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Review

Factors in the decline of the African penguin: Are contaminants of emerging concern (CECs) a potential new age stressor?

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Highlights

- Current stressors impacting the African penguin *Spheniscus demersus*
- Contaminants of emerging concern in the marine environment across the globe including South Africa
- Bioaccumulation and impacts of contaminants of emerging concern in different avian species
- Potential impact of contaminants of emerging concern on African penguin populations in South Africa

Abstract

The African penguin is currently experiencing a significant decline, with just over 10,000 breeding pairs left. A substantial body of research reflects the impacts of contaminants of emerging concern (CECs) on the marine environment, with wastewater treatment plants reported as one of the main sources of CEC release. In South Africa, CECs were identified contaminating the marine environment and bioaccumulating in several marine species. Approximately 70% of all African penguin colonies breed in close proximity to cities and/or harbors in South Africa. Currently, the impact of CECs as a stressor upon the viability of African penguin populations is unknown. Based on the search results there was a clear lack of information on CECs' bioaccumulation and impact on the African penguin. This narrative review will thus focus on the prevalent sources and types of CECs and examine the reported consequences of constant exposure in seabirds, particularly African penguins.

Introduction

Penguins are a group of large flightless marine birds belonging to the family Spheniscidae (Naruse and Parker, 2001). There are currently 18 extant penguin species found across the globe with most species living below the equator in South Africa, Namibia, New Zealand, Australia, Argentina, Chile, Galapagos Islands, Antarctica, and the sub-Antarctic Islands (Favaro et al., 2015). Out of the 18 species, the African penguin *Spheniscus demersus*is the only member of the Order Sphenisciformes and genus *Spheniscus* breeding on the southern parts of the African continent (South Africa and Namibia) (Shelton et al., 1984). Other penguins from this genus such as the Magellanic penguin *Spheniscus magellanicus* can be found breeding along the coast of Chile and Argentina (Gandini et al., 1996), the Humboldt penguin *Spheniscus humboldti* mostly resides along the coastal regions of Peru and in Chile (Squadrone et al., 2019) and the Galapagos penguin *Spheniscus mendiculus* can be found breeding on the Galapagos Islands (Vargas, 1996).

African penguins have 28 extant breeding sites all clustered between Namibia, the Western Cape, and the Eastern Cape of South Africa (Sherley et al., 2020). During the earlier parts of the 20th century, the African penguin was the most abundant seabird species in South Africa and Namibia, with an estimated population size of 1.5 to 3 million penguins (Crawford et al., 2007; Shannon and Crawford, 1999). However, by the late 21st century this number plummeted to an estimated 224,000 birds (Crawford and Boonstra, 1994), with the current population size of approximately 10,400 breeding pairs (Daniels, 2022). Alarmingly, it took just over 20years, between 1988 and 2010, for the African penguin to be listed as

Endangered on the IUCN Red List of Threatened Species (BirdLife International, 2021) which equates to a population loss of up to 65% (Sherley et al., 2020).

Various factors have contributed to the decline of this species including historic stressors such as excessive egg and guano harvesting (Frost et al., 1976) to current stressors such as oil-spillage, predation (Shannon and Crawford, 1999), climate change (Lei et al., 2014; Weller et al., 2014), parasites (Atkinson et al., 2000), human disturbances (Giese, 1996; Ludynia et al., 2014; Pichegru et al., 2022) and the overexploitation of pelagic fish (e.g. sardine and anchovy) by purse-seine fisheries (Crawford et al., 2011). Other potential stressors are contaminants of emerging concern (CECs), also known as emerging contaminants. CECs have gained attention over the past decade due to their on-going negative impacts on the health of the marine ecosystem. It has been estimated that 49% of marine ecosystems across the globe have been impacted by synthetic pollutants (Gaw et al., 2014) with South Africa being no exception.

According to the U.S. Environmental Protection Agency, CECs can be described as chemicals that pose a potential threat to the environment and to human health, or chemicals in which there is a lack of published health standards, or chemicals that are ‘emerging’ due to a discovery of their source or pathway into the environment. These chemicals include personal care products (parabens and fragrances), pharmaceuticals (for instance antibiotics, hormones, stimulants, antihistamine and analgesics), perfluoroalkyl and polyfluoroalkyl substances, flame retardants, plasticizers (Nilsen et al., 2019) and new generation pesticides (K'oreje et al., 2020). Globally, around 40,000 CECs have been detected as harmful with a daily addition of six new compounds to the list (Diamond et al., 2011; Halden, 2015). One of the major concerns of CECs in the marine environment is their bioaccumulative and transferable behavior (Lazarus et al., 2015) with the potential to cause direct and indirect ecological changes over time (Saaristo et al., 2018). For example, various studies have linked CECs to reproductive stress in mussels (Bringolf et al., 2010), antibacterial resistance in fish (Cabello, 2006; Jakimska et al., 2013) and feminization/masculinization of marine life (Sumpter and Jobling, 1995). Many CECs interfere with the endocrine system, compromising the release of reproductive hormones, and/or target the reproductive cells directly, for example by bypassing the blood-testis barrier (Marcu et al., 2023).

An electronic search was conducted on the Web of Science (WoS) and Google Scholar in which relevant published articles were retrieved to construct a database focusing on environmental contaminants' impacts on seabird species especially relating to the African penguin. Search terms and phrases included “African penguin, contaminants of emerging concern (CECs), penguin species, seabird species, avian species, South Africa, wastewater

treatment plants, marine water quality, pharmaceuticals, personal care products, persistent organic pollutants, environmental pollution, organic contaminants, stressors, threats, bioaccumulation, biomagnification and ecotoxicology". Based on the search results there was a clear lack of information on CECs' bioaccumulation and impact on seabird species in South Africa, especially on African penguin populations. Thus, this narrative review aims to i) appraise the established stressors on the African penguins and how they are being addressed, ii) understand whether CECs could be a potential anthropogenic stressor on penguin populations and iii) provide evidence for the need to increase research efforts in understanding the type and quantity of CECs in South Africa's aquatic environments.

Section snippets

Current pressures on the African penguin population in South Africa

Below we review the current stressors identified as contributing to the decline of this species (Fig. 1) and the current management strategies implemented.…

Contaminants of emerging concern (CECs) in the marine environment

Globally, millions of people daily utilize, or consume and dispose of numerous chemical compounds as a result of ageing, life style diseases, infections, and the ever-growing development of agrochemical, chemical, cosmetic, and pharmaceutical industries (Starling et al., 2019). With over 3000 research papers on CECs available online (Sandoval et al., 2024), it is clear that ecological water resources such as surface water, ground water, effluent wastewater and drinking water are contaminated…

Conclusion

Over the past few years, a significant amount of research has been conducted identifying diverse contaminants as a major threat to the environment (Ramírez-Malule et al., 2020). However, South Africa has fallen behind in this research area and consequently significant

knowledge gaps remain relating to the identities, concentration, sources, dispersal and fate of many CECs (Fairbairn et al., 2016; Necibi et al., 2021). With approximately 70% of all African penguin colonies breeding in close…

CRediT authorship contribution statement

Stephanie Dreyer: Writing – review & editing, Writing – original draft, Visualization, Supervision, Project administration, Investigation, Data curation, Conceptualization. **Daniel Marcu:** Writing – review & editing, Writing – original draft, Visualization, Software, Investigation, Formal analysis, Data curation, Conceptualization. **Shannen Keyser:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Investigation, Data curation. **Monique Bennett:** Writing – review &…

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.…

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