Scientific Literature Review

Environmental Impacts of Decommissioning Options

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Executive Summary

The Australian Petroleum Production and Exploration Association (APPEA) commissioned a scientific literature review of the environmental impacts of decommissioning options, to support industry and stakeholder understanding of relevance of existing decommissioning literature to Australia.

The key objectives of this study were to review relevant literature and technical studies with regard to:

- Decommissioning options and techniques;
- The impacts of oil and gas infrastructure on marine biodiversity;
- The risks and benefits of decommissioning options to biodiversity, fisheries, shipping, tourism and human health;
- Potential impact controls and environmental monitoring considerations for decommissioning; and
- Frameworks for the assessment of decommissioning options.

Legislative Influence on Decommissioning Options

A review of relevant legislation from the key decommissioning jurisdictions found that statutory requirements influence operators' selection of decommissioning options.

Australian regulations do not currently provide guidance with regard to which decommissioning options could be considered acceptable and under what circumstances (Techera & Chandler 2015). In accordance with Section 270 of the *Offshore Petroleum and Greenhouse Storage Act 2006* (OPGGS Act), the titleholder can only surrender a title if it has removed all property to the satisfaction of the National Offshore Petroleum Safety and Environmental Management Authority (NOPSEMA), or made arrangements that are satisfactory to NOPSEMA in relation to that property. A review of previously decommissioned infrastructure found no clear decommissioning precedents.

Decommissioning Options and Techniques

A review was undertaken of decommissioning options and techniques relating to the various components of oil and gas infrastructure, including:

- Surface infrastructure - Concrete and steel platforms including topsides and jackets;
- Floating installations - Floating production facilities and floating production storage and offloading vessels (FPSOs);
- Subsea systems - Wellhead, production manifolds, anchors, concrete gravity structures (CGS), mattresses;
- Pipelines; and
- Risers and turret moorings.

Information reviewed included the basic methodology, equipment needed, timeframes, approximate costs and technical considerations relating to various decommissioning options and techniques. These decommissioning options fell into the major areas of leaving the infrastructure in situ, partially removing the infrastructure, or removing it entirely. Examples of various options were also captured.

Influence of Oil and Gas Infrastructure on Marine Biodiversity

As part of this review The Decommissioning Ecology Group (DEG) provided access to the most relevant research and international studies to determine the influence of oil and gas infrastructure on marine biodiversity. Few local studies providing an Australian perspective exist on the impacts of oil and gas infrastructure on marine biodiversity, however several studies have been undertaken in the Gulf of Mexico, Southern California and the North Sea. Comparative studies involving other natural and man-made submerged infrastructure were also reviewed.

Several studies document the benefits of oil and gas infrastructure has on marine biodiversity. However, it is important to recognise that such benefits are dependent on a number of factors, such as the proximity of oil and gas infrastructure to natural reefs, the level of shelter and protection offered by the structure, and the type of species present in the area. It is also worth noting that certain species recruit to artificial structures at different stages in their lifecycles, which influences the level of benefit provided by its presence. In summary, the current body of relevant literature has provided evidence of the following:

- Artificial structures act as fish attracting devices for a number of adult, larval and juvenile fish, including commercially significant species;
- There are recorded instances of larval and fish recruitment to artificial structures. Artificial structures can intercept larvae in the plankton that would otherwise be lost from the ecosystem, and site fidelity of certain species also provides evidence of fish recruitment;
- Artificial structures may provide shelter, protection from fisheries and natural protection, thereby enhancing production levels of certain species within a region;
- Artificial structures can provide spawning habitat for certain species and may increase larval production within a region;
- Biodiversity value varies between different types of structures. Factors that influence biodiversity include structure type, depth relief, age and location; and
- The presence of artificial structures may increase the biodiversity of a region via the following mechanisms:
  - Providing increased hard substrate to the marine environment, thereby supporting a greater diversity of marine life through providing habitat for fish and other invertebrates that otherwise would not exist in a soft substrate environment ;
  - Providing high local relief. Species vary with depth along platforms, hence vertical orientation of platforms can increase local biodiversity; and
  - Providing a location for larval dispersal further from shore. Larval dispersal distance is greater from offshore platforms than nearshore habitats as offshore platforms are located

in deeper water and thus experience enhanced dispersal due to higher sustained larval flows in the offshore environment.

Risks and Benefits of Decommissioning Options

The risks and benefits of decommissioning options were assessed with regard to potential effects on biodiversity, fisheries, shipping and human health. Decommissioning options that were considered included:

- Leaving infrastructure in place;
- Partial removal; or
- Complete removal.

Risks associated with leaving infrastructure in place include:

- Corrosion of infrastructure resulting in the release of contaminants to the marine environment;
- Potential damage to fishing equipment including snagging hazard; and
- Navigational hazards to shipping

Existing literature provided information on the potential benefits of leaving oil and gas infrastructure in place to local and regional marine biodiversity, such as increased biodiversity and production.

Leaving infrastructure in place can also benefit fisheries through increased catch rates as a result of increased fish attraction and production. It may also benefit tourism through potential increased dive opportunities, though often offshore oil and gas infrastructure is remotely located and inaccessible for dive tourism. Leaving infrastructure in place also has the potential to reduce diving and fishing pressure on natural reefs.

Removal or partial removal of infrastructure will result in a decrease in biodiversity and decreased diving and fishing opportunities. Complete removal will also eliminate snagging, navigation and corrosion risks. Complete removal will require the use of more machinery and equipment than leaving in place, resulting in an increased risk of seabed disturbance and resuspension of contaminants, as well as increased waste disposal requirements and atmospheric emissions

Potential Impact Controls and Environmental Monitoring Considerations for Decommissioning

Relevant literature and previous decommissioning Environmental Impact Assessment (EIA) studies were reviewed to develop potential management controls for each of the risks.

Field based studies assessing the biodiversity value of oil and gas infrastructure can also be undertaken prior to selection of decommissioning options, to determine the potential risks and benefits to biodiversity.

Frameworks for the Assessment of Decommissioning Options

As the selection of decommissioning options is a complex decision-making process, an options assessment framework that balances the risks, benefits and trade-off between competing decommissioning options needs to be used. The use of a multi-criteria analysis (MCA) approach or net environmental benefit analysis (NEBA) to select options is recommended.

1 Introduction

APPEA has commissioned an international scientific literature review of the environmental impacts of decommissioning options as part of the APPEA Marine Environmental Science Program.

The main objective of this literature review is to seek out generic information, technical studies and case studies of:

- Decommissioning options and techniques for oil and gas infrastructure (Section 4);
- The impacts of oil and gas infrastructure on marine biodiversity (Section 5);
- The risk and benefits of decommissioning options to biodiversity, fisheries, shipping, tourism and human health (Section 6);
- Potential management controls and monitoring considerations for decommissioning (Sections 7 and 8); and
- Frameworks for the assessment of decommissioning options (Section 9).

The findings of this literature review will be used to support industry and stakeholder understanding of relevance of existing decommissioning literature to Australia.

In order to provide APPEA and its members with an understanding of the drivers for decommissioning, precedents and legislation from key decommissioning jurisdictions were also reviewed (Section 2 and 3).

1.1 Structure

The overall report structure is outlined in Figure 1. The report was undertaken in two major stages, described in Figure 1 as Stage 1 and Stage 2:

1.1.1 Stage 1

In order to guide the scope of the literature review, information was gathered regarding decommissioning options and techniques for identified infrastructure types. Decommissioning options and techniques were found to fall under three major categories:

1. Leave in place;
2. Partial removal / topple; or
3. Complete removal.

This was undertaken prior to assessing the risk and benefits of decommissioning options, as it provided information on the impacts to marine biodiversity of leaving oil and gas infrastructure in place.

Four major questions guided the research regarding marine biodiversity, as follows:

1. Are marine communities associated with oil and gas infrastructure likely to be a significant source of larvae to habitats for the broader region?

2. Do marine species (particularly fish) recruit to the structures or migrate to these structures as adults?

3. Does the biodiversity value of infrastructure vary between infrastructure types and to what extent?

4. Does existing oil and gas infrastructure increase the marine biodiversity in a region?

The information collected in this stage provided valuable background in considering the risks and benefits of decommissioning options to biodiversity, fisheries, shipping, tourism and human health.

1.1.2 Stage 2

Using the information collected in Stage 1, potential management controls were developed based on the risks associated with the various decommissioning options. Potential monitoring that may be undertaken to establish the risks and benefits to biodiversity prior to the selection of decommissioning options was also included.

As the selection of decommissioning options is a complex process, the use of an MCA or NEBA to select options is recommended.

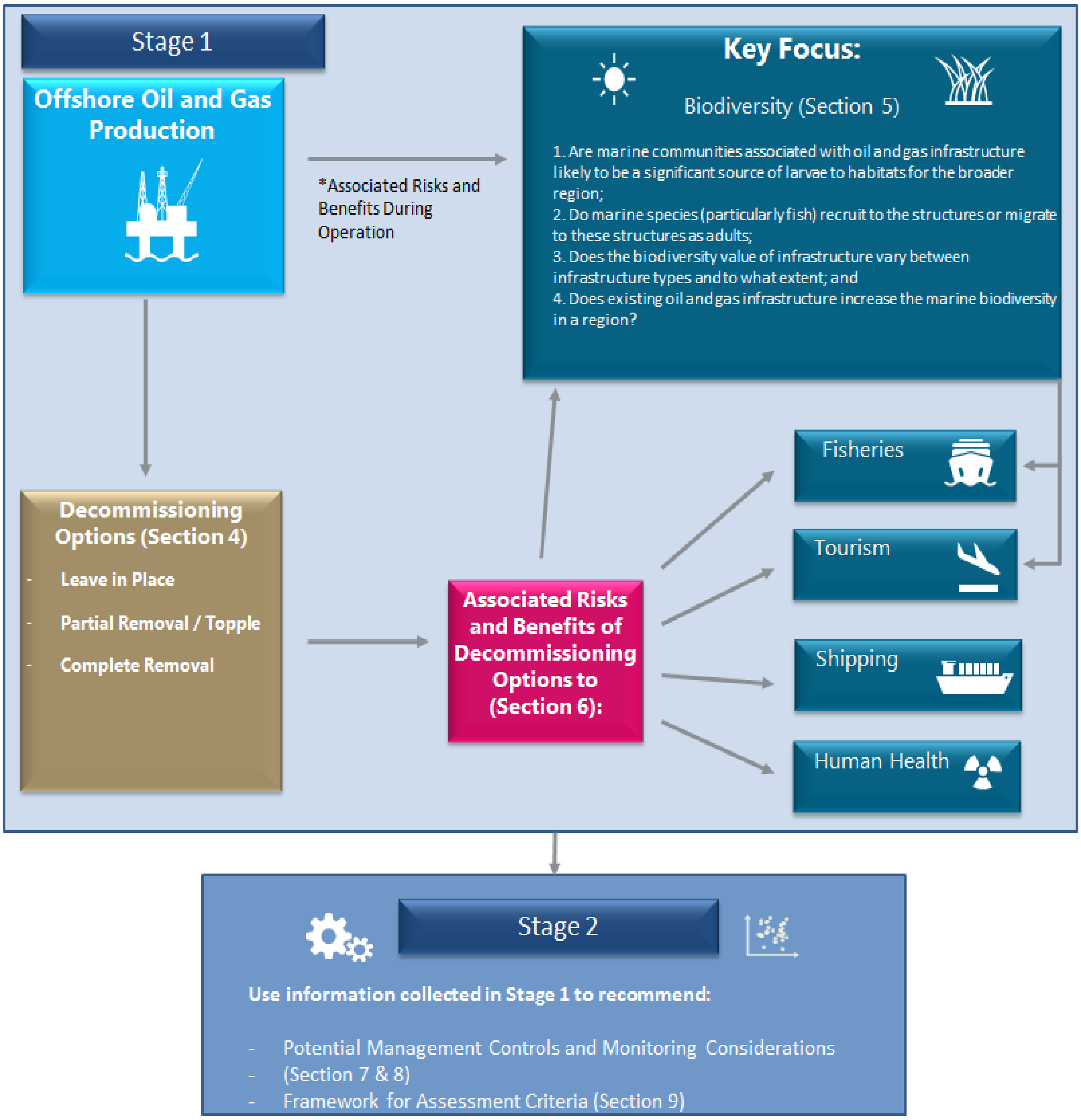


Figure 1: Report Structure

2 Current Regulatory Requirements

2.1 Introduction

Worldwide, regulations for the decommissioning of oil and gas infrastructure have been driven by international guidelines and treaties, some of which have been in place for over thirty years.

As regions have consecutively experienced the closure of offshore platforms, they have referred to such frameworks for guidance. However, changes in scientific knowledge, economic priorities and the political climate of different regions, means that states have usually tailored the recommendations of these guidelines when creating local legislation, in order to suit their local political and physical environment.

In some regions, such as the Gulf of Mexico, the smaller size of many platforms, as well as the political and financial environment, has allowed the Rigs to Reefs program to develop rapidly, whilst on the Californian Coast, legislative changes for such options have not been met with widespread public approval.

In Australia, we are largely influenced by the ideals of the United Kingdom (UK) in regards to platform decommissioning. Although the UK did not originally design platforms with removal in mind, social pressures meant that by the time platforms' production periods were ending, the public sought their complete removal wherever practicable. Historically, Australia's regulatory authorities have also sought complete removal of oil and gas infrastructure from offshore environments. However, our governing bodies have recently turned their attention to alternative approaches being implemented in the USA and the Asia Pacific region, where partial removal and leaving structures in place is more widely accepted.

A summary of Australia's current regulatory requirements and those of other countries, including the UK, Canada, the United States, Norway and Japan, has been provided below.

2.2 Australia

In Australia, the decommissioning of oil and gas infrastructure is regulated under either state or territory based authorities, or federal authorities, depending on whether the infrastructure lies within state or territory waters or further from shore.

State or Territory waters are defined as those waters that lie within three nautical miles of shore from a given state or territory. Oil and gas infrastructure within these waters must be decommissioned in accordance with state or territory based legislative requirements, which vary between locations. Examples of such legislative requirements are those governed by the *Petroleum (Submerged Lands) Act 1982* in Western Australia.

2.2.1 Regulatory Requirements in Commonwealth Waters

Australian waters that sit outside of areas controlled by state and territory jurisdictions are governed by the Australian Federal Government and are referred to as 'Commonwealth' waters. This includes all waters extending from three nautical miles offshore to the edge of the continental shelf, including the Economic Exclusion Zone (EEZ) (Techera and Chandler 2015). Oil and gas infrastructure in Australian Commonwealth waters is regulated by the OPGGS Act and the associated *Offshore Petroleum and Greenhouse Gas Storage (Environment) Regulations 2009 (*OPGGS(E)R).

NOPSEMA administers regulations under the OPGGS Act covering safety, well integrity and environmental management requirements for all offshore petroleum activities including decommissioning.

Prior to undertaking decommissioning activities in Australian federal waters, the petroleum duty holder must submit an Environmental Plan (EP) to NOPSEMA to demonstrate how the project will meet the criteria for acceptance listed in the *Offshore Petroleum and Greenhouse Gas Storage (Environment) Regulations 2009*. Criteria for an EP include that the plan:

- Is appropriate for the nature and scale of the activity;
- Demonstrates that the environmental impacts and risks of the activity will be reduced to ALARP;
- Demonstrates that the environmental impacts and risks of the activity will be of an acceptable level; and
- Complies with the OPGGS Act 2006 and its associated regulations.

Under Sections 586 and 587 of the OPGGS Act it is possible for titleholders to leave infrastructure in place provided arrangements have been made that are satisfactory to NOPSEMA in relation to the property. Under Section 586 of the OPGGS Act, the titleholder can only surrender the title if it has removed all property to the satisfaction of NOPSEMA or made arrangements that are satisfactory to NOPSEMA in relation to that property. Under Section 586 A the Commonwealth Minister may also provide remedial directions to current holders of permits, leases and licences.

2.2.1.1 Artificial Reef Creation

Operators within Australia may apply to the Department of the Environment (DotE) for a permit for dumping of material at sea or the placement of an artificial reef under the *Environment Protection (Sea Dumping) Act 1981* (Sea Dumping Act) and the subsequent regulations (Sea Dumping Regulations).

The Sea Dumping Act, and the associated regulations, are guided by the 1996 'Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter' (as amended in 2006), commonly known as the *London Protocol*. The aims of the London Protocol are to protect and preserve the marine environment from all sources of pollution, and to prevent, reduce and eliminate pollution by controlling the dumping of wastes and other materials at sea.

Key phases for preparing a sea dumping permit application include:

- Evaluation and securing of adequate resources;
- Investigation of potential impacts;
- Stakeholder consultation;
- Site selection;
- Material preparation;
- Determining the method of placement; and
- Preparing for post-placement monitoring and management.

2.2.2 NORMS regulations in Commonwealth Waters

In Australia, the Commonwealth Government and each state and territory have laws regarding radiation protection, which all include varying exemption levels and limits for exposure to radiation. Currently, Australia does not have a clear national approach to the regulation of NORM wastes and there is a lack of national guidance on management of NORM waste and residue (Radiation Health and Safety Advisory Council 2005).

The Petroleum (Submerged Lands) Act 1967 regulates the offshore storage and disposal of NORMs produced during standard operation of offshore oil and gas production facilities in Commonwealth Waters through the Petroleum (Submerged Lands) (Management of Environment) Regulations 1999, the Petroleum (Submerged Lands) (Management of Safety on Offshore Facilities) Regulations 1996 and the Petroleum (Submerged Lands) (Occupational Health and Safety) Regulations 1993. Furthermore, the Environment Protection and Biodiversity Conservation Act 1999 may also require proponents to assess the potential impacts on the disposal of NORMs on matters of national environmental significance (Radiation Health and Safety Advisory Council 2005).

In 2002, APPEA published guidelines for the petroleum industry. These guidelines provide guidance for NORM monitoring, management of occupational radiation exposure and decision-making in regards to NORMs waste disposal. The approach recommended by APPEA is similar to that followed in heavy mineral sands and uranium mining and milling activities (Radiation Health and Safety Advisory Council 2005).

2.2.3 Regulatory Requirements in WA State Waters

Oil and gas infrastructure in WA State waters is governed by the Petroleum (Submerged Lands) Act 1982. The Department of Mines and Petroleum (DMP) administers regulations under the Petroleum (Submerged Lands) Act covering safety, environment, pipeline and resource management requirements for all petroleum activities including decommissioning.

In accordance with the requirements of the Petroleum (Submerged Lands) (Environment) Regulations 2012 an approved EP is required for all petroleum activities including decommissioning. Criteria for EP approval are as follows:

- Is appropriate for the nature and scale of the activity;
- Demonstrates that the environmental impacts and risks of the activity will be reduced to ALARP;
- Demonstrates that the environmental impacts and risks of the activity will be of an acceptable level;
- Provides for appropriate environmental objectives, environmental performance standards and measurement criteria; and
- Demonstrates that there has been an appropriate level of consultation with relevant authorities and interested parties and organisations.

DMP recommend as a rough guide that infrastructure below the seabed or which is providing supporting structure to other infrastructure should be left in situ, however anything above the seabed would be required to be fully removed. (DMP pers comm, 2014).

2.3 United Kingdom

Decommissioning of oil and gas activities in the North Sea is regulated by the Department of Energy and Climate Change (DECC), which ensures Operators are compliant with the *Petroleum Act 1998* and *Energy Act 2008* (DECC 2011).

Legislation in the United Kingdom is influenced heavily by its international obligations, including the 1992 Convention for the Protection of the Marine Environment of the North East Atlantic (OSPAR Convention), the resultant North East Atlantic Environment Strategy, the OSPAR Decision 98/3 and the United Nations Convention on the Law of the Sea (UNCLOS) 1982 (Gibson 2002).

Under the OSPAR Decision 98/3, when projects are completed, all installations must be removed and disposed of on land, except gravity base installations, steel installations over 10,000 tonnes, and installations built before 1999 (OSPAR Commission 2016). It is assumed that exempt structures will still be completely removed unless a suitable alternative can be agreed upon (Royal Academy of Engineering 2013, DECC 2011). Pipelines are not covered by OSPAR Decision 98/3 and there are currently no international guidelines on the decommissioning of pipelines (DECC 2011, Gibson 2002). Under current regulations, pipeline decommissioning is undertaken on a case-by-case basis.

Under UK regulations, all oil and gas projects require a project-wide EIA to be undertaken before project sanction. However, due to the length of time between project authorisation and decommissioning, the requirement for a detailed EIA of decommissioning is deferred until closer to the end of production, and is submitted as part of the decommissioning program (DP).

Operators that opt for total removal must only address the impacts of the proposed decommissioning activity on the environment in their EIA. However, if any option other than total removal is proposed, the EIA must address not only the proposed disposal option, but also the practical availability and potential impacts of other options.

The assessment must also consider what management measures might be required to prevent or mitigate adverse consequences of disposal at sea, and shall indicate the scope and scale of any monitoring that would be required following decommissioning (DECC 2011).

2.4 Norway

Decommissioning legislation in Norway is similar to that in the United Kingdom, as it is also heavily influenced by the OSPAR Convention and North East Atlantic Environmental Strategy (Norwegian Ministry of Climate and Environment 2015, Sørgård 2015, Gibson 2002). As in the UK, the dumping, or leaving wholly or partly in place, of disused offshore installations is prohibited, with gravity base installations and steel installations over 10,000 tonnes being the exemption.

In accordance with the Petroleum Act (29 November 1996, amended 24 June 2011) Section 5.1 and Petroleum Regulation Section 45, Norway requires an environmental assessment, of the area where decommissioning is to take place, to be submitted by operators two to five years before the end of production. This decommissioning plan must contain an impact assessment of technical, safety, environmental and economic aspects for each decommissioning alternative, as well as an environmental monitoring plan (Norwegian Ministry of Climate and Environment 2015, Sørgård 2015).

The Norwegian Ministry of Petroleum and Energy determines the decision on the methodology for disposal and may dictate decommissioning protocols to the operator. The Ministry recognises that there is a need to be flexible in regards to decisions concerning whether pipelines should be left in situ or removed.

2.5 United States

Oil and gas decommissioning in the United States is complex, with laws varying greatly between California and those states that border the Gulf of Mexico (Bernstein et al. 2010). Decommissioning is regulated at a federal level by the Bureau of Safety and Environmental Enforcement (BSEE). Generally, structures must be removed. However under certain circumstances, and in accordance with federal and state law, alternative decommissioning options are allowed as part of the National Rigs-to-Reefs program, which was established in 1985. These include:

- Toppling the structure in current location;
- Removing the upper portion of the structure and placing on the sea bed in the vicinity of the lower portion in the current location; or
- Severing the structure and relocating to an offshore site established by the Government for reefing.

BSEE regulations do not mandate whether platform removal is to be undertaken mechanically or with explosives, as the most suitable option will vary for each situation (BSEE 2016).

The states of Louisiana, Texas and Mississippi are part of the National Rigs-to-Reefs program, with 469 decommissioned platforms having been donated to the project. California recently passed legislation to allow programs for building artificial reefs from oil and gas platforms, with the Assembly Bill 2503 becoming law in 2010 (BSEE 2016, Beitch 2015). The State assumes responsibility for the reefs upon placement within the reef permit area. In Louisiana and Texas, oil and gas companies that donate structures to the program are asked to contribute half of the disposal savings realised through a program participation trust fund (Schroeder and Love 2004).

In California, complete removal of the production facility and restoration of the seafloor to pre-production condition is required under existing offshore oil and gas leases. Laws and regulations have changed in recent years to allow alternative uses, but leases that predate these changes continue to require full removal (Henrion et al. 2014). To date, no oil and gas platforms have been donated to Rigs-to-Reefs in California.

As Rigs-to-Reefs programs often result in lower decommissioning costs for operators compared to complete removal, operators that are given permission to donate platforms to Rigs-to-Reefs programs must donate to the State a portion of the savings they made from not undertaking complete removal. In California, operators must allocate between 55% and 80% of their savings to the State, to have the State accept liability of the infrastructure once the platform has been decommissioned in accordance with regulations (Edwards 2012). This money is placed into specified state funds created for implementing the project (Edwards 2012). Under Californian law, the financial liability associated with any leakage from the oil well is retained by the previous operator (Blue Latitudes 2016).

Whilst Rigs-to-Reefs programs have been considered successful in the United States, it is important to recognise the differences between the USA and Australian oil and gas industry. The rigs converted to reefs within the USA are often much smaller structures than those seen off the coast of Australia therefore the relocation of oil and gas infrastructure is likely to be higher in Australia.

2.6 Canada

Compared to other major oil and gas regions, Canada has fewer references in existing laws and regulations to the decommissioning of offshore oil and gas infrastructure. This may be a result of it having had fewer projects that have reached the decommissioning phase of their lifecycle.

The National Energy Board (NEB) is an independent federal agency that regulates the oil and gas industry in Canada. Key legislation that pertains to decommissioning oil and gas infrastructure includes *The Canada Oil and Gas Operations Act*, which governs exploration, production, processing and transportation of resources in marine areas controlled by the Federal Government, and *The Canadian Environmental Assessment Act,* which establishes environmental requirements for offshore disposal at sea.

All offshore development projects in Nova Scotia are subject to Environmental Effects Monitoring (EEM), which involves monitoring the effects of activities on certain elements of the surrounding environment. EEM programs are conducted throughout the year, and program design is updated annually. The EEM process used in Nova Scotia was developed jointly by Environment Canada, Fisheries and Oceans Canada, the Canadian Environmental Assessment Agency and the Canada-Nova Scotia Offshore Petroleum Board (CNSOPB) in 2005 (CNSOPB 2016).

2.7 Japan

Requirements for decommissioning of offshore oil and gas infrastructure in the Asia-Pacific region are less well developed than other areas globally and this is reflected in a lack of specific legislation in Japan (Benjelloun 2014). Currently, Japan's national decommissioning regulations relate specifically to well abandonment and do not consider supporting infrastructure.

Decommissioning requirements for abandoned oil wells in Japan are regulated by the Japanese Ministry of Economy, Trade and Industry (METI) (IEA GHG 2009). Standards for abandoned oil wells are based on the *Mine Safety Act* and were specified in 1986.

Under METI, abandonment standards fall into two separate regulatory categories. One category specifies regulations for wells used for oil and natural gas production from structural reservoirs and the other regulates wells that produce natural gas dissolved in water (IEA GHG 2009).

Both sets of regulations state that in general, cement plugs should be used to plug abandoned wells. (IEA GHG 2009). The regulations include requirements for the depth of these plugs and the number of plugs required. The regulations include some flexibility with requirements, stating that plugs are not required in the well if it can be verified that formation fluid does not rise above the surface under its own pressure (IEA GHG 2009). The regulations state that casings and wellheads must be removed to a depth of at least 2 m. Furthermore, the area surrounding the well head must be covered, using cement, soil, sand or another appropriate material (IEA GHG 2009).

In general, standards for decommissioning oil and gas infrastructure within Japan and the wider Asia-Pacific region are driven by international guidelines and treaties to which they are signatories. These include UNCLOS1982, the London (Dumping) Convention 1972 and guidelines provided by the International Maritime Organisation (IMO), created in 1989.

UNCLOS 1982 requires all abandoned installations and structures to be removed to ensure safe navigation and to have due regard to fishing, protection of the marine environment and the rights of other States (Benjelloun 2014). The London (Dumping) Convention, updated in 2000, provides guidelines for the dumping of waste at sea, classification of what constitutes waste and also provides guidance on converting abandoned platforms to reefs (Benjelloun 2014). The IMO generally requires all offshore installations to be removed when production activities cease, although structures are allowed to remain partially or wholly in place in particular locations (Benjelloun 2014). Under IMO guidelines, any installations that are to remain on the seabed must be assessed on a case by case basis and there are strict removal requirements for smaller platforms that are located in shallow waters. Whilst international conventions and treaties theoretically provide requirements for oil and gas decommissioning, in reality it is unclear whether these requirements take precedence over local legislative requirements, both in the Asia Pacific region as well as globally.

In 2010, the Iwaki Platform was decommissioned off the coast of Japan via heavy lift. The process included 16 modular lifts for removal of the topsides facilities and module support frame ranging between 100MT and 1100 MT each. It also involved cutting the jacket into two pieces, lifting the 1500MT section and placing it onto the seabed. This upper section was then toppled adjacent to its original location and the remaining export pipeline was cut, plugged and stabilised (Sapura Acergy 2009). As this structure was not completely removed, it is not in compliance with international guidelines. This suggests that within Japan, local decision making is overruling international guidelines in regards to desired outcomes for decommissioning platforms.

3 Decommissioning Precedents Australia

An assessment of local precedents was undertaken by reviewing the list of NOPSEMA registered EPs involving decommissioning. Prior to the establishment of NOPSEMA, offshore decommissioning activities were subject to the *Petroleum (Submerged Lands) Act 1967* and its Regulations. The designated Authority would monitor EPs under these regulations, and a safety case supporting the decommissioning activity would require approval from the National Offshore Petroleum Safety Authority before the decommissioning of the facility could commence.

Since NOPSEMA became the statutory authority for EP approval, a number of decommissioning EPs have been approved, as summarised in Table 1. As outlined in Section 2.2 it is possible for titleholders to leave infrastructure in place or completely remove infrastructure provided arrangements have been made that are satisfactory to NOPSEMA in relation to the property. Therefore the onus is on the title holder to select the decommissioning method and ensure the risks associated with undertaking decommissioning are reduced to ALARP. At this stage there are no clear precedents in Australia with regard to decommissioning methods. In certain cases all infrastructure has been removed such as the Puffin field, in the case of the Jabiru and Challis, Griffin and Legendre Fields some infrastructure was left in place. It is important to note that the accepted EPs have not expressly gained consent to abandon infrastructure and relinquish titles; it is evident these approved EPs may need to be revisited in a 5-year timeframe as per any other petroleum activity EP.

Table 1: Local precedents overview

Region	Field / Asset	Legislative Context	Commissioned	Approved for Decommissioning	Abandonment Approach	Regulatory Decision
Bonaparte Basin: Big Bank, Timor Sea, (near to Joint Petroleum Development Area)	Nexen - **Buffalo Field** (Production Licences WA 19L and WA 21L) Field development consists of an unmanned wellhead platform standing in 27m of water supporting five wells producing to a nearby FPSO in 300 m of water	Pre NOPSEMA for environment approvals	1999 - First oil	Approval 2004 Production life end 2004 Buffalo Oil Field decommissioned 2004	Nexen Petroleum Australia Pty Ltd is proposing to leave FPSO anchor chains and the rigid flowlines on the sea floor while the wellhead platform will be removed by cutting piles one metre below the mudline. The wells will be abandoned in accordance with legislative requirements	Regulator "We have reviewed the Buffalo Field Decommissioning Plan and found that it is in accordance with regulatory requirements and accepted industry practice, and therefore see no technical reason for not approving it. We note that the Commonwealth Department of the Environment and Heritage approved the proposal." Anecdotal evidence suggests insurances were to be required for any infrastructure to be left in situ and therefore all infrastructure was removed despite this approval
North Herald and South Pepper Fields in the **Carnarvon Basin** between Onslow and Barrow Island	Apache - North Herald and South Pepper fields had two monopod structures tied back to the production facilities on Airlie Island via trunkline	Pre-NOPSEMA for environment approvals	North Herald – December 1987 South Pepper – January 1988.	North Herald and South Pepper fields decommissioned in October 1997. Island infrastructure decommissioned 2002. Monopods decommissioned and removed by Apache 2011 (Fugro 2013).	Cut and abandonment of two shallow water tripod platforms, seafastening and delivery onshore at Dampier. Equipment used included water remote operated vehicle, diamond wire saw, rope access crew, cargo barge and tug boat.	
80 km NW of Western Australian coast **Carnarvon Basin**	Eni - **Woollybutt** FPSO with wells	OPGGS Act OPGGS Act Safety Regulations OPGGS(E)R	2003	Woollybutt Decommissioning Phase 1 and 2 Accepted 28/11/2013	FPSO disconnected in 2013 Note: As required under *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) conditions, nothing is to be abandoned to seafloor Phase I: Removal of moorings, associated umbilicals, flowlines, anchors, gravity bases. Phase II: in-field surveys to determine condition of remaining infrastructure. A decision will need to be made as to whether remaining infrastructure will be removed of left in situ.	EPBC decision stated that ALL seafloor components had to be removed within 6 months of decommissioning National Offshore Petroleum Titles Administrator (NOPTA) licences contain no special conditions. As NOPSEMA is now the sole assessor of petroleum and greenhouse gas activities in Commonwealth waters in accordance with the Minister for the Environment's endorsement of NOPSEMA's environmental authorization process under Part 10, Section 146 of the EPBC Act, infrastructure can be left in place if arrangements have been made that are satisfactory to NOPSEMA in relation to the property.

Region	Field / Asset	Legislative Context	Commissioned	Approved for Decommissioning	Abandonment Approach	Regulatory Decision
Victoria **Bass Strait**	Roc Oil - **Basker-Manta-Gammy** or BMG	OPGGS Act OPGGS Act Safety Regulations OPGGS(E)R	2005	BMG non-production phase EP Accepted 08/06/2012	2011 FPSO left, flushed depressurised and preserved with inhibited water of the subsea equipment 2012 mooring systems and all mid-water equipment removed and trenched the flowlines Residual subsea infrastructure is to be left under 'Care and Maintenance" until a decision is made on phase 2 development	Approved for a Non Production Phase (Care and maintenance), not for abandonment.
640 km west of Darwin, **Timor Sea**	PTT Exploration and Production Public Company Limited - **Jabiru and Challis Fields** FPSO with wells	OPGGS Act OPGGS Act Safety Regulations OPGGS(E)R	1986 Ceased prod Sept '10 FPSO disconnected Nov '10	Jabiru and Chalis Fields (Decommissioning State) Environment Plan Accepted 15/05/2014	<u>Jabiru only as per safety case:</u> Phase 1: These were covered under first phase revised operations safety case and EP (as accepted by Northern Territory Department of Resources). FPSO disconnected, trees removed, wells plugged and abandoned Phase 2: Further revised safety case covers remaining decommissioning aspects: Riser turret mooring, mooring chains, flowlines, manifolds, umbilicals, subsea wells including wellheads and support bases <u>Jabiru and Challis EP summary:</u> Activities subject to EPBC approval (see next column) final EP covers both Jabiru and Challis fields Decommissioned in situ (as per sea dumping permit): Jabiru - Wells, 50 km of infield flowlines and some umbilicals Challis - Single Anchor Leg Rigid Arm Mooring (SALRAM), 80 km of flowlines Decommissioned in deep water (as per sea dumping permit): Jabiru - Riser turret mooring, mid depth buoys - removed, towed and flooded to sink in deeper waters in adjacent Challis Field next to Challis SALRAM Taken to shore: Manifolds, riser, skids and other 'wet stored' well related items removed and disposed of onshore	Challis decommissioning EPBC decision 2003/942. Conditions: 1. Must remove any flowlines or pipework on the SALARM containing naturally occurring radioactive materials (NORMS) 2. Must plug wells, remove wellheads and xmas trees for onshore disposal 3. Must dispose of SALARM in-situ consistent with conditions in sea dumping permit 4. Must start decommissioning activities within 10 years of date of approval Variation to EPBC conditions (Jan 2014) presented allowed a particular flowline in situ NOPTA licences contain no special conditions EP summary linked to EP that was submitted after completion of decommissioning activities as part of the EP process As stated in EP summary, activities associated with abandonment have been completed and no further actions are proposed for the decommissioned in situ infrastructure. No reference is made as to whether any continual inspections or long term monitoring is required

Region	Field / Asset	Legislative Context	Commissioned	Approved for Decommissioning	Abandonment Approach	Regulatory Decision
Ashmore and Cartier Area of the **Bonaparte Basin**	Sinopec - **Puffin** FPSO with wells	OPGGS Act OPGGS Act Safety Regulations OPGGS(E)R	2007	Puffin Field Decommissioning Activities EP Accepted 27/11/2015 Puffin Wells Abandonment EP Accepted 20/05/2014 Puffin Field Subsea Equipment (Non-production Phase) Accepted 25/02/2014	FPSO disconnected in 2009 Field left in non-production care and maintenance mode. Submerged turret and mooring system removed 2010 - Assume under separate EP and safety case. Plugging and abandonment of wells was carried out in 2014. The decommissioning scope of work included the removal of all equipment on seabed, water column and sea surface. The remaining equipment in the field consists of a manifold, static and dynamic flowlines, pipeline end manifolds (PLEMs), concrete mattresses, anchors and chains, dynamic riser clump weights and the field marker buoy and its clump weight.	NOPTA licences contain no special conditions
Timor Sea **(Joint Petroleum Development Area)**	**Elang / Kakatua**	Australian / Indonesian Joint Authority	1998	2007	Production was through four subsea wells connected to the FPSO Modec Venture 1, using flexible flowlines and well control umbilicals moored near the Elang field	Mid depth buoys and subsea heat exchangers were recovered Flexible flowlines, umbilicals, mooring chains and gravity bases were decommissioned in situ Riser turret mooring (RTM) was towed from site to Australian waters and dumped on seabed with a Commonwealth Permit

Region	Field / Asset	Legislative Context	Commissioned	Approved for Decommissioning	Abandonment Approach	Regulatory Decision
Balnaves Oil Field, Northern **Carnarvon Basin** off the North West Shelf of Western Australia	**Balnaves Field Development** FPSO with wells	OPGGS Act OPGGS Act Safety Regulations OPGGS(E)R	2013	Balnaves Development Commissioning and Operations EP Addendum – Operation Cessation has been accepted on 21/6/16	Ongoing preservation of the Balnaves subsea systems and RTM until RTM removal Vessel monitoring including subsea inspections by remotely operated vehicle (ROV) of the Balnaves field and RTM Disconnection and removal of flushed flowlines from manifold and installation of pressure caps on the wellheads Disconnection and recovery of flushed spools from wellheads and removal of manifold and supporting infrastructure Disconnection and removal of flushed risers and umbilicals Disconnection and removal of RTM and associated facilities Ongoing preservation of the Balnaves subsea systems until the wells are plugged and abandoned	Balnaves Operations Cessation EP was accepted on 20/7/16.
Griffin Field, Northern **Carnarvon Basin** off the North West Shelf of Western Australia	**FPSO, wells and flowlines**	OPGGS Act OPGGS Act Safety Regulations OPGGS(E)R	1994	Griffin Well Abandonment Accepted 23/4/2015.	Abandonment scheduled to occur in 2015/16 over six month period. Activity will require a semi-submersible mobile offshore drilling unit (MODU).	Well abandonment has been undertaken. Full field decommissioning and abandonment of remaining in situ development infrastructure will be undertaken at a future point in time.
Legendre, Field **Carnavon Basin** North West Shelf	Woodside / Apache / Santos Joint Venture. **Legendre Field,** Mobile offshore production unit and FSO.	OPGGS Act OPGGS Act Safety Regulations OPGGS(E)R	Production commenced 2001	Legendre Decommissioning EP Accepted 2/3/11	Field abandonment of export system including export flowline, recovery of 83 concrete saddles and CALM buoy with moorings. Equipment used included a WROV, CUT diamond wire saw, cal dive air spread, aquatic reel drive and tensioner, grabber frame, shears, chain hang off frame, cargo barge and tug boat.	

4 Decommissioning Options and Techniques

4.1 Overview

It is estimated that over one hundred offshore installations will need to be decommissioned in Australia over the next 25 years (Subsea Energy Australia, 2016). Decommissioning options include partial or complete removal or leaving the structure in place (Figure 2). The numerous infrastructure components that make up an operation require different forms of decommissioning, and for each component there are various options and techniques that may be considered. As operations vary in location, governance, materials and size, the decommissioning process is different each time, with no option being suitable for every single situation. The extent of the obligation to remove any oil and gas infrastructure depends on the risks and benefits such as contamination as well as stakeholder expectations and associated costs.

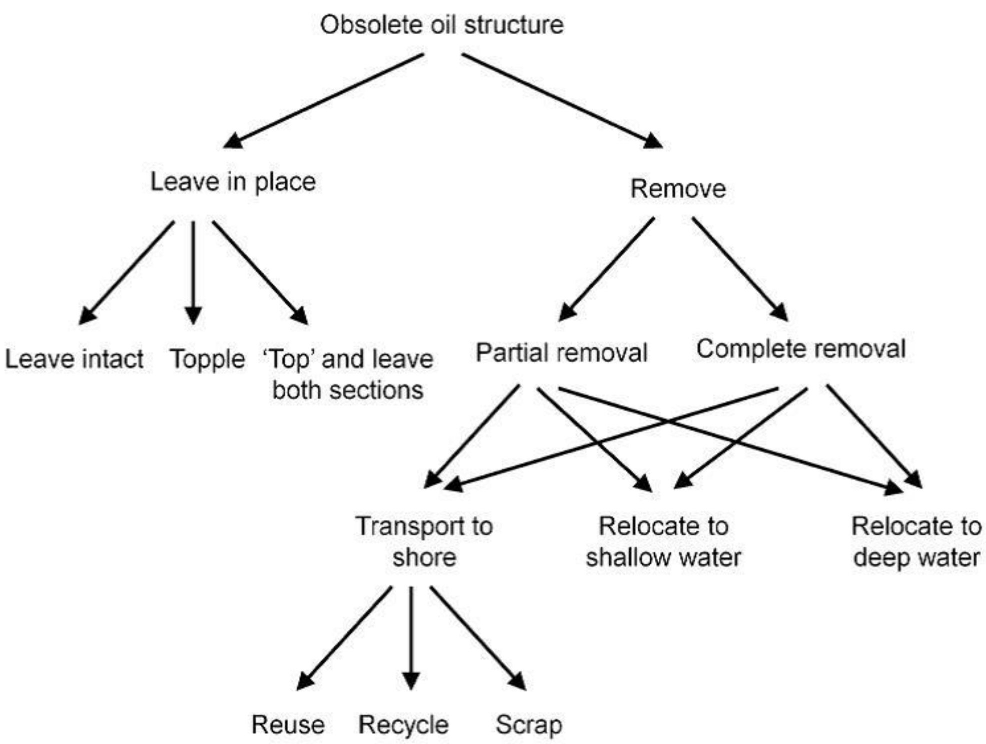


Figure 2: Decommissioning options for offshore installations

Major infrastructure that requires decommissioning at the end of a project may include the following components:

- Surface infrastructure - Concrete and steel platforms including topsides and jackets;

- Floating installations - Floating Production Facilities and FPSOs;
- Subsea systems - Wellhead, production manifolds, anchors, CGSs, mattresses;
- Pipelines (trunklines, rigid flowlines, flexible flowlines, umbilicals); and
- Risers and turret moorings.

These components and their relevant options and techniques are discussed below. A summary of decommissioning options, the equipment required, the duration of the activity and technical considerations for the process are provided in Table 2.

Table 2: Decommissioning options and considerations

Infrastructure	Decommissioning Options	Examples	Equipment Required	Technical Considerations	Activity Duration (based on time offshore)
Platform Topsides	Reverse installation	North West Hutton, Murchison, North Sea	Heavy lift crane ship with 2,000 to 5,000 tonne capacity, two or more cargo barges and tugs	Structural integrity, weather conditions, impacts to shipping, fuel requirements	6 months
	Piece small removal	SE Indefatigable, North Sea	200 tonne crane on cargo barge, crawler mounted cutting equipment	Structural integrity, length of process, suitability for older structures	2 weeks - 1 year
	Single lift	Yme and Brent D, North Sea (planned 2016 and 2017)	Heavy lift vessel (HLV) or specialised cargo barge	Structural integrity, weather conditions, fuel requirements	3 months
Platform Large Jackets	Leave in place completely intact	Sipidan	Survey vessel, navigation lights	Structural integrity of jacket, exclusion zones	6 months
	Leave in place toppled	Piper Alpha North Sea, Irawaki Japan	Diving support vessel (DSV) and tugs cutting equipment	Structural integrity, seabed condition	2 months

Infrastructure	Decommissioning Options	Examples	Equipment Required	Technical Considerations	Activity Duration (based on time offshore)
	Partial removal	North West Hutton, North Sea	250-1000 tonne crane on cargo barge or HLV and tugs	Structural integrity, seabed condition	6 months
	Complete removal - buoyancy tanks	Frigg, North Sea	Buoyancy tanks to suit jacket, jacket connection and DSV	Design of tanks and installation of connections, structural integrity, potential spread of invasive species	4 months
	Tow and place	None	Buoyancy tanks to suit jacket, jacket connection and DSV	Design of tanks and installation of connections, structural integrity, potential spread of invasive species	6 months
Platform Small Jackets	Removal in one lift with topsides	Thames Field, North Sea Gulf of Mexico Rigs to Reef Program	HLV or Cargo barge and 200 tonne crawler crane	Structural integrity, weather conditions	1 month

Infrastructure	Decommissioning Options	Examples	Equipment Required	Technical Considerations	Activity Duration (based on time offshore)
FPSO and Risers	Remove and sail away	Quito, Angola; Northern Producer, North Sea	DSV with 200 tonne crane and tugs	Weather conditions	2 months
Concrete Gravity Structures	Leave in place	Frigg and Brent, North Sea	DSV, pipes for hydrocarbon removal	Structural integrity	1 month
	Removal	None	Equipment not yet developed	Structural integrity, seabed conditions	-
Sea Bed Wellheads, Manifolds and Valves	Remove	Leadon, Veslefrikk, North Sea	DSV	Structural integrity, sea bed conditions, weather conditions	2 months
Wells	Plug and abandon	Don, Murchison, Brent, Miller North Sea	Drilling equipment	Weather conditions, well integrity	20 to 40 days per well
Mattresses	Leave in place	Viking Satellite Installations	None	Structural integrity of mattresses	-

Infrastructure	Decommissioning Options	Examples	Equipment Required	Technical Considerations	Activity Duration (based on time offshore)
	Removal	Thames, SE Indefatigable, Southern North Sea	DSV with subsea baskets or speed loaders, polypropylene ropes	Structural integrity of mattresses	30 days
Trunk Pipelines Oil or Gas	Clean cut ends and leave in place	Frigg, Miller, SE Indefatigable, Hutton	DSV with 200 tonne crane and ROV	Weather conditions, trawl sweep for snagging hazards	30 days
	Trench and bury	North West Hutton	DSV with work class ROV, vessel with trenching technology	Soil conditions, seabed disturbance	60 days
	Remove	None	DSV, barge / vessel to transport pipe to shore, dedicated installation vessel with trenching technology, cutting tools	Calm weather, future use	2 months
In Field Pipelines	Remove	Don North Sea	DSV with 200 tonne crane, ROV	Structural integrity, weather conditions	2 months

Infrastructure	Decommissioning Options	Examples	Equipment Required	Technical Considerations	Activity Duration (based on time offshore)
	Leave in place	Jabiru and Challis Fields North West Shelf	None	Presence of pollutants	-
Shell Mounds	Leave in place	None	None	Presence of pollutants	-
	Remove	None	Equipment to be developed	Disturbance to seabed, impacts of sediment suspension	Unknown
Drill Cuttings	Leave in place	Miller, North West Hutton, Ekofisk	Equipment to be developed	Presence of pollutants	-
	Remove	None	Equipment to be developed	Disturbance to seabed, impacts of sediment suspension	Unknown

4.2 Topsides

Topsides refer to the upper portion of oil and gas infrastructure which sits above sea level and outside of the splash zone, supported by the jacket, CGS or other floating structure, as shown in Figure 3.

Figure 3: Statfjord J topside being towed, June 1984 (Norsk Oljemusuem 2016)

For conventional steel platforms, in most cases decommissioning will likely include the removal of topsides and transport to shore for reuse / recycling or disposal. Prior to decommissioning, bulk hydrocarbons will need to be removed from the topsides processing plant and all trapped energy on the platform will need to be de-energised, regardless of which decommissioning option is selected. Large structures such as tanks may be cleaned using sand blasting. Several methods are used for removing installations.

The main classifications include:

- Reverse installation;
- Piece small; and
- Single lift.

4.2.1 Reverse Installation

Reverse installation is the method whereby topsides are cut into sections and removed in the reverse order to which they were installed, whether installed as modules or as individual structural components.

Equipment normally required for reverse installation includes:

- Heavy Lift crane ship with 2,000 to 5,000 tonne capacity; and

- Two or more Cargo barges and tugs.

This method of topside decommissioning has been successfully used in the past and is the most common option for topside decommissioning (Rigzone 2016, Clucas 2013). It requires good structural integrity of the topside infrastructure, good weather and large quantities of fuel, and can impact ship traffic (Clucas 2013). The North West Hutton platform in the North Sea was decommissioned via reverse installation in 2008. It took 22 modular lifts to complete the removal; the largest single module removed weighed 2800 tonnes (Smith 2016).

Removal of the topsides for a large oil or gas processing platform with four to twenty modules takes approximately six months. The time includes the preparation for the lifts as well as the lifts themselves.

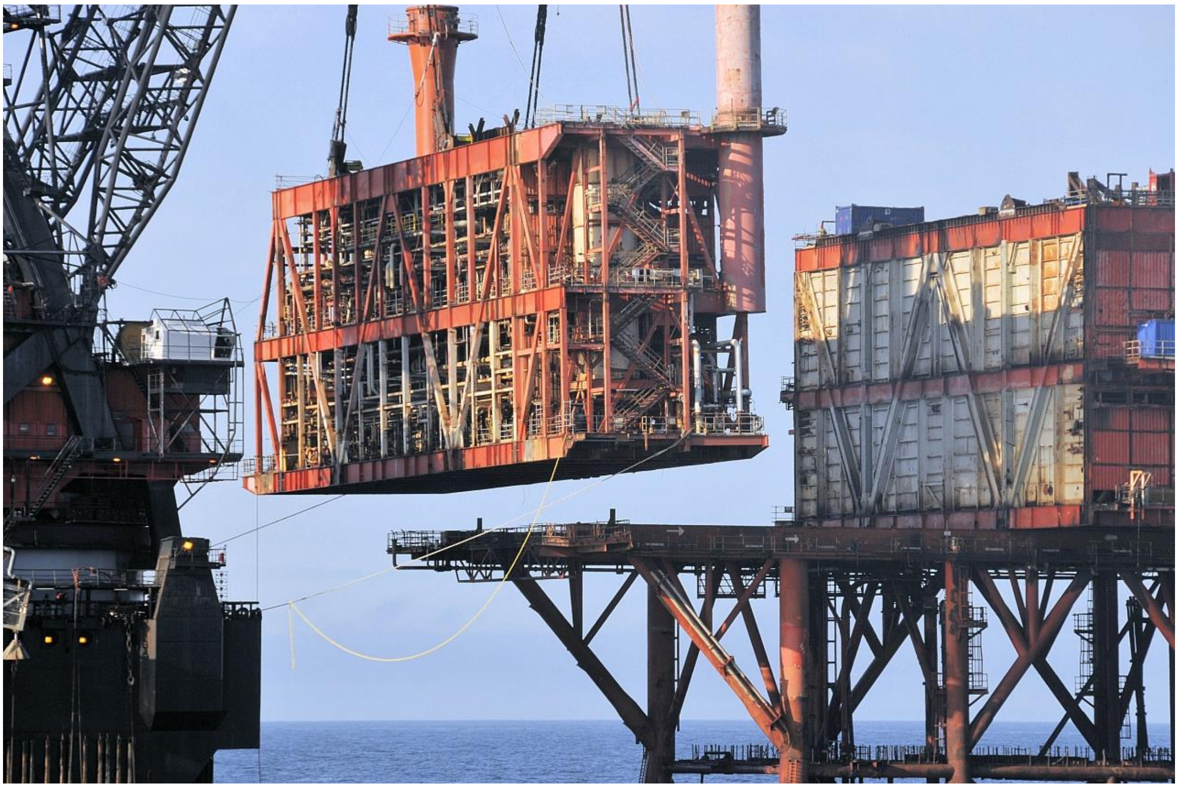


Figure 4: North West Hutton reverse installation decommissioning 2008 (Heerema 2016)

4.2.2 Piece Small Removal

The installation is dismantled offshore by cutting or dismantling into small sections that are shipped onshore in containers. This option has been used for small platforms and complex large platforms in areas where the cost of mobilising an HLV is high or there is a desire to minimise the local content of the decommissioning work.

Equipment normally required for 'piece small' decommissioning includes:

- 200 tonne crane on a cargo barge or ship alongside the platform; and
- Crawler mounted cutting equipment (shears, grabs and mechanical saws) on the ship decks.

Duration of works will depend on the size of the platform and can range from two weeks to one year. Good platform craneage (meaning the crane can access all areas of the platform) is necessary for this form of decommissioning.

This method of topside decommissioning has been successfully used in the past. It would be suitable for some older platforms with numerous smaller modules. It may be the only appropriate option for topsides with poor structural integrity. It requires greater logistical input and may be a slower process than other options (Clucas 2013). Piece small decommissioning requires smaller, less expensive cranes than reverse installation. However, as it is a slower process, it does not usually incur any savings for large structures (Rigzone 2016).

4.2.3 Single Lift

Single lift decommissioning involves the removal of the complete infrastructure component in one piece by either a large heavy-lift dedicated vessel such as a mono hull crane vessel or on a specialist cargo barge.

In South East Asia, several topsides were installed by the float-over method (e.g. Bayu-Undan). The topsides were fabricated in one piece. The one piece deck was carried by a specialist cargo barge to the jacket. On arrival the cargo barge was ballasted down, leaving the topsides supported by the jacket. This technique can be reversed if the structural integrity of the topsides is still adequate for the sea transportation loadings.

One piece lift removal is a relatively new technique for the decommissioning of oil and gas infrastructure, as previously no HLV was large enough for the task. In 2011, Versabar engineered an underwater lift device called 'The Claw' in order to reduce diver exposure during decommissioning. The Claw is able to retrieve topsides from the seafloor with minimal subsea preparation. Two identical grappling devices, weighing 1,000 tonnes each are controlled by a barge-mounted dual truss system called the VB 10,000 lift system. The giant steel 'jaws' of The Claw are able to operate independently but can be used in tandem for larger loads (Versabar 2013). The Claw is also used in conjunction with specially designed baskets, that can be lowered onto the seabed and act as a base upon which topsides can be brought to the surface. This ensures that no stress is placed on the topside itself during the lift and can therefore be used for more fragile infrastructure (Versabar 2013).

A variety of lifts have been undertaken using the VB 10,000 lift system and The Claw, including lifts up to 500 ft below sea level as well as above water removals (Versabar 2013).

Figure 5 - The VB 10,000 lift system in operation (Wikimedia Commons 2016)

Other single lift technologies that have been unveiled in recent years include the ALE 50,000te Mega Jack System and the Mammoet Push-Up system, which are marketed for commissioning but may be able to be used to more easily and safely decommission structures as well in the future, based on how they are originally installed.

In 2016, the offshore engineering company Allseas will complete construction of the vessel *Pioneering Spirit,* which is able to lift 48,000 tonnes at a time and will be used for single lift decommissioning. Allseas is also building a larger vessel, due for completion in 2020, which will have a topside lift capacity of 72,000 tonnes (Smith 2016).

Single lift is planned to be used to remove the Yme topsides, operated by Allseas in the Norwegian North Sea, and the Brent Delta topsides, operated by Shell in the UK North Sea, in 2016 and 2017 respectively. It requires good structural integrity, good weather and moderate quantities of fuel (Clucas 2013). Topsides that are able to be installed or removed via single lift may be safer to remove and less expensive than topsides that require modular removal.

Figure 6: Allseas vessel, *Pioneering Spirit*, has the capacity to lift 48,000 tonnes at a time. Here it is shown with platform topsides sitting on deck (Allseas 2016)

4.3 Jacket

A jacket is a large steel frame which supports the topsides and deck of a fixed offshore oil and gas platform whilst protecting the well conductors and pipelines. Jackets may be installed where depth does not exceed 500 m in benign waters or 250 m in severe waters. As the majority of oil and gas projects take place on the continental shelf, more than 95% of the world's offshore platforms are jacket designed (IAOGP 2010).

Figure 7 - Ekofisk Jacket, 2010 (Wikipedia 2016)

Decommissioning of jackets may involve the following options:

- Leave in place;
  - Leave completely intact; or
  - Topple,
- Partial removal - leaving sufficient clearance through the water column for safe navigation; and
- Complete removal.

For smaller platforms, there is also the option of removing the jacket in one single lift at the same time as the topsides. See Section 4.2.3 for details on the single lift process.

4.3.1 Alternative Use

A jacket can only be left in place if it is mothballed with an appropriate care and maintenance program for later decommissioning or alternative use. Installation and maintenance of navigation aids is required following topside removal, to make others aware of the presence of the jacket from a distance (Oil and Gas UK 2012).

Equipment normally required includes:

- Survey vessel; and
- Navigation lights.

Long term structural integrity is required for the jacket, and access to the jacket must be restricted for the safety of all with exclusion zones around the structure. An alternative user must accept the responsibilities of maintaining the structure safely and dispose of the structure when required. An example of a decommissioned oil and gas platform that has been left completely intact is shown in Figure 8.

Figure 8: Seaventures Dive Resort is a successful tourism operation run on a decommissioned oil rig that has been left completely intact in Malaysia (Asia Adventures 2016)

4.3.2 Leave in Place (Toppled)

Toppling involves severing the jacket legs close to the seabed or higher, and letting it fall sideways onto the seabed. The only trapped hydrocarbons in the toppled jacket may be in the pipeline risers which should be cleaned prior to toppling. Severing can be undertaken using explosive, mechanical or abrasive cutting.

Equipment and vessels required for toppling include:

- Diving support vessel (DSV) and tugs for cut and topple work; and
- Cutting equipment for jacket including explosives, mechanical shears and diamond wire. All are deployed from the DSV using ROVs or divers (depending on water depth).

The use of explosives for decommissioning activities in Australia is highly unlikely as it would not be considered ALARP if other cutting methods with lower environmental impacts such as diamond cutting could be used.

Important technical considerations include ensuring sufficient clearance through the water column for safe navigation and the structural integrity during the toppling, to ensure an intact structure lies on the seabed. Duration for large jacket toppling is typically 2 months. It usually takes 1 month to topple a smaller jacket.

The damaged Baram 8 platform in Malaysia was decommissioned using this method in 2004, as was the Iwaki Platform offshore Japan in 2009. Piper Alpha was toppled in place following the destruction of the platform in 1988, and is the only example of toppling an entire jacket in a decommissioning programme in the North Sea (Oil and Gas UK 2012).

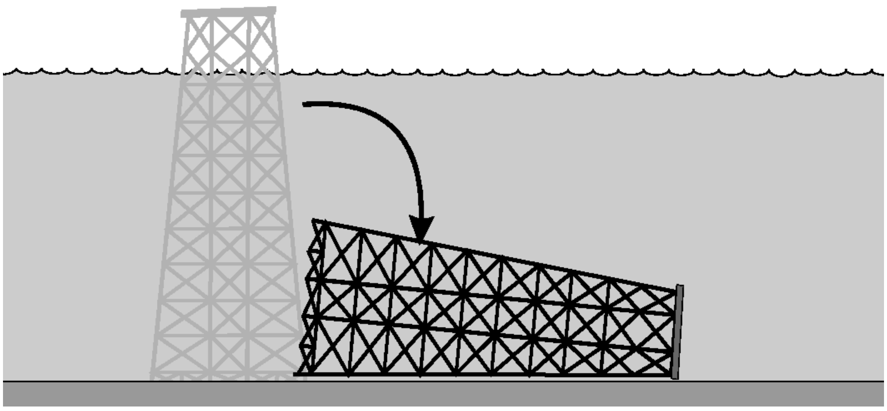


Figure 9: Left in place - toppled (Dauterive 2000)

4.3.3 Partial Removal

Partial removal decommissioning involves the removal of the top section of the jacket so that the remaining structure sits at a certain depth beneath the water's surface, allowing no hindrance to safe navigation or other users of the sea.

The methodology for a small jacket is that the legs are cut by explosives or mechanical shears, while the weight of the jacket is held by a crane on a barge or HLV. A large jacket may need to be cut into several sections.

Equipment normally required includes:

- A 250 tonne to 1000 tonne crane on a cargo barge or HLV; and
- Cargo barges and tugs for removals to shore or another site.

Depth requirements vary between locations, but generally partial removal in the Gulf of Mexico has required 'topping' jackets at 26 metres below sea level (Claisse et al. 2015). In the North Sea, International Maritime Organization regulations require jackets to be 'topped' at 55 metres below sea level (Oil and Gas UK 2012).

Once removed, the top portion of the structure can either be:

- Taken to shore for re use / recycling / disposal; or
- Placed on the seabed in a Rigs-to-Reefs site or a deep water disposal location;

Selecting which option is the most suitable will depend on local seabed conditions and the structural integrity of the top portion of the platform. Partial removal usually takes approximately 6 months.

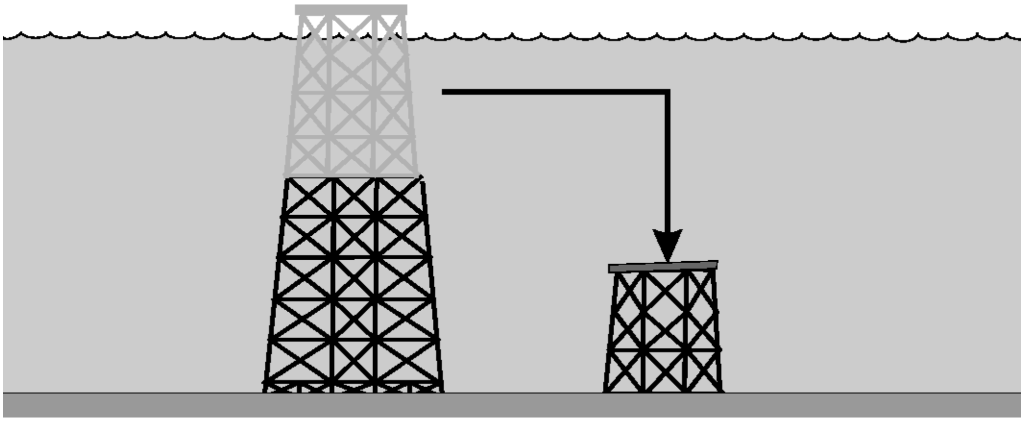


Figure 10: Left in place - partial removal, with top portion placed on the seafloor next to the remaining portion of the original jacket (Dauterive 2000)

4.3.4 Complete Removal

Complete removal is seen by many regulatory authorities and stakeholders as the best decommissioning option, as it reduces the chance of the jacket having ongoing adverse impacts on the environment. Numerous deep water and shallow water jackets have been completely removed with the use of HLVs, including the Frigg quarters platform, DP1 and DP2 jackets, Welland, Esmond, Gordon, four Viking ‘A’ platform jackets and jackets from Shell’s Inde Field (Oil and Gas UK 2012). Once removed, the jacket may be disposed in deep water at a site approved by regulatory bodies, may be moved to an appropriate artificial reefing site, or may be taken to shore (Bernstein et al. 2010).

Cleaning of marine growth from jackets prior to complete removal is a subject of ongoing discussion. Jackets in the North Sea and Gulf of Mexico have been taken to shore with marine growth intact. In the case of the North Sea, this is considered acceptable practice as no evidence to date suggests that non-native species occur on oil and gas structures in the North Sea. Therefore, risks associated with transferring non-native species during decommissioning by not cleaning marine growth from structures is considered low (Oil and Gas UK 2013). During onshore dismantling, the growth is collected and sent to landfill.

Methods of complete removal include single lift, multi lift, or piece medium and removal using buoyancy tanks. In order to sever the jacket from the gravity base structure or seabed beneath, explosive or mechanical removal may be used. Materials that have been transported to shore can be reused, recycled or scrapped. Piece small and single lift is described in Sections 4.2.2 and 4.2.3.

4.3.4.1 Buoyancy Tanks

Buoyancy tank decommissioning is undertaken by fixing buoyancy tanks to the four corner legs of the jacket to force a large jacket to the surface in a controlled manner. The jacket can then be towed to shore. Obstructions along platform legs must be removed and lift points installed at the top of each platform leg before the tanks are fixed (Oil and Gas UK 2012). The Frigg platform jacket, which was 8,200 tonnes, was removed in 2009 using a single lift and buoyancy tanks in the North Sea (Oil and Gas 2012). This method of decommissioning has relatively low fuel requirements compared to other methods of complete removal, and requires minimal offshore marine activity. It requires good structural integrity of the jacket (Clucas 2013). This method is suitable for the removal of most steel deep water jackets (Clucas 2013).

Equipment required for buoyancy tank decommissioning includes:

- Purpose built buoyancy tanks to that are attached to jacket prior to float; and
- DSV and tugs for deballasting and towage.

Designing the tanks used to lift the jacket is a complex task, and the installation of the connections offshore is time-consuming. Weather conditions must be taken into consideration as calm weather is required for the lift.

4.3.4.2 Tow and Place

Tow and place decommissioning involves severing the jacket from the seafloor using mechanical or explosive means, attaching it to a vessel with a cable, and towing it to an appropriate reefing site or deep water disposal location. The tow and place decommissioning method has been used in the Rigs-to-Reefs program in the Gulf of Mexico and in South East Asia (Dauterive 2000, Oil and Gas UK 2012).

Equipment required for tow and place decommissioning includes:

- Temporary buoyancy tanks;
- Connections on the jacket;
- DSV for positioning of the tanks and lift operations; and
- Tugs for towing the jacket to disposal site.

As discussed in Section 4.3.4.1, design of buoyancy tanks is complex and the installation of the connections offshore can be a time-consuming process. Calm weather is required for the lift and tow.

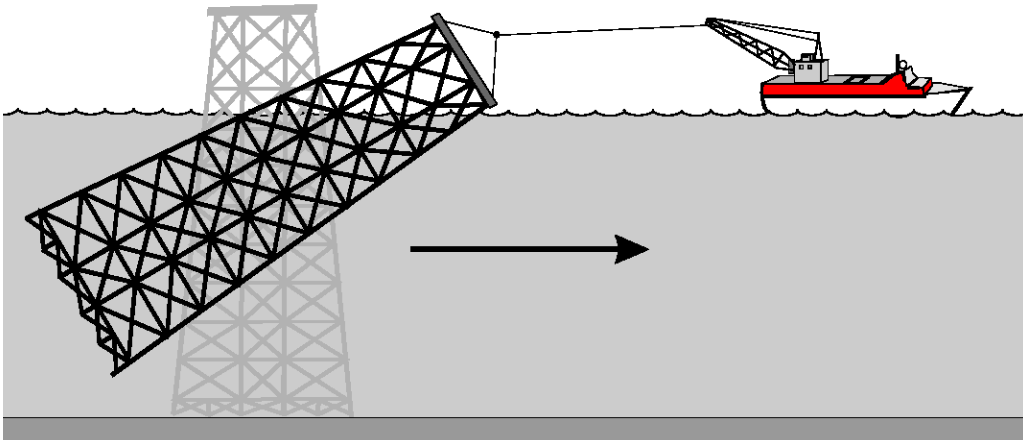


Figure 11: Complete removal - tow (Dauterive 2000)

4.4 Floating Production and Storage Offloading Vessels

An FPSO is used to produce and process hydrocarbons and to store oil. FPSOs can collect hydrocarbons directly from a field or from nearby platforms or subsea templates, process them and store the resulting oil until offloading onto a tanker, or in some instances, through a pipeline. Vessels which do not process oil and only store it are known as Floating Storage and Offloading vessels.

The most common decommissioning method for FPSOs is removal and reuse at a different location. As these structures are floating and not fixed, the use of FPSOs can greatly lessen decommissioning costs and makes it easier for operators to leave the marine environment as it was found. After cessation of production, the cargo tanks are emptied into a shuttle tanker, the topsides cleaned, all trapped energy de-energised and all topsides sea fastened for the tow to the disposal site. The anchor chains and flexible risers will be disconnected prior to the FPSO departing. A DSV can recover them for disposal onshore or reuse or they can be abandoned in-situ.

In Australia, FPSOs are typically disconnectable rather than permanently moored. A key feature of disconnectable FPSOs is their ability to be quickly removed prior to extreme weather events, such as the cyclones that hit Australia's North West Shelf. Disconnectable FPSOs have mooring and riser systems that can be optionally disconnected from the turret using a buoy that locks into a receptacle at the turret's lower end (Bluewater 2016).

Such a buoy is able to provide support to mooring lines and risers whilst the FPSO is disconnected, ensuring equilibrium at a required depth. Technologies, such as as the 'Arctic Turret' designed by Bluewater, assist in preventing jamming of the buoy by offering a two-step disconnection process (Bluewater 2016).

Disconnectable FPSOs are typically easier, safer and faster to decommission than those that are permanently moored, due to their design elements.

Equipment required for the decommissioning of FPSOs includes:

- DSV with 200 tonne crane; and
- Tugs for sea tow.

Calm weather is required for the disconnection of the moorings and risers and for the subsequent recovery.

Figure 12: Kuito FSPO, located offshore Angola (WorleyParsons slide image)

4.5 Concrete Gravity Structures

Some older oil and gas platforms, in particular those in the North Sea, have a concrete gravity base. Typically, these structures consist of large concrete legs which support the topsides above the sea with clusters of large concrete oil storage tanks or 'cells' at their base. They may be up to 50 m in diameter, stand in water up to 300 m deep, and can weigh up to 1.2 million tonnes. CGSs are generally found in the North Sea. However, Australia does have three offshore CGSs, being Wandoo B Offshore Oil Platform off the Western Australian coast, and West Tuna and Bream B, off the coast of Victoria.

Equipment normally required for decommissioning CGSs includes:

- DSV;
- Receptor cell for storing hydrocarbons; and

- ROV and pipes for hydrocarbon removal.

There are considerable risks and challenges associated with removing, lifting and transporting the reinforced concrete legs of gravity base structures. This is recognised by regulating authorities in the North Sea and therefore complete removal is not legally required. Technical and commercial constraints have meant that all concrete gravity base platforms decommissioned to date have obtained permission to leave their substructures in situ. To date, the removal of gravity base structures has never been attempted in the North Sea (Shell 2016). Potential decommissioning techniques discussed in the literature include complete removal by refloat, complete removal by offshore demolition, partial removal, or leaving the structure in place (IAOGP 2012).

Figure 13 - Concrete Gravity Structure under construction in Norway (Wikipedia 2016)

The storage cells of a CGS contain vast quantities of ballast, which is used to anchor the structure to the seafloor. Many cells were originally used for oil storage and contain contaminated sediment. Accessing the cells to remove contaminants presents great challenges, due to the depth and size of these structures as well as the thickness of their walls (Shell 2016).

The contents of cells, including attic oil, should be removed and transported to shore for recycling, treatment and/or disposal. Shell's technique for achieving this in the decommissioning of the

Brent Delta platform is to drill an access hole into each cell and install temporary flexible pipelines, which are laid across the tops of the cells so that attic oil and interphase material can be collected into a single receptor cell. The fluid extracted can then be replaced with water from the receptor cell. This may be performed from a vessel and does not require topsides to still be in place. It can also be performed with an ROV. Once materials have been extracted, the access holes can be sealed (Shell 2015).

The oil collected in the receptor cell may then either be removed via the existing oil pipeline prior to the removal of topside infrastructure, or may be pumped to a vessel if topside infrastructure has already been removed. It can then be transported to shore. As the attic oil and other cell contents are pumped out from the receptor cell, it will be replaced by seawater. Ensuring the cell is kept fully flooded will prevent any detrimental effect to the structural integrity of the cells or the CGS (Shell 2015).

4.6 Wells

Plugging and abandonment is the process by which a well is closed permanently, usually after either logs determine there is insufficient hydrocarbon potential to develop the well, or after production has ceased. All wells must be plugged and abandoned according to regulations once no longer in use and their connecting platform is being decommissioned. In Australia, plugging and abandonment of wells is done in accordance with an approved management plan.

Key stages in well abandonment are:

- Removing downhole equipment;
- Cleaning out the wellbore;
- Plugging open-hole and perforated intervals(s) at the bottom of the well;
- Plugging casing stubs;
- Plugging of annular space; and
- Placing a surface plug (Rigzone 2016).

The removal of downhole equipment can be undertaken using an existing drilling or conventional workover rig. This process aims to remove all equipment used by the operator, including packers, downhole pumps and production tubing (IEAGHG 2009).

Cleaning out the wellbore is done through flushing the bore with a circulation fluid. The fluid selected should have physical properties that allow pressure to be easily controlled to enable the removal of unwanted materials such as fill and debris. In some circumstances, other tools or additives may need to be used to ensure the wellbore is properly cleaned (IEAGHG 2009).

Plugging of the well is undertaken to ensure hydrocarbons do not leach into the environment and that the resource is protected. Therefore, an impermeable barrier must be installed. Whilst plugs may be made from various materials, Portland cement is the most commonly used within the oil and gas industry, as it hardens in place due to local pressure and temperature. Cement plugs are required to be of a certain length, depending on the regulatory authority governing well abandonment in a region. Cast iron bridge plugs are also common in North America.

Typically, no less than three plugs are placed during well decommissioning activities. These consist of the following:

- A cement squeeze at the level of the perforations;
- A plug located close to the middle of the wellbore; and
- A surface plug.

There are three major methods currently used for well plug placements. These are the balanced plug method, the dump bailer method, and the two-plug method. This is either performed 'rigless' or using a drill rig. Once a well has been plugged, testing must be undertaken to verify that the plug has been placed at a proper level and is providing zonal isolation. Testing methods include pump pressure testing and swab testing (IEAGHG 2009).

4.7 Sea Bed Wellheads, Manifolds and Valves

An offshore oil or gas field may have equipment located on the seabed. Typical equipment is subsea isolation valves on pipelines, wellheads, and manifolds. These should either be removed to leave a clear seabed or should be covered by rock dumping, anti-snag cages or concrete mattresses so they do not move or snag fishing nets. Anti-snag cages are protective frames that may prevent valves and corrosion monitoring spools from snagging on fishing equipment (ExxonMobil 2014).

Scale removal may also be undertaken during decommissioning of well bores, valves, pumps and downhole completion equipment. Common methods of removing scale that may contain pollutants are high-pressure water jetting and mechanical scraping or scrubbing. In some cases chemical cleaning methods may be used.

Equipment usually required in decommissioning seabed wellheads, manifolds and valves includes a DSV with 200 tonne crane. For a unit to be removed, good structural integrity is required. Decommissioning also requires calm weather conditions to ensure safe removal.

4.7.1 Mattresses

Mattresses are installed for protection, stabilisation and to prevent scour. Mattresses comprise several concrete blocks held together with polypropylene straps. Oil and Gas UK estimates that 35,000 to 40,000 mattresses are installed throughout the North Sea (Cumming 2015).

Mattresses can either be left in situ or removed. Currently, regulatory authorities in the United Kingdom recommend mattress removal and onshore disposal, but as many of these structures have been placed on the seafloor before regulations changed, they were not designed to be removed. Therefore, decommissioning can be costly, timely and complicated (Cumming 2015). In recognition of this, there is some flexibility from regulators and mattresses can sometimes be left in situ. If mattresses are removed, this may be done by divers manoeuvring the mattresses into a basket (ExxonMobil 2014).

Degraded mattresses are more difficult to remove and recover, and have less opportunity for reuse. Some mattresses tend to self-bury, whereas others remain intact and in good condition on the seafloor. When mattresses are left on the seafloor, they can be used to protect pipeline ends, which can be prone to snagging on trawling and fishing equipment (ExxonMobil 2014).

The most common way in which mattresses have been removed from the seafloor is with subsea baskets or speed loaders. As both of these methods present risks to divers, there has been a drive to move to less diver-intensive options (Cumming 2015). Rope deployment is another method that has been successfully executed in the past. Experience has shown that mattresses with polypropylene ropes are able to be successfully recovered while steel ropes corrode and are more difficult to remove (ExxonMobil 2014).

The structural integrity of the mattresses should be examined before they are removed, in order to determine the most appropriate decommissioning method.

4.8 Trunk Pipelines

Prior to abandonment, pipelines should be cleaned, flushed, and purged with a pig to remove any risks associated with seepage of hazardous fluids conveyed by the pipelines or introduced during decommissioning.

Decommissioning options for buried and unburied pipelines include:

- Leave in-situ and undertake remedial actions including partial selective burial, covering or removal to reduce risk to fishing activities;
- Trench and bury; and
- Partial / full removal.

4.8.1 Leave in Place

Leaving the pipelines in place is considered the best scenario for buried pipelines, as removal of buried pipelines is a difficult task that requires un-burying pipelines using trenching or water jets. Leaving pipelines in place involves flushing and cleaning, pipelines are then plugged at both ends using a cement or mechanical bung. Protection is also installed above buried ends to prevent snagging. Unburied pipelines pose a greater snagging risk then buried pipelines.

Equipment normally required to undertake this process includes a DSV with 200 tonne crane and an ROV.

Calm weather is required for cutting and removing the pipeline ends from the seabed. It is common practice in the North Sea to complete a trawl sweep test post-decommissioning to ensure snagging hazards have been removed. Further information on management controls is provided in Section 7.

4.8.2 Trench and Bury

Trenching of offshore pipelines may be undertaken using trenchers, ploughs or water jets depending on soil type, water depth and amount of rock to be removed.

Prior to trenching, the pipeline is cut and plugged before being surveyed with an ROV to determine soil type and seabed topography. The trench is dug either alongside the pipeline and the pipeline is rolled into it, or is dug beneath the pipeline. The trench is then either backfilled or left to backfill naturally.

The equipment normally required to undertake this process includes:

- DSV with ROV to monitor the operation, and a work class ROV to handle the cutting mechanism; and
- Vessel with chosen trenching technology - jetters, ploughs or trenchers.

Trench and bury decommissioning can be extremely complicated in very loose or cemented soil conditions. Soil types and methods of trenching are outlined in Figure 14. Soil types across the North West Shelf mainly consist of carbonate silts and carbonate sands (UWA, 2010), therefore sediment transportation and erosion is likely, hence burial may not be suitable in certain areas.

It is important to consider the potential impacts that sediment disturbance may have to local sea life before this decommissioning option is chosen.

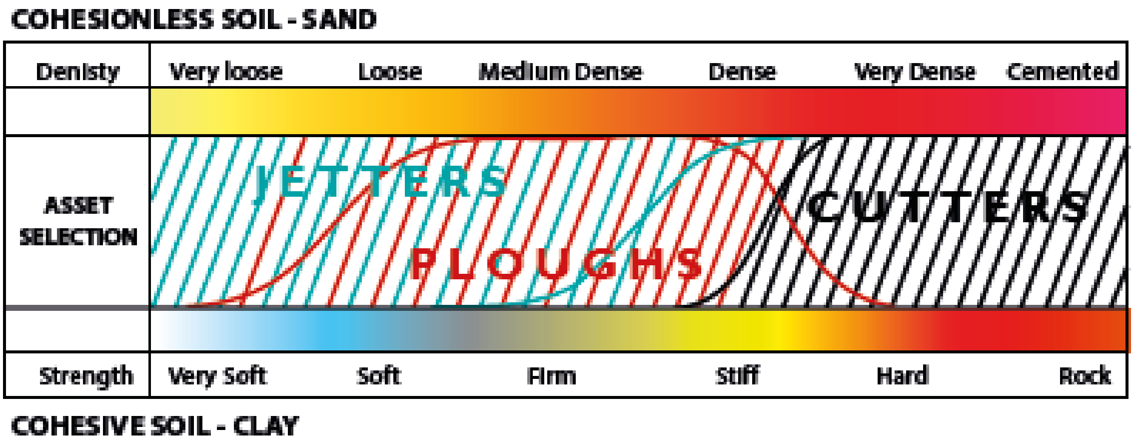


Figure 14 – Types of Soil and Trenching Methods Used (Source Oil and Gas UK, 2013)

4.8.3 Removal

Removal of buried pipelines involves unburying pipelines using trenching or water jets. The pipeline is then either cut or lifted by segments, or taken out via reverse installation using a dedicated installation vessel.

Equipment normally used for the removal of buried and unburied pipelines includes:

- DSV;
- Trencher/ jetter / dredger to support operations; and
- Barge or another vessel to transport pipe to shore.

Pipeline cutting tools commonly used include:

- Abrasive water jetting;
- Diamond wire cutting;
- Mechanical cutters / grinders;
- Explosives; and
- Hydraulic shears.

Pipeline unburying is a difficult task and has not been undertaken before. It may be difficult to achieve with conventional jetting or ploughing operations. The pipelines must have adequate structural integrity for lifting or reeling. The duration of the operation depends on method of cutting, weight and coating of the pipeline.

4.8.4 Partial Removal

Pipelines may be partially removed when it is considered appropriate to retrieve a high risk unburied pipeline section, whilst minimising further disruption to the seabed. In order to collect the pipeline section in a safe condition, the exposed areas are removed by cutting out sections, and then taken to shore for disposal or recycling. The equipment required for partial removal of pipelines is the same as the equipment required for removal as discussed in Section 4.8.3.

4.9 In Field Pipelines

The subsea wells and satellite platforms are connected to the central platform by flexible pipes, rigid steel pipes and umbilical cables. These may be removed as part of the abandonment work, but are also able to be left in place if appropriate regulatory approvals are obtained (Newfield Australia 2003). Prior to decommissioning, it is important to ensure all hydrocarbons are removed from in field pipelines and risers.

Equipment normally used for removing in field pipelines includes a DSV with 200 tonne crane and ROV.

Calm weather is required for the cutting and removal of subsea pipelines. The structural integrity at the end connections of the pipes and cables needs to be considered prior to the removal of the pipelines if they are to be removed in one piece.

The removal or relocation of the concrete mattresses used to cover the pipes in the vicinity of the platforms should also be considered, as the integrity of these mattresses may influence the preferred removal method. In addition, buried pipelines may require remediation work to ensure they remain buried.

4.10 Shell Mounds

Shell mounds are biogenic reefs that encircle some oil and gas platforms, created by an accumulation of mollusc shells that drop from the shallow areas of the platforms (Claisse et al. 2015).

Shell mounds can either be left in place or dredged and removed. Dredging and removal is preferred by some stakeholders as it aims to return the seabed to its natural state. However, those in support of leaving shell mounds in place argue that disturbing the material has greater adverse environmental impact than leaving the material settled in one location on the seafloor. Shell mounds have been found to be 'moderately productive fish habitats with comparable or higher production levels than natural rocky reefs in the same region at similar depths' (Claisse et al. 2015).

The equipment used for removing shell mounds is still to be developed.

4.11 Drill Cuttings

Drill cuttings are those excavated materials, usually broken bits of solid materials, which are expelled from a borehole that has been drilled by rotary, percussion or auger drilling methods. Cuttings are produced as rock is broken by a drill bit advancing through soil or rock. Drill cuttings from oil-rich shales and sands may also carry a high level of hydrocarbons, regardless of whether oil based muds have been used (Geehan, Gilmour and Guo 2007).

Prior to the 1980s, drill cuttings were usually disposed of overboard (Geehan, Gilmour and Guo 2007). More recently, the reinjection of drill cuttings has greatly reduced the amount of drill cuttings present on the seabed at the decommissioning stage. However, significant drill cuttings often remain for older structures.

The main options for disposal of these drill cuttings are leaving in place, covering, with or without the lowest part of the footings left in place, injecting down a well, or removing to shore for treatment (Ekins et al. 2006; Gerrard et al. 1999). Other options include chemical stabilisation, solidification and thermal treatments and bioremediation (Ball et al. 2012).

Equipment used for removing drill cuttings is still being developed., with new fully enclosed pneumatic technologies recently entering the market (Schlumberger 2016). The level of hydrocarbons within the drill cuttings needs to be considered in determining whether or not removal is a suitable decommissioning option, as is the distance of the drill cuttings pile from potentially sensitive receptors and natural reefs.

5 Decommissioning-Biodiversity Considerations

The previous section provided an outline of the different techniques by which oil and gas infrastructure may be decommissioned, including technical considerations, equipment used and times associated with various options. Another key consideration when choosing a decommissioning option is the risk and benefits of decommissioning on marine biodiversity. To determine the potential risks or benefit to biodiversity of removing such oil and gas infrastructure or leaving it in situ, the biodiversity values of these structures must at first be understood.

Many structures associated with oil and gas production act as artificial reefs during their productive lifetimes, with the potential to support fully functioning lifecycles and ecosystems. Initially, primary producers and epifauna settle on the hard substrate found at the structure. As plants, corals and primary producers settle and grow; greater numbers of fish are attracted to the structure for food, shelter and habitat to spawn. Access to an ample food supply, increases the total fish biomass. Spawning activity at the structure results in the production of larvae, which may recruit locally or disperse elsewhere on currents. Larger, pelagic fish may also visit the structure for food and shelter before moving on. The lifecycle of marine species on oil and gas infrastructure is depicted in Figure 16.

Existing literature based on Australian and international studies regarding the biodiversity values of oil and gas infrastructure or artificial reefs was reviewed to address the following questions:

1. Are marine communities associated with oil and gas infrastructure likely to be a significant source of larvae to habitats for the broader region?

2. Do marine species (particularly fish) recruit to the structures or migrate to these structures as adults?

3. Does the biodiversity value of infrastructure vary between infrastructure types and to what extent?

4. Does existing oil and gas infrastructure increase the marine biodiversity in a region?

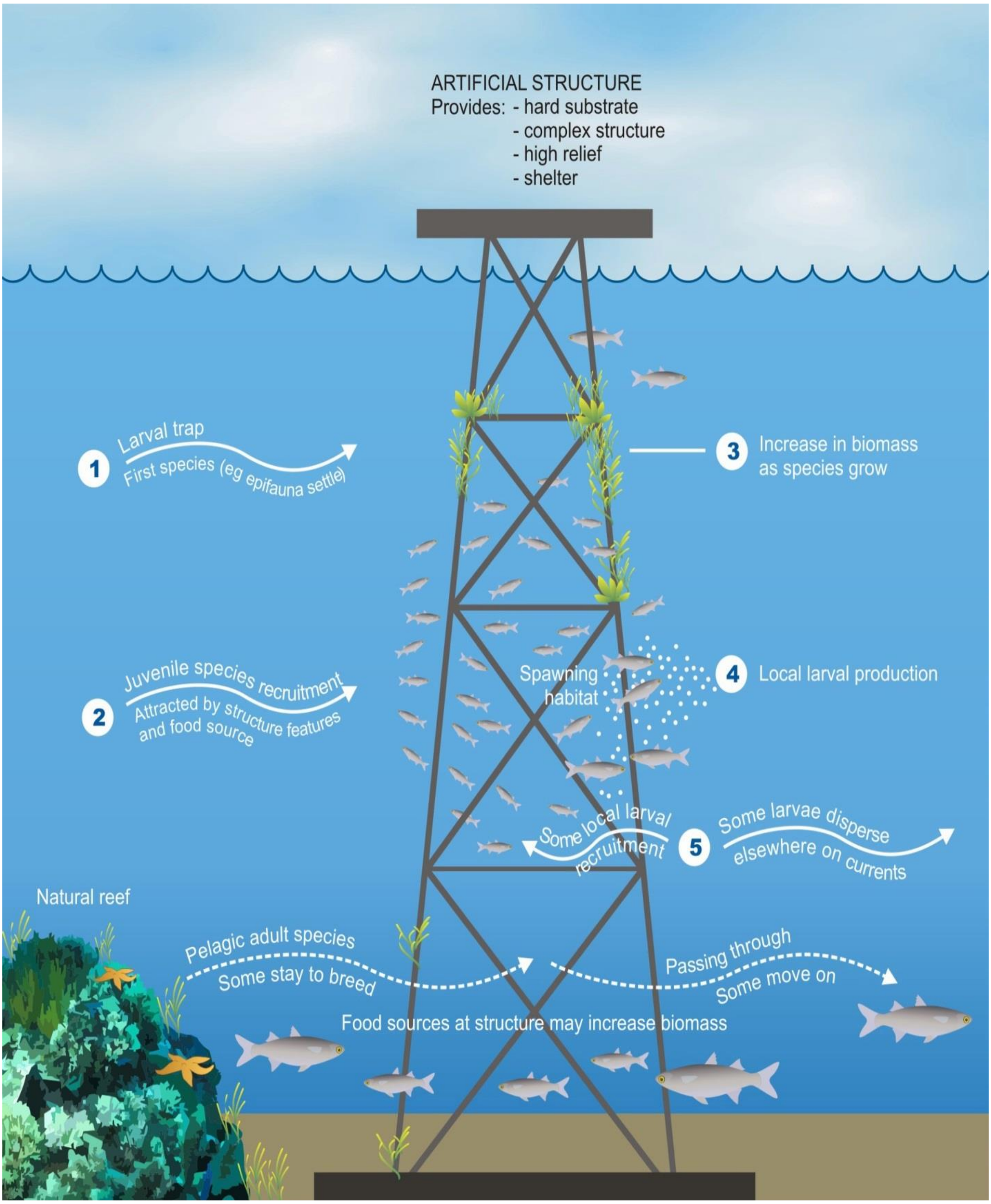


Figure 15: The lifecycle of an artificial reef

A review of the relevant literature found very little evidence to definitively answer the questions. There is little information on the impacts of oil and gas infrastructure on biodiversity, and existing studies tend to focus on species of economic importance (i.e. fisheries species). Not many studies exist in an Australian context on the impacts of oil and gas infrastructure on the marine biodiversity of the region, however several studies have been undertaken in the Gulf of Mexico, Southern California and the North Sea. Responses to these questions are outlined in Appendix B. The key findings are summarised in Figure 16.

Are marine communities associated with oil and gas infrastructure likely to be a significant source of larvae to habitats for the broader region?

Marine communities associated with oil and gas infrastructure can produce larvae as they provide spawning and reproductive habitat for species (Stevcic 1971, Campos and Gamboa 1989, Scarborough and Bull 1994, Pickering and Whitmarsh 1997, Friedlander et al. 2014).

Large abundances of mature adults indicate substantial larval production potential for some fish species (Shaw et al 2002, Claisse et al 2014, Berkley et al. 2004, Love et al 2005).

These marine communities may facilitate larval dispersal through increased connectivity, thereby increasing species range (Sammarco 2012, Thorpe 2012, Sammarco 2013, Simons et al. 2016).

These marine communities may act as valuable 'insurance' populations for larval supply ('reseeding') if natural reefs in the region experienced mortality (Atchinson 2005, Sammarco et al. 2012, Sammarco 2013, Friedlander et al 2014).

Do marine species (particularly fish) recruit to the structures or migrate to these structures as adults?

It is likely that recruitment and migration processes are occurring simultaneously at oil and gas infrastructure.

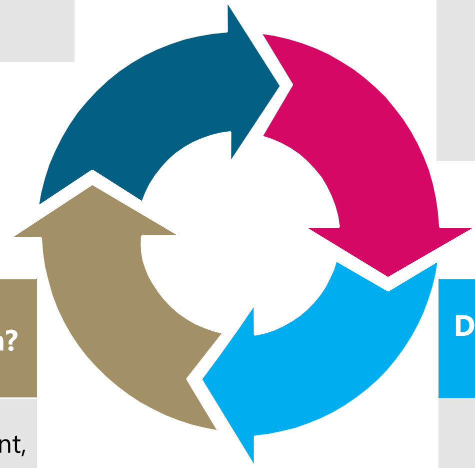
Evidence of recruitment of reef fish species was found on oil and gas infrastructure on the North West Shelf.

Vertical orientation and structural complexity of platforms is known to trigger settlement and subsequent recruitment to lower sections.

Evidence of larval recruitment has been found where natural habitats are scarce and also where artificial reefs are close to existing habitats (Emery et al 2006, Danner et al 1994).

Site fidelity provides indirect evidence of recruitment. High fidelity rates for red snapper were found at many sites in the Gulf of Mexico (Patterson and Cowen 2003, Strelcheck et al. 2007, Galllway et al 2009). As mortality rates are important in assessing the site fidelity of species, accurate determination of mortality rates is important.

Platforms provide shelter and protection from fisheries and natural predation, thereby enhancing recruitment at these platforms.



Does the biodiversity value of infrastructure vary between infrastructure types and to what extent?

Little specific research has been undertaken on the extent to which biodiversity value varies between different types of oil and gas infrastructure. Research undertaken to date has focused on comparing abundance and density of specific species between different infrastructure types (Love 2006, Pradella, 2014, Love and York 2005). Research on artificial reefs indicates biodiversity value does vary between different types of structures and the factors that influence biodiversity are; structure, depth relief, age and location, similar to natural reefs (Ajemian et al 2015).

Does existing oil and gas infrastructure increase the marine biodiversity in a region?

The presence of oil and gas infrastructure adds hard substrate to the marine environment, supporting a greater diversity of marine life by providing habitat for fish and other invertebrates that otherwise wouldn't exist in a soft substrate environment (Van Der Stap, 2016).

Species also vary with depth along platforms hence vertical orientation of platforms can increase local biodiversity.

The presence of artificial reefs can increase the ecological connectivity of an area by facilitating long range larval dispersal (Macreadie et al. 2011). Larval dispersal distance is greater from offshore platforms than nearshore habitats as offshore platforms are located in deeper water and thus experience enhanced dispersal due to higher sustained flows in the offshore environment

Figure 16: Lifecycle of marine species on artificial structures

6 Potential Risks and Benefits of Decommissioning Options

6.1 Overview

Potential risks and benefits associated with various decommissioning options (leave in place topple / partial removal and removal) were established through review of relevant literature, and through review of previous decommissioning options assessments undertaken such as the Sable Island Subsea Pipelines Decommissioning Project. The decommissioning options leave in place and removal are applicable to all infrastructure, the options partial removal and toppling are mainly applicable to jackets. The potential risks and benefits associated with various decommissioning options are outlined in Table 3.

Table 3: Benefits and Risks of Decommissioning Options

Benefits and Risks of Decommissioning Options			
	Leave in Place	Partial Removal / Topple	Removal
Benefits			
Increase in Biodiversity			
Recruitment			
Fish Attraction and Production			
Larval Production			
Increased Connectivity			
Reduced Pressure on Natural Reefs			
Fewer Obstructions for Trawlers			
Opportunities for Dive Tourism			
Risks			
Decrease in Biodiversity and Abundance			
Disruption to Ecosystem Function			

Benefits and Risks of Decommissioning Options			
	Leave in Place	Partial Removal / Topple	Removal
Spread of Invasive Species			
Discharges to Sea			
Seabed Disturbance			
Overfishing			
Damage to Fishing Equipment			
Decrease Visual Amenity			
Navigation Hazard			
Underwater Noise			
Atmospheric Emissions			
Water Generation			

The various decommissioning options and the key receptors that may potentially benefit from these options are outlined in Table 4.

Key receptors have been identified as:

- Biodiversity (B);
- Commercial and recreational fishers (F);
- Shipping (D);
- Tourism (T); and
- Human Health (HH).

The potential risks associated with the various decommissioning options, receptors potentially impacted, and management considerations to control the risk, are outlined in Table 5.

The potential benefits of decommissioning, applicable decommissioning options and receptors are discussed in further detail in Sections 6.2 through 6.9. The potential risks of decommissioning and applicable decommissioning options are discussed in Sections 6.10 through 6.21. Potential management controls associated with the key risks are discussed in Section 7. Monitoring may also be required prior to undertaking decommissioning to determine the potential risk and benefits of decommissioning on biodiversity. Monitoring considerations are outlined in Section 8.

Decommissioning options (leave in place, partial removal and removal) and associated techniques and activities such as mechanical cutting and vessel operations are discussed in Section 9. Risk and benefits associated with decommissioning options only are discussed in these sections, and not risks and benefits of associated techniques and activities. Risks associated with accidental events such as hydrocarbon releases from vessels and the accidental release of hydrocarbons or chemicals as a result of flushing operations have also been excluded, as the potential impacts are site and project specific.

Table 4: Decommissioning benefits and key receptors

Potential Benefits	Section Ref	Decommissioning Option	Receptors				
			B	F	T	S	HH
Increase in biodiversity - Caused by presence of hard substrate in soft substrate areas, complexity of structure and depth of structures	Section 6.2	Leave in place, partial removal, topple					
Recruitment - Larval and fish recruitment may be enhanced due to presence of hard substrate which can act as a settlement cue for larvae and attract fish	Section 6.3	Leave in place, partial removal, topple					
Fish attraction and production - High site fidelity can also lead to fish production	Section 6.4	Leave in place, partial removal, topple					
Larval production - High levels of fish production provide indirect evidence of larval production. Spawning habitat is also evidence of larval production	Section 6.5	Leave in place, partial removal, topple					
Increased connectivity - Artificial reefs may increase conductivity through long range larval dispersal	Section 6.6	Leave in place, partial removal, topple					
Reduced pressure on natural reefs - Fishing and diving at artificial reefs may reduce pressure on natural reefs	Section 6.7	Leave in place, partial removal, topple					

Potential Benefits	Section Ref	Decommissioning Option	Receptors				
			B	F	T	S	HH
Fewer obstructions for trawlers	Section 6.2	Leave in place, partial removal, topple					
Opportunity for dive tourism	Section 6.3	Leave in place, partial removal, topple					

*B=Biodiversity, F=Fisheries, T=Tourism, S=Shipping, HH=Human Health

Table 5: Decommissioning risks, key receptors and management considerations

Potential Risks		Decommissioning Option	Receptors B F T S HH	Potential Management Controls	Section Ref
Decrease in biodiversity and abundance - Complete or partial removal of infrastructure results in a decrease in associated species	Section 6.10	Partial removal, topple, complete removal		Monitoring	Section 8
Disruption to ecosystem function - Artificial structures may support larger predators which alters ecosystem function	Section 6.11	Leave in place		Monitoring	Section 8
Invasive species - Artificial reefs may act as stepping stones, facilitating the spread of exotic species. Relocation of infrastructure may also facilitate the spread of exotic species	Section 6.12	Leave in place, partial removal, topple and removal		Invasive marine pest risk assessment and inspections	Section 7.2
Discharges to the sea - Disturbance of drill cutting mounds, releasing contaminants. corrosion of infrastructure also results in the release of contaminants	Section 6.13	Leave in place, partial removal, topple and removal		Assessment of the risk at the point in which it becomes exposed to receptors	Section 7.3

Potential Risks	Section Ref	Decommissioning Option	Receptors B	F	T	S	HH	Potential Management Controls	Section Ref
Seabed disturbance - Removal of benthic habitats and resuspension of sediment smothering benthic habitats	Section 6.14	Leave in place, partial removal, topple and removal;						Anchor design and decommissioning planning	Section 7.4
Overfishing - Increased catch rates may result in overfishing and exploitation of stock	Section 6.15	Leave in place, partial removal, topple						Assessment of end use of infrastructure and retention of exclusion zones	Section 7.5
Damage to fishing equipment - Snagging hazard to trawlers	Section 6.16	Leave in place, partial removal, topple						Debris clearance and trawlability surveys	Section 7.6
Visual amenity	Section 6.17	Leave in place, partial removal, topple and removal						Not applicable	
Navigation hazard - Leaving in place / removal may aid navigation or pose a hazard	Section 6.18	Leave in place, partial removal, topple, removal						Installation of aids to navigation and update of nautical charts	Section 7.7
Underwater noise - Explosives used in removal cause severe underwater noise	Section 6.19	Partial removal, topple, removal						Modelling of risks and management in line with EPBC Policy Statement 2.1	Section 7.8

Potential Risks	Section Ref	Decommissioning Option	**Receptors**					**Potential Management Controls**	**Section Ref**
			B	F	T	S	HH		
Atmospheric emissions - Higher during removal operations due to large amount of equipment required	Section 6.20	Partial removal, topple, removal						Compliance with vessels planned maintenance schedules	Section 7.9
Waste - Higher volumes as a result of removal	Section 6.21	Leave in place, removal, partial removal, topple,						Consideration of re-use, recycle and correct waste classification	Section 7.10

6.2 Increase in Biodiversity

6.2.1 Applicable Options

Leaving submerged oil and gas infrastructure in place can enhance biodiversity by allowing complex communities of species to develop and thrive over time. As species richness varies with depth of structure, toppling and partial removal of infrastructure will reduce biodiversity in comparison to leaving the infrastructure in place. Complete removal of infrastructure will have the greatest impact on biodiversity by removing available substrate and habitat. The reduction in biodiversity caused by partial removal, toppling or complete removal of infrastructure is outlined in Section 6.10.

6.2.2 Biodiversity Benefits

Existing literature with regard to the impacts of oil and gas infrastructure and artificial structures on marine biodiversity has provided evidence of the following benefits to biodiversity:

- Presence of hard substrate increases diversity of marine life compared to biodiversity in soft sediment areas;
- Complex high relief structures can support abundant and diverse marine communities; and
- Species richness and diversity can vary with the depth of structure.

6.2.2.1 Hard Substrate Increases Biodiversity

Several studies have found that the presence of oil and gas infrastructure or artificial reefs adds hard substrate to the marine environment, supporting a great diversity of marine life by providing a habitat for fish and other invertebrates that otherwise would not exist in a soft substrate environment (Sammarco et al. 2013, Van Der Stap 2016, Jessee et al. 1985).

These new habitats are able to stimulate colonisation by species not naturally present in this region, where soft sediments dominate.

A study by Sammarco et al. 2013 shows that oil and gas infrastructure in the northern Gulf of Mexico, a mainly soft substrate area, supports substantial coral communities. Coral species and abundance is moderately high (up to 11 species) (Sammarco et al. 2013).

A recent study was undertaken on the ability of artificial reef structures to sustain populations of a small reef dwelling fish species in north-western Australia (Fowler and Booth 2012). The study species, red-belted anthias, is normally found on hard substrates such as coral and rocky reef outcrops. Post settlement movement of these species is generally restricted to distance of ≤50 m (Forrester 1990, Frederick 1997, Turgeon et al. 2010). As the artificial reefs are located on soft substrate with no hard substratum within at least 100 m, it is likely that the red-belted anthias would not exist in this area without the presence of the artificial reefs (Fowler and Booth 2012). The presence of hard substrate also facilitates larval and fish recruitment, outlined in Section 6.3.

6.2.2.2 Structure and Relief Increases Species Richness

It is generally agreed that high relief, complex reef habitat supports more abundant and diverse communities than low relief habitat. Therefore, complex three-dimensional infrastructure that projects upward into the water column (e.g. jackets) is likely to develop more diverse communities than low relief infrastructure (e.g. pipeline). Rigs with numerous cross beams and large interstitial spaces are more likely to support high fish diversity and abundance (Luckhurst and Luckhurst 1978, Hixon and Beets 1999).

A study undertaken in the Gulf of Mexico over a two year period (2012 and 2013) at three standing platforms and 12 artificial reef sites (oil and gas platform toppled or partially removed) found structure significantly influenced fish assemblages (Ajemian 2015). Fish assemblages varied between standing and toppled platforms; however there were no significant differences between standing and cut-off platforms. This provides evidence that the community characteristics of standing platforms can be best retained by maintaining the upright orientation and high vertical relief of these structures (Love et al. 2000).

The presence of benthic habitat on platforms also influences fish assemblages. A study of reef fishes inhabiting vertical strata of six production platforms and five nearby reefs over a three year period in Southern California found large macroalgae (kelps) were absent on platforms, therefore species associated with large macroalgae such as senoritas, kelp bass, kelp fishes and opal eye were relatively scare on platforms in comparison to natural reefs (Carr et al. 2003).

6.2.2.3 Species Variation with Depth

Leaving oil and gas infrastructure such as platforms in place is likely to increase species richness in the area, because different species associate with different depth zones. Previous studies of standing platforms have generally separated fish communities into three distinct groups in accordance with depth: a shallow “coastal” group (0-30 m), a mid-depth “offshore” group (30-60 m) and a deep “bluewater” group (>60 m). A study of artificial reef communities undertaken over a two year period in the Gulf of Mexico found a transition between fish assemblages at different depth ranges along the Texan continental shelf (Ajemian 2015). Species such as Greater Amberjack, Vermilion Snapper and Creolefish were more dominant in deep water. Species such as trigger fish usually common in coastal areas were found in shallower waters (Ajemian 2015).

Carr et al. (2003) found that fish assemblages occupying shallow (garibaldi, blacksmith halfmoon), mid depth (cabezon, copper, painted greenling, olive rick fish) and deep strata (sharpnose perch, and kelp rockfish) of platforms were distinctive (Schroeder and Love 2004, Carr et al. 2003). Vertical stratification is also related to the size and life stages of individual species. For example, the young of many shallow dwelling rock fish occurred only at shallower depths, whereas older stages occurred more frequently at greater depths (Carr et al. 2003, Gallaway et al. 2009). High densities of larger fish are usually found at platform bottoms, as most platforms are rarely fished and thus act as de facto marine reserves (Love et al. 2003, Schroeder and Love, 2004).

The study by Love et al. (2000) also found distinct differences in the fish assemblages living in the midwater and bottom habitats around a series of offshore platforms. Platform midwaters were dominated by young-of-the-year and juvenile rock fish up to two years old. The bottoms of the platforms were dominated by larger individuals, primarily adults and sub-adults. A greater number of species was found at the bottom, as bottoms are often largely comprised of shell mounds which may allow a greater number of species to coexist (Love et al. 2000).

Similar depth zonation also occurs with invertebrates and marine algae, as they preferentially survive within different depths in the water column depending on the amount of available light, current and wave activity.

6.3 Recruitment

6.3.1 Applicable Options

Leaving in place, topple or partial removal.

6.3.2 Biodiversity Benefits

The presence of hard substrate as a result of leaving infrastructure in place, toppling or partially removing infrastructure can provide a cue for settlement of planktotrophic larval species and facilitate larval recruitment. Site fidelity is an indicator of fish recruitment.

6.3.2.1 Larval Recruitment

Recruitment is broadly defined as the addition of new individuals to populations or successive lifecycles within a population (Caley et al. 1996). Recruitment may occur at different life stages of a particular species.

Evidence has been found of larval and fish recruitment on oil and gas infrastructure and artificial structures. Artificial reefs may intercept larvae in the plankton that would otherwise be lost from the ecosystem. Emery et al. (2006) demonstrated the importance of artificial reefs in the recruitment of Boccaccio (*Sebastes paucispinis*) off the coast of California. This study demonstrated that Boccaccio larvae would not have survived due to their current trajectory and lack of recruitment habitat. This study demonstrated that the presence of the Irene platform almost certainly increased the survival of Boccaccio larvae in this region.

The proximity of artificial reefs to existing habitats may increase the chance of transient fish encountering the reef, and the artificial reef may become an extension of existing habitat with possible benefits for fish recruitment (Danner et al. 1994).

Knowledge of larval dispersal trajectories could allow the strategic placement of rigs to increase recruitment success and help retain larvae that would otherwise be lost to inhospitable substrates. Atchison et al. (2008) showed that the genetic affinity of coral populations decreased with distance from natural source habitats, which led to the determination of the minimum distance (<65 km) of rig placement to intercept larval recruits from natural sources.

The presence of reef dwelling species with small post recruitment ranges at isolated offshore infrastructure provides evidence of pelagic larval recruitment. The study outlined previously (Section 6.2.1) on the ability of artificial reef structures to sustain populations of small reef dwelling fish in north-western Australia (Fowler and Booth 2012) also provides indirect evidence of pelagic larval recruitment.

Artificial reefs, through the provision of food and shelter, may allow more juveniles to survive to a size where they recruit to a fishery (Cripps and Abel 2002, Bohnsack 1989). Numerous studies suggest oil and gas platforms provide shelter for juveniles from anthropogenic pressures (trawl fisheries) and natural predation (Gallaway et al. 2009, Schroeder and Love 2004) for different species, suggesting that artificial reefs may play an important role in harbouring young-of-the-year and juveniles.

6.3.2.2 Fish Recruitment

Indirect evidence of recruitment at later juvenile stages is also provided through the site fidelity of species. Species with high site fidelity are also likely to have increased production. Production is discussed in further detail in Section 6.4.

Several tag and recapture studies have been undertaken to examine the site fidelity of red snapper at artificial reefs in the Gulf of Mexico (Szedlmayer and Shipp 1994, Watterson et al. 1998, Gallaway et al. 2009).

The study by Szedlmayer and Shipp (1994) of juvenile red snapper in the North Eastern Gulf of Mexico found the fish to have a high degree of site fidelity. The high site fidelity demonstrated from this tag and recapture study suggests that Alabama's artificial reefs provide suitable habitat for sustaining secondary (growth) production of juvenile red snapper, potentially assisting recruitment to adult populations.

Watterson et al. (1998) also observed high site fidelity in red snapper less than 3 years old in the Gulf of Mexico, although Hurricane Opal was observed to greatly decrease the site fidelity of fish that were at liberty when the hurricane passed. Patterson et al. (2001) continued with Watterson et al.'s 1998 study, and found site fidelity to be lower over a longer period of time in red snapper aged 3 or less (Gallaway et al. 2009), with only 55% of recaptures not at liberty during the hurricanes remaining at their release sites.

Peabody and Wilson (2006) also assessed local residency and site fidelity by installing a number of transmitters at different platforms in close proximity to one another, and also artificial reefs. They noted high levels of short term site fidelity and high levels of site residency, with 94% of the detected fish showing no movement between receiver locations on a daily, weekly or monthly basis. Site fidelity in the longer term, however was shown to be much lower than all previous studies. Peabody and Wilson (2006) hypothesise that this may be due to the close proximity of the infrastructure studied, leading to a large area of depleted prey in the surrounding soft bottom, forcing red snapper to forage further afield where they may lose sensory orientation. This would suggest that although red snapper recruit and become resident at these structures, they may migrate if they become overpopulated and foraging halos become extensive. Peabody and Wilson

(2006) also conclude that attraction or production is likely not mutually exclusive, and that fishing pressure at artificial reefs are likely to be the ultimate determining factor on whether attraction or production processes are dominant in the Gulf of Mexico.

6.4 Fish Attraction and Production

6.4.1 Applicable Options

The presence of oil and gas infrastructure as a result of leaving in place, partial removal or toppling infrastructure may attract a number of adult, larval and juvenile fish. The presence of oil and gas infrastructure may also increase production by providing shelter from unfavourable currents, increasing food and feeding opportunities.

6.4.2 Fishery Benefits

It is likely that both attraction and production processes are occurring concurrently at oil and gas infrastructure due to the range of species associating with artificial structures and their extreme differences in mobility and lifecycles. When resources such as food or habitat are abundant, the addition of an artificial reef may simply attract fish from a natural habitat into an artificial one without increasing regional abundance or biomass. In the short term this may have benefits to the fishing industry due to increasing catch rates, however, negative effect from attraction may occur if artificial reefs lure fish into an environment where mortality is high as a result of overfishing or poor habitat quality (Schroeder and Love 2004). Depletion of fish stocks has occurred in areas such as California where artificial reefs concentrated previously-depleted fish stock, making them easier to catch by recreational fishers. The risk of overfishing is discussed in Section 6.15.

Positive effects from attraction occur if the artificial reef provides a habitat which results in fish survivorship, biomass, abundance and growth. This is discussed in Section 6.4.

6.4.2.1 Fish Attraction

Oil and gas infrastructure, as well as other forms of artificial reef, are known fish attracting devices that draw in a number of adult, larval and juvenile fish, including commercially significant species (Ajemian et al. 2015, Pears and Williams 2005, Grossman et al. 1997).

This has benefits for both the recreational and commercial fishing industry, as fishery catch rates have been known to rise where these structures are installed (Ajemian et al. 2015, Pears and Williams 2005, Grossman et al. 1997), and anglers visiting offshore oil and gas infrastructure frequently report high catch rates (Grossman et al. 1997). A study undertaken off the coast of southern Portugal, by the Portuguese Institute of Marine Research, found that fishing yield by weight was up to 2.28 times higher at artificial reefs than at control sites, and that the average catch rate per unit effort (CPUE) as well as average CPUE species diversity were higher at an artificial reef in the study than at the control location (Santos and Monteiro 1998). As fishery catch rates have been known to rise where these structures are installed (Ajemian et al. 2015, Grossman et al. 1997), some countries such as Japan, South Korea and the Philippines have a history of installing artificial reefs to aid commercial fishing (Pears and Williams 2005). In certain regions, such as the Philippines, these have widespread government support, where the government has funded the construction of 21,600 artificial reef 'modules' (Pears and Williams 2005).

In the short term, leaving the structure in place is likely to assist fishers in optimising their catch rates (Pears and Williams 2005, Grossman et al. 1997). A study into the debate surrounding the Rigs-to-Reefs program in California found that recreational fishers are generally supportive of leaving structures in place for this reason (Edwards 2012). Recreational fishermen are generally strong supporters of Rigs-to-Reefs off the coast of California, who argue that it increases fish populations and provides good recreational fishing locations, which in turn increases interest in recreational fishing and hence revenue for the state (Edwards 2012, Grossman et al. 1997).

Currently, fishery exclusion zones of 500 m exist around fixed oil and gas platforms in Australia. Furthermore, a number of Australia's offshore oil and gas platforms are currently too far from shore to benefit recreational fishermen. However, following decommissioning rules regarding exclusion zones could be lifted, or infrastructure from these platforms could be towed and placed at locations that are more readily accessible. Artificial reefs for recreational fishery benefits have been successfully introduced in New South Wales, with positive reports from local fishermen (Department of Primary Industries 2015)

6.4.2.2 Fish Production

There is sufficient evidence in the literature to demonstrate that presence of oil and gas infrastructure can, in some circumstances, not only attract fish but increase overall biomass and abundance of some commercially significant species in particular locations (Claisse et al. 2014, Love et al. 2005, Shaw et al. 2002, Polovina and Sakai 1989). The reason for this is usually attributed to regional fish stock growth rates being limited by a lack of suitable hard bottom habitat, which is provided by the introduction of oil and gas infrastructure or other forms of artificial reef (Bohnsack 1989, Bohnsack et al. 1991, Polovina 1991). It is hypothesised that increased hard substrate provides valuable habitat for all life stages of fish for foraging, for adult fish for nesting and spawning, and valuable habitat for all life stages for hiding from predators (Grossman et al. 1997). An increase in biomass of commercially significant octopus was associated with the introduction of artificial reefs in Japan (Polovina and Sakai 1989). This was inferred from increases in catch rates per unit effort (CPUE). This study considered two adjacent fishing grounds, one with artificial reefs (West) and one without (East), in order to reduce the influence of variables such as changes in fishing power, year-class strength and market factors on results (Polovina and Sakai 1989). It was known that the populations of Pacific giant octopus (*Octopus dofleini*), were similar between the East and West bays between 1942 to roughly 1961. However, after 1961, catches began to increase in the West and by 1970, averaged rates five times higher than that in the East. There was speculation that the octopus may have been relocating from the East bay to the West bay, but as catch rates in the East bay were found to remain constant, it was considered most likely that the artificial reef habitats introduced in the West bay had provided suitable environments for the species to recruit and settle with lower risk of predation. The study found that populations of Pacific giant octopus increased by 4% per 1000 m^3 of artificial reef.

Oil platforms in the northern Gulf of Mexico support a commercially and recreationally valuable red snapper fishery, and Californian platforms provide important habitat for juvenile Boccaccio rockfish (Gallaway et al. 2009, Love et al. 2006, Polovina and Sakai 1989). Increased biomass, whether associated with increased numbers of individuals, larger individuals or both, provides an increase in total stock for a fishery. However, it is important to note that current research only indicates increased biomass of particular species and in certain circumstances.

A paper by Cripps and Aable (2002) argues that in theory, artificial reefs may provide more certainty about forecasted catch rates for commercial fishermen, which may result in greater income stability, provided the areas are not overfished. Whilst a potential increase in fish biomass is a benefit of leaving infrastructure in place, fishery management will determine whether this benefit has any real positive impact.

To date, there is no significant evidence that consuming fish caught close to an oil and gas platform presents health risks for consumers, provided that there have been no major oil spills in the area in recent months. Following the 2010 Deepwater Horizon oil spill in the Gulf of Mexico, fisheries were closed as a precautionary measure and species tested for levels of polycyclic aromatic hydrocarbons (PAHs) and levels were found to be either non-existent or in extremely low levels that were deemed safe for human consumption (Waters 2014).

Whilst toppled structures will still attract fish in a similar manner to standing structures, the toppling of a platform is likely to lead to mortality for those species that live in the surf zone and shallower portions of the structure (Cripps and Aabel 2002). As toppled structures may provide a less ideal habitat than a structure that has been left in place and encompasses the whole water column, they may result in less fish attraction and may not support all life stages of particular, commercially significant species of fish. Therefore, they may have less benefit for fisheries. The converse benefit of this is that the dispersal of stock may protect fisheries over the long term from overfishing, which is considered a risk of keeping oil and gas infrastructure in place.

Although they may not be as productive as structures that have been left in place, partially removed structures may still increase fish biomass in a region. A study determined that partial removal would have limited impacts on fish biomass on almost all of the platforms off the coast of California (Claisse et al. 2015). The study stated that on average, the platforms would retain 80% of fish biomass following partial removal, and 86% of secondary fish production, with many platforms having above 90% retention for both (Claisse et al. 2015). However, abundance and increase in biomass would fall for shallow dwelling species following partial removal (Claisse et al. 2015).

In summary, whilst the ability of artificial structures to increase biomass of a fishery is a widely discussed topic, limited research has been undertaken that draws conclusions on the matter (Love et al. 2006, Polovina and Sakai 1989, Ajemian 2015, Shaw et al. 2002, Foster et al. 1994). This is because of the difficulties associated with examining populations that are able to travel large distances and migrate between locations throughout their various life stages. Recent studies demonstrate that artificial structures can host areas of highly valuable habitat (Ajemian 2015, Shaw et al. 2002, Love et al. 2006, Stephens and Pondella 2002, Claisse et al. 2014). Where increases in biomass have been recorded, it has usually been species and site specific, with commercially significant species the main subject of research (Bohnsack 1989).

6.5 Larval Production

6.5.1 Applicable Options

The presence of infrastructure as a result of leaving infrastructure in place, toppling or partial removal may provide a spawning ground and result in larval production for a range of marine species including fish and invertebrates.

6.5.2 Biodiversity Benefit

Records demonstrate that in certain areas, such as off the coast of California, marine communities associated with oil and gas infrastructure and other forms of artificial reef may provide a significant larval source in the region (Ajemian 2015, Claisse et al. 2014, Love et al. 2005). These findings are based on both direct and indirect evidence of larval production. Direct evidence of larval production consists of observations of species breeding at platforms, as well as at other artificial structures, which demonstrate that these structures are able to provide suitable spawning grounds for fish and other marine species.

Direct evidence of spawning is difficult to capture (Shaw et al. 2002). However, fish spawning and courtship behaviour has been recorded around oil and gas platforms in Gabon, where red snapper (*Lutjanus dentatus*) have been observed spawning and yellow jack (*Caranx batholomaei*) have been observed engaging in what appear to be typical jack courtship behaviours (Friedlander et al. 2014). During another study, a sergeant major (*Abudefduf saxatilis*) was found guarding a nest of eggs inside a broken weld on a platform (Scarborough and Bull 1994). Spawning, mating and other reproductive behaviours, nests and large egg clusters have also been observed on other types of artificial reefs in regions as diverse as Costa Rica and the UK for a wide variety of marine organisms including crabs, nudibranchs and typical reef fish (Pickering and Whitmarsh 1997, Campos and Gamboa 1989, Stevcic 1971).

In addition to direct evidence of larval production provided by records of spawning events, there is substantial indirect evidence that larval production is occurring at locations where spawning has not yet been directly observed. This indirect evidence is based upon:

- Larval assemblages at an artificial structure matching closely with adult species present;
- Increased secondary production associated with artificial structures, provided species have high site fidelity and good reproductive health; and
- High densities of mature fish in and around structures.

A study undertaken in the Gulf of Mexico examined the fish assemblages at three oil and gas platforms (Shaw et al. 2002). It found that at the locations surveyed, larval assemblages matched closely with adult fish species present, indicating that the adult species were spawning at these sites and their larvae recruiting locally (Shaw et al. 2002). The study also examined the length frequency and development stages of reef taxa collected at the platforms, and concluded that the findings provided indirect evidence of potential spawning and nursery / recruitment habitat at the platforms. Whilst the study recognised that natural reefs could be the source of the larvae, the absence of hard bottom seabed and the number of platforms within viable larval distribution range make platforms the most likely source (Shaw et al. 2002).

In regards to increased secondary production, research has determined that oil and gas platforms off the coast of California have the highest secondary fish production per unit area of seafloor of any marine habitat that has been studied (Claisse et al. 2014), although this figure was highly variable among structures (Fowler et al. 2015). The species that were the focus of this research have strong site fidelity, meaning it is highly likely they will produce larvae at this location.

High densities of mature fish at platforms suggest that these populations have the potential to provide more larvae than natural habitats, per unit area. One platform, Gail, off the Californian coast, was found to have by far the greatest densities of both species and highest rate of potential larval production of any of the habitats surveyed; natural or artificial. The study by Love et al. (2005) estimated that removing Platform Gail would be equivalent to removing 12.57 hectares of average-producing natural habitat in southern California for cowcod or 29.24 hectares of average-producing natural habitat for Boccaccio rockfish.

6.6 Increasing Connectivity

6.6.1 Applicable Options

The presence of artificial reefs as a result of leaving in place, partial removal or toppling may contribute to local and regional hard substrate habitat and is likely to increase ecological connectivity (Cowan and Sponaugle 2009).

As the height of the platform increases dispersal distance, leaving in place is likely to result in higher dispersal distances than complete or partial removal options.

6.6.2 Biodiversity Benefit

The presence of artificial reefs may increase the ecological connectivity of an area through facilitation of long range larval dispersal (Macreadie et al. 2001).

A study was undertaken in the Santa Barbara channel comparing the dispersal of the non-native sessile invertebrate (*Watersipora subtoquata*) from nearshore habitats and offshore platforms (Simons 2016). This bryozoan has a planktonic larval duration (PLD) of 24 hours or less. The results of this study indicated that the dispersal distance was greater for offshore platforms than nearshore habitats. The offshore platforms are located in deeper water and thus experience enhanced dispersal due to the higher sustained current flows in the offshore environment. Species with short PLDs may only disperse a short distance in the nearshore, as they are exposed to slow flows during their brief planktonic stage (Simons 2016). The height Watersipora is released in the water column also affects dispersal distance; organisms may have short dispersal distances as they exhibit behaviour that allows them to remain close to the seafloor, increasing their likelihood of encountering a suitable habitat (Simons 2016).

6.7 Reduced Pressure on Natural Reefs

6.7.1 Applicable Options

Leaving infrastructure in place may increase the abundance and diversity of fish species which may result in increased fishing and diving opportunities, thus decreasing pressure on natural reefs.

6.7.2 Fishery Benefit

As outlined in Section 6.4, the presence of oil and gas infrastructure may result in fish attraction and production. Studies have shown that increase in production may result in increased catch effort (Polovina and Sakai 1989), thus reducing fishing pressure on natural reefs.

6.7.3 Tourism Benefit

The increase in popularity of scuba diving and the behaviour of divers and dive operators has meant that dive tourism can have a negative impact on natural reefs (Jakšić, Stamenković and Đorđević 2013). The degradation of these natural reefs can have flow on effects to the tourism values of the region. Some supporters of Rigs-to-Reefs programs suggest that introducing artificial reefs to an area can alleviate the tourism pressures on natural reefs by providing alternative diving destinations as well as providing alternative habitats for reef species (Jakšić, Stamenković and Đorđević 2013, Nichols 2013, Fadli et al. 2012, Charbonnel 2002, Rilov and Benayahub 1998, Rilov and Benayahub 2002, Davis and Tisdell 1996, Feary et al. 2011, Uy et al. 2008). Studies undertaken on the socio-economic risks and benefits of sunken warships have shown that in some instances, such as in the sinking of the USS Spiegel Grove in June 2002, increased popularity of wreck diving does correlate with a decrease in scuba diving on natural coral reefs in the area (Jakšić, Stamenković and Đorđević 2013).

In Australia, Ningaloo Reef attracts tourists who wish to snorkel and scuba dive in the area, putting pressure on the natural environment. There are a number of existing oil and gas platforms within the wider region. If managed appropriately, infrastructure from these platforms could be towed and placed close to shore during decommissioning to create artificial reefs. Such reefs would provide alternative diving and snorkelling habitat for tourists, alleviating pressure on the natural reef in the region.

It is important to note that tourism benefits are maximised where the structure is readily accessible to divers or recreational anglers. In many cases, oil and gas structures are located in very remote areas that are not easily accessible by boat and in many cases, access is strongly weather dependant.

6.8 Fewer Obstructions for Trawlers

6.8.1 Applicable Options

Complete removal of infrastructure results in decreased fish stocks and fewer obstructions for trawlers.

6.8.2 Fishery Benefit

As discussed in Section 6.16.2, commercial trawlers generally support the complete removal of oil and gas infrastructure, as there are risks associated with their equipment snagging on these structures. Within Australia, oil and gas fields overlap with trawl fisheries, including the Northern Prawn fishery,, the Western Deepwater Trawl Fishery and the North West Slope Trawl Fishery. In Bass Strait, oil and gas infrastructure also overlaps with the Central Zone Scallop Fishery, which uses towed dredges to collect scallops from the seafloor. Trawl fishermen argue for the long term protection of fish stocks through complete removal when discussing decommissioning. Recreational fishers, however, are generally supporters of leaving infrastructure in place, as it attracts large numbers of fish as well as large pelagic species of fish, which can be more difficult to find elsewhere (Edwards 2012). Decommissioning which involves the most removal of materials and leaves a clear seabed benefits the trawling industry by opening up these areas to trawling (Ekins 2006). However, it is important to note that the negative impacts of trawling on environmental resources are considered by some to be greater than those impacts of leaving oil and gas infrastructure in situ (Ekins 2006).

6.9 Opportunities for Dive Tourism

6.9.1 Applicable Options

Leaving infrastructure in place results in diverse and abundant marine communities which provide opportunities for dive tourism,. Partially removing or toppling infrastructure may result in the structure being too deep to be accessed by divers, resulting in a decrease in dive opportunities. Removal of infrastructure results in potential loss of opportunity for dive tourism.

Within Australia, most oil and gas platforms are located too far from shore and in too deep and open waters to be considered viable for dive tourism. However, if these structures were removed from their operational location and dragged elsewhere to create a new artificial reef, they could enhance nearshore dive experiences and provide a valuable tourism opportunity.

6.9.2 Tourism Benefit

The marine communities associated with oil and gas infrastructure are often diverse and abundant, supporting a wide range of species of interest to recreational divers. Globally, leaving oil and gas infrastructure in place after production activities have ceased may provide tourism opportunities related to diving, due to the aggregating effect of these structures on fish populations (Pears and Williams 2005, Ajemian et al. 2015). There is evidence that these structures may increase biodiversity and biomass in a region (Jessee et al. 1985, Love and York 2005, Claisse et al. 2014, Van Der Stap 2016), as discussed in Sections 6.2 and 6.4. This has flow-on effects for potentially increasing the tourism destination value of the whole area for dive based tourism.

The economic benefits that may be derived from new dive locations should not be underestimated, as marine area tourism is the tourism sector with the largest growth globally (Gladstone et. al 2013, UNEP 2009). It is estimated that worldwide, over 28 million people participate in scuba diving as a recreational activity (Jakšić, Stamenković and Đorđević 2013). In Australia alone, scuba diving tourism is estimated to be worth $1 billion Australian dollars in revenue (Edney 2006, Harriott 2002).

A study undertaken in Monroe County determined that the introduction of an artificial reef resulted in $32 million in income for the county and 2,300 new jobs (Jakšić, Stamenković and Đorđević 2013). Similarly, the sinking of the USS Spiegel Grove and the USS Vandenberg contributed to the local economy of the Florida Keys region through wreck diving (Jakšić, Stamenković and Đorđević 2013). The shipwreck SS Yongala near the Great Barrier Reef plays an important role in the local economy, and it is estimated that the wreck accounts for $1 million annually from organised visits (Edney 2006, Delgado 1998). This figure does not include profits associated with flights, accommodation, restaurants and dive gear rental (Edney 2006, Delgado 1998). The infrastructure may remain in place for over a hundred years.

Toppled or partially removed platforms, depending on the location of the infrastructure, may result in the structure being too deep or too far to be accessed by recreational divers, resulting in decreased diving opportunities.

There is evidence to suggest that the presence of standing platforms in a region relate to higher levels of biodiversity and provide for a wider range of life stages of many fish species (Rooker et al. 1997, Carr et al. 2003). This is because some species utilise different depths for different life stages (Carr et al. 2003, Gallaway et al. 2009). Toppling a structure or removing its upper portions may result in a loss in fish biodiversity and biomass. This would result in less 'interesting' reef for divers with fewer reef fish and less species. Shallow dwelling species are also most likely to attract divers, as deeper species may not be accessible.

A risk to tourism of removing oil and gas infrastructure is the loss of any potential dive that would have been associated with the structure for the rest of its 'lifespan'. As the infrastructure may remain in place for over a hundred years, it is important not to underestimate the long term economic benefits that could be associated with such an artificial reef. Similar structures are being deployed at great expense by governments around to globe to develop world-class diving reefs.

6.10 Decrease in Biodiversity and Abundance

6.10.1 Applicable Options

Partially removing, toppling or complete removal can cause a decrease in biodiversity.

6.10.2 Biodiversity Impacts

One of the benefits of leaving oil and gas infrastructure in situ is that fish assemblages vary with depth (Section 6.2.2.3). Carr et al. (2003) compared species composition of reef fishes inhabiting vertical strata of six production platforms and five nearby reefs over a three year period in Southern California. This study found removal of the upper portions (20-30 m) of the platform is likely to reduce the abundance of many whose depth range is restricted to that portion of the platform. Certain species may recruit as plankton to the upper portion of the water column and move to bottom depths as they get larger / older. Removal of the upper portions of the platform may prevent recruitment of these species and cause reductions or absence of these species on decommissioned platforms.

Carr et al. (2003) also found that the upper portions of platforms predominantly consisted of planktivore and the young stages of many species. Removal of the upper portions of platform would also curtail the recruitment of these species to these structures.

Sessile invertebrate (primarily mussels, barnacles and anemones) encrust pilings, cross beams and well pipes, and are dominant in the upper 15-24 m of the water column (Carlisle et al. 1964). Eventually the weight of the mussel becomes sufficiently large that they dislodge and fall to the bottom. They provide a habitat for fishes on platforms, and the mounds of shell litter provide habitat for small fishes beneath platforms. Shell mounds have been found to be moderately productive fish habitats (Claisse et al. 2015). Removal of the upper 20-30 m of structure will cause reductions or loss of species that use the mounds of mussel shells that form beneath platforms as recruitment habitat, adult habitat or as a source of food (Carr et al. 2003). Toppling a platform will also result in loss of sessile invertebrate from the top sections of the platform, and the loss of species that use the shell mounds as habitats. Shell mounds are not a likely feature of oil and gas developments in Australia; they are mainly a feature of temperate climates. Furthermore, many surface components of oil and gas infrastructure are cleaned every four to seven years by operators in order to prevent biofouling.

Studies have also found that toppling platforms may alter species type. A recent study on coral communities on standing vs toppled platforms in the Gulf of Mexico (Sammarco et al. 2013) found little variation in coral species density on standing vs toppled platforms; however a species-specific response to toppling was found. *Tubastraea coccinea* populations seemed to thrive better on toppled platforms than on standing ones; this is because this species is known to grow well on artificial substrates such as platforms but also in disturbed habitats (Sheehy and Vik 2010). The use of explosive to sever platforms also changes the composition of benthic species on the platform. This method dislodges numerous benthic invertebrates and kills many associated reef fish, thus leaving newly available space for settlement by incoming larvae or expansion of robust surviving species such as *Tubastraea coccinea*. Other coral species such as *M. decactis* require light for colony survival and growth. These colonies existing on standing platforms that were transported to deeper, darker, cooler waters upon toppling will not survive.

Total removal of a platform structure will kill the majority of organisms associated with oil and gas infrastructure, causing a dramatic reduction in local species diversity and abundance (Schroeder and Love 2004).

Disposal of the platform structure onshore will cause complete mortality for all the remaining attached invertebrates that were not dislodged by cleaning or removal operations (Schroeder and Love 2004).

After completion of decommissioning activities, local species composition will shift toward a soft-sediment community (if shell mounds are removed) or to a community similar to that occupying low relief cobbles if shell mounds are left in place. The rate of recovery depends on natural or human-caused disturbance rates (e.g. hurricanes, trawling), species migration rates and the degree of sediment contamination (Schroeder and Love 2004).

6.10.3 Fishery Impacts

As toppling in place alters the height of the structure in the water column and usually involves the use of explosives, it will disturb the existing ecosystem, potentially decreasing fish numbers and fishing opportunities.

Partial removal involves the ‘topping’ of a structure, leaving the remaining portion in place. Habitats associated with the top portion of the structure are therefore removed. The removal of the topsides involves removing the molluscs and shallow dwelling organisms that are associated with the upper parts of the structure. In some cases, these organisms can provide an important food source to the species living below, which may be significant commercial or recreational fishery species (Claisse et al. 2015).

The size and complexity of shell mound habitats are likely to be reduced following partial or complete removal of a platform (Claisse et al. 2015). This is because shell mounds are created by shells falling from the top of the structure. Shell mounds have been found to be moderately productive fish habitats (Claisse et al. 2015). Therefore, partial removal may have some impact on fish production, which will have subsequent impacts on fisheries. It has been suggested that augmenting habitat, by placing a partially removed platform or other enrichment material on the seafloor next to the base of the platform, may provide alternative fish habitat, thus mitigating these impacts (Claisse et al. 2015). Shell mounds are not likely to be a feature of most oil and gas developments in Australia; they are mainly a feature of temperate climates.

Complete removal is likely to result in dramatic reduction in local species diversity and abundance (Schroeder and Love 2004). In the short term, this is likely to result in severely reduced catch numbers for those fishing close to where the platform previously stood, which may have an economic impact on fisheries. The removal of hard substrate will also result in a lack of habitat for reef fish production if there is no surrounding natural hard substrate present. In summary, any benefits associated with fish attraction and potential production around infrastructure will be lost if the infrastructure is completely removed. This will have negative impacts on fishing opportunities in the area. Conversely, the dispersal of the fish population may protect the fishery over the longer term and provide a more sustainable fishing model into the future.

6.11 Disruption to Ecosystem Function

6.11.1 Applicable Options

Leave in place, topple and partial removal.

6.11.2 Biodiversity Impact

Structures can develop considerably different biological communities on them than surrounding habitats, even natural reef habitats. Depending on the ecological role of these new and different species, they may affect the functioning of natural systems, e.g. platforms may support more large predators than other habitats, potentially influencing the abundance and distributions of smaller prey species in the area (potentially reducing diversity if a few larger species become dominant (Gallaway et al. 2009).

Gallaway et al. (2009) found that the artificial reefs studied in the Gulf of Mexico harboured a high fraction of mature (aged two) red snapper. Prior to the placement of the reef habitat, the area had provided a nursery habitat to many species of fish (Shipp 1999, Cowen et al. 1999). Cowen et al. (1999) argued that the previous nursery function has been traded for a habitat consisting mainly of adult predators, resulting in modification of the ecosystem function.

Well's (2007) studies of artificial reef habitat in offshore Alabama also found that an increase in adult reef species has coincided with an increase in reef placement. However trawl samples have found that the addition of artificial reef habitat has not resulted in area-wide displacement or loss of soft bottomed ichthyofauna as characterised by Shipp (1999).

6.12 Invasive Species

6.12.1 Applicable Options

Leave in place, partial removal, topple and removal.

6.12.2 Biodiversity Impact

As the presence of artificial reefs may increase the ecological connectivity of an area through facilitation of long range larval dispersal, artificial reefs may also facilitate the spread of exotic species (Macreadie et al. 2001). Oil and gas infrastructure can facilitate the introduction of exotic species or species range expansions by serving as 'stepping stones' of vertical relief and hard substrate habitat across a soft seafloor environment (Gallaway and Lewbel 1982).

Exotic species harboured on oil and gas infrastructure may spread to surrounding habitats and out-compete local species for food and shelter, negatively impact local species (i.e. become invasive), thereby resulting in species loss (diversity loss). The presence of exotic species on oil and gas infrastructure may also reduce the abundance of native species and thus reduce the ecological services such as habitats and the support to the food chain which offshore platforms provide to natural inshore reefs (Page et al. 2006). Page et al. (2006) undertook a study of exotic invertebrate species inhabiting offshore oil and gas platforms of central and southern California, and found that the platforms harbour a high abundance of exotic bryozoan and anemone species. Although these platforms were located relatively close to natural reefs, exotic species were either not present or present in low numbers on these reefs. This provides evidence that platforms harbouring high abundances of exotic invertebrates produce no negative effects on biological communities in surrounding habitats.

Transport of platforms to other locations and deployment as artificial reefs in a Rigs-to-Reefs program can facilitate the spread of exotic species. Removal, partial removal or toppling of infrastructure could facilitate the dispersal of exotic species. Surveys for potential invasive species should be conducted on oil and gas infrastructure prior to removal or partial removal. Knowledge on the spread of exotic species and their potential for interaction and dispersal with native species are important considerations for decommissioning. Further detail on the management of the risk of invasive marine species is provided in Section 7.2.

6.13 Discharges to the Sea

6.13.1 Applicable Options

Routine vessel discharges such as deck drainage, grey water, sewage and ballast water occur through the use of vessels during decommissioning operations.

Non-routine discharges to the sea can occur during decommissioning activities, such as:

- Accidental releases such as marine fuel spills from vessel collisions; and
- Release of chemicals and hydrocarbons as a result of inadequate capture and storage during flushing.

Risks associated with vessel operations have been excluded, as this activity occurs regularly as part of oil and gas operations and the impacts are well understood. Risks associated with accidental events such as hydrocarbon releases from vessels and the accidental release of hydrocarbons or chemicals as a result of flushing operations have also been excluded, as the potential impacts are site and project specific.

Other sources of contaminants are produced formation water (PFW) and drill cuttings. Drill cuttings can accumulate on the seabed as a result of drilling activities, while some PFW constituents may be present on the seabed from years of operational discharge. PFW mainly consists of hydrocarbons, heavy metals and NORMS. Drill cuttings mainly consist of hydrocarbon contamination but may contain traces of heavy metals and NORMS. A review by Breuer et al. (2004) found that contaminants within cutting piles remained unchanged over time, and that contaminant levels within cutting piles were unlikely to change unless disturbed. Hence leaving infrastructure in place is unlikely to result in the release of contaminants from drill cuttings and sediment piles. Contaminants are more likely to be released if sediment is disturbed during toppling or partial removal activities.

Corrosion on infrastructure left in place may occur, resulting in the release of any retained contaminants to the water column.

6.13.2 Biodiversity Impacts

6.13.2.1 Drill Cuttings and Sediments

When drill cuttings are left in place, they are removed slowly by the natural processes of erosion, degradation and leaching over several or many decades. A review by Breuer et al. (2004) on drill cutting accumulations in the Northern and Central Northern Sea, comprised of oil based, synthetic and water based muds, found that hydrocarbon levels within cutting piles remained unchanged over time and that contaminant levels within cutting piles were unlikely to change unless disturbed.

An intact shell mound provides a natural cap to local contaminants such as drill cuttings piles. Removal or disturbance of cutting piles may result in the resuspension of contaminants into the water column (Schroeder and Love 2004). Field studies in the North Sea have demonstrated that effects from oil based cutting piles are typically confined to benthic communities within a 1-2 km radius of platform sites (Addy et al. 1987, Dicks et al. 1990). Re-exposed contaminants on the seabed will be more accessible to mobile benthic organisms, particularly epifaunal invertebrates, as well as benthic fishes that encounter contaminants during foraging activity. Contaminants that are resuspended and dissolved in the water column may be accessible to pelagic organisms, including plankton, mobile invertebrates and fish. Contaminants may be transferred through the food chain, concentrating in organisms at higher trophic levels. Mobile organisms may also spread contamination beyond the site, to other organisms through predatory interactions, or to humans through fishing. Dissolved contaminants in the water column may also be spread beyond the site by oceanographic processes.

Synthetic and water based muds are more commonly used in recent wells which minimises the risks from exposure to hydrocarbons.

6.13.2.2 Corrosion

Corrosion of pipelines over time may result in the release of the pipelines' external coatings, chemical residues from the pipeline interior, and actual pipeline materials into the water column.

Sacrificial anodes are used as protection on pipelines to reduce corrosion and maintain integrity during operational life. These anodes are made from aluminium and zinc and may contain trace amounts of mercury, copper, cadmium and lead. As anodes deplete there is a possibility that trace amounts of metals could accumulate in sediments and become bioavailable. The potential impact depends on the water depth, temperature, oxygen levels and flow over the surface of the pipeline, as well as the proximity or closeness of association of species inhabiting the structures. Impacts are unlikely as the rate of metal inputs is low and is rapidly diluted (Deborde et al. 2015).

Pipelines may have an external concrete or steel coating. The breakdown of concrete by chemical action will primarily be through chloride reaction and mechanical abrasion. Corrosion generally results in sand or gravel sized concrete fragments that have low reactivity in the marine environment (Hinwood and Denis 1998).

Other external coatings could be one of a number of polymers, commonly high density polyethylene or an epoxy. These high density polymers are very stable at depths where they are not exposed to sunlight, and are expected to remain intact for many decades. Abrasion may result in small fragments being removed, but these are chemically inert and will mix with natural seabed sediments (Hinwood and Denis 1998).

Steel coatings are mainly comprised of iron but may contain small quantities of carbon, manganese, phosphorous, sulphur, vanadium and titanium. Typical quantities of each element for a 250 tonne steel pipeline are tens of kilograms of phosphorous, sulphur and titanium, about 3 tonnes of manganese and about 246 tonnes of iron. While corrosion rates in seawater depend on ambient water temperature, biofouling, pH level, and oxygen level, it is estimated that the lifespan of a cathodically unprotected platform will range from 100 to more than 300 years (Quigel and Thorton 1989). The limited data on corrosion rates have been reviewed by the Australian Marine and Offshore Group Pty Ltd, which found a consistent corrosion rate of 0.13 mm per year. The corrosion rate, combined with the pipeline composition and the exposure surface area, will provide the rate of release of the pipeline constituents into the marine environment. The main constituent of steel - iron - is not however considered a significant contaminant in the sea, and even at elevated levels is unlikely to have adverse effects on marine biodiversity. Any leachate is likely to be quickly dispersed and diluted, hence impacts are likely to be small-scale and localised.

6.13.2.3 NORMS

PFW, having been in contact with various rock strata at elevated pressure and temperature, contains many soluble components including barium and the radioactive intermediates of the uranium and thorium decay series. As the water is produced, the temperature and pressure decreases, creating conditions in which the barium and radionuclides can co-precipitate inside separators, valves and pipework, forming an insoluble NORMS scale. Exposure of marine organisms to the NORMS scale may occur if pipelines corrode, which is likely to take 100 to 400 years.

The most significant radioactive element in NORMS scale and PFW is radium and in particular the isotope Ra226, which is an alpha emitter with a half-life of 1620 years. This scale typically has a low solubility and is resistant to leaching at ambient temperature (Neff 2002). As a result, radium has a very low concentration in solution in seawater and has a low bioavailability to marine organisms. It is also known that dissolved cations in seawater, particularly calcium and magnesium, inhibit the bioaccumulation of radium. Similarly, any radium associated with precipitated barite in seabed sediments would not be bioavailable to benthic organisms. Because of its low concentration in seawater and sediments, radium rarely accumulates to high concentrations in the tissues of marine plants and animals. Where bioaccumulation does occur in marine animals, the radium concentrations are higher in calcified skeletal structures of molluscs, crustaceans and fish than in their muscle and organ tissue (Oil and Gas UK 2016). For example, more than 40 percent of the radium accumulated by fish is in the bone, with only 6 percent in the edible flesh (Oil and Gas UK 2016).

Other chemicals such as corrosion inhibitors and biocides are likely to be used in the pipeline. Corrosion inhibitors are absorbed in the steel and not readily released to the marine environment. The majority of biocides are biodegradable and will not have any toxicity impacts.

Table 6: Expected corrosion rate of offshore pipelines

Component	Decay Rate
Breakdown of anti-corrosion coating	Designed for pipeline's operational life
Enhanced consumption of sacrificial anodes	20-50% remaining at end of operational life
Steel corrosion rate	0.2 mm/ year in seawater = 60 years for 12 mm steel Up to 400 years for fully buried pipelines 0.13 mm per year (Hinwood and Denis 1998)

Source: HSE (1997)

6.14 Seabed Disturbance

6.14.1 Applicable Options

Vessel anchoring may be required for all decommissioning options: leave in place, partial removal, toppling and removal. The level of seabed disturbance as a result of vessel anchoring is limited to the footprint of the anchors and the area adjacent to the site. Anchor design may need to be considered to prevent further impact from anchor drag.

Pipeline cutting, plugging and installation of protection structures may be required if infrastructure is being left in place. This can result in resuspension of marine sediment and localised smothering of benthic habitat.

Partial removal or toppling requires larger vessels and is likely to result in a larger disturbance footprint. Toppling of infrastructure will also result in seabed disturbance in the drop zone. Complete removal will result in disturbance of the entire infrastructure footprint.

6.14.2 Biodiversity Impact

Risks to fish are likely to be limited as they are highly mobile and relocate away from overly turbid waters if necessary. The area of impact is limited to the footprint of the equipment on the seabed and the area directly adjacent. The severity of the impacts depends on the species composition, abundance and location of benthic habitats in relation to the activity, and the expected extent of the increased turbidity and deposition. Benthic communities are expected to rapidly colonise any impacted areas following decommissioning activities (Currie and Isaac 2005).

6.15 Overfishing

6.15.1 Applicable Options

The presence of infrastructure as a result of leaving infrastructure in place, partial removal or toppling may result in fish attraction, which may cause increased fishing effort and overexploitation of fish.

6.15.2 Fishery Impact

Reports suggest that Rigs-to-Reefs programs have a greater impact on fish attraction than production, and that the installation of artificial reefs to improve fisheries is questionable (Ajemian et al. 2015, Pears and Williams 2005, Cripps and Aable 2002, Grossman et al. 1997). The extent to which production may be increased will vary on a case-by-case basis (Ajemian et al. 2015, Pears and Williams 2005).

A major concern of many stakeholders is that whilst it is commercially beneficial in the short term for a large number of an individual species to aggregate in one location, it may have dangerous long term impacts for stock levels (Bohnsack 1989, Polovina 1991, Pears and Williams 2005, Edwards 2012).

A review of the effects of artificial reefs on fish stocks by the Queensland Department of Primary Industries concluded that the potential for overfishing following attraction and the increased availability of already depleted fish stock is a serious risk of artificial reef deployment. The presence of oil and gas infrastructure may have negative effects on reef fish populations through increasing fishing efforts and catch rates, increasing potential for overexploitation of stock (Polovina and Sakai 1989, Grossman et al. 1997). Some stakeholders, including environmental groups and commercial fishers, argue that the ease with which fishermen can capture fish at these artificial reefs may lead to unsustainable levels of fishing, resulting in severe decreases in the overall fish stock and possibly even the extinction of commercially significant species from an area (Edwards 2012, Cripps and Aable 2002, Grossman et al. 1997, Bohnsack 1989).

A study undertaken in the Philippines considered the impacts of fish attracting devices (FADs) on tuna fisheries. The increase of tuna catches, from under 10,000 metric tonnes in 1970 to 266,211 tonnes in 1986, was attributed to the introduction of FADs (Aprieto 1988). The landings of fish then began to decline. As more than 90% of the tuna caught were under one year old during the boom period, there were concerns that the rate of fish mortality may have led to growth and recruitment overfishing (Aprieto 1988). Additionally, suggestions were made that the natural mortality rates of juvenile tuna were higher at FADs than in schools in the open ocean (Aprieto 1988).

Importantly, even when more fish are produced as a result of these structures, higher levels of fishing activity may counter any positive influence the artificial reef would have on overall fish production, unless carefully managed (Pears and Williams 2005). If this is found to be the case, which is likely, artificial structures could actually result in overfishing of limited fish populations, which may have come from natural reefs and aggregated at decommissioned oil and gas infrastructure. Management measures are outlined in Section 7.5.

6.16 Damage to Fishing Equipment

6.16.1 Applicable Options

Infrastructure left in place, partially removed or toppled has the potential to cause damage to fishing equipment.

6.16.2 Fishery Impact

The fish attraction associated with oil and gas infrastructure that has been left in place may result in greater percentages of total stocks living in and around these structures. This may result in increased fishing levels at these locations. Fishing close to large structures presents risks associated with the damage of equipment, with nets being particularly susceptible to snagging. Due to this, trawl fishermen are generally opposed to leaving infrastructure in place (Edwards 2012). Recreational fishers however, who generally fish with lines, are largely in support of Rigs-to-Reefs programs (Edwards 2012). Whilst damage to equipment is seen as a risk in the short term, leaving structures in place as artificial reefs could result in more fishers using long line fishing over the long term (Cripps and Aabel 2002). It is important to note that whilst this presents economic costs to commercial fishermen, it may increase the sustainability of the fishery and result in fishing with lower levels of bycatch (Cripps and Aabel 2002). Additionally, there is speculation that trawling may cause more damage to the seabed than that which is caused by oil and gas infrastructure (Banner 2015).

Partial removal is not generally a popular notion with the commercial fisherman of California (Edwards 2012). This is partially because the Californian commercial fishing industry is mostly reliant on trawlers, which can become caught on the partially removed structures, damaging their fishing equipment, reducing catch and reducing profits (Edwards 2012). Claims have been filed against Chevron after commercial fishermen have snagged on partially removed platforms, and there are concerns about the long term safety and legal liability issues associated with marking these platforms with buoys as navigational hazards. Whilst markers have been used in the past, there have been reports of them disappearing (Blue Latitudes 2014).

6.17 Visual Amenity

6.17.1 Applicable Options

Leaving infrastructure in place may impact visual amenity. Partial removal, toppling or full removal is likely to increase visual amenity.

6.17.2 Tourism Impacts

A risk of leaving oil and gas infrastructure in place is the impact that this may have on the scenic values of a tourist destination. The presence of a decommissioned oil and gas infrastructure may have an impact on a destination's amenity, especially if the infrastructure can be seen from shore (MMS 1986). The Proposed 5-Year Outer Continental Shelf Oil and Gas Leasing Program, January 1987-December 1991: Draft Environmental Impact Statement, Volume 2, states that the impact of infrastructure will be dependent on distance from shore and the existing recreational values of the stretch of coast adjacent to the location of the infrastructure.

The report provides an example of three platforms that were to be installed off Pigeon Point, south of Ano Nuevo. Whilst it was suggested that the platforms would have a 'very low' impact on recreation and tourism, it was stated that if the platforms were located further from shore they would have 'no impact', but if they were located 'closer to the three mile line' a 'high' impact to visual resources could be the result (MMS 1986).

The Central Californian Outer Continental Shelf (OCS) Oil and Gas Sale No. 73, 1983: Environmental Impact Statement, Volume 1 (MMS 1983), stated that offshore structures could present a moderate impact to tourism if grouped directly off the coast, but would be expected to have a lower impact if they were more scattered (MMS 1983). It is important to note that the document separated impacts on visual resources and impacts on tourism. For impacts to visual resources, the document stated that platforms located off particular beaches and bays would have a 'very high' impact, particularly if they were grouped together (MMS 1983).

Though it may not be directly recorded, leaving offshore platforms in place could deter beach and shore based tourists, especially environmentally minded tourists, and could negatively impact the promotion of 'eco-tourism' in a region.

The oil and gas industry already faces a lot of opposition from environmental groups (Edwards 2012). In California for instance, a lot of the opposition towards Rigs-to-Reefs programs have been related to the reduction in costs that would result for operators (Edwards 2012, Schroeder and Love 2004). When a platform is no longer in use, leaving it standing and in view from the shore or coastline may appear to send a message to both environmentalists and the tourism industry that the perpetual impact the infrastructure has on the local amenity is of little concern to the operator, as is any impact on the local environment.

When infrastructure can be seen from shore, toppling it or removing its upper portion so that it can no longer be seen would likely greatly benefit the local accommodation industry and may have positive impacts for local restaurants and other venues that overlook the ocean.

6.18 Navigation Hazard

6.18.1 Applicable Options

Leaving infrastructure in place may be a navigation hazard depending on whether it has adequate navigational aids such as lights installed.

6.18.2 Shipping Impacts

The IMO sets out international shipping rules and standards concerning maritime safety and navigation, which promote efficiency and protection of marine users and the wider marine environment. The London Protocol, enforced by the IMO, prohibits all dumping at sea, except for possibly acceptable wastes, including vessels, platforms and other man-made structures at sea. For acceptable wastes, permits are still required for dumping. The guidelines set out by the IMO are regulated in Australia by the Australian Maritime Safety Authority (AMSA). Australian law protects marine users from collision with dumped materials through strict requirements for navigational aids and safety measures.

A risk associated with having any structure in the open ocean is that it could interfere with shipping and be potentially dangerous if vessels were not aware of its presence. However, as exclusion zones have already been placed around existing oil and gas infrastructure when they were commissioned, leaving a structure in place, whether standing, partially removed or toppled, would not require an alteration of existing zones or add any extra risks associated with shipping.

Depending on the depth of the structure, navigation aids such as lights and buoys may need to be installed to mark its location to ships and it will need to be shown on charts (Cripps and Aabel 2002). In general, the requirements for navigational aids may become more restrictive if the structure lies closer to the surface (Schroeder and Love 2004). The legal responsibilities and liability for these aids may pose complications (Cripps and Aabel 2002). In the Gulf of Mexico, navigational aids on reefed platforms are paid for by the State. This funding is taken from the industry donation that must be given to the Rigs-to-Reefs program by the operator, to offset savings incurred from participating in the program rather than completely removing all infrastructure (Schroeder and Love 2004). It is important to recognise that even when navigational aids are installed, they can be lost.

Once a structure is completely removed, it provides no risk to shipping. Complete removal of oil and gas infrastructure requires increased marine vessel traffic. Any increase in traffic potentially increases the risk of accidents (MMS 1986). These accidents have the potential to result in personal injury, fatality, property damage and oil spills (MMS 1986). Additionally, conflicts could occur from the increased port congestion and competition for facilities at ports resulting from complete removal (MMS 1986).

6.19 Underwater Noise

6.19.1 Applicable Options

Vessel operations used for all options (leave in place, partial removal or topple) may cause underwater noise during thrusting to stay in position. Underwater noise is also caused by activities such as mechanical and explosive cutting used in partial removal, toppling or removal operations. The largest potential impacts to biodiversity are caused by explosive cutting. This option is currently being phased out due to marine impacts, and is often used during plugging and abandonment operations downhole.

6.19.2 Biodiversity Impact

Explosives are used to sever pilings and conductors during removal and toppling operations. The use of explosives greatly reduces the abundance and species richness by killing virtually the entire fish population present at a close range at the time of decommissioning.

Explosions generate intense shockwaves that cause instantaneous lethal impacts for marine life residing on or near the platform structure (Baxter et al., 1982). At a very close range, underwater explosions are lethal to most invertebrates and fish species regardless of size or shape. At a greater distance from the source, species with gas filled swim bladders suffer higher mortality than those without swim bladders. Lethal impacts to fish located at the surface of the water centred on the explosion are also likely. Fishes in this zone may die from rapid swim bladder expansion or explosion, as the initial shock wave reflects off the surface of the water and transforms into a decompression wave. Small fish are more susceptible to lethal concussion than larger fish.

Shock waves as a result of underwater explosions can cause severe impacts to marine mammals, depending on the size of the shock wave and the size and depth of the marine mammal (Yelverton et al. 1973). Gas containing organs such as the lungs and ears are particularly susceptible to injury. Exposure to the shock waves can cause lung haemorrhages, air embolisms and breathing difficulties, and rupture of intestinal walls (Yelverton et al. 1973).

Impacts to marine turtles as a result of underwater explosion are a result of physiological responses to both the type and strength of the acoustic signal and the shockwave generated by the explosion. Turtles in direct proximity to the explosion may suffer from lung haemorrhages or gastrointestinal tract injuries (Richmond et al. 1973). Exposure to shock waves may cause brain damage or massive inner ear trauma (Ketten, 1995). After 22 underwater explosions, 51 marine turtle were found dead on a Texas beach (Klima et al. 1998).

6.20 Atmospheric Emissions

6.20.1 Applicable Options

Atmospheric emissions are caused by the operation of vessels and other machinery required for all options. Levels of atmospheric emissions are higher for partial removal / topple or complete removal as more equipment is required.

6.20.2 Potential Impact

The operation of vessels and other machinery will result in the emission of greenhouse gases such as carbon dioxide (CO_2), methane and nitrous oxide along with other non-greenhouse gases such as sulphur oxides and nitrogen oxides. Atmospheric emissions from the decommissioning facilities are considered unlikely to have a significant impact on air quality at local and regional scales, as they are expected to be quickly dissipated into the surrounding atmosphere.

6.21 Waste Generation

6.21.1 Applicable Options

Waste is generated through vessel operations, pipeline flushing and removal of infrastructure. More waste is generated as a result of partial removal or complete removal, as disposal of infrastructure is required.

6.21.2 Potential Impacts

Various types of waste are generated when disused offshore installations are removed or partially removed. Reuse and recycling can form a major component of decommissioning programs. The decommissioning of the North West Hutton platform saw 98.3% of the waste reused or recycled. Of the estimated 38,000 tonne structure, 7,029 tonnes were reused (accommodation, module support frame, helideck, etc.), 20,925 tonnes were recycled and 473 tonnes disposed to landfill. The footings remained in situ, pursuant to an OSPAR Convention derogation.

Scale in pipelines may consist of hazardous materials such as NORMS, hydrocarbons and heavy metals. Scale is usually removed from inside pipelines and sent to a hazardous waste facility for disposal. A study undertaken by the Ministry of the Environment in Norway found that approximately four tonnes of active radioactive waste (scale, sludge and sediments) has been found in each offshore installation decommissioned in Norway (Ministry of the Environment 2010). Other hazardous materials that may require disposal include asbestos, paints containing polychlorinated biphenyl, hydrocarbons, chemicals and heavy metals.

Removal and disposal of asbestos poses risks to human health. Inhalation of even relatively small amounts of certain types of asbestos dust has been proven to increase the risk of several diseases such as asbestosis and cancer. Detailed asbestos inspections must be undertaken prior to decommissioning, and additional management measures must be implemented during removal and disposal to reduce exposure.

Exposure to NORMS may occur as a result of removal activities. Unprotected overexposure to radium dusts has been associated with an increased risk of lung cancer or leukaemia. Management considerations for disposal of NORMS are outlined in Section 7.10.1.

Onshore disposal of marine fouling often results in odour problems and should be disposed offshore if possible. Approximately 900 tonnes of biofouling waste from the Helena and Harry platforms were disposed to landfill after decommissioning (Schroeder and Love 2004).

7 Management Considerations

7.1 Overview

Existing literature, previous decommissioning environmental impact assessments and decommissioning EPs were reviewed to determine potential management controls for each of the risks identified outlined in Section 6. Potential management controls and examples (where possible) of their implementation are outlined below. Key considerations to inform decommissioning decisions are also considered.

7.2 Invasive Marine Pests Management

Artificial reefs and oil and gas infrastructure pose a potential risk to the spread of invasive marine species through an increase in connectivity (Section 6.6) and the potential for them to act as vectors if left in situ. They may also pose a risk during translocation if invasive marine species are present on the infrastructure, especially if they are transported through coastal waters. Risks associated with invasive marine pests are presented in Section 6.12.

The risk of invasive marine species should be considered on a site-by-site basis and will be dependent on the site location, the metocean conditions at the decommissioning site, and potential receiving environments. Risks should be assessed in line with the National System for the Prevention and Management of Marine Pest Incursions (the National System) which provides the assessment framework for the management of marine pests in Australia and will assist in determining the management controls required for decommissioning projects.

In Western Australia, the advice of the Department of Fisheries for decommissioning projects is that decommissioning Environment Plans or Environment Management Plans should include a biofouling risk assessment and the appropriate management measures. These management measures should at a minimum include an invasive marine pest inspection, but should also consider cleaning methods if invasive marine pests are found. In situ cleaning is often the preferred management control, especially in deep water environments where the invasive marine pests are unlikely to survive without the presence of hard infrastructure.

Additional management controls to reduce the risks of the introduction of marine pests through vessel activities during a decommissioning project are as follows:

- Records of Department of Agriculture, Fisheries and Forestry (DAFF) inspection and Quarantine Pre-Arrival Report is to be submitted to DAFF prior to entry into Australian waters;
- All vessels are to have Australian Quarantine and Inspection Service (DAFF) certification and an anti-fouling coating that complies with the requirements of Annex 1 of the International Convention on the Control of Harmful Anti-Fouling Systems on Ships;
- Ballast water from a foreign port will not be discharged into Australian waters less than 200 m deep or within 12 nautical miles from land;

- Ballast water records will be maintained on board the decommissioning facility and support vessel(s); and
- Biofouling records will be maintained on board the decommissioning facility and support vessel(s), which include details of anti-fouling coating used, dates and locations of cleaning, dry docking, anti-fouling applications, and date and locations of in-water inspections.

7.2.1 Key Considerations to Inform Decommissioning Decision

- What marine pests are present on the structures?
- Are they high risk invasive species?
- What is the risk of invasive marine pests being translocated to other sites?

7.3 Management of Discharges to Sea

The risks from discharges to sea are presented in Section 6.13. Risks include release of contaminants as a result of disturbance of sediments and drill cutting piles, and corrosion of infrastructure containing contaminants that may result in the discharge of contaminants to the environment.

7.3.1 Management of Contamination from Drill Cuttings and Sediments

Exploration activities have resulted in the accumulation of large quantities of drill cuttings on seabeds surrounding drill sites (Breuer et al 2004). If these contaminants are disturbed during the decommissioning process contaminants may be released resulting in impacts to water quality and marine species (Breuer et al 2004).

As such, it is prudent to ensure there is a good understanding of the surrounding environment including sediment quality, epifauna and infauna prior to the assessment of decommissioning options (Section 8) through a pre-activity sediment survey. This allows for an informed decision to be made on the potential environmental impacts from seabed disturbance of each decommissioning option. The management control is the selection of a decommissioning option which minimises the disturbance to any contaminated seabed material, as it is not feasible to remove these sediments from the environment without causing additional environmental impact.

7.3.2 Management of NORMS Risk

NORMS scale may build up in pipelines which may pose a risk to the environment if the integrity of the pipeline is compromised through corrosion.

A risk assessment should be conducted to determine the risk of NORMS being released to the marine environment as a result of decommissioning activities. If there is a risk of NORMS being released, a threshold concentration above which environmental impacts from NORMS may occur needs to be determined. The Department of Environment and Conservation has recommended environmental quality criteria for radionuclides in industrial buffer zones (based on Australian and New Zealand Environment and Conservation Council (ANZECC) guidelines) of 0.4 Bq/L. At present, Australia and New Zealand Food Authority does not specify maximum permitted concentrations for radionuclides in edible tissues, however, there is allowance for open water disposal of sediments containing up to 35 Bq/g of radionuclides (sum of gross alpha and gross beta) in the National Assessment Guidelines for Dredging – Commonwealth of Australia (CoA 2009). Radioactive material as defined in the *Environment Protection (Sea Dumping) Act 1981* means material that has an activity of more than 35 Bq/g.

Monitoring of expected NORMS concentrations can be done using radiation monitoring instruments such as dose rate meters or dosimeters (IOGP, 2016). These instruments can be mounted on an ROV a deployed from a survey vessel. NORMS concentrations can then be modelled in conjunction with the expected temporal integrity of the pipeline to assess whether the temporal risk is acceptable and falls within the defined thresholds. Decommissioning options for sections of pipelines containing higher radioactivity levels may vary. In order to manage and reduce the risk, burial or removal of sections of pipeline demonstrating an unacceptable risk may be considered.

In Australia the decommissioning of the Challis and Jabiru field involved the consideration of the management of NORMS scale in the flexible pipelines which were to be left in situ. An in situ survey was conducted to assess whether radioactivity levels were above background levels (Newfield Australia Pty Ltd 2003). In total, five flexible pipelines were shown to have levels above background. A rate of 400 uGy/h was used as an acceptable dosage rate in the Environmental Impact Assessment, as recommended in international guidelines (National Council on Radiation Protection & Measurements, International Atomic Energy Agency and United Nations Scientific Committee on the Effects of Atomic Radiation). The flexible pipelines are expected to remain in a condition to contain the NORMS for at least 100 years in the ambient environment. An assessment was made of the predicted dosage rate once the integrity of the pipeline starts to degrade, concluding that an expected dosage rate of 10 uGy/h may be present 1.5 m from the pipeline at a point in time when the integrity of the pipeline is expected to be compromised, which is an order of magnitude below the dosage rate used to determine an impact (400 uGy/h). By the time complete failure of the pipeline was predicted, it is expected that the pipelines would be buried or that NORMS scale would become mixed with the sediments, preventing direct exposure to NORMS scale. Based on this assessment, no control measures were recommended.

7.3.3 Key Considerations to Inform Decommissioning Decision

- What are the receptors and exposure pathways?
- Does the risk profile change over time (due to corrosion, etc.)?
- What thresholds will be used to assess the risk of contamination?

7.4 Management of Seabed Disturbance

Section 6.14 describes the risks associated with seabed disturbance. Management controls to minimise the risks from seabed disturbance will be dependent on the receptors / habitat at the project location and may not be required. However, the following mitigation measures can be implemented to reduce the potential for impacts of seabed disturbance during decommissioning activities:

- A pre-abandonment ROV survey to confirm the presence of marine growth and any significant seabed features to avoid, prior to any anchoring being undertaken; and
- Preparation of vessel anchoring procedures to optimise anchoring pattern and reduce the likelihood of anchor chain drag.

7.4.1 Key Considerations to Inform Decommissioning Decision

- Is there a risk of anchor drag impacting benthic habitats?
- Can the decommissioning program be designed to avoid these impacts?

7.5 Overfishing Management

Section 6.15 describes the risks associated with overfishing. Fishing pressures may have a significant influence on the ecological value of oil and gas infrastructure left in place. If attraction is the predominant process occurring at infrastructure, overfishing may lead to a regional decline in abundance of some species (Section 6.15 (Love and Schroder 2004), thus fisheries management should be considered at the options assessment stage.

Potential management controls are dependent on the purpose of the artificial reef. If the goal is to prevent overfishing of species that aggregate to the infrastructure, then management measures to prevent overfishing should be considered. However, if one of the primary benefits is trying to increase stocks of commercial fisheries through leaving infrastructure in situ, then it is important that management measures are in place to allow safe fishing.

Potential controls to manage overfishing include maintenance of an exclusion zone around infrastructure left in situ.

Artificial reefs and oil and gas infrastructure that is left in place act as a physical barrier to trawl fisheries, who avoid the areas due to snagging risks. In Western Europe the mere presence of these structures has been shown to prevent illegal trawl fishing over seagrass beds (Gonzalez-Correa et al. 2005). Oil and gas infrastructure and artificial reefs have also been used to passively enforce marine parks in Hong Kong (Wilson et al. 2002).

It should be noted, however, that recreational and trap fishing pressures may still be significant in these areas unless actively managed, and these passive management measures do not consider liability for damaged equipment.

In Malaysia the Department of Fisheries and the Fisheries Development Board of Malaysia regulate fishing in conservation areas, including those locations where artificial reefs are located, by banning fishing within 0.5 nautical miles of the structures. However, paradoxically, the Development Board of Malaysia has deployed artificial reefs to enable artisanal fishers to secure access to fish (Lyons et al. 2013 conference report). In Thailand, some artificial reefs have been fitted with anti-trawl devices that snag fishing nets to actively discourage trawl fishing over these reefs (Lyons et al. 2013).

7.5.1 Key Considerations to Inform Decommissioning Decision

- Is an exclusion zone in place and will it remain post decommissioning?
- Is the site readily accessible to recreational/commercial fishers?

7.6 Management of Damage to Fishing Equipment

The risks for damage to fishing equipment are presented in Section 6.16. Damage to fishing equipment typically occurs from rigs and infrastructure with high vertical relief left in situ; however low relief structures such as pipelines may also pose significant risks, with fishing nets being particularly susceptible to snagging.

To ensure the risks to trawl fisheries are managed to an acceptable level, it is common to undertake debris clearance surveys and trawlability tests post decommissioning.

Multibeam echosounder and side scan sonar surveys are typically completed post decommissioning, to identify any debris that may pose a hazard to shipping or fishing that may have been left in place on the seabed. Targets from these surveys are investigated using ROVs or divers to confirm whether debris remains or whether it requires removal.

Trawl testing may also be undertaken if infrastructure is completely removed to assess the suitability of fishing operations to recommence. Trawl tests are also undertaken if low relief infrastructure is left in place, to ensure trawlability criteria are met. Overtrawlability criteria defined by the United Kingdom Continental Shelf, UK fish safe database, and as accepted for decommissioning projects in Canada, is 0.8 m in height and 10 m in length. Objects larger than this overtrawlability criteria are removed prior to any trawlability tests. Trawlability tests are usually conducted in stages, with chain trawl gear used prior to the use of nets. A swath width of 200 m either side of pipelines is commonly used. On completion of the trawl tests without any snagging, a clear seabed certificate may be issued.

In Norway, overtrawlable structures have been put in place to minimise the hazards associated with overtrawling. Monitoring of overtrawl structures are generally recommended to ensure their ongoing integrity and to ensure they don't become a hazard in themselves.

Following the removal of the Frigg field infrastructure in the North Sea, two separate trawl tests were undertaken, initially using a chain trawl followed by a normal trawl net. The first trawl test took place following the removal of the pipelines, cables, corresponding concrete blocks / saddles, mattresses and bags. On completion, a clear seabed certificate was issued. The second trawl test saw the chain net snag on an anchor, steel pipe and conductor pipe, which were all removed along with the chain net prior to the issuance of a final clear seabed permit.

Options assessed for the Sable Island Subsea Pipelines and Decommissioning project in Canada also considered the snagging hazards for trawl fisheries of the pipelines, if left in situ.

7.6.1 Key Considerations to Inform Decommissioning Decision

- Is the decommissioning site within an important commercial fishing zone?
- What fishing method is used by commercial anglers around this location?
- If trawling, what parts of the subsea infrastructure present a hazard?
- Is the site readily accessible to recreational anglers?

7.7 Management of Navigational Hazard

The risks from navigational hazards are presented in Section 6.18. Any infrastructure that is left in situ that remains exposed to surface water may pose a risk to shipping.

To minimise the risk of impact with the infrastructure, aids to navigation should be installed. National and international maritime regulations should be considered when designing the aids to navigation. Consideration should be given to the distance from which the aid to navigation can be seen, the maintenance and upkeep of the system, and the responsibility for maintenance and servicing. Access for the installation and maintenance of the navigation aids should also be considered.

Information on any infrastructure that is left in situ should also be reported to the Australian Hydrographic Service who is responsible for the production and maintenance of navigational charts in Australia.

7.7.1 Key Considerations to Inform Decommissioning Decision

- What depth is the hazard?
- How will any aids to navigation be installed?
- What level of shipping is present in the area?

7.8 Noise Management Considerations

The risks from underwater noise sources are presented in Section 6.19. Noise sources may include the use of explosives, vessel noise, mechanical cutting and removal.

Impacts from underwater noise may result from a number of sources during a decommissioning program, and it is important to ensure the management measures are appropriate for the risk.

Impacts may range from chronic to acute impacts depending on the source. Management measures for the control of underwater noise are widely documented and often used in EP submissions for Australian waters, and for blasting and piling programs in state waters.

Potential noise impacts from decommissioning (including the use of explosives) should be modelled during the impact assessment, and appropriate management controls provided to manage these risks. To understand the risks and ensure appropriate management controls are used for each project, it is recommended that underwater noise modelling is conducted for significant noise sources to determine the sound exposure levels at potential sensitive receptors. Typically management measures aligned with the EPBC policy statement 2.1 are used in Australian waters in the absence of additional guidance on management measures.

Additional management measures that may also be considered for decommissioning operations may include the following where reasonably practicable:

- Establishing and managing an exclusion zone appropriate to the activity;
- Applying best practice industry standards for individual explosive weights;
- Using sequential explosive charges, staggered to minimise cumulative effects of the explosions using smaller, more frequent blasts, as opposed to less frequent, larger blasts;
- Considering the rise and fall time of the pulse of explosives. Some explosives have slower rise and fall times of the pulse from the explosives, explosives with a slower rise and fall time may be used if reasonably practicable;
- Considering marine fauna activities (e.g. whale migration, nesting, turtle nest emergence, migration) when planning explosives operations to avoid high impact works during high risk periods, through consideration of the decommissioning schedule;
- Visual monitoring within the zone of potential impact as defined by noise modelling through the use of trained marine fauna observers;
- Scheduling the use of activities generating significant noise sources for daylight hours only, to allow for effective visual monitoring;
- Considering collecting and removing fish kills between blasts to avoid subsequent blast exposure to scavenging marine fauna; and
- Validation of the noise modelling and area of potential impact through the deployment of hydrophones.

7.8.1 Key Considerations to Inform Decommissioning Decision

- What underwater noise sources are likely to be generated from the decommissioning activity?
- What receptors are present within the area of potential impact?
- Can activities be scheduled to reduce impacts?
- Can the decommissioning program be designed to minimise noise impacts (i.e. use of diamond cutting rather than explosives)?
- Can monitoring be used to reduce the likelihood of impact?

7.9 Management of Atmospheric Emissions

The risks from atmospheric emissions are presented in Section 6.20. Atmospheric emissions are not expected to pose a significant risk to the environment during decommissioning activities, and the risks are akin to those experienced in usual oil and gas construction operations. The following management measures are generally considered appropriate to manage risks to an acceptable level within Australia:

- All equipment and machinery should undergo planned maintenance to manufacturer's specifications to ensure it is operating at its optimal efficiency;
- All vessels should hold a current International Air Pollution Prevention Certificate, in accordance with Marine Order (MO) 97 (Air Pollution);
- As per MO 97 (Air Pollution) - Vessel engines (by class) should meet prescribed nitrous oxide emission levels;
- As per MO 97 (Air Pollution) - The sulphur content of any fuel oil used on-board shall not exceed 3.50% m/m;
- As per MO 97 (Air Pollution) - Ozone Depleting Substances should not be deliberately released; and
- As per the *Protection of the Sea (Prevention of Pollution from Ships) Act 1983*, an Ozone Depleting Substances Record Book shall be maintained if the vessel has a rechargeable system that contains ozone-depleting substances.

7.9.1 Key Considerations to Inform Decommissioning Decision

- Is there a significant difference in atmospheric emissions from the assessed decommissioning options?
- How can atmospheric emissions be minimised?
- Are there ozone depleting substances onboard the facility being decommissioned and how can they be managed?

7.10 Waste Management

Risks associated with waste management are presented in Section 6.21 and include the risks associated with disposal and exposure to hazardous wastes including NORMS.

7.10.1 Waste Disposal

Analysis and classification of all waste items should be completed to minimise incorrect waste disposal and minimise the volume of hazardous wastes. Reuse and recycling of materials should also be considered in the decommissioning plan to minimise environmental impacts and costs.

Identifying all the materials associated with a project can be a complex and time consuming exercise, especially for older structures. An assessment of the amount of metals, glass, plastic, hydrocarbon sludge, oils, production chemicals, drilling chemicals, asbestos, polychlorinated biphenyls, radioactive materials and biofouling to be removed will help in designing a comprehensive and effective waste strategy. This will ultimately help with determining where the best location is to sort and separate the waste and maximise reuse and recycling.

Particular consideration should be given to the removal of biofouling waste. Removal onshore can present odour impacts and significant volumes of waste for landfill.

Management of NORMS waste needs to be considered in the context of international conventions, including controls on the export / import of wastes governed by international regulations including the Basel convention and the Transfrontier Shipment of Waste Regulation 2007. Currently there is no suitable disposal facility available in Australia, thus the removal of any radioactively contaminated wastes should consider storage until a facility becomes available (expected to be 2020 at the earliest), which may pose a risk to human health.

Reuse and recycling can form a major component of decommissioning programs. The decommissioning of the North West Hutton platform saw 98.3% of the waste reused or recycled. Of the estimated 38,000 tonne structure, 7,029 tonnes were reused (accommodation, module support frame, helideck, etc.), 20,925 tonnes were recycled and 473 tonnes disposed to landfill. The footings remained in situ, pursuant to an OSPAR Convention derogation.

7.10.2 Waste Handling

The risks associated with handling wastes should be managed through a risk assessment process to determine suitable control measures to prevent exposure. These may include the use of suitable personal protective equipment or handling by qualified personnel. The correct classifications of wastes will help to ensure these risks are managed to an acceptable level.

7.10.3 Key Considerations to Inform Decommissioning Decision

- What wastes will be removed, what is their classification and what is the expected quantity of each waste stream?
- What options exist for the reuse and recycling of each waste stream?
- How can NORMS be safely stored prior to eventual disposal?
- What permits are required for the transfer of each waste stream?
- How can exposure risks be minimised?

8 Monitoring Considerations

Oil and gas operators routinely monitor the condition of subsea infrastructure as well as undertake a range of monitoring activities of the receiving environment in which they operate. Monitoring is often undertaken prior to work commencing in the field as part of baseline assessment and will then continue at a pre-determined interval during production. This is often specified in the EP for the facility.

Whether it is routine or opportunistic monitoring, the information collected can be used to assess potential benefits and risks to biodiversity (and other receptors) associated with decommissioning.

8.1 Monitoring to Inform Options Assessment

A number of the biodiversity benefits and impacts that may be associated with decommissioning oil and gas infrastructure will be determined at the options assessment and approvals stage of a project. The current levels of biodiversity and abundance can be determined using existing data collected during the life of the facility, including ROV footage from inspection and maintenance campaigns. This data provides useful information at the initial options screening stage to determine whether or not offshore infrastructure has ecological value for example.

Where additional information is required to assess the significance of local recruitment, connectivity and other biodiversity related parameters, additional monitoring and studies such as tag and recapture studies, baited remote underwater video, or analysis of fish otoliths may be used to inform the options assessment. These types of studies are of limited use where total or partial removal is preferred, but can provide a sound and scientific basis for justifying leaving subsea infrastructure in place.

The design and implementation of monitoring programs will vary depending on location and depth and the monitoring program objectives, which will be tailored to the specific risks / impacts for each decommissioning program. For example, the program for monitoring biodiversity and abundance at a remote platform would likely have a different design to that of a platform in close proximity to a natural reef, where connectivity processes may be important.

8.2 Monitoring to Assess Effects of Decommissioning

The monitoring of risks pre, during and post decommissioning should be considered to ensure the decommissioning phase does not impact the environment beyond what is described and approved within a project-specific decommissioning EP. There are generally two aspects that require consideration when designing and implementing the monitoring:

1. Monitoring Protocols - It is important that the design of monitoring programs considers the methodologies used to assess benefits / impacts at the pre-decommissioning stage to ensure results and conclusions are comparable. For example, ROV transects of the infrastructure may

provide markedly different results to baited remote underwater video surveys. A justification for the monitoring methods should be determined at the approvals stage; and

2. Monitoring Parameters - It is important that the design of the monitoring programs is based on parameters which are easy to monitor and are most susceptible to change from the decommissioning process.

8.2.1 Monitoring of Complete or Partial Removal

Complete or partial removal of infrastructure should be monitored to assess whether there is any residual sediment or water quality impacts from the operation. Final monitoring should be conducted after the final stages of decommissioning are complete and a debris clearance survey is commissioned, to confirm that (partial or total) the debris has been removed and completed as specified. In the UK for example, it is standard practice to monitor pre, during and post decommissioning. The monitoring campaign during the decommissioning program (especially for programs that stretch over multiple years or have a break in them) allows for semi-reactive management measures to be incorporated. Presumably this allows for mitigation strategies to be implemented where particular actions have been ineffective. Environmental surveys of the Frigg decommissioning program in the UK spanned over 10 years during the staged decommissioning campaign (Figure 17).

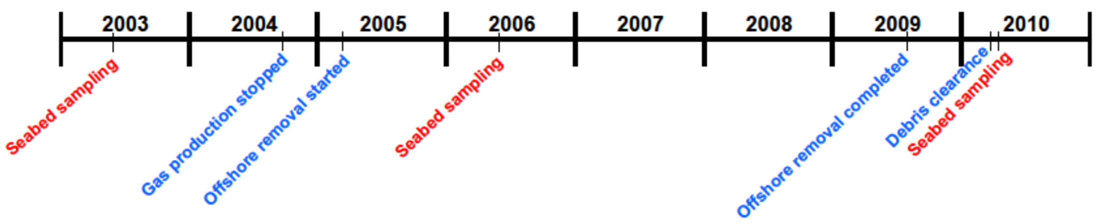


Figure 17: Timeline of environmental surveys for the decommissioning of the Frigg field (taken from Frigg Field Cessation Plan Close Out Report 2011)

These surveys were used as a basis to argue that further additional monitoring was not required beyond 2010.

8.3 Summary

Environmental monitoring involving a comparison of baseline data with post decommissioning data is normally required to demonstrate that the operation of the field, including the presence of subsea infrastructure, has not resulted in any long term impacts to the receiving environment.

Targeted and objectives based environmental monitoring may be required over a longer time period where toppling or partial recovery is the preferred decommissioning option.

9 Decommissioning Options Assessment Framework

9.1 Overview

It is important to assess the risks and benefits of decommissioning options early in the cessation stage (Cripps and Aabel, 2002).

As outlined in Section 2.1, the OPGGS(E)R requires an approved EP prior to undertaking any decommissioning activity. As part of EP approval, the operator must demonstrate that all decommissioning options were considered and the preferred decommissioning option is the one that reduced risk to a level that is ALARP.

Various frameworks are available for the assessment of decommissioning options. As decommissioning options involve many potential environmental risks that interact with safety, financial and socio-economic considerations and generate complex trade-offs, these frameworks must be based on an objective method for comparing the performance of multiple options across numerous selection criteria. NEBA and MCA are two options assessment frameworks that are considered in greater detail below.

Both NEBA and MCA can be undertaken using qualitative or quantitative methods. The NEBA approach outlined in this section was developed by Joe Nicolette, a key contributor to this report, and uses quantifiable metrics where possible.

9.2 Selection Criteria

Regardless of which framework is used to assess decommissioning options, the selection criteria is the most important component of the decision-making process because it defines what the decision should be based on (Kueppers et al., 2004). Selection criteria need to be comprehensive and reflect all considerations relevant to the decision.

The DECC Guidance Notes on Decommissioning of Offshore Oil and Gas Installations (DECC 2011) recommend the criteria outlined in Table 7 for the assessment of decommissioning options.

Table 7: Options selection criteria

Assessment Criteria	Matters to be Considered
Safety	Risk to personnel
	Risks to other users of the sea
	Risk to those on land
Environmental	Marine impacts
	Other environmental compartments (including emissions to the atmosphere
	Other environmental consequences including cumulative effects
Technical	Risk of major project failure
Societal	Fisheries impacts
	Amenities
	Communities
Economic	Cost of decommissioning or ongoing management

9.3 NEBA Approach

9.3.1 Background

NEBA is an options assessment framework that balances the risks, benefits and trade-offs between competing management options. Net environmental benefits are the gains in value of environmental services or other ecological properties attained by the action(s), minus the value of adverse environmental effects caused by the action(s). These options can include any actions that affect ecosystem service values[1]such as decommissioning options, site remedial options, oil spill response options, land management and development options, etc. In the context of offshore decommissioning, the approach is used to evaluate the net benefit of decommissioning options for offshore platforms and subsea equipment.

[1] The natural resources provided by the earth's ecosystems serve as the building block upon which human well-being flows. Ecosystems represent a complex and dynamic array of animal, plant, and microbe along non-living physical elements interacting as a functioning unit. This gives rise to many benefits, known as ecosystem services, which are the benefits people obtain from naturally functioning ecosystems (Nicolette et al. 2013).

The NEBA approach was first formalised into a structured framework by Efroymson et al. (2003, 2004) and within these publications, it was noted that NEBA was an extension or elaboration of ecological risk assessment. They identified the key difference between the two processes as the consideration of environmental benefits, which traditional risk assessment does not incorporate. The authors of this framework included the United States Environmental Protection Agency (USEPA), Oak Ridge National Laboratory, and a private consulting representative. This framework has been recognised by the National Oceanic and Atmospheric Administration (NOAA 2010); the USEPA and the USEPA Science Advisory Board (USEPA SAB 2009); the Interstate Technical and Regulatory Council (2006); and the Australian Maritime Safety Authority (2010).

9.3.2 NEBA Application for Decommissioning

The NEBA approach focusses on using quantifiable metrics where possible. The metrics are used to compare and rank the net environmental benefits of the options while considering the human health risks, ecological risks and costs associated with each option being compared. The formalised NEBA framework is depicted in Figure 18. Further detail on the NEBA approach and the development of quantifiable metric is provided in Appendix C.

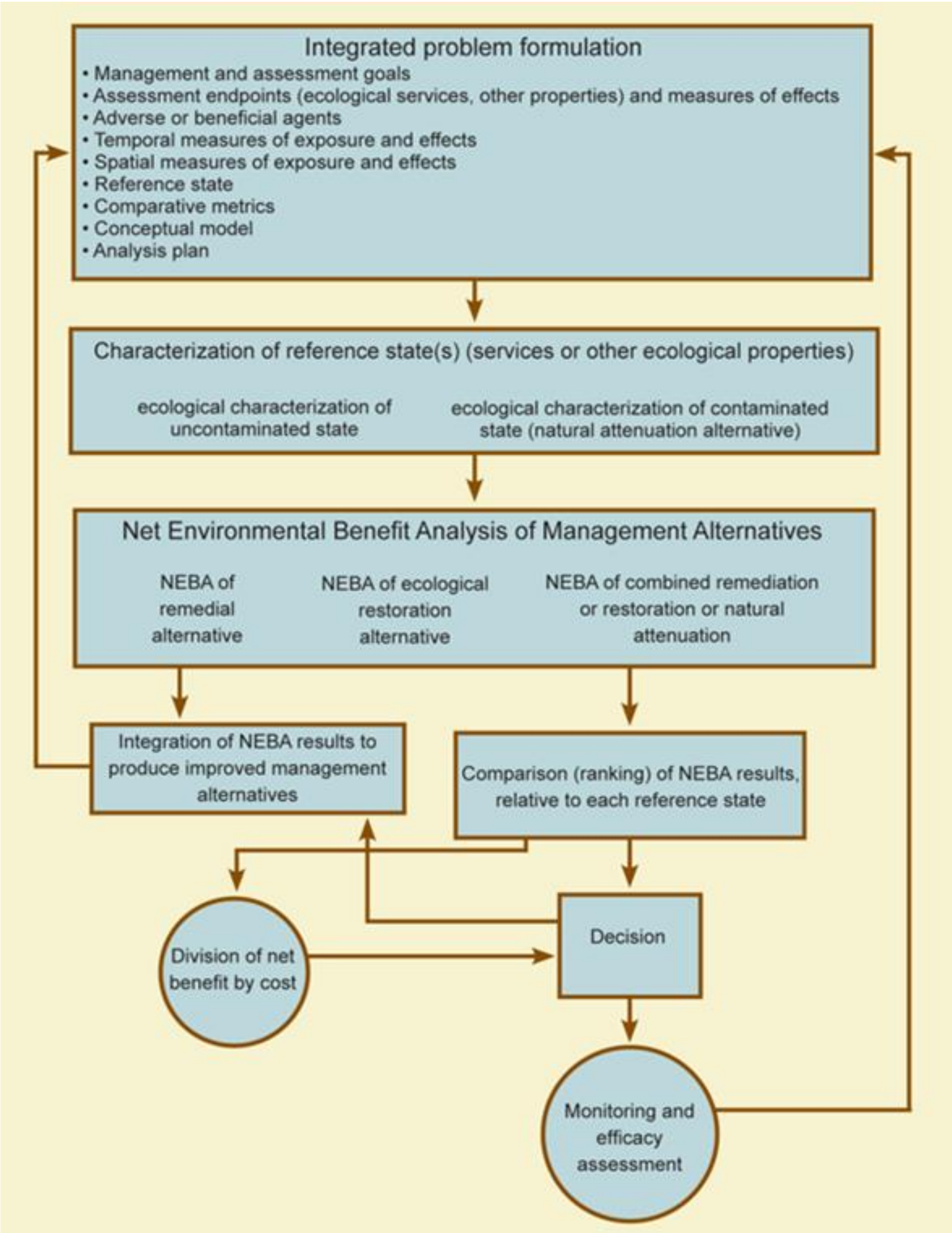


Figure 18: Framework for NEBA (from Efroymson, Nicolette and Suter 2003) as displayed in the USEPA Science Advisory Board report entitled "Valuing the Protection of Ecological Systems and Services: A Report of the EPA Science Advisory Board"

9.3.3 Examples of Application

NEBA has been applied in assessing offshore decommissioning options in in Northwest Australia, the North Sea, and off the coast of California. As these are confidential projects "in-progress", the amount of information that can be provided at this time is limited.

Northwest Australia

A NEBA approach has been conducted for an offshore subsea field in northwest Australia. The NEBA examined the habitat quality of the existing field and compared the projected change in value for both ecological and human use, as well as the potential risks for ecological and human use between implementation of various options. As this study is in progress, presentation of the results is not available at this time.

North Sea

A NEBA approach has been applied to the evaluation of a field consisting of three platforms. The analysis focussed on the net environmental benefit of options to remove the cuttings piles underneath the platforms. It was determined through the NEBA that the option for dredging and removal of the sediments associated with the cuttings piles would create significant harm to the benthic community and associated fish community. The NEBA indicated that the cuttings piles should remain in place as they have become encrusted over the past 40 years with benthic community shells, etc., that have essentially entombed any contaminants in the drilling muds. Disturbance of the cuttings piles during dredging would compromise the protection of the environment by exposing the nearby communities to contaminants once the encrusting layer was disturbed.

California

This project was presented in a paper for the Society of Petroleum Engineers in 2008. The paper was entitled "Use of Habitat Equivalency Analysis (HEA) to Determine the Environmentally Superior Project Alternative" (Gala et al. 2008). This project examined the stability of the shell mounds (drill cuttings piles) that would be disturbed if the decommissioning took place. As stated in this paper, "*The results of the HEA indicate that leaving the mounds in place and enhancing Carpinteria Salt Marsh provides the greatest net environmental benefit when compared with all other alternatives. Furthermore, results of the sensitivity analysis show that results of the HEA model are stable and will not experience large fluctuations from substantial changes in inputs values*".

9.4 Multi-Criteria Analysis

9.4.1 Background

MCA is useful for making environmental management decisions as it can incorporate the objectives of multiple stakeholder groups and handle a wide range of data types (Fowler et al. 2014).

Most MCA methods follow this general process:

- Decision objectives are defined;
- Selection criteria are established to reflect objectives;
- Decommissioning options are identified;
- The performance of each option is evaluated for each criterion;
- Criteria are weighted according to their importance;
- Criteria evaluations and weights are combined into an overall performance estimate for each option; and
- Options are selected based on the overall performance estimate.

Examples of selection criteria are provided in Table 7.

9.4.2 Application for Decommissioning

The MCA approach uses a pairwise ranking system to evaluate the performance of options for each criterion. Firstly a performance score is applied to the selection criterion. The selection criterion is also weighted so that more important criteria have a greater influence on the decommissioning decision than less important criterion.

As quantitative data is often not available for selection criterion, this method means the options merely need to be put in rank order regarding their performance for a particular criterion.

To identify the best performing option, an overall evaluation is undertaken that combines the performance scores for all criteria according to their respective weightings. The option that has the highest weighted criteria is considered the best performing option.

If no one option is approved for all criteria or the majority of the most important criteria, a pairwise comparison to determine the dominant option is undertaken.

Stakeholders can have direct involvement in the MCA process through involvement in the development of performance evaluation data and weightings for selection criteria.

9.4.3 Examples

California

An MCA was used to identify the decommissioning option that would provide the best environmental outcomes for Platform Grace in Southern California. At the time of options selection, a limited amount of environmental information was available on the platform.

Leave in place was considered the best performing option across 14 environmental selection criteria. Selection of this option was insensitive to potential variations in criteria weightings and performance ranks.

Canada-Coast of Nova Scotia

An MCA was used by Advisian to identify the most suitable option for decommissioning natural gas pipelines off the east coast of Nova Scotia. Leave in place was considered the best performing option for the export pipeline.

10 References

Addy JM, Levell D, Hartley JP, 1987, 'Biological monitoring of sediments in the Ekofisk oilfield. In: Proceedings of the Conference on the Assessment of Ecological Impacts of Oilspills' *American Institute Biological Sciences*, Kestone, Colorado, pp. 514-539.

Ajemian MJ, Wetz JJ, Shipley-Lozano B, Shively JD, and Stunz GW 2015, 'An Analysis of Artificial Reef Fish Community Structure along the Northwestern Gulf of Mexico Shelf: Potential Impacts of "Rigs-to-Reefs" Programs' *PLoS one*, Volume 10, Issue 5.

Allseas 2016, 'Pioneering Spirit', <http://allseas.com/equipment/pioneering-spirit/>Accessed: 5th July 2016.

Anthony KM, Love M and Lowe C 2013, 'Translocation, homing behaviour and habitat use of groundfishes associated with oil platforms in the East Santa Barbara Channel, California' *Bulletin of the Southern Californian Academy of Sciences*, Volume 111, Issue 2, pp. 1-27.

Aprieto VL 1988, 'Aspects of management of artificial habitats for fisheries: The Philippines Situation', in *Report of the workshop on artificial reefs development and management,* Doc No. ASEAN/SF/88/GEN/80, pp. 102-110, Penang, Malaysia.

Asia Adventures 2016, 'Seaventures dive rig near Sipidan and Mabul Island' http://whoaadventures.com/package/seaventures-dive-rig-near-sipadan-and-mabul-island Accessed: 5th July 2016.

Atchison A 2005, 'Offshore Oil and Gas Platforms as Stepping Stones for Expansion of Coral Communities: A Molecular Genetic Analysis' Department of Oceanography and Coastal Sciences, Louisiana Tech University.

Baine M and Side J 2003 'Habitat modification and manipulation as a management tool' *Reviews in Fish Biology and Fisheries*, Volume 13, Issue 2, pp. 187-199.

Balk L, Hylland K, Hanson T, Berntssen MGH, Beyer J, Jonsson G, Melbye A, Grung M, Torstenesen BE, Borseth JF, Skarphendinsdottir H, and Klungsoyr, J 2011, 'Biomarkers in Natural Fish Populations Indicate Adverse Biological Effects of Offshore Oil Production' *PLoS One*, Volume 6, Issue 5.

Ball A, Stewart R & Schliephake K 2012, 'A review of the current options for the treatment and safe disposal of drill cuttings' *Waste Management and Research,*May 2012, Volume 30, No. 5, pp. 467 – 478.

Banner A 2015, 'Decommissioning Efficiencies and Expectations' Department of Energy and Climate Change' Presented 9th February, 2015.

Baxter L, Hays EE, Hampton GR, Backus RH, 1982, 'Mortality of fish subjected to explosive as applied oil well severance on Georges Bank' Woods Hole Oceanographic Institution, Technical Report: WHOI-82-54.

Beitch G 2015, 'Implementing a Rigs-to-Reefs Retirement Solution Offshore California Case Study: Pt. Arguello Unit' North Sea Decommissioning Conference, Presented February 2015, Norway.

Benjelloun, C 2014 'Offshore Decommissioning: Challenges and Opportunities in the 21st century' EDHEC Business School, May 2014.

Berkley SA, Chapman C and Sogard S 2004, 'Maternal age as a determinant of larval growth and survival in marine fish, *Sebastes melanops' Ecology*, Volume 85, Issue 5, pp. 1258-1264.

Bernstein B, Bressler, A, Cantle, P, Henrion, M, DeWitt, J, Kruse, S, Pondella, S, Scholz, A, Setnicka, T and Swamy, S 2010, 'Evaluating Alternatives for Decommissioning California's Offshore Oil and Gas Platforms: A Technical Analysis to Inform State Policy' California Ocean Science Trust <https://www.researchgate.net/publication/265069796_Evaluating_Alternatives_for_Decommissioning_California's_Offshore_Oil_and_Gas_Platforms_A_Technical_Analysis_to_Inform_State_Policy_Co-authors>Access date: April 12th 2016.

Beyer J, Myhre, LP, Sundt, RC, Meier, S, Tollefsen K, Vabo R, Klungsoyr J, and Sanni, S 2012, 'Environmental risk assessment of alkylphenosl from offshore produced water on fish reproduction' *Marine Environmental Research*, Volume 75, pp. 2-9.

Blue Latitudes 2016, 'Rigs-To-Reefs' <http://www.rig2reefexploration.org/read-me/>Accessed: 30th June 2016.

Bluewater 2016 'Disconnectable Internal Turret Mooring systems' <http://www.bluewater.com/products-technology/mooring-systems/subsea-mooring-and-offloading-point-smop/disconnectable-internal-turreet-mooring-systems/ > Accessed: 28th October 2016.

Bohnsack JA, 1989, 'Are high densities of fishes at artificial reefs the result of habitat limitation or behavioural preference?' *Bulletin of Marine Science*, Volume 44, pp. 631-645.

Bohnsack JA, Johnson DL, and Ambrose, RF 1991, 'Ecology of artificial habitats and fishes' in W Seaman Jr (ed.), *Artificial habitats for marine and freshwater fisheries,* Academic Press, New York, pp. 61-99.

Breuer E, Stevenson AG, Howe JA, Carroll J and Shimmield GB 2004, 'Drill cutting accumulations in the Northern and Central North Sea: a review of environmental interactions and chemical fate', *Marine Pollution Bulletin*, Volume 48, pp. 12-25.

Bureau of Safety and Environmental Enforcement (BSEE) 2016, 'Decommissioning FAQ', <http://www.bsee.gov/BSEE-Newsroom/Publications-Library/FAQ/Decommissioning/>Accessed: 19th April 2016.

Burns E 2001, 'Comparison of the anti predatory mechanisms of Red Sea and Caribbean sponges' Master of Science thesis, Tel-Aviv University, Tel-Aviv (Hebrew; English summary).

Caley MJ, Carr MH, Hixon MA, Hughes TP, Jones GP and Menge BA 1996, 'Recruitment and Local Dynamics of Open Marine Populations' *Annual Review of Ecology and Systematics*, Volume 27, pp. 477- 500.

Campos JA, and Gamboa C 1989, 'An artificial tile-reef in a tropical marine system: a management tool' *Bulletin of Marine Science*, Volume 44, Issue 2, pp. 757-766.

Canada Nova-Scotia Offshore Petroleum Board 2016, 'Requirements to Operate' <http://www.cnsopb.ns.ca/offshore-activity/requirements-to-operate>Accessed: 18th April 2016.

Carr MH, McGinnis MV, Forrester GE, Harding J, Raimondi PT 2003, 'Consequences of alternative decommissioning options to reef fish assemblages and implications for decommissioning policy – Final Technical Study' Coastal Research Center, Marine Science Institute, University of California, Santa Barbara.

Charbonnel E 2002, 'Effects of increased habitat complexity on fish assemblages associated with large artificial reef units (French Mediterranean coast)' *ICES Journal of Marine Science*, Volume 59, pp. 208-213.

Claisse J, Pondella II D, Love M, Zahn L, Williams C, and Bull A 2015, 'Impacts from Partial Removal of Decommissioned Oil and Gas Platforms on Fish Biomass and Production on Remaining Platform Structure and Surrounding Shell Mounds' *PLoS One*, Volume 10, Issue 9, September 2015 <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4557934/>Accessed: 28th April 2016.

Claisse JT, Pondella DJ, Love M, Zahn LA, Williams CM, Williams JP and Bull AS 2014, 'Oil platforms off California are the most productive marine fish habitats globally', *Proceedings of the National Academy of Sciences of the United States of America*, Volume 111, Issue 43, pp. 15462-15467.

Clucas A 2013 'Comparisons of Removal Methods for Oil and Gas UK Rev2 (Ignoring Conductors)', Aker Solutions.

Cowen RK and Sponaugle S 2009, 'Larval dispersal and marine population connectivity' *Annual Review of Marine Sciences*, Issue 1, pp. 443-466.

Cresson P, Ruitton S and Harmelin-Vivien M 2014 'Artificial reefs do increase secondary biomass production: mechanisms evidenced by stable isotopes' *Marine Ecology Progress Series*, Volume 509, pp. 15-29.

Cripps SJ and Aable JP 2002, ''Environmental and socio-economic impact assessment of Ekoreef, a multiple platform rigs-to-reef development' *Journal of Marine Science*, Volume 59, pp. 300-308.

Cumming D 2015, 'Mattress Solutions', Doc No. DNS 01 r01c, Jee Ltd. on behalf of Zero Waste <http://decomnorthsea.com/uploads/pdfs/projects/DNS-Mattress-Solutions_JEE-Report_June-2015.pdf>Access Date: 27th April 2016.

Currie DR and Isaac LR 2005, 'Impact of exploratory offshore drilling on benthic communities in the Minerva gas field, Port Campbell, Australia' *Marine Environmental Research*, Volume 59, pp. 217-233.

Dahan M and Benayahu Y 1997 'Reproduction of Dendronephthya hemprichi (Cnidaria: Octocorallia): year-round spawning in an azooxanthellate soft coral' *Marine Biology*, Volume 129, pp. 573-579.

Danner EM, Wilson TC and Schlotterbeck RE 1994 'Comparison of rockfish recruitment of nearby artificial and natural reefs off the coast of Central California' *Bulletin of Marine Science,* Volume 55. Issue 2-3, pp. 333-343.

Dauterive L 2000 'Rigs-to-Reef Policy, Progress, and Perspective' OCS Report MMS 2000-073, Published by U.S Department of the Interior, <http://www.boem.gov/BOEM-Newsroom/Library/Publications/2000/2000-073.aspx>Accessed: 28th April 2016.

Davis D and Tisdell C 1996, 'Economic Management of Recreational Scuba Diving and the Environment' *Journal of Environmental Management*, Issue: 'February 1994', pp. 229-248.

Deborde J, Refait P, Bustamante P, Caplat C, Basuyaux O, Grolleau AM, Mahaut ML, Brach-Papa C, Gonzalez JL and Pineau S 2015, 'Impact of Galvanic Anode Dissolution on Metal Trace Element Concentrations in Marin Waters' *Water Air and Soil Pollution*, Volume 223, Issue 12, pp. 423-436.

Delgado JP 1988, 'The value of shipwrecks' in J Waldron Murphy (ed.), *Historic shipwrecks: Issues in management. Partners for Livable Places and the National Trust for Historic Preservation*, Washington DC. pp. 1-10.

Department of Energy and Climate Change (DECC) 2011, 'Guidance Notes: Decommissioning of Offshore Oil and Gas Installations and Pipelines under the Petroleum Act 1998 (Version 6), Offshore Decommissioning Unit', <https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69754/Guidance_Notes_v6_07.01.2013.pdf>Department of Energy and Climate Change, United Kingdom, Accessed: April 14th 2016.

Department of Primary Industries 2015, 'NSW Recreational Saltwater Fishing Guide' State of New South Wales through the Department of Industry, Skills and Regional Development, October 2015 < http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0012/600222/saltwater-recreational-fishing-guide-2016-17.pdf > Accessed online: 28th October 2016.

Dicks B, Bakke T and Dixon IMT 1990, 'Oil exploration and production and oil spills' in Salomons, W, Bayne BL, Duursma EK and Forstner, U (eds.), *Pollution of the North Sea: An Assessment,* Springer-Verlag, Berlin, pp. 24-537.

Downie RA, Babcock RC, Thomson DP and Vanderklift MA 2013 'Density of herbivorous fish and intensity of herbivory are influenced by proximity to coral reefs' *Marine Ecology Progress Series*, No. 482, pp. 217-225.

Edney J 2006, 'Impacts of recreational scuba diving on shipwrecks in Australia and the Pacific: A review' *Micronesian Journal of the Humanities and Social Sciences*, Volume 5, pp. 201-233.

Edwards E 2012 'Partial vs. Complete Removal: The Debate Surrounding California's Implementation of the Rigs-to-Reef Project' *Journal of the National Association of Administrative Law Judiciary*, Volume 32, Issue 2, pp. 758-807.

Emery BM, Washburn L, Love MS, *et al*. 2006. Do oil and gas platforms off California reduce recruitment of bocaccio (*Sebastes paucispinis*) to natural habitat? An analysis based on trajectories derived from high-frequency radar' *Fishery Bulletin,* Volume 104, pp. 391-400.

Environmental Protection (Sea Dumping) Act 1981 (Cwlth).

Ekins P, Vanner R and Firebrace J 2006, 'Decommissioning of offshore oil and gas facilities: A comparative assessment of different scenarios' *Journal of Environmental Management*, Volume 79, pp. 420-438.

ExxonMobil 2014, 'Sable Island Subsea Pipelines Decommissioning Project: Technical Decommissioning Options Study', Doc No. ZP-A00-S-87-0001.000, Prepared by INTECSEA, Canada.

Fabricius, KE, Genin, A, and Benayahu, Y 1995, 'Herbivory in asymbiotic corals' *Science*, Volume 268, pp. 90-92.

Fadli N, Campbell SJ, Ferguson K, Keyse J, Rudi E, Riedel A and Baird, AH 2012 'The role of habitat creation in coral reef conservation: a case study from Aceh, Indonesia' *Oryx*, Volume 46, Issue 4, pp. 501-507.

Feary DA, Burt JA and Bartholomew A 2011, 'Artificial marine habitats in the Arabian Gulf: Review of current use, benefits and management implications' *Ocean and Coastal Management,* Volume 54, Issue 10, pp. 742-749.

Forrester GE 1990, 'Factors influencing the juvenile demography of a coral reef fish' *Ecology* Volume 71, pp. 1666-1681.

Foster KL, Steimle FW, Muir WC, Krapp RK, and Conlin BE 1994, 'Mitigation potential of habitat replacement: concrete artificial reef in Delaware Bay, preliminary results' *Bulletin of Marine Science*, Volume 55, Issue 2-3, pp. 783-795.

Fowler AM and Booth, DJ 2012, 'Evidence of sustained populations of a small reef fish on artificial structures. Does depth affect production on artificial reefs?' *Journal of Fish Biology*, Volume 80, Issue 3, pp. 613-629.

Fowler AM, Macreadie PI, Bishop PD and Booth DJ 2015, 'Using otolith microchemistry and shape to assess the habitat value of oil structures for reef fish' *Marine Environmental Research*, Volume 106 pp. 103-113.

Frederick JL 1997, 'Post-settlement movement of coral reef fishes and bias in survival estimates' *Marine Ecology Progress Series*, No. 150, pp. 65-74.

Friedlander AM and Parrish JD 1998, 'Temporal dynamics of fish communities on exposed shorelines in Hawaii' *Environmental Biology of Fishers*, Volume: 53, pp. 1-18.

Friedlander AM, Ballesteros E, Fay M and Sala E 2014, 'Marine Communities on Oil Platforms in Gabon, West Africa: High Biodiversity Oases in a Low Biodiversity Environment' *PLoS One*, <http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0103709>Accessed: 16th May 2016.

Gallaway BJ, Szedlmayer ST and Gazey WJ 2009, 'A life history review for red snapper in the Gulf of Mexico with an evaluation of the importance of offshore petroleum platforms and other artificial reefs' *Reviews in Fisheries Science*, Volume 17, Issue 1, pp. 48-67.

Gallaway, BJ and Lewbel, GS 1982 'The Ecology of Petroleum Platforms in the Northwestern Gulf of Mexico: A Community Profile', Bureau of Land Management Open File Report 82-03, United States Department of the Interior.

Gerrard S, Grant A, Marsh, R & London C 1999, 'Drill Cuttings Piles in the North Sea: Management Options During Platform Decommissioning' Centre for Environmental Risk, Research Report No. 31, School of Environmental Sciences, University of East Anglia, United Kingdom.

Gibson 2002, 'The Decommissioning of Offshore Oil and Gas Installations: A Review of Current Legislation, Financial Regimes and the Opportunities for Shetland, KIMO International <http://www.kimointernational.org/WebData/Files/Decommissioning/oildecommissioningreport1.pdf > Accessed: 14th April 2016.

Gladstone W, Curley B and Shokri MR 2013, 'Environmental impacts of tourism on the Gulf and Red Sea' *Marine Pollution Bulletin*, Volume 72, pp. 375-388.

Goertner JF 1982, 'Prediction on underwater explosion safe ranges for sea mammals' Research and Technology Department, Naval Surface Weapons Centre, Silver Spring, Maryland.

Goodsell PJ and Chapman MG 2009,' Rehabiliation of habitat and the value of artificial reefs' in Wahl M (ed.), *Marine Hard Bottom Communities: Patterns, Dynamics, Diversity and Change*, Ecological Studies, Springer-Verlag, Germany, pp. 33-344.

Grossman GD, Jone GP and Seaman WJ Jr., 1997 'Do artificial reefs increase regional fish production? A review of existing data.' *Fisheries - Special issue on artificial reef management*, Volume 22, Issue 4, pp. 17-23.

Harriott VJ 2002, 'Marine tourism impacts and their management on the Great Barrier Reef, CRC Reef Research Centre' Technical Report No. 46, CRC Reef Research Centre, Townsville, Queensland.

Health and Safety Executive (HSE) 1997, 'The Abandonment of Offshore Pipelines. Methods and Procedures for Abandonment. Offshore Technology Report' Prepared by John Brown Engineers and Constructors Ltd, Her Majesty's Stationery Office, Norwich.

Heerema 2016, 'Decommissioning and Removal' <https://hmc.heerema.com/activities/decommissioning-and-removal/>Accessed: 5th July 2016.

Henrion M 2015, 'From Controversy to Consensus: A Decision Analysis for Decommissioning California's Offshore Oil Platforms' INFORMS, February 2015, Volume 42, Number 1 <https://www.informs.org/ORMS-Today/Public-Articles/February-Volume-42-Number-1/Rigs-to-Reefs> Accessed: April 28th 2016.

Henrion M, Berstein B and Swamy S 2014, 'A Multi-attribute Decision Analysis for Decommissioning Offshore Oil and Gas Platforms' Published 23rd September 2014, in review for *International Environmental Assessment and Management Journal*, California <http://www.lumina.com/uploads/case_studies/Oil_rig_decommissioning_decision_analysis_Henrion_et_al_2014.pdf>Access date: April 12th 2016.

Hinwood JB, Poots AE, Dennis LR, Carey JM, Houridis H, Bell RJ, Thomson JR, Boudreau P and Ayling AM 1994, 'Drilling activities' in Swan JM, Neff JM and Young PC (eds.), *Environmental Implications of Offshore Oil and Gas Development In Australia Findings of an Independent Scientific Review*, Australian Petroleum Production and Exploration Association, Canberra, Australia, pp. 123-207.

Hixon MA and Beets, JP 1989, 'Shelter characteristics and Caribbean fish assemblages: experiments with artificial reefs' *Bulletin of Marine Science*, Volume 44, Issue 2, pp. 666-680.

IEA Greenhouse Gas R & D Programme (IEAGHG) 2009, 'Long Term Integrity of CO2 Storage – Well Abandonment' Technical Study, Report No. 2009/05', November 2009 <https://hub.globalccsinstitute.com/publications/long-term-integrity-co2-storage-%E2%80%93-well-abandonment/2-well-plugging-and-abandonment> Accessed: 2nd May 2016.

International Association of Oil and Gas Producers (IAOGP) 2010, 'Risk Assessment Data Directory – Construction', Report no. 434 – 18, March 2010, <http://www.ogp.org.uk/pubs/434-18.pdf> Accessed: 29th April 2016.

International Association of Oil and Gas Producers (IAOGP) 2012, 'Decommissioning of offshore concrete gravity based structures (CGBS) in the OSPAR maritime area / other global regions' Report No. 484, November 2012 <http://www.ogp.org.uk/pubs/484.pdf>Accessed: 28th April 2016.

International Association of Oil & Gas Producers (2016) Managing Naturally Occurring Radioactive Material (NORM) in the oil and gas industry, Report No. 412, March 2016 < http://www.ogp.org.uk/pubs/412.pdf> Accessed 27th October 2016.

IEA Greenhouse Gas R&D Programme (IEA GHG) 2009, "Long Term Integrity of CO2 Storage – Well Abandonment", 2009/08, July 2009. Jakšić S, Stamenković I and Đorđević J 2013, 'Impacts of Artificial Reefs and Diving Tourism', *Turizam*, Volume 17, Issue 4, pp. 115-165.

Jessee WN, Carpenter AL and Carter JW 1985, ‘Distribution patterns and density estimates of fishes on a Southern California artificial reef with comparisons to natural kelp-reef habitats’ *Bulletin of Marine Science*, Volume 37, pp. 214-226.

Ketten, DR 1995 ‘Estimate of blast injury and acoustic trauma zones for marine mammals for underwater explosions’ in Kastelein RA, Thomas JA and Nachtigall PE (eds.) *Sensory Systems of Aquatic Mammals Worden*, De Spil Publishers, Netherlands, pp. 391-407.

Klima EF, Gitschlag GR and Renaud ML 1998, ‘Impacts of the explosive removals of offshore petroleum platforms and sea turtles and dolphins’ *Marine Fisheries Review,* Volume 50, Issue 3, pp. 33-42.

Love MS, Caselle JE and Snook L 2000, ‘Fish assemblages around seven oil platforms in the Santa Barbara Channel area’ *Fisheries Bulletin*, Volume 98, pp. 96-117.

Love MS and Goldberg SR 2009, ‘A Histological Examination of the Ovaries of Pacific Sanddab *Citharichthys sordidus,* Captured at Two Oil Platforms and Two Natural Sites in the Southern Californian Bight’ *Southern Californian Academy of Sciences Bulletin*, Volume 108, Issue 2, pp. 45-51.

Love MS, and York A 2005, ‘A comparison of the fish assemblages associated with an oil/gas pipeline and adjacent seafloor in the Santa Barbara Channel, southern California Bight’ *Bulletin of Marine Science*, Volume 77, pp. 101-117.

Love MS, Brothers E, Schroeder DM and Lenarz WH 2007, ‘Ecological performance of young-of-the-year blue rockfish (Sebastes mystinus) associated with oil platforms and natural reefs in California as measured by daily growth rates’ *Bulletin of Marine Science*, Volume 80, pp. 147-157.

Love MS, Schroeder DM and Lenarz W 2005, ‘Distribution of bocaccio (Sebastes paucispinis) and cowcod (Sebastes levis) around oil platforms and natural outcrops off California with implications for larval production’ *Bulletin of Marine Science*, Volume 77, pp. 397-408.

Love MS, Schroeder DM, Lenarz W, MacCall A, Bull AS, and Thorsteinson L 2006, ‘Potential use of offshore marine structures in rebuilding an overfished rockfish species, bocaccio (Sebastes paucispinis)’ *U.S National Marine Fisheries Service Fishery Bulletin*, Volume 104, pp. 383-390.

Lowe CG, Anthony, KM, Jarvis, ET and Bellquist, LF 2009, ‘Site Fidelity and Movement Patterns of Groundfish Associated with Offshore Petroleum Platforms in the Santa Barbara Channel’ *Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science*, Volume 1, pp. 71-89.

Luckhurst BE and Luckhurst K 1978, ‘Analysis of the influence of substrate variables on coral reef fish communities’ *Marine Biology*, Volume 49, Issue 4, pp. 317-323.

Lyons Y, Fowler A and Chou LM 2013, ‘International Workshop on Rigs-to-Reefs: Prospects for Large Artificial Reefs in Tropical Southeast Asia – Is there life after oil?’ Presented 12-13 November, NUS Conference, Singapore.

Macreadie PI, Fowler AM, Booth DJ 2011, 'Rigs-to-reefs: will the deep sea benefit from artificial habitat' *Frontiers in Ecology and the Environment*, Volume 9, pp. 455-461.

Matthews KR 1990, 'Underwater tagging and visual recapture as a techniquefor studying movement patterns or rockfish' *American Fisheries Society Symposium* Volume 7, pp. 168-172.

Michael SJ 1997, *Platform decommissioning corrosion estimate*, Chevron Corporation, Unpublished Report, 1997.

Minerals Management Service (MMS) 1983, 'Central Californian OCS (Outer Continental Shelf) Oil and Gas Sale No. 73, 1983: Environmental Impact Statement, Volume 1' Department of the Interior, <https://play.google.com/store/books/details?id=fCY3AQAAMAAJandrdid=book-fCY3AQAAMAAJandrdot=1>Accessed: 8th June 2016.

Minerals Management Service (MMS) 1986, 'Proposed 5-Year Outer Continental Shelf Oil and Gas Leasing Program, January 1987 – December 1991: Draft Environmental Impact Statement, Volume 2', Department of the Interior, <https://play.google.com/store/books/details?id=2GQRAAAAYAAJandrdid=book-2GQRAAAAYAAJandrdot=1> Accessed: 8th June 2016.

Ministry of the Environment 2010, 'Radioactive waste from the petroleum industry, draft reports from a working group headed by the Ministry of the Environment' May 2010.

Mumby PJ 2006, 'The Impact of Exploiting Grazers (Scaridae) On the Dynamics of Caribbean Coral Reefs' *Ecological Applications*, Volume 16, pp. 747-769.

Neff JM 2002, *Bioaccumulation in Marine Organisms: Effects of Contaminants from Oil Well Produced Water*, Elsevier Science, Amsterdam.

Neira F 2005, 'Summer and winter plankton fish assemblages around offshore oil and gas platforms in south-eastern Australia' *Estuarine, Coastal and Shelf Science*, Volume 63, pp. 589-604.

Newfield Australia (Ashmore Cartier) Pty Ltd (Newfield Australia) 2003, Challis Field Facilities Decommissioning Preliminary Information, Rev 0, April 2003.

Nichols RS 2013, 'Effectiveness of artificial reefs as alternative dive sites to reduce diving pressure on natural coral reefs, a case study of Koh Tao, Thailand' BSc Conservation Biology Thesis, University of Cumbria.

Norsk Oljmuseum, 'Statfjord C ble slept ut feltet I juni 1984' Arts Council Norway, < https://www.europeana.eu/portal/en/record/2022608/NOM_NOMF_02774_526.html/> Accessed: 27th October 2016.

Norwegian Ministry of Climate and Environment 2015, 'OSPAR: its mandate and way of working in offshore oil and gas', Hanne-GreteNilsen, Chair OIC, Presented at: 15th NPF North Sea Decommissioning Conference 9-11 February 2015, Scotland.

Offshore Minerals Act 2003 (Cwlth).

Offshore Petroleum and Greenhouse Gas Storage (Safety) Regulations 2009 (Cwlth).

Offshore Petroleum and Greenhouse Gas Storage Act 2006 (Cwlth).

Offshore Petroleum and Greenhouse Gas Storage Act 2006 (Cwlth).

Oil and Gas UK 2013, Decommissioning of Pipelines in the North Sea Region < http://oilandgasuk.co.uk/product/decommissioning-of-pipelines-in-the-north-sea-region-2013/> Accessed 28 October 2016

Oil and Gas UK 2013, 'The Management of Marine Growth During Decommissioning' <http://oilandgasuk.co.uk/wp-content/uploads/2015/04/experience-pdf.pdf>Accessed: 1st July 2016.

Oil and Gas UK 2016, 'Knowledge Centre: NORM Scale' <http://oilandgasuk.co.uk/knowledgecentre/normscale.cfm>Accessed: 5th July 2016.

Oil and Gas UK, 2012, 'Decommissioning of Steel Piled Jackets in the North Sea Region', October 2012, The United Kingdom Offshore Oil and Gas Industry Association Limited, <http://oilandgasuk.co.uk/wp-content/uploads/2015/04/steel-pipe-pdf.pdf>Accessed: 28th April 2016.

OSPAR Commission 2016, Offshore Installations,<http://www.ospar.org/work-areas/oic/installations> , Access Date: 14th April 2016, OSPAR Secretariat, United Kingdom.

Page HM, Dugan JE, Culver CS and Hoesterey JC 2006, 'Exotic invertebrate species on offshore platforms' *Marine Ecology Progress Series* Vol. 325 pp. 101-107.

Page HM, Dugan JE, Dugan DS, Richards JB and Hubbard DM 1999, 'Effects of an offshore oil platform on the distribution and abundance of commercially important crab species' *Marine Ecology Progress Series*, Volume 185, pp. 47-57.

Palumbi S 2004, 'Why mothers matter' *Nature*, Volume 430, pp. 621-622.

Patterson III, WF and Cowan JH 2003 'Site fidelity and dispersion of red snapper associated with artificial reefs in the northern Gulf of Mexico' *Transaction of American Fisheries Society Symposium*, Volume 36, pp. 181-193.

Patterson WF III, Watterson JC, Shipp RL and Cowan Jr. JH 2001 'Movement of tagged red snapper in the northern Gulf of Mexico' *Transactions of the American Fisheries Society*, Volume 130, pp. 533-545.

Peabody MB and Wilson CA 2006, 'Fidelity of red snapper (Lutjanus campechanus) to petroleum platforms and artificial reefs in the northern Gulf of Mexico' U.S. Department of the Interior, Minerals Management Service.

Pears R and Williams DMcB 2005, 'Potential effects of artificial reefs on the Great Barrier Reef: background paper' CRC Reef Research Center, Technical Report No. 60, p. 33.

Perkol-Finkel S and Benayahu Y 2005, 'Recruitment of benthic organisms onto a planned artificial reef: shifts in community structure one decade post-deployment' *Marine Environmental Research*, Volume 59, Issue 3, pp. 79-99.

Pickering H and Whitmarsh D 1997 'Artificial reefs and fisheries exploitation: a review of the 'attraction versus production' debate, the influence of design and its significance for policy' *Fisheries Research*, Volume 31, pp. 39-59.

Pitcher TJ and Seaman W Jr. 2000 'Petrarch's Principle: how protected human-made reefs can help the reconstruction of fisheries and marine ecosystems.' *Fish and Fisheries*, Volume 1, Issue 1, pp. 73-81.

Polovina TJ 1991, 'Ecological consideration on the applications of artificial reefs in the management of artisanal fishery' *Tropical Coastal Area Management*, Volume 6, Issue 1-2, pp. 1-4.

Polovina, JJ, and Sakai I 1989, 'Impacts of Artificial Reefs on Fishery Production in Shimamaki, Japan' *Bulletin of Marine Science*, Volume 44, Issue 2, pp. 997-1003.

Pradella N, Fowler AM, Booth DJ and Macreadie PI 2014 'Fish assemblages associated with oil industry structures on the continental shelf of north-western Australia' *Journal of Fish Biology*, Volume 84, Issue 1, pp. 247-255.

Quigel JC and Thorton WL 1989, 'Rigs to reefs- a case history' *Bulletin of Marine Sciences*, Volume 44, pp. 799-806.

Radiation Health and Safety Advisory Council 2005, 'Naturally Occuring Radioactive Material (NORM) in Australia: Issues for Discussion' prepared for the CEO or ARPANSA, 17th August 2005, <http://www.arpansa.gov.au/pubs/norm/rhsac_disc.pdf >Accessed: 27th October 2016.

Richmond DR, Yelverton JT and Fletcher ER 1973, 'Far-field underwater blast injuries produced by small charges' Report Number DNA 3081T, Lovelace Foundation, Albuquerque.

Rigzone 2016, 'Training: How does decommissioning work' <http://www.rigzone.com/training/insight.asp?i_id=354> Accessed: 28th April 2016.

Rilov G and Benayahub Y 1998, 'Vertical Artificial Structures as an Alternative Habitat for Coral Reef Fishes in Disturbed Environments' *Marine Environmental Research*, Volume 45, pp. 431-51.

Rilov Gil and Benayahu Y 2002, 'Rehabilitation of coral reef-fish communities: the importance of artificial-reef relief to recruitment rates' *Bulletin of Marine Science*, Volume 70, Issue 1, pp. 185-197.

Rooker JR, Dokken QR, Pattengill CV and Holt GJ 1997, 'Fish assemblages on artificial and natural reefs in the Flower Garden Banks National Marine Sanctuary, USA' *Coral Reefs*, Volume 16, pp. 83-92.

Royal Academy of Engineering 2013, 'Decommissioning in the North Sea: A report of a workshop held to discuss the decommissioning of oil and gas platforms in the North Sea', <http://www.raeng.org.uk/publications/reports/decommissioning-in-the-north-sea> Accessed: 14th April 2016.

Sammarco P 2013, 'Corals on Oil and Gas Platforms Near the Flower Garden Banks: Population Characteristics, Recruitment, and Genetic Affinity' Prepared under BOEM Cooperative Agreement, Louisiana State University.

Sammarco PW, Atchison AD, Boland GS, Sinclair J and Lirette A 2012, 'Geographic expansion of hermatypic and ahermatypic corals in the Gulf of Mexico, and implications for dispersal and recruitment' *Journal of Experimental Marine Biology and Ecology*, Volume 436-437, pp. 36-49.

Sapura Acergy 2009 'Iwaki Platform Decommissioning Project' <http://www.sapuraacergy.com/downloads/RET-74%20Corporate%20folder%20Loose%20Sheet%20-%20Decommisioning%20(Iwaki%20Project)%20120110.pdf> Accessed: 26th October 2016.

Scarborough Bull A and Kendall Jr. JJ 1994 'An Indication of the Process: Offshore Platforms as Artificial Reefs in the Gulf of Mexico' *Bulletin of Marine Science*, Volume 55, Issue 2-3, pp. 1086-1098.

Schlumberger 2016, 'Solids Control & Cuttings Management' <http://www.slb.com/services/drilling/solids_control.aspx> Accessed: 27th October 2016.

Schroeder DM and Love MS 2004, 'Ecological and political issues surrounding decommissioning of offshore oil facilities in the Southern California Bight' *Ocean and Coastal Management*, Volume 47, pp. 21-48.

Schroepfer RL, and Szedlmayer ST 2006, 'Estimates of residence and site fidelity for red snapper Lutjanus campechanus on artificial reefs in the northeastern Gulf of Mexico' *Bulletin of Marine Science*, Volume 78, Issue 1, pp. 93-101.

Schuhmacher H 1988, 'Development of coral communities on artificial reef types over 20 years (Eilat,Red Sea)' in *Proceedings of the 6th international coral reef symposium*, Volume 2, pp. 384-397.

Shaw RF, Lindquist DC, Benfield MC, Farooqi T and Plunket JT 2002, 'Offshore Petroleum Platforms: Functional Significance for Larval Fish Across Longitudinal and Latitudinal Gradients' U.S Department of the Interior, Minerals Management Service <http://www.boem.gov/2014-030/>Accessed: 16th May 2016.

Sheehy DJ and Vik, SF 2010, 'The role of constructed reefs in non-indigenous species introductions and range expansions' *Ecological Engineering*, Volume 36, pp. 1-11.

Shell 2015, 'Brent Delta Topside Decommissioning Programme' Shell Report Number BDE-D-TOP-AA-5880-00001, 22 June 2015,

<https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/441789/Brent_Delta_Topside_DP.pdf> Accessed: 28th April 2016.

Shell 2016, 'Brent Field Decommissioning Programme', <http://www.shell.co.uk/sustainability/decommissioning/brent-field-decommissioning/brent-field-decommissioning-programme.html> Accessed: 28th April 2016.

Shipp RL 1999, 'The artificial reef debate: Are we asking the wrong questions' *Gulf of Mexico Science,* Volume 17, Issue 1, pp. 51-55.

Shipp RL and Bortone SA 2009, 'A perspective of the importance of artificial habitat on the management of red snapper in the Gulf of Mexico' *Reviews in Fisheries Science*, Volume 17, Issue 1, pp. 41-47.

Simons RD, Page HM, Zaleski S, Miller R, Dugan, JE, Schroeder DM, and Doheny B 2016, 'The Effects of Anthropogenic Structures on Habitat Connectivity and the Potential Spread of Non-Native Invertebrate Species in the Offshore Environment' *PLoS One* <http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0152261> Accessed: 5th July 2016.

Sipadan.com 2016, 'Seaventures Dive Resort' <http://www.sipadan.com/Seaventures.php> Accessed: 28th April 2016.

Smith CL, and Tyler JC 1975 'Succession and stability in fish communities of the dome-shaped patch reefs in the West Indies' *American Museum Noviates*, No. 2572, pp. 1-18.

Smith D 2016 'Global decom boom brings disruption to heavy lifting' Decomworld, <http://analysis.decomworld.com/projects-and-technologies/global-decom-boom-brings-disruption-heavy-lifting> Accessed: 28th April 2016.

Sørgård, Tone 2015 'Environmental Requirements related to oil based drilling fluids and cuttings', Norwegian Environmental Agency, Presented at: North Sea Decommissioning Conference Bergen, February 2015.

Stephens J and Pondella D 2002 'Larval productivity of a mature artificial reef: the ichthyoplankton of King Harbor, California, 1974–1997' *ICES Journal of Marine Science: Journal du Conseil*, Volume *59*, pp. 51-58.

Stevcic Z 1971 'Laboratory observations on the aggregations of the spiny spider crab (Maja squinado Herbst)' *Animal Behaviour*, Volume 19, pp. 18-25.

Strelcheck AJ, Cowan Jr. JH and Patterson III WF 2007 'Site fidelity, movement, and growth of red snapper, Lutjanus campechanus: Implications for artificial reef management' in Patterson WF, Cowan Jr. JH, Fitzhugh, GR and Nieland DL (eds.), *Red Snapper Ecology and Fisheries in the U.S. Gulf of Mexico,* American Fisheries Society Symposium Series, Volume 60, pp. 147-162.

Subsea Australia 2016. The Current and Evolving Supply Chain. http://www.subseaenergy.org.au/the-current-and-evolving-supply-chain Accessed 25 October 2016.

Szedlmayer ST 1997 'Ultrasonic telemetry of red snapper, Lutjanus campechanus, at artificial reef sites in the northeast Gulf of Mexico' *Copeia*, Volume '1997', Issue 4, pp. 846-850.

Szedlmayer ST 2007 'An evaluation of the benefits of artificial habitats for red snapper, Lutjanus campechanus, in the northeast Gulf of Mexico.' *Proceedings of the Gulf and Caribbean Fisheries Institute*, No 59, pp. 223-230.

Szedlmayer ST and Schroepfer RL 2005 'Long-term residence of red snapper on artificial reefs in the northeastern Gulf of Mexico' *Transactions of the Americas Fisheries Society*, Volume 134, pp. 315-325.

Szedlmayer ST and Shipp RL 1994.' Movement and growth of red snapper, Lutjanus campechanus, from an artificial reef area in the Northeastern Gulf of Mexico.' *Bulletin of Marine Science*, Volume 55, Issue 2-3, pp. 887-896.

Techera E and Chandler J 2015, 'Offshore installations, decommissioning and artificial reefs: Do current legal frameworks best serve the marine environment?' *Marine Policy*, Volume 59, pp. 53-60.

Thorpe SA 2012, 'On the biological connectivity of oil and gas platforms in the North Sea' *Marine Pollution Bulletin,* Volume *64, Issue 12*, pp. 2770-2781.

Turgeon K, Robillard A, Gregoire JJ, Duclos V and Kramer DL 2010, 'Functional connectivity from a reef fish perspective: behavioural tactics for a moving in a fragmented landscape', *Ecology*, Volume 91, Issue 11, pp. 3332-3342.

UNEP (United Nations Environment Programme) 2009, 'Sustainable Coastal Tourism – An Integrated Planning Management Approach' p. 87.

Uy FA, Caindec VEC, Perez JLD and Dy DT 2008, 'Impacts of recreational scuba diving on a marine protected area in central Philippines: A case of the Gilutongan marine sanctuary' *The Philippine Scientist*, Volume 42, Issue 17, pp. 144-158.

UWA 2010, UWA researcher unravel North West Shelf seabed < http://www.news.uwa.edu.au/201007202683/offshore/uwa-researchers-unravel-north-west-shelf-seabed> Accessed 28 October 2016

Van Der Stap T, Coolen JWP and Lindeboom HJ, 2016, 'Marine Fouling Assemblages on Offshore Gas Platforms in the Southern North Sea: Effects of Depth and Distance from Shore on Biodiversity' *PLoS One* <http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0146324>Accessed: 5th July 2016.

Versabar 2013, 'Versabar – Engineering Solutions – The Claw ', <http://www.vbar.com/claw/index.html> Accessed: 27th October 2016.

Voskanian M and Byrd R 1997, 'Technical session: summary and recommendations' in Manago F and Williamson B (eds.) *Proceedings of the Public Workshop, Decommissioning and Removal of Oil and Gas Facilities Offshore California: Recent Experiences and Future Deepwater Challenges*, OCS Study MMS 98-0023. US Department of the Interior, Minerals Management Service, Pacific OCS Region, Camarillo, California, pp. 137-139.

Waters, H. 'Breaking Down the Myths and Misconceptions About the Gulf Oil Spill' Smithsonian.com, April 17 2014. < http://www.smithsonianmag.com/science-nature/clarifying-myths-and-misconceptions-about-gulf-oil-spill-180951136/?no-ist > Accessed: 28th October 2016.

Watterson, JC, WF Patterson III, Shipp RL, and Cowan JH Jr 1998, 'Movement of red snapper, *Lutjanus campechanus*, in the north central Gulf of Mexico: Potential effects of hurricanes' *Gulf of Mexico Science,* Volume 1, pp. 92-104.

Wilson KDP, Leung AWY and Kennish R 2002, 'Restoration of Hong Kong fisheries through deployment of artificial reefs in marine protected areas' *ICES Journal of Marine Sciences,* Volume 59, pp. 157-163.

Wikimedia Commons 2016, 'File:SP-57 A to WD-89 (11442548985).jpg' Bureau of Ocean Energy Management, photo cite d as provided by Louisiana Department of Wildlife and Fisheries<https://commons.wikimedia.org/wiki/File:SP-57_A_to_WD-89_(11442548985).jpg> Accessed: 28th October 2016.

Wikipedia 2016, 'Jacket (Platform)' <https://no.wikipedia.org/wiki/Jacket_(plattform)> Accessed: 27th October 2016.

Wikipedia 2016[2] 'Condeep' < https://en.wikipedia.org/wiki/Condeep> Accessed: 28th October 2016.

Wiper Trip 2016, 'Waste Management – Transport of cuttings to shore for disposal' Wiper Trip.com Drilling and Well Engineering Resources, <http://www.wipertrip.com/qhse/waste-management/29-waste-management-transport-of-cuttings-to-shore-for-disposal.html> Accessed: 1st July 2016.

Yelverton JT, Richmond DR, Fletcher ER and Jones RK 1973, 'Safe distances from underwater explosions for mammals and birds' Lovelace Foundation for Medical Education and Research, Albuquerque, NM for Defence Nuclear Energy, Washington DC.

Appendix A: Acronyms and Key Definitions

Acronym	Full Title
11ALARP	As Low as Reasonably Practicable
ANZECC	Australian and New Zealand Environment and Conservation Council
APPEA	Australian Petroleum Production and Exploration Association
BSEE	Bureau of Safety and Environmental Enforcement
CGS	Concrete Gravity Structures
CNSOPB	Canada-Nova Scotia Offshore Petroleum Board
CO2	Carbon Dioxide
CPUE	Catch Rate per Unit Effort
DAFF	Department of Agriculture, Fisheries and Forestry
DECC	Department of Energy and Climate Change
DEG	Decommissioning Ecology Group
DMP	Department of Mines and Petroleum
DotE	Department of the Environment
DP	Decommissioning Program
DRET	Department of Resources Energy and Tourism
DSV	Diving Support Vessel
EPBC Act	Environment Protection and Biodiversity Conservation Act 1999
EEM	Environmental Effects Monitoring
EEZ	Economic Exclusion Zone
EIA	Environmental Impact Assessment
EP	Environment Plan

Acronym	Full Title
FAD	Fish Attracting Device
FPSO	Floating Production, Storage and Offloading Vessel
HEA	Habitat Equivalency Analysis
HLV	Heavy Lift Vessel
MCA	Multi-Criteria Analysis
MO	Marine Order
NEB	National Energy Board
NEBA	Net Environmental Benefit Analysis
NOAA	National Oceanic and Atmospheric Administration
NOPSEMA	National Offshore Petroleum Safety and Environmental Management Authority
NOPTA	National Offshore Petroleum Titles Administrator
NORMS	Naturally Occurring Radioactive Substances
OCS	Outer Continental Shelf
ODS	Ozone Depleting Substances
OPGGS Act	Offshore Petroleum and Greenhouse Gas Storage Act 2006
OPGGS(E)R	Offshore Petroleum and Greenhouse Gas Storage (Environment) Regulations 2009
OSPAR	Oslo / Paris Convention (for the Protection of the Marine Environment of the North-East Atlantic)
PFW	Produced Formation Water
PLD	Planktonic Larval Duration
ROV	Remotely Operated Vehicle
RTC	Real Time Closure
RTM	Riser Turret Mooring

Acronym	Full Title
SALRAM	Single Anchor Leg Rigid Arm Mooring
UK	United Kingdom
UNCLOS	United Nations Convention on the Law of the Sea
USEPA	United States Environmental Protection Agency

Key Definitions

Item	Definition
Aggregation	The collecting of units or parts into a mass or whole
Annulus	The space between the inside face of an outer casing string and the outside face of the next smaller casing string
Anode	The positively charged electrode by which the electrons leave an electrical device
Artificial Reef	An unnatural structure that has been colonised by marine life
Attraction	The action that causes movement to a place by offering something of interest or advantage
Benthic	Living on (or in) the bottom of the ocean and intertidal areas
Bioaccumulation	The accumulation of a toxic chemical in the tissue of a particular organism
Biocide	A poisonous substance, especially a pesticide
Biofouling	The fouling of underwater pipes and other surfaces by organisms such as barnacles and algae
Biomass	The weight of living material, often including the dead parts of living organisms (e.g., the shell of a snail). Measured as the amount of living material per unit area or volume
Buoy	A float of any type used as a marker

Item	Definition
Concrete Gravity Base Structure	A concrete substructure which is not fixed into the seabed by piles but resists wind and wave force by its own bulk and weight
Conductor or Drive Pipe	A large diameter pipe driven into the seafloor to protect the surface casing and to protect against a shallow gas blowout
Contaminants	Unwanted chemicals in the environment or living organisms which may be harmful to plants, animals or humans
Continental Shelf	The seabed and subsoil beyond the territorial water over which a country has sovereign rights for the purpose of exploring for and exploiting natural resources
Corrosion	The natural process by which a refined metal is converted to a more stable form, such as an oxide, hydroxide or sulphide. It is the gradual destruction of materials by chemical and/or electrochemical reaction with their environment.
Decommissioning	The process of deciding how best to shut down operations at the end of a field's life, then closing the wells, cleaning, making the installation safe, removing some or all of the facilities and disposing or reusing them
De-Energise	Undergo loss of electrical power
Drill Cuttings	The broken bits of soil material removed from a borehole drilled by rotary, percussion or auger methods
Epifauna	The animals that live on the upper surface layers of ocean floor sediments (Epiphytes are microalgal organisms that live on a surface)
Epoxy	A term used to denote both the basic components and cured end products of epoxy resins, as well as another term for the epoxide functional group. Epoxy resins are a class of reactive prepolymers and polymers which contain epoxide groups
Fish Attraction Device	A manufactured object placed in ocean surface waters around which fish tend to aggregate
Floating Production Storage and Offloading vessel	A floating vessel used to produce and process hydrocarbons and to store oil

Item	Definition
Habitat	The home or environment of an animal, plant or other organism
Hydrophone	A microphone designed to be used underwater for recording or listening to underwater sound
Infauna	The animals that live in the soft sediment layers of the ocean floor
Infrastructure	The basic physical structures and facilities needed for the operation of an enterprise
In situ	In the original position, on site
Jacket	The portion of a platform extending from the seabed to the surface used as a template for pile driving and as a lateral bracing for the pile
International Maritime Organization	The United Nations body charged with shipping safety and navigation issues
Larvae	The distinct planktonic juvenile form many animals undergo before metamorphosis into adults
Marine Growth	Sea life (e.g. barnacles) attached to hard objects submerged in the sea
Migration	Movement from one location to another
Mortality	Death, especially on a large scale
North Sea	The sea bounded primarily by the coasts of Great Britain, Norway, Denmark, Belgium, Germany, Sweden, France and the Netherlands
Offshore	Operations carried out in the ocean as opposed to on land
Operator	The company either solely or in a joint venture which manages the operation of oil and gas production for itself or on behalf of the partners
Particulate	Matter in the form of minute separate chemicals
Pelagic	Living in the water column offshore of the coastal zone (i.e. seaward of the downward break in the continental slope)
Pig	A plug, forced through a pipeline by liquid or gas, used to clean the pipe's interior or separate different fluid mediums

Item	Definition
Pile	Steel pipe driven into the seabed to secure and support an offshore structure
Pipeline	A conduit of steel pipe extending from platform to platform or platform to shore used to transport oil and/or gas
Planktivore	An aquatic organism that feeds on planktonic food, including zooplankton or phytoplankton
Plankton	Microscopic organisms living suspended in the water column
Polymer	A large molecule, or macromolecule, composed of many repeated subunits. Polymers have unique physical properties including toughness and viscoelasticity
Polychlorinated Biphenyl	An organic chlorine compound. Polychlorinated biphenyl is a persistent organic pollutant and toxic environmental contaminant
Primary Productivity	The rate at which biomass is produced per unit area by plants
Receptor	A thing, process or activity that is impacted by an occurrence
Scale	A deposit or coating formed on the surface of metal, rock or other material. Scale is caused by chemical reactions, changes in pressure and temperature or changes in the composition of a solution
Secondary Production	The generation of biomass of the consumer (heterotrophic) organisms in a system
Shell Mound	A biogenic reef that surrounds an oil and gas platform, resulting from the accumulation of mollusc shells that have fallen from the shallow areas of the platform
Processing Facilities	Part of the topsides that treat oil and gas, remove impurities and pump the product into pipelines to shore
Productivity	The rate at which biomass is produced per unit area by any class of organisms
Radionuclide	A radioactive nuclide. A nuclide is an atomic species characterised by the specific constitution of its nucleus

Item	Definition
Recruitment	The addition of individuals of a specified size or age to a population. In a fisheries context, recruitment refers to the addition of individuals to the size (or age) groups that can legally be caught. Otherwise, recruitment typically refers to the known addition of 'newborns' (see Young of the Year) to a population following settlement from the water (also see Settlement)
Rig	The derrick or mast, drawworks, and attendant surface equipment of a drilling or work over unit
Rigs-to-Reefs	A national policy in the United States enshrined in legislation, promoting the conversion of disused platforms into artificial reefs for marine lift at designated sites
Riser	The portion of a pipeline that rises from the seabed to the water surface, supported by the platform jacket
Settlement	Many marine organisms that live on the bottom (see Benthic) have early developmental stages that grow in the water column (see Plankton and Pelagic). Settlement refers to the event when the young leave the water column permanently to take up life on the bottom
Spawning	The process of releasing or depositing eggs or sperm
Subsea	Situated or occurring beneath the surface of the sea
Topsides	The facilities which contain the plant for processing oil and gas and accommodations.
Trawling	Fishing with a strong, large fishing net that is dragged along the sea floor behind one or more vessels
Turret Mooring System	A fixed turret column held by an internal or external vessel structure via a bearing arrangement. The vessel-bound components are able to weather-vane freely around the turret, which is fixed via a number of anchor lines to the seabed
Well	The holes drilled through the seabed into the reservoir where oil or gas is trapped, often two thousand or more metres below the seabed. The hole is lined with piping which extends up through conductors onto the platform deck

Item	Definition
Wellhead	The wellhead sits on top of the drive pipe. Casing and tubing strings are suspended from the wellhead. Valves on the wellhead allow the entrance to the tubing and the casing annuli
Young-of-the-Year	The young of a species that were born in this year; typically applied to fishes (also see Settlement and Recruitment)

Appendix B: Biodiversity Queries

1. Are marine communities associated with offshore oil and gas infrastructure likely to be a significant source of larvae to habitats for the broader region?

Assessing whether marine communities associated with offshore oil and gas infrastructure are likely to be a significant source of larvae to habitats for the broader region is of critical importance in understanding the influence that these structures have on regional marine biodiversity and fish production. Almost no research has been done within Australia regarding this area (Pradella et al. 2014, Fowler and Booth 2012). Therefore, papers relating to other locations were considered and reviewed, as well as papers that talked about other forms of artificial reefs, such as breakwaters. The impact of oil and gas infrastructure on reproductive health of marine organisms was also explored, as this would have potential long term impacts on whether such communities could be significant sources of larvae.

In order to determine whether marine communities associated with offshore oil and gas infrastructure are likely to be a significant source of larvae to habitats for a broader region, it first must be determined as to whether these communities actually produce larvae at all. Direct evidence of larval production includes accounts of spawning and reproductive events at these communities. Indirect evidence of larval production includes high levels of secondary production, high numbers of larger fish, high numbers of fish with high site fidelity and in particular, high numbers of juveniles of these species. Discussions regarding direct evidence and indirect evidence for larval production are presented below.

1.1. Oil and Gas Infrastructure as Spawning and Reproductive Habitat

It is globally recognised that oil and gas infrastructure provides valuable habitat for a number of fish species and other marine organisms (Ajemian et al. 2015, Pradella et al. 2014, Claisse et al. 2014, Cresson et al. 2014, Love et al. 2005, Polovina and Sakai 1989). However, for decades, it has been debated whether oil and gas infrastructure can increase regional or local production or whether it only attracts fish and other organisms that were already present in the region (Ajemian 2015, Pradella et al. 2014, Shaw et al. 2002, Page et al. 1999, Scarborough Bull and Kendall 1994, Gallaway and Lewbel 1982). Observations of species breeding at platforms, as well as at other artificial structures, would suggest that this infrastructure may provide suitable spawning grounds, and therefore a source of larvae, to broader regions. Direct evidence of spawning is difficult to capture (Shaw et al. 2002). However, fish spawning and courtship behaviour has been recorded around oil and gas platforms in Gabon, where red snapper (*Lutjanus dentatus*) have been observed spawning and yellow jack (*Caranx batholomaei*) have been observed engaging in what appear to be typical jack courtship behaviours (Friedlander et al. 2014). During another study, a sergeant major (*Abudefduf saxatilis*) was found guarding a nest of eggs inside a broken weld on a platform (Scarborough and Bull 1994). Spawning, mating and other reproductive behaviours, nests and large egg clusters have also been observed on other types of artificial reefs in regions as diverse as Costa Rica and the United Kingdom for a wide variety of marine organisms, including crabs, nudibranchs and typical reef fish (Pickering and Whitmarsh 1997; Campos and Gamboa 1989; Stevcic 1971). Such records demonstrate that certain species use oil and gas infrastructure as spawning grounds and that these communities are a source of larval production. However, they are anecdotal accounts that are not sufficient to determine whether the presence of such habitat is *likely* to lead to increased larval production within a region.

1.2. Larval Production Associated with Oil and Gas Infrastructure

In areas such as the north-east Gulf of Mexico, where little natural reef habitat exists, it is considered likely that the introduction of oil and gas infrastructure has enhanced fish populations (Shaw et al. 2002, Gallaway and Lewbel 1982). A study undertaken in the region looked into the fish assemblages at three oil and gas platforms (Shaw et al. 2002). It found that at the locations surveyed, larval assemblages matched closely with adult fish species present, indicating that the adult species were spawning at these sites and their larvae recruiting locally (Shaw et al. 2002). The study also examined the length frequency and development stages of reef taxa collected at the platforms and concluded that the findings provided indirect evidence of potential spawning and nursery / recruitment habitat at the platforms. Whilst the study recognised that natural reefs could be the source of the larvae, the absence of hard bottom seabed and the number of platforms within viable larval distribution range make platforms the most likely source (Shaw et al. 2002).

Another study determined that oil and gas platforms off the coast of California have the highest secondary fish production per unit area of seafloor of any marine habitat that has been studied (Claisse et al. 2014), although this figure was highly variable among structures (Fowler et al. 2015). Increased secondary production provides indirect evidence of increased larval production, provided the species have high site fidelity and mature individuals have good reproductive health and are producing larvae prior to mortality. For species with pelagic larvae, larval production at offshore platforms may provide a significant source to the wider region.

A study was undertaken off the coast of California to determine whether platforms might be significant as sources of larvae production for a number of overfished, commercially important species, on both a local and regional basis (Love et al. 2005). The study compared adult densities and potential larval production of chosen species at a series of oil and gas platforms and natural outcrops off the Californian coast. It was found that densities of mature cowcod (*Sebastes Levis*) and Boccaccio rockfish (*Sebastes Paucispinis*) were low at both natural reefs and platforms, but the average densities for both species was higher around platforms than at natural outcrops. Mature Boccaccio rockfish were found at three platforms, and at two of these, individuals were larger than those found at any natural reef. One Platform, Platform Gail, was found to have by far the greatest densities of both species and highest rate of potential larval production of any of the habitats surveyed; natural or artificial. The size of adults within a population is important as for some species of rockfish, larger females produce much more larvae than smaller females and also larvae that is more likely to survive (Palumbi 2004). A study undertaken by Berkley et al. (2004) found that the eggs of older female rockfish of the genus *Sebastes* produced higher amounts of larvae, were more resistant against starvation and grew faster than larvae from the eggs of younger females. High densities of mature fish at platforms suggest that these populations have the potential to provide more larvae than natural habitats, per unit area. In this way, the relatively small footprint of a platform has the potential to produce disproportionately large numbers of larvae. The study by Love et al. (2005) estimated that removing Platform Gail would be equivalent to removing 12.57 ha of average-producing natural habitat in southern California for cowcod or 29.24 ha of average-producing natural habitat for Boccaccio rockfish. This study suggested that Platform Gail may be significant larvae source for these species, and its removal would have implications for population numbers (Love et al. 2005). Another study off the Californian coast looked at populations of juvenile Boccaccio rockfish at platforms and highlighted the high densities of this species that were supported by this habitat, which hosted approximately 20% of juveniles in the geographic range. The study claimed that without these structures, many of these juveniles would not survive to adulthood (Love et al. 2006). As rockfishes tend to have high site fidelity (Matthews 1990, Lowe et al. 2009, Anthony at et al. 2013), high numbers of juvenile individuals' fidelity could be expected to result in increased larval production at the location, as this species does not move elsewhere to spawn. As rockfish have pelagic larvae, it is likely that larvae produced at the platform acts as a larval source for the wider geographic area. The high proportion of individuals present at the platforms relative to natural outcrops and reefs suggest that this larval source associated with marine communities at platforms may be significant for the broader region.

An Australian study, undertaken by Fowler and Booth (2012) examined the length frequencies and age structures of resident red-belted anthias *Pseusanthias rubrizonatus* at four isolated artificial structures previously used in the oil and gas industry, off the North West of Australia, to determine whether these structures supported full populations of this species, or were only attracting adult fish. The structures surveyed were steel, of rectangular prismoidal shape and were due for removal. The study found that the structures were capable of developing and sustaining populations of reef fishes through arrival of pelagic larvae over a timescale of years. Fowler and Booth (2012) state that the isolation of the structures surveyed, lack of surrounding natural reef and presence of large predators make it unlikely that red-belted anthias identified on site moved following settlement and it is highly likely that they were produced at this location (Fowler and Booth 2012) and given the lack of natural hard substrate in the area, they argue that the structures may be important for local production of this species, including larval production, as the species examined have high site fidelity. As the species have pelagic larvae, they may also provide a source of larvae to the broader region. Another study on Australia's North West Shelf focussed on fish assemblages around wellheads, finding that relatively small pieces of oil and gas infrastructure provide habitat for large numbers of reef based fish, including commercial species (Pradella et al. 2014). As these fish are associated with the structures and unlikely to move elsewhere to spawn, the community associated with the structure is likely to be a source of larval production.

1.3. Larval Production Associated with Artificial Reefs

Whilst the ability of artificial structures to increase production is a widely discussed topic, limited research has been undertaken that draws conclusions on the matter (Polovina and Sakai 1989, Foster et al. 1994, Shaw et al. 2002, Love et al. 2006, Ajemian 2015). This is because of the difficulties associated with examining populations that are able to travel large distances and migrate between locations throughout their various life stages. Recent studies are demonstrating that artificial structures can host areas of highly productive habitat (Shaw et al. 2002, Stephens and Pondella 2002, Love et al. 2006, Ajemian 2015). However, this has only been demonstrated within particular regions and under the right circumstances and studies generally relate to overall production rather than focussing on larval production.

A key study that focusses on larval production is a long term study undertaken of the breakwater in King Harbor, California. The breakwater is an isolated structure in the southern Santa Monica Bay, built from quarry rock. The nearest natural rock reefs are 9 kilometres to the south west and 4 kilometres to the north and to the west. This study looked to determine whether the associated artificial reef was a larval source for the region. Twenty four years' worth of data was captured on a monthly basis regarding larvae density at the breakwater. This data was compared with data elsewhere in the Southern Californian Bight. The majority of larvae caught at King Harbour were early-hatch stages of local reef inhabitants. It was found that annual larval densities of a number of reef dwelling species were significantly higher in King Harbour samples, while no species were significantly more abundant in bight-wide samples (Stephens and Pondella 2002). Of total larvae captured, the fraction of reef produced larvae in King Harbour samples was considered extremely high (mean 51%, range 30% - 75%) compared to the fraction of reef produced larvae being produced elsewhere in the bight (mean 5%, range 2% - 8%). This indicated that the breakwater 'represents a mature artificial reef and contributes to the reef fish larval pool of the bight, acting as a source rather than a sink' (Stephens and Pondella 2002). The study determined that the artificial reef was productive and contributes 'generously' to the reef fish larval pool of the broader region.

One of the first studies to provide evidence that artificial reefs can increase species production was undertaken off Shimamaki, a rural village in Japan (Polovina and Sakai 1989). This study considered two adjacent fishing grounds, one with artificial reefs and one without, in order to reduce the influence of variables such as changes in fishing power, year-class strength and market factors, on results (Polovina and Sakai 1989). It was known that the populations of Pacific giant octopus (*Octopus dofleini)*, were similar between the East and West bays between 1942 to roughly 1961. However, after 1961, catches began to increase in the West and by 1970, averaged rates five times higher than that in the East. There was speculation that the octopus may have been relocating from the East bay to the West bay, but as catch rates in the East bay were found to remain constant, it was considered most likely that the artificial reef habitats introduced in the West bay had provided suitable environments for the species to recruit, settle, hide and feed with lower risk of predation. The study found that populations of Pacific giant octopus increased by 4% per 1000 m^3 of artificial reef. Whilst it was believed that recruitment for both bays came from elsewhere for the octopus, it could be expected that the increased number of octopus in the bay with artificial reefs would eventually lead to higher overall levels of larval production in the wider region, provided that the local population a chance to reproduce before capture. One study, undertaken in Delaware Bay, found that compared with prior levels of infauna, epifauna was observed to be between 147 and 895 times greater after the introduction of an artificial reef (Foster et al. 1994). Provided that at least some of these species were those with high site fidelity, the marine community is likely to be a source of larval production. If any of these species produce pelagic larvae, which is considered highly likely, then the larvae may source the broader region.

1.4. Larval Dispersal Associated with Oil and Gas Infrastructure

Research suggests that marine communities supported by oil and gas infrastructure have the ability to facilitate species range expansions and the introduction of species into new areas (Simons et al. 2016, Sammarco et al. 2012). Whilst fish production has been shown to be higher around oil and gas platforms than at natural sites in some regions, there is little evidence that the same is true for corals. A study undertaken by Sammarco (2013) showed that coral settlement was significantly lower on platforms than on natural structures in Flower Garden Banks in Gulf of Mexico. However, whilst lower settlement levels of corals on platforms may suggest lower levels of subsequent larval production from platforms than from existing natural sites, studies suggest that platform populations do facilitate coral geographic expansion (Sammarco 2012, Sammarco 2013).

A study undertaken by Simons et al. (2016) used three-dimensional biophysical modelling to determine whether larval dispersal amongst platforms was a plausible explanation for the spread of the colonial species, red-rust bryozoan (*Watersipora subtorquata*), a variety of colonial 'moss animal' ,from one platform in 2001 to four platforms by 2013. The modelling determined that larval dispersal via currents could account for the increase in distribution of the species, although it is important to note that hull fouling was also considered a possible alternative explanation. The results also suggested that dispersal from a platform rather than nearshore habitat can increase dispersal distances for larvae with a planktonic larval duration of 24 hours or less (Simons et al. 2016), which are driven by larval behaviour, the local hydrodynamic environment and larval release higher above the seafloor (Simons et al. 2016). Unfortunately, the study did not determine whether platform release rather than nearshore release would also increase dispersal distances for species with longer larval durations. As most species have larval durations over 24 hours and some have larval durations in excess of 15 days, this is an important limitation of the findings. The study showed that the presence of oil and gas infrastructure in a region can increase species ranges, allowing larvae to settle and recruit in previously unreachable habitats. This extension of species range may indirectly increase both species production and species diversity within the broader region. The connectivity values of platforms for marine organisms have also been documented in the North Sea (Thorpe 2012). Tidal current flows allow 60% of platforms in the southern UK sector and 23% in the northern UK sector to be interconnected with regard to larval dispersal and genetic interchange. In this way, the spread of species has been aided in the region through the interconnectivity of the marine communities associated with oil and gas infrastructure (Thorpe 2012).

1.5. Marine Communities Associated with Oil and Gas Infrastructure as Potential 'Re-Seeding' Sites of Larval Production

Multiple studies have suggested that marine communities associated with oil and gas platforms could provide valuable sources of reseeding if natural reefs experienced increased mortality from either natural or anthropogenic processes (Atchinson 2005, Sammarco et al. 2012, Sammarco 2013). A study undertaken into the genetics of corals on platforms near the Flower Garden Banks in the Gulf of Mexico found that whilst some platforms had very isolated populations, there was one platform that was found to be a potential larval source for two other platforms and appeared to exchange genetic information with both the East Flower Garden Bank and the West Flower Garden Bank. This platform appeared to act as a potential larval source for natural sites and provided an 'insurance' population in the case of a disturbance (Atchinson 2005).

Similarly, a study off the coast of Gabon, West Africa suggests that platforms off the coast of Gabon are likely sources for replenishment of other platforms and scarce reefs in the region, acting like distinct populations in a metapopulation (Friedlander et al. 2014). This study states that the marine communities associated with oil and gas infrastructure could be of significant value to fisheries conservation (Friedlander et al. 2014).

1.6. Reproductive Health

Impacts to reproductive competence as a result of pollution stress have been demonstrated in fish (van der Oost et al. 2003). There is increasing evidence to suggest that fish populations can experience decreases in fecundity as a result of low level pollution, which may result in long term decline, or even extinction, of species (van der Oost et al. 2003). Reproductive health may act as a limiting factor on potential larval production at marine communities associated with oil and gas infrastructure. Therefore, the impacts of oil and gas production on reproductive health need to be considered.

A study undertaken in the North Sea indicated that offshore oil production has wide ranging and adverse biological effects for natural fish populations (Balk et al. 2011). Polycyclic aromatic hydrocarbons (PAH) metabolites were found in elevated levels in fish within the North Sea, indicating exposure and uptake. A number of other biomarkers were also examined and it was found that a general relationship existed between intensity of oil production and biomarker responses (Balk et al. 2011).

A study undertaken off the Californian Coast in 2009 (Love and Goldberg 2009) looked into the occurrence of atresia, a form of reproductive impairment on fish living around oil and gas infrastructure and fish living in natural locations. It was found that whilst a few fish with pronounced atresia were collected at one platform and one natural location, there was no evidence of widespread atresia at any of the four sites examined. This study suggested that bottom dwelling fish that live around oil and gas infrastructure and prey on organisms that live on the sea floor are not reproductively inhibited (Love and Goldberg 2009).

Another study, undertaken in the North Sea, looked into concerns relating to the impact of alkylphenols in produced water discharges on fish reproductive health (Beyer et al. 2012). Alkyphenols, which are released in waste water during hydrocarbon production, have been associated with disruption to estrogen reception mediated processes for development, growth and reproduction in fish species (Beyer et al. 2012). This study consisted of an environmental risk assessment which modelled fish distribution information, produced water discharge data, plume fate information and uptake and elimination information of produced water alklphenols. This study suggested that the current environmental exposure of fish to the alkyphenols from produced water is most likely too low to affect reproduction levels within wild fish populations in the North Sea (Beyer et al. 2012). However, environmental monitoring should be undertaken to ensure that levels are monitored and potential impacts are recorded.

Further study into this area is recommended as insufficient research has been undertaken to draw conclusions on how oil and gas infrastructure impacts species reproductive health at this stage. Ongoing monitoring of species populations and health is vital to ensure that any unforeseen impacts are discovered and mitigated as soon as possible.

1.7. Conclusions

In some regions, such as the Flower Garden Banks in the Gulf of Mexico, natural reefs still appear by far the most significant source of larvae, despite a high number of platforms being located in the area (Atchinson 2005). However, where existing reef habitat is limited, such as off the coast of California, marine communities associated with oil and gas infrastructure may provide a significant larval source in the region (Love et al. 2005, Claisse et al. 2014, Ajemian 2015). Where increases in production have been recorded, it has usually been species specific, with commercially significant species the main subject of research (Bohnsack 1989). Furthermore, there is no proof that increased production will result increased larval production. Further research is required to determine whether oil and gas infrastructure increases larval production, and to what extent across different species (Bohnsack 1989).

The tendency of such marine communities to produce a significant source of larvae is influenced by a wide range of factors, including the relative biomass of mature adults, linked to the quantity and quality of habitat provided relative to natural reefs in the area, the reproductive health and potential of populations inhabiting structures, the distance of infrastructure from other larval sources to originally seed the community, the depth of the infrastructure and surrounding currents and flows (Atchinson 2005, Sammarco 2013, Simons et al. 2016). In some cases, platforms may not produce as much larvae as natural sites, but could provide stability to existing natural reef populations and 'island hopping' of larvae from platform to platform, allowing species to further their distribution and therefore provide a source of larvae to habitats in the wider region that did not previously have a larvae source close enough to result in recruitment and settlement.

1.8. Key Findings

- Overall, there has currently been too little research undertaken to determine whether marine communities associated with oil and gas infrastructure are likely to be a significant source of larvae to habitats for the broader region;
- There is evidence that these marine communities can produce larvae as they provide spawning and reproductive habitat for species. Examples have been discussed below, but to say that it is *likely* that these communities will make a significant contribution is not possible;
- In some instances, larval production occurring at marine communities associated with oil and gas infrastructure may be a significant for the broader region through facilitating the dispersal of larvae into new habitats, increasing the range of one or more species. In some instances, larval production occurring at marine communities associated with oil and gas infrastructure may be a significant for the broader region through acting as a valuable potential 're-seeding' site of larval production for a broader region, that would be critical for species conservation in case of mortality on natural reefs; and
- The impact of oil and gas production on the reproductive health of species in local marine communities requires further research.

2. Do marine species (particularly fish) recruit to the structures or do they migrate to these structures as adults?

2.1. Overview

As discussed in section 1, measuring the relative rates of production versus attraction is key to understanding the biological value of marine structures to regional ecosystems and is still debated in the available literature (Bohnsack 1989, Grossman et al. 1997, Pitcher and Seaman 2000, Baine and Side 2001, Gallaway et al. 2009, Goodsell and Chapman 2009, Shipp and Bortone 2009). Section 1 focussed on whether communities associated with oil and gas infrastructure and other artificial reefs can increase the production of larvae within a broader region. This section focusses instead on production, or increase in total biomass, that is associated with the recruitment of larval and juvenile fish and other organisms to structures and their subsequent growth.

Recruitment is defined as the addition of individuals to a population during specific life stages, and focuses particularly on newborns and young of the year. Successful recruitment involves production, as the species grow into adult fish at the location to which they have recruited, increasing the total biomass at that location. Recruitment differs from attraction, or migration, as attraction / migration focusses solely on the movements of adult fish and does not imply any level of site fidelity or growth of fish at the location.

Many studies have sought to identify whether recruitment and production or migration and attraction is the dominant process. In reality it is likely that both processes are occurring concurrently due to the range of species associating with artificial structures and their extreme differences in mobility and lifecycles. The balance between these processes is highly site dependent.

Directly assessing the regional ecological impacts of decommissioning options and determining the strength of these processes is often hindered by identifying the spatial pattern of the effects (determined by the movement of larvae, young and adults among reef habitats). Ascertaining the actual fate of species that migrate or recruit once dispersed from a local population and detecting the small magnitude of that effect over the large area that individuals are dispersed can be difficult (Carr et al. 2003).

Recruitment may occur at different life stages depending on the lifecycle of a particular species. This section considers recruitment through settlement of pelagic larvae in an adult habitat by examining whether there is evidence that reef dwelling species with small post recruitment ranges are present at isolated offshore infrastructure (section 2.3) and what processes may be important in this process (section 2.2).

We also examine whether there is evidence of recruitment at later juvenile stages through evidence of site fidelity (section 2.4) to provide circumstantial evidence of recruitment. For species demonstrating high site fidelity we also examine studies that compare secondary production between artificial and natural habitats to determine whether there may be a net benefit when these species recruit to artificial structures.

In this section we examine the literature for evidence of these processes across studied species on the North West Shelf of Australia, the Gulf of Mexico and California. Much of the literature is focussed on commercially important species such as Red Snapper, however we also examine studies focussed on smaller reef dwelling species that are not directly important to commercial fisheries.

2.2. Larval Recruitment

Recruitment may occur across varying life stages dependent of the species and location of infrastructure. Whilst there is evidence that some species of larvae have strong homing tendencies (Gerlach et al. 2006), the planktonic nature of early larval stages means that passive and active dispersal allows larvae to move to new locations including oil and gas infrastructure, within ocean currents.

The presence of mature reef communities on hundreds of oil and gas platforms throughout the world has demonstrated that coral larvae, and other reef dwelling larvae, recruit to the hard substrate associated with oil and gas structures. Following installation, submerged surfaces of platforms are rapidly colonized by algal spores and invertebrate larvae (Wolfson et al. 1979).

Oil and gas platforms, with their high ratio of structural surface to seafloor area, effectively act as 'fixed plankton collectors', aggregating larval invertebrates and fishes that passively drift in currents (Neira 2005, Claisse et al. 2014). The high vertical relief of such structures also allows for a range of habitats within the one area of the water column, including suitable nursery grounds for larvae and pelagic juveniles (Claisse et al. 2014).

Due to the distances over which larvae may disperse, it is almost impossible to determine whether larvae that recruit to oil and gas structures would have found another environment to settle on if the structure was not present (Pickering and Whitmarsh 1997). However, as total larval numbers are often far greater than the number able to settle on a reef (Sale 1980), suitable environment on which to settle is thought to be a major factor in limiting total reef populations (Randall 1963, Smith and Tyler 1975, Hixon and Beets 1989). Therefore, in environments where there are minimal alternative hard surfaces, it could be expected that the presence of oil and gas infrastructure would increase overall recruitment levels and overall species production.

There has been previous speculation that the light sources produced by active oil and gas platforms may attract larvae at night. However, levels of larvae found surrounding oil and gas platforms off the South East coast of Australia do not reflect this, with similar levels found during daylight and night time hours (Neira 2005).

Emery et al. (2006) further supported the potential importance of artificial reefs in larval recruitment of Boccaccio off the coast of California. They use ocean current models in a habitat limiting environment to hypothesise that during two separate years the Boccaccio larvae would not have survived due to the current trajectory and lack of recruitment habitat. This study demonstrated that the presence of Platform Irene almost certainly increases the survival of Boccaccio larvae in the Point Conception-Point Arguello region off California and also highlights the necessity to understand regional recruitment habitats (natural and artificial) in the context of regional oceanographic processes.

Location of artificial habitat, oceanographic current patterns and presence / absence of suitable natural habitat and its distribution likely determine the balance between settlement on an artificial reef and settlement on natural habitat.

2.3. Recruitment of Small Reef Dwelling Species

A series of studies off Australia's North West Shelf (Fowler et al. 2015, Booth 2012) looked at different scientific techniques to the usual tag and recapture techniques to investigate the residency of a small reef dwelling fish, the Red Belted Anthias (*Pseudanthias Rubrizonatus)*. The studies aimed to determine whether recruitment events as preserved in age structure at the wellheads are frequent enough or large enough to maintain populations of reef fishes.

The Red Belted Anthias, a reef dwelling species normally found on coral or rocky outcrops was studied at four wellhead locations. Post recruitment movement of small reef fish species including the Red-Belted Anthias is generally restricted to distances <50 m (Fowler and Booth 2012). With no natural hard sub-stratum within 50 m of each of the individual sampling locations for these studies, it can be assumed that these fish settled at the wellheads in their larval phase.

Relative abundance of the Red Belted Anthias is not implied from these studies (Booth and Fowler 2012, Booth and Macreadie 2014, Fowler et al. 2015) and due to sampling technique limitations, however the presence of this species at these wellhead locations suggest that the wellheads studied are capable of providing suitable recruitment habitat, at least for this species.

Fowler et al. (2015) studied the microchemistry of the otoliths from the fishes captured during these studies to examine the residency of the Red Belted Anthias once they had recruited to the wellhead structures. Studying otolith microchemistry allows a comparison of larger sample numbers when examining recruitment and residency in comparison with tag and recapture or underwater acoustic tagging techniques.

The focus on a single species in these studies does not allow conclusions to be drawn as to whether attraction or recruitment are the dominant processes at these wellhead locations or whether the wellheads indeed contribute to biodiversity or abundance regionally but they do provide a new method for investigating residency and they also confirm that recruitment of a common small reef fish is occurring at some scale at these wellhead locations.

2.4. Recruitment and Site Fidelity of Juveniles

Circumstantial evidence of increased production of red snapper (*Lutjanus campechanus)* in the Gulf of Mexico is prevalent, with increased catches of Red Snapper being associated with an increase in artificial reefs in the region. Multiple studies have assessed site fidelity of Red Snapper using a variety of tagging and recapture methodologies to assess whether Red Snapper recruit to these structures and if so whether they remain resident or whether the structures are important to certain life stages (Gallaway et al. 2009).

Szedlmayer and Shipp (1994) studied the movement, abundance, age and growth of Red Snapper in the North Eastern Gulf of Mexico to determine whether the high catches of Red Snapper in the area can be associated with production at these sites, or whether attraction is the dominant process. Artificial reef construction varies drastically in this area from car bodies to oil rigs and sunken liberty ships. Szedlmayer and Shipp (1994) focussed on juvenile Red Snapper (less than 3 years of age) with 1,155 small (177-410 mm) Red Snapper tagged and released. Of the known re-capture locations, 76% were recaptured within 2 km of their release site. Distances between release and re-capture locations were not shown to be related to the time between release and re-capture with a maximum period of 430 days between release and re-capture. The data was interpreted to suggest a high degree of site fidelity. The high site fidelity demonstrated from this tag and recapture study suggests that Alabama's artificial reefs provide suitable habitat for sustaining secondary (growth) production of juvenile red snapper.

Watterson et al. (1998) also observed high site fidelity in Red Snapper less than 3 years old in the Gulf of Mexico, although Hurricane Opal was observed to greatly decrease the site fidelity of fish that were at liberty when the hurricane passed. Patterson et al. 2001 continued with Watterson et al.'s (1998_ study and found site fidelity to be lower over a longer period of time in Red Snapper age 3 or less (Gallaway et al. 2009), with only 55% of recaptures not at liberty during the hurricanes remaining at their release sites. However, of those fish re-captured 97% remained at the site of release with only 3% (5 fish) changing location. Patterson et al. (2001) infer that site fidelity may have been even lower due to tag shedding in older fish, where distance from site of release was shown to linearly increase with age.

The reported lower site fidelities in Patterson et al. (2001) suggest that young red snapper in the North East Gulf of Mexico may visit these structures rather than recruit to them. Gallaway et al. (2009) examined the site fidelity estimates from Patterson et al. (2001) and Patterson and Cowan (2003), and re-examined the importance of tag shedding and the mortality rates used to calculate site fidelity in these studies, suggesting that the site fidelity estimates from Patterson and Cowan (2003) are too low when mortality rates from Szedlmayer (2007) are considered. Gallaway et al. (2009) also argue that the reefs studied by Patterson et al. (2001) are low in complexity (constructed from 55 gallon drums) increasing exposure of red snapper and the reef itself to the passing hurricanes. This suggests that recruitment of juvenile red snapper may be dependent on the reef complexity, especially in regions exposed to cyclonic activity.

Re-capture numbers in these early studies were relatively high (Szedlmayer and Shipp 1994, Watterson et al. 1998, Patterson et al. 2001). Szedlmayer and Shipp (1994) reported 37 fish with known re-capture locations, Watterson et al. (1998) recaptured 167 of 1,604 released fish and Patterson et al. (2001) recaptured 519 of 2,932 released fish. These high levels of recapture suggest high levels of site fidelity. However, it should be recognised that these studies only provide a temporal snapshot.

Strelcheck et al. (2007) increased the number of tagged Red Snapper aged 3 years or less to 4,317 at 14 experimental artificial reef locations with 629 fish re-captured. Most recaptured fish (86%) showed limited movement (less than 2 km) from the release site with a mean time at liberty of 401 days and ranging from 1 to 1,587 days. Site fidelity estimates were again calculated using the methodology in Patterson and Cowan 2003 with results ranging from 48-52%, however, Gallaway et al. (2009) have since revised this estimate to a site fidelity of 75% using Szedlmayer's (2007) estimation of red snapper mortality. This further highlights the necessity to understand local mortality rates when assessing site fidelity to support recruitment or migration theories. Another key variable that needs to be considered in these mark-and-recapture studies is the positional accuracy of the data. A large proportion of the recapture data from these studies were provided by recreational fisherman. The accuracy of this data can obviously have a significant impact on the site fidelity estimates.

More recent studies (Szedlmayer, 1997; Szedlmayer and Schroepfer, 2005; Schroepfer and Szedlmayer, 2006; Peabody and Wilson, 2006) have attempted to improve the positional accuracy and thus the accuracy of site fidelity estimates in the Gulf of Mexico through the use of ultrasonic telemetry, using underwater acoustic tags to provide positional information for released fish. These studies also have the benefit of continuously tracking fish rather than recording a snapshot in time when the fish are recaptured, which allows an estimate of residency time and behavioural patterns to be developed.

Szedlmayer (1997) reported residence times on artificial reefs of 17–597 days, and Szedlmayer and Schroepfer (2005) estimated red snapper were resident on an artificial reef for a mean of 212 days, with an individual fish staying at one reef for up to 597 days. The size of fish in these studies was generally larger than the previous tag and recapture studies to accommodate the ultrasonic tagging devices. Szedlmayer (1997) demonstrated that there was limited movement of red snapper with repeated locations of the red snapper at the same artificial reef suggesting high site fidelity, supporting the theory that these species recruit to these structures at a young age and remain at the structure to which they recruit.

Peabody and Wilson (2006) also assessed local residency and site fidelity by installing a number of transmitters at different platforms in close proximity to one another and also artificial reefs. The mean total length of the 125 Red Snapper fitted with acoustic transmitters was 360 mm. Of the 125 red snapper fitted with transmitters 97 were detected throughout the study. Peabody and Wilson (2006) noted high levels of short term site fidelity and high levels of site residency with 94% of the detected fish showing no movement between receiver locations on a daily, weekly or monthly basis. Site fidelity in the longer term, however was shown to be much lower than all previous studies. Peabody and Wilson (2006) hypothesise that this may be due to the close proximity of the infrastructure studied leading to a large area of depleted prey in the surrounding soft bottom, forcing red snapper to forage further afield, where they may lose sensory orientation. This would suggest that although red snapper recruit and become resident at these structures, they may migrate if they become overpopulated and foraging halos become extensive. Peabody and Wilson (2006) also conclude that attraction or production is likely not mutually exclusive and that fishing pressure at artificial reefs will likely be the ultimate determining factor on whether attraction or production processes are dominant in the Gulf of Mexico.

Gallaway et al. (2009) reviewed the suite of site fidelity studies on red snapper in the Gulf of Mexico and concluded that the relatively high site fidelity of red snapper from previous studies (when Szedlmayer 2007 mortality rates are used) demonstrate that habitat limitation is a significant factor in driving recruitment to these artificial structures, especially for aged 2-7 Red Snapper.

When assessing site fidelity and the ability for oil and gas infrastructure to increase the biomass of a species through recruitment it is important to consider long term anthropogenic pressures including fishing and any long term management measures (Peabody and Wilson 2006) as well as considering the protection these systems may offer from natural predation when assessing site fidelity and mortality rate (Szendlmayer and Lee 2004 and Piko and Szendlmayer 2007).

This may be particularly important when considering whether abundance of juveniles plays an important role in increasing abundance of the later life stages. Galaway et al. 2009 for example hypothesise that artificial reefs in the Gulf of Mexico are important for Juvenile red snapper in a period of their lifecycle when mortality is high from natural predation and by-catch from trawl fisheries, up until a time when mortality from predation decreases, which leads to an overall increase in red snapper abundance in the Gulf of Mexico.

Love et al. 2006 studied the importance of artificial reefs to the regeneration of rock fish (*Bocaccio*). Love et al. 2003 estimated that approximately 20% of the average number of juvenile rock fish that survive annually may be associated with these artificial reefs making them important when considering the re-generation of the population.

Love et al. 2006 conclude by moving away from the attraction versus production debate to an assessment of the ecological performance of fishes at these reefs through the consideration of the following:

- A comparison of the survival rate of young fishes (including predation, growth rates, and survival after emigration, if that occurs) at the two habitat types;
- The density of recruiting juveniles at a human-made reef versus that at surrounding natural reefs;
- The possibility that a human made reef is drawing recruiting juvenile fishes from nearby natural reefs; and
- The source of juvenile fishes found on a human made reef - either from the plankton or from natural reefs.

There are many studies that suggest artificial platforms provide shelter for juveniles from anthropogenic pressures (trawl fisheries) and natural predation (Galaway et al. 2009, Schroeder et al. 2005) for different species, suggesting that artificial reefs may play an important role in harbouring young of the year and juveniles. There is circumstantial evidence that reefs may not only provide protection from predation through structural refuge (crevices and cracks in the infrastructure) but also that there may be less predators and piscivoreous species associated with oil and gas infrastructure (Love et al. 2003) which enhances the recruitment at these platforms.

Several studies have also shown that young of the year rock fish recruit to platforms offshore California from plankton rather than attracting previously settled fish from natural reefs (Love et al. 2006). By analysing regional coastal currents Emery et al. 2006 also conclude that rather than filtering these pelagic juveniles away from natural reefs, that without the oil and gas infrastructure they would not have survived. This suggests there is a habitat limiting environment for rock fish offshore California and that oil and gas infrastructure not only recruits these juvenile rock fish and larvae, but that it increases the regional populations of rock fish, making them important for the overall fisheries stock.

The site fidelity of rock fish has been shown to vary with species tagged at offshore oil and gas infrastructure, with individuals being recaptured at natural reefs (Hartman 1987). However, at other platforms especially in deeper waters, including platform Gail, young-of-the-year rock fish that were recruited from larvae remain at the platform area as they mature into adults (Love et al. 2006). Love et al. 2006 speculate that the vertical nature and structural complexity of the platforms provide a strong stimulus to trigger settlement even in years where recruitment at natural reefs is low (Love et al. 2006) making them regionally significant to the rock fish fishery.

2.5. Key Findings

- It is likely that recruitment and migration processes are occurring simultaneously at oil and gas infrastructure;
- Evidence of recruitment of reef fish species was found on oil and gas infrastructure on the North West Shelf;
- Vertical orientation and structural complexity of platforms is known to trigger settlement and subsequent recruitment to lower sections;
- Evidence of larval recruitment has been found where natural habitats are scarce and also where artificial reefs are close to existing habitats (Emery et al. 2006, Danner et al. 1994);
- Site fidelity provides indirect evidence of recruitment. High fidelity rates for red snapper were found at many sites in the Gulf of Mexico (Patterson and Cowen, 2003, Strelcheck et al. 2007, Galllway et al. 2009). As mortality rates are important in assessing the site fidelity of species, accurate determination of mortality rates is important; and
- Platforms provide shelter that provides protection from fisheries and natural predation, thereby enhancing recruitment at these platforms.

3. Does biodiversity vary between infrastructure types and to what extent?

3.1. Overview

Marine biodiversity is defined variability among living organisms from all sources and includes diversity within species, between species and ecosystems. Little specific research has been undertaken on the extent to which biodiversity values vary between different types of oil and gas infrastructure. Research undertaken to date has been focussed on comparing abundance and density of specific species between different infrastructure types (Love, 2006, Pradella, 2014 and Love and York, 2005). Research on artificial reefs indicates biodiversity value does vary between difference types and the factors that influence biodiversity are; structure, depth relief, age and location, similarly to natural reefs (Ajemian et al. 2015).

For example high relief, complex reef habitat supports more abundant and diverse communities than low relief habitat. Therefore, complex three-dimensional infrastructure that projects upward into the water column (e.g. jackets) is likely to develop more diverse communities than low relief infrastructure (e.g. pipeline).

A single study was found relating to the variation of fish assemblages between infrastructure types in the North West (Pradella et al. 2014). This study undertaken at wellheads at a range of depths found that fish assemblages and density varied amongst structures. The species range was diverse ranging from small planktivorous species to large predators. These structures are likely to have provided a permanent habitat for smaller reef attached species as the closest reef is at least 100 m away (Fowler and Booth 2012).

3.2. Structure and Relief

A study undertaken in the Gulf of Mexico over a two year period (2012 and 2013) at three standing platforms and 12 artificial reefs sites (oil and gas platform toppled or partially removed) found structure significantly influenced fish assemblages (Ajemian 2015). Bermuda Chub was more dominant at standing platforms due to the greater availability of photosynthetic forage in the shallower portions of water column (Downie et al. 2013). Fish assemblages varied between standing and toppled platforms however there were no significant differences between standing and cut off platforms. This provides evidence that the community characteristics of standing platforms can be best retained by maintaining the upright orientation and high vertical relief of these structures.

The highest species richness was found at a reef platform deck with the highest counts of grey and vermilion snapper. This may be attributed to the rugosity and surface area of the platform deck. Surface rugosity is an important ecological parameter (Freidlander and Parrish 1998). Areas of high rugosity are likely to provide more cover for reef fish and more places of attachment for algae, corals and various sessile invertebrates (Mumby 2006).

The composition of benthic habitat on platforms also influences fish assemblages. A study of reef fishes inhabiting vertical strata of six production platforms and five nearby reefs over a three year period in Southern California found large macroalgae (kelps) be absent on platforms, therefore species associated with large macroalgae such as senoritas, kelp bass, kelp fishes and opaleye were relatively scare on platforms in comparison to natural reefs (Carr et al., 2003). The lower rugosity of the platform structure in comparison to natural reefs may have contributed to a lower density of species such as sheephead, longcod, gopher and black-yellow rock fishes (Carr et al., 2003).

A survey of pipelines in Southern Californian Bight found fish densities and species richness were a lot greater along the pipeline than on the seafloor (Love and York, 2005). The structure and relief of the pipeline influences the species richness. Generally the pipeline fish assemblages are similar to those that occupy low relief habitats such as cobbles, boulders and shell mounds such as rockfishes, cowcod and lingcod. Dominant seafloor species are those that characterise soft substrata in Southern California (Allen et al. 2002). Species characteristic of high relief substrata such as adult bocaccio were absent from the pipeline habitat but abundant on platforms in the area indicating that structure types do affect species abundance. Areas of the pipeline that have been undercut and harbour structure forming invertebrate such as sea anemones have a greater fish density and habitat complexity (Love and York 2005)

Carr et al. (2003) compared species composition of reef fishes inhabiting vertical strata of six production platforms and five nearby reefs over a three year period in Southern California. This study found removal of the upper portions (20-30 m) of the platform is likely to reduce the abundance of many whose depth range is restricted to that portion of the platform. Certain species may recruit as plankton to the upper portion of the water column and move to bottom depths as they get larger / older. Removal of the upper portions of the platform may prevent recruitment of these species and cause reductions or absence of these species on decommissioned platforms. Sea mussels (*Mytilus*) species are found in the upper 20 m of the water column, they provide a habitat for fishes on platforms and the mounds of shell litter provide habitat for small fishes on bottom beneath platforms. Removal of the upper 20-30 m of structure may cause reductions or loss of species that use the mounds of mussel shells that form beneath platforms as recruitment habitat, adult habitat or as a source of food (Carr et al. 2003).

A recent study on coral communities on standing vs toppled platforms in the Gulf of Mexico (Sammarco et al., 2013) found little variation in coral species density on standing vs toppled platforms; however a species specific response to toppling was found. *Tubastraea coccinea* populations seemed to thrive better on toppled platforms than on standing ones; this is because this species is known to grow well on artificial substrates such as platforms but also in disturbed habitats (Sheehy and Vik, 2010). The use of explosive to sever platforms also changes the composition of benthic species on the platform. This method dislodges numerous benthic invertebrae and kills many associated reef fish thus leaving newly available space for settlement by incoming larvae or expansion of robust surviving species such as *Tubastraea coccinea*. Other coral species such as *M. decactis* require light for colony survival and growth. These colonies existing on standing platforms that were transported to deeper, darker, cooler waters upon toppling will not survive.

3.3. Depth

Fish assemblage and abundance was found vary with depth along the height of platforms. Previous studies of standing platforms have generally separated fish communities into three distinct groups in accordance with depth; a shallow "coastal" group (0-30 m), a mid-depth "offshore" group (30-60 m) and a deep "bluewater" group (>60 m). A study of artificial reef communities undertaken over a two year period in the Gulf of Mexico found a transition between fish assemblages at different depth ranges along the Texan continental shelf (Ajemian 2015). Species such as Greater Amberjack, Vermilion Snapper and Creolefish were more dominant in deepwater. Species such as trigger fish usually common in coastal were found in shallower waters (Ajemian 2015).

Carr et al. 2003 found that fish assemblages occupying shallow (garibaldi, blacksmith halfmoon), mid depth (cabezon, copper, painted greenling, olive rick fish) and deep strata (sharpnose perch, and kelp rockfish) of platforms were distinctive (Schroeder and Love 2004, Carr et al. 2003). Vertical stratification is also related to the size and life stages of individual species, For example young of many shallow dwelling rock fish occurred only at shallower depths, whereas older stages (juveniles and adults) occurred more frequently at greater depths (Carr et al. 2003, Gallaway et al., 2009).

High densities of larger fish are usually found at platform bottoms as most platforms are rarely fished and thus act as de facto marine reserves (Love et al. 2003) and provide shelter and platforms provide shelter and feeding throughout the water column (Gallaway et al. 2009).

3.4. Age

Monitoring undertaken over a 10 year period on a purpose built artificial reef structure found a distinct shift in the species composition of benthic communities over time (Perkol-Finkel and Benayahu 2005). The study found a lower species diversity in the artificial reef compared to the adjacent natural reef indicating that the benthic community of the artificial reef was still undergoing changes and reshaping its features even 10 year post deployment.

In the first 2-10 months post deployment the artificial reef was dominated by fouling assemblages typically comprised of hydrozoans, polychaets, mollusks and sponges. This initial colonisation plays an important role in elevating the complexity of the artificial reefs substratum making it suitable for coral settlement (Schuhmacher, 1988). Thus the age of an artificial reef greatly affects the community structure as some species only recruit after initial settlers have increased the complexity of the structure making it suitable for secondary settlers (Bohnsack et al. 1991). Soft coral (*Dendronephthya hemprichi*) was observed 8 months post deployment and was the most dominant coral recruit these 2 year post deployment. The dominance of Dendronephthya may be as a result of the structure of the artificial reef that consists of an inclined surface. The inclined surface of the reef exposes it to currents that provide a constant supply of food particles such as phytoplankton (Fabricius et al. 1995), enabling year round spawning and a unique mode of colonial propagation (Dahan and Benayahu 1997).

Sponge species (*Crella cyatophora*) was found to dominate the artificial reef community by year 10. Sponges frequently occur on manmade structures in marine waters and it dominance may be the consequence of its extremely rapid growth rate particularity among newly settled individuals along with prolonged reproductive periods (Burns, 2001). Overall the artificial reef exhibited a lower coral cover and diversity to the adjacent natural reefs. This indicates that the benthic community of the artificial reef was still undergoing changes and reshaping its features even 10 years post deployment. Previous studies have found that development of an advanced benthic community takes in excess of 10 years (Perkol-Finkel and Benayahu 2005).

3.5. Location

The location of artificial reefs in relation to existing hard substrate effects species density and diversity across the reef (Jessee et al. 1985). The location of artificial; reefs in an area far from existing natural hard substances increases the presence of fish and mollusc species associated with hard substance that were previously absent in the area. The proximity of artificial reefs to existing habitats may increase the chance of transient fish encountering the reef and the artificial reef may become an extension of existing habitat with possible benefits for fish recruitment (Danner et al. 1994).

The location of platforms in offshore deeper waters appears to expose them to the recruitment of species whose young (larvae and pelagic juveniles) are delivered in far fewer numbers to shallow reefs closer to the shore. Hence higher densities of juvenile blacksmith and several rock fish species that occur throughout the water column (Carr et al. 2003).

4. Does existing oil and gas infrastructure increase marine biodiversity in a region?

4.1. Overview

Several studies have been undertaken comparing species richness and diversity on natural with artificial reefs. There is some evidence to indicate that oil and gas infrastructure supports different biological communities to natural reef habitats, thereby adding to the biodiversity within the respective regions (Rooker et al. 1997, Carr et al. 2003). However, the amount of habitat provided by oil and gas infrastructure is usually an immaterial fraction of the amount of natural reef habitat within an area. There are therefore few locations where sufficient oil and gas habitat is provided to allow the associated communities to impact on regional diversity.

4.2. Presence of Hard Substrate

The presence of oil and gas infrastructure adds hard substrate to the marine environment, supporting a great diversity of marine life by providing a habitat for fish and other invertebrates that otherwise wouldn't exist in a soft substrate environment (Van Der Stap 2016).

A recent study was undertaken on the ability of artificial reef structures to sustain populations of small reef dwelling fish in north-western Australia (Fowler and Booth 2012). The study species red-belted anthias and shallow dwelling sea goldie (*Pseudanthias squamipinnis)* are normally found on hard substrates such as coral and rocky reef outcrops. Post settlement movement of these species is generally restricted to distance of less ≤ 50 m (Forrester 1990, Frederick 1997, Turgeon et al. 2010). As the artificial reefs are located on soft substrate with no hard substratum within at least 100 m it is likely that species would not exist in this area without the presence of the artificial reefs (Fowler and Booth 2012). A survey of pipelines in Southern Californian Bight found fish densities and species richness were a lot greater along the pipeline than on the seafloor (Love and York 2005). Generally the pipeline fish assemblages were characteristic of those that occupy how relief hard substrates such as cobble and small boulders. Many of the species found along the pipeline were absent from the seafloor indicating that the hard substrate provides a habitat for fish that wouldn't normally exist in the soft substrate environment.

4.3. Depth

Several studies have found that fish species vary with height along platforms; this is discussed in detail in Section 3.

4.4. Connectivity

The presence of artificial reefs can increase the ecological conductivity of an area as the presence of artificial reefs facilitates long range larval dispersal (Macreadie et al. 2001).

A study was undertaken in the Santa Barbara channel comparing the dispersal of the non-native sessile invertebrate (*Watersipora subtoquata*) from nearshore habitats and offshore platforms (Simons 2016). The *Watersipora* has a PLD of 24 hours or less. The results of this study indicated that the dispersal distance was greater for offshore platforms than nearshore habitats. The offshore platforms are located in deeper water and thus experience enhanced dispersal due to the higher sustained flows in the offshore environment. Species with short PLDs may only disperse a short distance in the nearshore as they are exposed to slow flows during their brief planktonic stage (Simons 2016). The height *Watersipora* is released in the water column also affects dispersal distance; organisms may have short dispersal distances as they exhibit behaviour that allows them to remain close to the seafloor increasing their likelihood of encountering a suitable habitat (Simons 2016).

4.5. Complexity and Size of Structure

The extensive variability if marine life observed around oil and gas production prohibits generic predictions regarding the effects of different decommissioning options on marine biodiversity. Offshore position, depth zonations and biogeographic and oceanographic influences will all impact the ability of oil and gas infrastructure to act as an effective artificial reef. Details regarding this are discussed further in section 3.2,

Appendix C: NEBA Approach

1. Overview

1.1. Net Environmental Benefit Analysis Overview

NEBA is an approach for balancing the risks, benefits, and trade-offs between competing management options. Net environmental benefits are the gains in value of environmental services or other ecological properties attained by the action(s) minus the value of adverse environmental effects caused by the action(s). These options can include any actions that affect ecosystem service values[2] such as decommissioning options, site remedial options, oil spill response options, land management and development options, etc. In the context of offshore decommissioning, the approach is used to evaluate the net benefit of decommissioning options for offshore platforms and subsea equipment.

The NEBA approach was first formalised into a structured framework by Efroymson et al. (2003; 2004) and within these publications, it was noted that NEBA was an extension or elaboration of ecological risk assessment. They identified the key difference between the two processes as the consideration of environmental benefits, which traditional risk assessment does not incorporate. The authors of this framework included the USEPA, Oak Ridge National Laboratory, and a private consulting representative. This framework has been recognised by the National Oceanic and Atmospheric Administration (2010); the USEPA and the USEPA Science Advisory Board (USEPA SAB 2009); the Interstate Technical and Regulatory Council (2006); and the Australian Maritime Safety Authority (2010).

In Australia, the Australian government (Commonwealth of Australia 2011) has supported the consideration of the net environmental benefit analysis of decision-making as part of recommendations that, in conjunction with the Department of Environment, Water, Heritage, and the Arts and other relevant Commonwealth agencies, the Australian Maritime Safety Authority should revise the National Marine Oil Spill Contingency Plan and the National Marine Chemical Spill Contingency Plan to develop a clear plan and delivery mechanism for the provision of environmental advice, preparation and maintenance of *Net Environmental Benefit Analysis*, wildlife response and monitoring for spills where the Commonwealth is the lead agency.

1.2. NEBA Origin and Background

The incorporation of a NEBA-type process was first emphasized in decision-making for oil spill response and planning as part of the oil spill remedial efforts conducted as part of the 1990 Exxon Valdez response. The purpose of this effort was to evaluate whether a mechanised "rock -

[2] The natural resources provided by the earth's ecosystems serve as the building block upon which human well-being flows. Ecosystems represent a complex and dynamic array of animal, plant, and microbe along non-living physical elements interacting as a functioning unit. This gives rise to many benefits, known as ecosystem services, which are the benefits people obtain from naturally functioning ecosystems (Nicolette et al. 2013).

washing” technique would be used during the response actions on impacted beach areas of Prince William Sound. As a result of the NEBA evaluation, NOAA stated that there was "no net environmental benefit to be gained by shoreline excavation and washing" and that "this technology has the potential of aggravating the injury to the environment caused by the spill.” This case is important because it was one of the first projects where a remedial action was deemed to cause more harm than benefit (that is, the cure was worse than the disease) based on available scientific studies. This first NEBA is described by NOAA in a recent (2010) document associated with the Gulf of Mexico Deepwater Horizon release (NOAA 2010). Within this document NOAA references the first formalised framework for implementing NEBA (Efroymson et al. 2003, 2004). As stated above, this NEBA framework has subsequently been recognised by Interstate Technical Regulatory Council (2006) and the USEPA Science Advisory Board (USEPA SAB 2009). Subsequent recognition of the framework has been incorporated into oil spill planning and response actions for multiple incidents. Examples include the Deepwater Horizon Gulf of Mexico response (NOAA 2010) and the 2009 Montara response off the coast of Australia (AMSA 2010).

2. NEBA Approach

The NEBA approach focusses on using quantifiable metrics where possible. The metrics are used to compare and rank the net environmental benefits of the options while considering the human health risks, ecological risks, and costs associated with each option being compared. The formalised NEBA framework is depicted in (Figure A).

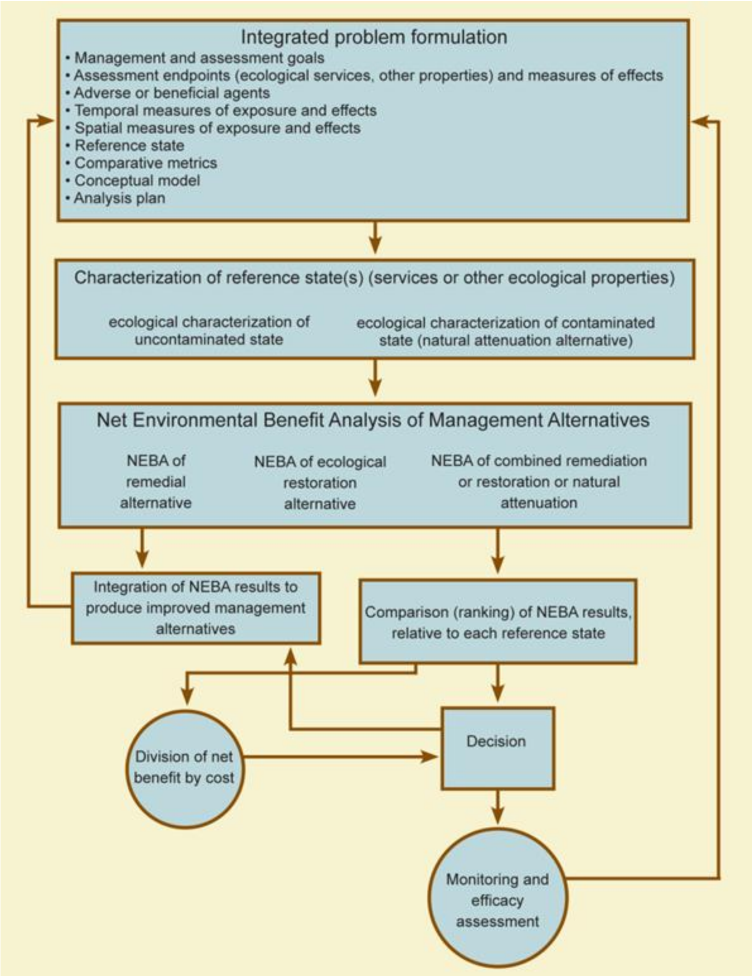


Figure A: Framework for Net Environmental Benefit Analysis NEBA (from Efroymson, Nicolette and Suter 2003) as displayed in the USEPA Science Advisory Board report entitled "Valuing the Protection of Ecological Systems and Services: A Report of the EPA Science Advisory Board"

2.1. NEBA Approach for Decommissioning

A NEBA for offshore decommissioning involves determining how multiple quantitative parameters will change given implementation of potential options. The number of options can vary and are usually bounded by the "full" removal and "no" removal options. Multiple variations between these bounding options can also be evaluated within the NEBA process. For example, a partial removal scenario (or variations thereof) can be considered as part of the process. Once the initial decommissioning options to consider are identified, then the analysis focuses on the identification and evaluation of parameters that will be used to compare between the options. The proposed options may result in physical or chemical impacts, or a combination of both. A NEBA seeks to provide an understanding of these effects so that stakeholders can make an informed decision.

By "informed," I mean an approach that is:

- Systematic;
- Transparent and understandable to stakeholders;
- Non-arbitrary;
- Scientifically-based and defendable;
- Quantitative in nature where possible;
- Based on internationally recognised concepts and approaches; and
- Considerate of all stakeholder concerns thus providing a holistic perspective to the decision-making process.

3. NEBA Considerations

NEBA incorporates the use of ecosystem service valuation concepts and methods (HEA) that have been litigation-tested and upheld in United States Federal court (United States 1997, 2001) to evaluate changes in habitat value over time. In addition, a variety of human use economics-based models can be incorporated into a NEBA to evaluate changes in human use value (recreational, commercial, aesthetic, educational, scientific, etc.) over time. A NEBA also incorporates implementation risks, chemical contamination risks, and a variety of proxy metrics (e.g. greenhouse gases) to help in differentiating between options.

The NEBA evaluation typically considers the following:

1. Ecosystem Services (including ecological risks):

- Ecological services (direct and indirect areas of influence):
  - Implementation Risks; and
  - Chemical Risk Evaluation (NORMS and/or petroleum).
- Human Use Services (recreational, commercial, aesthetic):
  - Implementation Risks; and
  - Chemical Risk Evaluation (NORMS and/or petroleum).

2. Human Health Risks:
   - Implementation Risks; and
   - Chemical Risk Evaluation.

3. Greenhouse Gas Emissions; and

4. Costs.

The NEBA approach incorporates a variety of parameters and each of these parameters has specific data needs and are discussed in detail below.

3.1. Ecosystem Services- Ecological Services

An integral part of the NEBA approach is to understand the value of ecological services being provided within the study area. Importantly, the net environmental benefits will be assessed using the current status of the environment (the project baseline) against which the potential change in environmental values associated with each of the decommissioning options will be compared.

A NEBA relies on readily available information on the ecological complexity of the existing marine habitats being provided by the subsea infrastructure to indicate the ecological value of the subsea components in their current state. If this information is not readily available, the identified data needs can be satisfied with field studies. Changes in ecological value will then be projected into the future under the different decommissioning options being considered. Different habitat values may be provided by different subsea structures. It is important to understand both the horizontal and vertical physical characteristics of the structure as the complexity of the structure may provide varying levels of protective cover and habitat for fish and invertebrates. The differences in structure physical dimensions and complexity are important when assessing the overall ecological value of different types of subsea infrastructure that could potentially be left in place.

Importantly, the ecological value provided by subsea infrastructure will be assessed within the context of natural habitat known to occur within the general vicinity of the field. Currently, it would be assumed that the natural seabed habitat is comprised of predominantly flat sediment-dominated terrain with little or no vertical structure. The NEBA would assess the natural habitat characteristics expected within the general vicinity of the Field under study as well as identifying any nearby reef areas that may provide higher value habitat. The aim is to provide an estimate of the ecological value of artificial habitat provided by the subsea structure compared to natural habitats baseline habitats to illustrate the value of maintaining artificial habitats, where they are providing valuable ecological services. The NEBA weighs these ecological services against any potential adverse impacts that may be associated with physical removal or residual contamination.

The primary method by which changes in ecological services (i.e. habitat quality) associated with the various options would be evaluated is through the use of the HEA methodology referenced earlier. Actions potentially affecting ecological services include both physical implementation impacts as well as impacts associated with chemical releases and/or residuals. The NEBA requires the evaluation of available data to select and identify an appropriate metric(s) that will represent overall habitat service flows from the environment. A NEBA should include direct habitat impacts as well as indirect impacts (i.e. influences on adjacent areas, etc.).

Because many ecological habitat services are not traded in the marketplace, they do not have a direct monetary value. The HEA approach is a service quantification approach that evaluates ecological habitat service losses and gains based on non-monetary metrics over time. It is important to recognise that ecosystem services are not static measurements but represent a flow of benefits over time. Primary applications of HEA have been associated with balancing the negative ecological habitat impacts of an action with the positive ecological habitat benefits associated with a compensatory restoration action. The balancing (i.e. equivalency) concept is based on the assumption that the public can be compensated for past and/or projected estimated losses in ecological habitat services through the provision of similar services of the same type in the future assuming the value the public places on losses and gains in ecological habitat services is the same.

This also assumes that indirect (passive and non-consumptive) values are incorporated within the ecological service value as well. While restrictive, an implication of this assumption is that it is not necessary to attempt to place a monetary value on the injured and restored ecological service flows. That is, despite the fact that HEA is an economic model, it uses ecological metrics to measure the flow of services. This provides an advantage over other methods of determining equivalent value because it can reduce the data and analysis requirements. The HEA methodology is flexible and can be adapted to individual sites and situations. The HEA methodology would be used to quantify changes in ecological service values between the identified options.

The HEA approach uses an environmental metric to measure changes to ecological habitat services and focuses on quantifying the area (e.g. hectares) and level of impact over time in units typically represented as service-hectare-years. HEA allows for service losses and gains associated with an action to be quantified in the same units so that offsetting mitigation, if needed, can be scaled equivalent to the adverse impact. The formal HEA methodology concurrently calculates both the level of impact and, given the characteristics of potential restoration, the appropriate level of restoration to compensate for those losses. However, the HEA methodology can be adapted to independently quantify either the relative impacts or benefits, independent from each other, associated with actions. It is in this manner that HEA is applied to the various options being evaluated.

Ecological service losses and gains can be measured using a variety of indicator metrics and units. In many cases, the quantification of changes in ecological service flows is based upon selecting or developing an indicator (can be one or more metrics) that acts as a surrogate to represent the ecological service flows provided over time by the habitat and expressing the changes in services (for that indicator) under the different options as a percentage change from a baseline or reference condition. Ecosystem studies, literature-based information, or a combination thereof, can be used to estimate how ecosystem services may change given an action. The metrics or indicators are selected based upon the site, habitats, and the scientific knowledge of those conducting the evaluation. The metric(s) are typically incorporated into a curve that represents the loss or gain of services over time. The available data (e.g. biological, chemical, physical, etc.) and information from the Operator or Competent Authority can be used to develop appropriate metric(s) from which to evaluate relative changes in ecological value between options.

An ecosystem service screening process is a good way to identify those parameters and metrics that a NEBA should focus on in regards to decommissioning decision-making.

Aside from a base year, the calculations involve a discount rate that allows for the gains and losses to be evaluated from a net present value standpoint. Within the HEA methodology, calculations of ecological service losses and gains associated with a project are computed over time and represent time accumulated service flows. In these cases, the units are typically displayed as a discounted service hectare year which represents an ecological habitat value. The discount rate is the rate at which the public is indifferent to consuming goods now or sometime in the future. In evaluating ecological habitat service flows, applications of the HEA methodology must account for the absolute difference in the flow of services from the ecological resources resulting from an action and how those services are distributed over time. In addition, for any given action, it is likely that the ecological habitat service loss or gain may not always be constant over time. An assessment of the shape of the various ecological habitat service flow curves over time is necessary. Quantifying the ecological service value of a given action can be conducted prior to project implementation through the use of projected metrics based on scientific data and professional judgment. Use of the HEA methodology has been incorporated into the European Union Environmental Liabilities Directive and has been upheld in United States Federal court as an appropriate method to evaluate changes in ecological habitat services associated with an action.

Data Needs

Examples of data needs required for ecological service quantification include the following:

Examples of data required for ecological service quantification include:

- Distribution, relative abundance, life span and productivity of biota in the area of impact as well as areas outside the zone of influence (segregated by areas of influence given the specific options being considered). This data may be obtained through existing ROV surveys. It is good to stratify the data by physical area and equipment type;
- Information on biological conditions of adjacent areas;
- Potential use by any Special Significance species (i.e. threatened or endangered species);
- Areas physically influenced by the actions associated with each option; and
- Areas that may be chemically influenced by the actions proposed. Modelling could be conducted to support this assessment (for example, developing and modelling chemical concentrations related to petroleum and naturally occurring radioactive material (NORMS) constituents). This data will support the evaluation of the potential for ecological risks associated with potential chemical releases and residuals, etc. This information would include:
  - The potential concentrations (and areas) and time frames over which NORMS may be released given the set of option actions;
  - Information on areas of NORMS deposits in sediments as modelled or predicted: basis, e.g. numerous studies have confirmed that concentration levels are closely related to grain size distribution of the sediments (i.e. the largest concentrations occur where the fine fractions of the sediments accumulate); and
  - Evaluation of the potential for ecological risks given the potential exposures and durations, and potential uptake mechanisms segregated by equipment type, area, etc.

3.2. Ecosystem Services – Human Use Services

Recreational

Many offshore fields may be located in areas where they can provide human use values such as commercial (e.g. harvest) and recreational values (fishing, diving, photographic, educational, etc.). From a recreational value standpoint, conducting primary economic studies to survey and count recreationists may often be infeasible given the cost and time required collecting and analysing these data. Therefore, a NEBA can incorporate estimating commercial and recreation services using benefit transfer methods.

Benefit transfer refers to methodologies that use knowledge gained from past studies regarding the value of similar services at comparable locations and employs this knowledge at a new location. There are several ways to transfer values including unit-value or mean value transfer, a benefit function transfer, and a meta-analytic transfer. Transferred values are adjusted for population, income, and other factors in order to obtain an estimate of the value at the project location. Valuation using benefit transfer methods requires quantification of recreational trips and the net change in value resulting from the project. Quantification of trip equivalents should include all the different activities available, the number of users for the different activities, and other information such as variability and seasonal use. Estimation should be adjusted for any anticipation in the change in the number of trips taken per season due to project implementation. Monetisation of direct use can be estimated by transferring per trip consumer surplus values estimated at other locations for each activity. This will involve calculating the recreational value associated with the area. The recreational value will be represented as two metrics: 1) user-days by class; and 2) the dollar value associated with each class. Estimates of recreational resource service values for the property will require estimates of the following key information:

- How many potential users?
- How often will they use this site for a particular activity?
- What is the net economic value that users hold for this activity?

Based on this information, a NEBA incorporates an estimate the net present value of the potential recreational value that the area will provide and may be influenced by the decommissioning action.

Understanding the fishing value of the field under study should include allocating time to query a limited number of local area boat marinas, and commercial and recreational fishing ventures in order to understand any potential recreational and commercial uses that are not initially considered.

Commercial Value

Estimates of the potential commercial value associated with a specific field can be developed through an analysis of the species composition, location of the field, commercial harvest rates, etc., to understand the potential surplus value of stock harvest, as well as provide an indication of stock protection value. Based on publically available data and literature, the NEBA would estimate the potential gain or loss in consumer and producer surplus from commercial fishing in the area. The areas directly around the subsea infrastructure and adjacent areas would in fact be closed indefinitely to commercial fishing as they would remain intact. It is unclear whether the impact to the commercial fishery will be positive or negative. On the one hand, there is essentially a Real Time Closure (RTC) in the area of the subsea infrastructure which prevents fishing and the potential for a loss in economic benefits (consumer and producer surplus loss). However, RTCs have been used by fishery managers in Australia and other parts of the Commonwealth (Scotland) to reduce mortalities of juveniles without a reduction in fishing effort (Marine Scotland Sciences 2013). In addition to the de facto RTC of the bottom habitat, the subsea infrastructure provides additional vertical habitat which encourages accumulation of hard structure loving organisms such as mussels, barnacles and Lophelia. These reef communities can encourage fish production so that the surrounding areas from the rig open to fishing may be more productive.

The NEBA would incorporate an estimate of the potential sustainable catch levels within the survey area and then value the producer and consumer surplus of that catch over time using existing fisheries data and literature values.

Aesthetic Value

Impacts to the gain or loss of recreational services from changes in the quality of aesthetics can be incorporated into a NEBA. These values can be estimated by using appropriate literature values to adjust the net benefit value to a visitor day. Using a benefits transfer methodology which has been developed and accepted by the primary environmental and natural resource agencies to assess recreation losses associated with natural resources, a preference calibration can be used to quality adjust these user day values due to alleged impacts. For some areas, the changes in quality may be so great that visitation rates diminish thereby implying a complete loss of recreational value. The recreational analyses are attempting to estimate the visitation rates and associated quality with the recreational experience before the event and then compare any projected decline in recreation visitation rates and quality changes after the event. The analysis would rely upon estimates provided in the affidavits of record as well as secondary sources from local, regional and national studies of recreational use.

Data Needs

The data needs required for human use service quantification include the following:

- Estimate of the number of tourists per year (and local residents) that partake in various recreational opportunities such as sport-fishing, whale watching, etc. Information by specific location is beneficial;
- Estimated of people's 'willingness to pay' to partake in any of the recreational opportunities in the area;
- Estimates of the number of subsistence fisherman in the area;
- Estimates of commercial fish catches, etc.;
- Estimates of the economic value of the fish catches (e.g. monetary revenues generated for the area);
- Ex-vessel prices for fish and shellfish species;
- Estimates of fleet size; and
- CPUE for areas similar to the subject area.

It should be noted that recreational, commercial, and aesthetic values would be independently evaluated between decommissioning options in a NEBA.

3.3. Human Health Risks

As part of a NEBA, the potential impacts of the options on human health risks would be evaluated. These risks may be related to physical implementation of each option or due to exposure to chemicals released, or projected to be released over time.

Physical risks should be evaluated in terms of the potential to cause an injury or fatality. Health and safety risks from option implementation will be preliminarily evaluated and represented as either a potential loss of life or potential injury rate.

A review of the current safety case for the field under study should be reviewed to identify risk levels to people as a result of incidents on, or in reaching, the facilities for the following cases:

- Baseline risk levels associated with the current field activities (i.e. Non-Production Phase Safety Case); and
- Identification of safety risk associated with the mobilisation, operation, and demobilisation of equipment to site (e.g. helicopters, survey vessels, ROV handling, diving support, lifting operations and other actions with a human interface) as required for each decommissioning option.

Chemical risks should be evaluated as the probability to cause an adverse effect on humans. Potential risks may arise from releases of NORMS and petroleum hydrocarbons:

- Presence of NORM scale in flowlines, and other locations; and
- Presence of residual hydrocarbons in equipment or from pipelines and wells that may lead to an oil or gas release.

Where pipelines, etc., have been disconnected and flushed, the presence of potential NORMS contamination should be considered.

Data Needs

- Safety Case Non-Production Phase, and Operating Phase (for Formal Safety Assessment (FSA) related to marine risks in the vicinity of the field, etc.;
- Transit route for support equipment (e.g. helicopters, marine vessels);
- Well Operations Management Plan (WOMP);
- NORM Survey results from pre-existing surveys, and current known equipment positions (i.e. confirmation that locations match current drawings);
- For understanding physical risks associated with each option, would need to understand the level of effort for implementation. This includes man-hours and day estimates by job category (e.g. diver, on-deck); and
- For chemical risks, would need to understand the concentrations, time intervals of releases, and exposures predicted given each option.

- The information for both NORM and petroleum hydrocarbons should include the potential for food chain transfer of chemicals to humans and an evaluation of the potential for risks to humans to exist, relative to each scenario.

3.4. Greenhouse Gas Emissions

As part of the NEBA, an understanding of the potential greenhouse gas emissions associated with implementation of each option would be used to inform the ultimate decommissioning decision.

This analysis is typically a quantitative preliminary analysis of the greenhouse gas emissions associated with implementation of each of the decommissioning options identified. The incorporation of these quantified data into the NEBA will provide an increased layer of transparency, backed by scientifically defendable methods, from which stakeholders can further support a decision regarding handling of the subsea infrastructure. Typical parameters would include the following:

Carbon Footprint - Carbon dioxide emissions (CO2 equivalents - CO2e) will be estimated for each of the options compared and, depending upon the level of effort associated with the projected options, may also include particulate air emissions:

- Air emissions from additional vehicle (e.g. barge, boat) traffic - diesel particulate matter (DPM); and
- Air emissions from dredging activity equipment and transport - fine particulate matter (PM2.5).

The preliminary carbon footprint analysis would be conducted to illustrate the importance of considering this performance metric within the NEBA framework. The carbon footprint analysis is likely to identify significant differences between the options that may not be considered without the presentation of these data in a transparent fashion. Given climate change issues globally, greenhouse gas emissions resonate with stakeholders and can influence acceptance of nominated decisions.

The following approach could be used in the greenhouse gas and particulate matter assessment:

1. Determine boundary of the assessment. The boundary will depend on each of the options being evaluated and understanding where they differ in implementation. The activities and processes will be assessed to determine in the first instance, what constitutes the physical site boundary for the study, and what facilities and activities will be included in the assessment based on various assessment methodologies;

2. Identify what data may be required to calculate greenhouse gas emissions. This may include actual and predicted fuel combustions and emissions, power generation profile, flaring regimes, ship type and operation schedule, equipment specification;

3. Determine the most appropriate methodology to calculate emissions based on available information. The methodology will depend on data availability;

4. Develop an Excel workbook for populating with fuels, facilities and activities. This workbook will incorporate any emission factors used in the calculations;

5. Collate data regarding activities being assessed. This may require modification of methodology once data is reviewed and assessed;

6. Assess the uncertainty associated with the inventory calculations; and

7. Develop a summary analysis outlining any assumptions applied.

3.5. Decommissioning Support Specific Data Needs

The emissions calculations would require a list of the types and number of equipment (boats, barges, and specialist shore-based equipment required for onshore handling for certain decommissioning options, etc.) and associated specifications such as fuel consumption, power-ratings, etc., that will be utilised to implement each option. This could also include daily run-times and length of each proposed option including kilometres travelled, etc. If this data is unavailable, consistent assumptions should be applied where necessary.

4. Decommissioning Option Costs

In addition to understanding the potential impacts that each option could have on the above-listed parameters, a NEBA also considers the estimate of the cost to implement each option. An estimate of the cost helps to understand the net benefit per unit cost and identify the point of diminishing returns on capital spent.

4.1. Examples

It should be recognised that NEBA evaluations have been conducted for well over 100 projects in multiple countries. These projects cross over several areas and include remedial actions, land management actions, restoration and mitigation actions, etc.. It has not been until recently that NEBA concepts have been applied to offshore decommissioning issues.

Given the growth in oil and gas production and the development of offshore platforms and associated infrastructure in the North Sea, Gulf of Mexico, Southeast Asia and Arctic regions, the development of approaches for decommissioning offshore facilities and infrastructure is of key importance. Within recent and developing guidelines for siting and decommissioning, sustainable development is an obligation incorporated into option decision-making. This obligation focusses on balancing the economic, environmental and social factors associated with the selected siting and decommissioning options. A NEBA approach helps decision-makers to balance the risks, benefits and trade-offs associated with competing options that focusses on the environmental, economic and social factors inherent within the potential options. The approach provides a non-arbitrary, transparent, and quantitative approach to compare between option actions using litigation-tested technical and scientific methodologies. The approach helps stakeholders to manage costs while managing site risks, creating environmental, social and economic value, and providing a demonstrable net benefit to the public (e.g. documenting environmental sustainability and stewardship).

There are a few example applications of NEBA to offshore decommissioning issues. These have been conducted off of the coast of Australia, in the North Sea, and off the coast of California. These are briefly discussed below. As these projects are "in-progress" we are limited in how much information can be provided for each site at this time.

Northwest Australia

A NEBA approach has been conducted for an offshore subsea field in northwest Australia. The NEBA examined the habitat quality of the existing field and compared the projected change in both ecological and human use value, as well as the potential for ecological and human use risks between implementation of various options. As this study is "in-progress", presentation of the results is not available at this time.

North Sea

A NEBA approach has been applied to the evaluation of a field consisting of three platforms. The analysis focused on the net environmental benefit of options to remove the cuttings piles underneath the platforms. It was determined through the NEBA that the option for dredging and removal of the sediments associated with the cuttings piles would create significant harm to the benthic community and associated fish community. The NEBA indicated that the cuttings piles should remain in place as they have become encrusted over the past 40 years with benthic community shells, etc., that have essentially entombed any contaminants in the drilling muds. Disturbance of the cuttings piles during dredging would compromise the protection of the environment by exposing the nearby communities to contaminants once the encrusting layer was compromised.

California Coast

This project was presented in a paper for the Society of Petroleum Engineers in 2008. The paper was entitled "Use of HEA to Determine the Environmentally Superior Project Alternative" (Gala et al. 2008). This project examined the stability of the shell mounds (drill cuttings piles) that would be disturbed should the decommissioning take place. As stated in this paper, "*The results of the HEA indicate that leaving the mounds in place and enhancing Carpinteria Salt Marsh provides the greatest net environmental benefit when compared with all other alternatives. Furthermore, results of the sensitivity analysis show that results of the HEA model are stable and will not experience large fluctuations from substantial changes in inputs values*".