

Chapter 7

Environmental Toxicology



Adil Sidahmed Omer Ahmed

7.1 Introduction

7.1.1 Overview

One of the severe problems made by humans and affecting the environment are facing today is the discharge of huge quantities of hazardous chemical compounds into the environment. Understanding these chemicals' effects on an ecosystem's components is vital to predict and control their harmful effects. The major areas of environmental toxicology include the impact of chemicals on environmental testing for toxins, risk assessment, radioactivity in the environment, laws, environmental monitoring, and the effects of industrial development on the environment in the future (Chadwick 1998).

Two interrelated subjects could be distinguished within environmental toxicology as follows.

Environmental health toxicology is the branch that utilizes standard animal models and epidemiological evaluation of exposed human populations to infer the adverse effects of chemicals on human health.

Ecotoxicology is defined by Forbes and Forbes (1994) as “the field of study which integrates the ecological and toxicological effects of chemical pollutants on populations, communities, and ecosystems with the fate (transport, transformation, and breakdown) of such pollutants in the environment.”

Environmental toxicology is still crucial (e.g., single-species checking out for screening purposes). However, ecological toxicology (Ecotoxicology—extra realism in assessments, check species and exposures) is needed to predict actual global

A. S. O. Ahmed (✉)

Division of Marine Biology and Fisheries Research, Institute of Marine Research, Red Sea University, Port Sudan, Sudan

outcomes and site-particular evaluation (Chapman 2002). It is mentioned that toxicological research of the surroundings may be frequently characterized as environmental toxicology. Such research is carried out independently from ecological concerns and possibly, in the end, as compared to ecological research in a burden-of-proof approach (Ingersoll et al. 1997). Consideration of ecology is commonly extrinsic as opposed to intrinsic. In different words, assessments are, in lots of cases, carried out with organisms that may conveniently be obtained, cultured, and tested. The ecological importance of the check organisms is a secondary consideration. Thus, for example, freshwater rainbow trout toxicity assessments are utilized in Canada even for effluents discharging into marine waters (Abudegoon and Ali 2013).

7.1.2 *Definition*

Environmental Toxicology concentrates, in general, on the examination of chemical substances that contaminate food, water, soil, or the atmosphere. It additionally offers poisonous materials that input our bodies of water together with lakes, streams, rivers, and oceans. This sub-area addresses the query of ways numerous flora, fauna, and human beings are stricken by publicity to poisonous materials. Wayne et al. (2018) define environmental toxicology as (the study of the effects of pollutants on the structure and function of ecological systems). Environmental toxicology takes and assimilates from several disciplines. Terrestrial and aquatic ecologists, chemists, molecular biologists, geneticists, and mathematicians play a crucial role in assessing the effects of chemical substances on organic structures. According to Hughes (2005), Environmental toxicology is the examination of the poisons around us. A fashionable definition of environmental toxicology is those poisons' unsafe outcomes on human fitness.

On the other hand, Ecotoxicology has been described in the literature in many methods over the last decades. Depending on their study objectives, particularly their essential or carried out training, many authors limit themselves to an extra or much less constrained region of investigation. For example, consistent with Butler (1978), "Ecotoxicology is focused on the poisonous outcomes of chemical and bodily dealers on dwelling organisms, particularly on populations and groups inside described ecosystems; it consists of the switch pathways of these dealers and their interactions with the surroundings. Environmental toxicology is a multidisciplinary technology encompassing numerous various regions of examination, together with biology, chemistry (natural, analytical, and biochemistry), anatomy, genetics, physiology, microbiology, ecology, soil, water, and atmospheric sciences, epidemiology, economics, law, and others. Environmental toxicology is a fantastically younger branch of technology compared to many different examination fields. However, its significance as a place of examination is now broadly recognized. Indeed, it is one of the maximum unexpectedly developing fields of research. This is apparent if we consider the vast range of environmental toxicology-associated journals and books posted in the latest years, Ming (2001).

7.1.3 Importance of Eco/Environmental Toxicology

The area of environmental toxicology is therefore drawn in synchronous directions. Regulation entails standardized checking out. This is rapid and economical, with consequences that can be carried out in a modern concept. This has led to an emphasis on simplified scenarios, together with the conventional mortality check and the usage of the most effective one-check species and one-check compound. Toxicological studies, however, increasingly exhibit the significance of complicated interactions among physiological techniques, species, character organisms, countless environmental elements, and a couple of anthropogenic compounds. On the other hand, Ecotoxicology's primary goal of Ecotoxicology is to examine structural and practical disturbances induced inside the short, medium, and longtime through infection elements on ecological structures.

7.2 Sources of Environmental Toxicology

Industrial development has led to the manufacturing more than 100,000 new chemical substances typically utilized in consumer products (Yang et al. 2014). This, accompanied by insufficient control of anthropogenic wastes, has extended the advent of various poisonous chemical substances to the environment. Toxic chemical substances polluting the surroundings are called environmental or ecotoxicants (Sánchez-Bayo 2011). Environmental toxicants may be categorized into two classes consistent with their origin.

7.2.1 Natural Sources

Some environmental toxicants originate naturally from the physical environment or some living organisms. Accordingly, they could be inorganic or organic chemicals, respectively. Wind and water movements erode inorganic toxic metals, metalloids, and anions from the earth's crust. However, they only become toxic when they are released in excess by man activities such as mining, industries, and agriculture. Organic toxicants are the metabolites produced by living organisms, such as the toxins produced by certain species of marine phytoplankton, blue-green algae, some terrestrial plants, and the venom of snakes. Toxins produced by living organisms are referred to as biotoxins (Still and Mohapatra 2009).

Of the metals and metalloids, the group commonly known as heavy metals is associated with contamination and toxicity (Tiwari and Lata 2018; Pourret and Hursthouse 2019). Similarly, Anions, such as nitrates and phosphates, introduced in excess to the environment through agricultural practices, are reported to exhibit

Table 7.1 Classification of biotoxins according to the organism of origin

No.	Biotoxins class	Organism of origin
1	Microbial toxins	Bacteria and fungi
2	Mycotoxins	Fungi
3	Phycotoxins	Plants
4	Phycotoxins	Algae
5	Zootoxins	Animals

toxicity (Walker et al. 1997). All these environmental toxicants may eventually accumulate in the food web and cause sublethal to lethal toxicity to living organisms.

Some living organisms, from single-celled microorganisms to some large vertebrates, produce biotoxins to combat biotic and abiotic stressors (Picardo et al. 2018). Biotoxins are broadly classified according to the organism of origin, as in Table 7.1.

Aquatic biotoxins (fresh and marine water) have received immense scientific attention due to their high potential to accumulate through the food web and their ability to cause health issues in humans who consume aquatic food products such as shellfish and bivalves (O Mahony 2018). Among aquatic biotoxins, algal biotoxins, produced by microalgal blooms known as harmful algal blooms (HABs), are particularly significant to human and food safety. In freshwater bodies, biotoxins are produced by toxic cyanobacteria or blue-green algae and are reported to exert hepatotoxic and neurotoxic effects (Murk et al. 2019). In marine environments, 100 species of phytoplankton are known to produce persistent mycotoxins that cause intoxication or even death to humans and animals (Visciano 2016).

7.2.2 Anthropogenic Sources

Environmental toxicants from anthropogenic sources are primarily synthetic chemicals utilized in agriculture, industries, and households, to name a few. This category includes organic chemicals, such as dioxins, pesticides, polychlorinated biphenyls (PCB), polycyclic aromatic hydrocarbons (PAH), solvents, and chemical warfare agents, as well as metals, such as arsenic, cadmium, chromium, lead, and mercury, together with their inorganic or organic compounds (Bogusz 2000). Manufactured environmental toxicants are persistent, non-degradable, and bioaccumulative in living tissue.

7.3 Classes of Environmental Toxicants

Environmental toxicants are classified based on their impacts on humans and other living organisms. These impacts are generally manifested on cellular or whole system levels. Accordingly, they are classified as below.

7.3.1 Carcinogens

These are chemicals with sufficient evidence of causing cancer in humans. They interfere with cellular processes, such as cellular metabolism or DNA replication, which induces uncontrolled cell division that eventually leads to the formation of tumors (Liu 2020). Examples of these chemicals may include aflatoxin B1, a naturally occurring mycotoxin, and Per- and poly-fluoroalkyl substances (PFAS), a large class of environmentally persistent chemicals used in industrial and consumer products.

7.3.2 Mutagens

Mutagens are chemical and physical agents, known as genotoxic chemicals, in the environment that induce genetic mutations or increase mutation rates during human life (Yagi 2017). Genotoxic environmental toxicants cause a mutation by binding to an organism's DNA and producing mutant cells during DNA replication (Walker et al. 2016). Mutant cells may cause abnormal growths leading to tumor formation. Therefore, most mutagens may act as human carcinogens. Examples of mutagens are polycyclic aromatic hydrocarbons (PAHs), which are components of smoke, soot, and crude oil and are commonly found in urban areas in locations of oil spillage.

7.3.3 Teratogens

Teratogens are chemical compounds and environmental conditions which interfere with normal fetal/embryo development (Hall 2016). Teratogens can interact with some genes, modifying morpho-functional patterns and resulting in a significant susceptibility or resistance to harmful substances (Mazzu-Nascimento et al. 2017). The resulting teratogenic effects are spontaneous abortion, fetal loss, embryo-fetal morphological abnormalities, intrauterine growth restriction, and functional disabilities, such as intellectual disability.

7.3.4 Allergens

Allergens exposure to environmental toxicants affect the immune system and causes allergies and asthma (Yang et al. 2014). The immune system's overreaction to these allergens triggers symptoms similar to being sick. Examples of allergens may include heavy metals, phthalates, diesel exhaust particles, and tobacco smoke.

7.3.5 *Neurotoxins*

Neurotoxins are natural or manufactured compounds that disturb the standard transmission of impulses along nerves, nerve junctions, and between nerve endings and cells of muscles and glands (Tseng 2018). Naturally occurring neurotoxins may include ciguatoxin acid produced by the marine phytoplankton species *Gambierdiscus* spp. Synthetic neurotoxins may include some widely used compounds such as pesticides and herbicides. Also, neurotoxins could be of metallic, organic, and organo-metallic natures. Prominent metallic neurotoxins are heavy metals (e.g., lead and aluminum) that are naturally occurring. Most organic and organometallic are synthetic. Neurotoxins can lead to symptoms like slurred speech, loss of muscle control, and even death.

The human hormones system regulates growth, development, sexual maturity, brain function, and appetite.

7.3.6 *Endocrine Disrupters*

Some environmental toxins, such as endocrine-disrupting chemicals (EDCs), are similar to hormones and can imitate the action of steroid hormones and promote endocrine and reproductive disorders, both in animal and human studies (Yang et al. 2014). Sources of these toxicants are some drugs and chemicals in plastics.

7.4 **Fundamental Concepts in Aquatic Ecotoxicology**

Ecological structures are indeed characteristic of moves and interactions among abiotic elements, which signify the physiochemistry of the biotopes, and biotic elements, which relate to the organic aspect. This aspect can be tested at many tiers, from the cell and molecular foundation to the biocenosis (all of the species on the atmosphere level), thru the mediator tiers of organism and population (all the individuals of a single species), Boudou and Ribeyre (1989). Pollution through the manner of a method of heavy metals has ended up a severe environmental and public fitness danger since the concentrations launched into the surroundings from commercial techniques regularly exceed permissible tiers. Due to their bioaccumulative and non-biodegradable properties, heavy metals represent a central institution of aquatic pollution, Vutukuru et al. (2007). Their excessive toxicity, even in low concentrations, can produce cumulative deleterious outcomes in the vast form of fish and different aquatic organisms. Environmental contaminants are regularly counseled as the capacity number one elements or cofactors in amphibian's declines (Alford and Richards 1999; Blaustein et al. 2003; Sih et al. 2004). There is powerful correlational proof from landscape-scale facts that windborne insecticides have

contributed to the decline of *Rana muscosa* within the California Sierra Nevada (Davidson and Knapp 2007). Correlational proof also shows declines, such as those of *Acris crepitans* (Reeder et al. 2005). Furthermore, *Desmognathus fuscus* (Bank et al. 2006) has been caused by surface-borne pollutants.

7.4.1 Impacts of Environmental Toxicology on Fresh Water

Human societies are changing herbal structures on an international scale (Imhoff et al. 2004; Rockstrom et al. 2009; Tollefson and Gilbert 2012). If modern traits succeed, this can result in losses in biodiversity and atmosphere capabilities essential for human societies (Cardinale et al. 2012; Hooper et al. 2012; MEA 2005). Species in freshwater ecosystems are amongst the ones dealing with the best extinction risks (Heino et al. 2009; MEA 2005; Pereira et al. 2010; Revenga et al. 2005). Many stressors contribute to the ecological deterioration of freshwater ecosystems, which can be observed through toxicants, eutrophication, entry of natural rely, and habitat degradation (Vorosmarty et al. 2010; Woodward et al. 2012). The principal agencies of toxicants cited within the Millennium Ecosystem Assessment embody insecticides and heavy metals (MEA 2005). Moreover, salinization is indexed as a primary element changing freshwater quality. Thus, salts can also be considered toxicants (Kefford et al. 2002). Most of the grasp at the outcomes of toxicants on freshwater ecosystems comes from laboratory research or research carried out in experimental structures (Beketov and Liess 2012; Mayer-Pinto et al. 2010). For example, a literature evaluation suggested that the most effective 0.6% of research on the outcomes of insecticides on freshwater invertebrates had been achieved within the area (Beketov and Liess 2012). This follows the paradigm that randomized experiments can most effectively and convincingly achieve insights into causal relationships (Shiple 2004), e.g., in laboratory or managed area settings. However, for the reason that laboratory and mesocosm systems also can moreover vary from grass systems regarding trends collectively with species composition and sensitivity (Beketov and Liess 2008), availability of recolonization pools (Sundermann et al. 2011), species interactions, and co-going stressors (Liess and Beketov 2011), research scope is essential for the validation of insights achieved from synthetic structures (Carpenter 1996; Mayer-Pinto et al. 2010). Compared to experimental settings, the status quo of a causal hyperlink between toxicant publicity and determined ecological styles is regularly irritated through the prevalence of probably collinear confounding elements (Liess et al. 2008). In addition, toxicants, together with insecticides, are hard to reveal below area situations due to the fact they commonly arise episodically in freshwater ecosystems. The episodic prevalence is because of (1) particular software intervals and (2) access paths, which can be partially related to sturdy precipitation events (Guo et al. 2004; Kreuger 1998; Leu et al. 2004). Since even short-time period of pesticide exposure of some hours can also additionally motivate unfavorable ecological outcomes (Andersen et al. 2006; Hose et al. 2003; Schulz and Liess 2000), aiming at a practical ecological

danger evaluation of insecticides requires sampling techniques which are appropriate to seize short-time period pulses (Mortimer et al. 2007). Conversely, the chemical speciation of metals and the increase of phytoplankton are tightly related, as proven for some oceanic and coastal algal species (Sunda 1988). Experimental proof suggests that increase and toxicity are frequently a characteristic of the pastime of the loose steel cation (Sunda and Guillard 1976; Campbell 1995). For example, trace metals, copper, and zinc are crucial micronutrients for algae but are poisonous at excessive concentrations. The full copper and zinc concentrations in freshwater ecosystems are typically better than in ocean waters (Bruland et al. 1991; Sigg 1994). In Lake Greifen, a eutrophic lake in Switzerland, it has been observed that generally dissolved copper turned into within the range of 0.5 to 2.8 31,028 M (Xue and Sigg 1993), and generally dissolved zinc turned into within the range of one to a few three 1028 M (Xue and Sigg 1994). The corresponding loose Cu₂₁ and Zn₂₁ concentrations ranged from 10,214 to 10,216 M and 1028 to 1029 M, respectively (Xue and Sigg 1993, 1994).

Another examination added by Katja et al. (1996) declared that the algae increase confirmed an excessive tolerance closer to excessive intracellular copper and zinc concentrations, showing that the cells can also immobilize the metals intracellularly. Correspondingly, let us speak about Chromium (Cr); this substance is going on detail observed in rocks, animals, plants, and soil, predominantly in its insoluble trivalent form [Cr(III)]. Intense industrialization and different anthropogenic sports have brought about the worldwide prevalence of soluble Cr(VI), conveniently leached from soil to groundwater or floor water in concentrations above permissible tiers. Moreover, the Ecotoxicology of Cr (VI) is related to its environmental challenge and the capacity to result in unfavorable outcomes in biological structures, including fish (Vutukuru et al. 2007). In the waters abounding in grass and/or aquaculture facilities, fish are regularly uncovered to Cr waste and display cumulative deleterious outcomes as a time characteristic. Steinhagen et al. (2004) tested the impact of Cr (VI) on carp (*Cyprinus carpio*)-derived immune cells. The consequences validated that at concentrations between 2 and 200 $\mu\text{mol Cr L}^{-1}$, the steel precipitated cytotoxicity and reduced the activation of mitogen-precipitated lymphocytes, in addition to phagocyte capabilities. Neutrophils collectively confirmed modifications in mobile form with decreased nitric oxide and reactive oxygen manufacturing at concentrations much decreased than for the cytotoxic outcomes. The altered lymphocyte and neutrophil capabilities replicate the reduced resistance to pathogens determined in fishes below the continual Cr challenge. Hereafter, we will conclude that Cr (VI) categorized carcinogens owning each mutagenic and teratogenic properties. Acidifying our surface waters is presently one of the maximum severe environmental pollution issues. Acid precipitation happens in localized regions and regions downwind from substantial commercial complexes. For example, in the United States, measures taken to take advantage of regional acidification trouble, the elimination of seen particulate relying on smoke, and the setup of taller

smoke stacks can also additionally boom the geographical dispersion of the gaseous emissions. Electric energy plant life, smelters, and metallic mills, i.e., the industries that use vast quantities of coal for fuel, are ideal to be the foremost supply of sulfuric oxides, while petroleum-burning cars are the primary supply of nitric oxides. Poikilothermal organisms and fish no longer preserve a steady blood pH (Omer 2017; Omer and Ali 2014; Howell et al. 1970); instead, an alternate in blood pH with temperature parallels the impact of temperature upon the pH of impartial water. Howell et al. (1970) indicated that the blood pH of maximum ectothermic vertebrates is maintained at steady relative alkalinity compared to the impartial water factor over the complete variety of temperatures encountered.

7.4.2 Impacts of Environmental Toxicology on Marine Water

Environmental toxicants input the marine surroundings from numerous factors (e.g., manufacturing facility outlets) and subtle sources (e.g., agricultural farms). They can also be constituted of marine phytoplankton together with dinoflagellates and diatoms. The prevalence of those toxicants withinside marine ambiances has attracted great interest because of the excessive ecological, socioeconomically, and cultural values related to these ambiances. Natural toxicants of dwelling organisms' ancestors appear to be the essential toxicants going on withinside the marine surroundings, as can be inferred from the extent of studies undertaken on this issue. Most of these studies focus on the effect of marine biotoxins on human health, which arises thru the intake of seafood (Picardo et al. 2018) and leisure sports. As cited earlier, mycotoxins are produced via the massive increase of marine phytoplankton referred to as herbal algal blooms (HAB). Events of the fish kill and different animal mortalities in regions wherein blooms are endemic are becoming more and more related to post-bloom exposures of biota to their phytotoxins (Landsberg et al. 2009).

Additionally, the brown pelican, the ocean bird, was also suggested to have an effect via means of phycotoxins. The historically regarded heavy metals impact marine lifestyles thru direct poisonous outcomes of steel factors (e.g., Pb, Cd, and Hg) or via way of means of transferring the equilibrium of essential hint metals (e.g., Fe, Cu, and Zn) that could end up poisonous at excessive concentrations. Recently, Metal Engineered Nano Particles (ENP) rising as a brand new toxicant has raised issues approximately their toxicity for marine lifestyles. In this regard, copper oxide ENP has been reviewed to supply measurable toxicity effects in the marine version of diatom *Pheodactylum tricornutum* (Franzitta et al. 2020). Heavy metals acquire withinside the tissues of marine organisms (e.g., fish, seaweeds, and invertebrates) alongside the food web, inflicting crucial implications for human beings' health.

7.5 Risk Assessment

7.5.1 Overview and Definition

Risk assessment sits on the uneasy interface of technology and coverage. Almost all choices approximately risk assessment techniques require concerns of problems in each coverage and technology. The reason for risk assessment and the underlying technology of this is to help societal decision-making. Risk assessment is the approach through which democratic societies try to apprehend technology's detrimental and unintentional outcomes, Ted (2016). In any other manner, risk assessment is the way of studying toxicological and epidemiological data for a suspected toxicant and then, if warranted, estimating permissible exposures. Four steps represent the way: (1) toxicant identification, (2) toxicant evaluation, (3) publicity evaluation, and (4) chance estimation, Hughes (2005).

7.5.1.1 Identification of Toxicant

A review of the present literature, which can also consist of toxicity assessments and epidemiology, can be used to perceive a toxicant. With relevant literature, descriptive toxicity checking out can be achieved. Thus, the dose-reaction conclusions of descriptive toxicology are enough for toxicant identity. The backside line of toxicant identity is: Does the agent motivate the unfavorable impact?

7.5.1.2 Evaluation of Toxicant

A cognizance of interspecific (among species) and intraspecific (inside species) variability in toxicity checking out is essential while comparing non-human assessments. Careful interest in variability in age, sex, diet, circadian rhythms, hormonal status, and biotransformation potential is needed. Questions to be requested can also include: What form of check turned into an accomplished need to a continual toxicity check had been used as opposed to an acute check, or turned into a check accomplished to decide teratogenic pastime? What responses had been measured? What is the opportunity of staring at those identical responses in human beings? Are the consequences scientifically valid can the consequences be reproduced in some other laboratory using identical techniques of toxicity checking out? Were there issues with the check techniques, preference of check organisms, doses tested, or within-side the said consequences or interpretation of consequences?

7.5.1.3 Exposure Evaluation

With the top experimental design, publicity of a suspected toxicant is regulated at some point of toxicity checking out. Descriptive toxicologists predetermine the publicity parameters, including the organisms uncovered, the path of access, dose,

frequency (how regularly), and duration (how long) of dosing. Publicity evaluation desires to be pursued with identical diligence as toxicant identity and assessment. The evaluation must study exposures presently skilled and those expected below distinctive situations. For example, publicity for non-carcinogenic toxicants is expressed as most day-by-day doses (MDD) (mg/kg/day), while publicity for cancer agents is said as lifetime typical day-by-day dose (LADD) (mg/kg/ day/lifetime).

7.5.1.4 Risk Estimation

Risk is the possibility of an undesirable organic reaction because of the publicity of a toxicant (Hughes 2005). Estimating chance requires an integration of the toxicity conclusions (toxicant identity and dose-reaction evaluation) and publicity assessment (MDD or LADD). Risk is approximated through the equation:

$$R = T \times E$$

in which chance = R, toxicity = T, and publicity = E. However, because dose-reaction relationships are not linear (as withinside the feature sigmoidal graph lines), publicity is extra appropriately expressed as a function (f), as visible within-side the following equation:

This equation is the supply of chance statements consisting of 1 in 1000 people who will broaden toxicity (a selected disease) if a toxicant is uncovered to a selected dose (MDD or LADD) for a certain duration.

7.6 Risk Management

Risk is frequently offered as a declarative statement without interpretation. To be of price to humanity, danger as soon as characterized ought to be applied to regulatory guidelines that advantage society. The motive of danger control is to study danger evaluation facts and, wherein needed, increase regulatory alternatives that deal with public fitness and social and financial concerns. Risk management uses risk assessment records to manipulate these consequences.

A “competent” method to determine a reasonable chance is to reply to the subsequent questions: Is the substance truly needed? Could alternate, much less poisonous substitutes be used? What is the sensible quantity of public exposure? What are the dangers as opposed to advantages for persevered use of the agent? What is the environmental effect of the substance? Does the procurement of the agent use up an environmental resource? Does the present generation allow the “final” disposal of the substance? If used, can we have the generation to ensure the substance’s “safe” use?

7.7 Conclusion

The examination of environmental toxicology stems from the popularity that: (a) human survival relies upon the wellbeing of different species and the provision of smooth air, water, and food; and (b) anthropogenic chemical substances in addition to clearly going on chemical substances will have destructive outcomes on dwelling organisms and ecological techniques. Therefore, Environmental toxicology is concerned with how environmental toxicants, thru their interplay with human beings, fauna, and flora, affect the fitness and welfare of those organisms. The function of environmental toxicology could be more effective in perceiving environmental toxicants and their mode of motion; however, it helps the assessment and backbone of problems regarding suited danger and safety secure doses for human beings and different species. Moreover, environmental toxicology facts need to set off us to limit or restrict the usage of dealers' poisonous flora and fauna in our atmosphere. The destiny of all species, inclusive of our own, relies upon our capacity to apprehend and correctly manipulate the "ripples" generated via way of means of environmental toxicants.

References

- Abudegoon A, Ali S (2013) On some reproductive aspects of the sky emperor (pieces) *Lethrinus massena* in the Sudanese Red Sea. Sudan J Basic Sci (SJBS) B 18:51–62
- Alford RA, Richards SJ. (1999). Global Amphibian Declines: A Problem in Applied Ecology. *Annu Rev Ecol Evol Syst* 30:133–165. <https://doi.org/10.1146/annurev.ecolsys.30.1.133>
- Andersen H, Tjornhoj R, Wollenberger L, Slothuus T, Baun A (2006) Acute and chronic effects of pulse exposure of *Daphnia magna* to dimethoate and pirimicarb. *Environ Toxicol Chem* 25:1187–1195
- Bank MS, Crocker JB, Davis S, Brotherton DK, Cook R, Behler J, Connery B (2006) Population decline of northern dusky salamanders at Acadia National Park, Maine, USA. *Biol Conserv* 130(2):230–238. <https://doi.org/10.1016/j.biocon.2005.12.033>
- Beketov A, Liess M (2008) An indicator for effects of organic toxicants on lotic invertebrate communities: Independence of confounding environmental factors over an extensive river continuum. *Environ Pollut* 156:980–987
- Beketov A, Liess M (2012) Ecotoxicology and macroecology—time for integration. *Environ Pollut* 162:247–254
- Blaustein AR, Romansic JM, Kiesecker JM, Hatch AC (2003) Ultraviolet radiation, toxic chemicals, and amphibian population declines. *Divers Distrib* 9(2):123–140. <https://doi.org/10.1046/j.1472-4642.2003.00015.x>
- Bogusz J (2000) Environmental poisons. In: Bogusz MJ (ed) *Handbook of analytical separations*, vol 2. Elsevier Science B.V
- Boudou A, Ribeyre F (1989) Fundamental concepts in aquatic ecotoxicology. In: *Aquatic ecotoxicology: fundamental concepts and methodologies*, vol 1. CRC Press, Boca Raton, FL, pp 35–75
- Bruland W, Donat R, Hutchins A (1991) Interactive influences of bioactive trace metals on biological production in oceanic waters. *Limnol Oceanogr* 36:1555–1577
- Butler C (1978) *Principles of ecotoxicology*. Wiley & Sons, Chichester

- Campbell C (1995) Interactions between trace metals and aquatic organisms: a critique of the free-ion activity model. In: Tessier A, Turner DR (eds) *Metal speciation and bioavailability in aquatic systems*. John Wiley & Sons, New York, pp 45–102
- Cardinale J, Duffy E, Gonzalez A, Hooper U, Perrings C, Venail P (2012) Biodiversity loss and its impact on humanity. *Nature* 486:59–67
- Carpenter RA (1996) Ecology Should Apply to Ecosystem Management: A Comment. *Ecol Appl* 6(4):1373–1377. <https://doi.org/10.2307/2269615>
- Chadwick J (1998) *Principles of environmental toxicology*, 1st edn. CRC Press. 216 pp
- Chapman PM (2002) Integrating toxicology and ecology: putting the “Eco” into ecotoxicology. *Mar Pollut Bull* 44:7–15
- Davidson C, Knapp RA (2007) Multiple stressors and amphibian declines: dual impacts of pesticides and fish on yellow-legged frogs. *Ecol Appl* 17(2):587–597. <https://doi.org/10.1890/06-0181>
- Forbes V, Forbes T (1994) *Ecotoxicology in Theory and Practice*. Chapman & Hall Ecotoxicology Series 2: London
- Franzitta M, Feijão E, Cabrita M, Gameiro C, Matos A, Marques J, Goessling J, Reis S, Fonseca V, Pretti C, Caçador I, Duarte B (2020) Toxicity going nano: ionic versus engineered Cu nanoparticles impacts on the physiological fitness of the model diatom *Phaeodactylum tricornutum*. *Front Mar Sci*. <https://doi.org/10.3389/fmars.2020.539827>
- Guo L, Nordmark E, Spurlock C, Johnson R, Li Y, Lee M (2004) Characterizing dependence of pesticide load in surface water on precipitation and pesticide use for the Sacramento River Watershed. *Environ Sci Technol* 38:3842–3852
- Hall G (2016) Pediatric diseases and epigenetics. In: Tollefsbol TO (ed) *Medical epigenetics*. Academic Press, pp 415–442. <https://doi.org/10.1016/B978-0-12-803239-8.00023-5>
- Heino J, Virkkala R, Toivonen H (2009) Climate change and fresh water biodiversity: detected patterns, future trends and adaptations in northern regions. *Biol Rev* 84:39–54
- Hooper U, Adair C, Cardinale J, Byrnes E, Hungate A, Matulich L (2012) A global synthesis reveals biodiversity loss as a major driver of ecosystem change. *Nature* 486:105–108
- Howell BJ, Baumgardner FW, Bondi K, Rahn H (1970) Acid-base balance in cold-blooded vertebrates as a function of body temperature. *Am J Physiol*. 218(2):600–6. <https://doi.org/10.1152/ajplegacy.1970.218.2.600>. PMID: 5412482
- Hose C, Lim P, Hyne V, Pablo F (2003) Short-term exposure to aqueous endosulfan affects macroinvertebrate assemblages. *Ecotoxicol Environ Saf* 56:282–294
- Hughes W (2005) *Essentials of environmental toxicology, the effects of environmentally hazardous substances on human health*. Taylor & Francis Group, London
- Imhoff M, Bounoua L, Ricketts T, Loucks C, Harriss R, Lawrence W (2004) Global patterns in human consumption of net primary production. *Nature* 429:870–873
- Ingersoll G, Dillon T, Biddinger R (1997) *Ecological risk assessment of contaminated sediments*. SETAC Press, Pensacola, FL
- Katja K, Renata B, Laura S (1996) Effects of free CU21 and ZN21 ions on growth and metal accumulation in fresh water algae. *Environ Toxicol Chem* 16(2):220–229. SETAC PRESS
- Kefford J, Papas J, Crowther D, Nugegoda D (2002) Are salts toxicants? *Australas J Ecotoxicol* 8:63–68
- Kreuger J (1998) Pesticides in stream water within an agricultural catchment in Southern Sweden, 1990–1996. *Sci Total Environ* 216:227–251
- Landsberg JH, Flewelling LJ, Naar J (2009) *Karenia brevis* red tides, brevetoxins in the food web, and impacts on natural resources: decadal advancements. *Harmful Algae* 2009(8):598–607
- Leu C, Singer H, Stamm C, Muller SR, Schwarzenbach RP (2004) Simultaneous assessment of sources, processes, and factors influencing herbicide losses to surface waters in a small agricultural catchment. *Environ Sci Technol* 38:3827–3834
- Liess M, Beketov M (2011) Traits and stress: keys to identify community effects of low levels of toxicants in test systems. *Ecotoxicology* 20:1328–1340

- Liess M, Schäfer B, Schriever A (2008) The footprint of pesticide stress in communities—species traits reveal community effects of toxicants. *Sci Total Environ* 406:484–490
- Liu X (2020) Exposure to carcinogens and its effects in the formation of cancer. *J Cancer Res Immunooncol* 6:123. <https://doi.org/10.35248/2684-1266.20.6.123>
- Mayer-Pinto M, Underwood J, Tolhurst T, Coleman A (2010) Effects of metals on aquatic assemblages: what do we really know? *J Exp Mar Biol Ecol* 391:1–9
- Mazzu T, Melo G, Morbioli G, Carrilho E, Vianna S, da Silva A, Schuler-Faccini L (2017) Teratogens: a public health issue—a Brazilian overview. <https://doi.org/10.1590/1678-4685-GMB-2016-0179>
- MEA (2005) Ecosystems and human wellbeing: synthesis. Island Press, Washington, DC, p 137
- Ming-Ho Y (2001) Environmental toxicology: impacts of environmental toxicants on living systems. CRC Press LLC, 2000 N.W
- Mortimer M, Mueller M, Liess M (2007) Sampling methods in surface waters. In: Nollet LML (ed) Handbook of water analysis. CRC Press, Taylor & Francis Group, Boca Raton, pp 1–45
- Murk AJ, Nicolas J, Smulders FJM, Bürk C, Gerssen A (2019) Marine biotoxins: types of poisoning, underlying mechanisms of action and risk management programs in Chemical hazards in foods of animal origin. *ECVPH Food safety assurance*, 7:207–239. https://doi.org/10.3920/978-90-8686-877-3_09
- O'Mahony M (2018) E.U. regulatory risk management of marine biotoxins in the marine bivalve mollusc food-chain. *Toxins* 10(3):118. MDPI AG. Retrieved from <https://doi.org/10.3390/toxins10030118>
- Omer A (2017) Review on fish identification tools and their importance in biodiversity and fisheries assessments. *Int J Sci Basic Appl Res (IJSBAR)* 36(6):118–126
- Omer A, Ali S (2014) Biological investigations on the Sky Emperor Lethrinus Massena in the Sudanese Red Sea Waters. *Nile Basin Res J Al Neelain Univ* 17(9):32–45
- Pereira M, Leadley W, Proenca V, Alkemade R, Scharlemann W, Fernandez-Manjarres F (2010) Scenarios for global biodiversity in the 21st century. *Science* 330:1496–1501
- Picardo M, Filatova D, Nuñez O, Farré M (2018) Recent advances in the detection of natural toxins in fresh water environments. *TrAC Trends Anal Chem.* <https://doi.org/10.1016/j.trac.2018.12.017>
- Pourret O, Hursthouse A (2019) It's time to replace the term “heavy metals” with “potentially toxic elements” when reporting environmental research. *Int J Environ Res Public Health* 16(22):4446. <https://doi.org/10.3390/ijerph16224446>
- Reeder AL, Ruiz MO, Pessier A, Brown LE, Levengood JM, Phillips CA, Wheeler MB, Warner RE, Beasley VR (2005) Intersexuality and the cricket frog decline: historic and geographic trends. *Environ Health Perspect* 113(3):261–5. <https://doi.org/10.1289/ehp.7276>. PMID: 15743712; PMCID: PMC1253749.
- Revinga C, Campbell I, Abell R, de Villiers P, Bryer M (2005) Prospects for monitoring fresh water ecosystems towards the 2010 targets. *Philos Trans R Soc B-Biol Sci* 360:397–413
- Rockstrom J, Steffen W, Noone K, Persson A, Chapin FS, Lambin EF (2009) A safe operating space for humanity. *Nature* 461:472–475
- Sánchez-Bayo F (2011) Sources and toxicity of pollutants. In: Ecological impacts of toxic chemicals. Bentham Science Publishers. <https://doi.org/10.2174/978160805121210003>
- Schulz R, Liess M (2000) Toxicity of fenvalerate to caddisfly larvae: chronic effects of 1-hr vs. 10-hr pulse-exposure with constant doses. *Chemosphere* 41:1511–1517
- Shipley B (2004) Cause and correlation in biology. Cambridge University Press, Cambridge
- Sigg L (1994) Regulation of trace elements in lakes. In: Buffle J, Vitre D (eds) Chemical and biological regulation of aquatic systems. Lewis, Boca Raton, pp 177–197
- Sih A, Bell A, Johnson J (2004) Behavioral syndromes: An ecological and evolutionary overview. *Trends Ecol Evol* 19(7):372–378. <https://doi.org/10.1016/j.tree.2004.04.009>
- Steinhagen D, Helmus T, Maurer S, Michael RD, Leibold W, Scharsack JP (2004) Effect of hexavalent carcinogenic chromium on carp *Cyprinus Carpio* immune cells. *Dis Aquat Org* 62(1–2):155–161. [PubMed: 15648842]

- Still R, Mohapatra A (2009) Biotoxins. In: Information resources in toxicology, pp 91–102. <https://doi.org/10.1016/b978-0-12-373593-5.00010-0>
- Sunda G (1988) Trace metal interactions with marine phytoplankton. *Biol Oceanogr* 6:411–441
- Sunda G, Guillard L (1976) The relationship between cupric ion acidity and the toxicity of copper to phytoplankton. *J Mar Res* 34:511–529
- Sundermann A, Stoll S, Haase P (2011) River restoration success depends on the species pool of the immediate surroundings. *Ecol Appl* 21:1962–1971
- Ted W, Simon (2016) Environmental Risk Assessment. A Toxicological Approach, 1st Edition. CRC Press, 2000
- Tiwari S, Lata C (2018) Heavy Metal Stress, Signaling, and Tolerance Due to Plant-Associated Microbes: An Overview. *Front Plant Sci* 9:452. <https://doi.org/10.3389/fpls.2018.00452>. PMID: 29681916; PMCID: PMC5897519
- Tollefson J, Gilbert N (2012) Rio Report Card. *Nature* 486:20–23
- Tseng CY (2018) Effects of atypical neurotoxins on the developing fetal brain. In: Erkekglu P, Ogawa T (eds) Medical toxicology. <https://doi.org/10.5772/intechopen.89755>
- Visciano P, Schirone M, Berti M, Milandri A, Tofalo R, Suzzi G (2016) Marine Biotoxins: Occurrence, Toxicity, Regulatory Limits and Reference Methods. *Frontiers in Microbiology*, 7: 207058. <https://doi.org/10.3389/fmicb.2016.01051>
- Vorosmarty J, McIntyre B, Gessner O, Dudgeon D, Prusevich A, Green P (2010) Global threats to human water security and river biodiversity. *Nature* 467:555–561
- Vutukuru S, Prabhath A, Raghavender M, Yerramilli A (2007) Effect of arsenic and chromium on the serum amino-transferases activity in Indian major carp, *Labeo rohita*. *Int J Environ Res Public Health* 4(3):224–227. [PubMed: 17911661]
- Walker CH, Hopkin SP, Sibly RM, Peakall B (1997) Principles of ecotoxicology. Tylor & Francis, London. 321 pp.
- Walker CH, Sibly RM, Peakall DB (2016) Principles of Ecotoxicology. <https://doi.org/10.1201/b11767>
- Wayne G, Ruth M, Ming-Ho (2018) Introduction to Environmental Toxicology. Molecular Substructures to Ecological Landscapes. Tylor & Francis Group, London.
- Woodward G, Gessner O, Giller S, Gulis V, Hladyz S, Lecerf A (2012) Continental scale effects of nutrient pollution on stream ecosystem functioning. *Science* 336:1438–1440
- Xue HB, Sigg L (1993) Free cupric ion concentration and Cu(II) speciation in a eutrophic lake. *Limnol Oceanogr* 38:1200–1213
- Xue HB, Sigg L (1994) Zinc speciation in lake waters and its determination by ligand exchange with EDTA and differential effects of copper and zinc on fresh water algae pulse anodic stripping voltammetry. *Anal Chim Acta* 284:505–515
- Yagi T (2017) A perspective of genes and environment for the development of environmental mutagen research in Asia. *Genes Environ* 39:23. <https://doi.org/10.1186/s41021-017-0083-y>. PMID: 29021869; PMCID: PMC5623060
- Yang S, Hsieh C, Kuo H, Lee M, Huang M, Kuo C, Hung C (2014) The effects of environmental toxins on allergic inflammation. *Allergy Asthma Immunol Res* 6(6):478–484. <https://doi.org/10.4168/aaair.2014.6.6.478>