A multi-criteria decision approach to decommissioning of offshore oil and gas infrastructure

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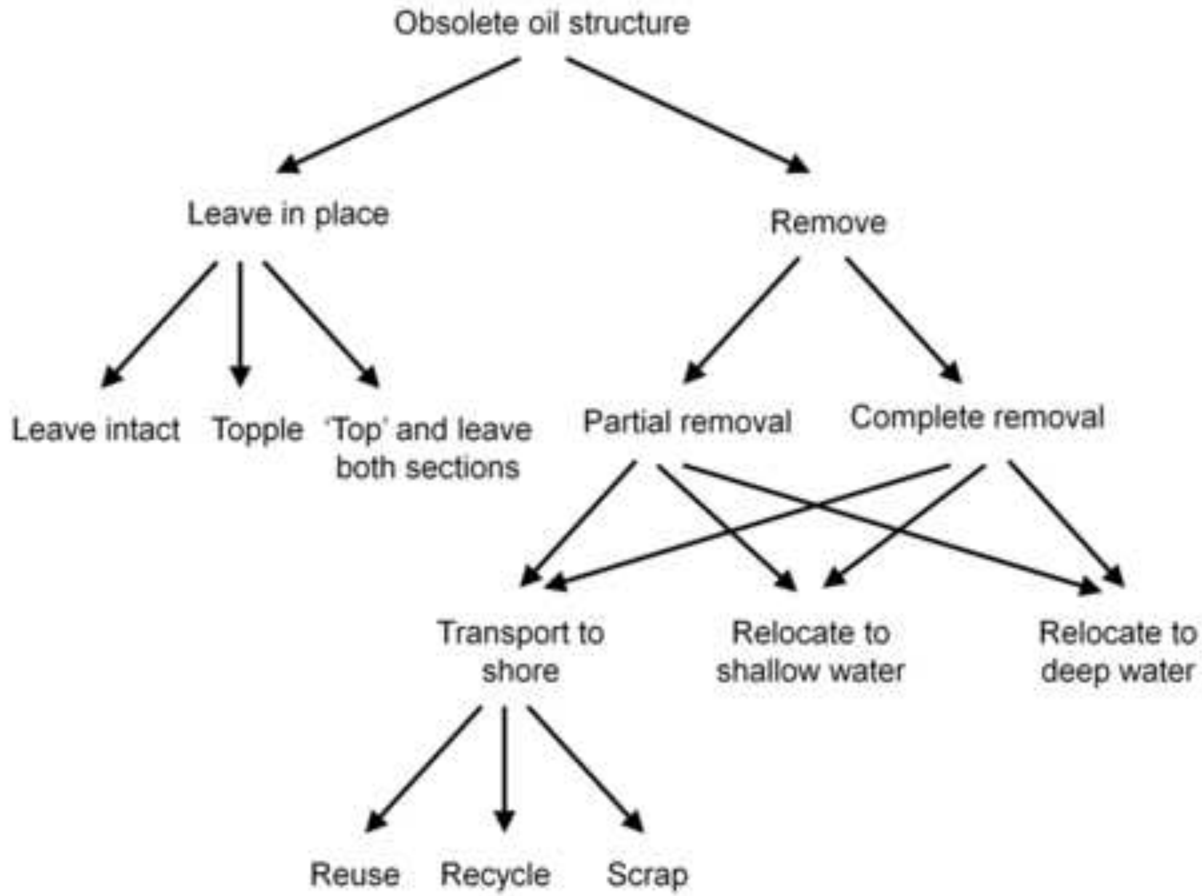
Graphical Abstract



Abstract

Thousands of the world's offshore oil and gas structures are approaching obsolescence and will require decommissioning within the next decade. Many nations have blanket regulations requiring obsolete structures to be removed, yet this option is unlikely to yield optimal environmental, societal and economic outcomes in all situations. We propose that nations adopt a flexible approach that allows decommissioning options to be selected from the full range of alternatives (including 'rigs-to-reefs' options) on a case-by-case basis. We outline a method of multi-criteria decision analysis (Multi-criteria Approval, MA) for evaluating and comparing alternative decommissioning options across key selection criteria, including environmental, financial, socioeconomic, and health and safety considerations. The MA approach structures the decision problem, forces explicit consideration of trade-offs and directly involves stakeholder groups in the decision process. We identify major decommissioning options and provide a generic list of selection criteria required for inclusion in the MA decision process. To deal with knowledge gaps concerning environmental impacts of decommissioning, we suggest that expert opinion feed into the MA approach until sufficient data become available. We conducted a limited trial of the MA decision approach to demonstrate its application to a complex and controversial decommissioning scenario; Platform Grace in southern California. The approach indicated, for this example, that the option 'leave in place intact' would likely provide best environmental outcomes in the event of future decommissioning. In summary, the MA approach will allow the environmental, social, and economic impacts of decommissioning decisions to be assessed simultaneously in a transparent manner.

keywords: decision-making; decommissioning; environmental impact; oil rig; platform; rigs to reefs

1. Introduction

The world's offshore oil and gas infrastructure is ageing (Doyle et al., 2008), and the global community is rapidly approaching a decommissioning crisis. There are currently > 7500 structures built for the hydrocarbon industry (e.g. rigs, platforms, hereafter 'oil structures') located in offshore waters, ~85% of which will become obsolete and require decommissioning within the next decade (Parente et al., 2006). Most nations require complete removal of obsolete structures, which presents substantial engineering challenges and is estimated to cost the oil and gas industry in excess of 40 billion USD (Salcido, 2005). A large proportion of this cost will be passed on to the general public through tax concessions afforded to industry (estimated 30-70% in the UK, Ekins et al., 2006). These costs are likely to have wider socioeconomic impacts owing to effects on local and regional economies.

Policies of complete removal are based on the assumption that 'leaving the seabed as you found it' represents the most environmentally-sound decommissioning option. However, we now know that oil structures are capable of developing abundant and diverse marine communities during their production lives, with some structures supporting communities of regional significance (Macreadie et al., 2011). Examples include oil platforms in the northern Gulf of Mexico that support a commercially and recreationally important red snapper (*Lutjanus campechanus*) fishery (Gallaway et al., 2009), and platforms off southern California that support substantial juvenile populations of a declining rockfish species (*Sebastes paucispinis*, Love et al., 2006). In other cases, oil structures may provide important habitat to ensure connectivity of populations, as has been speculated for the cold-water coral, *Lophelia pertusa*, in the North Atlantic (Bell and Smith, 1999). Removal of such structures is unlikely to represent best environmental practice and recognition of this has resulted in some nations leaving obsolete structures in place as artificial reefs ('rigs-to-reefs', RTR). RTR programs are extremely controversial and debate regarding their validity is ongoing in most regions (e.g. OSPAR nations, Jørgensen, 2012; Macreadie et al., 2012).

While nations consider whether to leave oil structures in place or not, we argue a broader perspective is required to achieve optimal decommissioning outcomes. Oil structures are located in a wide range of ecosystems, from shallow coral reefs through to the deep-sea. Consequently, inhabiting communities differ greatly among structures, as do the surrounding communities and habitats. It is therefore unlikely that a single decommissioning option, complete removal or otherwise, will provide optimum environmental outcomes in all scenarios. Similarly, a single option is unlikely to optimize social or economic outcomes in all scenarios. For example, RTR options are more likely to optimize social values in the northern Gulf of Mexico, where obsolete structures support an important recreational fishery (Stanley and Wilson, 1990), than in the North Sea where recreational angling on oil structures is minimal (Sayer and Baine, 2002). Numerous decommissioning options are available which fall between the extremes of complete removal and ‘leave in place’ (Schroeder and Love, 2004). A case-by-case approach to decommissioning is required where the most suitable option is selected from the full range of alternatives, based on the unique decommissioning scenario.

Selection of optimal decommissioning options represents a complex decision-making problem. Decommissioning involves many environmental impacts that differ among alternative options and decommissioning scenarios (Cripps and Aabel, 2002). Environmental aspects of decommissioning also interact with financial and socioeconomic considerations, generating complex trade-offs. The quality of data used to evaluate the performance of options varies greatly among considerations. Lastly, decommissioning decisions are extremely controversial because they affect a wide range of stakeholder groups with differing interests. Research into decision analysis indicates basic methods of decision-making (e.g.

pros and cons comparisons) are unlikely to result in optimal decisions in such complex scenarios (Kiker et al., 2005). Basic methods tend to oversimplify decision problems, losing valuable information and failing to consider conflicting objectives in the process.

Borrowing from the field of decision analysis, we propose a multi-criteria approach for making decommissioning decisions that allows identification of the best performing option across numerous selection criteria, including environmental, financial, socioeconomic, and health and safety considerations. The approach is user-friendly and readily adaptable to specific decommissioning scenarios. We outline the main components of the approach, identify major decommissioning options and provide a generic list of selection criteria required for the decision process. Given the controversial nature of decommissioning decisions, we suggest a participatory method to decision-making that includes both technical experts and stakeholder groups. A method of expert elicitation is described that can be used to assist relative performance evaluations of alternative options until sufficient empirical data become available. Lastly, we identify research that will assist in refining the method for maximum benefit. Our aim is to provide a holistic and transparent approach for optimising decommissioning decisions across the global range of decommissioning scenarios. We present information in a format that is accessible to environmental scientists, managers, and industry representatives not necessarily familiar with the technical aspects of multi-criteria decision support.

2. The multi-criteria approach to decommissioning

Multi-criteria decision analysis (MCDA) refers to a suite of methods developed to assist complex decisions, such as those required for decommissioning. These methods provide a structured and objective framework for comparing the performance of multiple options across numerous selection criteria. MCDA is particularly useful for environmental management decisions because it can incorporate the objectives of multiple stakeholder groups and handle a wide range of data types (Mendoza and Martins, 2006). MCDA has been successfully applied in forestry management (Kangas and Kangas, 2005), fishery management (Mardle and Pascoe, 1999), protection of natural areas (Brown et al., 2001), waste disposal (Merkhofer et al., 1997), and water use (Keeney et al., 1996). Oil companies are beginning to integrate MCDA into their decommissioning planning, for example Shell UK is currently using a participatory MCDA approach to develop recommendations for decommissioning of concrete storage cells in the Brent Field in the North Sea. However, the type of MCDA used is often unclear, and to our knowledge there are no studies available in the primary literature that investigate the general application of MCDA to offshore decommissioning (see Cripps and Aabel, 2002 for a case-study).

The type of MCDA should be chosen to suit the specific decision problem at hand. Most methods follow a general process: 1) decision objectives are defined, 2) selection criteria are established that reflect the objectives, 3) alternative options are identified, 4) the performance of each option is evaluated for each criterion, 5) criteria are weighted according to their importance, 6) criteria evaluations and weights are combined into an overall performance estimate for each option and 7) an option is selected based on overall performance (Ananda and Herath, 2009; Linkov et al., 2004). However, methods differ in the procedures used to execute each step and are only suitable for particular applications. A compromise must also be struck between the depth of analysis achieved and the comprehensibility of the process, particularly in scenarios involving non-technical stakeholder groups (Kangas and Kangas, 2005). Complex methods may exploit available data more completely and provide more comprehensive performance evaluations, but they are usually more difficult to understand and implement.

We propose the use of Multi-criteria Approval (MA) for decommissioning decisions. MA was specifically designed for decisions involving mixed datasets of low quality (Fraser and Hauge, 1998), and can incorporate both the qualitative (e.g. environmental impacts) and quantitative data (e.g. cost) involved in multi-criteria decommissioning decisions. Because MA is based on simple voting principles, it can also be easily understood by non-technical stakeholder groups, distinguishing it from the numerous mathematically-complex MCDA approaches available. Lastly, MA is known to favor conservative decisions that represent a compromise between vastly differing decision objectives (Kangas and Kangas, 2003). This characteristic minimizes the chance of selecting a poor option, and is likely to reduce conflict between stakeholder groups with opposing interests. The major components of an MA approach to decommissioning decisions are outlined below.

2.1 The decision matrix

A decision matrix is a two-dimensional array that lists alternative options on one axis and selection criteria on the other. It provides an explicit representation of the decision problem, and forces users to consider alternative options and selection criteria important to the decision. Once options and criteria have been agreed upon, the matrix is used to tabulate performance 'scores' for each option with respect to each criterion (see below).

2.1.1 Decommissioning options

Thirteen major decommissioning options for oil structures were identified from the literature (Figure 1, Ekins et al., 2006; Lakhal et al., 2009; Macreadie et al., 2011; Osmundsen and Tveterås, 2003; Picken and McIntyre, 1989; Schroeder and Love, 2004). Options range from complete removal and scrapping on shore through to leaving structures in place intact. Although options present as a logical hierarchy, with the primary consideration being whether or not to leave material in place, they are considered equal and treated separately during the decision process. Previous studies have considered ‘reefing’ as a separate option from other alternatives (e.g. ‘deep-water disposal’, see Schroeder and Love, 2004); however, we believe this is misleading because all options that retain structure in the marine environment may provide reef habitat, including the option to leave structures in place. The potential for structures to act as reefs should be a decision consideration for all options that retain structure, not just those designated as specific reefing alternatives.

The list of decommissioning options can be modified to suit the specific decommissioning scenario without affecting subsequent steps in the decision process. Numerous minor variations of the options presented here can be envisaged, and these can be added for specific decommissioning scenarios as required. Similarly, options that do not apply to a particular scenario can be removed from the list. Structural configurations vary greatly among types of oil structure and will dictate the range of decommissioning options available. Fewer options will be available for oil structures without substantial vertical extent, because these structures cannot be toppled or ‘topped’ (e.g. pipelines). Regulatory requirements may also prevent the use of particular options.

2.1.2 Selection criteria

The list of selection criteria is one of the most important components of the decision process because it defines what a decision will be based on (Kueppers et al., 2004). Criteria lists should be comprehensive, and reflect all considerations relevant to the decision. Decommissioning decisions involve a broad range of considerations, including potential environmental impacts, financial costs to industry, socioeconomic impacts, and health and safety concerns. Various stakeholder groups are also likely to have additional considerations that are specific to their interests; for example, coastal property owners are likely to value unobstructed ocean views (Schroeder and Love, 2004). These considerations are often overlooked during decommissioning decisions, yet are likely to be important for ensuring equality and avoiding conflict during the decision process.

We have compiled a generic list of criteria relevant to most offshore decommissioning decisions (Table 1). Although criteria lists have been proposed before, they have either focused on particular areas of consideration (e.g. environmental impacts, Cripps and Aabel, 2002), or have not provided criteria of sufficient resolution (e.g. the criterion of 'marine impacts' in Ekins et al., 2006). Criteria in the current study are grouped under major headings that assist comprehension of the decision problem for those involved. The groupings also assist identification of additional criteria that should be included. The generic list provided here should be used as a starting-point for further refinement for specific decommissioning scenarios. Because selection criteria represent the objectives of those involved in a decision, the criteria list should be refined in consultation with all stakeholders (see Implementation section).

2.2 Performance scoring and criteria weighting

The MA approach uses a dichotomous scoring system to evaluate the performance of options for each criterion. Options are either 'approved' or 'disapproved' for a criterion based on a threshold value of performance. Threshold values may be selected to reflect some minimum degree of acceptable performance for a criterion, or may simply be determined by averaging performance data across all options. The approval-disapproval process populates the decision matrix with binary performance data that serve as input for multi-criteria evaluation (see Kangas and Kangas, 2003 for an example).

The scoring system used in MA is useful for evaluating the performance of decommissioning options because it allows the use of ordinal data. Quantitative performance data are not available for most of the criteria listed in Table 1, especially environmental impacts. Approvals-disapprovals for such criteria can be based on a threshold rank, instead of a threshold value, so options merely need to be put in rank order regarding their performance for particular criteria (Laukkanen et al., 2002). Even data restricted to a few descriptive categories (e.g. ‘poor’, ‘fair’, ‘average’, ‘good’, ‘excellent’) can be utilized. Options may share a rank when their performance cannot be separated for a particular criterion. This eliminates forced separation of options when there is little actual difference in their performance. The provision for ordinal data in MA also allows uncertainty to be incorporated into the decision process. Quantitative data with high uncertainty can be transformed into ordinal data, thereby reducing the potential for erroneous distinction among alternative options. The downside of the MA scoring system is the loss of some information for criteria with quantitative data of high certainty (e.g. financial cost).

We suggest mean (or median) values be used to define performance thresholds for decommissioning criteria. Approval for criteria would therefore only occur for those options with above-average performance; a system which is consistent with optimal strategies in voting theory (Kim and Roush, 1980). Relative assessment of performance is also more appropriate for decommissioning options than set limits of performance because: 1) decommissioning must go ahead in some form, i.e. elimination of all options is not practical, and 2) performance data for many criteria are likely to be too poor to define set limits. However, if minimum performance standards were developed for particular criteria in the future (e.g. energy use), thresholds could be artificially set in these cases.

The selection criteria in Table 1 must be weighted in such a way that more important criteria have a greater influence on decommissioning decisions than less important criteria. Criteria weightings can strongly influence decision outcomes (Weber and Borcherding, 1993), and the method used to weight criteria is therefore critical to making sound decisions.

Weightings in MCDA are often based on an interval scale, where each criterion is assigned a value that reflects its relative degree of importance. For example, the Direct Point Allocation Method involves dividing a set number of points (e.g. 100) among criteria, so that a criterion with a weighting of ‘2’ could have twice the influence on the final decision than a criterion with a weighting of ‘1’ (Pöyönen and Hämäläinen, 2001), depending on the method of multi-criteria evaluation. Interval weightings imply detailed knowledge of the relationships between criteria, which is unlikely to be the case in decommissioning decision problems. For example, it is unlikely that the criterion of a ‘clear seabed’ could be said to be 3 times more important than the criterion of ‘unobstructed ocean views’. The MA approach only requires that criteria be put in rank order of importance, which incorporates a degree of uncertainty into weightings (Kangas and Kangas, 2003). Ordinal weightings are likely to be particularly beneficial for decommissioning decisions, because input from numerous stakeholders can be obtained relatively easily and cheaply, and participants are not required to make judgments that are beyond the limits of available data or their technical skill.

2.3 Overall performance evaluation

To identify the best-performing option, an overall evaluation is required that combines the performance scores for all criteria according to their respective weightings. Evaluations in MA are similar to the selection of candidates in an election. Voters in an election vote for all candidates that meet their approval, and the candidate with the most votes is selected. In MA, voters are replaced by criteria and candidates are replaced by alternative options. Essentially, the option that receives approval for the greatest number of important (highly-weighted) criteria is considered the best-performing option (Fraser and Hauge, 1998).

If no one option is approved for all criteria, or the majority of the most important criteria, a process to determine the dominant option is initiated. The performance of options is compared in a pairwise manner, starting with the highest-weighted criteria and proceeding to successively lower-weighted criteria. The performance value for one option is subtracted from the value of the other for each successive criterion. If the cumulative value of successive comparisons remains above 0, the option is said to dominate over the other (see Fraser and Hauge, 1998 for detailed methods). The underlying principle is that approval for a more important criterion can completely offset disapproval for a less important criterion. The process is repeated for all combinations of options to determine which (if any) options dominate over others. Dominance assessment can have 3 potential outcomes. Firstly, a single ordinally dominant option can be identified, which dominates over all other options. Secondly, a deadlocked scenario may eventuate, where two or more options are approved for exactly the same criteria. Lastly, the result may be indeterminate, where no option dominates over all others.

The simplicity of the evaluation method in MA relative to other MCDA approaches will increase transparency and reduce conflict regarding decommissioning decisions. Decommissioning decisions are known to be highly controversial, involving strongly opposed stakeholder groups that often view each other with suspicion and hostility. For example, the decision to dispose of the Brent Spar storage facility in the deep sea in 1995 generated such hostility from environmental organizations that the structure was eventually disposed of onshore (the Brent Spar controversy, Löfstedt and Renn, 1997). Subsequent analyses suggest that hostility arose from a miscommunication of information to stakeholder groups, rather than the actual environmental threat posed by deep sea disposal (Hamzah, 2003; Löfstedt and Renn, 1997). Because performance evaluations in MA are based on simple voting principles, they can be understood and even completed by non-technical participants in the decision process. This reduces the likelihood of data or process manipulation and engenders trust in the decision process. Other MCDA approaches (e.g.

outranking approaches) use considerably more complicated evaluation techniques in which selection among alternative options is essentially a ‘black box’ to non-technical participants (Kangas et al., 2006b).

2.4 Sensitivity

A basic understanding of how sensitive overall performance evaluations are to variations in criteria weightings and performance evaluations for individual criteria is essential for sound decommissioning decisions. The MA approach, and MCDA approaches in general, may identify a single best-performing option despite there being little actual difference in performance relative to other options (Kangas et al., 2006a). This is appropriate if input data are accurate and precise, because the best option, however marginally, is still identified. However, minor distinctions between decommissioning options are unlikely to be meaningful, given the uncertainty surrounding both criteria weightings and performance evaluation data. In the worst-case scenario, slight data error may be compounded across numerous selection criteria and result in the selection of a sub-optimal option.

A simple method for assessing sensitivity in MA decommissioning decisions would involve recalculations of overall performance (see preceding section) following systematic variations of both weightings and performance evaluations for selection criteria (see Triantaphyllou and Sánchez, 1997). This will identify critical criteria for which slight changes in weighting or performance evaluation, or both, change the outcome of overall performance evaluations, if such criteria exist. Decision outcomes in MA may be particularly sensitive to the weighting of criteria, because options may be quickly eliminated during the evaluation process if they are disapproved for a highly-weighted criterion (Kangas and Kangas, 2003). Similarly, data uncertainty that results in erroneous disapproval for a highly-weighted criterion may adversely affect decision outcomes. Identifying if decisions hinge on slight differences in particular criteria is essential for determining the robustness of decommissioning decisions and directing research effort into key areas.

3. Implementing the MA approach

3.1 Expert opinion for performance evaluations

Perhaps the greatest challenge for decommissioning decisions is the paucity of data available on environmental impacts (Macreadie et al., 2011). Research has primarily focused on impacts occurring during the active exploration and production phase, for example physical disturbance from drill-cutting discharge (e.g. Jones et al., 2012), and impacts of obsolete structures left in place, for example fish attraction-production (see Gallaway et al., 2009). Although such research is useful for predicting some impacts of decommissioning, it does not provide the level and breadth of information required for direct performance comparisons among decommissioning options across the full range of environmental criteria (Table 1). The impacts of options involving redeployment of structures are especially uncertain. Highly-regulated nations (e.g. the UK) require EIAs prior to commencement of decommissioning activities, which may yield more detailed data on potential impacts. However, these investigations are relatively short-term and site-focused. EIAs are therefore unlikely to yield information necessary for predicting longer-term impacts of decommissioning, or the numerous off-site impacts that may arise from options involving transport or redeployment of structures (e.g. redeployment in deep water). Furthermore, pre-drilling monitoring requirements for oil companies in most nations have been insufficient to ascertain environmental baselines for assessment of subsequent impacts.

Given the lack of empirical data for environmental impacts, and the increasing urgency of decommissioning decisions, we propose expert opinion be used to generate performance data for environmental criteria in the decision matrix. Expert opinion is increasingly being used in environmental decision-making where empirical data are either uncertain or unavailable (Kuhnert et al., 2010; Martin et al., 2012). Expert opinion has already been applied to a wide range of environmental problems, including spatial distribution modeling of declining species (Murray et al., 2009), assessment of climate change impacts (Morgan et al., 2001), and forestry management (Crome et al., 1996). For decommissioning decisions, independent experts in environmental aspects of oil structures could be asked to rank options according to their expected performance for each criterion, following consideration of site-specific information provided by the EIA. Independent rankings could then be combined using equal-weighted group averages, where the input from each expert is equally incorporated into a single estimate of relative performance. This method of combining expert judgments is simple to implement and capable of delivering accurate estimates relative to more complex procedures (Martin et al., 2012). In this way, expert opinion could be used to generate ordinal data for input into the decommissioning decision matrix.

3.2 Direct stakeholder participation

The MA approach to decommissioning decisions outlined in Section 2 is likely to achieve best results if stakeholders are directly involved in the process. Direct stakeholder participation is defined here as involvement in data input, as well as development of the decision model itself through contribution to model components and component interactions (following Mendoza and Prabhu, 2005). Direct stakeholder participation is increasingly being used in environmental decisions because: 1) it leads to a more holistic understanding of the decision problem, 2) decisions are more likely to be optimized for multiple stakeholders with conflicting objectives and 3) it promotes trust and acceptance of final decisions (Reed, 2008; Sheppard, 2005). Historically, decommissioning decisions have been made with either no stakeholder participation, or indirect participation, where stakeholder opinions are obtained in a qualitative way with no structured approach to their inclusion in the decision process. Such an approach is unlikely to identify all stakeholder objectives or incorporate them sufficiently into final decisions. Reduced stakeholder participation is also likely to promote mistrust in decommissioning decisions, for example, the suspicion of environmental organizations that their objectives are underrepresented.

Focus groups could be used to obtain direct stakeholder input on selection criteria and their weightings for application of the MA decision model to specific decommissioning scenarios. Oil companies routinely use focus groups to obtain stakeholder and public opinion regarding industry operations, and the following approach merely represents an extension of their application. Stakeholder representatives would be presented with the generic list of selection criteria (Table 1) and asked to propose additional criteria required to meet their specific objectives. Technical experts would then refine additional criteria to ensure they are suitable for inclusion in the decision model, i.e. new criteria must be comparable among alternative options and relatively independent of existing criteria (Gregory et al., 1993). Stakeholders would then review the new criteria list to ensure all of their objectives are represented. This process can continue iteratively until stakeholders and technical experts agree on a final criteria list (Sheppard, 2005). The only restriction required for the process is equality in the final number of criteria added by each stakeholder group, otherwise some groups may have greater influence over decisions than others (Kangas et al., 2006b). Once a final criteria list is agreed upon, stakeholders and technical experts would be asked to order criteria from most to least important. Mean weightings for criteria would then be generated by averaging ordinal preferences across all participants. This ‘public MCDA’ approach has been successfully trialed for forestry management and marine-protected area decisions with surprising agreement between technical experts and stakeholders on preferred options (Brown et al., 2001; Sheppard and Meitner, 2005).

Stakeholders could also provide performance evaluation data for selection criteria that directly relate to their objectives, and for which little technical data exist. Stakeholders are an important and often underutilized source of scenario-specific information, particularly regarding their own interests and objectives (Reed, 2008; Sheppard, 2005). Their interests may also be highly specific or difficult to quantify, and technical data is often not available for assessing the relative performance of alternative options for such criteria (e.g. recreational fishing opportunities). For decommissioning, stakeholders could be asked to order decommissioning options from best to worst regarding perceived performance for the criteria of interest, e.g. representatives from recreational diving associations could order decommissioning options with respect to the criteria of 'diving opportunities' (Table 1). This would provide ordinal performance evaluation data for inclusion in the MA decision model (see Section 2.2). Importantly, such data would directly reflect the interests of parties affected by the decision.

Some nations are already increasing stakeholder participation in decommissioning decisions. For example, for each installation nearing the end of its production life, oil companies in the UK are working directly with stakeholders to develop a decommissioning program; a document that describes the decommissioning process and is required by the regulator (Department for Energy and Climate Change [DECC]) before an installation can be decommissioned (required under the UK Petroleum Act 1998). During the development of the program, decommissioning options are communicated to stakeholders through websites, one-to-one meetings and at regular independently-coordinated stakeholder events (focus groups). Stakeholder feedback is then used to expand and refine criteria lists suggested by DECC, and this information feeds directly into decommissioning recommendations within the program. However, the process by which stakeholder input is converted into representative selection criteria is usually unstructured and undefined, raising concerns regard the equitability of the process. Additionally, stakeholders are rarely involved in weighting the importance of criteria to the decision, or evaluating the performance of options for specific criteria. A notable exception is Shell UK's incorporation of stakeholder weightings into decision models for upcoming decommissioning operations in the Brent Field in the North Sea. Explicit and equitable methods for incorporating stakeholder input into decision models such as those described for the MA approach here are required to ensure decommissioning decisions are optimized for all stakeholders.

3.3 Research requirements

Although the MA approach to decommissioning decisions can be implemented immediately, considerable environmental and decision-based research will be required to optimize the process. A greater understanding of the environmental impacts of oil structures on marine ecosystems is required to refine the list of environmental criteria in Table 1, and to understand the relative importance of these impacts to decommissioning decisions. Critical knowledge gaps include the biodiversity value of oil structures and their contribution to regional biomass (i.e. the attraction-production issue, Macreadie et al., 2011), as well as the potential for oil structures to spread invasive species (Wanless et al., 2010) and alter ecosystem function (e.g. altered trophic webs, Cowan et al., 1999). Given the increasing urgency of decommissioning decisions, a full review of environmental impacts is necessary to consolidate existing knowledge and direct research into key areas if empirical data are to be obtained in a timely manner.

Research that directly compares environmental impacts among alternative decommissioning options is required to inform performance evaluations (see Section 2.2).

Relative performance evaluations among options are currently based on predicted outcomes from general knowledge of oil structure ecosystems, rather than empirical data. For example, it is predicted that removing the top section of oil platforms ('topping', Fig. 1) in California will reduce production of rockfishes relative to an option that leaves structures intact, due to known associations of juveniles with upper platform sections (Carr et al., 2003). While such predictions appear sound, they require confirmation before the performance of alternative options can be reliably distinguished, even at an ordinal level. Manipulative experiments that examine the impacts of multiple decommissioning options simultaneously are required to determine the extent to which impacts differ among options (Schroeder and Love, 2004). Research is particularly needed for decommissioning options that are not currently employed in most nations (e.g. partial or complete relocations, Fig. 1), because impacts associated with these options are least understood. The large scale and logistical difficulties involved with an experimental approach will require unprecedented cooperation between the oil and gas industry and environmental researchers.

Trial applications of the MA approach to decommissioning decisions are required to refine methods of stakeholder participation before large-scale implementation is attempted. Although participatory approaches to environmental management decisions are expected to have numerous benefits, their application is often criticized (Mendoza and Prabhu, 2005), and growing disillusionment in the process has been reported by both technical experts and stakeholders (Sheppard, 2005). Key aspects of concern are the potential for power inequality among stakeholder groups, irreconcilable differences among opposing stakeholder groups or technical experts, or both, and 'consultation fatigue', where stakeholders perceive they are engaged in repeated consultations with little progress (Reed, 2008; Sheppard, 2005). Pilot studies will be essential for determining whether, and to what extent, these issues are involved with decommissioning decisions, as well as identifying any additional issues that may be specific to decommissioning scenarios. Pilot studies will also be important for refining effective methods of communication between technical experts and stakeholders, for example, the potential benefit of visual simulations for communication of alternative decommissioning options (Sheppard and Meitner, 2005). To our knowledge, there is no published information available on effective methods for stakeholder participation in the decommissioning process, either direct or indirect.

Research into potential sources of bias in expert opinion regarding decommissioning decisions is required to ensure the validity of performance evaluations for environmental criteria. Decommissioning is a global issue and opinions are likely to vary greatly among experts, depending on prior experiences, extent of training, and technical and personal backgrounds. Varying opinions may be beneficial to the decision process, allowing local and regional knowledge to direct decisions relevant to specific decommissioning scenarios. However, systematic biases may result in sub-optimal decisions if they are not recognized and controlled for. Given the international context of decommissioning, cultural backgrounds and language uncertainty are likely to be major sources of bias (Kuhnert et al., 2010). Methods of communication and phrasing of selection criteria may be critical for regional adaptation of the MA approach (see Kyne, 2008). Historical controversies regarding the oil and gas industry (e.g. the Brent Spar controversy in the North Sea) may also result in hindsight biases, where too much emphasis is placed on past experiences or events (Jørgensen, 2012). The controversial nature of decommissioning decisions may also lead to emotional or motivational biases, where strong perceptions of the ‘right’ answer prevent an objective assessment of alternative options.

4. Case study – Platform Grace, southern California

We conducted a limited trial of the MA decision approach to demonstrate its application to a real-world decommissioning scenario. Twenty-seven petroleum platforms are located offshore of southern California. These platforms are approaching the end of their economic lives and will require decommissioning within the next decade. The few platforms decommissioned to date have been removed, generating strong opposition from certain stakeholder groups (e.g. recreational anglers; Schroeder and Love, 2004). In 2010, a controversial bill (Assembly Bill 2503) was passed which provides legal facility for platforms to be partially left in place at the discretion of the State. This policy change increased the complexity of future decommissioning decisions by increasing the range of available options. Environmental scientists have suggested that decommissioning decisions in southern California should be made on a case-by-case basis after consideration of the net environmental benefit provided by each platform (Schroeder and Love, 2004). We considered that the MA approach would assist future decisions in this complex and contentious region.

Platform Grace was selected for this case study because it represents a common decommissioning scenario in southern California. Grace is a mid-sized platform (bottom footprint: 3120 m^2), and is located at an intermediate water depth (97 m; Page et al., 2008). A limited amount of environmental information is also available for this platform, offering a useful test of the decision approach in a data-poor scenario, while still providing at least some basis for separation of options with respect to environmental criteria. The platform was installed in 1979 and is currently active.

4.1 Implementation of the decision approach

The MA approach was used to identify the decommissioning option that would provide best environmental outcomes for Platform Grace and the surrounding area. Expert opinion was used as a data source, and the current authors were treated as a limited panel of environmental experts. The approach was therefore restricted to environmental criteria (Table 1). Although the authors are not experts in the southern Californian region, they are familiar with the primary literature available for oil structures in this region, and have each published numerous peer-reviewed articles on environmental aspects of offshore structures. Each expert was asked to: 1) rank the criteria in order of importance to the decision and 2) rank decommissioning options (from Figure 1) in order of their performance for each criterion. Criteria ranking and performance evaluations were conducted independently to reduce potential biases resulting from collaboration. Assessments took < 2 hours to complete.

Independent assessments were averaged to produce a single weighted list of criteria and a single matrix of performance evaluations. Criteria ranks were first standardized to account for differences in the total number of ranks among experts. This arose because some experts gave equal rankings to a greater number of criteria than other experts. The median rank for each criterion was then calculated from standardized values to generate the weighted list (Table 2). A single matrix of performance evaluations was produced by calculating median performance ranks for options with respect to each criterion.

Decommissioning options were 'approved' and 'disapproved' for each criterion using median performance thresholds. Options whose performance ranked higher than the median were approved, while options whose performance ranked the same or lower than the median were disapproved (Table 3). Median performance ranks were not equivalent across criteria because some criteria had a greater number of equally-ranked options than others. Approvals were assigned a value of 1, while disapprovals were assigned a value of 0. Options were then compared using the overall performance evaluation method outlined in Section 2.3 to determine the best-performing option(s). Sensitivity analysis was performed to determine how much variation in performance ranks for individual criteria was required to affect the outcome of overall performance evaluations.

4.2 Results

'Production of exploitable biomass' was identified as the most important criterion to the decommissioning decision for Platform Grace, followed by 'provision of reef habitat' and then 'protection from trawling' (Table 2). Criteria considered least important to the decision were 'habitat damage from scattering of debris', 'alteration of hydrodynamic regimes', and 'smothering of soft-bottom communities'. The criteria 'energy use' and 'gas emissions' were considered equally important, as were 'contamination' and 'spread of invasive species'. Criteria importance varied greatly among experts, for example, ranks for 'contamination' ranged from 1 through to 10 out of 14. However, criteria receiving a high median rank generally obtained high ranks from all experts (e.g. production of exploitable biomass, Table 2).

'Leave in place intact' was identified as the single best-performing option for decommissioning Platform Grace (Table 3). This was the only option approved for all environmental criteria; therefore, further pairwise analyses were not required to ascertain the dominance of this option over others (see Section 2.3; Fraser and Hauge, 1998). The options 'topple in place' and 'top and leave both sections' also performed highly, obtaining approvals for 12 out of 14 criteria, and only receiving disapprovals for criteria of low importance. Most options performed poorly, with 9 options receiving ≤ 5 approvals out of 14 (Table 3). The worst-performing options were ‘partially remove, transport to shore, scrap’ and ‘completely remove, relocate to deep water’. Both of these options were only approved for a single criteria, with the option ‘partially remove, transport to shore, scrap’ only approved for the least important criterion ‘habitat damage from scattering of debris’.

Overall evaluation results were robust to variations in both criteria weightings and performance evaluations for individual criteria. Variation in criteria weightings would not affect the selection of the option ‘leave in place intact’ as the single best-performing option, because this was the only option approved for all criteria. In such cases, the order of criteria does not influence the outcome of overall performance evaluations (Fraser and Hauge, 1998). Systematic variation of performance ranks for the top-three options indicated ranks for individual criteria would have needed to differ substantially from those obtained to alter overall evaluation results. Even decreasing the rank of the best-performing option by 1 across all criteria did not alter its outright dominance. In order for either of the two second-best options to draw level with the best-performing option, they would have required approval for two additional criteria, ‘smothering of soft-bottom communities’ and ‘habitat damage from scattering of debris’. For this to occur, options would have needed the criterion ‘habitat damage from scattering of debris’ to be ranked at least 5 ranks higher than the actual rank obtained. Approval of the criteria ‘smothering of soft-bottom communities’ would have required at least 1 rank higher than the actual rank obtained.

4.3 Implications and considerations

The case study of Platform Grace demonstrates the capability of the MA decision approach to facilitate a rapid and transparent decommissioning decision, while still integrating a wide range of considerations into the process. A single option was identified as the best-performing across 14 environmental criteria, and selection of this option was insensitive to potential variations in criteria weightings and performance ranks. The method also provided an indication of the performance of other options, with the majority of options likely resulting in poor environmental outcomes. Importantly, the approvals-disapprovals matrix allows identification of specific criteria for which an option has below-average performance. For example, the poor performance of most removal options with regard to maintenance and enhancement of marine communities (Table 3). Such information is likely to be particularly useful in scenarios where avoiding specific environmental impacts is essential.

Although there is no way to verify whether the decision is 'correct', i.e. whether the best-performing option has actually been identified, this concern applies equally to other decision approaches (e.g. heuristic methods). The current approach at least provides transparency of the overall outcome, by allowing the result to be traced back through various stages of calculation (e.g. the approvals-disapprovals stage). Additionally, the integration of opinions from multiple experts in the current approach results in a majority decision, which is likely to avoid extreme outcomes. A potential criticism of the MA decision approach is that it facilitates decisions in scenarios where empirical data could be considered too poor to allow a sound conclusion. Indeed, the approach allowed a decision to be made for Platform Grace despite incomplete environmental data. However, decommissioning decisions within the next decade will likely need to be made without adequate empirical data, owing to vast knowledge gaps regarding the environmental impacts of oil structures on marine ecosystems. Such data can be progressively integrated into the decision approach as they become available.

Application of the complete MA decision approach will be more involved than the restricted case study provided here. Our study was restricted to environmental criteria owing to the knowledge-base of available experts, and the difficulty involved in comprehensive stakeholder consultations for a specific decommissioning scenario without the assistance of the relevant industry partner. Full stakeholder consultation, as described in Section 3.2, will be required to ensure decisions incorporate the full range of relevant considerations. The expansion of the criteria list will also require consultation of a wider range of technical experts for performance evaluations. Decision outcomes for the case study may differ considerably when financial, socioeconomic, and health and safety criteria are included in the process, depending on the extent of trade-offs between conflicting criteria.

Conclusions

The multi-criteria approach outlined here addresses many of the inherent challenges involved with upcoming decommissioning decisions of offshore oil and gas infrastructure. Perhaps most importantly, it provides a way to optimize decisions despite the existence of numerous alternative options, a wide range of conflicting criteria, and data gaps. Such complex decisions present exactly the type of problem humans are ill-equipped to solve unassisted (Kiker et al., 2005). The transparency and objective nature of our approach will assist in minimizing known conflicts between stakeholder groups typically involved in the decommissioning process. Additionally, the simplicity of MA will make the approach efficient and cheap to implement relative to other more complex methods of decision analysis (Laukkanen et al., 2002). Lastly, the approach can be adapted to a wide range of decommissioning scenarios through simple adjustment of the criteria and option lists in the decision matrix. However, the approach may not be the most appropriate for all decommissioning scenarios. Considerable research will be required to determine the extent of applicability and to refine various components, especially methods of stakeholder participation and elicitation of expert opinion.

Ultimately, the shift toward a flexible and holistic decommissioning approach will be limited by the regulatory environment. Most nations currently allow few alternatives to complete removal (e.g. OSPAR nations), and the utility of the decision approach presented here will be limited until such restrictions are lifted. Although historical events have overshadowed decommissioning debates in certain regions, recent policy changes in California (passing of the 'rigs-to-reefs' bill, A.B. 2503, 2010) have indicated potential flexibility in regulatory environments. As nations broaden the range of acceptable decommissioning options, decision approaches such as that proposed will be essential for optimizing these complex problems.

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Table captions

Table 1. Selection criteria for decommissioning decisions. Criteria are not listed in a particular order.

Table 2. Ranks of environmental criteria according to their importance to the decommissioning decision for Platform Grace. Ranks are based on the opinion of 4 experts in environmental aspects of oil structures. A rank of 1 indicates highest rank.

Table 3. Approvals (1) and disapprovals (0) of decommissioning options for Platform Grace according to performance across a range of environmental criteria. Approval was granted to options whose performance was ranked above the median for each criterion. Relative performance of options was determined using expert opinion. Criteria are ordered from most important to least important, as determined by expert opinion.

Figure captions

Figure 1. Decommissioning options for obsolete oil structures.

Table 1

Environmental	Financial	Socioeconomic	Health and safety	Additional stakeholder concerns
Energy use	Mobilisation of support vessels	Taxation concessions	Navigation hazards	Commercial fishing access
Gas emissions	Personnel	Employment opportunities	Fishing hazards	Recreational fishing opportunities
Contamination	Onshore processing	Economic stimulus	Crushing accidents	Diving opportunities
Production of exploitable biomass	Landfill	Cultural impingements	Exposure to drilling mud	Clear seabed
Provision of reef habitat	Replacement of construction materials	Public access	Exposure to toxic construction materials	Unobstructed ocean views
Enhancement of diversity	Monitoring of structures left	Public sentiment		
Protection from trawling	Maintenance of structures left			
Spread of invasive species	Liability for property damage			
Loss of the developed community	Liability for personal injury			
Facilitation of disease				
Alteration of trophic webs				
Alteration of hydrodynamic regimes				
Habitat damage from scattering of debris				
Smothering of soft-bottom communities				

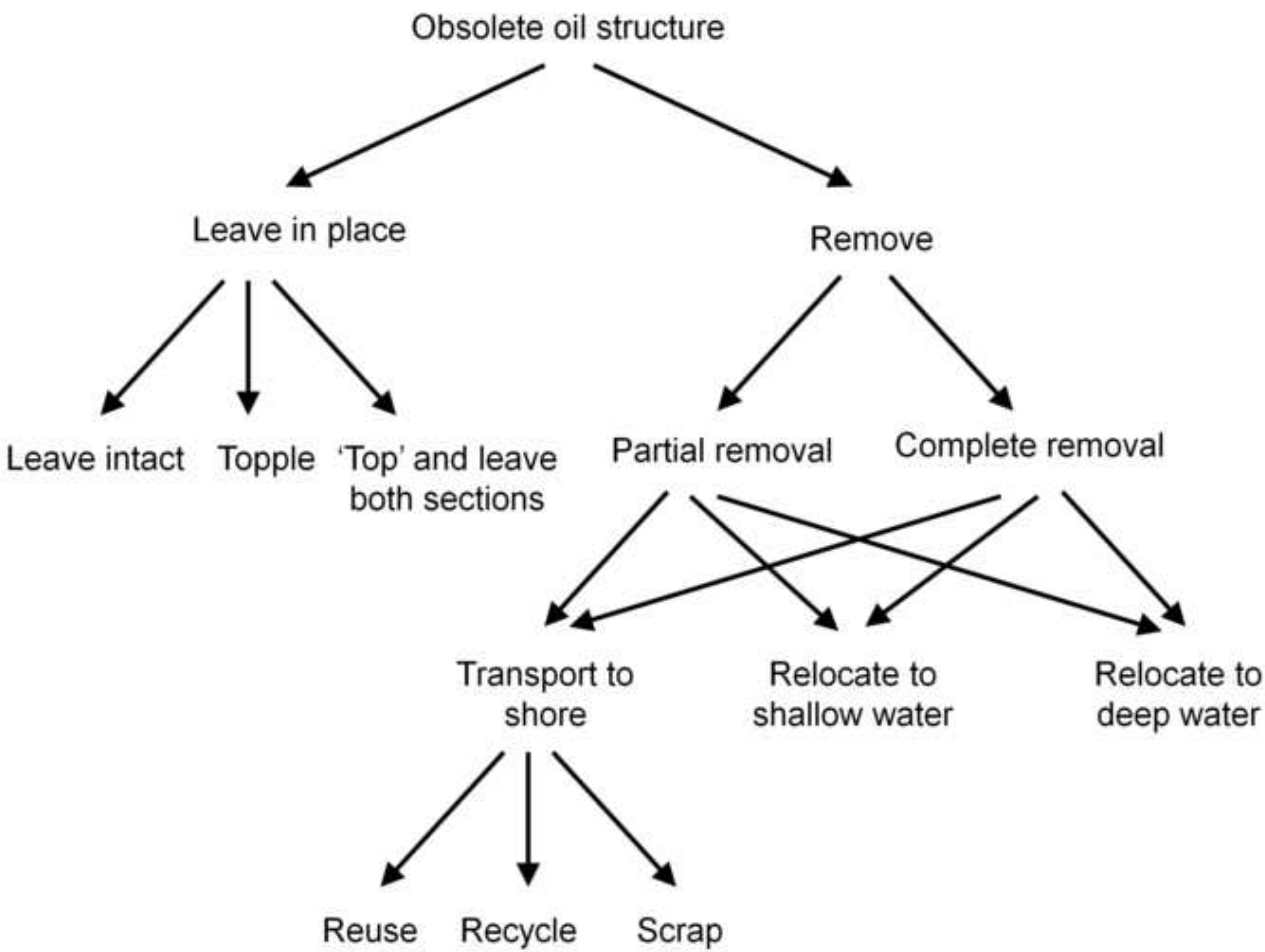
Table 2

Criteria	Ranks				Standardized ranks				Median value	Weighted list
	Expert 1	*Expert 2*	*Expert 3*	*Expert 4*	*Expert 1*	*Expert 2*	*Expert 3*	*Expert 4*		
Energy use	2	1	8	5	0.17	0.08	0.89	1.00	0.53	6
Gas emissions	1	2	8	5	0.08	0.17	0.89	1.00	0.53	6
Contamination	6	10	1	3	0.50	0.83	0.11	0.60	0.55	7
Production of exploitable biomass	4	5	2	1	0.33	0.42	0.22	0.20	0.28	1
Provision of reef habitat	7	1	4	1	0.58	0.08	0.44	0.20	0.32	2
Enhancement of diversity	8	3	5	2	0.67	0.25	0.56	0.40	0.48	5
Protection from trawling	3	7	4	1	0.25	0.58	0.44	0.20	0.35	3
Spread of invasive species	9	6	1	3	0.75	0.50	0.11	0.60	0.55	7
Loss of the developed community	5	4	6	1	0.42	0.33	0.67	0.20	0.38	4
Facilitation of disease	9	11	5	4	0.75	0.92	0.56	0.80	0.78	9
Alteration of trophic webs	9	8	5	2	0.75	0.67	0.56	0.40	0.61	8
Alteration of hydrodynamic regimes	10	11	7	5	0.83	0.92	0.78	1.00	0.88	11
Habitat damage from scattering of debris	11	9	9	5	0.92	0.75	1.00	1.00	0.96	12
Smothering of soft-bottom communities	12	12	3	3	1.00	1.00	0.33	0.60	0.80	10

Table 3

Criteria	Options: Leave in place intact	Topple in place	'Top' and leave both sections	Partially remove, transport to shore, reuse	Partially remove, transport to shore, recycle	Partially remove, transport to shore, scrap	Partially remove, relocate to shallow water	Partially remove, relocate to deep water	Completely remove, transport to shore, reuse	Completely remove, transport to shore, recycle
Production of exploitable biomass	1	1	1	0	0	0	1	1	0	0
Provision of reef habitat	1	1	1	0	0	0	1	0	0	0
Protection from trawling	1	1	1	0	0	0	1	0	0	0
Loss of the developed community	1	1	1	0	0	0	1	1	0	0
Enhancement of diversity	1	1	1	0	0	0	1	1	0	0
Energy use	1	1	1	1	1	0	1	0	0	0
Gas emissions	1	1	1	1	0	0	1	1	0	0
Contamination	1	1	1	1	0	0	0	0	0	0
Spread of invasive species	1	1	1	0	0	0	1	0	0	0
Alteration of trophic webs	1	1	1	0	0	0	1	0	0	0
Facilitation of disease	1	1	1	0	0	0	1	1	0	0
Smothering of soft-bottom communities	1	0	0	0	0	0	0	0	1	1
Alteration of hydrodynamic regimes	1	1	1	0	0	0	0	0	1	1
Habitat damage from scattering of debris	1	0	0	1	1	1	0	0	0	0
Total approvals	14	12	12	4	2	1	10	5	2	2

Criteria	Options Completely remove, transport to shore, scrap	Completely remove, relocate to shallow water	Completely remove, relocate to deep water
Production of exploitable biomass	0	1	0
Provision of reef habitat	0	1	0
Protection from trawling	0	1	0
Loss of the developed community	0	0	0
Enhancement of diversity	0	1	0
Energy use	0	0	0
Gas emissions	0	0	0
Contamination	0	0	1
Spread of invasive species	0	0	0
Alteration of trophic webs	0	0	0
Facilitation of disease	0	0	0
Smothering of soft-bottom communities	1	0	0
Alteration of hydrodynamic regimes	1	0	0
Habitat damage from scattering of debris	0	0	0
Total approvals	2	4	1


Obsolete oil structure
Leave in place
Remove
Leave intact
Topple
'Top' and leave both sections
Partial removal
Complete removal
Transport to shore
Relocate to shallow water
Relocate to deep water
Reuse
Recycle
Scrap

Ethics statement

This research did not require animal care and ethics approval, because animals were not involved in any way. The funder of this research, Chevron Australia, had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript. The authors have no personal affiliation with the funder.