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# The Guardians of the Sea: Echinoderms as Sentinels of Marine Pollution

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## Abstract

Every year tons of heavy metals, plastic, pesticides, industrial chemicals, and sewage reach the oceans. Many of these compounds are not biodegradable and have a prolonged half-life, occurring and causing effects even several years after application. The consequences are diverse as biomagnification of toxins, infertility, neoplasia, hormonal alteration, or malformations. Sentinel species can be barometers for current or potential negative impacts on individuals, animal populations and ecosystem health, helping to identify hidden risks to human health and predict future changes. Several bioindicators allow us to evaluate the status of ecosystems, echinoderms are one of them. Their diversity of habitats, diet, sensibility to changes in the environment and position of the trophic zones makes them one the most ideal marine sentinels. This paper aims to present a summarized review with the latest information available that is related to the echinoderms as a sentinel of human, animal and environmental health.

## 1. Introduction

Ocean pollution is a major problem in the 21st century and is getting worse every year. Sea life is threatened, rapidly deteriorating, and disappearing[1,2]. According to literature published since the 1970s, about 80 per cent of pollutants in marine ecosystems are from terrestrial origin (e.g., agriculture, industry, transport)[3–5]. Industrial chemicals, pesticides, fertilizers, detergents, pharmaceuticals (e.g., antibiotics, hormones), heavy metals, radioactive waste, sewage, and plastics are among the pollutants that affect marine environments. Every year around 220 million tons of hazardous waste are dumped directly into oceans, rivers, and lakes. In 2021 it was estimated that existed roughly 50-75

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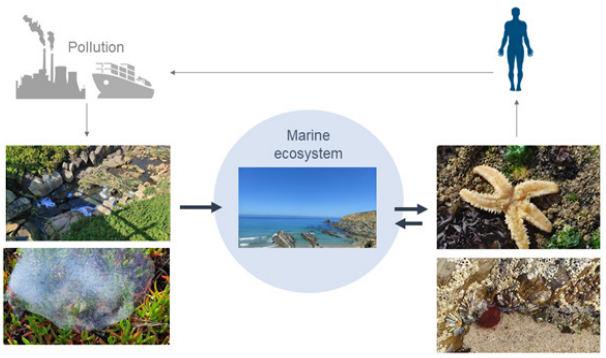



**Figure 1.** Diagram representing the flux of pollution on marine ecosystems.

trillion pieces of plastic and microplastics in the ocean. The latest censuses show that 3.8 billion litres of sewage were dumped in the oceans in 2021[3]. It is estimated that due to pollution there has been a loss of 1-5% in marine ecosystem services, which results in $500 billion to $2.5 trillion lost per year[6]. However, due to their vast area and the difficulty or inability to access them, the impact of human activity on marine environments remains unknown[7–9]. Many of the pollutants are highly toxic and in high concentration can lead to episodes of mortality of local fauna and flora (e.g., oil spill disaster). Chronic exposure to pollutants also has adverse effects on marine life, including lower infertility, growth and development, immune suppression, cancer, endocrine disruption, teratogenic effects, and neurological and behavioural alterations[3]. Furthermore, marine animals may accumulate such chemicals in their tissues. Thus, pollutants could reach very high concentrations in first-order predators such as sharks, tuna, polar bears and humans, as they move along the food chain[3,4].

Bioindicators are natural indicators used to detect changes in the environment, whether positive or negative and their impact on humans, non-human animals, and ecosystems. Today, are widely used to detect environmental changes resulting from the One Health context[10], sentinel species, which could act as bioindicators, are very important not only to monitor ecosystem health but also to predict and prevent the occurrence of environmental disasters with potential impacts on the fauna and flora and human health (Figure 1). Echinoderms could be considered a sentinel species of marine pollution[11–14]. Echinodermata phylum is composed of around 7000 species, each with its unique colour and morphology of marine invertebrates. It is divided into five main classes: asteroids (sea stars), crinoids (feather stars), echinoids (sea urchins), ophiuroids (brittle stars), and holothurians (sea cucumbers) (Figure 2)[15].

Among the reasons why these invertebrates should be considered an important potential sentinel species from a "One Health" perspective, we quote: 1) the benthic behaviour. Echinodermata has a benthic lifestyle (living on the seabed at all depths), being constantly exposed to environmental pressures such as temperature and pH fluctuations, hypoxia, ultraviolet light, chemical contaminants and predation from other animals or humans[15]; 2) expanded external epithelia that continuous uptake of dissolved substances from the sediments; 3) susceptibly to biomagnification processes due to their position in the trophic chain; 4) well-characterized developmental biology[16]; 5) socio-economic importance



**Figure 2.** Example of Echinoderms, class asteroids (sea stars), common starfish (*Asterias rubens,* Linnaeus 1758).

(recreation, alternative medicine, gastronomy). Some species of echinoderms are consumed by humans due to their high nutritional value high protein content, low-fat content, and amino acid structure. As an example, Sea cucumbers, are very popular in Asia as traditional medicine, gastronomic delicacies, and aphrodisiacs[17,18]; 6) in biological processes, such as regeneration; that is amenable to toxicological analyses; in 7) in a large abundance, diversity, and distribution; 8) ability to move and migrate to other regions; 9) rapid response and high susceptibility to the presence of several types of pollutants[12]. Humans are intimately linked to marine habitats (food source, transport, minerals, climate balance), thus, understanding the health of marine ecosystems is essential for human survival (Figure 2). Hence, this work aims to compile studies that use Echinoderms as a sentinel species for marine pollution.

## 2. Heavy Metals

One of the main challenges facing marine habitats is the accumulation of heavy metals. Heavy metals are metallic chemical elements that originated from the earth's crust and possess a relatively high-density possess poisonous at low concentrations. Examples of heavy metals include Mercury (Hg), Arsenic (As), Chromium (Cr), and Lead (Pb). They are non-biodegradable, remain in the environment and can accumulate in the food chain[19,20]. They get into organisms through food, water, and air, and some of them can mimic essential metals and therefore have access to important molecular targets[21–23]. At high concentrations, heavy metals can be extremely toxic, resulting in instantaneous death. Chronic exposure at low levels and accumulation of heavy metals can cause alteration of embryonic development, malformations, infertility, neurologic alterations, expression of metallothionein, apoptosis, neoplasia, stress protein induction, and immunosuppression, among others[22,24]. In the last decades, the vast majority of heavy metals in the marine ecosystem have been caused by anthropogenic activities, including industrial and agricultural activities[19,25]. These compounds flow into the sea through polluted effluents, sewage, direct discharged from industries into the sea or dissolved from atmospheric pollution[22]. They are usually concentrated in sediment on the seabed due to their low solubility in seawater and their propensity to adsorb to particles[21,22,24].

Echinoderms, as benthic organisms, feed/filter sediments or debris on the sea floor, which are rich in these compounds. This behaviour led them to accumulate metallic and non-metallic pollutants from the environment in their tissues[26]. Additionally, their abundance, low mobility, large sizes and long-life spans and position in the marine trophic chain (biomagnification) made these species interesting organisms in the study of the heavy metal impact on marine environments. Echinoderms are considered simple model systems simultaneously to study how certain metals affect animal development, and to understand the mechanisms of reaction to this aggression, such as cellular death[22].

Table 1 presents some of the heavy metal studies carried out on echinoderms. In all the studies described, heavy metals were detected at different concentrations and accumulated in different tissues based on their tropism. The majority of the investigations (n=22) were conducted in Europe, mainly in the Mediterranean Sea (n=7) and North Sea (n=6). Several studies per species were studies such as *Paracentrotus lividus* (n=8 studies), *Asterias rubens* (n=5) and *Holothuria tubulosa,* (n=2), *Holothuria parva* (n=1), *Holothuria mammata* (n=1), *Holothuria polii* (n=1), *Diadema setosum* (n=1), *Anthocidaris crassispina,* (n=1), *Stichopus japonicus* (n=1), *Arbacia lixula* (n=1), *Amphipholis squamata* (n=1), *Scorpaena porcus* (n=1), *Apostichopus japonicus* (n=1), *Psammechinus miliaris* (n=1). Cadmium (Cd) (n=21), lead (Pb) (n=20) and zinc (Zn) (n=13) were the most studied metals.

The substances studies were observed in all the animals that were included in the studies in different concentrations and accumulated in different tissues according to their tropism. It is interesting to note that most of the studies indicate that they were conducted in very polluted areas. In the research carried out by Portocali *et al.,* (1997) in Greece, samples from urban and industrialized areas of the Gulf of Patraicos (Patras) showed significantly higher concentrations of zinc (metal bound to the urban layer) compared to the Gulf of Korinthiacos (Akoli), a nonindustrial region[13]. In a study in Ssrfjord, Norway, levels of cadmium, mercury and zinc from marine invertebrates and fish obtain in 1980, declined when smelter discharges were reduced in 1986[26].

**Table 1.** Review of some articles that evaluated heavy metals in echinoderms regarding the substance type, species, year, country and sea

| Substance type | Species | Year | Country | Sea | References |
|---|---|---|---|---|---|
| Cd, Cu, Fe, Pb, Zn | *Holothuria tubulosa* | 1998 | Marseille, France; Ischia, Italy; Calvi, Corsica | Mediterranean Sea | 18 |
| Cd, Pb | *Holothuria parva* | 2014 | Iran | Arabian Sea | 27 |
| Cu, Zn, Ni | *Arbacia lixula, Paracentrotus lividus* | 1997 | Greece | Ionian Sea | 13 |
| Pb, Cd, Zn | *Asterius rubens* | 1998 | Norway | Norwegian Sea | 26 |
| Fe, Cu, Mn, Zn, Cr, Co, V, Ni, Cd, Pb, As | *Holothuria mammata, Holothuria polii, Holothuria tubulosa* | 2017 | Turkey | Aegean Sea | 28 |
| Zn, Pb, Cd, Fe, Cr, Cu, Ti | *Diadema setosum* | 1997 | Singapore | South China sea | 29 |
| Pb, Hg, Cd | *Paracentrotus lividus* | 2015 | Italy | Adriatic Sea | 30 |
| Cu, Cd, Pb | *Asterias rubens* | 2001 | Netherlands | North Sea | 31 |
| Cd, Cu, Fe, Pb, Zn | *Amphipholis squamata* | 2000 | Spain | Mediterranean Sea | 32 |
| Zn, Cu, Cd, Pb | *Asterias rubens L.* | 2006 | Belgium | North Sea | 14 |
| Zn, Pb, Cd, Fe, Cr, Cu, Ti | *Paracentrotus lividus* | 1998 | Marseille, France; Ischia, Italy; Calvi, Corsica | Mediterranean Sea | 18 |
| Ar, Cd, As, Hg, Pb | *Anthocidaris crassispina, Stichopus japonicus* | 2014 | South Korea, | The Yellow Sea and Japan Sea | 33 |
| Pb, Cd, Hg | *Paracentrotus lividus* | 2020 | Italy | Mediterranean Sea | 34 |
| As, Cd, Cr, Cu, Hg, Ni, Pb, Zn | *Scorpaena porcus* | 2018 | Italy | Mediterranean Sea | 31 |
| Zn, Cu, Cd, Pb | *Asterias rubens* | 2004 | Belgium | North Sea | 35 |
| Zn, Cu, Cd, Pb | *Asterias rubens, Psammechinus miliaris* | 2003 | Germany, Netherlands | North Sea | 36 |
| Cu, Zn, Cr, Pb, Cd, As, Hg | *Apostichopus japonicus* | 2015 | China | Bohai and Yellow seas | 17 |
| Cd, Cu, Pb, Zn | *Paracentrotus lividus* | 2012 | Algeria | Alboran Sea | 37 |

| | | | | | |
|---|---|---|---|---|---|
| Al, As, B, Ba, Cd, Co, Cr, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Sb, Se, Sn, Sr, Te, Ti, Zn | *Parancetrotus lividus* | 2020 | Italy | Mediterranean Sea | 21 |
| Zn, Pb, Cd, Fe, Cr, Cu, Ti, Hg | *Asterias rubens L.* | 1997 | Netherlands | North Sea | 38 |
| Zn, Ag, Cd, Am | *Paracentrotus lividus* | 1996 | France | North Sea | 39 |
| As, Cd, Cr, Ni, Pb, Cu, Zn, Hg | *Paracentrotus lividus* | 2003 | Italy | Mediterranean Sea | 40 |

*Chromium—Cr; Copper—Cu, Nickel- Ni, Lead—Pb; zinc—Zn; Cadmium—Cd; Manganese—Mn; Mercury-Hg; Aluminum—Al; Calcium—Ca; Iron—Fe; Magnesium—Mg, Arsenic—As, Strontium—Sr; Americcium—Am; Caesium—Cs; Plutonium—Pu; Cobalt—Co; titanium -Ti; Silver-Ag; Antimony – Sb; Tellurium – Te; Molybdenum -Mo; Boron – B; Barium – Ba;*

## 3. Persistent Organochlorine Contaminants (POCs), Endocrine Disrupters, and other Contaminants

Persistent Organochlorine Contaminants (POC), such as Polychlorinated Biphenyls (PCBs), Dichlorodi phenyltrichloroethane (DDT) and polybrominated diphenyl ethers (PBDEs), have been detected in aquatic environments. These pollutants enter the sea via industrial discharges, agriculture, sewage, and mining[3]. Although its use has been banned in many countries because they are non-biodegradable, have long half-lives and are highly lipophilic, they can still be found in remote areas, such as marine polar environments[3,41]. Exposure to these pollutants may have harmful effects on marine wildlife[3,16]. Even though high concentrations are associated with death, PCB studies focus primarily on their bioaccumulation effects. Research carried out on *P. lividus* has demonstrated that PCB exposure causes the accumulation of this contaminant in the body wall, spines, digestive tract, and gonads[42]. PCBs accumulate in the fat tissue of sea cucumbers and can result in death. If they are predated occurs bioaccumulation in the trophic chain, leading to problems at higher levels (e.g., seabirds, cetaceans, or humans) as hepatic and neuronal disorders[43]. Other studies on sea urchins have found that PCB-28, PCB-118, PCB-138 and PCB-180 have negative effects on larval development and growth[44]. One of the most studied regions due to PBCs pollution is the North Sea. Several studies were conducted in this region from 2001 to 2006 on echinoderm species, including *A. rubens*[14,35,36,45].

In all studies consulted, very similar results were observed: PCBs were found in the body wall of *A. rubens*. Also, *A. rubens* and *P. miliaris* embryos exposed to sediments contaminated with PCB during their development showed a significant reduction in the percentage of normal larvae and damage to the immune system (including the production of Reactive Oxygen Species (ROS) by amoebocytes) in *A. rubens*[14,35,36,35]. The sediments of this region also presented a great concentration of PCBs and other chemical pollutants. The southern bay of the North Sea is especially exposed to anthropogenic contamination due to urbanization and industrialization[35].

Another unique phenomenon associated with PCBs is the infestation of the Great Barrier Reef and other reefs by the sea star (*Acanthaster planci*). The *A. planci* in large numbers are responsible for destroying coral reefs in a short time. It seems that chemical pollutants such as DDT, DDE, 1,2,3,4,5,6-Hexa- chlorocyclohexane, mixed isomers (BHC), Dieldrin, Endrin and PCBs, are associated with other factors such as elevated water temperature can be responsible by this outbreaks of *A. planci* in coral reefs. These compounds result in a decline in juvenile and adult predators, resulting in an increase in starfish populations in these areas[46].

Polycyclic Aromatic Hydrocarbons (PAHs), such as fluorene, naphthalene, 1-methylnaphthalene, phenanthrene, chrysene, acenaphthylene, acenaphthene and 2-methylnaphthalene have been observed in high concentrations in different tissues of *P. lividus*. Concentration would be seasonal and habitat-dependent, associated with regional pollution levels. It appears that sea

**Table 2.** Review of some articles that evaluated Persistent Organochlorine Contaminants (POCs) Persistent organochlorine contaminants and other contaminants in echinoderms regarding the substance type, species, year, country, and sea

| Substance type | Species | Year | Country | Sea | References |
|---|---|---|---|---|---|
| PBC | *P. lividus* | 1994 | Italy | Tyrrhenian Sea | 42 |
| PCB-28, PCB-118, PCB-138 and PCB-180 | *P. lividus* | 2013 | Spain | Atlantic Sea | 44 |
| PBC | *Asterias rubens, L.* | 2006 | Belgium | North Sea | 14 |
| PBC | *Asterias rubens* | 2001 | Netherlands | North Sea | 14 |
| PBC | *Asterias rubens* | 2004 | Belgium | North Sea | 35 |
| PBC | *Asterias rubens* | 2005 | Belgium | North Sea | 48 |
| DDT, DDE, 1,2,3,4,5,6-Hexa-chlorocyclohexane, mixed isomers (BHC), Dieldrin, Endrin and PCBs, | *Acanthaster planci* | 1972 | Great Barrier Reef, Guam, Mariana Islands, Caroline Islands, Marshall Islands, Palau Islands, New Hebrides, Solomon Islands, Fiji Islands, Western Samoa, Cook Islands, Tahiti, Hawaiian Islands, Philippine Islands, Taiwan, and Ceylon, Viet Nam, Tanzania, Tonga Islands, Gilbert Islands, Nauru, Papua, New Caledonia, Ko Khao (Wake, the Tuamotu Archipelago, Port Sudan | Pacific and Atlantic Sea | 46 |
| Fluorene, naphthalene, 1-methylnaphthalene, phenanthrene, chrysene, acenaphthylene, acenaphthene and 2-methylnaphthalene | *P. lividus.* | 2018 | Portugal | Atlantic Ocean | 47 |
| Phenanthrene, fluorene, pyrene and fluorinate | *P. lividus* | 2008 | Spain | Atlantic Sea | 49 |

urchins living in sediment are more likely to accumulate two-ring PAHs, whereas sea urchins living on bedrock accumulate three-ring PAHs[47]. Table 2 presents a listing of PAH studies carried out in echinoderms.

Specimens collected on the southwestern Atlantic coast, an area with low anthropogenic activity and low levels of pollution, showed low levels of PAHs in their eggs/gonads. On the other hand, high levels of tributylphosphate have been found in the gonads of sea urchins on the coast of Vila Chã, a more polluted area likely associated with the textile industry[34]. PAHs also can absorb radiation and become protective molecules. Inside organisms, they can transfer their energy to oxygen molecules that produce reactive anions (superoxides) that are responsible for oxidative damage to tissues. This phenomenon has been observed in studies performed on larvae of *P. lividus*,

where phenanthrene, fluorene, pyrene and fluorinate have been found to reduce larval growth by 30%, 40%, 65% and 90% respectively during the development[49].

Polycyclic Aromatic Hydrocarbon (PAHs) such as phenanthrene (C14H10I) is found on the surface of polystyrene microparticle. Sea cucumbers (*Holothuria leucospilota* and *Stichopus hermanni*) that experimentally ingested phenanthrene showed: damage to the intestine, accumulation of ammonia in their tissues, spawning, contraction of the buccal tentacles, evisceration, body stretching, body swelling, and dissolution of the skin with development of external lesions. When associated with stressful environments (e.g., hypoxia) clinical signs have become more serious with increased mortality[50].

Endocrine Disruptors (EDCs) are chemicals that can mimic/inhibit/interfere with hormones in the endocrine system of living organisms at very low doses[16]. So, they have been linked to a range of human and animal health issues, affecting the growth, reproduction, and immune system of organisms, as well as ecosystem balance[51]. The presence of EDCs in the environment can be originating from natural and synthetic sources. Detergents, flame retardants, cosmetic components, pharmaceuticals, plastic additives and pesticides (e.g., POC), are some examples of synthetic EDCs[52]. These compounds enter the marine environment also via effluents from sewage, industry, and agriculture discharges. Because of their low solubility in water, endocrine disruptors are quickly divided and can persist for a long time in sediments[52]. Studies of EDCs on echinoderms are still scarce. Several authors suggested the possible involvement of steroid processes as regeneration in Echinoderms. Echinoderm usually regenerates to replace the traumatic losses of different body compartments (Figure 3). It is proposed that endocrine-neuroendocrine mechanisms control this process[52]. Table 3 describes the effects of EDCs on the regeneration of echinoderms. There are studies described in *Ophioderma brevispina, Antedon Mediterranea and Paracentrotus lividus.* From the studies performed regeneration is inhibited by Tributyltin, Triphenyltin, 4-nonylphenol, Cyproterone acetate, p,p′-DDE and Cyproterone acetate. On other hand, substances such as Polychlorinated biphenyls, Fenarimol,

**Table 3.** EDC Compounds analyzed and their effect on the regeneration process of echinoderms

| Species | Compound | Inhibit regeneration | Accelerated regeneration | Reference |
|---|---|---|---|---|
| *Ophioderma brevispina* | Tributyltin | x | | 53 |
| | Triphenyltin | x | | |
| *Antedon Mediterranea* | 4-nonylphenol | x | | 16,51,52 |
| | Polychlorinated biphenyls | | x | |
| | Fenarimol | | x | |
| | Triphenyltin | | x | |
| | Methyltestosterone | | x | |
| *Paracentrotus lividus, Antedon mediterranea* | Cyproterone acetate | x | | 51 |
| | Triphenyltin | | x | |
| | Fenarimol | | x | |
| | Methyltestosterone | | x | |
| *Antedon mediterranea* | p,p′-DDE | x | | 52 |
| | Cyproterone acetate | x | | |



**Figure 3.** Example of regeneration in a common starfish (*Asterias rubens*, Linnaeus 1758).

Triphenyltin, and Methyltestosterone help to accelerate the regeneration in those animals.

Concerning the effects of EDCs on the reproductive function of echinoderm, exposure to these compounds leads to decreased fertility, abnormalities and inhibition of larval growth[49,54,55]. Long-term exposure to phenol in *Antocidaris crassispina* origins anomalies in spermatogenic processes (e.g., abnormal mitochondria development)[56]. *A. rubens* exposed to diverse EDCs (e.g., PBCs, Zn, Cd) leads to alteration in the Mono-Oxygenase (MO) system, reduced ovary growth and offspring quality in pyloric caeca and/or gonads[45,57].

In sea urchins, it is reported that POC, which can act as EDCs, can lead to alterations in embryonic development and infertility. In a study performed by Pesando *et al.,* (2004) using Methoxychlor (MXC), dieldrin and lindane (γ-HCH) on *P. lividus*. showed that these three compounds in high concentrations had different impacts on the reproduction of these animals, but the three lead to a delay in the synthesis of DNA during the first mitotic divisions of the zygotes due to the alteration of cyclins and protein kinases. The MXC caused inhibition of the early development of the eggs, especially in gastrulation, which generated an amorphous larva. Lindane caused alterations in the immune (immunodeficient) and reproductive system (in sperm mobility, polyspermy rate, alterations in the acrosomal reaction and blockage of the first divisions of the new zygotes). Dieldrin had similar effects on the reproductive system as lindane[58].

## 4. Conclusions

Marine pollution is an extremely serious problem around the world. Marine waters are the point of accumulation of a variety of pollutants from diverse anthropogenic sources (e.g., agriculture, industry, fishing), which are discharged every day without control. The actual impact of contaminants on marine biota is still unknown, as the effects of some pollutants are not observed until several years later. But we are starting to observe some of their impacts on the animals that inhabit them and on the different human activities which sustain economically and socially millions of people around the planet. The benthic behaviour, its large dispersion and its long lifespan have made Echinoderms an important biological indicator of the health of the marine environment. However, important knowledge gaps remain, as these animals are often overlooked and neglected in marine epidemiological surveillance.

Moving forward, it will be important to develop One Health projects that will include echinoderms as sentinels of marine and terrestrial pollution, climate change and other anthropogenic threats. Under the One Health system, we can identify threat factors, understand their impact, establish measures to prevent or minimize their

consequences and predict the appearance or re-emergence of diseases in the different ecosystems, particularly the marine. Ecosystems have become increasingly threatened. There is an urgent need to use all available means to prevent or at least delay the destruction of our planet. Studies conducted at Echinoderms showed that there are measures that can be effective. This makes it worthwhile to take more and more action to combat pollution.

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