Conservation Biology

Review

Emerging conservation challenges and prospects in an era of offshore hydrocarbon exploration and exploitation

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Abstract: *Globally, extensive marine areas important for biodiversity conservation and ecosystem functioning are undergoing exploration and extraction of oil and natural gas resources. Such operations are expanding to previously inaccessible deep waters and other frontier regions, while conservation-related legislation and planning is often lacking. Conservation challenges arising from offshore hydrocarbon development are wide-ranging. These challenges include threats to ecosystems and marine species from oil spills, negative impacts on native biodiversity from invasive species colonizing drilling infrastructure, and increased political conflicts that can delay conservation actions. With mounting offshore operations, conservationists need to urgently consider some possible opportunities that could be leveraged for conservation. Leveraging options, as part of multi-billion dollar marine hydrocarbon operations, include the use of facilities and costly equipment of the deep and ultra-deep hydrocarbon industry for deep-sea conservation research and monitoring and establishing new conservation research, practice, and monitoring funds and environmental offsetting schemes. The conservation community, including conservation scientists, should become more involved in the earliest planning and exploration phases and remain involved throughout the operations so as to influence decision making and promote continuous monitoring of biodiversity and ecosystems. A prompt response by conservation professionals to offshore oil and gas developments can mitigate impacts of future decisions and actions of the industry and governments. New environmental decision support tools can be used to explicitly incorporate the impacts of hydrocarbon operations on biodiversity into marine spatial and conservation plans and thus allow for optimum trade-offs among multiple objectives, costs, and risks.*

Keywords: deep sea, fossil fuels, hydrocarbons, marine biodiversity, marine conservation, natural gas, offshore drilling, oil

El Surgimiento de Obstáculos y Prospectos para la Conservación en una Era de Exploración y Explotación Marina de Hidrocarburos

Resumen: *A nivel mundial, grandes áreas marinas que son importantes para la conservación de la biodiversidad y el funcionamiento de los ecosistemas están siendo sujetas a la exploración y explotación petrolera y de recursos de gas natural. Dichas operaciones se están expandiendo a aguas profundas previamente inalcanzables y a regiones remotas, mientras que la legislación y la planificación relacionadas con la conservación son escasas. Los retos para la conservación que emergen de la extracción de hidrocarburos marinos incluyen una gama amplia. Estos retos incluyen amenazas para los ecosistemas y las especies marinas causadas por los derrames de petróleo, los impactos negativos sobre la biodiversidad nativa por parte de*

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especies invasoras que colonizan la infraestructura de excavación y extracción, y el aumento de conflictos políticos que pueden retrasar las acciones de conservación. Con el incremento de plataformas petroleras, los conservacionistas necesitan considerar urgentemente oportunidades que podrían tener influencia en la conservación. Estas oportunidades, como parte de las operaciones multimillonarias de hidrocarburos marinos, incluyen el uso de las instalaciones y del costoso equipo de la industria de hidrocarburos profundos y ultra-profundos para la investigación y el monitoreo a grandes profundidades, así como establecer nuevos fondos para la investigación, las prácticas y el monitoreo de la conservación, y también para esquemas ambientales de compensación. La comunidad de la conservación, que incluye a los científicos de la conservación, debería involucrarse en las fases tempranas de la planificación y exploración, y permanecer involucrada a lo largo de las operaciones, para así influir en la toma de decisiones y promover el monitoreo continuo de la biodiversidad y los ecosistemas. Una pronta respuesta a los desarrollos marinos de petróleo y gas por parte de los profesionales de la conservación, puede mitigar los impactos de las decisiones y acciones futuras de la industria y de los gobiernos. Se pueden utilizar nuevas herramientas de apoyo para la toma de decisiones ambientales para incorporar explícitamente, los impactos de las operaciones de hidrocarburos sobre la biodiversidad en la planificación marina espacial y de la conservación, que permita compensaciones óptimas entre múltiples objetivos, costos y riesgos.

Palabras Clave: biodiversidad marina, combustible fósil, conservación marina, excavación petrolera en mar abierto, gas natural, mar profundo, petróleo

Emerging and Current Offshore Hydrocarbon Operations

The majority of undiscovered hydrocarbon reserves and unexploited fossil fuels outside the Middle East are located in deep-sea deposits reaching depths of 4000 m (Ahlbrandt et al. 2003). While the vast depths of many of these deposits have previously prevented commercial exploitation, recent technological advances allow the hydrocarbon industry to venture into increasingly deeper waters and other new frontiers (Pinder 2001; IEA 2013; Merrie et al. 2014). Since 2009, one-third of global oil production and one-fourth of natural gas production has originated from offshore platforms (Maddahi & Mortazavi 2011). This proportion is expected to increase (IEA 2013). In fact, offshore areas comprised nearly 70% of the major oil and gas discoveries worldwide in the first decade of the 21st century (Sandrea & Sandrea 2010). Capital expenditure on deep-water oil and gas is expected to grow by 130% from 2014 to 2018 relative to the preceding 5 years (total $260 billion globally) (Rangi 2014). While steps are being taken to encourage the use of alternative renewable energy sources, there are strong financial incentives to search for marine oil and gas and to lease large marine areas for hydrocarbon operations.

The environmental threats posed by offshore oil and natural gas operations draw much public and media attention. This is especially evident following major oil spills, such as the 2009 Montara well blowout in the Timor Sea off Australia and the 2010 BP Deepwater Horizon oil spill in the Gulf of Mexico (over 750 million liters spilled [Norse & Amos 2010]). Earlier spills, such as the 1989 *Exxon Valdez* tanker accident in the Gulf of Alaska and the extensive oil spills during the 1990–1991 Persian Gulf War (approximately 908 million liters [Etkin 1999]) also drew wide public attention. These well-publicized spills, however, represent just a portion of the environmental risks and impacts on marine and coastal ecosystems associated with oil and gas exploration, development, production, transport, and well abandonment (Fig. 1).

Nevertheless, the impacts of deep-sea offshore activities on biodiversity remain understudied, and knowledge is often based on data from relatively few locations (e.g., Smith et al. 2008). Research gaps in deep-sea ecosystems (below 500 m) are substantial (Barbier et al. 2014; Danovaro et al. 2014; Jobstvogt et al. 2014; Levin et al. 2014; Mengerink et al. 2014), albeit with important exceptions, such as research on the hydrocarbon-seep chemosynthetic communities in the Gulf of Mexico (MacDonald et al. 1989; Fisher et al. 2007; Cordes et al. 2009). Major research and practice gaps also exist regarding the governance and management of the deep sea and of related socioeconomic factors (van den Hove & Moreau 2007; Barbier et al. 2014). Ecological restoration in the deep sea remains understudied and is expected to cost at least 2–3 orders of magnitude more than the restoration of shallow marine systems (Van Dover et al. 2014). To understand the responses of deep-sea communities to oil and gas operations and plan accordingly (Barbier et al. 2014; Fisher et al. 2014; Mengerink et al. 2014) these knowledge gaps need to be filled.

Conservation Challenges of Offshore Hydrocarbon Operations

Environmental impacts of routine offshore hydrocarbon operations can occur at the exploration, development, production, transport, or well-abandonment phases. Each threat must be explicitly accounted for in marine conservation plans and decisions.

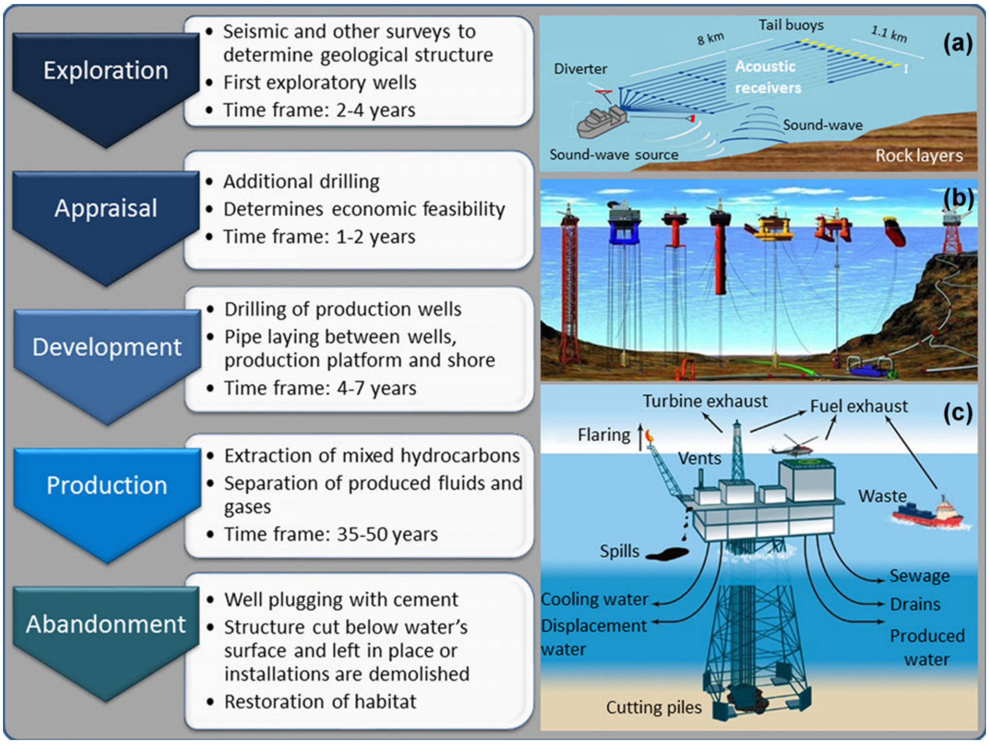

Figure 1. An overview of marine oil and gas exploitation stages, from exploration to production and abandonment: (a) seismic survey and exploratory drilling, (b) appraisal of reservoir size and quality and development of well infrastructure; (c) production and abandonment when the pressure in the well drops to a level at which it is no longer economically viable. The drawing in (b) was adapted from http://oceanexplorer.noaa.gov/explorations/06mexico/background/oil/media/types_600.html and the drawing in (c) was adapted from the OSPAR (2009) report.

Exploration

During exploration, marine environments that previously had minimal human impact are exposed to activities such as seismic surveys (Richardson & Würsig 1997; Gordon et al. 2003), exploration drilling, and pile cutting (Benn et al. 2010). Exploration drilling is a risky part of the operations, and major accidents, such as the 2010 BP Gulf of Mexico disaster, have occurred during this phase. Noise caused by seismic operations can lead to stress, evasive and stranding behavior in marine mammals, turtles, fish, and cephalopods (McCauley et al. 2000; McCauley et al. 2003; Fewtrell & McCauley 2012). Various technological advances aim to address these threats, such as the use of bubble curtains for noise reduction (Kuo & Fulton 2013). The U.K.'s Joint Nature Conservation Committee (JNCC) guidelines for minimizing acoustic disturbance of marine mammals by the oil and gas industry's seismic surveys provide a basis for other international noise pollution mitigation measures (JNCC 2010).

Construction and Extraction

Oil spills and natural gas leaks can occur at various stages of hydrocarbon operations. During the drilling and production stages chemicals and oil (and to a lesser extent gas) are discharged from drilling muds and produced water (water associated with oil in the reservoir). Produced formation water is considered the largest pollution source after spills, and the total volume discharged annually has been estimated at 7500–11500 t (Holdway 2002). Pile cuttings released during drilling operations are normally considered a local effect, restricted to a zone within 100 m of the discharge (Neff 2010). Yet, they can contaminate sediments and surface waters, and their spatial impact can increase with water depth. This may, in turn, lead to biological effects, such as smothering and mortality of epibenthic species and ecological changes to the benthos (Ellis et al. 2012). Oil sheens from currently admissible concentrations of hydrocarbons on the water surface can damage seabird feathers (O'Hara & Morandin 2010) and lead to mortality and reduced breeding success (Wiese et al. 2001).

Large oil spills are a major threat to biodiversity (e.g., Kingston 2002; Barron 2012; Mendelssohn et al. 2012; White et al. 2012). Spills affect many marine species, can have long-term consequences for coastal habitats (Peterson et al. 2003), and can also affect areas far from the spill source when oil is carried by winds and sea currents (e.g., Goldman et al. 2015). In 2000 oil released from the sinking tanker *MV Treasure* near Robben and Dassen Islands of the South African Cape affected >17,000 endemic and endangered African Penguins (*Spheniscus demersus*) and led to a costly international rescue effort (about US$100 for each successfully treated and released bird [Whittington 2003; IUCN 2013]). Biodiversity impacts include mortality following an oil spill event (e.g., an estimated 250,000 seabird deaths from the 1989 *Exxon Valdex* oil spill) and chronic exposure to sediment pollution over many years (Peterson et al. 2003). Too little is known about the ecological and socioeconomic impacts of spills to produce accurate models of oil-spill effects on marine habitats, their ecosystem services, and species (Peterson et al. 2012).

The 2010 BP Deepwater Horizon oil spill and gas disaster in the Gulf of Mexico persisted for months and affected biodiversity throughout the water column. It negatively impacted marine animals, plants (Barron 2012), deepwater coral assemblages (Fisher et al. 2014), deepwater ecosystems, and coastal habitats (beaches, marshes, wetlands, estuaries [Mendelssohn et al. 2012; White et al. 2012; Montagna et al. 2013]). Because knowledge of deep-ocean ecosystems in the Gulf was very limited at the time of the spill, baseline information for measuring impacts and building restoration plans was lacking (Norse & Amos 2010). Company-reported accidents related to offshore platforms (e.g., blowouts, fires, injuries, pollution) tend to increase as water depth increases (Muehlenbachs et al. 2013). Deepwater drilling is technologically challenging, and drilling failures can be complex to fix (National Commission 2011). The well drilled at the time of the BP Deepwater Horizon disaster began at 1600-m depth. One of the deepest offshore well operations currently in progress starts at 2900 m (Shell Oil's Gulf of Mexico Stones), and drilling operations are going deeper, requiring the development of additional safety indicators for all operation phases (Skogdalen & Vinnem 2011).

The recovery of degraded marine ecosystems from large oil spills may occur naturally over time or may require active restoration efforts. While parts of the system may recover within years (Kingston 2002), more complete recovery may take decades (Borja et al. 2010) or longer. Subsurface oil from the *Exxon Valdez,* for example, persisted for at least 16 years (Peterson et al. 2003; Short et al. 2007). Recovery rates in the deep sea may be on the scale of centuries based on the slow rates of metabolic activity, growth, and reproduction there (Montagna et al. 2013).

Secondary Effects

Gas and oil operations also have multiple secondary effects. Gas leaks from drilling operations over the life cycle of a well have been estimated to account for 1.7–7.9% (Howarth et al. 2011) of greenhouse gas methane emissions globally (Alvarez et al. 2012; Tollefson 2012). They can potentially create anoxic zones in the ocean (EPA 2010; Alvarez et al. 2012). Structures and seabed pipelines, shipping traffic, and other transportation associated with the hydrocarbon industry present pathways for invasive species through ballast water, biofouling organisms, transferred sediment, and linear infrastructure (e.g., pipelines) (Rivas et al. 2010). Some pathways are addressed in international treaties and regulations (e.g., the Ballast Water Management Convention adopted by the International Maritime Organization in 2004).

New infrastructure poses challenges for marine conservation planning. Linear infrastructure running perpendicular to the shore into deep water (e.g., pipelines) can be difficult to plan and zone around. The risks these pipelines (buried or unburied) pose to biodiversity are understudied. Offshore operations are also associated with new infrastructure on land (e.g., for transportation, storage and refinement [O'Rourke & Connolly 2003]) that can affect coastal and terrestrial ecosystems. The risks of deserted wells to marine and coastal ecosystems are another relatively understudied topic (Jackson 2014).

Future Challenges of Gas Hydrates

Natural gas hydrates represent a hydrocarbon that will likely be further exploited in the near future. Methane hydrate is a highly concentrated, naturally occurring frozen compound, which is formed when water and methane combine at moderate pressure and relatively low temperature conditions (Ruppel 2011). It is estimated that gas hydrates (onshore and offshore) comprise about half of the world's organic carbon sources (Collet et al. 2009). Present mapping of gas hydrates reveals their occurrence along ocean margins worldwide, and new technologies that will allow their economical production are being developed (Collet et al. 2009; Ruppel 2011; Ruppel et al. 2011). While commercial production of gas hydrates has not yet begun, it presents unknown conservation challenges and threats to biodiversity (Sloan 2003). The destabilization of methane hydrates due to increases in the temperature of bottom waters may also enhance global warming and cause widespread regional ocean deoxygenation (Sutherland et al. 2012).

International Conflict Potential and Conservation

Oil and gas discoveries motivate countries to focus attention on frontier areas. Operations are expanding rapidly into sensitive and unique marine habitats, such as the Arctic, West Africa, and the enclosed Mediterranean Sea (Fig. 2 & Supporting Information). Discoveries of

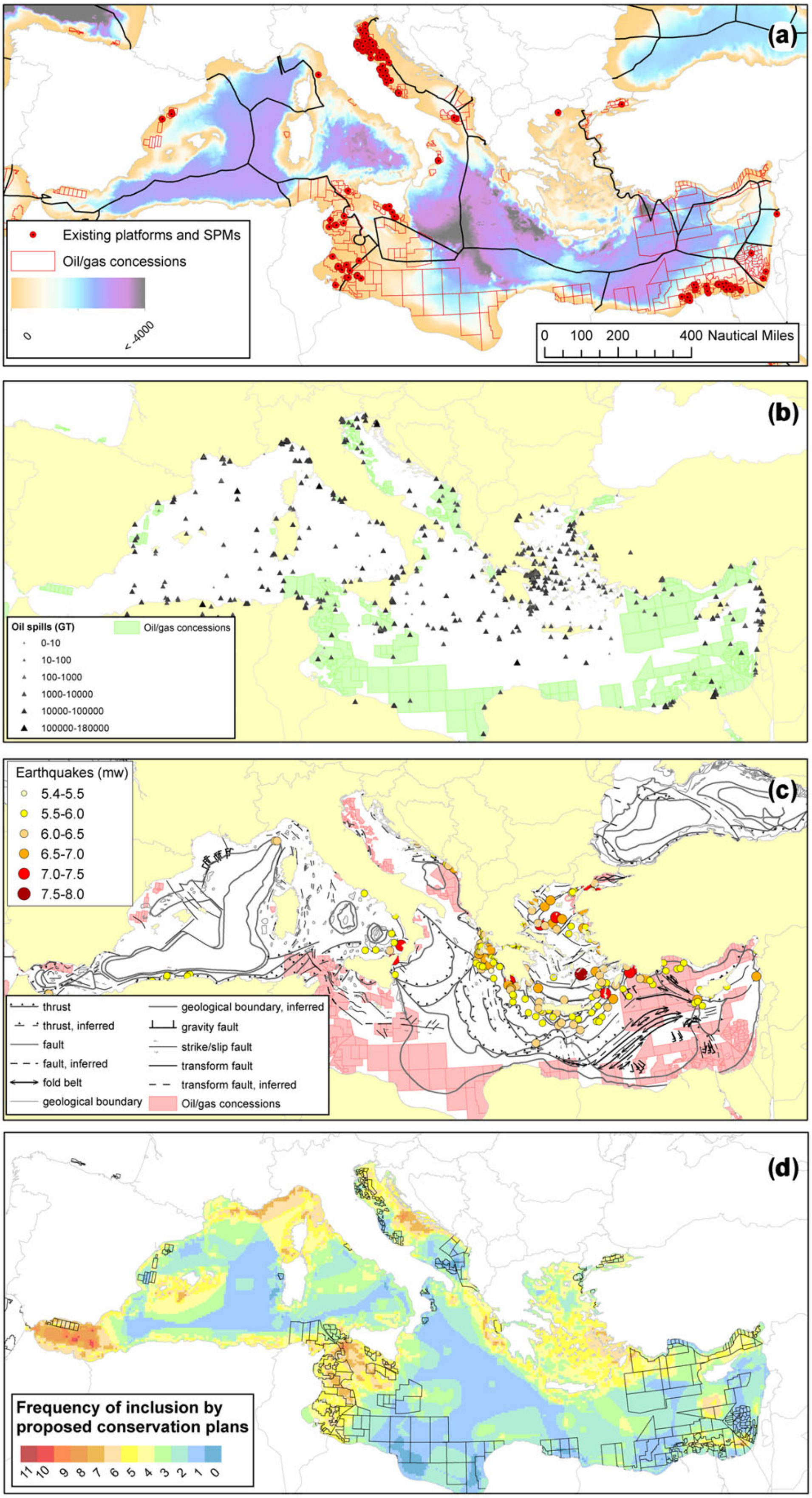

Figure 2. Oil and natural gas concession areas and active platforms in the Mediterranean Sea. Concession areas, existing oil and gas platforms, and offshore single point moorings (SPM) based on data from Infield Offshore Energy Database (Infield 2013): (a) location of concessions areas and existing drilling with respect to the bathymetry and marine boundaries of exclusive economic zones (thick black lines) (source VLIZ 2012), (b) recorded oil spills in Mediterranean concessions in the period between January 1977 and July 2013 (n = 778; Supporting Information; REMPEC 2013), (c) seismic activity (major earthquakes in the 20th century) and major faults in the Mediterranean relative to oil and gas concessions (fault data, Asch 2003; earthquakes data, ISC 2013), and (d) oil and natural gas concessions (black outline) relative to proposed conservation priority areas shared between five or more proposed schemes (adopted from Micheli et al. [2013]).

Table 1. Glossary of terms related to sovereignty and maritime jurisdictions.

UNCLOS	UN Convention on the Law of the Sea (UNCLOS); from December 1982, provides for the basic sovereign rights and duties of the coastal states and the international community of states in the ocean
Territorial waters	areas within 12 nautical miles from the baseline of a coastal state, where that state exercises full sovereignty (UNCLOS Part II)
Contiguous zone	zone contiguous to a state's territorial sea and within 12 nautical miles beyond territorial waters; coastal state may exercise the control necessary to prevent and punish infringement of its customs, fiscal, immigration, or sanitary laws and regulations within its territory or territorial sea (Article 33 of UNCLOS)
Exclusive economic zone (EEZ)	declared by coastal states; a region reaching up to 200 nautical miles from the coastal baseline in which nations have sovereign rights over all natural resources, but additionally, the responsibility for the conservation and management of the zone (Part V and Article 61 of UNCLOS)
Continental shelf	area in which coastal states have sovereign rights to explore and exploit resources (according to UNCLOS); can be as far as 350 nautical miles from state's baselines or, when it is more favorable to the coastal nation, to 100 miles beyond the 2500-m isobaths (Roy 2012; Article 76 of UNCLOS); boundary of the shelf is sometimes debated, and extent of continental crust is still being explored (opening further debates around territorial claims) (James 2011)
High seas	all parts of the sea or ocean that are not part of the exclusive economic zone, the territorial waters, or the internal waters of a state; not part of the archipelagic waters of an archipelagic state; usually refers to the water rather than the seabed (Article 86 of UNCLOS)
Areas Beyond National Jurisdiction (ABNJ)	also known as high seas and international waters; refers to the seabed and minerals therein (Part XI and Article 1 of UNCLOS)
International Seabed Authority (ISA)	an autonomous international organization established under UNCLOS that has jurisdiction over mineral resources in international waters; recommended that conservation policies should become an integral part of international seabed regulation before ISA grants the first exploration and mining licenses (Van Dover 2011)
Convention on Biological Diversity (CBD)	entered into force on 29 December 1993; objectives are the conservation of biological diversity, sustainable use of the components of biological diversity, and fair and equitable sharing of the benefits arising from use of genetic resources
International Maritime Organization (IMO)	the United Nations' specialized agency with responsibility for the safety and security of shipping and the prevention of marine pollution by ships

exploitable hydrocarbon reservoirs have motivated some nations (e.g., South Africa [Sink & Attwood 2008] and eastern Mediterranean countries [Supporting Information]) to advance the declaration of their exclusive economic zones (EEZ) and extend their continental shelf claims (see Table 1 for definitions). However, despite the fact that fossil fuel operations are already underway, most Mediterranean countries, for example, have not yet declared their EEZ (Fig. 2a; Supporting Information) (Katsanevakis et al. 2015).

Hydrocarbon discoveries in deep waters can be a catalyst for international conflicts and boundary disputes (Naylor 2011; Khadduri 2012). Cross-boundary coordination (Kark et al. 2009, 2015) is required for development of plans aimed at minimizing large-scale negative impacts of hydrocarbon operations on biodiversity (Mazor et al. 2013, 2014) in deep waters, particularly in areas beyond national jurisdictions (Mengerink et al. 2014). Coordination is particularly challenging where long-lasting economic or political disputes exist (e.g., Levin et al. 2013). Maritime jurisdiction interests can also incentivize countries to establish large marine protected areas so as to assert their ownership of the area, as in the case of the Chagos (De Santo et al. 2011).

Legal and Political Framework

Countries experienced with the offshore hydrocarbon industry (e.g., OSPAR Convention members in Europe, the United States, and Australia) have put in place laws and regulations aimed at reducing the industry's harm to ecosystems and biodiversity (OSPAR 2009). However, even in these nations, the regulations, technology, and practices related to containing and cleaning up spills do not sufficiently address the risks associated with deepwater drilling (National Commission 2011). Regulation enforcement and monitoring of operations far from shore are often inadequate (UNEP 2007), and a substantial number of environmental statements are not of "satisfactory quality" (Barker & Jones 2013). In many cases, specific hydrocarbon operation legalization is absent, particularly in the high seas (Table 1), where governance and regulations are lacking (Van Dover 2011). According to the World Bank, the majority of developing countries have limited environmental regulations, and where they exist they are often not effectively enforced (Alba 2010). This is especially relevant in regions where political strife and security threats focus attention. Ecological concerns are too rarely the top priority of governments, including some

OECD (Organization for Economic Cooperation and Development) countries, where one would expect rigorous standards to be enforced.

Politics plays a major role in the future of marine conservation in areas beyond territorial waters. The key players are nations that have sovereignty in the oceans directly, through international conventions, or through regulatory bodies. Although countries are primarily responsible for conservation, governments face many other immediate pressures (Korngold 2014). Maritime boundaries are often determined by politics rather than ecological factors, and their jurisdiction is often incompatible with the scale of conservation challenges. Furthermore, most leaders are not in office long enough to fully establish, implement, or take ownership of ecosystem management issues that may require long-term planning (Korngold 2014).

Deep-sea drilling usually occurs in areas beyond territorial waters (Table 1) that are not fully covered by standard national environmental regulations or monitoring programs. Coordination among the multiple organizations regulating activities such as oil and gas development, shipping, and fishing should be a priority for managing environmental threats in areas beyond national jurisdictions (Barbier et al. 2014; Gobin & da Fonseca 2014). This could be done under international environmental law and the UN Convention on the Law of the Sea (UNCLOS) (Table 1) to provide better oceans governance (Gobin & da Fonseca 2014) and instruments such as binding dispute-resolution mechanisms (Boyle 1999). As such, UNCLOS and other international agreements constitute an important pillar in nations' obligations to protect the marine environment. However, as for other international agreements, UNCLOS and the CBD (Table 1) need to be concretized and implemented (via national laws, regional protection systems, or empowerment of international organizations). Regional treaties (e.g., Barcelona Convention of the Mediterranean and OSPAR [Oslo and Paris Conventions for the Protection of the Marine Environment of the North-East Atlantic]) further elaborate on nations' responsibilities to protect the marine realm. However, not all countries have established the necessary laws and regulations to comply with these international treaties.

Multinational extractive companies often work across international boundaries and markets, they respond to global stakeholders, and often consider time horizons as long as 40–50 years to recoup investments. Thus, global corporations with their international scope, resources, marketplace incentives, and global workforces (Korngold 2014), can play a key role in the success or failure of cross-boundary management plans for protecting marine biodiversity. Corporate self-interests should align with at least some of the strategies required to tackle the very environmental problems brought about by their own industry. They share with the conservation community the aim of avoiding disasters, although their motivations may be quite different. This may lead to successful joint initiatives (see Supporting Information) and can potentially be leveraged by the conservation community early in the policy-shaping and operation-planning process.

Emerging Prospects to Leverage for Conservation

With mounting offshore operations, including in deep water (Ramirez-Llodra et al. 2011), conservation scientists and practitioners need to urgently consider the possible opportunities that could be leveraged for conservation.

Environmental Research and Marine Oil and Gas Extraction

As marine hydrocarbon exploration is speedily progressing, there is need to clearly map threatened deep-sea ecosystems for which major basic knowledge gaps exist (Davies et al. 2007; Ramirez-Llodra et al. 2010). Because conservation resources are limited, a lag occurs between the start of hydrocarbon exploration and attaining the much-needed scientific information required for conservation planning and actions. Deep-ocean research is costly and operationally challenging (Ban et al. 2014; Barbier et al. 2014; Danovaro et al. 2014). Facilities for deep and ultra-deep industry operations can provide an in situ scientific base for deep-sea conservation research and monitoring, and conservation professionals should be allowed access to the industry's relevant data, infrastructure, and equipment, which will advance deep-sea environmental and conservation research.

Recent discoveries have been made in deep-sea ecology via technological advances in submersible vehicles, remotely operated underwater vehicles, fiber optic communications, imaging and molecular tools, sensors, and in situ instruments (Barbier et al. 2014; Danovaro et al. 2014). Discoveries made possible by such advancements indicate that the deep-sea harbors many diversified assemblages (Snelgrove & Smith 2002) and provides unique refuge habitats, including for example canyons, seamounts, cold seeps, and hydrothermal vents for a range of marine species, such as cold-water corals, fish (Ramirez-Llodra et al. 2010), and cephalopods (e.g., Boyle & Daly 2000; Voight 2000; Landman et al. 2004). Deep-sea ecosystems appear critical for global ocean functioning (Danovaro et al. 2008; Loreau 2008; Cerrano et al. 2010). Efforts are being undertaken to fill knowledge gaps (Danovaro et al. 2014), including the Census of Marine Life and EU projects (HERMIONE, HERMES) aiming to determine how deep-sea biodiversity supports ecosystem functioning.

The deep sea encompasses one of the most extensive ecosystems globally and represents the largest biomass reservoir (Lenton 2000; Danovaro et al. 2008). While most marine species remain undescribed or unstudied (Costello et al. 2010), deep-sea ecosystems with complex geosphere-biosphere and ecological interactions are being discovered. These ecosystems highlight the importance of chemosynthetic production in fueling biodiversity (Danovaro et al. 2014). Such findings challenge previous perceptions of the deep sea as food-poor and metabolically inactive and suggest it is an important component in global carbon cycles (Danovaro et al. 2014). Biodiversity loss in deep-sea ecosystems may lead to an exponential reduction of deep-sea ecosystem functioning (Danovaro et al. 2008), including mutualistic interactions (Loreau 2008).

De Facto No Take Zones, Conservation Monitoring, and Enforcement Efforts

Existing and planned offshore hydrocarbon facilities could be leveraged for biodiversity protection. For example, UNCLOS (Article 60) recommends a safety zone of 500 m (or larger where security is a problem) around drilling platforms where fishing and commercial activities. If such areas are managed in collaboration with conservation authorities and distances are increased, off-limit zones could present opportunities for larval recruitment and increased biomass, as has been demonstrated for no-take marine protected areas (Lester et al. 2009). Offshore platforms may locally enhance recruitment and reproduction of rare or endangered fishes (Consoli et al. 2013), algae, and corals (e.g., Davies et al. 2007). However, offshore platforms are also associated with invasive non-native species, and once invasive species are present on offshore platforms, there are additional management and policy problems for decommissioning of these platforms (Page et al. 2006).

Due to the chronic and potentially catastrophic environmental impacts associated with offshore hydrocarbon operations, governments should consider collecting funds from the industry to be designated specifically for conservation activities (Armstrong 2013). For example, the impact of platforms should be further examined, potentially by establishing independent research grant schemes. Potential contribution of the industry to biodiversity and ecosystem monitoring should also be considered (Supporting Information).

Increasing Awareness of Large-Scale Marine Conservation Planning

Concerns about the impacts of marine oil and gas operations can incentivize marine spatial planning initiatives and conservation efforts. For example, establishment of the Australian Great Barrier Reef (GBR) Marine Park Authority (1975) was partly driven by concerns about oil drilling (Ruckelshaus et al. 2008). In 1994 a long-term strategic plan for managing and preserving the GBR World Heritage Site was established (Fernandes et al. 2005), and a new long-term sustainability plan was published in 2015 (http://www.canberraiq.com.au/downloads/2015-1-19-1.pdf). While the GBR has one of the largest and most exemplary conservation zoning plans globally (Agardy 2010), it faces major challenges related to the hydrocarbon industry, such as oil spills (e.g., the 2010 spill from the bulk coal carrier MV Shen Neng 1) and threats from ports, shipping, current and planned dredging activities, and dumping of dredge spoil (excess material) in and near the park (Grech et al. 2013).

Collaboration Conflicts and Opportunities

Conservationists are often reluctant to collaborate with gas and oil enterprises. Such collaboration is relatively rare, but not unprecedented (Flemming & McCall 2000) (Supporting Information). Mutually beneficial agreements can be reached in which the relevant factors are accounted for and weighted. For example, the Energy and Biodiversity Initiative (EBI) was formed by energy companies (BP, ChevronTexaco, Shell, Statoil) and conservation organizations (Conservation International, The Nature Conservation, Fauna & Flora International, Smithsonian Institute, IUCN). The aim of the initiative was to develop and promote biodiversity conservation practices relative to energy development, and it operated from 2001 to 2007. The partnership produced practical guidelines, tools, and models aimed at improving the environmental performance of energy operations, minimizing harm to biodiversity, and creating opportunities for conservation where oil and gas resources are extracted (Tully 2004) (Supporting Information).

It has long been recognized that partnerships formed between governments and the industry can enhance oil spill response. Efforts have been put in place over the past 25 years to enable cross-boundary response. The International Convention on Oil Pollution Preparedness, Response and Co-operation (1990) defines avenues for collaboration between national authorities and the oil and shipping industries to unify response efforts (Moller et al. 2003). The global initiative, launched in 1996, provides an oil spill preparedness and response program through which governments and industry cooperate. It is implemented by the International Maritime Organization, a UN specialized agency, and IPIECA (International Petroleum Industry Environmental Conservation Association) (Taylor et al. 2011). In 2013 the Arctic Council (Canada, Denmark, Finland, Iceland, Norway, Russia, Sweden, United States) signed an agreement on Cooperation on Marine Oil Pollution Preparedness and Response in the Arctic. Such agreements can potentially provide an important way for conservationists to become involved and advance actions emphasizing conservation.

Legislation Drivers

In places where the marine hydrocarbon industry is new and fast progressing, there should be a strong driver for public discussion that can prompt further action by legislators and regulators in a conservation context. The magnitude of damage from several recent oil spills should increase both scientific and public discussion in regions that until now were far from public attention. Subjects such as deep-sea operations, high seas and open sea marine conservation strategies and protected areas, cross-boundary marine parks, the need to update laws and regulations to cover ecosystem risks the industry poses, corporate responsibility issues, and the potential to include conservation in hydrocarbon operations should become a greater part of conservation science discourse.

In the case of frontier activities (e.g., deep-sea drilling), anachronistic legislation and spatial jurisdiction ambiguity may result in "regulatory capture" (i.e., regulatory agencies favoring the hydrocarbon industry at the expense of environmental protection, precaution, or conservation) (Portman 2014). The conservation community and scientists therefore have an important role in explicitly raising the conservation agenda early on and taking part in shaping extraction and conservation plans in the deep sea.

The natural gas industry is sometimes supported by environmentalists who argue that use of natural gas is more efficient and pollutes less than other fossil fuels (e.g., coal) (Gagnon et al. 2002). In the marine environment, liquid petroleum seeps usually have a longer-term presence than gas seeps because gases are more quickly assimilated into the surrounding water or more rapidly lost to the atmosphere (Kvenvolden & Cooper 2003). Marine transport of liquefied natural gas is expected to be safer because its leakage from ships is less probable (Pitblado et al. 2005). Nevertheless, while offshore natural gas reserves may be environmentally compelling compared with oil, they too pose challenges for conservation. Methane (a greenhouse gas) leaks during production are larger than previously thought (Alvarez et al. 2012; Tollefson 2012). Therefore, further discussion within the conservation community about the relative impacts of different energy sources is important.

Conservation Prioritization in the Face of Emerging Threats

Micheli et al. (2013) examined the spatial overlap between conservation priority areas as defined in multiple conservation schemes proposed for the Mediterranean Sea (Fig. 2d). Only 2 of the 12 conservation proposals explicitly took into account oil or gas activity areas. These priority areas show substantial overlap of approximately 130,000 km^2 among the hydrocarbon exploration and exploitation concession areas in the Mediterranean. Future conservation planning efforts should explicitly incorporate hydrocarbon industry infrastructure and threats. Such information could be included in conservation planning through a range of conceptual and practical approaches. For example, it could be incorporated as an "insurance factor" (Allison et al. 2003), by identifying the optimal inter-reserve distance necessary to minimize the risk that several reserves will be affected by a single oil spill (Wagner et al. 2007), and by explicitly including threats through the use of spatial prioritization software (Game et al. 2008). Recently developed decision support tools (e.g., Marxan with Probability) allow one to explicitly incorporate threats (e.g., probability of extinction due to oil spills), multiple objectives (e.g., Marxan with Zones; Watts et al. 2009), and trade-offs between conservation and economic or industry objectives (Mazor et al. 2014).

Leveraging Prospects

The primary motivations of the hydrocarbon industry and of conservationists rarely overlap. The industry's main goal is to provide energy sources and be profitable, while conservationists aim to maintain and restore native, threatened, and representative biodiversity and reduce damage to long-term ecosystem functioning and services. No industry player, however, wants bad public relations or to bear the tremendous cost of large spills. This desire presents a common ground for discussion, and corporate responsibility for industrial activity should lead to an incentive to minimize environmental impact (Shrivastava 1995). In practice, the offshore oil and natural gas industry, supported by governments and large businesses, is effectively moving ahead with or without the conservation community's involvement. Therefore, conservationists may have little choice but to respond quickly and aim to introduce conservation considerations into spatial plans as early as possible to minimize environmental damage and leverage opportunities for conservation. This includes arguing urgently for new conservation and monitoring funds (which can be termed open seas funds) and environmental offsetting schemes as crucial parts of multi-billion dollar marine hydrocarbon operations. It also includes clearly demonstrating to the fossil fuel industry that taking costly actions in the short-term may help prevent far more costly fines and negative impacts to ecosystems in the long term. The conservation community, including scientists, should become involved in the earliest planning and exploration phases and remain involved throughout operations so as to influence practical decision making and promote continuous monitoring of biodiversity and ecosystems. Experience and successful strategies from around the world should be shared across the global conservation community. Transparent and productive long-term relationships between industry personnel and conservation professionals can also help industry become more aware of the risks of their operations to biodiversity. This may eventually lead to changes in industry operations that will help prevent, minimize, and address future threats (Supporting Information) (Esty & Winston 2009).

Collaboration may lead to delays in conservation action. It may lack transparency due to agendas of industry stakeholders, handling of proprietary information, and a lack of trust across the communities. This may lead to further conservation delays, added costs and further threats to biodiversity and ecosystems. The discussion of when, where, how, and to what extent conservationists will collaborate with the hydrocarbon industry must be weighed and determined for each case and must be an explicit part of conservation planning and strategic conservation decisions and actions.

The effects of fossil fuel operations on biodiversity provide an important area for research and inter-disciplinary collaboration. Advancements in the science of oil spill modeling (Ji et al. 2011) allow scientists to better estimate the risk of oil spills for marine and coastal areas. However, there are important gaps in understanding of deep-sea currents, their spatial and temporal patterns, and their interactions with the various chemical components of oil and gas discharges, as well as understanding of effects on biodiversity and required actions and restoration following spills. An important future direction should be to develop collaborative research among marine hydrogeophysicists, ecologists, and conservation professionals, which may provide a better foundation for predicting the impacts of spills and recognizing actions to best mitigate threats to biodiversity (e.g., Goldman et al. 2015). Future work would benefit from further exploration of how to better incorporate ongoing hydrocarbon operations into spatial conservation planning and how the fossil fuel industry can better incorporate conservation needs, including in deep-sea and frontier regions.

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Supporting Information

Detailed examples of oil and gas operations in the Mediterranean Sea (Appendix S1) and Congo Basin (Appendix S2) and examples of collaborations between the oil and gas industry and conservation (Appendix S3) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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