 2015. Microplastics in the marine environment: distribution, interactions and effects. - In: BERGMANN M., L. GUTLOW, M. KLAGES (Eds.): *Marine anthropogenic litter*. Switzerland. Springer International Publishing, pp. 245-307. [DOI].

LYONS B.P., J.E. THAIN, HYLLAND K., I. DAVIS, A.D. VETHAAK. 2010. Using biological effects tools to define good environmental status under the Marine strategy framework directive. – *Marine Pollution Bulletin*, 60: 1647-1651. [DOI].

MANSOUR S.A., M.M. SIDKY. 2002. Ecotoxicological Studies. 3. Heavy metals contaminating water and fish from Fayoum Governorate, Egypt. - *Food Chemistry*, 78(1): 15-22. [DOI].

MARCOVECCHIO J.E. 2004. The use of *Micropogonias furnieri* and *Mugil liza* as bioindicators of heavy metals pollution in La Plata river estuary, Argentina. -

Science of the Total Environment, 323: 219-226. [DOI].

Maria V.L., Ahmad I., Oliveira M., Serafimb A., Bebianno M.J., Pacheco M., Santos M.A. 2009. Wild juvenile *Dicentrarchus labrax* L. liver antioxidant and damage responses at Aveiro Lagoon, Portugal. – *Ecotoxicology and Environmental Safety*, 72: 1861-1870. [DOI].

Marin-Morales M.A., B. de Campos Ventura-Camargo, M.M. Hoshina. 2013. Toxicity of herbicides: Impact on aquatic and soil biota and human health. - In: Price A., J.A. Kelton (Eds) *Herbicides – Current Research and Case Studies in Use*. Croatia. In Tech, pp. 399-443.

Maruya K.A., N.G. Dodder, R.A. Schaffner, S.B. Weisberg, D. Gregorio, S. Klosterhaus, D.A. Alvarez, E.T. Furlong, K.L. Kimbrough, G.G. Lauenstein, J.D. Christensen. 2014. Refocusing Mussel Watch on contaminants of emerging concern (CECs): The California pilot study (2009–10). - *Marine Pollution Bulletin*, 81(2): 334-339. [DOI].

Melwani A.R., D. Gregorio, Y. Jin, M. Stephenson, G. Ichikawa, E. Siegel, D. Crane, G. Lauenstein, J.A. Davis. 2014. Mussel watch update: Long-term trends in selected contaminants from coastal California, 1977-2010. - *Marine Pollution Bulletin*, 81(2): 291-302. [DOI].

Mendil D., Ö.D. Uluözlü. 2007. Determination of trace metal levels in sediment and five fish species from lakes in Tokat, Turkey. - *Food Chemistry*, 101(2): 739-745. [DOI].

Mersch J., Ph. Wagner, J.-Cl. Pihan. 1996. Copper in indigenous and transplanted zebra mussels in relation to changing water concentrations and body weight. – *Environmental Toxicology and Chemistry*, 15(6): 886-893, [DOI].

Milačič R., T. Zuliani, J. Vidmar, P. Oprčkal, J. Ščančar. 2017. Potentially toxic elements in water and sediments of the Sava River under extreme flow events. - *Science of the Total Environment*, 605-606: 894-905. [DOI].

Mishra R., S.P. Shukla. 2003. Endosulfan effects on muscle malate dehydrogenase of the freshwater catfish *Claria batrachus*. – *Ecotoxicology and Environmental Safety*, 56: 425-433, [DOI].

Moiseenko T.I., L.P. Kudryavtseva. 2001. Trace metal accumulation and fish pathologies in areas affected by mining and metallurgical enterprises in the Kola Region, Russia. - *Environmental Pollution*, 114(2): 285-297. [DOI].

Moiseenko T.I. 2005. Ecotoxicological approach to water quality assessment. - *Water Resources*, 32(2): 163-174. [DOI].

Mondon J.A., S. Duda, B.F. Nowak. 2001. Histological, growth and 7-ethoxyresorufin O-deethylase (EROD) activity responses of greenback flounder *Rhombosolea tapirina* to contaminated marine sediment and diet. - *Aquatic Toxicology*, 54(3-4): 231-247. [DOI].

Murthy K.S., B.R. Kiran, M. Venkateshwarlu. 2013. A review on toxicity of pesticides in fish. - *International Journal of Open Scientific Research*, 1(1): 15-36.

Næs K., K. Hylland, E. Oug, L. Föorlin, G. Ericson. 1999. Accumulation and effects of aluminum smelter-generated polycyclic aromatic hydrocarbons on soft-bottom invertebrates and fish. - *Environmental Toxicology and Chemistry*, 18(10): 2205-2216. [DOI].

Naimo T.J. 1995. A review of the effects of heavy metals on freshwater mussels. - *Ecotoxicology*, 4: 341-362. [DOI].

Naser H.A. 2013. Assessment and management of heavy metal pollution in the marine environment of the Arabian Gulf: A review. - *Marine Pollution Bulletin*, 72: 6-13. [DOI].

Ndimele P.E. 2010. A review on the phytoremediation of petroleum hydrocarbon. - *Pakistan Journal of Biological Sciences*, 13(15): 715-722.

NRC (National Research Council). 1987. Biological markers in environmental health research. - *Environmental Health and Perspective*, 74: 3-9.

Oikari A. 2006. Caging techniques for field exposures of fish to chemical contaminants. – *Aquatic Toxicology*, 78(4): 370-381. [DOI].

Olmedo P., A. Pla, A.F. Hernández, F. Barbier, L. Ayouni, F. Gil. 2013. Determination of toxic elements (mercury, cadmium, lead, tin and arsenic) in fish and shellfish samples. Risk assessment for the consumers. - *Environment International*, 59: 63-72. [DOI].

Olsen G.H., E. Sva, J. Carroll, L. Camus, W. De Coen, R. Smolders, H. Øveraas, K. Hylland. 2007. Alterations in the energy budget of Arctic benthic species exposed to oil-related compounds. - *Aquatic Toxicology*, 83: 85-92. [DOI].

Ondarza P.M., M. Gonzalez, G. Fillmann, K.S.B. Miglioranza. 2011. Polybrominated diphenyl ethers and organochlorine compound levels in brown trout (*Salmo trutta*) from Andean Patagonia, Argentina. - *Chemosphere*, 83(11): 1597-1602. [DOI].

Öztürk M., G. Özözen, O. Minareci, E. Minareci. 2009. Determination of heavy metals in fish, water and sediments of Avsar dam lake in Turkey. - *Iranian Journal of Environmental Health Science and Engineering*, 6(2): 73-80. [DOI].

Pandey S., S. Parvez, R. Ahamd Ansari, M. Ali, M. Kaur, F. Hayat, F. Ahma, S.H. Raisuddin. 2008. Effects of exposure to multiple trace metals on biochemical, histological and ultrastructural features of gills of a freshwater fish, *Channa punctatus* Bloch. - *Chemico-Biological Interactions*, 174(3): 183-192. [DOI].

Paul D. 2017. Research on heavy metal pollution of river Ganga: A review. - *Annals of Agrarian Science*, 15: 278-286. [DOI]

Paul D., S.N. Sinha. 2013. Assessment of various heavy metals in surface water of polluted sites in the lower stretch of river Ganga, West Bengal: a study for ecological impact. - *Discovery Nature*, 6: 8-13.

Peebua P., M. Kruatrachuea, P. Pokethitiyook, P. Kosiyachinda. 2006. Histological effects of contaminated sediments in Mae Klong River tributaries, Thailand, on Nile tilapia, *Oreochromis niloticus*. - *Science Asia*, 32: 143-150,

Pereira S., A.L. Pinto, R. Cortes, A. Fontaínhas-Fernandes, A.M. Coimbra, S.M. Monteiro. 2013. Gill histopathological and oxidative stress evaluation in native fish captured in Portuguese northwestern rivers. - *Ecotoxicology and Environmental Safety*, 90(1): 157-166. [DOI].

Pérez Cid B., C. Boia, L. Pombo, E. Rebelo. 2001. Determination of trace metals in fish species of the Ria de Aveiro (Portugal) by electrothermal atomic absorption spectrometry. - *Food Chemistry*, 75(1): 93-100. [DOI].

Picado A., M.J. Bebianno, M.H. Costa, A. Ferreira. 2007. Vale Biomarkers: a strategic tool in the assessment of environmental quality of coastal waters. - *Hydrobiologia*, 587: 79. [DOI].

Pinto A., S. Varandas, A. Coimbra, J. Carrola, A. Fontaínhas-Fernandes. 2009. Mullet and gudgeon liver histopathology and macroinvertebrate indexes and metrics upstream and downstream from a wastewater treatment plant (Febros River-Portugal). - *Environmental Monitoring and Assessment*, 169: 569-585. [DOI].

Powers D.A. 1989. Fish as model systems. - *Science*, 246(4928): 352-3588. [DOI].

Pragst F., K. Stieglitz, H. Runge, K.-D. Runow, D. Quig, R. Osborne, C. Runge, J. Ariki. 2017. High concentrations of lead and barium in hair of the rural population caused by water pollution in the Thar Jath oilfields in South Sudan. - *Forensic Science International*, 274: 99-106. [DOI].

QIAO M., C. WANG, S. HUANG, D. WANG, Z. WANG. 2006. Composition, sources, and potential toxicological significance of PAHs in the surface sediments of the Meiliang Bay, Taihu Lake, China. - *Environment International*, 32 (1): 28-33. [DOI].

QIAO-QIAO C., Z. GUANG-WEI, A. LANGDON. 2007. Bioaccumulation of heavy metals in fishes from Taihu Lake, China. - *Environmental Sciences*, 19: 1500–1504. [DOI].

QUASIMEME. 1992. *Quality Assurance of Information for Marine Environmental Monitoring in Europe*. Available at: [quasimeme.org]. Accessed: 10.05.2018.

RAHMAN M.S., A.H. MOLLA, N. SAHA, A. RAHMAN. 2012. Study on heavy metals levels and its risk assessment in some edible fishes from Bangshi River, Savar, Dhaka, Bangladesh. - *Food Chemistry*, 134: 1847-1854. [DOI].

RAINBOW P.S. 1993. The significance of trace metal concentrations in marine invertebrates. - In: DALLINGER R., P.S. RAINBOW (Eds.): *Ecotoxicology of metals in invertebrates*. Boca Raton. Lewis Publishers, pp. 3-23.

RAISUDDIN S., J.-S. LEE. 2008. Interdisciplinary studies on environmental chemistry - Biological responses to chemical pollutants. - In: Murakami Y., K. Nakayama, S.-I. Kitamura, H. Iwata S. Tanabe (Eds.): *Fish models in impact assessment of carcinogenic potential of environmental chemical pollutants: an appraisal of hermaphroditic mangrove killifish Kryptolebias marmoratus*. Tokyo. TERRAPUB, pp. 7-15.

RAJESHKUMAR S., J. MINI, N. MUNUSWAMY. 2013. Effects of heavy metals on antioxidants and expression of HSP70 in different tissues of Milk fish (*Chanos chanos*) of Kaattuppalli Island, Chennai, India. - *Ecotoxicology and Environmental Safety*, 98: 8-18. [DOI].

RAO L.M., G. PADMAJA. 2000. Bioaccumulation of heavy metals in *M. cyprinoids* from the harbor waters of Visakhapatnam. - *Bulletin of Pure and Applied Science*, 19A(2): 77-85

RASHED M.N. 2001a. Cadmium and lead levels in fish (*Tilapia nilotica*) tissues as biological indicator for lake water pollution. - *Environmental Monitoring and Assessment*, 68(1): 75-89. [DOI].

RASHED M.N. 2001b. Monitoring of environmental heavy metals in fish from Nessar Lake. - *Environmental International*, 27: 27-33. [DOI].

REES H.L., J.L. HYLAND, K. HYLLAND, C.S.L. MERCER CLARKE, J.C. ROFF, S. WARE. 2008. Environmental indicators: utility in meeting regulatory needs. An overview. – *ICES Journal of Marine Science*, 65: 1381-1386.

ROMEO T., B. PIETRO, C. PEDÁ, P. CONSOLI, F. ANDALORO, M.C. FOSSI. 2015. First evidence of presence of plastic debris in stomach of large pelagic fish in the Mediterranean Sea. - *Marine Pollution Bulletin*, 95: 358-361. [DOI].

ROUANE-HACENE O., Z. BOUTIBA, B. BELHAOUARI, M.E. GUIBBOLINI-SABATIER, P. FRANCOUR, C. RISSO-DE FAVERNEY. 2015. Seasonal assessment of biological indices, bioaccumulation and bioavailability of heavy metals in mussels *Mytilus galloprovincialis* from Algerian west coast, applied to environmental monitoring. - *Oceanologia*, 57(4): 362-374. [DOI].

ROWAN D.J. 2013. Bioaccumulation factors and the steady state assumption for Cesium isotopes in aquatic foodwebs near nuclear facilities. - *Journal of Environmental Radioactivity*, 121: 2-11. [DOI].

SAKTHIPRIYA N., M. DOBLE, J.S. SANGWAI. 2015. Bioremediation of coastal and marine pollution due to crude oil using a microorganism *Bacillus subtilis*. - *Procedia Engineering*, 116: 213-220, [DOI].

SANCHEZ W., J.M. PORCHER. 2009. Fish biomarkers for environmental monitoring within the Water

Framework Directive of the European Union. - *Trends in Analytical Chemistry, Elsevier*, 28: 150-158. [DOI].

SANDVIK M., J.BEYER, A. GOKSØYR, K. HYLLAND, E. EGAAS, J.U. SKAARE. 1997. Interaction of benzo[a]pyrene, 2,3,3',4,4',5 hexachlorobiphenyl (PCB 156) and cadmium on biomarker responses in flounder (*Platichthys flesus* L.). – *Biomarkers*, 2(3): 153-160. [DOI].

SANKAR T.V., A.A. ZYNUDHEEN, R. ANANDAN, P.G. VISWANATHAN NAIR. 2006. Distribution of organochlorine pesticides and heavy metal residues in fish and shellfish from Calicut region, Kerala, India. - *Chemosphere*, 65: 583-590. [DOI].

SCARDI M., S. CATAUDELLA, P. DI DATO, E. FRESI, L. TANCIONI. 2008. An expert system based on fish assemblages for evaluating the ecological quality of streams and rivers. - *Ecological Informatics*, 3(1): 55-63. [DOI].

SCHLENK D. 1999. Necessity of defining biomarkers for use in ecological risk assessments. - *Marine Pollution Bulletin*, 39: 48-53. [DOI].

SCHMITT CH. J., J.J. WHYTE, A.P. ROBERTS, M.L. ANNIS, T.W. MAY, D.E. TILLITT. 2007. Biomarkers of metals exposure in fish from lead-zinc mining areas of Southeastern Missouri, USA. - *Ecotoxicology and Environmental Safety*, 67(1): 31-47. [DOI].

SCHÖNE B.R., R.A. KRAUSE JR. 2016. Retrospective environmental biomonitoring - Mussel Watch expanded. - *Global and Planetary Change*, 144: 228-251. [DOI].

SCHØYEN M., I.J. ALLAN, A. RUUS, J. HÅVARDSTUN, D.Ø. HJERMANN, J. BEYER. 2017. Comparison of caged and native blue mussels (*Mytilus edulis* spp.) for environmental monitoring of PAH, PCB and trace metals. - *Marine Environmental Research*, 130: 221-232. [DOI].

SEKABIRA K., H. ORYEM ORIGA, T.A. BASAMBA, G. MUTUMBA, E. KAKUDIDI. 2010. Assessment of heavy metal pollution in the urban stream sediments and its tributaries. - *International Journal of Environmental Sciences and Technology*, 7(3): 435-446. [DOI].

SHAH A.Q., T.G. KAZI, M.B. ARAIN, J.A. BAIG, H.I. AFRIDI, G.A. KANDHRO, S. KHAN, MK. JAMALI. 2009. Hazardous impact of arsenic on tissues of same fish species collected from two ecosystem. - *Journal of Hazardous Materials*, 167: 511-515. [DOI].

SHAHBAZ M., M.Z. HASHMI, R.N. MALIK, A. YASMIN. 2013. Relationship between heavy metals concentrations in egret species, their environment and food chain differences from two Headworks of Pakistan. - *Chemosphere*, 93: 274-282. [DOI].

SHERMAN K. 1994. Sustainability, biomass yields, and health of coastal ecosystems: an ecological perspective. - *Marine Ecology Progress Series*, 112: 277-301.

SHINN C., F. DAUBA, G. GRENOUILLET, G. GUENARD, S. LEK. 2009. Temporal variation of heavy metal contamination in fish of the river Lot in southern France. - *Ecotoxicology and Environmental Safety*, 72: 1957-1965. [DOI].

SIVAPERUMAL P., T.V. SANKAR, P.G. VISWANATHAN NAIR. 2007. Heavy metal concentrations in fish, shellfish and fish products from internal markets of India vis-a-vis international standards. - *Food Chemistry*, 102: 612-620. [DOI].

SONG Y., B. SALBU, L. SORLIE HEIER, H.C. TEIEN, O.C. LIND, D. OUGHTON, K. PETERSEN, B.O. ROSSELAND, L. SKIPPERUD, K.E. TOLLEFSEN. 2012. Early stress responses in Atlantic salmon (*Salmo salar*) exposed to environmentally relevant concentrations of uranium. - *Aquatic Toxicology*, 112-113: 62-71. [DOI].

SONNE C., O. ASPHOLM, R. DIETZ, S. ANDERSEN, M.H.G. BERNTSSEN, K. HYLLAND. 2009. A study of metal concentrations and metallothionein binding capacity in liver, kidney and brain tissues of three Arctic seal species. - *Science of the Total Environment*, 407: 6166-6172. [DOI].

SOUNDERAJAN S., G.K. KUMAR, A.C. UDAS. 2010. Cloud point extraction and electrothermal atomic absorption spectrometry of Se (IV)-3,3′-Diaminobenzidine for the estimation of trace amounts of Se (IV) and Se (VI) in environmental water samples and total selenium in animal blood and fish tissue samples. - *Journal of Hazardous Materials*, 175(1-3): 666-672. [DOI].

SPARKS C., J. ODENDAAL, R. SNYMAN. 2014. An analysis of historical Mussel Watch Programme data from the west coast of the Cape Peninsula, Cape Town. - *Marine Pollution Bulletin*, 87: 374-380. [DOI].

SREBOTNJAK T., G. CARR, A. DE SHERBININ, C. RICKWOOD. 2012. A Global Water Quality Index and hot-deck imputation of missing data. - *Ecological Indicators*, 17: 108-119. [DOI].

STAMENKOVIĆ S.S., LJ.M. TATJANA, V.J. CVETKOVIĆ, N.C. KRSTIĆ, R.M. BAOŠIĆ, M.S. MARKOVIĆ, N.D. NIKOLIĆ, V.LJ. MARKOVIĆ, M.V. CVIJAN. 2013. Biological indication of heavy metal pollution in the areas of Donje Vlase and Cerje (Southeastern Serbia) using epiphytic lichens. - *Archives of Biological Sciences*, 65(1): 151-159. [DOI].

STEINBERG C.E.W., R. LORENZ, O.H. SPIESER. 1995. Effects of atrazine on swimming behavior of zebra fish, *Brachydanio rerio*. - *Water Research*, 29: 981-985. [DOI].

SUBOTIĆ S., S. SPASIĆ, Ž. VIŠNJIĆ-JEFTIĆ, A. HEGEDIŠ, J. KRPO-ĆETKOVIĆ, B. MIĆKOVIĆ, S. SKORIĆ, M. LENHARDT. 2013. Heavy metal and trace element bioaccumulation in target tissues of four edible fish species from the Danube River (Serbia). - *Ecotoxicology and Environmental Safety*, 98: 196-202. [DOI].

SUN X., F. ZHU, J. XI, T. LU, H. LIU, Y. TONG, G. OUYANG. 2011. Hollow fiber liquid-phase microextraction as clean-up step for the determination of organophosphorus pesticides residues in fish tissue by gas chromatography coupled with mass spectrometry. - *Marine Pollution Bulletin*, 63: 102-107, [DOI].

TAPIA J., C. BERTRÁN, C. ARAYA, M.J. ASTUDILLO, L. VARGAS-CHACOFF, G. CARRASCO, A. VADERRAMA, L. LETELIER. 2009. Study of the copper, chromium and lead content in *Mugil Cephalus* and *Eleginops Maclovinus* obtained in the mouths of the Maule and Mataquito rivers (Maule region, Chile). - *Journal of the Chilean Chemical Society*, 54: 36-39. [DOI]

TAWEEL A., M. SHUHAIMI-OTHMAN, A.K. AHMAD. 2013. Assessment of heavy metals in tilapia fish (*Oreochromis niloticus*) from the Langat River and Engineering Lake in Bangi, Malaysia, and evaluation of the health risk from tilapia consumption. - *Ecotoxicology and Environmental Safety*, 93: 45-51. [DOI].

THAIN J.E., A.D. VETHAAK, K. HYLLAND. 2008. Contaminants in marine ecosystems: developing and integrated indicator framework using biological-effect techniques. – *ICES Journal of marine Science*, 65: 1508-1514.

TOLLEFSEN K.-E., E. BRATSBERG, O. BOYUM, E.F. FINNE, I.K. GREGERSEN, M. HEGSETH, C. SANDBERG, K. HYLLAND. 2006. Use of fish *in vitro* hepatocyte assays to detect multi-endpoint toxicity in Slovenian river sediments. - *Marine Environmental Research*, 62: S356-S359. [DOI].

TURJA R., A. SOIRINSUO, H. BUDZINSKI, M.H. DEVIER, K.K. LEHTONEN. 2013. Biomarker responses and accumulation of hazardous substances in mussels (*Mytilus trossulus*) transplanted along a pollution gradient close to an oil terminal in the Gulf of Finland (Baltic Sea). - *Comparative Biochemistry and Physiology, Part C*, 157: 80–92. [DOI].

TÜRKMEN A., M. TÜRKMEN, Y. TEPE, I. AKYURT. 2005. Heavy metals in three commercially valuable fish species from Iskenderun Bay, Northern East

Mediterranean Sea, Turkey. - *Food Chemistry*, 91: 167-172. [DOI].

UNEP. 2016. Marine plastic debris and microplastics - Global lessons and research to inspire action and guide policy change. United Nations Environment Programme, Nairobi.

UNEP/RAMOGE. 1999. *Manual on the biomarkers recommended for the MED POL Biomonitoring Programme*. United Nations Environment Programme Mediterranean Action Plan, Athens, UNEP, 94 p.

Usero J., C. Izquierdo, J. Morill, I. Gracia. 2004. Heavy metals in fish (*Solea vulgaris*, *Anguilla anguilla* and *Liza aurata*) from salt marshes on the southern Atlantic coast of Spain. - *Environment International*, 29(7): 949-956. [DOI].

van der Oost R., H.Heida, K. Satumalay, F.–J. van Schooten, F. Ariese, N.P.E. Vermeulen. 1994. Bioaccumulation, biotransformation and DNA binding of PAHs in feral eel (*Anguilla anguilla*) exposed to polluted sediments: a field survey - *Environmental Toxicology and Chemistry*, 13(6): 859-870. [DOI].

van der Oost R., J. Beyer, N.P.E. Vermeulen. 2003. Fish bioaccumulation and biomarkers in environmental risk assessment: a review. - *Environmental Toxicology and Pharmacology*, 13(2): 57-149. [DOI].

Vestheim H., K. Langford, K. Hylland. 2012. Lack of response in a marine pelagic community to short-term oil and contaminant exposure. - *Journal of Experimental Marine Biology and Ecology*, 416-417: 110-114. [DOI].

Vethaak A.D., I.M. Davies, J.E. Thain, M.J. Gubbins, C. Martínez-Gomez, C.D. Robinson, C.F. Moffat, T. Burgeot, T. Maes, W. Wosniok, M. Giltrap, T. Lang, K. Hylland. 2015. Integrated indicator framework and methodology for monitoring and assessment of hazardous substances and their effects in the marine environment. - *Marine Environmental Research*, 124: 11-20. [DOI].

Viarengo A., L. Canesi. 1991. Mussels as biological indicators of pollution. – *Marine Pollution Bulletin*, 7: 225-243. [DOI].

Wang X., T. Sato, B. Xing, S. Tao. 2005. Health risks of heavy metals to the general public in Tianjin, China via consumption of vegetables and fish. - *Science of the Total Environment*, 350(1-3): 28-37. [DOI].

Weisberg R.H., Z. Lianyuan, L. Yonggang. 2017. On the movement of Deepwater Horizon Oil to northern Gulf beaches. - *Ocean Modelling*, 111: 81-97. [DOI].

Wepener V., N. Degger. 2012. Status of pollution research in South Africa (1960-present). - *Marine Pollution Bulletin*, 64: 1508–1512. [DOI].

Wester P.W., J.H. Canton. 1991. The usefulness of histopathology in aquatic toxicity studies. - *Comparative Biochemistry and Physiology, Part C*, 100: 115-117. [DOI].

WHO International Programme on Chemical Safety (IPCS). 1993. *Biomarkers and risk assessment: concepts and principles*. - Environmental Health Criteria 155, World Health Organization, Geneva.

Widdows J., P. Donkin. 1992. Mussels and environmental contaminants: bioaccumulation and physiological aspects. - In: Gosling E. (Ed.): *Developments in aquaculture and fisheries science. The mussel Mytilus: ecology, physiology, genetics and culture*. Amsterdam. Elsevier, pp. 383-398.

Wilberforce J.O. 2016. Phytoremediation of metal component of oil spill site using common vegetables. - *Middle-East Journal of Scientific Research*, 24(3): 962-966. [DOI].

Yadav A.S., A. Bhatnagar, M. Kaur. 2010. Assessment of genotoxic effects of butachlor in fresh water fish, *Cirrhinus mrigala* (Hamilton). - *Research Journal of Environmental Toxicology*, 4: 223-230, [DOI].

YANCHEVA V., S. STOYANOVA, I. VELCHEVA, S. PETROVA, E. GEORGIEVA. 2014a. Metal bioaccumulation in common carp and rudd from the Topolnitsa reservoir, Bulgaria. - *Archives of Industrial Hygiene and Toxicology*, 65(1): 57-66. [DOI].

YANCHEVA V.S., E. GEORGIEVA, I. VELCHEVA, I. ILIEV, T. VASILEVA, S. PETROVA, S. STOYANOVA. 2014b. Biomarkers in European perch (*Perca fluviatilis*) liver from a metal-contaminated dam lake. - *Biologia*, 69(11): 1615-1624. [DOI].

YANCHEVA V., I. VELCHEVA, S. STOYANOVA, E. GEORGIEVA. 2015. Fish in ecotoxicological studies. - *Ecologia Balkanica*, 7(1): 149-169.

YANCHEVA V., I. VELCHEVA, S. STOYANOVA, E. GEORGIEVA. 2016a. Histological biomarkers in fish as a tool in ecological risk assessment and monitoring programs: a review. - *Applied Ecology and Environmental Research*, 14(1): 47-75. [DOI].

YANCHEVA V., S. STOYANOVA, I. VELCHEVA, E. GEORGIEVA. 2016b. Assessment of gill histological responses in common carp (*Cyprinus carpio* L.) and common rudd (*Scardinius erythrophatalamus* L.) from Topolnitsa reservoir, Bulgaria. - *Acta Zoologica Bulgarica*, 68(1): 103-109.

YANCHEVA V., I. MOLLOV, I. VELCHEVA, E. GEORGIEVA, S. STOYANOVA. 2016c. Effects of cadmium (Cd) on the lysosomal membrane stability and respiratory rate of two freshwater mollusks under *ex situ* exposure: preliminary data. - *South-Western Journal of Horticulture, Biology and Environment*, 7(1): 27-34.

YANCHEVA V., I. MOLLOV, I. VELCHEVA, E. GEORGIEVA, S. STOYANOVA. 2016d. Heavy metal effects on the lysosomal membrane stability and respiratory rate in Chinese Pond mussel (*Sinanodonta woodiana*) under *ex situ* exposure: Preliminary data. - *Biharean Biologist*, 10(1): 55-57.

YANCHEVA V., I. MOLLOV, E. GEORGIEVA, S. STOYANOVA, V. TSVETANOVA, I. VELCHEVA 2017. *Ex situ* effects of chlorpyrifos on the lysosomal membrane stability and respiration rate in Zebra mussel (*Dreissena polymorpha* Pallas, 1771). - *Acta Zoologica Bulgarica*, S8: 85-90.

YI Y., Z. YANG, S. ZHANG. 2011. Ecological risk assessment of heavy metals in sediment and human health risk assessment of heavy metals in fishes in the middle and lower reaches of the Yangtze River basin. - *Environmental Pollution*, 159: 2575-2585. [DOI].

YOHANNES Y.B., Y. IKENAKA, S.M.M. NAKAYAMA, A. SAENGTIENCHAI. 2013. Organochlorine pesticides and heavy metals in fish from Lake Awassa, Ethiopia: Insights from stable isotope analysis. - *Chemosphere*, 91: 857-863, [DOI].

YUAN G.L., C. LIU, L. CHEN, Z. YANG. 2011. Inputting history of heavy metals into the inland lake recorded in sediment profiles: Poyang Lake in China. - *Journal of Hazardous Materials*, 185: 336-345. [DOI].

ZATTA P., S. GOBBO, P. ROCCO, M. PERAZZOLO, M. FAVARATO. 1992. Evaluation of heavy metal pollution in the Venetian lagoon by using *Mytilus galloprovincialis* as a biological indicator. - *Science of the Total Environment*, 119: 29-41. [DOI].

ZHANG R., L. ZHOU, F. ZHANG, Y. DING, J. GAO, J. CHEN, H. YAN, W. SHAO. 2013. Heavy metal pollution and assessment in the tidal flat sediments of Haizhou Bay, China. - *Marine Pollution Bulletin*, 74: 403-412. [DOI].

Received: 07.12.2017
Accepted: 10.04.2018