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The implications of global oil exploration for the conservation of terrestrial wildlife ☆

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ABSTRACT

Global dependence upon fossil fuels persists in the 21st century. With known deposits of oil diminishing, technological advancements and alternative financing have facilitated explorations into a number of sensitive habitats around the world. Such pursuits challenge global priorities relating to the ideals of energy production versus those of biodiversity protection. Presently, the implications of oil extraction on terrestrial wildlife, for instance, are unclear, undermining the ability to meet this challenge. We synthesized the literature to quantify the range of documented impacts of oil extraction on terrestrial wildlife and to identify prevailing knowledge gaps. Our review returned 31 studies documenting various effects of oil extraction, across the exploration, development, production, and abandonment phases, on terrestrial wildlife. These studies were most often based in North and South America, tended to focus on the development phase of oil extraction projects, and often focused on the impacts on mammals. We found that terrestrial wildlife were generally negatively impacted by oil extraction through road development, seismic surveys, hydraulic fracturing, installation of oil wells, contamination, and other extraction disturbances. We also considered the implications of this review on oil extraction in Murchison Falls National Park and the broader Murchison Falls Conservation Area, a highly biodiverse region in Uganda. Herein, we detected an important knowledge gap relating to the ways in which various oil extraction activities may increase the potential for human-wildlife conflict. Reviews of this type are essential for quantifying the effects of oil extraction on terrestrial wildlife and can inform future decision-making on natural resource extraction in ecologically-sensitive habitats globally.

1. Introduction

The consumption of fossil fuels by the global human population exhibited tremendous growth in the 20th century (Longwell 2002). Despite considerable efforts to diversify sources of energy (Dresselhaus and Thomas, 2001), the world continues to depend heavily upon fossil fuels, with <15% of energy demands presently met by alternative renewable sources (Dale, 2007; Liu et al., 2007; Lund, 2007; Arbuthnott and Dolter, 2013). Crude oil, for instance, remains the most sought after energy source and is predicted to remain so into the foreseeable future (Krichene, 2006). At the current consumption rates, known oil reserves could be exhausted within the next few decades (Shafiee and Topal, 2009; Mirchi et al., 2012; Hook and Tang, 2013). Given this reliance on oil, reserve depletion presents a serious and looming threat to the world's energy system, particularly in light of predicted human population growth (see Kerr, 1998). Consequently, efforts to locate new oil deposits around the world have intensified (Finer et al., 2008; Nyambuu and Semmler, 2014; Abas et al., 2015).

Coupled development in efficient and affordable oil extraction technologies and financial lending practices (e.g., public/private partnerships; Nielson, 1989; Chen et al., 2000) have made previously known, but hard-to-reach deposits, economically viable to pursue (Tang et al., 2012; Frassy et al., 2015). China's Belt and Road Initiative, for example, is an extensive infrastructure development project across some 70 countries globally that, among other things, facilitates more efficient transport of natural resources, such as oil (Laurance and Arrea, 2017). Due to their remoteness, formerly hard-to-reach oil deposits tend to have comparatively higher levels of biodiversity and, correspondingly, greater vulnerability to anthropogenic disturbance (Dou et al., 2004b; Sovacool, 2007; Ramirez and Mosley, 2015). Consequently, future oil extraction presents a series of risks to the environment and biodiversity.

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The process of extracting oil is inherently complex and time-intensive. The exploration phase, in which potential new sources of oil are geologically surveyed and appraised, can take between five and 15 years to complete (Tsui, 2011). On site during this phase, seismic surveys are undertaken and exploratory wells are dug, with roads and other infrastructure built as needed (Kityo, 2011; Abas et al., 2015). Unconventional oil projects, such as tar sands or shale oil plays, may require longer exploration phases due to the particular difficulties of extracting these types of oil (Chilingarian, 1978). Once government contracts and permits are signed, the project can move into the development phase, in which the limited extraction apparatus, treatment sites, and other infrastructure are expanded to prepare for commercial production. This can take between four and 10 years (Polus and Tycholiz, 2016). When complete, oil development then enters the extraction phase, producing barrels of oil for as long as the deposit remains commercially viable. The extraction phase is also where infrastructure is developed to store and transport recovered oil on vehicles, ships, and via pipelines. After this, when the formation runs dry of oil or it is no longer cost-effective to continue extraction, the project enters the abandonment phase in which companies decommission the extraction sites in line with the local regulation (Barclay et al., 2001). Depending on the strength of regulation and any requirement for environmental monitoring, this phase can take decades (Darko, 2014).

Perhaps because of this complexity, time-scales, and the simple fact of working with a hazardous materials, the oil extraction process is susceptible to mishaps (Gill et al., 2012; Lee and Jeong-Hwan, 2014; Weszkalnys, 2014). The Deepwater Horizon oil leak, for example, resulted in the discharge of over three million barrels of crude oil into the Gulf of Mexico in 2010 (Ladd, 2012; Cope et al., 2013). This leak harmed and killed untold numbers of animals, devastated the livelihoods of people dependent upon the Gulf, and continued to impact ecosystem and human health many years thereafter (Drescher et al., 2014; Cherry et al., 2015). Similarly, the 1989 Exxon Valdez oil spill in Prince William Sound, Alaska demonstrated what could go wrong when transporting oil through sensitive habitats (Peterson et al., 2003; Atlas and Hazen, 2011). An oil tanker ran aground on Bligh Reef and leaked 42 million liters of crude oil covering approximately 750 km of coastline in Alaska (Garrott et al., 1993; Paine et al., 1996; Peterson et al., 2003). Hundreds of harbor seals (*Phoca vitulina*), thousands of sea otters (*Enhydra lutris*), an estimated 250,000 seabirds, and inestimable numbers of marine invertebrates died via drowning, smothering, hypothermia, and poisoning (Garrott et al., 1993; Paine et al., 1996; Peterson et al., 2003). These accidents show that, though oil extraction may address the energy crisis, it is an important concern for biodiversity conservation (Cleveland and Kaufmann, 2003; Osti et al., 2011; Butt et al., 2013; Ruoppolo et al., 2013).

Current rates of biodiversity loss demonstrate that the world is in the midst of the sixth mass extinction event and the first principally accelerated by human actions (Wake and Vredenburg, 2008; Barnosky et al., 2011; Pievani, 2014; Casetta et al., 2015; Newbold et al., 2016). With global energy crises leading to oil exploration in sensitive habitats, there is a need to understand the potential effects of these activities on biodiversity. Though these effects have been studied in marine ecosystems, the lack of an understanding of these effects on terrestrial wildlife presently hampers efforts to guide decision-making (Butt et al., 2013). To quantify the prevailing knowledge gaps, we conducted a review assessing the effects of oil extraction on terrestrial wildlife globally. We documented these effects across the four phases of oil extraction including exploration, development, production, and abandonment. We discuss the knowledge gaps that became evident across these phases and among the species and places where oil extraction presently occurs. We discuss the implications of our results for the decisions that will ultimately be made to extract oil in biodiverse-rich regions in the context of Murchison Falls National Park (located at 1.9289° N, 31.6644° E) and the surrounding conservation area (MFCA), Uganda where active oil extraction is ongoing. This study represents the first of its kind to link a review of oil exploration effects on terrestrial wildlife with an ecological system currently featuring oil development.

2. Material and methods

2.1. Literature review

We conducted a literature review (completed in June 2019) to identify studies assessing the impacts of oil extraction on terrestrial wildlife around the world. We elected to exclude Ecological Impact Assessments (EIA), which are a common prerequisite for oil extraction, because EIAs are neither peer-reviewed nor broadly accessible to science and society, thus their generalizability is limited. Moreover, their rigor can be doubted as public scrutiny alone, by which EIAs are judged, has been shown to be inadequate and unreliable for documenting the impacts of oil extraction when compared to scientific peer-review (Cashmore, 2004; Naser, 2015; Nzeadibe et al., 2015; Loomis and Dziedzic, 2018).

To ensure a broad coverage of the peer-reviewed literature, we conducted this review in bibliographic subject databases indexing general science, wildlife studies, engineering, and geology. In implementing this search, we used the Web of Science Core Collection, Wildlife and Ecology Studies Worldwide (WESW), and Engineering Village, which included both the GEOBASE and Compendex databases. Within each database we used identical search terms (*oil extraction* AND *wildlife*) to maintain consistent results. The search in Web of Science and WESW was conducted as a basic search of the *topic field*. We conducted the search in Engineering Village across *all fields*. We compared the results of the different literature searches and eliminated duplicate references captured from more than one search engine. We then read each study and eliminated from consideration those that had objectives that were inconsistent with our analysis (i.e., did not directly involve assessments of terrestrial wildlife impacts from oil extraction). Following this step, we read all resulting studies and categorized the effects documented on terrestrial wildlife across the four phases of oil extraction including exploration, development, production, and abandonment (Davidsen et al., 1990).

3. Results

Our literature review returned 106 peer-reviewed studies on oil extraction and terrestrial wildlife, of which 29% ($n = 31$) were consistent with the objectives of our analysis. Several studies assessed terrestrial wildlife effects across more than one oil extraction phase. Over half of these studies (61%, $n = 19$ of 31) documented the effects of the oil development phase on terrestrial wildlife, 10 studies (32%) covered the production phase while eight studies (26%) addressed the extraction phase and one (3%) covered the abandonment phase (Fig. 1). There were no studies, however, that concurrently reported terrestrial wildlife effects across all four oil extraction phases. These studies evaluated effects on amphibian, avian, and mammal species and were largely concentrated in North and South America (Fig. 2).

Among this literature, we detected seven processes of oil extraction that have been found to have effects on terrestrial wildlife including road development, seismic surveys, hydraulic fracturing, extraction disturbance, infrastructure development, oil well establishment, and contamination. Across all four oil extraction phases, road development was the most-commonly studied category occurring in 42% ($n = 13$ of 31) of all studies. Infrastructure development was the next most-commonly investigated category (23%, $n = 7$ of 31) followed by seismic surveys and extraction disturbance (16%, $n = 5$ of 31 each). Oil well establishment and contamination were categories among three studies (10%) each and hydraulic fracturing was assessed in two studies.

The vast majority of the effects of oil extraction on terrestrial wildlife were negative and involved changes to behavior, occurrence, movement, and population abundance, among others (Tables 1 – 3). These

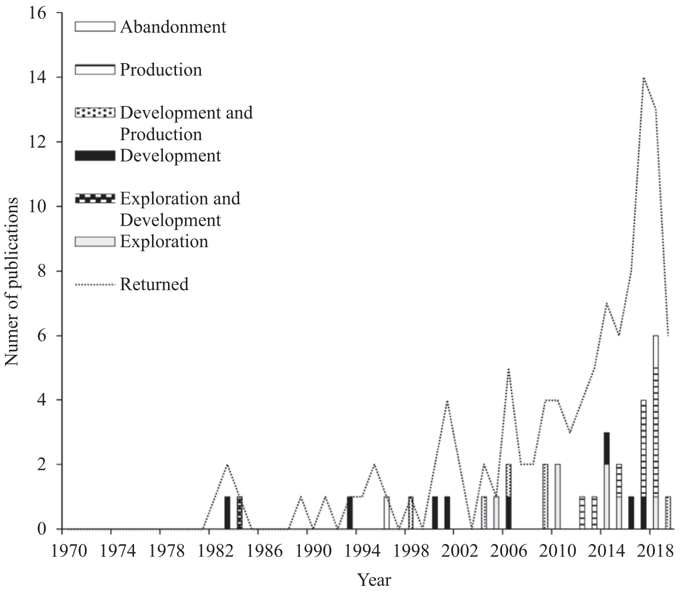

Fig. 1. Temporal growth in the number of peer-reviewed studies, published between 1970 and 2019, documenting the effects of oil extraction, across the exploration, development, production, and abandonment phases, on terrestrial wildlife.

effects were observed across the exploration (Table 1), development (Table 2), and production (Table 3) phases. There was only one study that evaluated terrestrial wildlife effects in the abandonment phase which detected a positive effect in successional regrowth of primary productivity in habitat formerly disturbed by oil development and higher densities of herbivores (see Fuda et al., 2018). Among this literature, there was only one other study that detected a positive effect. That was an indirect effect of higher nest success rates for prairie chickens (*Tympanuchus phasianellus*) nesting closer to oil pads that predators avoided because of human disturbance (Burr et al., 2017; Table 3). The majority (3/5) of the studies that found no detectable impact of oil extraction on terrestrial wildlife were partly sponsored by major oil companies. Studies by Cronin et al. (2000) and Cronin et al. (1998) were partly sponsored by BP Alaska while Johnson et al. (2019) was partly sponsored by ConocoPhillips.

4. Discussion

Via this review, we investigated the effects of oil extraction on terrestrial wildlife globally. This research was largely positioned in the Americas, particularly Canada and the United States. At the same time, only a handful of studies undertook research in Africa, while no studies were returned for Asia or Oceania. The lack of peer-reviewed studies herein is particularly troubling as these areas host approximately 11% of the world's known oil reserves, 24% of those outside the Middle East (OPEC, 2022), and comparatively high rates of species richness and endemism (Butt et al., 2013). Thus, this information gap may hinder decision making relating to oil extraction in light of biodiversity recovery. We also found the research in our review to be taxonomically biased. From our sample, 22 studies (71%) focused on mammals, while five studied birds (16%), and just one study (3%) assessed the potential implications of oil extraction on amphibians. Even among the studies that assessed mammals, however, nearly a quarter were dedicated to just one species: the caribou (*Rangifer taradus*). At the same time, we found no studies that explored oil effects on reptiles ~~or plants~~. Further, over half of the studies (61%, $n = 19$ of 31) documented the effects of the oil development phase on terrestrial wildlife, 10 studies (32%) covered the production phase while eight studies (26%) addressed the extraction phase. Only one (3%) covered the abandonment phase (Fig. 1). This demonstrates that a considerable amount of additional research is required to quantify the effects of oil extraction on the ecology and conservation of a diversity of terrestrial wildlife globally.

Road development for transporting oil was the most-commonly studied effect, occurring in 42% of studies returned by our search. Many species of terrestrial wildlife experienced negative impacts on population size and activity levels from roads. Several species faced direct pressure from increased poaching that was facilitated by roads, while others had higher levels of mortality from traffic collisions (Tables 1–3). Perhaps as a consequence, some species actively avoided roads or, like wolverines (*Gulo gulo*), increased their movement when near roads (Scrafford et al., 2018). Ocelots (*Leopardus pardalis*), however, were found to have experienced little impact from roads. For instance, no statistically significant difference was detected in ocelot activity patterns or density in areas with road development when compared to those without (Kolowski and Alonso, 2010). A similar conclusion was drawn by Noel et al. (2004), who found no difference in the density of adults and calf caribou in the area of a road, before and after its construction. When analysing the same data, however, Joly et al. (2006) concluded that there had been a 72% drop in abundance of calving caribou after road construction. Herein, the authors suggested that the caribou had responded to the road development by shifting the calving area of the herd south (Dyer et al., 2001).

Elephants (*Loxondata africana*), chimpanzees (*Pan troglodytes*), and black bears (*Ursus americanus*) were found to change their movements and behavior in relation to seismic surveys. Ocelots, once again, showed no detectable impact. Similarly, the installation of oil wells was found to disrupt terrestrial wildlife habitat and to concentrate human pressure on key wildlife areas (Tables 2 and 3), sometimes acting as ecological traps (Atuo et al., 2018). However, northern bobwhites (Dunkin et al., 2009) and black bears (Tietje and Ruff, 1983) were found to show no detectable change in home range patterns with respect to the presence of

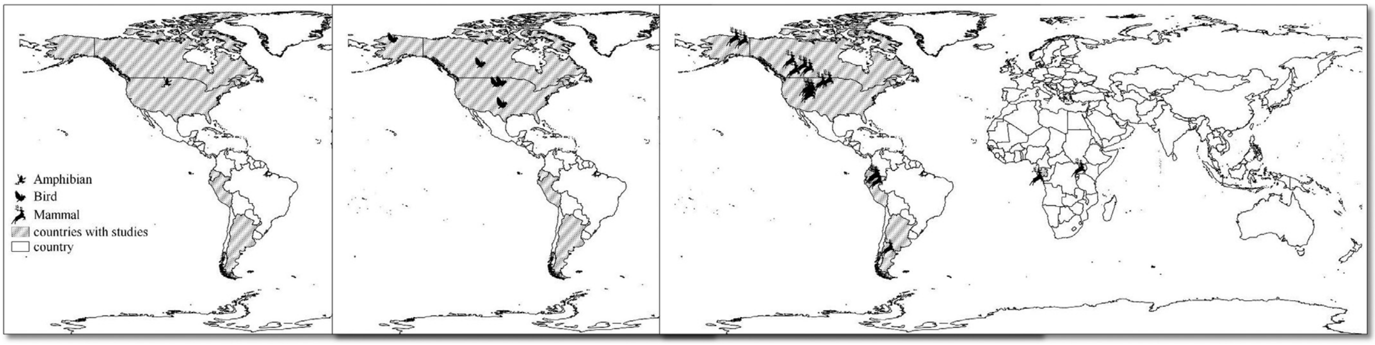

Fig. 2. The spatial extent of the study areas featured in the peer-reviewed studies, published between 1970 and 2019, documenting the effects of oil extraction, across the exploration, development, production, and abandonment phases, on terrestrial wildlife.

Table 1
The peer-reviewed studies, published between 1970 and 2019, documenting the effects of oil extraction, across the exploration phase, on terrestrial wildlife.

Oil activity	Main effect	Common name	Species	Reference
Road development	Detected guanaco population decline from road development due to increased poaching.	Guanaco	*Lama guanicoe*	Radovani et al., 2015
Seismic surveys	Found an indirect negative effect on landscape use by grizzly bears associated with seismic survey cutlines that increased distanced between suitable vegetation patches.	Grizzly bear	*Ursus arctos*	Linke et al., 2005
Seismic surveys	No detectable impact of seismic surveys on ocelot activity and population size.	Ocelot	*L. pardalis*	Kolowski and Alonso, 2010
Seismic surveys	Detected African elephant avoidance of seismic survey areas at several spatial scales.	African elephant	*Loxondata africana*	Rabanal et al., 2010
Seismic surveys	Detected chimpanzee avoidance of seismic survey areas at small and intermediate scales.	Chimpanzee	*Pan troglodytes*	Rabanal et al., 2010
Seismic surveys	Found that Black bears prefer to cross forested landscapes using seismic lines. This may allow easier location of ungulate prey, driving prey population sizes down.	Black bear	*Ursus Americanus*	Tigner et al., 2014
Hydraulic fracturing	The highest density of otters was detected in an area with the lowest disturbance from hydraulic fracturing.	River otter	*L. canadensis*	Godwin et al., 2015
Extraction disturbance	Wildlife were displaced from suitable habitat, elimination of critical unique habitats, interference with free movement of wildlife, direct harassment of wildlife, attraction of carnivores and scavengers to food waste areas, and local pollution of biological systems	Numerous species of large mammals		Klein, 1984

oil wells. Contamination, as would be suspected, had negative effects on terrestrial wildlife (Table 3). Hydraulic fracturing, which itself can lead to contamination, was found to have led to habitat destruction, oil and noise pollution, and the introduction of invasive species (Olive, 2018). River otters (*Lontra canadensis*), for example, were found to avoid areas of hydraulic fracturing disturbance (Godwin et al., 2015). The suggestion of ubiquitous negative effects from these processes prompts an acute need to understand their effects on more species. From the evidence collected in this review, we can conclude that the impact of oil extraction on terrestrial wildlife globally is understudied. We detected localised pockets of research inquiry in relation to certain oil extraction phases, certain species, and to certain regions of the world. However, a more comprehensive understanding of generalizable principles in required to inform progressive decision making.

To illustrate the importance of broader and deeper research on the impact of oil extraction on terrestrial wildlife, we will consider ongoing efforts in East Africa as a case study. The Albertine Rift Valley has vast oil deposits situated in landscapes with some of the highest levels of biodiversity globally (Osti et al., 2011; Augé, 2015; Edmunds, 2015), several of which are in the early stages of oil exploration and extraction (Dou et al., 2004a, 2004b; Uganda, 2008). For example, oil extraction is presently underway inside of MFCA, Uganda which sits at the northern extent of the Albertine Rift and is home to 56 species listed as threatened and 126 further listed species, according to the IUCN (Table 4). The 2019 Uganda Wildlife Statute, section 6-h, presently permits oil exploration inslude of wildlife conservation areas in the country proividing that the effects to wildlife and the environment are controlled and monitored. Although the existence of oil inside the park had been known for more than a century, *Energy Africa* drilled the first test well in 2006 confirming the presence of commercially-viable quantities of oil (Anderson and Browne, 2011; Van Alstine et al., 2014). In response, the Ugandan government partitioned the areas with potential for oil into three oil blocks (Uganda, 2008; AfDB, 2009). More than 50 oil exploration wells were drilled in these blocks, mostly within the boundaries of MFCA (Fig. 2; Kityo, 2011). Results of two-dimensional (2D) and three-dimensional (3D) seismic tests estimated that 3.5 billion barrels of recoverable oil were in and around MFCA (Watkins, 2010; Anderson and Browne, 2011; KPMG reference; Augé, 2015) making it one of the largest discoveries of oil anywhere in the world in modern times (Anderson and Browne, 2011). The development had its final investment agreement approved in 2022, with expectations of commercial production beginning in 2025 (Offshore Technology, 2022). Concurrently, since 2013, the Ugandan government has been in the process of establishing a 30,000 barrel-per-day oil refinery 100 km south of MFCA (Ojambo et al., 2013; Polus and Tycholiz, 2016). Once operational, this oil refinery will process crude oil piped from MFCA. Furthermore, to transport this crude oil to a deepwater port, the East African Crude Oil Pipeline (EACOP), an almost 1500 km line heading south through Uganda and then cutting across the full length of Tanzania before reaching its terminus along the Indian ocean is being proposed. This pipeline is presently being debated with many highlighting the potential ecological catastrophes that could occur if sections of the pipeline experienced an oil leak (Bogrand et al., 2020; Ogwang and Vanclay, 2021).

Using the information collected from our review, we consider the impacts of oil extraction on wildlife in MFCA to identify where further research is needed. As has been found in studies in South America (Suárez et al., 2013; Espinosa et al., 2014), road development for oil infrastructure and transportation could enable natural resource extraction including the poaching of terrestrial wildlife inside of the protected area (Kotze, 2002). Concurrently, a multi-lane tarmac road has been built directly through the MFCA. Consequently, the speed with which vehicles can travel has increased and so too as the frequency and severity of vehicle strikes with wildlife. Susceptibility of wildlife inside of MFCA to poachers and vehicle strikes could be quite high given that many roads in the park are thin dirt tracks used predominantly by tourists. As wildlife have not historically needed to avoid roads in MFCA and may, thus, be more vulnerable (Fuda et al., 2018).

Although much of the seismic surveying of the oil deposits in MFCA has now been completed, given their high sensitivity to tremors, sound, and chemical signals elephants were to generally avoided seismic sites (Mudumba et al., 2012; Plumptre et al., 2014, 2015). There is also evidence that chimpanzees were negatively affected by seismic surveys (Rabanal et al., 2010). Given the proposed construction of the EACOP, research on the effects of the pipeline construction and crude oil transfer on wildlife will need to be assessed. While there is some evidence that elephants can become accustomed to oil extraction activities, especially with sound management strategies implemented by the oil companies (Munshi-South et al., 2008; Kolowski et al., 2010), disturbance of both of these species can lead elephants and chimpanzees into human villages, potentially increasing human-wildlife conflict (Mudumba et al., 2012; Plumptre et al., 2014, 2015).

Human-wildlife conflict is perhaps the most influential and understudied of the potential impacts of oil extraction on wildlife in MFCA. Unlike many of the study sites used in the research collected by this review, MFCA is surrounded by a relatively high-density human population (Hartter et al., 2016). As discussed above, roads and seismic

Table 2
The peer-reviewed studies, published between 1970 and 2019, documenting the effects of oil extraction, across the development phase, on terrestrial wildlife.

Oil activity	Main effect	Common name	Species	Reference
Road development	Construction of roads led to local depletions of spider and howler monkey populations.	Howler monkey; spider monkey	*Ateles belzebuth; Alouatta seniculus*	Franzen, 2006
Road development	Detected a two-fold increase in bushmeat poaching and an expansion in the spatial extent of poaching areas in response to road development.	Numerous faunal species		Espinosa et al., 2014
Road development	Detected no significant difference in ocelot density or activity between areas with road development and those without.	Ocelot	*L. pardalis*	Salvador and Espinosa, 2016
Road development	Found no difference in the density of adults and calves near a road before and after its construction. Argued that there was no evidence that the overall decline in population size was related to road development.	Caribou	*Rangifer tarandus caribou*	Noel et al., 2004
Road development	Argued that an oil firm's provision of transportation subsidies on their roads to local indigenous peoples induced the emergence of a wild meat market and higher rates of hunting.	White-lipped peccary; paca; wooly monkey	*Tayassu pecari; Cuniculus pac; Lagothrix poeppigii*	Suárez et al., 2009
Infrastructure and road development	72% drop in abundance of calving caribou within oilfield after road construction. Main calving area for herd shifted to south of oilfield.	Caribou	*Rangifer tarandus*	Joly et al., 2006
Infrastructure and road development	Dispersed oil extraction structures, fences, and other low-density infrastructure had broadly neutral effects on area use by bobwhites.	Northern bobwhite	*Colinus virgianus*	Dunkin et al., 2009
Infrastructure and road development	Caribou avoided seismic lines, roads, and well sites with increasing intensity, following the increase in levels of human activity across these structures.	Caribou	*Rangifer tarandus caribou*	Dyer et al., 2001
Infrastructure and road development	Pronghorns avoid roads and sites of human development but not oil and gas wells located in their preferred habitat type.	Pronghorn	*Antilocapra americana*	Christie et al., 2017
Infrastructure development	Population size, sex and age structures, and landscape use were not found to differ significantly pre- and during development	Black bear	*Ursus americanus*	Tietje and Ruff, 1983
Extraction disturbance	Increased likelihood of disturbance of denning polar bears.	Polar Bear	*Ursus maritimus*	Amstrup et al., 1993
Infrastructure development, extraction disturbance, and hydraulic fracturing	Fracking and horizontal drilling has induced habitat destruction, oil and noise pollution, invasive species, and road infrastructure. Each of these have negatively impacted local fauna.	Numerous faunal species		Olive, 2018
Oil well establishment	No detectable population-level impact of oil and gas fields. Population size increased fourfold during development period.	Caribou	*Rangifer tarandus*	Cronin et al., 2000
Oil well establishment	No detectable herd-level negative impacts of development. Suggest that oil fields can provide protection from hunting and insect pests	Caribou	*Rangifer tarandus*	Cronin et al., 1998
Oil well establishment	Found no evidence that oil development displaced broods or nests	Yellow-billed loons	*Gavia adamsii*	Johnson et al., 2019

Table 3
The peer-reviewed studies, published between 1970 and 2019, documenting the effects of oil extraction, across the production phase, on terrestrial wildlife.

Oil activity	Main effect	Common name	Species	Reference
Road development	Road construction facilitated hunting, agriculture and urbanization which negatively affected the mammal community.	Numerous faunal species		Vanthomme et al., 2013
Road development	Wolverines avoided and increased speed near roads, of which construction was shown to degrade habitats.	Wolverine	*Gulo gulo luscus*	Scrafford et al., 2018
Infrastructure and road development	Increased densities of wells and roads were associated with decreased abundance of pronghorns, likely driven by traffic collisions and habitat fragmentation.	Pronghorn	*Antilocapra americana*	Christie et al., 2015
Infrastructure development	Gravel oil pads acted like ecological traps: killdeer preferred to nest in oil pads but nests were more likely to fail.	Killdeer	*Charadrius vociferus*	Atuo et al., 2018
Extraction disturbance	Presence of energy developments allowed for higher nest success rate in more developed area by reducing predation but indirectly lead to increased predation in adjacent areas.	Prairie chickens	*Tympanuchus phasianellus*	Burr et al., 2017
Extraction disturbance	Reuse of nest sites was lower in higher oil extraction intensity areas. Longer term population declines were predicted.	Ferruginous hawk	*Buteo regalis*	Wiggins et al., 2017
Contamination	Wildlife were exposed to oil-polluted soils and river sediments.	Numerous faunal species		Rosell-Mele et al., 2017
Contamination	Abundance of amphibians declined with greater concentrations of chloride. Effect was particularly strong near older wells.	Numerous amphibian species		Hossack et al., 2018
Contamination	Four species, important for local indigenous people's diets, were found to be consuming oil-contaminated soils and water.	Tapir; paca; red-brocket deer; collared peccary	*Tapirus terrestris; Cuniculus paca; Mazama americana; Peccary Tajacu*	Orta-Martinez et al., 2018

Table 4
The count of species in taxonomic groups and levels of International Union for Conservation of Nature (IUCN) protected status inhabiting Murchison Falls Conservation Area that could potentially be affected by oil extraction. Data used for the table was derived from the Uganda Redlist Report 2015.

	Taxonomic group						
IUCN status	Mammals	Birds	Reptiles	Amphibians	Fish	Plants	Total
Threatened							56
Critically endangered	3	4	1	0	1	0	9
Endangered	2	6	0	0	4	6	18
Vulnerable	3	18	1	1	2	4	29
Other categories							126
Data deficient	5	3	7	4	0	0	19
Near threatened	3	6	5	1	0	0	15
Least concern	38	7	29	16	0	0	90
Not applicable	0	0	1	1	0	0	2

surveys have been shown to induce avoidance behaviours in wildlife in MFCA. So too have active oil pads, which have been found to be avoided by lions (*Panthera leo*; Mudumba and Jingo, 2015), elephants, buffaloes (*Syncerus caffer*), giraffes (*Giraffa camelopardalis*), some smaller mammals, and many birds (Prinsloo et al., 2011). Increased human-wildlife interaction could occur in areas near oil activity centers (Fuda et al., 2018) and perhaps even with local communities surrounding MFCA (Chiyo and Cochrane, 2005; Rode et al., 2006; Naughton-Treves, 2008; Mudumba et al., 2012; Plumptre et al., 2014, 2015). Further research on the prevalence of human-wildlife conflict in MFCA is essential as the oil construction phase ends and commercial production begins.

We also identify that potential oil contamination is an important area of future research. While none of the studies in our review documented research on contamination in Africa, there are two reasons why this dearth of research is concerning. First, while the oil development in MFCA will not implement hydraulic fracturing (which can produce large quantities of polluted water), the project will use water injection wells to improve ease of access to oil (Michael and Sonia, 2019). Evidence from our review suggests that amphibians, present in

MFCA (Table 4), may be particularly vulnerable to water contamination (Hossack et al., 2018). There is concern for freshwater contamination as the pipeline joining MFCA oil pads to the central network crosses ecologically-important riverine habitat used as a watering site by vast numbers of wildlife (Fuda et al. 2018). Second, contamination of terrestrial wildlife at lower trophic levels can lead to bioaccumulation of toxic compounds in consumers up the trophic system (Kaukeinen, 1982). The African white-backed vulture (*Gyps africanus*) is a species that is particularly at risk of bioaccumulation and is nationally listed as critically endangered. The lappet-faced (*Torgos tracheliotos*) and Rüppell's griffon vulture (*Gyps rueppelli*) are both listed as vulnerable to extinction (Conservation, 2016). The issue of contamination, therefore, must be closely monitored across trophic levels. We did detect some evidence that terrestrial wildlife were not negatively impacted by the oil abandonment. Giraffes, for example, were found to have a higher density in areas of restored oil pads, perhaps attracted to primary productivity regrowth (Fuda et al., 2018). Additional research across species is needed to identify how various terrestrial wildlife respond to the oil abandonment phase.

In conclusion, our current understanding of the impact of oil extraction on terrestrial wildlife globally is limited by studies that are geographically clustered and restricted to certain species and specific phases in the process. Additional research on the phases of oil extraction (exploration, development, production, and abandonment) and across a broader array of terrestrial species globally is required to guide decisions to confront the respective energy and biodiversity crises. Importantly, decisions to exploit oil reserves inside of protected areas depend upon societal values for meeting energy demands and those for conserving biodiversity. Better understanding of the linkages between biodiversity and the functioning of the natural world, including connecting to the climate crisis, could importantly inform these decision-making processes. Our study also identified important knowledge gaps within these dialogues including how oil development activities may increase contact points between humans and wildlife potentially leading to conflict. Preliminary evidence suggests that these dynamics are presently occurring within MFCA with scalable principles, pending detailed exploratory research necessary to elucidate these patterns, for other systems around the world. In summary, our review makes clear that additional research is required to provide the weight of evidence necessary to make these complicated decisions with implications for energy and biodiversity.

Data availability statement

Data is available through Radovani et al., 2014; Linke et al., 2005; Kolowski and Alonso, 2010; Rabanal et al., 2010; Tigner et al., 2014; Godwin et al., 2015; Klein, 1984; Franzen, 2006; Espinosa et al., 2014; Salvador and Espinosa, 2016; Noel et al., 2004; Suárez et al., 2009; Joly et al., 2006; Dunkin et al., 2009; Dyer et al., 2001; Christie et al., 2017; Tietje and Ruff, 1983; Amstrup, 1993; Olive, 2018; Cronin et al., 2000; Cronin et al., 1998; Johnson et al., 2019; Vanthomme et al., 2013; Scrafford et al., 2018; Christie et al., 2015; Atuo et al., 2018; Burr et al., 2017; Wiggins et al., 2017; Rosell-Melé et al., 2018; Hossack et al., 2018; and Orta -Martínez et al. 2018

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.

CRediT authorship contribution statement

Tutilo Mudumba: Supervision, Formal analysis, Methodology, Conceptualization. **Benjamin Stimpson:** Supervision, Data curation, Methodology, Writing – original draft. **Sophia Jingo:** Supervision, Data curation, Methodology, Writing – original draft. **Robert A. Montgomery:** Supervision, Formal analysis, Methodology, Conceptualization.

Data availability

No data was used for the research described in the article.

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