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Offshore Oil and Gas Platforms as Novel Ecosystems: A Global Perspective

Sean van Elden*, Jessica J. Meeuwig, Richard J. Hobbs and Jan M. Hemmi

School of Biological Sciences, The University of Western Australia, Crawley, WA, Australia

Offshore oil and gas platforms are found on continental shelves throughout the world's oceans. Over the course of their decades-long life-spans, these platforms become ecologically important artificial reefs, supporting a variety of marine life. When offshore platforms are no longer active they are decommissioned, which usually requires the removal of the entire platform from the marine environment, destroying the artificial reef that has been created and potentially resulting in the loss of important ecosystem services. While some countries allow for these platforms to be converted into artificial reefs under Rigs-to-Reefs programs, they face significant resistance from various stakeholders. The presence of offshore platforms and the associated marine life alters the ecosystem from that which existed prior to the installation of the platform, and there may be factors which make restoration of the ecosystem unfeasible or even detrimental to the environment. In these cases, a novel ecosystem has emerged with potentially significant ecological value. In restoration ecology, ecosystems altered in this way can be classified and managed using the novel ecosystems concept, which recognizes the value of the new ecosystem functions and services and allows for the ecosystem to be managed in its novel state, instead of being restored. Offshore platforms can be assessed under the novel ecosystems concept using existing decommissioning decision analysis models as a base. With thousands of platforms to be decommissioned around the world in coming decades, the novel ecosystems concept provides a mechanism for recognizing the ecological role played by offshore platforms.

Keywords: novel ecosystems, Rigs-to-Reefs, decommissioning, artificial reefs, environmental impacts, offshore oil and gas

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****Correspondence:***
Sean van Elden
sean.vanelden@research.uwa.edu.au; svanelden@gmail.com

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INTRODUCTION

Since 1947, when Ship Shoal Block 32 in the Gulf of Mexico became the world's first offshore oil drilling platform (Aagard and Besse, 1973), the offshore energy industry expanded rapidly to currently number over 12,000 offshore installations globally (Ars and Rios, 2017). Offshore platforms are situated on the continental shelves of 53 countries, making offshore oil and gas production a major global industry (Parente et al., 2006). Significant advances in engineering over the last 70 years have not only increased the number of rigs, but also the environmental conditions which they can withstand: offshore platforms are now larger and found in deeper waters, further from shore. These technological advances have implications for decommissioning, which occurs when hydrocarbon production ceases or the lease ends and the platform is shut down. The decommissioning process now takes longer, requires more specialized equipment and, by extension, has become more costly (Kaiser and Liu, 2014).

A 2016 study by the IHS Markit forecast the global decommissioning of over 600 offshore structures between 2017 and 2021, with a further 2,000 projects by 2040, resulting in a total cost between 2010 and 2040 of US $210 billion (IHS Markit, 2016). In countries where total removal is the legal requirement, decommissioning involves the plugging of wells, cleaning, capping and possibly removal of pipelines, removal of production equipment and removal of the structure (Hakam and Thornton, 2000). In United Kingdom waters alone, decommissioning expenditure is forecast to amount to £17 billion between 2017 and 2025 (Oil and Gas UK, 2017). Even a nation with comparatively low oil and gas production, such as Australia (0.9% of global production), has a future decommissioning liability of US $21 billion over the next 50 years (NERA, 2016). The process of decommissioning is far from straightforward in many cases, and is often complicated by the process of transferability, whereby an existing platform is sold to a company which can continue production at lower profit margins (Parente et al., 2006).

From a biological viewpoint, increasing evidence suggests that offshore oil and gas platforms provide significant ecosystem services while active. The installation of these platforms creates hard substrate in open waters which is colonized by a variety of sessile organisms and results in the formation of artificial reefs (Shinn, 1974; Scarborough-Bull, 1989). Because they may exclude commercial fishing, particularly trawling, and in some cases recreational fishing, these platforms can also act as important refuges for a variety of taxa (Frumkes, 2002; Claisse et al., 2014). The potential ecological value of offshore platforms raises the question of whether there may be alternatives to the standard decommissioning process that might have important positive ecological outcomes, and ecological factors are more recently being included in decommissioning assessments (Fowler et al., 2014; Henrion et al., 2015; Sommer et al., 2019). The successes of various Rigs-to-Reefs projects, particularly in the Gulf of Mexico, have demonstrated that these structures can be effectively repurposed as artificial reefs (Frumkes, 2002; Kaiser and Pulsipher, 2005; Sammarco et al., 2014). However, to date only a few countries around the world have successfully implemented Rigs-to-Reefs programs (summarized in Bull and Love, 2019).

Evaluating offshore platforms as novel ecosystems would provide a mechanism for considering the ecological importance of these platforms in the decommissioning process. Novel ecosystems is a relatively recent ecological concept, brought into focus by Hobbs et al. (2006), where human activity has altered ecosystems to a point where restoration may not be feasible. In a world that is increasingly being altered by human activity, the concept of novel ecosystems recognizes that in some cases, ecosystems changed from their historical state by human intervention may not feasibly be able to be restored (Hobbs et al., 2006). With many case studies throughout a variety of ecosystems around the world (Hobbs et al., 2013b), novel ecosystems provide an approach for recognizing value in altered ecosystems, rather than implementing restoration for restoration's sake. In the cases of both active and decommissioned platforms, it is possible that the concept of novel ecosystems can be applied as a way to describe the ecosystems created by the presence of the platforms. The aim of this review is to evaluate the ecological role of offshore oil and gas platforms, and to assess these platforms against the criteria of the novel ecosystems concept.

DECOMMISSIONING

Decommissioning, the end of life stage for offshore infrastructure, is a process which is regulated internationally, regionally and nationally. The 1996 Protocol to the London Dumping Convention (London Protocol) aimed to protect the marine environment from all sources of pollution, and regulates against the dumping of "… platforms or other man-made structures at sea; and any abandonment or toppling at site of platforms or other man-made structures at sea, for the sole purpose of deliberate disposal." (Elizabeth, 1996). However, the London Protocol does not expressly prohibit decommissioning of structures *in situ* (Techera and Chandler, 2015), stating that dumping does not include "placement of matter for a purpose other than disposal thereof, provided that such placement is not contrary to the aims of this Protocol (Elizabeth, 1996)." There are four alternatives to complete removal: (1) leave wholly in place with appropriate navigational aids; (2) partial removal, usually of the superstructure); (3) tow-and-place by moving the structure to a new location; and (4) toppling by laying the structure on its side (Schroeder and Love, 2004; Macreadie et al., 2011; Fowler et al., 2014).

Decommissioning regulations and options in various countries and regions have been reported on and assessed extensively in the literature. While decommissioning in the North Sea and the United States (US) has been well studied (e.g., Reggio, 1987; Löfstedt and Renn, 1997; Dauterive, 2000; Cripps and Aabel, 2002; Schroeder and Love, 2004; Kaiser and Pulsipher, 2005; Jørgensen, 2012; Claisse et al., 2015), there has been more recent focus on decommissioning policy in relatively "new" oil and gas producing regions, such as south-east Asia (Zawawi et al., 2012; Al-Ghuribi et al., 2016; Fam et al., 2018; Laister and Jagerroos, 2018), Australia (Fowler et al., 2015; Techera and Chandler, 2015; Chandler et al., 2017), and Brazil (Barros et al., 2017; Mimmi et al., 2017). Two recent reviews (Bull and Love, 2019; Sommer et al., 2019) provide comprehensive assessments of the literature on the decommissioning process, options, and regulations around the world. These two reviews complement each other by focusing on somewhat different aspects of decommissioning. Sommer et al. (2019) focuses on the ecosystem functions and services provided by platforms, and suggests a more ecosystems-based approach to decommissioning. Bull and Love (2019) provides the most in-depth review to date of the literature on offshore oil and gas platforms, including platform installation, decommissioning, relevant legislation, and platform ecology. While this review is mainly focused on the United States, it does briefly review Rigs-to-Reefs programs in other regions around the world.

RIGS-TO-REEFS

Rigs-to-Reefs is a potential decommissioning outcome for offshore oil and gas structures whereby obsolete infrastructure is re-purposed as artificial reefs instead of being brought back to shore for disposal (Kaiser and Pulsipher, 2005). The first examples of Rigs-to-Reefs occurred in the 1980s, when platforms were removed from production in Louisiana and transported to Florida where they were repurposed as artificial reefs (Kaiser, 2006; Jørgensen, 2009).

By April 2018, approximately 532 offshore platforms have been re-purposed as artificial reefs in the Gulf of Mexico, mostly in Louisiana and Texas (Ajemian et al., 2015; Bureau of Safety and Environmental Enforcement, 2018). This represents just over 11% of the total number of platforms decommissioned in the Gulf of Mexico (Bull and Love, 2019).

Offshore oil and gas platforms are spatially complex structures and their value as artificial reefs has been discussed in numerous studies (Shinn, 1974; Dugas et al., 1979; Bohnsack and Sutherland, 1985; Guerin et al., 2007). Offshore platforms have not only been shown to have a higher fish biomass than sandy bottom areas but even natural reefs (Claisse et al., 2014). This results in offshore platforms having an "enhanced fishing zone" of 200–300 m for pelagic species and 1–100 m for demersal species (Bohnsack and Sutherland, 1985). Fishing and diving around offshore rigs, in countries where it is allowed, is a major component of the local tourism industries (Stanley and Wilson, 1989). In Louisiana, recreational fishing is centered around offshore platforms – over 70% of recreational fishing trips into the EEZ are in direct association with offshore platforms, where pelagic fish densities are 20–50 times higher than surrounding areas (Dugas et al., 1979; Reggio, 1987; Dauterive, 2000). As such, sport fishers and recreational divers generally support Rigs-to-Reefs programs (Frumkes, 2002).

Both active and decommissioned offshore platforms can have a negative impact on commercial trawl fishing, and the prevention of trawling is a common criticism of Rigs-to-Reefs programs (Macdonald, 1994; Hamzah, 2003). The issue of allowing fishing around platforms is one that is still uncertain and needs to be handled carefully. In some cases where platforms have become key habitat for threatened or economically important species, it may be prudent to continue to exclude all fishing from these areas if they are converted into artificial reefs, as they can then be used to bolster populations at surrounding natural reefs where fishing occurs in the same way that marine protected areas (MPAs) do (Mcclanahan and Mangi, 2000).

In sandy, flat-bottom areas with generally limited physical structure, such as the north-west shelf of Australia, the Adriatic Sea and parts of the North Sea, offshore platforms present some of the only obstacles to trawl nets (Rijnsdorp et al., 1998; Wassenberg et al., 2002; Fabi et al., 2004). While the prevention of trawling is detrimental to commercial fisheries, it is ecologically beneficial in offering protection to benthic habitats; in a study to determine the effect of trawling on sponge communities of the north-west shelf of Australia, sponges were caught in 85% of trawls, with a mean catch of 87.2 kg per half-hour (Wassenberg et al., 2002).

Evidence on the success of Rigs-to-Reefs programs and the suitability of oil platforms as artificial reef habitat suggests that these structures can provide significantly more ecological value than other cases of "dumping" (Ajemian et al., 2015). However, it is important to note that just because Rigs-to-Reefs has been successful in a certain area (e.g., the Gulf of Mexico), it does not mean it would automatically be an ecologically beneficial exercise in the North Sea, California or Australia. Every ecosystem is different and needs to be evaluated as such; creating a reef, simply because there is a platform that needs to be decommissioned, is indeed little more than waste disposal (Macdonald, 1994; Salcido, 2005).

A major obstacle in the path of Rigs-to-Reefs legislation is the relative lack of ecological research on offshore structures. For example, despite the presence of over 40 offshore oil and gas installations on the continental shelf of north-west Australia, there has been a limited number of published studies on the ecology of the structures in this region (e.g., Fowler and Booth, 2012; Pradella et al., 2014; McLean et al., 2017, 2018; Bond et al., 2018). Macreadie et al. (2012) concluded that environmental research must be part of the development of Rigs-to-Reefs policy, pointing to the case of California, where a Rigs-to-Reefs bill was vetoed in 2001 based on a lack of evidence that reefed platforms produce net environmental benefits. Macreadie et al. (2012) argue that the subsequent successful passing of a Rigs-to-Reefs bill in 2010 was due in large part to the years of subsequent research by Dr. Milton Love and colleagues (Schroeder and Love, 2002, 2004; Love et al., 2006).

ECOLOGY OF OFFSHORE PLATFORMS

Offshore oil and gas platforms can play important ecological roles for various taxa (Friedlander et al., 2014). They provide substrate for sessile organisms such as sponges and corals and act as a refuge for fish and megafauna such as seals and whales (Forteath et al., 1982; Todd et al., 2016). When a platform is installed, the establishment of a faunal community occurs quickly, with fish appearing within hours (Bohnsack, 1989), and ecological succession results in a complex reef-type habitat within 5–6 years (Driessen, 1986). Offshore platforms can be an important source of habitat not only for fish, but also for sessile invertebrates where hard substrate is limited. Where offshore platforms are isolated from natural reefs, the free-swimming larval stages of invertebrates that settle on offshore platforms would otherwise not likely survive due to a lack of "hospitable" substrate (Driessen, 1986; Thomson et al., 2003; Macreadie et al., 2011). However, the addition of hard substrate means that offshore platforms can also provide habitat for invasive species (Page et al., 2006; Pajuelo et al., 2016).

There is considerable debate as to whether fish associated with artificial structures are actually being produced there for a net gain, or are simply being attracted from nearby natural reefs. Attraction is thought to be detrimental to fish populations, especially those which are targeted by fisheries, as previously sparsely distributed populations become concentrated, making them vulnerable to exploitation (Bohnsack, 1989). However, in the case of offshore platforms, attraction could be beneficial to pelagic species in some regions, where the platforms can act as a temporary refuge from fishing pressure. Macreadie et al. (2011) discuss the importance of habitat limitation as a factor in the attraction vs. production debate; specifically that a habitat-limited fish population would see an increase in regional biomass due to the addition of suitable habitat via artificial structures. Fowler and Booth (2012) found that offshore platforms in north-west Australia could sustain complete size- and age-structured populations of the Serranidae *Pseudanthias rubrizonatus*, with a presumed age range in sampled individuals of 22 days to 5 years. However, production of fish varied among individual platforms. The relative scales of "attraction vs. production" therefore may vary between offshore oil and gas platforms, as biotic and abiotic conditions vary from platform to platform. The presence of larval fish may not be enough to assume production, based on the proximity of other reefs (Bohnsack, 1989; Macreadie et al., 2011). In addition, production is more important in the case of demersal species, which are more dependent on benthic habitat than highly mobile pelagic species (Bohnsack, 1989).

The ecosystem created by offshore platforms means, like natural reefs, they provide economic benefits. In regions where recreational fishing is permitted, these platforms have been highly popular locations for decades (Dugas et al., 1979). "Fishing the rigs" is a major portion of the recreational fishing activity in the Gulf of Mexico, particularly Louisiana, where species caught at the platforms include sharks, billfish, and barracuda (Driessen, 1986). While recreational fishing occurs around offshore platforms, a number of commercial gear types such as trawl and longline are generally excluded from the waters around these structures due to the risk of damage to both fishing gear and subsea infrastructure such as pipelines (de Groot, 1982; Demestre et al., 2008).

In some regions, the exclusion of all vessels, including recreational and commercial fishers, can be legally mandated, and these "exclusion zones" vary in size between countries. In the North Sea, the exclusion from fishing around offshore oil platforms that have been in place for decades, has resulted in a network of *de facto* MPAs (de Groot, 1982; Fujii and Jamieson, 2016). In Australia, the "petroleum safety zones" surrounding offshore platforms extend up to 500 m from the outer edge of any well or structure (Commonwealth of Australia, 2010), while the exclusion zone around a drilling platform in the Jubilee Field in Ghana is five nautical miles (Chalfin, 2018). In 2003, Mexico created an "area of exclusion" of 5,794 km^2 around oil platforms in the Campeche region of the Gulf of Mexico (Quist and Nygren, 2015).

Various studies have described oil platforms around the world as *de facto* MPAs. Because of the exclusion of trawl fishing at all platforms in Gabon, and the exclusion of all types of recreational fishing at some platforms due to security restrictions, Friedlander et al. (2014) concluded that these platforms are functioning as *de facto* MPAs. In California, offshore oil platforms provide a significant refuge for commercially important rockfish species (Frumkes, 2002; Claisse et al., 2014; Fowler et al., 2015). Marine vessels are discouraged from entering the 150 m buffer zone surrounding platforms, meaning that fishing activity is limited, and Schroeder and Love (2002) found that rockfish surrounding an oil platform were larger and greater in density compared with the populations at recreationally and commercially fished sites. In addition, eight offshore oil and gas platforms off southern California supported 430,000 juveniles of the highly overfished and IUCN Critically Endangered Bocaccio rockfish *Sebastes paucispinis*, accounting for 20% of the average annual number of surviving juveniles of this species. In these instances, the refuges provide much higher recruitment and survival rates than natural but fished nursery grounds (Love et al., 2006).

NOVEL ECOSYSTEMS

Human activities are transforming ecosystems on a global scale (Foley et al., 2005; Mccauley et al., 2015; Laurance and Watson, 2016). Many studies and conservation efforts focus on restoring altered ecosystems to their historical states (Sanchez-Cuervo et al., 2012; Graham and Mcclanahan, 2013), but over the last two decades, the term "novel ecosystems" has emerged as a way of defining ecosystems altered by human activity, where restoration is at best unlikely (Hobbs et al., 2013a). There has been criticism that the concept may exclude restoration and may provide companies a license to trash ecosystems (Aronson et al., 2014; Murcia et al., 2014). However, the novel ecosystem concept is not intended to replace ecological restoration, but is meant to provide a management option for ecosystems where restoration is not feasible or may actually result in the loss of ecosystem value (Hobbs et al., 2014). In some cases, the novel ecosystem may provide ecosystem services that are more beneficial than those provided by the historical state. Backstrom et al. (2018) have suggested that the novel ecosystems concept is most useful in a decision or management context and in terms of meeting social, ecological and economic objectives.

The term novel ecosystems was first used in 1997 (Chapin and Starfield, 1997) but was introduced into terrestrial conservation and restoration ecology fields in 2006 (Hobbs et al., 2006). The concept has more recently been adopted by some marine ecologists, where studies on marine novel ecosystems have generally focused on coral reefs which have been altered by direct human activity, disease, climate change or introduced species (Graham et al., 2013, 2015; Yakob and Mumby, 2013; Hehre and Meeuwig, 2015). However, the concept has not yet gained significant traction amongst marine ecologists. Schläppy and Hobbs (2019) provide a comprehensive decision-making framework for applying the novel ecosystems concept to altered marine ecosystems. This framework creates a mechanism for the novel ecosystems concept to be more widely applied to marine ecosystems in future. While Schläppy and Hobbs only briefly discuss offshore platforms, Sommer et al. (2019) suggest that the ecosystem-level shifts occurring around offshore platforms are "consistent with the science on. . . novel ecosystems." However, while drawing parallels between offshore platforms and novel ecosystems, the authors do not explore the concept further, nor do they discuss the application of the concept to some or all offshore platforms.

The degree to which offshore platforms can usefully be considered a novel ecosystem may assist in assessing decommissioning options. Offshore platforms can be broadly assessed in a novel ecosystems context by evaluating these platforms against the criteria outlined in the most recent novel ecosystems definition from Hobbs et al. (2013b):

> Criterion 1: *The abiotic, biotic and social components of the system "differ from those that prevailed historically."* In the case of offshore oil and gas platforms, the abiotic and biotic states of the target ecosystem have clearly been altered due to anthropogenic forcing, specifically due to the installation of a large artificial structure and the associated disturbance of the ecosystem. Examples of this include the growth of cold-water corals on platforms in the North Sea (Gass and Roberts, 2006) and the aggregation of whale sharks around platforms in Qatar (Robinson et al., 2013) both of which are novel qualities not previously present in the historical state of the ecosystem.
>
> Criterion 2: *The ecosystems have a "tendency to self-organize and manifest novel qualities without intensive human management."* In the case of offshore oil and gas platforms, the marine life associated with offshore platforms is not managed in any way, apart from limited maintenance cleaning to remove sessile invertebrates. These ecosystems persist over the lifespan of the platform, with reports of thousands of tons of invertebrate growth on the subsea structures of platforms (Foster and Willan, 1979; Culwell, 1997). Novel qualities manifested by platforms include higher productivity of algae and invertebrates (Chou et al., 1992) and higher fish biomass (Love et al., 2006).
>
> Criterion 3: *Novel ecosystems are prevented from returning to their historical states by practical limitations, in the form of ecological, environmental and social considerations.* In the context of offshore platforms, these considerations can include many of the factors evaluated by stakeholders during the decommissioning process (**Table 1**). However, some considerations may be context specific rather than absolute, and vary among regions. For example, in California where there are relatively few platforms, their role in providing habitat for economically important species such as rockfish makes individual platforms ecologically important, particularly as some platforms produce more of these species than others (Schroeder and Love, 2002). Conversely, in an area such as the Gulf of Mexico with thousands of platforms, the ecological value of an individual platform within a regional context is not necessarily as high and therefore may not be an important ecological consideration (Schroeder and Love, 2004).

Environmental limitations could prevent the removal of offshore platforms, which means that the ecosystem cannot be returned to its historical state. Complete removal decommissioning is a potentially hazardous process both to the environment and personnel, and particularly in regions with harsh weather conditions, decommissioning could be more of a risk than leaving structures in place (Löfstedt and Renn, 1997; OGP Decommissioning Committee, 2012; Ars and Rios, 2017). Additionally, offshore platforms are known as vectors for invasive species, as they are transported long distances at low speed (Page et al., 2006; Pajuelo et al., 2016). The potential transport and spread of the many sponge, algae, coral, and even fish species associated with platforms, could be a factor preventing platform removal, and therefore restoration to historical state.

Perhaps the most significant consideration in the case of offshore platforms is the social aspect. Social factors could prohibit removal of platforms, due to prohibitive costs or platform design making removal unfeasible (Faber et al., 2001; OGP Decommissioning Committee, 2012). The social benefits derived from a platform, in the form of an artificial reef utilized by recreational divers and fishers, could be lost if the platform is removed. Conversely, social opposition to the presence of offshore platforms, as is the case in California (Pietri et al., 2011), or legislation prescribing complete removal, as is the case in Australia (Techera and Chandler, 2015) could lead to the complete removal of platforms, thereby possibly returning the ecosystem to its historical state.

It is important to avoid a blanket classification of all offshore platforms as novel ecosystems. Offshore platforms always result in the creation of habitat, but this does not by default mean that they result in novel ecosystems. For example, a platform placed near a natural reef may not significantly alter the abiotic or biotic components of the ecosystem, and may rather act simply as an "extension" of the existing reef. However, a platform placed in an area with little natural hard substrate significantly alters the abiotic nature of the ecosystem by increasing the hard substrate available, leading to changes in the community of species within the ecosystem, thereby transforming the ecosystem from its historical state.

The novel ecosystems concept can be applied to offshore platforms, so long as it is applied on a case-by-case basis. This is particularly important if the concept is used as part of the decommissioning process, as there may be incentive for energy companies to suggest platforms are novel ecosystems to avoid the costs associated with complete removal. The concept should therefore be applied conservatively and with robust evidence from ecological studies. Various studies have proposed decision analysis frameworks which assess different decommissioning alternatives based on multiple attributes (e.g., Fowler et al., 2014; Bernstein, 2015; Henrion et al., 2015). Some of these attributes can be placed within the novel ecosystems criteria as demonstrated in **Table 1**. Therefore, an assessment can be made of whether an offshore platform is a novel ecosystem simply by using existing decommissioning analysis tools. From an ecological perspective, decommissioning of offshore platforms is an ecological restoration issue. Novel ecosystems provides a tool for recognizing and retaining ecological value created through human activity, as an alternative to ecological restoration. In the same way, Rigs-to-Reefs provides the same tool, as an alternative to complete platform removal.

The decision framework for managing altered marine systems proposed by Schläppy and Hobbs (2019) would

TABLE 1 | Examples from the literature of practical considerations preventing offshore platform sites from being returned to their historical state.

Practical limitations	Example	References
Ecological considerations	Refuge for endangered and/or economically important species	Love et al., 2006
	Proportion of regional hard substrate provided by the platform	Love et al., 2003
	Attraction of fish from natural habitats, making them more vulnerable to fishing	Cowan and Ingram, 1999
	Risk of environmental contamination during removal	OGP Decommissioning Committee, 2012
	Highly productive ecosystem	Claisse et al., 2014
Environmental considerations	Spread of invasive species during removal/transport	Page et al., 2006
	Environmental damage caused by use of explosives during removal process	Kaiser and Pulsipher, 2003
	Disturbance of shell mounds and remobilization of toxic chemical contaminants	Phillips et al., 2006
	Cost of decommissioning	OGP Decommissioning Committee, 2012
Social considerations	Platform design making removal unfeasible	Parente et al., 2006
	Public support for Rigs-to-Reefs programs	Kaiser and Pulsipher, 2005
	Legal frameworks prescribing complete removal	Techera and Chandler, 2015
	Public opposition to the presence of platforms	Frumkes, 2002
	Obstruction to commercial fishing	Fabi et al., 2004

be a useful starting point for broadly classifying offshore platforms as novel ecosystems – however, because of the suite of complex, and in some cases contentious, issues surrounding oil and gas platforms, there are more factors that need to be taken into account. In this regard, the decommissioning decision analysis frameworks cited above could be used to assess a platform as a novel ecosystems even if decommissioning isn't yet being considered. For example, using the PLATFORM computer model for decommissioning analysis, Henrion et al. (2015) evaluated the impact of decommissioning options on attributes such as cost, benthic impacts, fish productivity, and water quality, all of which can be considered under novel ecosystems criterion 3 in this review.

CONCLUSION

Offshore oil and gas platforms play an ecological role for a wide variety of marine life, from corals and sponges (Gass and Roberts, 2006; Friedlander et al., 2014), to fish and sharks (Dugas et al., 1979; Schroeder and Love, 2002; Pradella et al., 2014), to marine megafauna (Robinson et al., 2013; Todd et al., 2016). At the end of their productive life, these platforms are generally removed completely and disposed of onshore, effectively removing the hard substrate and associated marine growth from an ecosystem that has developed over upward of 30–40 years (Driessen, 1986; Ferreira and Suslick, 2001). There is strong opposition to offshore drilling, and the negative perceptions of oil companies and their intentions is a big obstacle in the path of Rigs-to-Reefs programs (Löfstedt and Renn, 1997; Pietri et al., 2011). The costs of decommissioning offshore oil and gas infrastructure over the next 20–30 years run into the tens of billions of US dollars, with thousands of structures set to reach their end-of-life in this period (IHS Markit, 2016; Oil and Gas UK, 2017). In some countries, governments (and therefore taxpayers) cover some of the decommissioning costs; in the North Sea alone, this government expenditure could reach US $6.3 billion (Parente et al., 2006). Conversely, the ecosystems created by these offshore platforms have an intrinsic value in terms of fisheries, tourism, and conservation that cannot be ignored. As such, the ecological cost of decommissioning in the form of the destruction of these ecosystems must be an integral part of the decommissioning debate.

Based on the analysis of the novel ecosystems concept, many offshore oil and gas platforms can be defined as novel ecosystems, depending on a variety of factors. These platforms warrant further study, on a case-by-case basis, within the framework of novel ecosystems. This does not mean that restoration of these ecosystems should no longer be considered, as restoration may be feasible in many cases and therefore should be an option when a particular platform is to be decommissioned. However, classifying suitable offshore platforms as novel ecosystems allows for the recognition of the established, yet underappreciated, ecological value that these platforms provide.

The novel ecosystems concept can contribute to the consideration of decommissioning options using existing decommissioning decision analysis tools. Hobbs et al. (2017) proposed implementing a portfolio of approaches whereby management goals are based on the relative values of ecosystems. This approach recognizes the importance of altered ecosystems, while still allowing for conservation of high-value unaltered ecosystems. Applying this approach to decommissioning would involve identifying ecologically important platforms to be left in place for the ecosystem services they provide, while focusing decommissioning resources and effort on less ecologically valuable platforms.

One of the key arguments against novel ecosystems is that they give companies a "'license to trash' or 'get out of jail' card" (Murcia et al., 2014). This echoes the core opposition to Rigs-to-Reefs; namely that it is simply an excuse for dumping at sea (Macdonald, 1994). This argument, in both cases, ignores the potential ecological value of anthropogenically altered ecosystems. While it is undeniable that companies benefit financially from

Rigs-to-Reefs programs, this does not automatically mean that these programs are environmentally detrimental. It should be possible to ensure that any Rigs-to-Reefs policy is robust and comprehensive enough to ensure that any reefing of offshore platforms will benefit the environment.

AUTHOR CONTRIBUTIONS

SE and JM conceived the study. SE wrote the first draft of the manuscript. All authors contributed to the manuscript revision, read, and approved the submitted version.

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