ICES VIEWPOINT: Assessment of the biological effects of chemical pollution for better management of the marine environment

Summary

Chemical pollution is the introduction, through human activities, of chemical substances that have potential toxicity to marine organisms into the marine environment. Over the past several decades, the chemical environment of the seas has evolved as a result of these activities. There has been a continuous introduction of new substances and a general shift from high concentrations of a few chemicals to low concentrations of many. This situation is likely to persist in the future. The main groups of chemical pollutants that are of concern – trace metals and organic contaminants – have at least one of the following characteristics: they are persistent, bioaccumulative, and/or toxic to marine organisms.

There are several well documented examples of the impact of chemical pollutants on marine populations, at different trophic levels from invertebrates to marine mammals, via multiple mechanisms of toxicity. In addition, there is evidence of the sublethal effects of chemical pollution at the organismal level on biological functions, strongly linking to pathology and disease. The biological effects of chemical pollution need to be assessed directly, supporting the need for field-based assessments.

ICES advises to adopt the approach of biological effects methods for monitoring within the integrated chemical-biological monitoring and assessment framework as an absolute prerequisite for the provision of a holistic assessment of the impacts of pollution on marine ecosystems. ICES also recommends several measures for the effective implementation of field-based biological effects methods. The new knowledge should be effectively brought into regulatory frameworks.

Recommendations

1. Fully adopt the biological effects methods monitoring approach within the integrated chemical-biological monitoring and assessment framework for accurate and realistic assessment of chemical pollution and its impacts, including the effects of chemical mixtures.
2. Include appropriate monitoring methods that quantify the most important toxicity mechanisms: carcinogenicity, genotoxicity, neurotoxicity, immunotoxicity, cardiotoxicity, and endocrine disruption.
3. Further develop and implement quality assurance programmes and intercalibration exercises on a larger number of chemical and biological determinants to ensure comparability of data between laboratories and to promote free accessibility of data.
4. Continue to bring in new evidence of the biological effects of chemical pollution into national and international regulatory frameworks.

Introduction to the issue

The marine environment contains a mixture of different natural and man-made chemicals. Consequently, organisms are exposed to a range of chemical pollutants, many of which have the potential to cause effects on individuals, populations, species, and communities through changes in traits such as growth, reproduction, and survival. The major concerns are that some contaminants: (i) may be so persistent that they will remain in the marine environment for a very long time, even for centuries, (ii) may accumulate efficiently in organisms and biomagnify in food chains, resulting in high concentrations in biota, even in pristine areas, and (iii) may cause effects, including combined effects, even at low concentrations (ng/L or less).

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The effects vary according to the type and concentration of individual pollutants and their mixtures and are also dependent on the organisms being exposed. In addition, new chemical pollutants are being released into the seas and are emerging in environmental samples. This requires continuous efforts in developing methods and tools to deliver advanced knowledge that underpins management advice.

What is chemical pollution and what are the main groups of contaminants of concern?

Chemical pollution is the introduction, through human activities, of chemical substances that have potential toxicity to marine organisms into the marine environment. These substances can be solely man-made (e.g. synthetic organic pollutants and substances in pesticides, pharmaceuticals, and products for industrial and domestic applications) or of both human and natural origin (e.g. trace metals and polycyclic aromatic hydrocarbons [PAHs]). They are present at elevated concentrations as a result of land run-off, land-based or offshore effluents, transport, accidental spills, and industrial activities, among others. Over the past several decades, the chemical environment of the seas has evolved as a result of human activities, with the continuous release of new chemical pollutants.

The main groups of chemical pollutants that are of concern in marine ecosystems have at least one of the following characteristics: they are persistent, highly bioaccumulative, and/or highly toxic to marine organisms.

Trace metals

Trace metals are inorganic contaminants that cannot be degraded. Some (e.g. copper and zinc) are essential to all living organisms, but some (e.g. lead, gold, silver, and mercury) have no known biological function. Even essential trace metals may be present at concentrations sufficiently high for them to be harmful to marine environments.

Organic contaminants

Persistent organic pollutants (POPs) – including legacy contaminants such as polychlorinated biphenyls (PCBs), dioxins, brominated flame retardants, and chlorinated pesticides – are often present at very high concentrations in long-lived organisms that are high up in the foodweb. This is despite first regulations of, for example, PCBs in the early 1970s and their definite regulation in 1992. PAHs are of concern because of their carcinogenity and mutagenicity. Contaminants of emerging concern (CECs) include compounds continuouly released into the marine environment, such as per- and polyfluoroalkyl substances (PFAS), which are of major concern because of their persistence and largely unknown toxic properties. The release of CECs as well as pharmaceuticals and personal care products, mainly through wastewater treatment plants, is also a current threat to marine biota.

Anthropogenic particles such as nanoparticles and nano-/microplastics are present in marine ecosystems and may cause harm. They are not included in this Viewpoint.

What is known about the effects of chemical pollution on marine life?

Chemical pollutants can cause various health effects in marine species at different trophic levels, from invertebrates to marine mammals. Several well documented cases are available that show clear evidence of contaminants having impacted marine populations. In addition, there is some evidence of various sublethal effects of chemical pollution at the organismal level on biological functions, strongly linked to pathology and disease.

Endocrine disruption caused by the antifouling agent tributyltin (TBT) has led to the complete disappearance of some populations of the gastropod *Nucella lapillus* in the UK, with up to 100% of the females being sterile in some of the remaining populations. Flatfish species in the Puget Sound (northwest US) had neoplasms (tumour developments) present in up to 25% of their populations as a result of exposure to sediments contaminated with PAHs.

Chinook salmon (*Oncorhynchus tshawytscha*) and Pacific staghorn sculpin (*Leptocottus armatus*) from the Puget Sound presented signs of disruption of metabolic parameters measured in plasma samples, indicating a starvation-like physiologicial response to the bioaccumulation of a high number of chemicals of emerging concern, including pharmaceuticals, personal care products, and several industrial compounds. However, organismal condition indices did not show any alterations.

In the Baltic Sea, the significant population decrease in the grey seal (*Halichoerus grypus*) in the 1980s was partly caused by reproductive failure associated with the accumulation of POPs. Reproductive failure in the European killer whale (*Orcinus orca*) populations has been and is still associated with the accumulation of organic pollutants (particularly PCBs) in blubber.

Laboratory experiments have shown that the concentrations observed in coastal waters of a range of chemicals are sufficient to affect the health and fitness of marine organisms. However, under field conditions it is often difficult to prove causality given that endo- and exogenous factors other than environmental contaminants can also affect an organism's growth, survival, and reproduction. Several fundamental gaps in knowlege related to the effects of both single substances and mixtures limit our understanding of the effects of chemical pollutants; furthermore, a multistressor environment is the reality that organisms experience in nature, and chemical pollution contributes to deleterious effects at varying degrees.

Why are chemical analyses alone insufficient to assess contaminant toxicity?

There are programmes in place in several marine areas to monitor concentrations of a range of chemicals both in the environment and biota. However, the outcomes of these programmes do not enable the evaluation of the effects of chemical pollutants in marine organisms because there is not necessarily a direct relationship between the chemical proxy (i.e. the concentration of contaminants in the tissue of an organism) and health impacts. Analytical tools for chemicals are also not able to detect and quantify all potential contaminants present in a sample and do not provide any information on their potential mixture toxicity. The following argumentation can be provided: (i) the bioaccumulated contaminants are generally stored in particular compartments or forms with limited immediate availability for the biochemical and cellular processes of organisms; (ii) if effects are present, they are likely caused by a mixture of various contaminants; (iii) some contaminants, including endocrine disruptors, cause effects without bioaccumulating; and, (iv) the effects arise in the intersection between contaminant stress and the general health status of an organism. This supports the need for measurements of biological effects directly in field-caught organisms.

What actions can be taken to identify, quantify, and manage the biological effects of pollution?

The biological effects of pollution on marine organisms can be accurately assessed only through sampling and analysis of organisms from natural populations. The strategy recommended below makes it possible to identify and quantify the effects to help reduce or even prevent the effects of chemical pollution. The following actions are suggested:

Adopting a common monitoring and assessment approach

For a quantitative assessment of the impacts of chemical pollution on marine ecosystems, a full adoption of biological effects methods for monitoring is required within the integrated chemical-biological monitoring and assessment frameworks. Such a holistic approach provides a more realistic assessment of chemical pollution and its impacts.

In the integrated chemical-biological monitoring and assessment frameworks, parameter-specific assessment criteria for biological effects are established based on predefined levels of response that indicate a potential threat to the health of a species or population. This includes indicating threshold response values for background conditions, polluted conditions, and conditions potentially harmful to populations. In this approach, responses of different mechanisms of toxicity are assumed to be additive.

Applying robust biological effects monitoring methods

Biological effects methods are based on the measurement of sublethal contaminant-related responses (i.e. biomarkers) that reflect different mechanisms of toxicity and have explicit links to the health of individual organisms as well as potential impacts at population and community levels. The main toxicity mechanisms to be routinely monitored (with some generic examples on individual health and population-level effects) are:

Carcinogenicity – tumour formation;

Genotoxicity – carcinogenicity, compromised offspring, reduced reproductive output;

Neurotoxicity – increased mortality, reduced food uptake, behavioural changes;

Immunotoxicity – suppression of immune function; increased disease susceptibility;

Cardiotoxicity - reduced cardiac output, reduced growth, reduced swimming ability;

Endocrine disruption – changed sex ratio, sterilization, reduced growth, disrupted maturation.

Advancing and strengthening the suite of methods also requires: (i) establishing robust biomarkers for immunotoxicity and cardiotoxicity, and (ii) evaluating new monitoring methods such as metabolomics, proteomics, and transcriptomics.

It should be ensured that the methods are able to distinguish the effects of pollution from those of natural factors (e.g. the effects of seasonality in food availability and temperature and individual parameters such as age, sex, and maturation status) and either prove them insiginificant or account for them in the assessment.

Assuring data quality and comparability

Quality assurance programmes must be implemented and kept active to ensure comparability of results from different laboratories, geographical regions, and time periods. Quality assurance protocols and intercalibration exercises for biological effects methods have already been developed and implemented in several countries and these should, together with the lessons learned, be shared to promote the development of programmes in regions where they do not currently exist. It is also critically important to promote free data accessibility.

Revising regulations

Regulatory actions have in many regions resulted in a significant reduction in the use and emission of chemicals with a known high toxicity. As a result, in the marine environment a general shift has been observed from high concentrations of a few chemicals to low concentrations of many. New chemicals are continuously being produced and released into the marine environment. Such a situation is likely to continue and progress in the future. This requires periodically revisiting and revising the regulatory frameworks based on new evidence of the biological effects of pollution to support further strengthening of regulatory measures to manage emissions.

Additional considerations

There are already several examples available of the incorporation of biological effects monitoring into national monitoring programmes. Lessons learned from these programmes make invaluable contributions to the effective implementation of the common monitoring and assessment framework, as recommended in this Viewpoint.

Sources

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