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Assessing early oil industry awareness of the impacts of fossil fuels on coral reefs using a novel AI agent

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Global warming threatens to eradicate Earth's tropical corals. As legal interventions addressing climate change expand, fossil fuel companies' historical awareness of their products' damaging effects is increasingly important. We searched historical documents using a large-language-model-based agent, finding that carbon majors were aware by the 1980s of prospective impacts of fossil fuels on corals from ocean acidification, marine heatwaves, sea-level rise, and intensified storms and later funded efforts downplaying such impacts.

The world's tropical coral reefs are under imminent threat of collapse from global warming. Living corals have declined by approximately 50% worldwide since the 1990s, with global warming now the greatest threat to future survival¹. Global warming kills corals primarily through increased ocean temperatures and more frequent and intense marine heatwaves, which cause coral bleaching (loss of coral symbionts), exacerbated by ocean acidification (from increased carbon dioxide levels), which weakens coral health, and intensified storms (from increased sea surface temperatures), which physically destroy coral assemblages, all ultimately caused by fossil fuels¹. Approximately one billion people worldwide depend directly on coral reefs for livelihoods, food security, and protection from storms and coastal erosion, and coral reefs provide shelter and nourishment to over 30% of the world's named marine species². Economically, coral reefs provide an estimated 10 trillion USD per year in ecosystem services, including tens of billions of dollars per year in coral reef tourism³, and potential efforts to restore reefs lost over the last decade alone have been estimated to cost around 1 trillion USD². Mass coral bleaching and mortality from marine heatwaves driven by global warming is ongoing⁴. The Intergovernmental Panel on Climate Change (IPCC) predicts mortality of 70–90% of the world's reef-building corals at global warming of 1.5 °C and mortality of more than 99% at 2 °C¹.

Legal interventions may play a critical role in helping to protect the world's coral reefs and associated ecosystems (for example, by securing funding for reef monitoring and rehabilitation) and in compensating affected communities for economic losses associated with climate-change-driven coral impacts. In this context, the history of fossil fuel industry awareness of the foreseeable impacts of climate change on coral reefs is highly relevant. Climate lawsuits against governments, fossil fuel producers,

and other parties have expanded in number and sophistication over the past decade⁵ and have recently cited impacts on coral reefs⁶. Additionally, the 2024 and 2025 advisory opinions from the International Tribunal for the Law of the Sea (ITLOS)⁷ and the International Court of Justice (ICJ)⁸ on climate change clarified, respectively, that greenhouse gases are marine pollutants under the United Nations Convention on the Law of the Sea (UNCLOS) and that best efforts to attain the 1.5 °C warming limit of the United Nations Framework Convention on Climate Change (UNFCCC) Paris Agreement are legally binding on governments under international law, strengthening the basis for legal actions seeking to mitigate global warming and obtain reparations for damages. Research on the fossil fuel industry's internal knowledge of global warming⁹, public-facing denial and minimization of the problem^{10,11}, and false assurances to be solving it¹² has clarified global warming as not only a scientific and technological problem but also one of corporate corruption subject to legal correction and remedy¹³. Such research has so far informed dozens of ongoing legal actions seeking industry accountability for climate change¹⁴.

Searching historical documents using AI

To investigate the fossil fuel industry's historical awareness of global warming's foreseeable impacts on coral reefs, we used the Corporate Litigation and Accountability Research Assistant (CLARA), developed by us and available online¹⁵. CLARA is an agentic retrieval augmented generation (RAG) system that analyzes document collections in response to user prompts by iteratively invoking tools for passage retrieval, entity-relationship exploration, and close document inspection¹⁶. CLARA includes a passage search tool that uses a high-recall hybrid retrieval strategy, which first retrieves a broad set of potentially relevant passages using both retrieval-tuned dense embedding and SPLADE-based learned sparse retrieval^{17,18}. These passages are then combined using reciprocal rank fusion¹⁹, re-ranked using a neural re-ranker, and supplied to a large language model (LLM) for synthesis²⁰. CLARA also includes a graph-based retrieval tool for searching entities and relationships across documents, enabling collection-wide analysis of companies, individuals, topics, locations, dates, and relationships between them²¹. The system can also inspect individual documents in detail, allowing researchers both to search across collections and interrogate particular documents closely, including retrieval of verbatim excerpts. CLARA returns answers with page-specific citations and links to original source documents for manual review. This is the first academic study to utilize CLARA, and we anticipate the system will be useful for research with document collections across a range of subjects. We are currently preparing a fuller technical description of CLARA for publication.

We submitted a series of prompts to CLARA regarding fossil fuel companies' internal, historical awareness of the potential impacts of climate change on coral reefs (see Supplementary Information), searching the University of California, San Francisco Industry Documents Library Fossil

Fuel collection, a leading research collection containing over 14,000 pages of historical fossil fuel industry documents (over 1100 documents), including key documents often discussed by historians of climate science, climate disinformation, and fossil fuels^{11,22}. We began, for example, by asking CLARA, “Can you find where fossil fuel companies internally acknowledged the impacts of climate change on coral reefs?” We verified results returned by CLARA by reviewing original source documents cited in each relevant answer. Even with manual verification and interpretation of documents, we found CLARA significantly increased the efficiency of research compared to traditional keyword search methods. Moreover, CLARA’s search architecture provided robustness to variations in nomenclature over time and across documents, such as ocean acidification often being discussed in terms of carbonate chemistry in earlier documents²³.

Industry awareness in the 1970s and 1980s

With this approach, we identified five documents most clearly describing fossil fuel companies’ awareness of the prospective impacts of their products on coral reefs. First, in 1978, Exxon (now Exxon-Mobil) Research & Engineering scientist James Black, in a presentation to management discussing research on carbon dioxide and climate change being considered for funding by the U.S. Department of Energy, noted the agency’s interest in “determin[ing] whether shallow water carbonates are dissolving because of CO₂ levels,” with a list of the Department of Energy’s research priorities including, “ARE SHALLOW WATER CARBONATES DISSOLVING[?]”²⁴ This document evidences Exxon’s (now ExxonMobil’s) awareness by 1978 that excess atmospheric carbon dioxide from fossil fuels could cause ocean acidification and dissolution of shallow water carbonates such as corals.

Additionally, an internal research memorandum at Exxon (now ExxonMobil), which is undated but which appears to date from around 1982–1984 from its reference list and its observation that then-current global carbon dioxide emissions from fossil fuels totaled around 18 billion metric tons per year²⁵, discussed how to address the high carbon dioxide content of a gas field discovered in the 1970s near the Natuna Islands in the South China Sea²⁶. Exxon scientists Brian Flannery, Andrew Callegari, Bahlin Nair, and Wayne Roberge noted that the gas field contained over 70% carbon dioxide, which if vented to the atmosphere during production would make the field the largest point source of carbon dioxide in the world, which “raise[d] concern with respect to its effect on the CO₂ greenhouse problem”²⁶. As an alternative to atmospheric venting, the scientists modeled the possibility of sparging (injecting into seawater) the produced carbon dioxide at a depth of 140 m but found that doing so would increase ocean acidity over an area of around 1000 km², causing dissolution of aragonite and calcite structures (such as corals), and that the injected carbon dioxide would diffuse to the atmosphere within a decade anyway²⁶. “[T]he chemistry of CO₂ in seawater is well understood,” Exxon’s scientists noted, “and has received much attention recently in the context of the role of the oceans as a sink for atmospheric CO₂ in the CO₂ greenhouse problem”²⁶.

Around the same time, in 1983, Alvin Natkin, a manager at Exxon’s Office of Environmental Affairs, circulated an internal letter in which he noted that subsea disposal of carbon dioxide and hydrogen sulfide from the Natuna gas field would “create[] a zone around the underwater sparger which may be more toxic to marine life” and recommended Exxon carry out a series of studies to evaluate the effects of such subsea disposal on marine life, including “studies ... to resolve whether and to what extent shellfish would be affected in the area by higher carbonate concentrations”²⁷. Natkin advised that directly releasing the gases into the atmosphere would “be the most difficult to ‘sell’ given the rising level of concern in North America and

Europe over the ‘acid’ rain issue and the emergence of the CO₂ ‘Greenhouse Effect’ as a global environmental issue”²⁷.

These documents, although relating to the effects of carbon dioxide injected into the ocean at depth rather than absorbed at the surface due to elevated atmospheric levels, illustrate Exxon’s sophisticated internal understanding that elevated carbon dioxide levels in the ocean could harm calcium-carbonate-based marine organisms.

Similarly, at Shell, a confidential assessment of global warming from the “Greenhouse effect working group” completed in 1986 and issued internally in 1988 discussed the anticipated impacts of ocean acidification from fossil fuels, explaining:

“[I]t is clear pCO₂ [partial pressure of carbon dioxide] in ocean surface water is rising, with a rate comparable to the atmospheric increase. ... The oceanic CO₂ concentration has increased 1–2% over this last century. ... Concurrent slight decrease in pH (attached as 0.06 pH units) will not be measurable effect, as the ocean surface pH varies between 8.0 and 8.3. Further increases of the CO₂ concentration will certainly lead to detectable effects on pH.

If the increasing atmospheric CO₂ causes significant changes in the global climate, indirect effects on primary production can be expected. If there were to be locally increasing cloudiness then this reduces the solar energy reaching the ocean and consequently also the primary production. Any warming of the upper layers [of the ocean] would increase the formation of stable water masses, thereby reducing vertical mixing. The subsequent depletion of nutrients in the euphotic zone will cause a decrease in primary production.

If CO₂ is added to the ocean surface, the pH decreases and the tendency for dissolution of carbonate minerals (e.g., calcite and aragonite), either in bottom sediments or suspended in the water column, increases, thereby increasing both the alkalinity and the total DIC [dissolved inorganic carbon] ... However, CaCO₃ is also a major constituent of shells of calcareous organisms and corals. Particularly in near-shore areas these organisms will be exposed to waters rich in CO₂ and with a low pH. Dissolution of shells and corals and subsequently local but massive deaths of organisms on a local [sic] scale is therefore not unrealistic”²⁸.

The document later lists fifteen “Potential effects of global warming induced by greenhouse gases,” including “Decrease in [ocean] pH” causing an “Increasing tendency of dissolution of carbonate shells (e.g., shellfish), corals and sediments”²⁸. Another section of the report on “Socio-economic implications” of global warming identifies “Acidification of seawater” as an impact, explaining, “Dissolution of CaCO₃ increases with a decreasing pH. Particularly in shallow coastal areas, characterized by high concentration of respiratory CO₂ and a low pH, dissolution of carbonate materials (shells, corals, and sediment) could be quite rapid and result in damage of natural resources and of natural protection of shorelines, and disappearance of complete coral islands”²⁸.

These excerpts show that by 1986, Shell personnel were aware of the potential for “massive deaths of organisms,” including of corals, from ocean acidification caused by fossil fuels.

Finally, the proceedings of the Second North American Conference on Preparing for Climate Change, held in Washington, D.C. in 1988, included discussions of coral bleaching from global warming. The conference was co-sponsored²⁹ by various commercial fossil fuel interests including Texaco (now Chevron), the American Petroleum Institute (which over time has included over one thousand companies as members, including present day carbon majors BP, Chevron, ConocoPhillips, ExxonMobil, Shell, and Total or their predecessors or subsidiaries)³⁰, the American Gas Association (which does not make its membership public), and the Motor Vehicle Manufacturers Association (which included major U.S. automobile

manufacturers such as General Motors, Ford, and Chrysler, and which in 1992 was renamed the American Automobile Manufacturers Association, in 1999 became the Alliance of Automobile Manufacturers, and in 2019 became the Alliance for Automotive Innovation³¹.

One presentation at the conference, by James Hansen and other scientists from the U.S. National Aeronautics and Space Administration (NASA) Goddard Institute for Space Studies and the National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center, reviewed anticipated effects of global warming in regions around the world, noting that “One impact in the Caribbean could be on coral reefs, since many coral populations are unable to survive if water temperatures rise above 30 °C” and that global warming was expected to increase storm intensities, including in the Caribbean³². Another presentation, by George A. Maul from NOAA, surveyed the implications of climate change in the Caribbean, including the potential for sea level rise to outpace coral reef growth, potential increased hurricane activity, and increased ocean temperatures³³. Maul noted that marine organisms in the tropics tend to live close to their maximum thermal tolerance and that global warming of 1.5 °C would raise average summer temperatures to around 30.5 °C over much of the Caribbean, which would affect at least some corals³³. Although Maul suggested that other environmental stresses on corals would be more important than climate change, he warned that “with increased temperature, the likelihood of ‘hot snaps’ [i.e., marine heatwaves] increases; the 1987 Caribbean coral bleaching event was attributed to ‘hot snaps’ by some researchers ... The complexities of the ecosystem could be greatly affected by slight temperature changes,” as well as that “socio-economic effects on tourism” from global warming due to “coral reef mortality” could occur, and that among ecosystems most vulnerable to global warming, coral reefs represented one of the “most critical habitats to be mapped”³³. The conference also included a presentation by David Stoddard from the University of California at Berkeley on the “Implications of climate change for coral reefs and islands, mangrove swamps and wetlands in the Caribbean,” which was not preserved in the available conference proceedings.

These excerpts from the Second North American Conference on Preparing for Climate Change, sponsored by commercial fossil fuel interests (including oil and gas producers and automobile manufacturers), illustrate how the petroleum industry had information available by 1988 that global warming from fossil fuels could injure coral reefs by raising average ocean temperatures, increasing the likelihood of marine heatwaves, and causing more frequent and intense tropical storms.

Like other studies of industry awareness of climate change, our findings reflect the industry’s practice of monitoring the scientific literature and the research and policy communities for threats to the fossil fuel business³⁴. Industry awareness has often predated consensus statements from the IPCC, which was formed only in 1988 and issued its first assessment report in 1990. Scholars have observed that IPCC statements have often erred on the side of downplaying climate change risks³⁵, are directly influenced by commercial and political interests, and tend to lag the scientific literature. The IPCC First Assessment Report in 1990, for example, downplayed the threat to coral reefs from marine heatwaves, stating, “Temperature rise may trigger bleaching events in some corals, but it is expected that the other stresses [...] will be more important”³⁶. A few years later, the 1992 Supplement to the First Assessment Report cautiously acknowledged the threat to reefs, noting, “A new source of information that supports higher sea surface temperatures in many tropical regions over the last decade concerns evidence that the bleaching of tropical corals has apparently increased. Bleaching has been shown to be related (in part) to episodes of sea surface temperature warmer than the normal range of tolerance of these animals, though increasing pollution may be having an influence”³⁷. It was not until

the Second Assessment Report in 1996 that the IPCC fully acknowledged the vulnerability of coral reefs to climate change, warning that “Coral reefs are the most biologically diverse marine ecosystems; they also are very sensitive to climate change. Short-term increases in water temperatures on the order of only 1–2 °C can cause ‘bleaching,’ leading to reef destruction. Sustained increases of 3–4 °C above long-term average seasonal maxima over a 6-month period can cause significant coral mortality,” and that “Increased coral bleaching will occur as a result of a predicted 2 °C increase in average global atmospheric temperature by 2050. [...] No adaptive responses to coral bleaching, even on a regional scale, will be available if average global temperature increases 2 °C by 2050”³⁸. Thus, IPCC statements, while reflecting a broad consensus, do not represent the full range of information available to fossil fuel producers, who often internally acknowledged the impacts of climate change years before they were fully acknowledged by the IPCC.

Disinformation supported by industry

Fossil fuel companies’ subsequent downplaying of the urgency and seriousness of climate change has been documented elsewhere³⁹, but of note here is disinformation regarding coral reefs supported by the industry. In 2012, for example, the Cato Institute (a US-based think tank funded by ExxonMobil, the American Petroleum Institute, the Koch family foundations, Murray Energy, Southern Company, and other corporations and anti-regulatory groups)⁴⁰ published a 200-page report called “Addendum: Global Climate Change Impacts in the United States,”⁴¹ presenting it as a definitive and superior update to a 2009 report from the U.S. Global Change Research Programme (USGCRP) (called “Global Climate Change Impacts in the United States”), which had been a key basis for the U.S. Environmental Protection Agency’s 2009 “endangerment finding” that greenhouse gases threaten public health and welfare and therefore fell within the Agency’s regulatory jurisdiction under the U.S. Clean Air Act⁴². Unlike the USGCRP’s report, the Cato Institute’s report (which featured not only the same title but also nearly identical graphics on the cover) downplayed the existence and seriousness of global warming and the effectiveness and importance of reducing climate pollution, with “key findings” including, “Impacts of observed climate change have little national significance,” “Sea level rise caused by global warming is easily adapted to,” “Life expectancy and wealth are likely to continue to increase,” “Species and ecosystems will change with or without climate change,” and “Policies enacted by the developed world will have little effect on global temperature”⁴¹.

Regarding the impacts of fossil fuels on coral reefs, the Cato report claimed, “The scientific literature ... does not support alarming statements such as that we are in ‘the last decades of coral reefs on this planet ... unless we do something very soon to reduce CO₂ emissions,’ or that ‘reefs are starting to crumble and disappear,’ that ‘we may lose those ecosystems within 20 or 30 years,’ and that ‘we’ve got the last decade in which we can do something about this problem’ [internal citations omitted]”⁴¹. In discussing sea level rise, the report reassured that “Coral reefs, for example, evolved and their compositions changed over millennia as new reefs grew while older ones were submerged in deeper water [from past changes in sea level]. So while there have been ecological changes, it is unknown whether the changes were for better or worse. ... When it is generally assumed that an ecological change is necessarily worse for man and nature, that is theology, not reason.”⁴¹. Regarding coral bleaching: “there are a number of compelling observational reasons indicating that global warming is not the threat that it is feared to be. There is substantial documentation of severely bleached corals not only surviving but thereafter exhibiting various degrees of phenotypical acclimation and/or genetic adaptation to subsequent episodes of equally severe or even stronger warming”⁴¹. In discussing ocean

acidification, the report cited a study finding no change in ocean pH from 1708 to 1988 (sidestepping the period of greatest fossil fuel pollution) and even suggested that warming might increase coral growth⁴¹. “Similar findings are ubiquitous,” the Cato Institute’s report reassured, “showing increasing rates of coral calcification in the face of rising temperatures and atmospheric CO₂ concentrations”⁴¹.

These false and misleading reassurances directly contradicted the conclusions of the IPCC’s Fourth Assessment Report, published years earlier in 2007, which contained extensive warnings of the observed and expected impacts of climate change on coral reefs, including from increased sea surface temperatures, ocean acidification, and intensified storms⁴³. The Report’s Working Group II Contribution (on impacts, adaptation, and vulnerability), for example, contained the word “coral” over 700 times and warned that “Many studies incontrovertibly link coral bleaching to warmer sea surface temperature [internal citation omitted] and mass bleaching and coral mortality often results beyond key temperature thresholds. Annual or bi-annual exceedance of bleaching thresholds is projected at the majority of reefs worldwide by 2030 to 2050 [internal citations omitted]”⁴³. The report repeatedly identified coral reefs as one of the world’s most vulnerable ecosystems in the face of global warming, starkly summarizing the scientific literature as predicting “All coral reefs bleached” below 2 °C warming and “Extinction of remaining coral reef ecosystems” globally around 3 °C warming⁴³.

Conclusion

In sum, review of over 14,000 pages of historical documents pertaining to fossil fuel companies and global warming, assisted by a novel AI agent we developed, shows that Exxon (now ExxonMobil) by 1978 was aware of the potential for ocean acidification from fossil fuels to damage coral reefs and by around 1982 had a sophisticated internal understanding of how elevated carbon dioxide levels could increase ocean acidity and dissolve calcium-carbonate-based organisms, that Shell by 1986 predicted that ocean acidification from fossil fuels could cause “massive deaths of organisms” and “disappearance of complete coral islands”, and that numerous fossil fuel companies (including through the American Petroleum Institute) by 1988 had notice of the potential for increased ocean temperatures and marine heatwaves to damage coral reefs under global warming of 1.5 °C. We find that even after the IPCC extensively warned of the imminent, existential threat to coral reefs from global warming, fossil fuel companies continued to fund disinformation downplaying the threat. Our findings align with and build upon the scholarly literature on climate disinformation and obstruction, further detail the history of climate denial, deception, and delay from fossil fuel producers, contextualize the ongoing destruction of coral reefs from global warming and ocean acidification, and may inform legal and policy efforts to protect corals, seek compensation for reef damage, and define the liabilities and responsibilities of fossil fuel producers as they cause the collapse of the world’s tropical coral ecosystems.

Data availability

No datasets were generated or analyzed during the current study.

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Author contributions

B.F. supervised the development of CLARA, conducted the research, and drafted the manuscript. M.P. and J.R. developed CLARA and helped revise the manuscript.

Competing interests

B.F. is a testifying and/or consulting expert for plaintiffs in ongoing and potential climate-change-related legal actions, including those concerning coral reefs. The other authors declare no competing interests.

Additional information

Supplementary information The online version contains supplementary material available at <https://doi.org/10.1038/s44183-026-00215-z>.

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