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***Danio rerio*: A sustainable model for monitoring pollutants in the aquatic environments**

Hakan Çelebi ^{1*}, Tolga Bahadır ², İsmail Şimşek ³ and Şevket Tulun ⁴
Aksaray University, Department of Environmental Engineering

¹Aksaray University, Department of Environmental Engineering

²Aksaray University, Department of Environmental Engineering

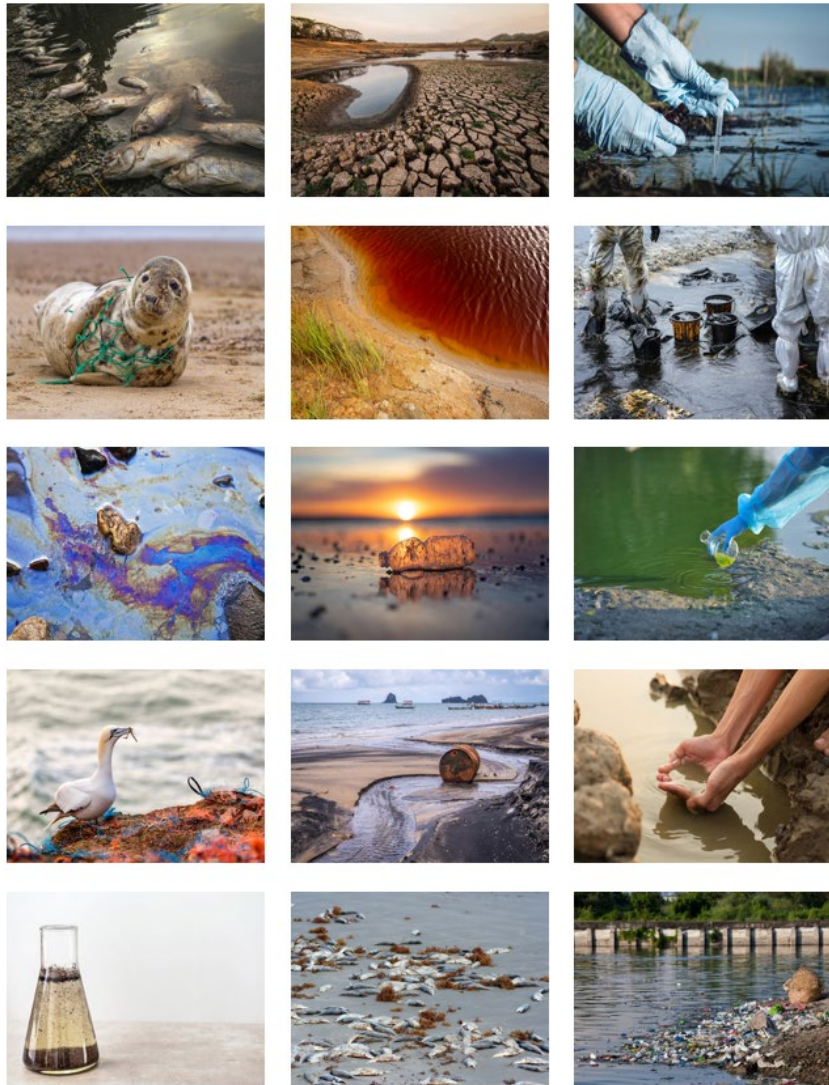
³Aksaray University, Department of Environmental Engineering

⁴Aksaray University, Department of Environmental Engineering

* Corresponding author: hakancelebi@aksaray.edu.tr

Abstract: Since the beginning of humanity, many sectors have continued to produce different chemicals. These chemicals are the main actors of environmental pollution and have become a global problem with irreversible effects in terms of single health. For this, countries have set a target of "a pollution-free planet". We need to determine target-specific strategies to both eliminate pollution and protect only health. To date, traditional methods of monitoring in receiving aquatic environments have been used and do not provide information on toxic levels of pollutants. For this reason, researchers have focused on "bio-indicator" or "bio-monitor" living things. Since organisms are in equilibrium with the aquatic environment, it can also be considered as an integrated sampling tool and may indicate potential contamination. *Danio rerio* (Zebrafish) is considered a promising model organism for single health studies in terms of its biological structure. This review aims to present *Danio rerio*'s characteristics, susceptibility to environmental pollutants, and risks associated with pollutants in the aquatic environment.

Keywords: Aquatic environment; Bio-indicator; *Danio rerio*; Environmental pollutants



Introduction

Environmental change poses a devastating risk to human and environmental health. Change, that is, environmental pollution is the most difficult test of all countries in the world, as it affects all living things and ecosystems under the concept of one health [1-3]. A rapid study of water conditions is necessary to monitor, assess and address this global health hazard. Bioindicators or biological monitors can monitor water quality changes in real time, Zebrafish (*Danio rerio*) are ideal bioindicators for detecting environmental changes due to their biomedical equipment, widespread geographic distribution and well-characterized specific properties against environmental pollutants [4,5]. Many chemicals *Danio rerio*, which has become a viable model in terms of counter-toxicity types has recently emerged as one of the most active models in the detection and research of diseases in experimental studies [6].

Introduction

In general, a good animal model should have all or most of the following characteristics: (i) structural simplicity, but also incorporate the basic cellular processes that more complex organisms have; (ii) easy accessibility for research; (iii) easy and economical to manufacture in the laboratory; (iv) prone to genetic changes; and (v) if possible have a relatively small and stable genome [7]. The most popular fish species preferred in experimental processes are listed as *Danio rerio*, *Carassius auratus*, *Oryzias latipes*, *Poecilia Reticulata*, *Gasterosteus aculeatus*, *Oncorhynchus mykiss*, *Takifugu rubripes*, and *Xiphophorus hellerii*. Research on zebrafish has become more popular in the last decade. *Danio rerio*'s high fertility rate (ability to fertilize approximately 200-300 eggs every 5-7 days), economic maintenance, and ease of genetic modification make *Danio rerio* an alternative and valuable vertebrate model compared to other species [8].



The use of zebrafish as a model for all toxicity studies is carried out according to standards. These standards are; Zebrafish Toxicity Test is listed as British standard **BS/EN/ISO 7346-3-1998**, German standard **DIN/EN/ISO 7346-3-1998** and Chinese standard **GB/T13267-91**, **OECD n° 203-236-473-487-489-490** [9,10]. *Danio rerio* (Cyprinidae family: freshwater teleost) is considered as a model organ-ism in many research areas, especially in health and pollution detection. In this study, we describe the criteria for the use of a fish species as a model for research in environmental toxicology and argue that *Danio rerio* is an ideal bioindicator for detecting the toxicity of pollutants.

Methodology

Literature search related to zebrafish used as a model in ecotoxicity assessments was made in databases such as Web of Science, Science Direct, Scopus and PubMed. The following keywords were used in the search process: *“Zebrafish” and “Ecotoxicity”, “Danio rerio” and “Acute toxicity”, “Zebrafish development” and “Fish assay” and “Zebrafish embryo test” and “Exposure”* etc. A total of 225 articles were reviewed in all databases. Studies that did not comply with the study purpose were not included in the evaluation. Of the 225 articles published until January 2023, 92 were thoroughly reviewed. Each article used in the study was compiled according to the following parameters: (i) publication year; (ii) the type of pollutant; (iii) exposure factors; (iv) toxicity; (v) stage of development; (vi) types of tests; and (vii) ecotoxic effects (Figure 1). [1, 11,12].

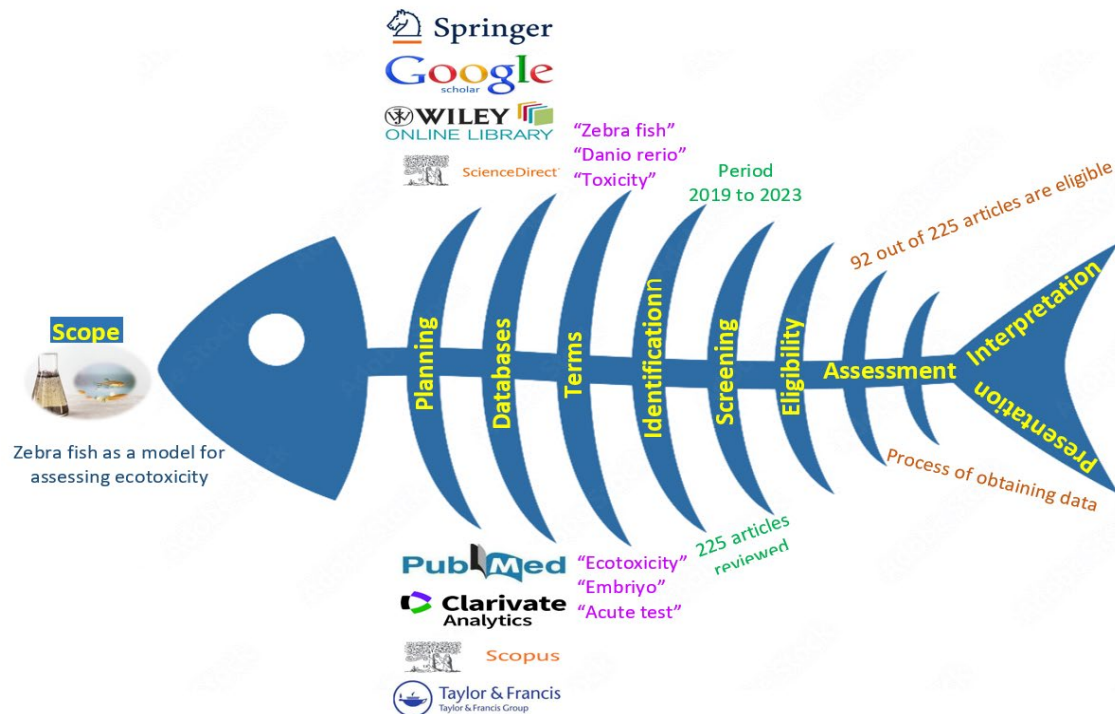
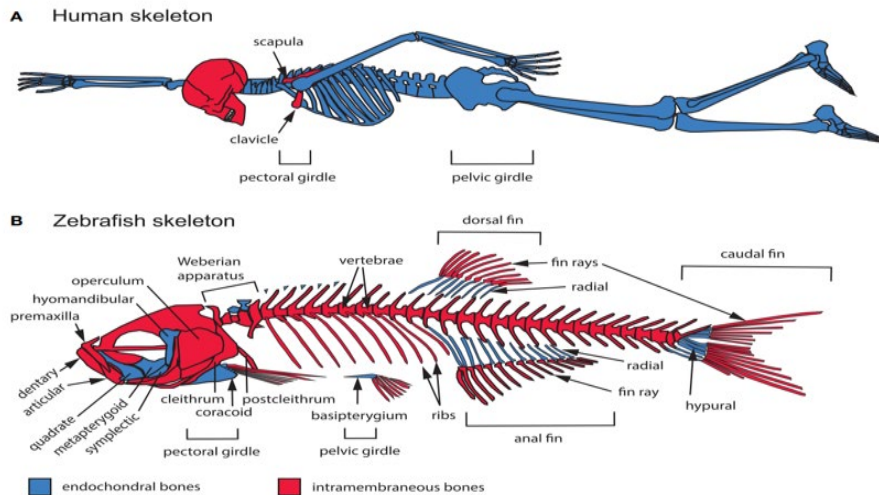
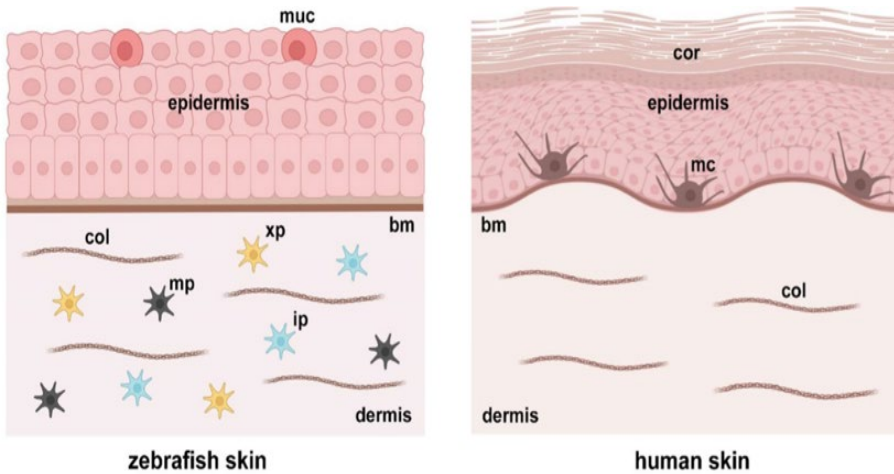


Figure 1. Systematic review methodology.

Advantages and disadvantages of zebrafish in ecotoxicity tests

Zebrafish is a successful monitoring model applied in both medicine and environmental pollution [13]. Zebrafish has been widely used in ecotoxicity studies in recent years due to its advantageous features such as **reproduction process and developmental stage** [14]. One of the main advantages of this model is that **experimental studies can be carried out in the embryo process** [13]. Rapid development is an excellent feature in all toxicity studies with animal models as it allows instant monitoring of toxic exposure [17]. In addition, 70% of zebrafish genes are similar to human genes [8]. In recent years, zebrafish has been evaluated as an alternative ecotoxicity model to replace mice and other fish species. **Among the disadvantages of zebrafish, it can be said that different reactions occur according to the sex type and the embryo development pools are large.**



Development and Distribution of Zebrafish

The zebrafish was described in 1882 by Francis Hamilton, who found it near the Ganges River in India [19]. After George Streisinger first used the zebrafish to study vertebrate development in the 1980s, it has become one of the most important laboratory animals with unprecedented speed [8]. Zebrafish are native to most of the Indian subcontinent, from Pakistan in the west through India, Nepal and Bangladesh to Myanmar in the east. Zebrafish can be found in a wide variety of habitats. The adult zebrafish is 2 to 4 cm long, and its body is characterized by zebra-like stripes (Figure 2).



Figure 2. Adult zebrafish illustration.

Development and Distribution of Zebrafish

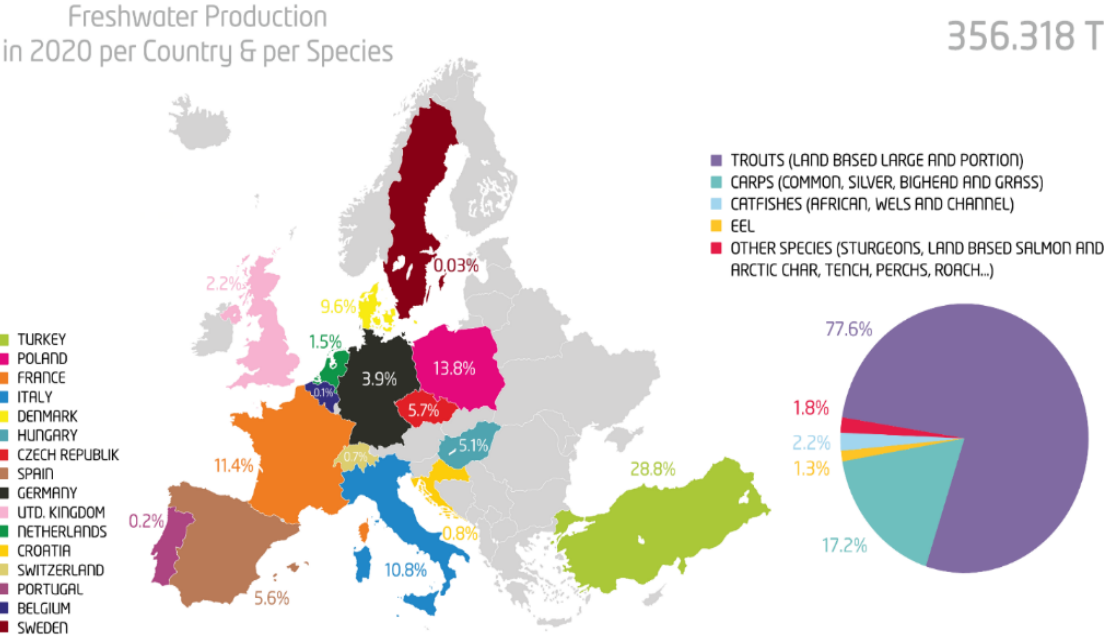
In toxicological studies, and especially in order to determine the toxic levels of environmental pollutants, parameters close to the natural environment of zebrafish should be provided in the laboratory environment. In this context, water quality parameters come to the fore (Table 1) [20-23].

Table 1. Physico-chemical properties of water for lab-raised zebrafish

Parameters	Unit	Permissible Limits	Optimum Limits
Temperature	$^{\circ}\text{C}$	6.5-42	26
Hardness	mg/L	72-198	100
pH	-	5.5-9.0	7.7
NaCl	ppt	0.1-14	0.65
Ammonia (NH_4^+)	mg/L	0-0.05	0.02
Nitrite (NO_2^-)	mg/L	0-0.5	0.2
Nitrate (NO_3^-)	mg/L	15-200	50
Phosphate (PO_4^{3-})	mg/L	150-300	250
Dissolved Oxygen	mg/L	5.5-8.0	7.5
Conductivity	μS	200-4000	1250

Development and Distribution of Zebrafish

Zebrafish are found in rivers, streams, canals and rice fields of India, Pakistan, Bangladesh, Nepal, Myanmar and Bhutan [22]. Wild zebrafish distribution includes Brazil, Colombia, Malaysia, Sri Lanka, Thailand and the United States [21,23]. Native zebrafish is found in more than 3000 institutions in more than 100 countries and is a popular aquarium fish [22,24]. In research studies with zebrafish in the literature, China (26.7%), Brazil (14.8%), France (12.5%), Germany (8.5%), India (6.3%) and Italy (5.1%) take the lead [1]. Also, the University of Oregon in the United States is home to the Zebrafish International Resource Center (ZIRC), the world's first and largest zebrafish resource center located on the Zebrafish Information Network (ZFIN). According to the data of the Federation of European Aquaculture Producers (FEAP), this type of fish is produced at a rate of 1.8% (<https://feap.info/>)



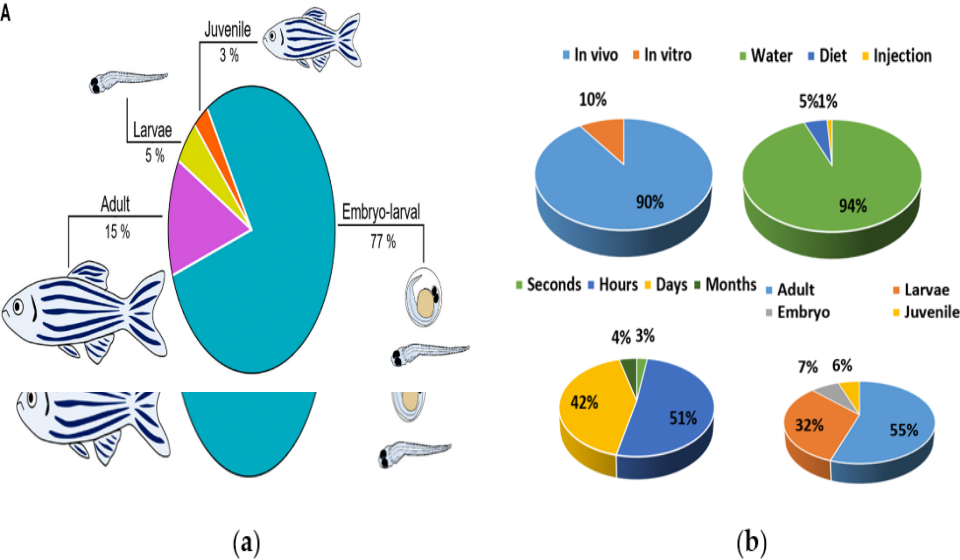


Figure 3. Danio rerio development (a), type of studies in vivo and in vitro; zebrafish exposure route; exposure time; developmental stages (b) [1, 11].

Tablo 2. Different toxicity studies in literature

Test Type	Exposure-Pollutant	References
Zebrafish embryo test	Crude oil component	[25]
Danio rerio long-term exposure	Metformin	[26]
Zebrafish antagonistic test	Deltamethrin	[27]
Adult zebrafish behavioural test	Cannabinoids	[28]
Early life stage zebrafish assay	Sediment	[29]
Acute-Chronic test	Lead	[30]
Early life stage zebrafish assay	Sodium Hypochloride	[31]
Combined toxicity test	Agrochemicals	[32]
Adult zebrafish behavioural test	Triclosan	[33]

Zebrafish Based Experimental Applications

Experimental design is an important factor besides fish species in ecotoxicity studies. The type of exposure (in vivo or in vitro), exposure route, exposure times, and stage of development are considered experimental parameters in data generation [13]. The majority of tests were performed in vivo (90.3%) compared to in vitro tests (9.7%) (Figure 3). Embryos (7.3%) and larvae (32.1%) were used less frequently than adults (55.8%) in ecotoxicity evaluation according to the development process (Figure 3). In terms of exposure route and duration, water (94.9%) and hour (51.1%) were evaluated at the highest rates, respectively (Figure 3). In Table 2, toxicity studies for which zebrafish are models are given.

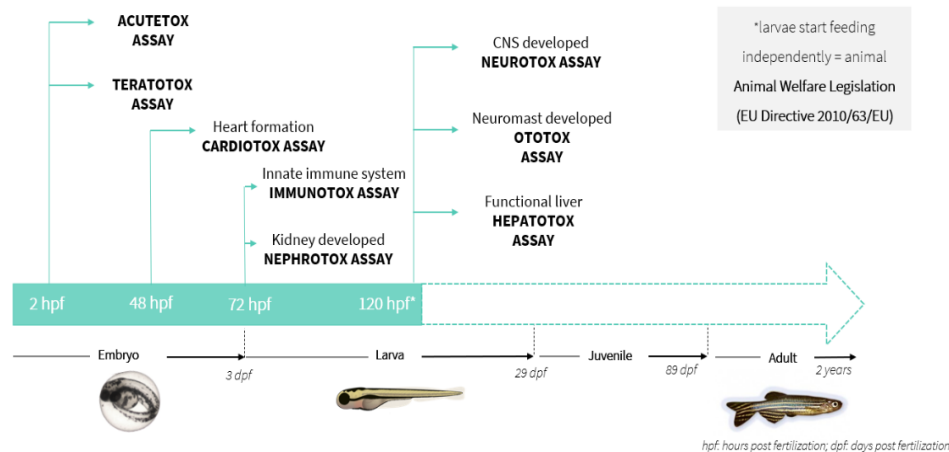


CONCLUSIONS



Zebra fish; Small size, being resistant to biotic and abiotic conditions, rapid development process, short reproduction period, being compatible with laboratory conditions, easy supply, being economical, high fertility, being open to manipulation of embryos, genetic similarity with humans increase the importance of this species for toxicity studies. Thanks to these advantages, zebrafish can be used instead of other living models in scientific research and can support the 3R rule. As a result of studies researched in international databases, it is thought that different uses of this species will be widespread and it will be a key model organism in the future.

Zebrafish Development Process





Thank You

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