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Oil spills at sea, their effects on birds and main treatments: a systematic review

Derramamento de petróleo no mar, efeitos sobre as aves e principais tratamentos: uma revisão sistemática

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A B S T R A C T

Oil is a fossil fuel of great economic importance. However, it is highly toxic, causing harmful effects to the environment and the life that inhabits it. In this sense, the present study aimed to present the main impacts of oil on birds and possible solutions to the problem, through a systematic literature review. For the review, the *Web of Science* database was used, in which two sets of keywords were searched: "*oil spills seabirds*" and "*oil spills birds*," followed by three search refinements: only publications that included the keywords in the title, only publications of the "article" type, only articles published between 2012 and 2022. The main topics discussed in the literature were: detection of oil at low concentrations in individuals; main compounds found in organs; physical and physiological effects of oil; cause of mortality; and treatment and rehabilitation of individuals. The main topics covered in the literature were: detection of oil at low concentrations in individuals; main compounds found in organs; physical and physiological effects of oil; cause of mortality; and treatment and rehabilitation of individuals. Eleven articles were selected to comprise the present review, these addressed four spills: Deepwater Horizon, Prestige, MV Tricolor, and the Tsushima spill. Despite the relevant results of the research, the short period of time covered in the review and the use of a single database resulted in some limitations in the research, making it necessary, therefore, to conduct more extensive studies in the future.

R E S U M O

O petróleo é um combustível de origem fóssil de grande importância econômica, no entanto, é altamente tóxico, causando efeitos nocivos ao ambiente e à vida que o habita. Neste sentido, o presente estudo objetivou apresentar os principais impactos do petróleo sobre as aves e possíveis soluções para o problema, por meio de uma revisão sistemática de literatura. Para a revisão foi utilizada a base de dados *Web of Science*, na qual foram pesquisados dois conjuntos de palavras-chave: "*oil spills seabirds*" e "*oil spills birds*", seguidas por três refinos de pesquisa: apenas publicações que incluíssem as palavras-chave no título, apenas publicações do tipo "artigo", apenas artigos publicados entre 2012 e 2022. Os principais temas abordados na literatura foram: detecção de petróleo em baixas concentrações nos indivíduos; principais compostos encontrados nos órgãos; efeitos físicos e fisiológicos do petróleo; causa da mortalidade; e tratamento e reabilitação dos indivíduos. Foram selecionados 11 artigos para compor a presente revisão, estes abordaram quatro derramamentos: Deepwater Horizon, Prestige, MV Tricolor e o derramamento de Tsushima. Os principais temas abordados foram: detecção de petróleo em baixas concentrações nos indivíduos; principais compostos encontrados nos órgãos; efeitos físicos e fisiológicos do petróleo; causa da mortalidade; e tratamento e reabilitação dos indivíduos. Apesar dos resultados relevantes da pesquisa, o curto período abordado na revisão e a utilização de uma única base de dados resultaram em algumas limitações na pesquisa, fazendo-se necessária, portanto, a realização de estudos mais abrangentes futuramente.

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Introduction

Petroleum is a product of fossil origin, being considered as one of the main sources of energy and raw material today, and therefore of great economic importance (Craig et al., 2012; Guerra, 2015). As a result, an increase in oil exploration and transportation in marine environments has been observed in recent years, activities that pose a high risk of accidents due to human and/or mechanical causes (Mishra & Kumar, 2015). Oil has high toxicity and low density in relation to water, so its effects on the marine environment are very harmful and long-term, and can cause damage to property and marine life (Craig et al., 2012; Guerra, 2015; Mishra & Kumar, 2015).

Among the substances contained in petroleum, Persistent Organic Pollutants (POPs) and Polycyclic Aromatic Hydrocarbons (PAHs) stand out, which due to their toxicity and persistence, can accumulate along the food chain (Ossai et al., 2020; Silva et al., 2021). Due to their lipophilic property, PAHs are absorbed into organs such as the hepatopancreas and digestive gland in crustaceans, mollusks, and annelids and the liver in fish, mammals, and birds, where they can alter membrane structure and interfere with cell function (Silva et al., 2021).

Due to their various foraging strategies, behaviors, and need for rest, seabirds are in constant contact with water, and in cases of spills, oil adheres to their plumage (Boor & Ford, 2019; Haney et al., 2014, 2017; Silva et al., 2021). Crude oil affects the integrity of feathers, reducing the impermeability, thermal insulation, and buoyancy of individuals (Troisi et al., 2016). In addition, sublethal exposure, i.e., by an amount of oil insufficient to cause immediate death, poses a major long-term risk to birds, with waterfowl, seabirds and colonial waterbirds being the most endangered groups (Fallon et al., 2018).

In this sense, the present research aimed to systematically review studies related to the deleterious effects of oil on birds at different levels of organization of ecological systems (individual, population, and community), as well as possible solutions to the impacts caused by spills on avifauna.

Methodology

For the development of this research, the systematic literature review method was adopted, which can be defined as the rigorously planned synthesis of relevant studies related to a given topic, thus aiming to reduce research bias (Galvão & Pereira, 2014; Mariano & Santos, 2017). According to Galvão e Pereira (2014), for the preparation of a systematic review, the following methods should be followed: “(1) research question elaboration; (2) literature search; (3) selection of articles; (4) data extraction; (5) methodological quality assessment; (6) data synthesis (meta-analysis); (7) assessing the quality of the evidence; and (8) writing up and publishing the results."

This review aimed to answer the following question: "What are the main effects of oil on seabirds at different levels of organization of ecological systems (individual, population, and community)?" as well as to present possible solutions to the impacts caused by oil on the avifauna affected by spills.

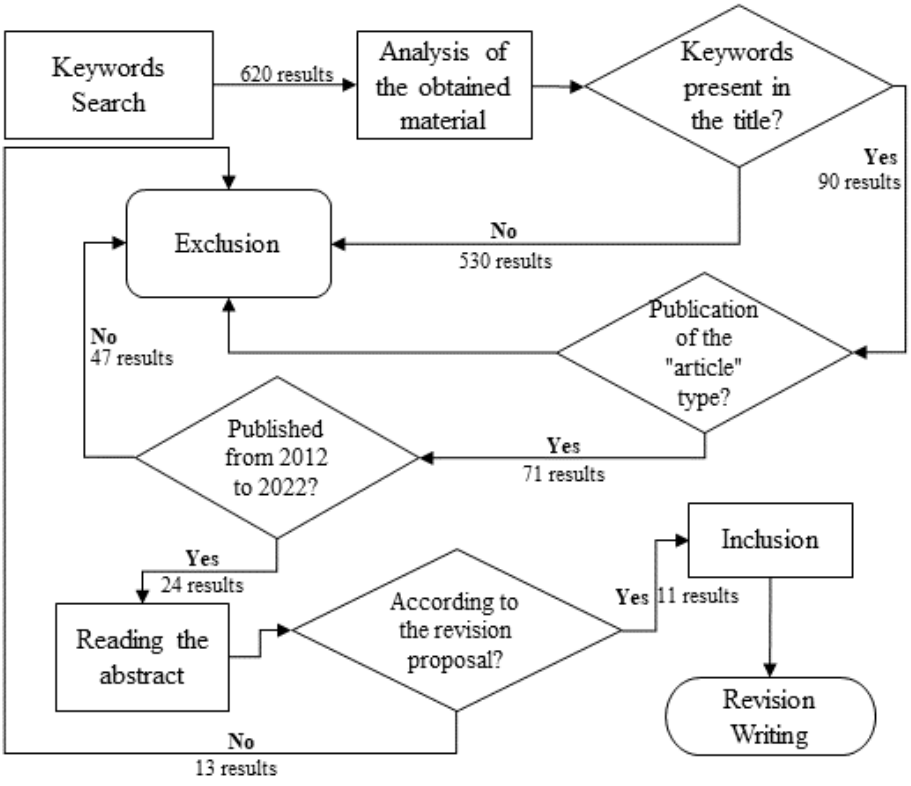
The search for the articles was conducted in the month of September 2022, using the *Web of Science* (WoS) database. WoS is a multidisciplinary journal database, which currently indexes more than 12,000 journals, published since the early 20th century (Mariano & Santos, 2017).

The search was conducted for two sets of keywords "oil spills seabirds" *or* "oil spills birds", because in this way the result could encompass experimental studies conducted with non-marine species, but which apply to marine species. The keyword search resulted in 620 publications.

The following eligibility criteria were defined: (1) keywords should be present in the title of the publication, (2) publications should include only articles, and (3) these should cover a period of 10 years (2012 - 2022), totaling 24 publications. After the search, the titles and abstracts of the 24 articles were read in order to identify which ones fit the review proposal. Figure 1 shows the flowchart with details about the process of exclusion and inclusion of articles in the review.

Figure 1.

Flowchart of the article selection process for the review.



Source. Prepared by the authors.

Results and Discussion

After reading, 11 articles were selected to compose the present review (table 1).

Table 1.

Publications selected for the review.

Authors/Publication year	Title
Barros et al., 2013	Long-term reproductive impairment in a seabird after the Prestige oil spill
Champoux et al., 2020	An investigation of physiological effects of the Deepwater Horizon oil spill on a long-distance migratory seabird, the northern gannet
Fallon et al., 2018	Hematological Indices of Injury to Lightly Oiled Birds from the Deepwater Horizon Oil Spill
Fallon et al., 2020	Ultraviolet-assisted oiling assessment improves detection of oiled birds experiencing clinical signs of hemolytic anemia after exposure to the Deepwater Horizon oil spill
Finlayson et al., 2018	Efficacy of seawater for washing oiled birds during an oil spill response
Franci et al., 2014	Endocrine status of a migratory bird potentially exposed to the Deepwater Horizon oil spill: A case study of northern gannets breeding on Bonaventure Island, Eastern Canada
Haney et al., 2017	Challenges to Oil Spill Assessment for Seabirds in the Deep Ocean
Mochizuki et al., 2013	Contents of Various Elements in the Organs of Seabirds Killed by an Oil Spill around Tsushima Island, Japan
Perez et al., 2017	Low level exposure to crude oil impacts avian flight performance: The Deepwater Horizon oil spill effect on migratory birds
Troisi et al., 2016	Impacts of oil spills on seabirds: Unsustainable impacts of non-renewable energy
Vidal e Domínguez, 2015	Did the Prestige oil spill compromise bird reproductive performance? Evidences from long-term data on the Kentish Plover (*Charadrius alexandrinus*) in NW Iberian Peninsula

Source. Prepared by the authors.

The publications reviewed covered a total of four spills: the *Deepwater Horizon* (DWH) in the Gulf of Mexico was the most cited (n = 6), followed by the *Prestige* off the coast of Galicia, Spain (n = 2), in addition to these, Norway's *MV Tricolor* and the Tsushima Island spill were cited once each.

The main themes addressed in the literature were: (I) detection of oil at low concentrations in individuals; (II) main compounds found in organs; (III) physical and physiological effects of oil; (IV) cause of mortality; and (V) treatment and rehabilitation of individuals. These topics will be addressed below.

Oil presence detection

Detection and quantification of the rate of oil present in the body of birds affected by spills can be done remotely, by observation or photographs of individuals, or directly, by analysis of blood physiology or ultraviolet (UV) fluorescence (Haney et al., 2017).

In order to test the effectiveness of UV fluorescence in detecting the presence of oil on the body surface of birds, Fallon et al. (2020) conducted an experiment in which two methods were used: (A) direct observation and (B) observation with portable UV lights to test 705 individuals belonging to five species found at sites affected by the DWH spill: black skimmer (*Rynchops niger* Linnaeus, 1758), brown pelican (*Pelecanus occidentalis* Linnaeus, 1766), great egret (*Ardea alba* Linnaeus, 1758), clapper rails (*Rallus crepitans* JF Gmelin, 1789) and seaside sparrow (*Ammospiza maritima* Wilson, 1811). These species were selected because they have diverse ecological niches, and therefore have different levels of susceptibility to spills (Fallon et al., 2020).

Of the 705 individuals evaluated, 138 showed some conspicuous evidence of oil in the body. However, after the use of UV light, the number of individuals containing some level of oil on the body surface increased to 397, that is 259 more individuals than observed with the naked eye (Fallon et al., 2020). In addition, an increase in the proportion of oil present in approximately 160 individuals (40%) was found following the application of UV light for visualization (Fallon et al., 2020).

Elements present in the organs

In a study published in the year 2013, researchers compared the concentrations of various elements present in the internal organs of birds found dead and individuals rescued from oil spill areas around Tsushima Island, Japan in 2006 (Mochizuki et al., 2013).

A total of 29 individuals were collected, including 19 pacific loons (*Gavia pacifica* Lawrence, 1858; females = 7, males = 8, and unknown = 4), two black-throated loons (*G. arctica* Linnaeus, 1758; males = 2), seven Gaviidae not identified to species level due to

excessive oil on the body (females = 2, males = 4, and unknown = 1), and one unknown species (male = 1) (Mochizuki et al., 2013).

Samples of kidney and liver were taken from the individuals, packed in ice and transported to the laboratory, where the analyses were performed. Eight elements present in the birds' organs were analyzed: cadmium (Cd), copper (Cu), chromium (Cr), molybdenum (Mo), lithium (Li), titanium (Ti), thallium (Tl), and vanadium (V) (Mochizuki et al., 2013).

According to the results obtained by the authors, there was a tendency towards higher mean concentrations of the elements present in the liver of individuals found dead in relation to those who died after being rescued, with significant differences being observed for the elements V and Tl (Mochizuki et al., 2013). For kidney samples, only the Ti element showed significantly higher concentration for individuals found dead (for details of the mean concentrations of the eight elements, see Mochizuki et al., 2013, tables I and II). According to the authors, the concentration of elements found in individuals affected by the oil spill mainly reflect the environment in which the species live, in addition to where they feed (Mochizuki et al., 2013).

Physical effects of oil on birds

One of the main physical effects suffered by birds due to oil spills is the alteration in the structure of their feathers, which results in a loss of buoyancy and impermeability, as well as making it difficult for the individuals to move around. In order to test the hypothesis that after a spill, oiled birds show reduced performance in returning to their habitat, American scientists conducted an experiment in which two groups of rock dove (*Columba livia* Gmelin, 1789) were trained to return home from a distance of 81 km (Perez et al., 2017).

The experiment was approved by the Institutional Animal Care and Use Committee of the University of Nevada, and consisted of an evaluation of the performance of two groups of doves, a group of individuals covered by small concentrations of crude oil and a control group (Perez et al., 2017). The following parameters were evaluated: flight duration, flight speed and stop duration (Perez et al., 2017).

The results of the study showed reduced flying ability and increased time needed to complete journeys by individuals affected by oil, even if in small amounts and for a single time (Perez et al., 2017). Reduced performance was also observed for up to 35 days after exposure, indicating a long-term persistence of the oil's effects on exposed individuals (Perez et al., 2017). The oiled individuals showed a higher mean flight speed. However, they increased the duration of stopping compared to individuals in the control group (Perez et al., 2017).

Physiological effects of oil on birds

In order to investigate the occurrence of oil-induced changes on two hormones important for reproductive success (prolactin and corticosterone) in birds that overwintered

between 2010 and 2011 in the Gulf of Mexico (exposure area) compared to birds that migrated along the Atlantic Coast (reference area), Franci et al. (2014) collected blood samples from northern gannets (*Morus bassanus* Linnaeus, 1758) in the early and late incubation period.

In the Gulf of Mexico, individuals showed higher prolactin levels at the early incubation stage compared to individuals from the Atlantic Coast, however, no difference in the levels of this hormone at the late incubation stage was found for both areas (Franci et al., 2014). As for corticosterone levels, there was no difference in the early or late incubation period between the Gulf of Mexico and the Atlantic Coast (Franci et al., 2014).

Another study conducted at the same time (2010-2011) by Fallon et al. (2018), analyzed the hematological effects in individuals belonging to four species: black skimmer, brown pelican, great egret and american oystercatcher (*Haematopus palliatus* Temminck, 1820). The sites studied were the coasts of Louisiana and Mississippi (exposure areas) and South Carolina and Georgia (reference areas).

The researchers found that in the potential impact areas, birds had higher Heinz bodies/1000 red blood cells, a 35% higher average number of reticulocytes, lower red blood cell volume, and lower hemoglobin concentration compared to individuals in the reference sites (Fallon et al., 2018).

Finally, research published in 2020 assessed the impacts of oil exposure on a population of northern gannets, which nests on Bonaventure Island (Canada) and migrates to the Gulf of Mexico and the Atlantic Coast during winter. Blood and feather samples were collected from adult individuals at the nesting site. Source and alkylated PAHs; trace metals; stable isotopes of C, N, and H; and biological endpoints (genetic, immunological, thyroid, steroid, and retinoid) were analyzed (Champoux et al., 2020).

21 source PAHs were analyzed, of which two (naphthalene and biphenyl) were observed in less than 50% of the samples and four in more than 50%. The remaining 15 were not detected in any samples. 28 alkylated PAHs were analyzed, of these, two (C2- and C4-benzo(a)anthracene/chrysene) were present in all samples, 16 in more than 50%, three in less than 50%, and seven were not detected (Champoux et al., 2020).

No wintering site-related differences were detected for the presence of eight elements (As, Cu, Fe, Ni, Rb, Se, V, Zn) found in blood. 14 elements (As, Ba, Cd, Cu, Fe, Mn, Mo, Pb, Rb, Se, Sn, Sr, V and Zn) detected in feathers also showed no significant differences between wintering sites (Champoux et al., 2020).

Birds from the Gulf of Mexico showed a significantly higher number of lymphocytes and on the calibration curves of thyroid hormone concentration FT_4 and TT_4 compared to individuals from the Atlantic Coast. It was observed that δ13C and δ2H values in feathers developed during winter were lower for individuals in the Gulf of Mexico, however, δ15N values were higher at this location (Champoux et al., 2020). An increase in DNA damage after

exposure to methyl methane sulfonate was also observed, but significant differences in genotoxicity, gene transcription, morphometry and biochemical variables between wintering sites were not observed (Champoux et al., 2020).

Effects on reproductive success

The effects of the oil spill on the reproductive success of birds were examined by (Barros et al., 2013). The authors used European shag (*Gulosus aristotelis* Linnaeus, 1971) colonies affected by the Prestige spill in the Iberian Peninsula as the basis for their study (Barros et al., 2013). A linear mixed model was used, including area (with oil or without oil), period (up to 8 years before and 10 years after the spill), North Atlantic Oscillation (NAO) and Sea Surface Temperature (SST) (Barros et al., 2013).

The results obtained by the authors indicate that the annual reproductive success of European shag was most affected by the interaction between area (with and without oil) and period (pre- and post-spill). A reduction of about 45% in reproductive success was observed for colonies in oiled areas, and a 40% reduction in the number of feathered young per pair compared to colonies in non-oiled areas (Barros et al., 2013). The climate (SST and NAO) at the study site did not vary after the spill, so it did not have a significant influence on the reproductive success of the species (Barros et al., 2013).

Another study that aimed to evaluate the effects of oil spills on the reproductive success of birds was conducted between 1996 and 2011. In this study, Vidal e Domínguez (2015) analyzed, in addition to reproductive success, egg quality, the occurrence of desertion in nests, and the quality of females, using as focus species the Kentish Plover (*Charadrius alexandrinus* Linnaeus, 1758), also affected by the Prestige spill.

Visits were made in which observations were made of the nests. Observations included the main reproductive parameters: general hatching rate and fertility. To determine the quality of the eggs, length, width and weight were measured, these measurements were used to estimate the volume of the eggs. Egg size was estimated from the average volume (based only on nests containing three eggs) and volume of the A-egg, i.e. the first egg of the clutch. Nest desertion was considered real when, after two visits, the following were observed: lack of evidence of the presence of adults, absence of the species' footprints and low egg temperature (Vidal & Domínguez, 2015).

During the 16-year period (1996-2011) of the study, 1559 nests were observed, of which 1103 had their egg sizes measured. No differences in egg size were observed in the pre- and post-spill periods. Over the 16 years, only 10% of the Kentish Plover nests hatched and the differences between periods (pre- and post-spill) were not significant. Of all the nests that hatched, 75% were successful, among the remaining 25%, there was abortion of at least one of the eggs. The egg fertility rate was 87% and, in this case, significant differences were observed between the pre- and post-breeding periods (Vidal & Domínguez, 2015). A significant

difference in A-egg volume was observed in the pre- and post-spill periods. However, the average egg volume showed no significant difference between periods. There was a low rate of nest desertion over the 16 years (2.4%), but significant differences were observed in the first year's post-spill (2003-2007 = 4.5%) and a reduction in the difference in subsequent years (2008-2011 = 2.7%). Finally, significant differences were found between periods for body mass of females (Vidal & Domínguez, 2015).

Rehabilitating individuals

Survival rates of birds after oil spill events remain very low, despite investments in the rehabilitation of affected individuals. Considerable efforts have been made to recover, clean up, and rehabilitate birds affected by oil spills and to reintroduce them to the wild (Troisi et al., 2016). The following is a study in which a new method of oil removal in birds affected by spills was proposed.

In order to evaluate the efficiency of seawater in removing oil from the body surface of birds and its effects on the impermeability of the feathers of treated individuals, Finlayson et al. (2018) conducted four experiments: (I) seawater wash/seawater rinse, (II) freshwater wash/seawater rinse, (III) seawater wash/freshwater rinse, (IV) freshwater wash/freshwater rinse. The experiments were conducted with the Mallard species (*Anas platyrhynchos* Linnaeus 1758).

Initially, 44 subjects were used, however, due to complications, eight of these were removed from the study. The evaluated individuals were classified as adequately cleaned, since the oil was completely removed by washing with fresh or salt water. Saltwater washing had a significantly longer duration as well as higher water consumption. The rinsing time showed a significant difference between groups, with treatment III showing the longest average time (21 min) and treatment IV the shortest (11 min). As for the time required to waterproof the feathers after treatment, there was also a significant difference, with individuals who underwent treatment III taking only one of the three treatment days to regain waterproofness (Finlayson et al., 2018).

The results of the study demonstrated efficiency of using saltwater for oil removal on the feathers of spill-affected individuals, as despite the greater time and amount of water required for cleanup, the scarcity of resources such as freshwater in remote areas is considered. The effectiveness of the treatment, however, may vary by species (Finlayson et al., 2018).

Final considerations

Through the present review, it was found that the main topics addressed in the last decade were: the physical and physiological effects of oil on birds, its impacts on reproductive success and causes of mortality, and proposals for new methods to detect oil in small quantities

and for treatments for recovery and rehabilitation. However, the number of publications reviewed is too low to draw any concrete conclusions.

A geographical restriction to countries belonging to Asia, Europe, and North America was observed in the studies. This is due to the fact that the WoS database consists mainly of European and North American publications. Therefore, in order to obtain broader results, it is necessary to use other databases.

Another limiting factor to the present review was the short period of time covered (10 years). Thus, large spills, such as the Exxon Valdez, which occurred in 1989 in Alaska, for example, had their impacts more widely addressed between the 1990s and 2000s. Thus, surveys with wider time intervals are also needed.

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