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# Rigs-To-Reef; Impact or Enhancement on Marine Biodiversity

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## Abstract

Decommissioning of offshore oil and gas platforms raises many complex issues to consider before accomplishing a successful strategy to undertake these activities in an environmentally effective, efficient and equitably safe manner not only for the operators and the regulatory authorities but for the physical and biological surroundings. There are many factors to evaluate and issues like liability, reputational risk, cost, cumulative impact, technical development, regulatory framework, and climate change would all have to be considered on a case-to-case scenario as opposed to adopting a regular strategy for all facilities. The debate is focused about whether the structure or facilities left in place or like an artifical reef habitat constitute valuable habitat and deliver ecosystem services, or in contrast impact the biological environment and should be removed. Some offshore facilities, although deployed as artifical reefs for a very long time, have not developed the diversity of benthic or fish assemblages comparable to that found on natural reefs. South East Asia hosts many aging offshore facilities and the shortage of decomissioning yards and a lack of policy framework and financial support play a big role in order to conduct these activities in a way that safeguard the environment and the biodiversity of the marine environment.

**Keywords:** Artificial reef; Asset; Biodiversity; Decommissioning; Ecosystem services; Habitat; Jacket; Platform; Sustainable development; Rigs to reef

## Introduction

Unproductive fields and current oil prices have led to an increase in decommissioning of upstream facilities and operators are now looking at different factors in order to safely close the fields and retire the assets. Oil and Gas fields are many times developed in areas with great Marine and Coastal Biodiversity resources. Biodiversity was defined by the United Nations Environmental Program [1] as the variability among living organisms and the interrelated and complex linkage within species, between species and ecosystems. Decommissioning of oil and gas infrastructure may affect the fundamental biodiversity at both the site of decommissioning and other interrelated locations.

Oil and Gas operations have been identified as among the world's most polluting industries according to *The 2015 World's Worst Pollution Problems* [2], consequently it is not only important but imperative to address issues related to decommissioning now before further activities in this sector adds additional stress to the environment already weakened by climate change and other human activities. In order to meet challenges in the upstream sector the Energy and Biodiversity Initiative (EBI) was formed in 2001 and ceased in 2007. The EBI was made up of leading energy companies e.g. Shell, Statoil, Bp and ChevronTexaco and conservation organizations, e.g. IUCN, TNC, FFI and The Smithsonian Institution and its aim was to produce practical guidelines, tools and models for integrating biodiversity conservation into upstream oil and gas development. Now when upstream activities are about to cease, the industry is missing these important guidelines and initiatives, nevertheless must deliver the decommissioning activities in an environmentally effective, efficient and equitably safe manner not only for the operators and the regulatory authorities but for the physical and biological surroundings. One issue that derives from applying decomissioning activities is whatever the different decommissionings options may impact differently on the environment and the related biodiversity and bidiversity functions.

When an oil and gas company is operating in areas that sustain high biodiversity they essentially integrate more considerations into the planning and decision- making process. These considerations may include latest and best scientific research, and community engagement to strengthen capacities and support transparency. As observed in many offshore concession areas, by prevention of human intrusion into the oil fields, the biodiversity and abundance is many times higher inside than outside the project area. These offshore areas function as marine protected areas and "no take zones" or as a network of small protected areas for source populations that may bring influx of organisms and richness to other areas. This indirect and positive effect of the assets would disappear for a particular location when the asset goes for onshore recycling or is converted in an artificial reef or disposed of in deep waters. These potential negative impacts on biodiversity from oil and gas decommissioning are difficult to estimate.

Decommissioning may impact directly and indirectly on biodiversity and the impacts may be caused both during and after decommissioning depending on the selected decommissioning option and the associated activities and other issues like technical expertise and methodologies. The direct impacts may be alleviated with mitigation measures drafted in the impact assessment; however the indirect impacts are difficult to estimate quantitatively or qualitatively and may have a large impacts (positive or negative) resulting in changes to the local food webs either through bottom-up or top-down related feedback. Because of this it is important to understand the potential impact on biodiversity of different decommissioning options. Impacts on biodiversity, whether negative or positive, can be monitored using indicators, which provide a measure of change in the surrounding environment. Without an establishment of these parameters and in the absence of a consistent regulatory and policy framework, decommissioning programs are left

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to develop site- or country specific guidelines. The question remains as to whether companies are willing to go beyond minimising impacts and to take actions that benefit biodiversity. Addressing biodiversity issues early can help a Company to reduce risk and enhance both Company reputation, stakeholder's agreement and safeguard the environment. Alternatively, poor performance may result in costly project delays and damage to a Company's reputation.

Biodiversity and biodiversity conservation is recognised as a key factor that contributes to healthy ecosystems in environmental management. The main idea of environmental management is to safeguard and enhance the environment, as well to sustain economic and social benefits from the ecosystems [3]. Legislation increasingly reflects this importance; however there are many capacity gaps and insufficient legislation worldwide to address the importance of protecting biodiversity. How operators integrate biodiversity considerations into their management systems and operations varies widely. In some countries, the process is managed by government agencies, while in others the responsibility is assumed by the private sector. Often there is a requirement to develop an approved Environmental and Social Impact Assessment (ESIA) but that does not always assure a high level consideration of biodiversity matters with any particular benchmark to be met even in highly sensitive and vulnerable areas. A commissioned Net Environmental Benefit Analysis (NEBA) or Best Practicable Environmental Option (BPEO) assessment often accompanies an ESIA but this may still not necessarily apply the right weighting and importance to the environment being impacted. As such, the energy companies responsible for decommissioning aging infrastructure may be left without policies and enforcement of laws to perform only to high environmental analyses.

## Decommissioning

Decommissioning entails severals steps designed to safely retire facilities or processes that are no longer needed. Equipment and structures are cleaned and secured so that the facility does not pose a risk to public health or the environment. The general steps are:

1. Cessation of production

2. Plugging and abandonment (P&A) of wells and making them safe, and

3. Removal and disposal of redundant facilities

Generally, where decommissioning has occurred, oil and gas companies have sought to remove and/or recycle offshore platforms. This can be achieved via a number of different approaches including; complete or partial removal and recycling, re-manufacture or refurbishment, or re-use of the facilities for mariculture, aquaculture, breakwaters, development of platforms for renewable energy hubs (eg wind/wave turbines), rescue platforms, conversion to tourist hotels or artificial reefs.

The dismantling, removal and disposal of these facilities represents unique challenges and risks to decommissioning personnel and to marine ecosystems. In the North Sea the OSPAR convention [4] requires the removal of all assets; however in other areas of the world the assets may be left *in situ* or placed, as artificial reefs through a program often designates as a rigs-to-reefs (R2R). The decision to leave an asset in place may save the benthic communities establish on and around these facilities but will expose the environment to other risks. One important environmental concern from decommissioning is the release of contaminants [5]. In order to identify potential environmental impacts from asset abandonment, surveys are often needed to estimate key factors such as: level of biofouling; the state of external coating and stabilizers on the structure; seafloor conditions; and ecological populations. Many times these studies are not performed.

For example, the potential impact of mercury from produced hydrocarbons is an emergent issue and specific regulations with regard to residual mercury concentrations in production systems (either as scale or complexed in the grain-boundary of metals) are not currently available in all areas. Mercury adsorbs and chemisorbs to carbon steel surfaces, primarily through amalgamation and diffusion into the scale, making carbon and stainless steel excellent mercury scavengers. Other contaminants related to structures decommissioning include metals such as arsenic, cadmium, chromium, naturally occurring radioactive material (NORM) or technically enhanced radioactive material (TENORM). Other factors typically found in decommissioning materials can include precipitated materials such as microbial factors (MIC; microbes that induce corrosion), PH and temperature. Little is known when and how contaminants enter the food chain and bio-accumulate through decommissioning activities, although [6] suggested that contaminant levels remain unchanged within the sediment surrounding rigs unless disturbed. However, bio accumulative contaminants released through the decommissioning process would be expected to enter the food chain through typical bioaccumulation mechanisms.

## Rigs-To-Reefs

### Background

The application of artificial reefs has a long history, as early as in the seventeenth century the practice of placing sunken objects in the waters started in Japan [7]. Artificial reefs may vary from complex structures using a wide range of materials to simple structures. A succinct definition of an artificial reef can be found by Seaman et al. [8].

> *"An artificial reef may be described as one or more objects of natural or human origin deployed purposefully on the seafloor to influence physical, biological or socioeconomic processes related to living marine organisms."*

Furthermore, the term "reef" means different things to different groups. To geologists and paleontologists reefs are hard structure formations which have been built by organisms such as corals in the past but which may no longer be alive. To the biologist a reef is similar to submerged forest a complex and fragile ecosystem. For Oil and Gas operators an artificial "reef" is composed of natural or man-made structures such as steel structures from platforms. These can be either left "*in situ*", or transported to a new "rigs to reef" location [9]. This practice fo re-use of decommissionied platforms is referred to as Rigs-to-Reefs (R2R) and is somewhat controversial globally. Whilst R2R is commonly used in the Gulf of Mexico as an offshore decommissioning option, it is not considered as an option in all parts of the world. For example, in the UK and the North Sea, removal of offshore installations is generally perceived as the more desirable decommissioning option [9].

There are many variables to consider when selecting R2R as the best practicable decommissioning strategy including technical and non-technical risk as well as environmental health and safety performance. To evaluate if oil and gas structures are sustained as effective and functioning artificial reefs that provide ecological benefits and/or deliver ecosystem services is important, especially if artificial reefs or R2R programmes are going to be a common practice in the future in areas like South East Asia, that host the highest marine biodiversity on the planet.

## Ecosystem Services

Ecosystem services valued by the society are often underpinned by provisioning and cultural services, however ecosystem services may be divided into four categories

Millennium Ecosystem Assessment [10]:

- *Provisioning services* – products or goods such as water, fish, or timber
- *Regulating services* – ecosystem functions such as flood control and climate regulation;
- *Cultural services* – non-material benefits such as recreational, aesthetic, and spiritual benefits and
- *Supporting services* – fundamental processes such as nutrient cycling, biological production, and habitat

In order to determine the best outcome for a decommissioned strucure including R2R options, many key technical and non-technical risks must be considered as well.

## Technical Risk

Technical criteria for consideration should include the evaluation of the following on a case by case basis. The following Criteria for reefing is formulated by the national Artificial Reef Plan (NARP) in the US (Table 1).

### Removal and construction

- Material selection (e.g. stability and durability)
- Removal method and associated impacts. The most applied technology for removal of the structures from the seabed involves different cutting methodologies like the most applied, abrasive water technique. Other techniques involve diamond wire cutting, and the use of explosives. The concern over the use of explosives stems from their potential impact on sensitive seabed communities, sea turtles and marine mammals.

### Siting of the artificial reef or R2R location

Siting or determination of the location of the artificial reef is one of the most important factors to evaluate and plays a significant role in influencing the success of reef establishment. Atchinson et al. [11] showed that the genetic affinity of coral population decreased with distance from natural source habitats, this led to the determination of the minimum distance (≤65 km) of reef placement to intercept larval recruitment. These criteria often limit the number of structures that can feasibly be considered for rigs to reef programme as a part of a decommissioning strategy. Access to larval sources for recruitment of new individuals plays a key role in determining the success of the reef. Other factors that are important include: oceanographic conditions (e.g., wave height, water depth, currents); water quality (e.g., turbidity, pH, salinity); geographic criteria (e.g., proximity to river input, proximity to natural reefs, fishing zones), and geological aspects of the site (e.g., substrate, deposition, erosion, sediment quality).

| Criteria | |
|---|---|
| Material Selection | • Function<br>• Durability<br>• Stability<br>• Compatibility |
| Management | • Maintenance<br>• Monitoring |
| Siting | • Biological<br>• Water quality<br>• Hydrography<br>• Wave height<br>• Water depth |
| Construction | |
| Liability | • Transfer of liability |
| Source: National Artificial Reef Plan (NARP), US, 2015 | |

**Table 1:** Criteria for reefing of facilities according to national artificial reef plan (US).

## Non-Technical Risk

Whilst there are significant costs associates with complete removal of offshore structure the costs associated with artificial reefs creation are also substantial, but neverthless minor.

### Technology development

The potential exists that more suitable removal and/or disposal facilities and techniques will be available in the future to support new development, resulting in reduced environmental impacts and enhanced benefits.

**Cumulative impacts:** Environmental impacts may be minimised if related activities could be spatially and temporally phased, such that impacting activities are not repeated in the same area for allowance of recovery and possible re-colonisation.

**Changes in legal requirement:** It is likely that legal requirements, policy framework, guidelines and standards with regards to decommissioning activities may change, as might the management of legacy issues. Traditionally, environmental legislation regarding decommissioning has become more stringent with the years and is expected to continue to do so for a foreseeable future.

**Climate change:** Decommissioning activities would add additional pressure to an area that at the same time are experiencing climate change event. Moreover, some of the predicted climate change impacts like increased water temperatures, acidification and intensification of storm events; provide a more hostile natural environment for the artificial reef to thrive. In addition, an increase in number and strengthening of storm events and ocean acidification may accelerate degradation of the assets placed as artificial reefs and not only contaminate the natural reefs but impact them physically by breakdown.

**Robustness of regulatory management framework:** Although a country's regulatory framework may allow for implementation of R2R programmes as a part of the company's decommissioning strategy it is important to understand the supporting regulatory framework in place for ongoing management of the artificial reef, once established. Well established policies and management plans need to be developed, and implemented by government regulators to ensure that the viability of the artificial reef is sustained over the long term. This also requires significant commitment and investment in enforcement resource by Government.

**Stakeholders interest:** Stakeholder interests (e.g. shareholders, non-governmental organisations, Government, the fishing community, recreation groups etc.) may increase in the future. More stakeholder groups may find interests in the areas or establish new projects, each with differing opinions and therefore possibly interfere with future decommissioning activities and options.

Aquaculture projects are many times established in close vicinity to offshore assets in South East Asia and seabed contamination is of big concern.

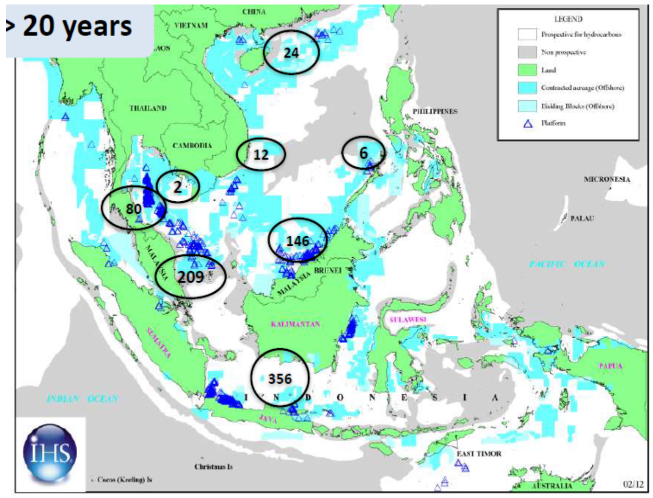
**Reputational risk:** Many of the technical and non-technical risks described above have the potential to expose oil and gas companies to reputational risks. In particular, the likely increased interest by stakeholders in future decommissioning could heighten the risk of reputational impacts.

**Liability:** There are many ongoing discussions about the regulatory process associated with decommissioned assets. Concepts like ownership and liability are being evaluated and the transfer of assets between private and governmental stakeholders is pending due to not only a lack of guidelines, but funding to maintain and monitor the structures accordingly. Liability remains for the decommissioned assets placed as an artificial reef or left "*in situ*". However, the risk of liability differs depending on the decommissioning option selected and the location. Liabilities of relevance include the potential for residual material or contaminants to leak (resulting in the need for clean-up), or as a result of snagging of fishing gear (resulting in claims for compensation), or collision of fishing boats. Some jurisdictions have attempted to address this issue recently. For example, in the USA, California has recently developed regulation requiring a portion of the cost saving associated with various leave-in-place options to be paid to the State for liability/ownership transfer. This, however, does not include liability on existing well infrastructure for any future leakage or spills. Other approaches involve transfer of liability or acceptance of ownership to other entities e.g., local governments; non-profit trusts; limited liability companies; or other private organisations.

## Case Studies

### South east asia

Industry databases reveal that the seas of Southeast Asia, which include the South China Sea (SCS), the Gulf of Thailand and the Sulu-Celebes Sea, host 1,390 offshore oil and gas platforms. Of these, more than 800 are over 20 years old, and close to 400 are more than 30 years old (Figure 1) [12]. In the Asia-Pacific region there are 1,800 offshore oil and gas platforms and since 2000, more than 800 structures have been installed in over16 countries [13]. Indonesia, Thailand, Malaysia and Brunei Darussalam are the Southeast Asian countries that have jurisdiction over the largest number of these obsolete platforms.



Source: National University of Singapore [9]

**Figure 1:** Offshore facilities mayor >20 years offshore South East Asia.

**Thailand:** Thailand has more than 80 offshore installations that are 20 years old or older [9]. The Thailand Department of Mineral Fuels (DMF) is the chief regulatory body and this department has developed together with industry partners the Guidelines for the Decommissioning of upstream exploration and production facilities. DMF has commissioned to develop a manual for the decommissioning environmental assessment. Thailand takes stakeholder engagement very seriously and the decommissioning processes that are currently undergoing discussion in Thailand will serve as a template to replicate in other areas of South East Asia. Thailand has created an Artificial Reef Committee with the main objective to manage overfishing and resource depletion. The Artificial Reef Committee allows use of legislations of Fisheries Department and Marine Department to issue permits relevant to fisheries alteration and construction of any structures in water. Moreover, in South East Asia, Thailand is the only country that legally addresses the handling and disposal of mercury waste [14].

**Malaysia:** In Malaysia, of the 300 fixed offshore platforms located in shallow waters, 60% are nearing the end of their production life [15]. Malaysia lacks governing legislation for decommissioning. The 2008 PETRONAS proposed Guidelines for Decommissioning of Upstream Installations [16] is the only framework in Malaysia that requires "*decommissioning of facilities to be evaluated on a case by case basis based on the standards imposed*". The PETRONAS Guidelines [16] are very much based on key international conventions such as the London Dumping Convention1972/1996 [17] United Nations Convention on the Law of the Sea [18]; and the International Maritime Organizations (IMO) Guidelines and Standards [17]. The Guidelines are revised every three years and includes a BPEO and an Environmental Management Plan (EMP) as per [19].

In Malaysian waters there has been one major R2R programme implemented to date. Baram-8, now well known as the Kenyalang Reef, was the first R2R developments in the South China Sea. The conversion of Baram-8 to an artificial reef was requested from the local fisheries department. The toppled structure was relocated to shallow water depth of around 20 metres after it collapsed 25 nautical miles offshore. Decommissioning first started in 2001 after intensive consultation with external stakeholders (e.g., local fishermen, local councils, etc.) and approval from the National Oil Company PETRONAS. A post-decommissioning study in 2005 conducted by the National University of Singapore and the Fisheries Research Institute [20] showed the presence of invertebrate populations of *Polychaeta*, *Crustacea* and *Mollusca*. Another marine survey in 2012 [20] found that the sunken Baram-8 platform hosts populations of soft corals of the family *dendronephthya,* and some fishes, however, there has been very few published monitoring studies of the success of the R2R programme. Baram-8 associated benthic assemblages is still in a premature stage and more research on post-decommissioning development of R2R areas is needed. Other decommissioned platforms in Malaysia have adopted onshore disposal for the jacket as the primary option identified in BPEO studies, however recent studies do consider the R2R programmes as feasible.

**Brunei Darussalam:** In Brunei Darussalam, offshore oil and gas production fields comprise a total of 1,407 wells, 214 platforms and 2,160 pipelines, and of these 212 wells, 15 platforms and 795 pipelines are subject to decommissioning and restoration activities. The current guidelines for Decommissioning, Abandonment and Restoration of the Oil and Gas Industry Assets in Brunei Darussalam, dates from 2009 and this guideline is still in a draft format The Energy Department Prime Minister's office (EDPMO) will replace this document with a new version of the guidelines. Brunei hosts several artificial reefs in different locations and studies [21] reveal different benthic and fish assemblage success, according to their relative location and fishing pressure. Additional studies of the ecological performance of artificial reefs in Brunei Darussalam are needed to more accurately understand how these reefs function.

**Indonesia:** Indonesia represents less than 1% of the world's oil and gas production, but a recent report stated that Indonesia has the largest proportion of ageing platforms in Asia-Pacific with approximately 450 offshore oil rigs in Indonesian waters, three quarters of which are more than 20 years old [22]. These old offshore installations are mostly located in the archipelagic waters, with only a small number within their exclusive economic zone. There are currently no decommissioning regulations in place and many production contracts were signed 20 - 30 years ago with no agreement as to how or when decommissioning should happen other than that it should take place "at the end of life" of a well. In Indonesia there is currently no planned artificial reef or R2R programmes in place [23], however recreational dive operators on several islands are interested in the R2R programme for tourist and sport diving sites.

**Other areas:** The Association of South East Asian Nations (ASEAN) has prepared the ASEAN Council of Petroleum (ASCOPE) Decommissioning Guidelines (ADG) for Oil and Gas Facilities [24]. According to criteria in an approved decommissioning plan, the operator has to address all the necessary resources to carry out decommissioning activities to ensure the achievement of safe operations and with limited impact to the environment. If there is any deviation from the plan, the operator has an obligation to report to the country authority agent for re-approval of the revised plan. Furthermore, operators shall prepare report to summarise post-decommissioning activities with inclusion of a lesson learnt for recording as a country database and further improvement of the decommissioning activities. The main objective with these guidelines is to achieve a high standard of decommissioning activities to ensure safe operations, environmental friendly procedures, cost effectiveness, and protection of the rights of other stakeholders of the sea. The operator has to prepare and address all required steps for the approval process aligned with the global conventions and guidelines, but specific requirements of the approval process depends on the country authority agency.

**United States:** The United States hosts the largest R2R programme in the world, the Louisiana Artificial Reef Program. In America by law, various coastal states and the federal government share the administration of submerged lands and seabed off the United States. Responsibility for the fate of platforms in Federal waters rests with the Bureau of Ocean Energy Management, Regulation and Enforcement (BOEM). Hence, depending on where platforms are positioned, it's either under State or Federal jurisdiction, although the final decisions are based on consultation and mutual agreements among a number of agencies. State agencies do not have jurisdiction in federal waters but may comment in the decision-making process. Federal agencies that are consulted in the decommissioning process include the: Environmental Protection Agency, Army Corps of Engineers NOAA (National Oceanic and Atmospheric Administration) Fisheries and the Coast Guard. Decommissioning activities are also subject to the National Environmental Protection Act (NEPA) and the Coastal Zone Management Act which is reviewed by an appropriate State agency for consistency with the state's coastal zone management programme.

Traditionally, R2R was easy to implement but developments in 2011 via the United States Congress and the Texas State legislature (through the National Fishing Enhancement Act and Chapter 89, Texas Parks and Wildlife Code respectively [25] sought to limit liability during artificial reef establishment. This new directive requires that oil and gas companies remove non-producing platforms rapidly, within five years of cessation of production. The initiative was aimed at cleaning up what the industry calls "idle iron" (i.e., inactive wells and platforms that pose hazards to shipping). These inactive platforms present some of the greatest risks of leaks and accidents after storms. This new directive was prompted by damage from Hurricane Katrina in 2005 and came just months after the Deepwater Horizon well blowout that discharged millions of barrels of oil into the Gulf in 2010. Conversion of R2R can still be adopted by enforcing the newly created Rigs to Reef Habitat Act, 2013 that outlines several steps to be taken, including removal of the top decks, maintaining an anode system and navigation aids, and paying into a Reef Maintenance Fund created by the Rigs to Reef Habitat Protection Act. In terms of liability it is assumed that the state maintains ownership for the donated platforms and manages them as part of the state's asset as waste or as artificial reef.

In California**,** laws used to require the operators to remove the structures entirely and to restore the seabed to its pre-drilling condition. But in 2010 a new bill regarding decommissioning of oil and gas facilities was enacted, and under the "Assembly Bill 2503" the States may authorise platform operators to leave facilities at least partially in place to form "rigs-to-reefs". The bill enables provision for a public hearing to review the environmental documents.

All partial removal projects must comply with the California Environmental Quality Act (CEQA), which requires agencies to evaluate all potentially significant environmental impacts of a proposed project, consider alternatives to the project, and mitigate all significant impacts to the extent feasible. Under AB 2503 the State must take ownership of any platform in federal waters before it may be partially removed and the State becomes responsible for development of management plans and their implementation. The owner or operator retains continuing liability associated with seepage or oil spill and moreover, the operator must agree to indemnify the state against any liability claims, including "active negligence", costs of defending against those claims. This indemnification may take the form of insurance policy, cash settlement etc. A portion of the "*cost savings resulting from the partial removal of an offshore oil structure compared to full removal of the structure*," must be paid to the state before approval, together with funds for all the State's activities relating to the decommissioning procedure, as well as "*sufficient funds for overall management of the structure by the department*." The law has been heavily debated as it suffers from apparent major flaws that cast doubt on its ability to evaluate potential R2R conversions based on sound legal, scientific, and policy principles. To date, AB 2503 remains in place but has not yet been implemented.

## Rigs to Reef Enhancement and Impact to Marine Biodiversity

The generic rule for reef planning is to first establish objective or goal of the artificial reef [26]. The primary focus of development of artificial reefs globally is to augment marine habitat to develop additional ecological resources [27-30]. This is important because marine resources have been declining all over the world since the 1950s [31,32].

Management of biodiversity is often equated with the management of biodiversity services [5]. Ecosystem services associated with R2R are often related to provisioning services (marine resources) or cultural services (recreational activities e.g., fishing) and other biodiversity values and services are heavily underrepresented. This is includes the supporting services which are vastly under studies. In addition, to provisioning and cultural services, some scientists debate that R2R create new food webs and that these promote marine biodiversity [33] and artificial reef would further enhance ecosystem supporting and regulating services. However, recent studies have concluded that R2R and other artificial reef systems likely do provide important supporting services such as biodiversity and biomass production [34].

The most common arguments for artificial reef deployments are:

- Creation of new habitat
- Restoration of damaged habitat and
- Protection of valuable habitat

## Creation of new habitat

Artificial reefs create new habitat for marine organisms and the difficulty is to understand the ecological value or impact that may have on the surrounding fauna and flora. This development of new habitat results in both increases in abundance of organisms through attracting nearby organism to the new habitat [35], and ultimately through production of new biomass as the reef matures and develops [34,36].

New reef habitat indisputably increases the local fish and invertebrate abundance and acts as a fish aggregation device (FAD) that can be exploited by the fishermen. Increased fishing pressure may therefore contribute to decreased fish stocks in the long run. Artificial reefs attracts fish and other organisms because they provide shelter from currents and predators, reproduction and incubation sites and artificial reefs supply reef associated organisms' attachment, a point hard elevated substrate that give further access to plankton and light.

The complete removal of the subtidal infrastructure during decommissioning will unquestionably impact the ecological resources currently living on and near the jacket, but the environmental costs and benefits of artificial reefs deployment in the long term are not as clearly defined. In contrast to mobile fauna, many adult marine invertebrates cannot be attracted to artificial reefs due to their localized or sessile life history. Therefore, colonization and growth of such organism will likely represent only small increases in biomass initially. As a reef develops and matures, recruitment of invertebrate species through larval settlement contribute to increases in secondary production of these species. For example, macro algae and nearly all major invertebrate taxa, including corals, anemones, hydroids, sponges , sessile bivalves, intertidal molluscs, and polychaetes have all been observed on artificial reefs [37-39].

Some researcher maintain that R2R serve as an important spawning grounds and nursery habitat for fish and colonization areas for epifauna such as barnacles, bivalves, and sponges [21,40,41]. The endangered hawksbill turtle (*Eretmochelys imbricata*) has been often observed foraging in close vicinity of the artificial reefs site in offshore Borneo [42]. Other scientist have argued that by placing an artificial reef, the water currents are altered around the facilities and therefore enhance the feeding opportunities for organisms, especially if reefs are placed in areas with strong currents [43]. A flowing water mass through artificial reefs may attract fishes that feed on plankton; this has been observed on many occasions with high numbers of fusiliers (*Caesionidae)* present around the assets [21]. Moreover, R2R provide shadowy crevices to hide for large predatory fish and the rigs also supply invertebrates and smaller fishes, hence increase the diversity of food for predatory fishes [44-46]. Many large transient predatory fish are often observed in close vicinity to the rigs deployed as reefs offshore Borneo [21]. Other fish observed associated with the structures included wrasses (*Labridae*) and threadfin breams (*Nemipteridae*).

It was also detected that many fishing nets were found around the structures in Borneo and that the reefs attracted more recreational fishermen if they are placed in shallower waters. These studies have found that although deployed for a very long time, they have not developed the diversity of fish assemblages comparable to that found on a natural reef. This fact may potentially be due to the heavy fishing pressure at these reef locations.

An assessment was carried out in the Gulf of Mexico to compare the success rate of biofouling communities inhabiting the structures of decommissioned assets [47]. In the study the structures were compared in relation to their distance from shore. The authors found that the benthic communities in the nearshore or shallow zones were dominated by molluscs and sponges, with hydrozoans and algae as secondary species. The near shore community biodiversity was high, but taxonomic richness was low.

The study reported that vertical zonation on platforms was the most important factor in determining what biofouling communities dominated the structure not the distance from shore. This study highlights the fact that simply reefing in shallower water does not increase benthic assemblage success rate as much as does the three dimensionality of the reefed structure through the water column.

It has been noted that fish density and biomass are about one order of magnitude higher, around a working platform than one converted to an artificial reef, either toppled, "*in situ*", partial removal or placed as rigs to reef [33]. To study the effect reefing a platform plays on the surrounding fish communities [33] observed the communities associated with a toppled, partially removed, and standing platform. The standing platform was characterised by the same type of community of fish that was observed at other structures in similar water depths. Time of day and depth stratum severely affected the fish communities structure and distribution however, the density patterns did not follow a predictable pattern and were likely site-specific. Fish density and fish size are greater near the surface than the bottom, and it was determined that fish communities are most likely found shallower than 30 m to the surface on either the toppled or partially removed platform.

Studies of the decommissioning of platforms in California demonstrated that residual shell mounds (i.e., the shell debris accumulated over the life of the platform) on the sea floor around areas where platforms were fully removed were more productive than the surrounding soft bottom areas [48-51]. In these studies it was found that the shell mounds functioned similarly to a natural reef and contributed both fish and invertebrate production at the decommissioning site. These studies demonstrate that even with minor augmentation of soft bottom resources, when applied correctly, hard structure can result in increased ecological value and services.

To determine that marine enhancement is provided efficiently by establishment of rigs to reef, United States requested the Gulf of Mexico Fishery Management Council to designate oil and gas platforms as Essential Fish habitat, (EFH). The term "essential fish habitat" is defined under the US Magnuson-Stevens Fishery Conservation and Management Act (MSA) and refers to waters and substrate necessary for fish to spawn, breed, feed or grow to maturity. Essential fish habitats are those necessary to maintain fish production consistent with a sustainable fishery and the managed species contribution to a healthy ecosystem. Based on this, the Gulf of Mexico Fishery Management Council decided to appoint an ad hoc Advisory Panel in 2012 that comprised members of the oil and gas industry, members of state artificial reef programs, and recreational and commercial fishing interests to review the issue in the near future. At this point, a decision has not been made on designating artificial structures as EFH.

In addition, a study co-authored by The Select Scientific Advisory Committee on Decommissioning, a team of scientists from several campuses of the University of California concluded that "*in light of the lack of strong evidence of benefit and the relatively small contribution of platforms to reef habitat in the region, evaluation of decommissioning alternatives in our opinion should not be based on the assumption that platforms currently enhance marine resources*" [52].

Despite this, platforms, while not specifically designed as artificial reefs have been shown to provide reef-like habitat and support secondary fish production. In a detailed study of offshore platforms in California has shown the secondary production of marine resources including fishes and invertebrates on existing platforms are among the highest observed in marine habitats, globally. In this study the ecological resources secondary production were measured at platforms located offshore of southern California over a 15 year period.

The effect of artificial reefs on sediment physicochemical characteristics, benthic communities and trophodynamics are poorly studied [53]. While there exists much information on how artificial reefs perform in coastal areas in relation to fisheries resources, fewer studies address the response and impact of reef placement on seabed communities. Similarly, not everyone supports the contention that placing a reef on a soft bottom environment increases biodiversity simply by its placement. What it does is to facilitate the replacement of the biodiversity associated with a soft bottom habitat with that of a hard structure reef, and if placed in an area which is important for sandy-bottom species, may actually have a negative impact by displacing or smothering the soft bottom organisms [54].

The physical presence of artificial reefs on the seabed can create environmental changes due to changes in the hydrodynamic and sedimentation regimes [55,56]. Many colonised epifauna on an artificial reef are filter feeders that remove suspended particulate matter from the water column and produce faecal pellets. These pellets are released into the water and settle on the seabed. Filter feeders therefore act to selectively enrich the organic content of benthic habitat through this trophic transfer mechanism [57]. By doing this the organic constituents in the water body is reduced and bio filtration occurs [58,59]. Filter feeders play role in in process of nutrient recycling therefore artificial reefs have been called "biofiltration units" [60,61]. Hence nutrient flux are modified and new and complex food webs are created by changing the density and granulometry of particles and leading to change in the physicochemical characteristics of nearby environments, which lead to changes in food availability quantity and quality [57]. The sediment and the benthic organisms interact and the possible new production of both nitrogen and phosphorus, which are essential nutrients for marine productivity, may also cause eutrophication and give birth to toxic blooms. Studies have shown that macro benthos surrounding R2R locations generally exhibits a stronger response to variation in sediment granulometry with increase in faunal abundance and diversity [62]. The role of artificial reefs improvising increased secondary production needs to be further studied, particularly in the tropical regions.

Reefing of platforms may contribute to changes in water quality, water circulation, wave action, sedimentation rate, seabed ecology and chemistry that indirectly affects marine environment and biodiversity in a way yet not estimated and properly assessed. Moreover, there are reports of invasive species associated with platforms in California [39]. Developing R2R or other artificial reefs may facilitate invasive species settlement by offering unoccupied habitat for colonisation [63,64] in particular if they are close to major shipping lanes. Love et al. [65] predicted that the loss of a single rig structure from southern California would be equivalent to removing as much as 13 ha of average producing natural habitat in southern California for cowcod (*Sebastes levis*) and 29 ha of fish producing biomass for bocaccio rockfish (*Sebastes paucispinis*). These data are supported by the conclusions of [34] related to fish production at platform sites in California. Similar studies need to be conducted in tropical environments before these conclusions can be translated from the temperate waters of California to other systems. It is important that environmental managers and oil and gas operators keep the geographical setting in mind for artificial reef creation. Differences in width of continental shelf, temperature, fish communities and seabed structure will all play a role in the function and establishment of the artificial reef, hence research outcome are likely to be site specific

### Restoration of damaged habitat

A R2R programme provides the opportunity to place rigs in locations that may maximize ecological benefits. Knowledge of larval dispersal trajectories [66] could allow the strategic placement of R2R sites to increase recruitment success and retain larvae that otherwise would be "lost" to inhospitable substrates. Other arguments for the artificial reef placement claim that the facilities restore areas of damaged habitat and provide an alternative in areas where coral bleaching or other impacts have heavily impacted and reduced habitat for fish, sea turtles etc. Some environmental managers are concerned about restrictions and safety issues resulting from leaving obstructions in the water and potential damage and impact to the natual environment especially under the threat of climate change. Furthermore, if artificial reefs are placed in an ecosystem that is severely overfished, it is likely that recruitment and reef development may be severely impacted due to continued high fishing pressure. In southeast Florida despite construction of artificial reef habitats that would be ideal for economically important, in many cases the most abundant and greatest fish species biomass was represented by grunts (*Haemulidae*) [67-69].

### Protection of valuable habitat

Rigs themselves have been described as "de facto marine protected areas" [70] because they exclude trawl fishing and their large internal spaces offer shelter to fish and other marine organism. Artificial reefs are many times deployed with the intention to be used as barrier and protect natural habitat from overfishing e.g., reduce the impact from trawling; however there are little research on the efficiency of this. Many artisanal fishermen use illegal fishing methodologies like explosives or poison (e.g., cyanide) in South East Asia and many foreign vessels are often found trawling illegally in designated protected areas. It is clear that the placement itself of an artificial reef is not enough to provide protection of the natural habitat areas without regular surveillance and monitoring. Moreover, the artificial reef sector is moving away from materials of opportunity to designed reef modules, based on good engineering and sound biological research [71].

## Conclusion

While it is clear that R2R can and has been deployed in specific areas around the globe, it is clear that more information is needed to fully understand the impacts and benefits of such programs. The environmental issues and considerations discussed here needs to be taken forward and considered alongside with new research and technology to safeguard and conserve the marine biodiversity in the event that the decommissioning plan identifies R2R as their best decommissioning strategy.

In the absence of supporting guidelines in many jurisdictions it is important that these be addressed prior to development of a R2R programme. Development of suitable guidelines and regulations needs to have input from all stakeholders including industry, government, and public resources. These should also take into consideration all impacts including climate change in addition to the sustainable feasibility and liability of the R2R program. The most important aspect for consideration in development of guidelines is the establishment of suitable locations for R2R in local geographies. As shown in this study, simply building a reef is not sufficient, but it needs to be developed in the most advantageous location to achieve enhancement of the marine ecology and minimise the impact. Without this forethought and research, the reef has a low probability of success. Artificial reefs or R2R deployment is only viable after a process assessing these different factors and criteria, and with consideration of the trade offs of priorities, location, environmental risks and biodiversity conservation. There are still many uncertainties around the development of R2R programmes that require additional research before full -scale reefing efforts in developing areas such as South East Asia begin.

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