Society of Environmental Toxicology and Chemistry

Technical Issue Paper

OMICS: Complete Systems, Complete Analyses

The term OMICS refers to scientific disciplines that study different types of biological molecules that make up complete biological systems. The suffix "-omics" comes from the Greek word "-ome," which means "whole." Recent advances in laboratory methods, known as high-throughput techniques, allow for automation and thus increased efficiency in classical cell biology techniques, which has enabled progress in OMICS fields.

Examples of Biological Molecules

- DNA (deoxyribonucleic acid) contains all necessary information for the make-up of the organism and transfers this information across organisms' generations.
- RNA (ribonucleic acid) is known as the "messenger gene" and is essential in carrying information from the DNA to other biological molecules and regulating gene expression.
- Proteins execute tasks and functions, such as transport and storage (e.g., hemoglobin), cell-to-cell communication (e.g., hormones), defense against infection (e.g., antibodies), and catalysts to regulate chemical reactions (e.g., enzymes).
- Lipids are the building blocks of cellular membranes. They play important roles in long-term energy storage and as messenger molecules such as steroid hormones (e.g., estrogen).
- Carbohydrates are the major short-term storage locations for energy and nutrients. They include simple sugars (e.g., glucose) as well as polysaccharides (e.g., cellulose).

Examples of OMICS Disciplines

- Genomics is the study of the genome, which is the entire set of genes (DNA) in an organism.
- Transcriptomics is the study of all messenger genes (RNA) transcripts under specific conditions, which is the transcriptome.
- Proteomics is the study of proteins, which are important components of organisms.
- Metabolomics is the study of the metabolome, which are the molecules involved in metabolism including sugars, lipids, and amino and nucleic acids.
- Toxicogenomics is the study of the relationship between the genome and the adverse biological effects of external agents.
- Lipomics is the study of cellular lipids.
- Glycomics is the study of cellular carbohydrates.

OMES Are All Related

There is a strong relationship between the various omes in organisms, see Figure 1 as an example.

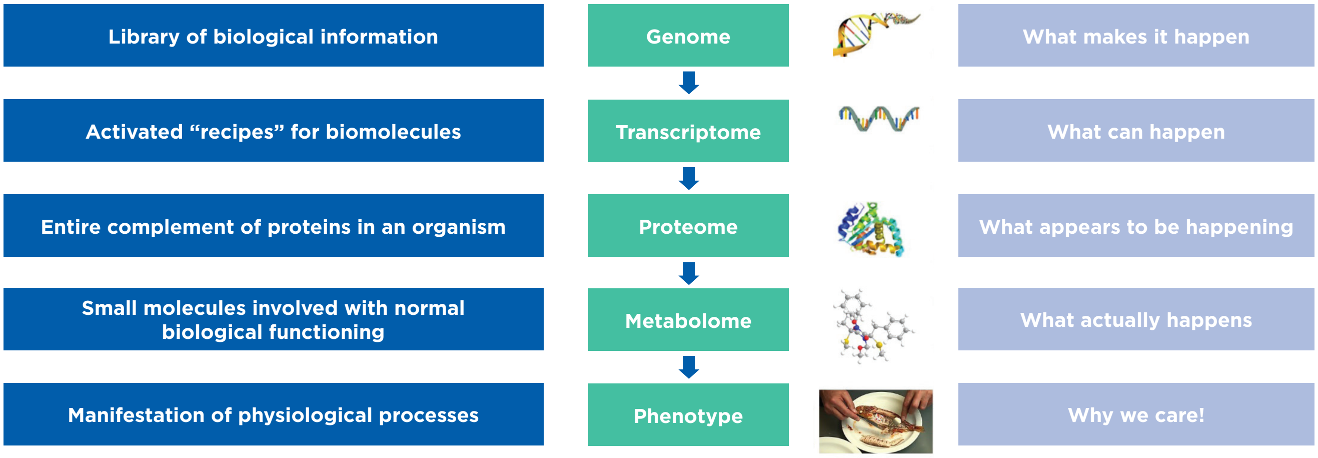

Figure 1. Example of a cascade of interactions among some of the main biological molecules in organisms.

OMICS and Environmental Sciences

Various environmental factors or stressors, of a physical, biological, or chemical nature, can affect the structure and function of biological molecules and, subsequently, influence the processes in which they are involved. Molecular changes can, in turn, affect individual organisms by affecting their development, growth, and reproduction, which can ultimately lead to effects on the entire ecosystem to which they belong (Figure 2). Increasingly, OMICS tools are being used to understand how environmental stressors may affect molecular systems, internal mechanisms, and in turn, organisms in the environment (a process known as environmental risk assessment[1]).

OMICS - Discovery of Mode of Action

Once a stressor enters an organism, it commonly interacts with one or many different biological molecules. The way a stressor interacts with the biological molecules within an exposed organism is called mode of action. These interactions can be short-term or long-term, reversible or not, and can cause positive or negative changes in the exposed organisms. Most pharmaceuti-

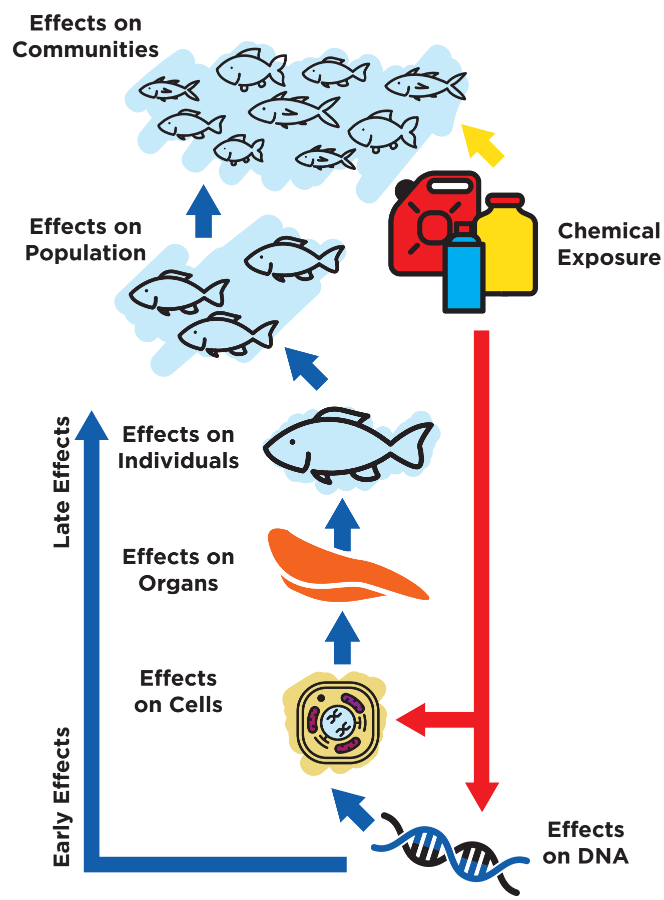

Figure 2. Example of effects, starting at the molecular level and moving up to communities.

[1] View the SETAC Technical Issue Paper: Environmental Risk Assessment of Chemicals at https://www.setac.org/page/TIPS.

cals instigate favorable effects when taken as a remedy for a disease or illness. Some chemicals could cause adverse outcomes (effects) to organisms after exposure.

It is important to note that several mechanisms, at the biological molecular level, can influence the effects of stressors in organisms after exposure such as detoxification, compensatory, or adaptive mechanisms.

For example, when exposed to harmful chemicals, the production of some special enzyme types increases as an adaptive measure to metabolize and excrete the chemical from the organism, thereby preventing any long-term harm. In another example, some worms that live in mercury contaminated sediments store the mercury in their tail and then discard their tails to get rid of the mercury in a mechanism of detoxification. Examples like these are the reasons why it is very important to understand the molecular patterns that lead to or prevent adverse effects, and this is where OMICS can be very helpful.

As an example of how an OMICS study is conducted, please see Figure 3 depicting a transcriptomic study. In the example, blood is sampled from fish A (exposed to a chemical) and fish B (not exposed). The RNA (transcriptome) is extracted from the blood samples. The scientist analyzes the RNA to understand changes on the DNA transcription pattern—whether particular genes are turned on or off after chemical exposure. This study provides valuable information about the chemical's mode of action and potential outcomes to the fish.

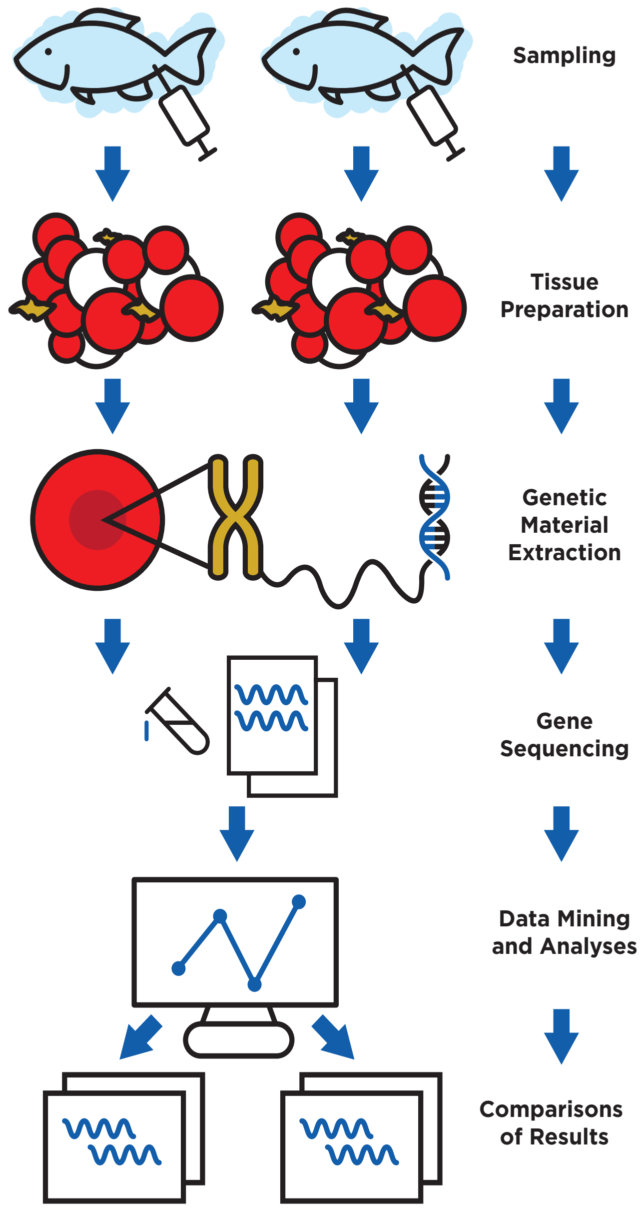

Figure 3. Schematic representation of a transcriptomic study.

OMICS - Applications in Environmental Management

Environmental management refers to approaches used to minimize risk to health and the environment from stressors. Environmental management requires information regarding a wide range of environmental stressors and their potential effects on a great variety of organisms. Unfortunately, there are many cases in which the necessary data are not always available. Currently, environmental scientists handle the lack of data by using estimation, modeling, and extrapolation. However, OMICS data can fill those data gaps. An advantage of OMICS studies, over traditional stress response studies, is that they do not require animal testing. Another advantage is that OMCIS high throughput techniques are efficient and thus enable quick acquisition of toxicity data on many stressors.

OMICS Use in Chemical Classification

One of the most promising applications of OMICS methodologies is related to chemical hazard classification as used in chemical management. OMICS can be very helpful in that regard. Chemical hazard classification attempts to group chemicals based on their mode of action. For example, chemicals that can cause cancer are classified as carcinogens while those that cause birth defects are called teratogens. OMICS high-throughput techniques give us the ability to test a high number of chemicals and determine hazard classification. This provides valuable information for policy makers and enables the management of the production and the use of chemicals in ways that minimize significant adverse impacts on the environment and human health. OMICS use in hazard classification data can also spur the development of chemical products and processes that reduce or eliminate hazardous substances.

OMICS Use in Effects Evaluation

OMICS tools can be used to extrapolate chemical and stress effects data between species more accurately. The effects of many chemicals and stressors are only tested on a limited number of laboratory model species, and results are applied to other species. OMICS-based tools are now available, which use genomic data to infer the probabilities of a chemical affecting other, non-tested species, based on the known effects of the tested ones. OMICS use enables more accurate extrapolations and reduces uncertainty.

OMICS Use in Environmental Monitoring

OMICS tools can be used to test the effect of environmental components (e.g., water from a specific stream) for environmental monitoring. For example, where environmental managers want to determine which branch of a river is causing the most harm downstream, OMICS tools can be used to test waters from several streams for adverse effects to pinpoint the culprit. This is highly useful for evaluating the effects of exposure to low levels of a stressor or stressor mixtures, both of which are conditions typical of natural environments.

Current Research

As with any field that generates lots of data, harmonized approaches are key. Currently, there are several scientists and institutions around the world who are focusing on standardizing the procedures to conduct studies that generate OMICS environmental data. Researchers are focusing on standardizing experimental design, sample collection and preparation methods, as well as strategies for statistical analysis. In fact, guidelines are already available for some OMICS disciplines such as genomics and transcriptomics.

Future Directions

Although OMICS research has already made important contributions to environmental science, we are only beginning to discover all potential applications. This follows the pattern that emerged when OMCIS data was first applied for human health. The OMICS data from the human genome project provided early success in understanding and treating some single-gene diseases, but now it is becoming apparent how such data could be used in personalized medicine. Assuming the same pattern holds true for environmental applications, we look forward to great advances in environmental management and protection enabled by OMICS. We are at a turning point, where information from OMICS technologies is becoming mature enough to evolve from a predominantly specialized scientific niche to powerful and accepted tools that can be used in support of environmental management in order to protect us and our ecosystems from environmental stressors.

Acknowledgments

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