Integrated Environmental Assessment and Management — Volume 11, Number 4—pp. 594–609
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A Multi-Attribute Decision Analysis for Decommissioning Offshore Oil and Gas Platforms

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(Submitted 10 October 2014; Returned for Revision 23 November 2014; Accepted 16 July 2015)

EDITOR'S NOTE:

This article represents 1 of 7 articles that investigate the biological, socioeconomic, and environmental costs and benefits of the most feasible and likely options for decommissioning oil and gas platforms offshore southern California. The articles stem from an in-depth technical analysis conducted as part of a California Department of Natural Resources project that examined decommissioning options for offshore oil and gas platforms.

ABSTRACT

The 27 oil and gas platforms off the coast of southern California are reaching the end of their economic lives. Because their decommissioning involves large costs and potential environmental impacts, this became an issue of public controversy. As part of a larger policy analysis conducted for the State of California, we implemented a decision analysis as a software tool (PLATFORM) to clarify and evaluate decision strategies against a comprehensive set of objectives. Key options selected for in-depth analysis are complete platform removal and partial removal to 85 feet below the water line, with the remaining structure converted in place to an artificial reef to preserve the rich ecosystems supported by the platform's support structure. PLATFORM was instrumental in structuring and performing key analyses of the impacts of each option (e.g., on costs, fishery production, air emissions) and dramatically improved the team's productivity. Sensitivity analysis found that disagreement about preferences, especially about the relative importance of strict compliance with lease agreements, has much greater effects on the preferred option than does uncertainty about specific outcomes, such as decommissioning costs. It found a near-consensus of stakeholders in support of partial removal and "rigs-to-reefs" program. The project's results played a role in the decision to pass legislation enabling an expanded California "rigs-to-reefs" program that includes a mechanism for sharing cost savings between operators and the state. *Integr Environ Assess Manag* 2015;11:594–609. © 2015 SETAC

Keywords: Decision analysis Decommissioning Multi-attribute utility Oil and gas platforms Rigs-to-reefs

INTRODUCTION

There are currently 27 operating oil and gas platforms in California state tidelands and on the federal Outer Continental Shelf (OCS) of southern California. They will need to be decommissioned as they reach the end of their useful oil and gas production lifetimes between 2015 and 2030 (Proserv Offshore 2010), although no decommissioning dates have yet been confirmed. Existing leases require lessees in both state and federal waters to completely remove the production facility and to restore the seafloor to its preplatform condition when production ends. However, technological advances and changes to laws and regulations in the time since most of these leases were signed have created feasible alternatives to full removal. Alternative uses range from aquaculture to alternative energy production to artificial reefs intended to preserve the biological communities supported by the platforms and enhance biological production and/or fishing opportunities.

Decommissioning these platforms involves complex tradeoffs that have become a matter of public controversy, reflecting stakeholders' differing values and perspectives. For example, platform owners and operators are concerned about the large expense of complete removal, which may exceed $1 billion (in 2009 US$) for the 27 platforms (Proserv Offshore 2010), air quality regulators are concerned about the air emissions from decommissioning activities (Cantle and Bernstein this issue). Some resource managers seek to preserve the rich ecosystems and biological production associated with platforms (Pondella et al. this issue), and some environmental advocates prefer a strict compliance approach that would hold operators to the terms of their original leases, which require complete platform removal (Bernstein et al. 2010). The strength of feeling associated with these perspectives exists against the backdrop of the disastrous 1969 Santa Barbara oil spill caused by a blowout during drilling operations on Union Oil's Platform A.

To better understand the range of decommissioning options and assess the full array of potential impacts, the California Natural Resources Agency requested the California Ocean Science Trust (Cal OST) to commission a comprehensive policy analysis (Pietri et al. 2011). We were members of the team contracted by OST to conduct the analysis (Bernstein et al. 2010). In this article, we describe the use of a mathematical decision model (PLATFORM) for the analysis and some key results and insights it provided. The model was

All Supplemental Data may be found in the online version of this article.

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DOI: 10.1002/ieam.1693

intended to broaden informed participation in decision making by enabling an integrated synthesis of a full range of competing outcomes and values and by providing all stakeholders an analytic tool that supports examination of tradeoffs across a range of decision options. A key function of the model and its companion report (Bernstein et al. 2010) was to help resolve long-standing conflicts by assembling a comprehensive, validated summary of all existing science relevant to the decisions about decommissioning. The primary audiences for PLATFORM were regulatory agency managers and staff, legislative staff, the oil and gas industry, environmental advocates, and the academic and consulting scientists supporting these various interests.

To accomplish these goals, we adopted methods from decision analysis, including

- Decision trees to identify policy strategies
- Influence diagrams to structure the analysis
- A multi-attribute utility model to represent the stakeholders' objectives and preference structure
- Probability distributions to express uncertainties
- Sensitivity analysis to explore the effect of varying assumptions, particularly the importance stakeholders ascribed to objectives

We applied these methods and conducted the analysis in a computer model, PLATFORM, implemented in Analytica (Lumina Decision Systems 2012). Companion articles in this series provide details of key scientific and economic inputs to the decision analysis, including decommissioning costs (Bressler and Bernstein this issue), impacts on fish production (Pondella et al. this issue), air emissions (Cantle and Bernstein this issue), and socioeconomic impacts (Kruse et al. this issue).

We begin by outlining the wide range of possible decisions associated with alternative decommissioning approaches and outcomes and describe how we pruned the initial large decision tree down to 2 major options (complete and partial platform removal) and a small number of variants for more careful evaluation. We then describe the key criteria or attributes used to evaluate these options. Three attributes (monetary costs, fish production, and changes to ocean access) were assessed using quantitative models, whereas other attributes (impacts on air and water quality, marine mammals and birds, benthic [sea floor] ecosystems, and strict compliance with lease agreements) were assessed on qualitative scales. We describe how the model treats uncertainty and perform an illustrative sensitivity analysis on costs. We present a multi-attribute decision framework to provide a comprehensive comparison of the decommissioning options against both quantitative and qualitative attributes. We then analyze the sensitivity of the preferred decision for each platform to stakeholder values to see how the relative importance assigned to each attribute affects the resulting recommendation, with a special focus on the controversial issue of compliance with lease requirements. We conclude with a summary of the key findings and a discussion of how this study informed the policy process. A key outcome of this process was California State Bill AB 2503, legislation that enables conversion of platforms to artificial reefs, transfer of ownership to the State of California, and sharing of the savings between operators and a public fund. Of particular interest is how this approach helped transform an issue that originally aroused considerable controversy into a policy for which there is now widespread support.

DECISION OPTIONS

Knowing the basic structure of offshore platforms is useful in understanding the decommissioning options. Each platform (Supplemental Data Figure S1) consists of 5 major sections

1. The deck structures above water, commonly called the topsides, which also include
2. Oil and gas processing equipment and piping, which must be treated separately because of potential contamination issues
3. Well conductors that are pipes from the top deck to the well (on the seafloor) for conducting drills and drilling muds down and oil and gas up for production
4. The jacket, a steel lattice structure that supports the deck and anchors it to the seafloor, and
5. Shell mounds and drill cuttings. These last are debris on the seafloor around the platform, including the fallen remains of shellfish and other marine organisms that grew on the jacket, mixed with rock fragments and mud residue from drilling operations

Potential options

Over the past decades, a number of alternatives have been proposed to the complete removal of decommissioned offshore oil and gas platforms, including their use for

- Artificial reefs, either left in place or transferred to a designated reefing location (rigs-to-reefs)
- Offshore wind energy projects, either as sites for wind turbines or as an offshore maintenance and logistics base
- Offshore wave energy projects, either as a site for anchoring wave energy generating equipment or as an offshore maintenance and logistics base
- Liquefied natural gas (LNG) terminals
- Platforms for solar panel arrays
- Aquaculture projects, either as a site for anchoring aquaculture facilities or as an offshore maintenance and logistics base
- Ocean instrumentation or tourism

Only the rigs-to-reefs option eliminates the ultimate need for platform removal. The others merely postpone the decision because the platform, even if converted to an alternate use (e.g., wind energy, aquaculture), will eventually reach the end of its structural life.

In addition to the options described above, there are several related options for disposing of platform sections removed:

- Onshore dismantling and recycling, or landfilling for platform components at shipyards in the Los Angeles or Long Beach area or elsewhere
- Placement of the clean upper jacket and lower deck structure on the ocean bottom at the base of the platform as part of an artificial reef
- Deep water disposal for jacket and lower deck structures that are not contaminated by hydrocarbons or other pollutants

These disposal-related decision options are illustrated in the upper center portion of Figure 1.

There are 3 subsidiary options. Complete removal requires a decision on whether to use explosives (instead of nonexplosive cutting methods) to sever the platform jacket and conductors, and whether to remove shell mounds or leave them in place. Partial removal may include enhancing the resulting artificial reef with quarry rock around the base of the platform. As explained in more detail by Bernstein et al. (2010) each of these decisions involves a number of tradeoffs. For example, explosives can be a cheaper method of cutting platform structures underwater but may increase risks to marine mammals. Decisions about whether to remove shell mounds (a combination of drilling muds and shell debris from biological communities living on the platform structure) that have accumulated under platforms involve a complex set of short- and long-term risks. This issue arises only for the complete removal option; partial removal will leave the platform structure near the bottom in place, thus preventing any dredging activity. Because drilling muds have become progressively cleaner over time, shell mounds are effectively capped by cleaner, newer sediments. Dredging to remove shell mounds will thus unavoidably expose deeper, more contaminated layers and increase the risk of short-term contaminant dispersal. Leaving shell mounds in place avoids this short-term risk but accepts a risk that contaminants might leach over the long term (There is no evidence to date that such leaching is occurring.) The difficulty associated with resolving these short- and long-term risks has prevented a decision about the final disposition of shell mounds remaining from the decommissioning of platforms Hazel, Heidi, Hilda, and Hope (known as the 4H project) in 1996. Complicating the issue further, many of the platforms offshore southern California are in water much deeper than any previously dredged, so that shell mound removal may not always be feasible.

Options selected for analysis

Not all reuse or disposal options are viable technologically, economically, or politically. The project's Expert Advisory Committee (EAC), made up of 15 managers, scientists, and researchers from state, federal, and local agencies, academia, and industry (Pietri et al. 2011) identified these criteria to use in screening the full suite of potential options for more detailed analysis

- Viability within a 10-y timeframe
- Existing legal framework for implementation
- Technical feasibility
- Economic viability
- Acceptability to state and federal managers from agencies with decision-making authority
- Degree of interest from proponents
- Relevance to the majority of southern California platforms

We applied these criteria qualitatively and found that options sorted clearly into the 2 categories in the prioritization column of Table 1 (Evaluated in Detail or Examined Briefly and Eliminated). Two use options (complete removal and partial removal as part of conversion to an artificial reef) and 1 disposal option (onshore dismantling) warranted detailed analysis. The analysis of the partial removal option included a suboption: placement of the clean upper jacket and lower deck structure on the ocean bottom as reef enhancement.

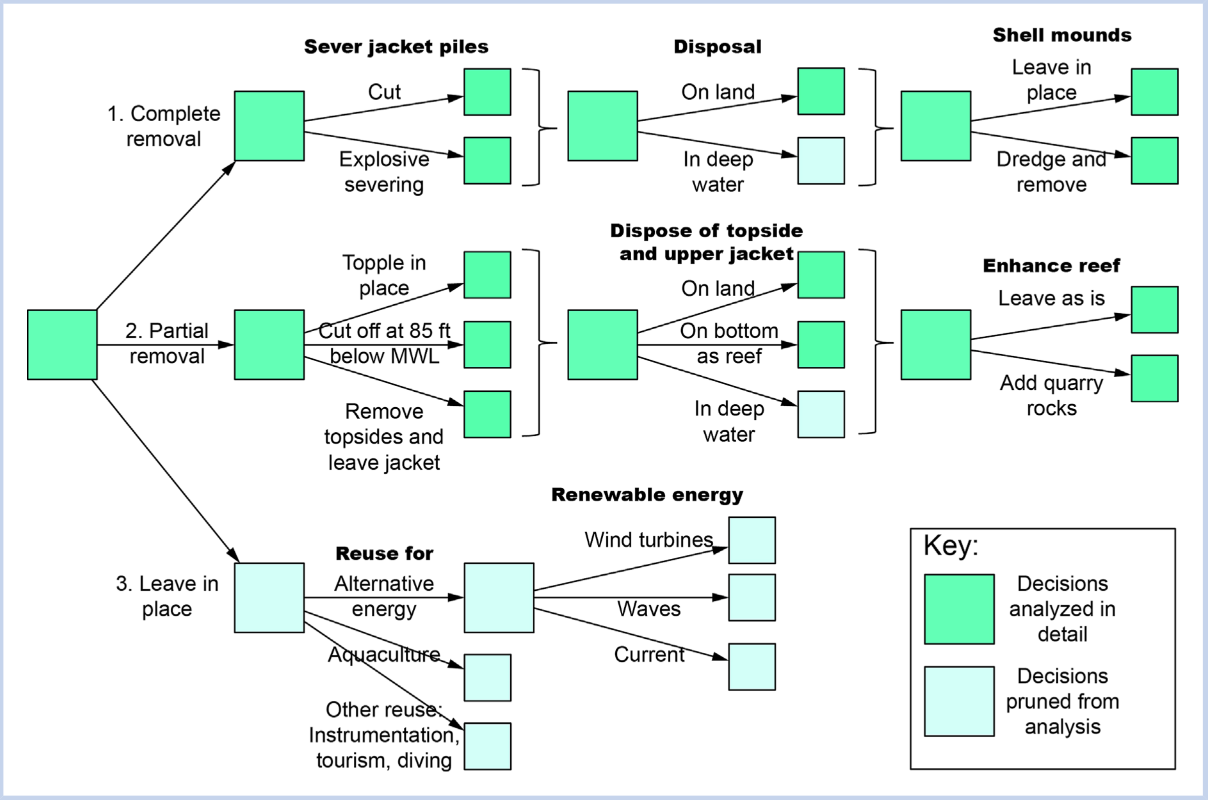


Figure 1. Decision tree showing decommissioning options considered. Options with green boxes were analyzed in greater detail, whereas options in gray boxes were omitted from quantitative analysis (see Bernstein [this issue] for more detail).

Table 1. Summary of alternative use and disposal options considered

Option	Prioritization	Pros	Cons
Alternate uses			
1. Complete removal	Evaluated in detail	• Required in leases • Highly valued by key stakeholders • Technically feasible for all platforms • Costed out in detail by MMS (now BOEM/BSEE)	• Reduces flexibility • Foregoes fiscal incentive for operators and state
2. Artificial reefing			
Partial removal and artificial reefing	Evaluated in detail	• Highly valued by key stakeholders • Abundant precedent in Gulf of Mexico • Fiscal incentive for both operators and state • Technically feasible for all but 3 state platforms • Detailed costs based on estimates for complete removal	• Restricts access to some commercial fishers • Retains infrastructure in ocean
Artificial reefing using entire platform	Examined briefly and eliminated	• Highly valued by key stakeholders • Preserves additional ecological habitat and recreational opportunities • Fiscal incentive for both operators and state	• Increased liability due to retention of surface structure makes this of much less interest to state • State managers dismissed this option for now
3. Leave for reuse			
Alternative energy	Examined briefly and eliminated	• Some preliminary interest in California and in Gulf of Mexico	• No projects implemented on platforms • Current technology not suitable for use with platforms • Not technically feasible at large majority of platforms • No current interest by project proponents • Economic viability not demonstrated
Aquaculture	Examined briefly and eliminated	• Some historical interest in California and in Gulf of Mexico	• No projects implemented on decommissioned platforms • Current technology not suitable for use with platforms • Economic viability not fully demonstrated
Others (e.g., instrumentation, hotels)	Examined briefly and eliminated		• Little interest • Economic viability not demonstrated • Current ocean instrumentation technology not suitable for use with platforms

(*Continued*)

Table 1. (*Continued*)

Option	Prioritization	Pros	Cons
Disposal			
Onshore dismantling	Evaluated in detail	• Required for deck structures containing hydrocarbons and other pollutants • Required for complete removal option (assuming no deep water disposal) • Technically feasible • Costed out in detail by MMS (now BOEM/BSEE)	• Local shipyards may be resistant because of space constraints and odor impacts
Place upper portion on bottom	Evaluated in detail	• Useful as reef enhancement under the partial removal option • Valued by key stakeholders • No objection from state or federal managers	
Deep water disposal	Examined briefly and eliminated	• Legal under federal and international law • Potential fiscal incentive for operators	• No interest among state and federal managers

Options removed from detailed analysis

Several other options did not meet threshold levels of interest from managers or demonstrate technical and/or economic feasibility over the 10-y timeframe for the analysis. As the following brief descriptions show, in each case the rationale for excluding the option was so clear cut that we judged it unnecessary to include it in the decision model. Although including them all would have made the model more complete, it would have substantially increased modeling effort and complexity, and, more importantly, would reduce its clarity for stakeholders.

Deep water disposal of offshore oil and gas platforms is legal under US (Ocean Dumping Act) and International (London Convention) law but would require extensive environmental assessments, involving comprehensive, lengthy, and expensive data collection, related to identifying and designating an appropriate disposal site. This process is much more complex than that for scuttling steel or concrete vessels at sea. Because US Environmental Protection Agency (USEPA) regulations and authority under the Ocean Dumping Act apply to any materials transported from the United States to international waters, disposal of California's offshore oil and gas platforms in international waters would not circumvent these requirements. After considering this information, staff at the California Coastal Commission and the federal Minerals Management Service (the agency's name at the time of the study) indicated they would most likely not approve deep water disposal.

An upsurge of interest in the potential of offshore alternative energy sources, primarily wind and wave energy, led to policy and regulatory initiatives to support such development, including the West Coast Governors' Agreement Alternative Energy Working Group, a federal programmatic Environmental Impact Statement (EIS) for the outer continental shelf (MMS 2007), and regulations that enable reuse of oil and gas platforms for alternative purposes (MMS 2009). For example, offshore platforms have been proposed as service and electrical interconnection hubs for offshore wind and wave farms and as potential sites for wind turbines. Despite this, there are no plans to use platforms in any wind or wave projects currently in the planning phase in either Europe or the United States. The number and location of California platforms do not match design requirements of current wind farm proposals (e.g., only 4 California platforms are in water depths <100 feet and these have poor wind energy potential) and only 4 California platforms north of Point Conception are in an area with high wave energy potential. No wave energy projects in this area currently consider the use of platforms as service sites. Similarly, designs for current and tidal energy technology projects envision large submerged turbines and oil platforms would interfere with turbine operation. The lack of serious interest by any project proponents and the mismatch between platform locations and energy potential led us to remove this reuse option from detailed consideration.

Of the several liquefied natural gas (LNG) terminals proposed for the West Coast in the past several years (California Energy Commission 2010), only one, the Clearwater Port project, included an offshore platform (Platform Grace located 12.6 miles off Oxnard, CA) in its design. Because the proposal to reconfigure the platform as a receiving terminal and build a 28-mile underwater pipeline raised serious concerns about environmental impacts, the US Coast

Guard suspended the review process in October 2007 with a request for additional analysis (California Energy Commission 2010). In March 2010, the California State Lands Commission suspended the project application for lack of activity. Meanwhile, Platform Grace resumed production in 2007 as oil prices rose. At the same time the Clearwater Port project was experiencing difficulties, a similar project in Oregon moved forward, the LNG terminal in Ensenada, Baja California became operational in 2008, and Spectra Energy continued development of a pipeline that would link natural gas supplies in the Rocky Mountain to markets on the West Coast. These alternative avenues for natural gas transport combined with the finding in 2007 that the Clearwater Port project would, "result in significant and unmitigated impacts to California's air quality and marine life" (http://www.energy.ca.gov/lng/projects.html) removed any interest in siting a LNG terminal in southern California for the foreseeable future.

Increasing demand for seafood is outstripping the resources of wild-capture fisheries. It has heightened interest in marine aquaculture to fill this demand and relieve pressure on wild fishery stocks. The United States has laid the legal and regulatory framework for offshore aquaculture in both state and federal waters (Bernstein et al. 2010). A number of projects in the Gulf of Mexico have attempted to use offshore platforms as a base for aquaculture operations. In each case, the project was abandoned due to interference from oil and gas operations, high costs, and/or permitting problems. Only 1 platform-based aquaculture project has been proposed for federal waters in California (Platform Grace), abandoned when the platform resumed production in 2007. Although there are currently 5 offshore aquaculture facilities in the United States, neither these or other similar projects elsewhere in the world make use of offshore platforms in their operations. Finally, the rapid development of new technologies for independently moored aquaculture facilities has removed the need for fixed structures such as platforms. It thus appears unlikely that any aquaculture project offshore southern California would use a decommissioned platform in the next 10 years.

Other potential options included use of decommissioned platforms as offshore hotels and as mooring platforms for elements of ocean observing systems. Although a design for an offshore hotel sited on a decommissioned platform won the 2008 grand prize for Radical Innovations in Hospitality (http://www.radicalinnovationsinhospitality.com) there have been no serious attempts to acquire platforms or permit them for this purpose. Neither of the 2 ocean observing systems in California has seriously considered using platforms for siting instruments. Large structures may interfere with measurements, and platforms are not ideally located for the pattern of measurements desired. Pruning away these options that proved to be clearly impractical or uneconomic based on initial investigation dramatically reduced the number of branches in the decision tree, making a clearer and more tractable analysis.

PLATFORM: A DECISION ANALYSIS TOOL

We developed PLATFORM as a computer model to evaluate alternative decommissioning decision strategies and the conflicting criteria (attributes) involved. Key objectives in the design for PLATFORM were to

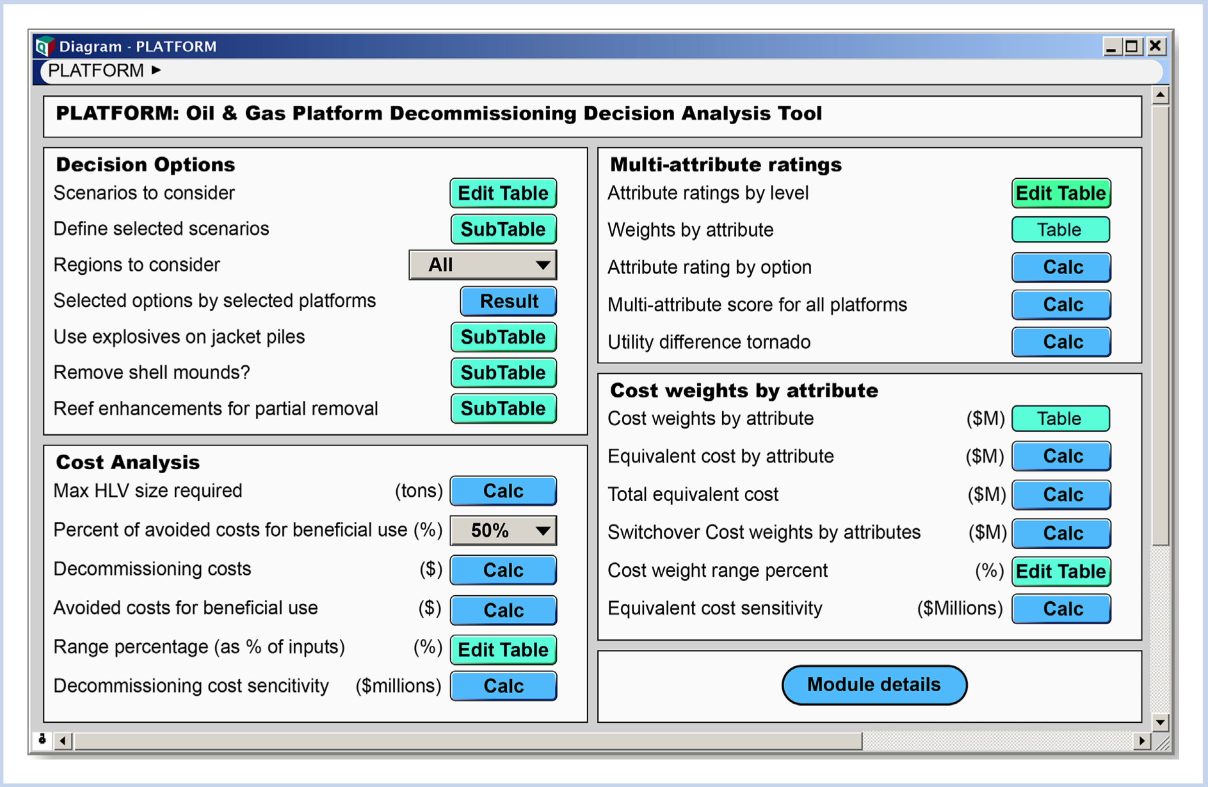
1. Provide a transparent structure for review and evaluation of the conceptual structure, assumptions, and formulas in the analysis
2. Improve the analysis team's productivity and ability to share insights across separate portions of the overall analysis
3. Support sensitivity and uncertainty analysis to identify how inputs or assumptions affect conclusions
4. Provide stakeholders a tool for interactive exploration of decision strategies from varying perspectives, especially the relative importance placed on each attribute

Model development

PLATFORM was developed in Analytica, a general purpose visual environment for building quantitative decision models (Lumina Decision Systems 2012). Figure 2 shows the top-level user interface for PLATFORM, as implemented in Analytica. The model incorporates user interfaces, a hierarchy of influence diagrams to build and organize the model, range sensitivity analysis to identify key sources of uncertainty or disagreement, and Monte Carlo simulation to analyze uncertainties. Model dimension, including platforms, decision options, scenarios, attributes, and so on, make use of Intelligent Arrays^{TM}.

The 27 platforms differ considerably in their age, size, water depth, location, and the type of biological communities present. This affects the cost and environmental effects of complete or partial removal, as well as their suitability for artificial reefing. The preferred decommissioning method may therefore vary among platforms. A key requirement for decommissioning is a heavy lift vessel (HLV)—a large ship with a crane of capacity up to 4000 tons to lift platform sections from the ocean onto barges for transport to shore. The cost to bring an HLV to California from either the North Sea or the Far East is a significant portion of the overall decommissioning cost (Bernstein et al. 2010; Bressler and Bernstein this issue). The economics dictate that multiple platforms should be decommissioned in a combined operation to share HLV transport and rental costs. The decision analysis must therefore consider entire decision strategies for some or all platforms together rather than treat each platform separately. Accordingly, PLATFORM lets users define and compare scenarios, each of which selects decommissioning options separately for one, some, or all of the 27 platforms (Table 2). Decision options include complete removal with or without explosive severing and removal of shell mounds, or partial removal with the option of adding quarry rock enhancement for the reefing option.

Model details are organized as a hierarchy of modules, each structured as an influence diagram (Figures 3 and 4). The project team's domain experts developed separate modules to estimate decommissioning costs (Bressler and Bernstein this issue), fish production (Pondella et al. this issue), socioeconomic effects (Figure 3), and air quality impacts (Cantle and Bernstein this issue) in collaboration with the project's decision modelers. Each diagram identifies key variables, including data sources, uncertainties (oval nodes), decisions (rectangular nodes), and result variables, with the influences drawn as arrows between them. For each component, the team first developed an influence diagram identifying the top level conceptual structure, and progressively added detail as necessary to complete the analysis. Thus, influence diagrams were initially purely qualitative, with detail added to structure the analysis as data gathering and evaluation progressed. Domain experts added numerical inputs and formulas to quantify the relationships expressed in each influence diagram.



PLATFORM: Oil & Gas Platform Decommissioning Decision Analysis Tool

Decision Options

Scenarios to consider	Edit Table
Define selected scenarios	SubTable
Regions to consider	All
Selected options by selected platforms	Result
Use explosives on jacket piles	SubTable
Remove shell mounds?	SubTable
Reef enhancements for partial removal	SubTable

Cost Analysis

Max HLV size required	(tons)	Calc
Percent of avoided costs for beneficial use	(%)	50%
Decommissioning costs	($)	Calc
Avoided costs for beneficial use	($)	Calc
Range percentage (as % of inputs)	(%)	Edit Table
Decommissioning cost sencitivity	($millions)	Calc

Multi-attribute ratings

Attribute ratings by level	Edit Table
Weights by attribute	Table
Attribute rating by option	Calc
Multi-attribute score for all platforms	Calc
Utility difference tornado	Calc

Cost weights by attribute

Cost weights by attribute	($M)	Table
Equivalent cost by attribute	($M)	Calc
Total equivalent cost	($M)	Calc
Switchover Cost weights by attributes	($M)	Calc
Cost weight range percent	(%)	Edit Table
Equivalent cost sensitivity	($Millions)	Calc

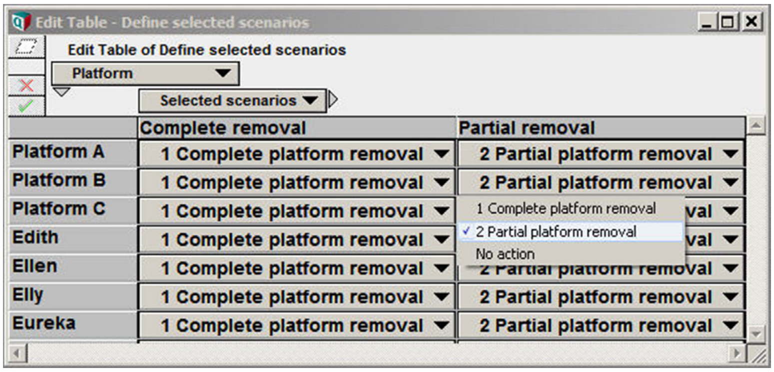
Figure 2. The main user interface for PLATFORM, with separate components to define decision options or scenarios, perform a quantitative cost analysis of the scenarios, and conduct multi-attribute analyses including all attributes.

Companion articles in this series describe the details of each of these separate analyses.

Sensitivity analysis lets users explore which uncertainties have the most effect on results and whether plausible changes in component estimates might change the preferred choice among options. Using decommissioning costs as an example, Figure 4 shows a “tornado chart“ generated by PLATFORM using Analytica’s built-in sensitivity analysis tools. It illustrates the effect on the total decommissioning cost for Platform Gilda of changing each cost component from a low value (−25%) to a high value (+25%), holding all other components at their base value. The input variables are sorted from most sensitive (widest bar) at the top to least sensitive at the bottom, giving the characteristic “tornado“ look. The most sensitive variable is the cost of platform and structural removal, not surprising given that it is the largest cost element in the entire decommissioning process (Bressler and Bernstein this issue).

Continuing with the cost example, it is useful to treat uncertainties about decommissioning costs using probability distributions. Studies of 40 decommissioning projects involving 120 structures from 1994 to 2005 found that actual costs averaged approximately 12% higher than estimated costs, with a geometric standard deviation of 23% (Byrd et al. 2014). Assuming that similar bias and variation would apply to the California platforms, we applied an uncertainty factor to costs using a lognormal distribution with median of 1.12 and geometric standard deviation of 1.23. Figure 4 shows the resulting uncertainty about costs for complete removal and partial removal for Platform Henry.

Table 2. Defining a scenario by selecting an option for each platform



Edit Table of Define selected scenarios

Platform

Selected scenarios

	Complete removal	Partial removal
Platform A	1 Complete platform removal	2 Partial platform removal
Platform B	1 Complete platform removal	2 Partial platform removal
Platform C	1 Complete platform removal	val
Edith	1 Complete platform removal	val
Ellen	1 Complete platform removal	2 Partial platform removal
Elly	1 Complete platform removal	2 Partial platform removal
Eureka	1 Complete platform removal	2 Partial platform removal

1 Complete platform removal
✓ 2 Partial platform removal
No action

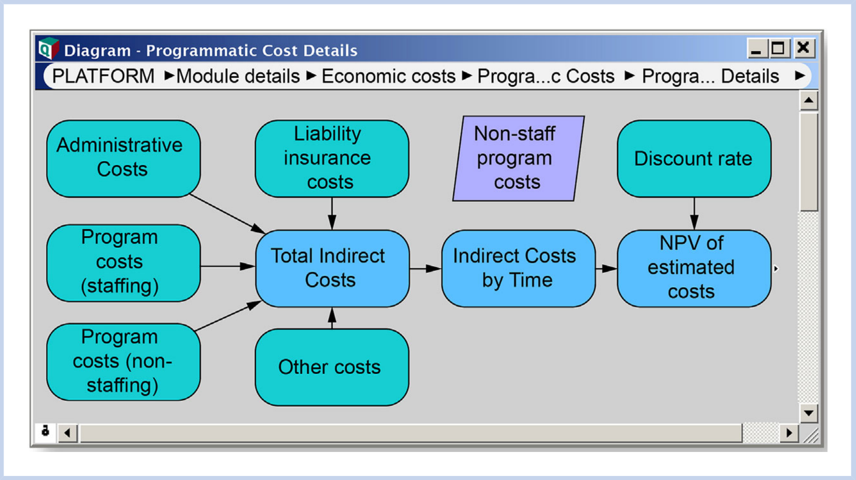


Figure 3. An Analytica influence diagram showing selected variables and influences involved in calculating the programmatic costs for decommissioning (see Bernstein and Bressler [this issue] for additional detail). NPV = Net Present Value.

STRUCTURING MULTIPLE OBJECTIVES OR ATTRIBUTES

Like many public policy decisions, platform decommissioning is complicated by multiple conflicting objectives (attributes) and stakeholders' differing views about their relative importance. To ensure we captured key stakeholders' major objectives, we reviewed the extensive literature and history of this topic (Bernstein et al. 2010) to create an initial list of concerns. We then refined and confirmed these attributes with the project's Expert Advisory Committee We supplemented the committee's input with our own outreach to parties to past decommissioning projects in government, consulting, academia, and conservation organizations. Based on this input, we organized the objectives as the 8 attributes shown in the influence diagram in Figure 5 (each node is a module in PLATFORM containing additional detail, as in Figures 3 and 4) and described in Table 3.

Some attributes, such as cost, can readily be quantified. Others, such as impacts on marine mammals, are difficult to quantify due to inadequate data and/or incomplete understanding of causal processes and are therefore assessed and scored in narrative terms. All too often, analyses focus on those attributes that can be quantified easily, even though other harder-to-quantify attributes may be of equal or greater

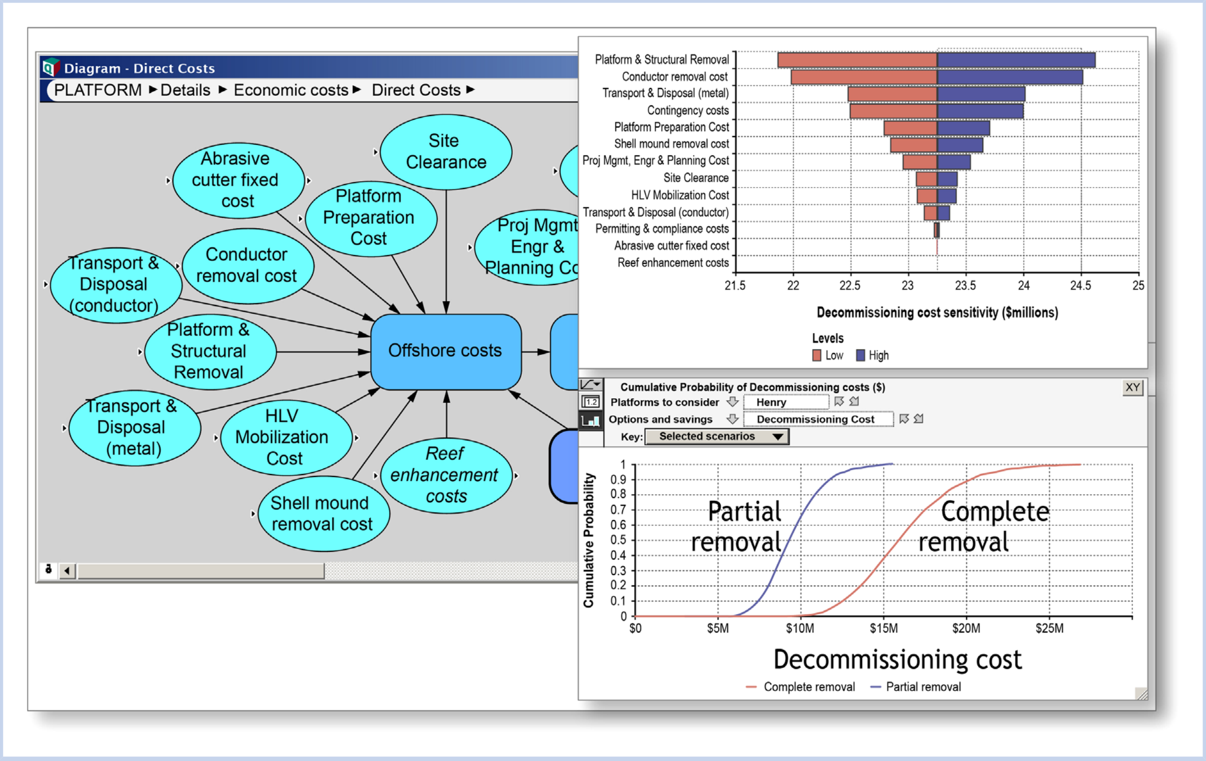


Figure 4. A composite figure illustrating (**1**) an influence diagram for the module that estimates direct decommissioning costs (left portion). The oval nodes depict key uncertain quantities that affect total cost (see Bernstein and Bressler this issue for additional detail). (**2**) A Tornado chart (upper right portion) showing the range sensitivity of the decommissioning cost for complete removal of Platform Gilda. Each bar shows the effect on total cost of modifying each selected cost variable from low to high value (±25% around their base value), while keeping the other variables at their base values. (**3**) Uncertainty about decommissioning costs for complete removal and partial removal for Platform Henry shown as cumulative probability distributions (lower right portion).

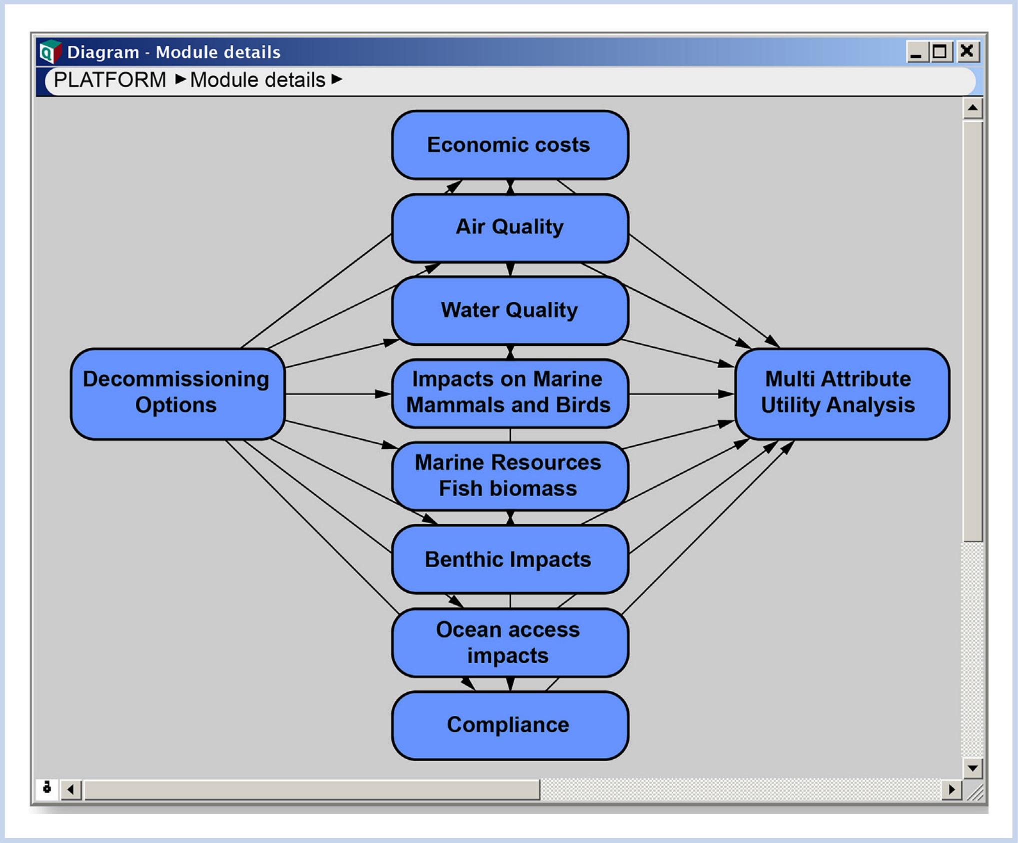


Figure 5. Influence diagram showing how the multi-attribute analysis is based on the results of analysis of the 8 key attributes is used to evaluate the costs and benefits of alternative decommissioning options.

importance. In this study, we used a multi-attribute framework to treat all identified attributes, whether quantitative or qualitative, as potentially important to any stakeholder. Table 3 summarizes these attributes, and how they were treated.

The "Strict Compliance" attribute is a special case because it reflects a categorical preference for 1 option (complete removal) rather than a gradient of costs–benefits (e.g., impacts on marine mammals). We included this attribute because it acts as a surrogate that captures a number of related issues that are difficult to quantify, such as potential residual risk to animals and ecological processes from remaining debris, potential interference with natural ecosystem processes, potential risk of long-term pollution from shell mounds, and potential reduction in resilience of the marine ecosystem from additional, long-term, cumulative impacts. This strongly held preference is often expressed as some form of a precautionary principle that requires "cleaning up" after human activities in the ocean wherever possible. Because this attribute has had such a strong influence on decisions about decommissioning and artificial reefing, we believed it important to include it in the decision model.

Multi-attribute decision analysis

Multi-attribute utility theory (MAUT) provides a principled approach to evaluate decisions under uncertainty on multiple objectives or attributes based on von Neuman and Morgenstern decision and utility theory (Keeney 1968; Fishburn 1970; Keeney and Raiffa 1976). It provides ways to represent a person's preferences over alternatives characterized by n uncertain attributes, $(x_1, x_2, \ldots x_n)$ as a scalar utility function $U(x_1, x_2, \ldots x_n)$. Additive independence means that a person's preferences show no interactions among attributes—preferences over values of one attribute are not affected by the level of other attributes. For example, preferences over levels of impact on marine mammals should be independent of decommissioning costs. Additive independence is often a reasonable approximation to people's preference structures with limited uncertainty. Informal discussion with selected stakeholders suggested that it is a reasonable assumption in this case. Additive independence allows decomposition of the aggregate utility function into a simple weighted sum of attribute-specific utilities (Keeney and Raiffa 1976)

$$U(x_1, x_2 \ldots x_n) = \sum_{i=1}^{n} w_i u_i(x_i). \quad (1)$$

The multi-attribute utility $U()$ and single-attribute utility functions $u_i(x_i)$ are constrained to be in the range 0 to 1, and the weights normalized to sum to 1

$$0 \leq U(x_1, x_2, \ldots x_n) \leq 1, 0 \leq u_i(x_i) \leq 1, \sum_{i=1}^{n} w_i = 1. \quad (2)$$

This assumption lets us assess the utility function for each attribute separately from each other and from the weights used to combine them into a multi-attribute utility function. Applying this approach involves these steps

1. Identify and organize attributes (as described above)
2. Define a clear scale for each attribute, either cardinal, meaning quantified, as in US$ for direct costs, or ordinal, meaning a list of outcomes in order of preference
3. Define a single-attribute utility function to score the possible levels of each attribute into a utility from 0 (worst outcome) to 100% (best outcome)

Table 3. Summary findings and characteristics of the 8 attributes included in the multi-attribute analysis

Attribute description	Characteristics and methods	Reference
Costs: The direct costs of decommissioning, including acquiring required permits, obtaining equipment such as heavy lift vessels (HLVs), cutting up the platform, removing some or all parts, transporting them to a disposal or recycling site, and processing removed equipment; programmatic costs included for reefing option	• Actions identical in both options (e.g., deck removal) did not affect choice of option and were excluded from analysis • Quantified in US dollars (2009) based on official MMS cost estimates for each component of the decommissioning process • Detailed costs estimated separately for each platform • Model assigns HLV and its costs based on size and weight of platform components • Model allows user to specify either complete or partial removal and all relevant suboptions for each platform individually	Bressler and Bernstein this issue
Air quality: Much of the equipment used to dismantle, lift, and transport the elements of the platform runs on fossil fuel, usually diesel, emitting CO_2 and criteria pollutants; only on-site emissions during decommissioning project are considered, excluding emissions from transit of HLVs from the North Sea or east Asia	• Quantified only for worst case, the largest platform (Harmony) • Air emissions estimated for range of pollutants (e.g., CO_2, CO, NO_x, PM10, PM2.5) • Emissions estimates based on diesel engine fuel and operating characteristics for specific HLV needed forHarmony decommissioning, as well as other major equipment required • Operating hours based on MMS decommissioning project specifications for southern California • Qualitative estimates for other platforms based on size comparison with Harmony	Cantle and Bernstein this issue
Water quality: Removal of platforms, oil and gas processing equipment, and dredging of shell mounds and debris below the platform may have some impact on water quality due to dispersal of contaminants	• Qualitative based on relative risk of spills, dispersal, past monitoring studies • No formal modeling used; scoring based on narrative description of best-to-worst case possible outcomes	Bernstein et al. 2010
Marine mammals: Seals, sea lions, and other marine mammals often visit platforms due to the local concentration of fish; complete removal of platforms will remove this food source; removal of platforms, especially if explosives are used to sever steel supports, may disturb or injure marine mammals in the vicinity	• Qualitative based on potential use of explosives, relative amount of vessel traffic, behavior and migration patterns, past monitoring studies • No formal modeling used; scoring based on narrative description of best-to-worst case possible outcomes	Bernstein et al. 2010
Marine birds: Marine birds use platforms for roosting, enabling them to feed with shorter flights than from onshore roosting; at the same time there are some fatalities from flight collisions with platforms; both options will remove surface structures, thus having the same impact on birds	• Qualitative based on past monitoring studies • No difference between options, therefore did not affect choice and was not examined in detail or modeled	Bernstein et al. 2010
Benthic impacts: The benthic zone is the ecological region on the seafloor, including surface and subsurface sediments; complete removal of platforms will have some impact from anchoring the HLV, extracting the jacket piles, piping, and cabling, and dredging or covering the shell-mounds; partial removal will have much smaller impacts on the benthos	• Qualitative based on relative size of platform and shell mound, relative degree of disturbance, past monitoring studies • No formal modeling used; scoring based on narrative description of best-to-worst case possible outcomes	Bernstein et al. 2010
Fish productivity: Biological productivity around the platforms provides sustenance for fish, including rockfish, some of which are "listed" species and others of which are of value to fishermen, and is an attraction for recreational divers; complete removal will remove all such habitat and reduce productivity; partial removal will not reduce rockfish productivity because recent studies show that larvae settle below the level (85 feet below the sea surface) at which the platform structure would be removed in the partial removal/artificial reefing option	• Quantified as Kg/y by platform for the several platforms with fish monitoring data • Spatially explicit model used monitoring data to estimate fish abundance and population structure in different depth zones • Data on platform structure was used to estimate fish density per structure area and to define habitat zones • Monitoring data supported estimates of larval settlement • Quantitative model produced estimates of growth, reproduction, mortality, and production in Kg/y for each depth zone at each modeled platform • Data gaps prevented quantitative modeling of the regional impacts of platform-associated fish production	Pondella et al. this issue

(*Continued*)

Table 3. (*Continued*)

Attribute description	Characteristics and methods	Reference
Ocean access: Partial removal option increases ocean area accessible for shipping and some fishing vessels, but reduces or leaves unchanged access to other user groups; value of each option depends on the specific user group	• Quantified changes to access in square nautical miles for each option and each of 5 user groups (recreational and commercial fishing, nonconsumptive boating, nonconsumptive diving use (SCUBA), shipping • Estimated economic value for nonconsumptive diving; data gaps prevented quantitative estimation for other uses • Classified user group preferences as pro, con, or neutral for each option; different commercial fishing gear groups had different preferences • Data gaps, large uncertainties, and small size of impacts relative to local economy restricted analysis to the immediate vicinity of platforms	Kruse et al. this issue
“Strict compliance”: The original oil and gas leases required lessees to remove the platforms entirely at the end of their productive life and restore the seafloor to its original condition; used as a surrogate for a broader set of perspectives related to stewardship, environmental restoration, minimization of long-term pollution risk	• Categorical based on requirement for strict compliance or willingness to consider other options • Some environmental groups view this objective as paramount • No modeling or other analysis involved	Bernstein et al. 2010

Note that the analysis focused on identifying the difference between the complete and partial removal options across all 8 attributes.

4. Select swing weights (or equivalent costs) to model stakeholder preferences about relative value or cost for each attribute from which to obtain weights w_i using the SMARTS method (see the next section for details)
5. Combine the swing weights and attribute scores into an overall multi-attribute utility for each decision option

For the qualitative attributes, we developed a 5-point scale, ordered from the worst to best outcome plausibly possible for any platform. Intermediate points are labeled poor, medium, and good. Table 4 shows an example for rating potential impacts on marine mammals. It describes levels, from the worst—“Disturbance, disorientation, and possible mortality“—to the best—“No impact.“ It also identifies the corresponding decision option that might produce each outcome—from “Complete removal with explosive severing“ for the worst level, to “No action“ for the best level. The last column in Table 4 specifies the score for each level as a utility between 0% and 100%. By definition, the worst and best outcomes are scored at 0% and 100%, and so are not modifiable. Users of PLATFORM may select scores between 0% and 100% for each intermediate level (as illustrated in Table 4). Users may think about assessing the score for an intermediate level x} as the probability p that would make them indifferent between level x} and a lottery with probability p of the best outcome and probability $(1 - p)$ of the worst outcome.

Table 5 defines the scale and provides scores for the strict compliance attribute. In this example, the user specified a score of 0% for the medium level—the same as the worst level—viewing it as just as noncompliant with the lease agreement, because it leaves part of the platform and the shell mounds in place.

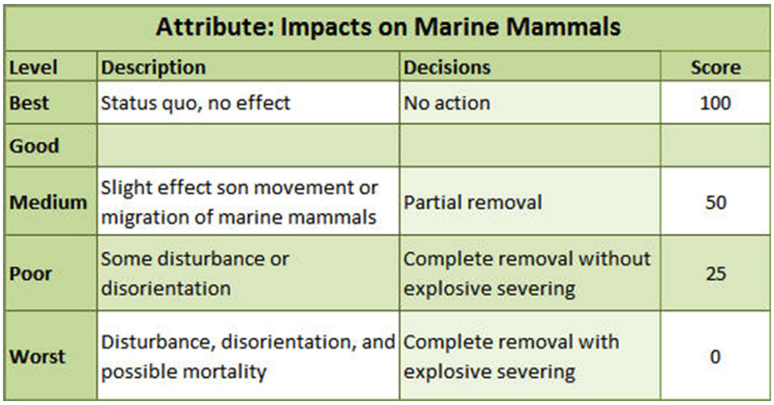
The 3 attributes based on quantitative models are decommissioning cost, fish production, and changes in ocean access. From a public policy perspective, the maximum range of effects on these attributes are only a tiny percentage of, respectively, annual spending by the state of California or oil and gas companies, fish production in California waters, or the area of accessible ocean. It is therefore reasonable to assume a linear utility function for each of these attributes over the range of interest for these decisions, the default method in PLATFORM.

Figure 6 shows normalized score by attribute for platform Harmony for the complete and partial removal options. It is noteworthy that partial removal scores higher than complete removal on cost and all environmental impacts, except on birds for which they score the same, because both options remove the above-water platform structure. Complete removal performs slightly better on changes to ocean access because it removes the underwater parts of the jacket that must be avoided by many commercial fishing gear types. Strict compliance is the key exception to this pattern: partial removal scores zero and complete removal scores 100. Thus, the choice between complete and partial removal depends almost entirely on the judged importance of strict compliance relative to the costs and environmental impacts.

Combining attributes and swing weights

PLATFORM offers 2 methods for assessing weights for aggregating over attribute scores, simple multi-attribute rating tool with swing weights (SMARTS) and an equivalent cost method that lets users express preferences for each attribute scores in terms of cost. The original SMART method proposed by Edwards (1977), like many simple methods for multi-criteria decision making, treats the weights w_i as representing the relative importance of each attribute in the abstract. Edwards and Barron (1994) extended SMART to SMARTS by adding swing weights. Swing weights recognize that the importance of each attribute should depend on the range of each attribute: asking whether dollar cost is more important than impact on marine mammals in the abstract is an ill-defined question. It is more meaningful to ask whether the range of cost from zero to $250 million is more important to a stakeholder

Table 4. Definition of levels for impact on marine mammals, a qualitative attribute, including a description and the conditions or options that would give rise to that level

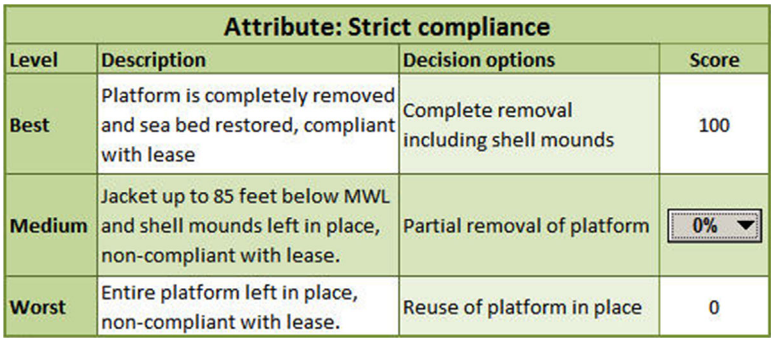


Attribute: Impacts on Marine Mammals

Level	Description	Decisions	Score
Best	Status quo, no effect	No action	100
Good			
Medium	Slight effect son movement or migration of marine mammals	Partial removal	50
Poor	Some disturbance or disorientation	Complete removal without explosive severing	25
Worst	Disturbance, disorientation, and possible mortality	Complete removal with explosive severing	0

Scores of 70% and 50% are example scores to illustrate user input.

Table 5. For the strict compliance attribute, the levels, description, decision options, and score from the PLATFORM model



Attribute: Strict compliance

Level	Description	Decision options	Score
Best	Platform is completely removed and sea bed restored, compliant with lease	Complete removal including shell mounds	100
Medium	Jacket up to 85 feet below MWL and shell mounds left in place, non-compliant with lease.	Partial removal of platform	0% ▼
Worst	Entire platform left in place, non-compliant with lease.	Reuse of platform in place	0

than the range of outcomes on marine mammals from no impact to the death of 20 sea lions.

Table 6 shows the user-interface screen that assists stakeholders in specifying swing weights for each attribute. A user first selects an attribute whose range they view as most important. For example, cost would be most important if one considers that shifting cost over its full range from its worst level ($250 million, the cost of completely removing the largest platform, Harmony) to its best cost level (zero) to be worth more than changing any other attribute from its worst to its best level. Users set the most important attribute to the highest swing weight of 100. Then, they order the other weights from the second most important down to the least important, again based on each attribute's full range. Finally, users specify a

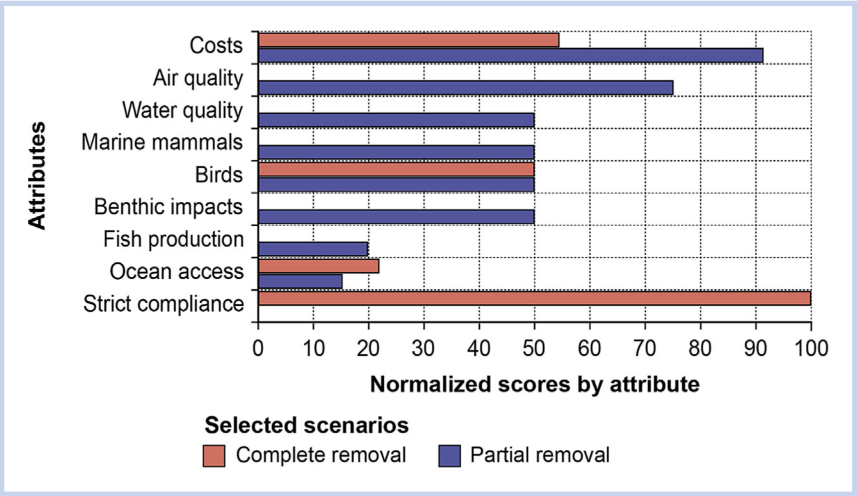
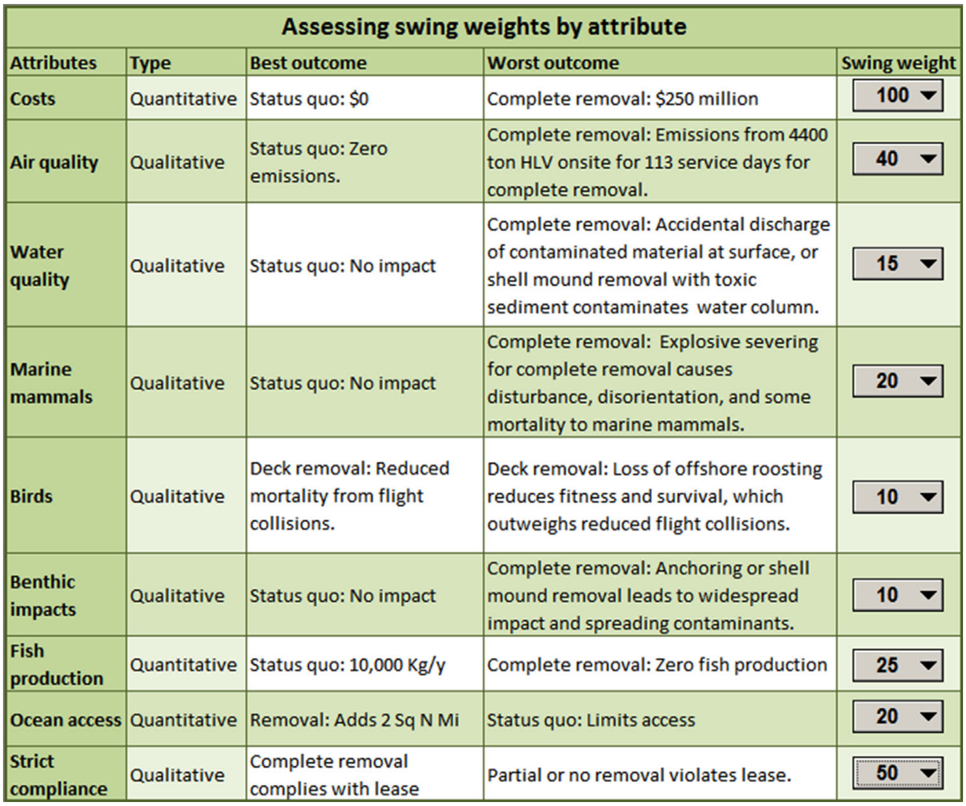


Figure 6. Normalized score by attribute for platform Harmony for complete and partial removal. Higher scores reflect better outcomes (e.g., lower costs, better water quality).

Table 6. User interface screen to assist users in assessing swing weights for each attribute to estimate the value to a stakeholder of changing each attribute from its worst to its best outcome, relative to most important attribute



Assessing swing weights by attribute

Attributes	Type	Best outcome	Worst outcome	Swing weight
Costs	Quantitative	Status quo: $0	Complete removal: $250 million	100
Air quality	Qualitative	Status quo: Zero emissions.	Complete removal: Emissions from 4400 ton HLV onsite for 113 service days for complete removal.	40
Water quality	Qualitative	Status quo: No impact	Complete removal: Accidental discharge of contaminated material at surface, or shell mound removal with toxic sediment contaminates water column.	15
Marine mammals	Qualitative	Status quo: No impact	Complete removal: Explosive severing for complete removal causes disturbance, disorientation, and some mortality to marine mammals.	20
Birds	Qualitative	Deck removal: Reduced mortality from flight collisions.	Deck removal: Loss of offshore roosting reduces fitness and survival, which outweighs reduced flight collisions.	10
Benthic impacts	Qualitative	Status quo: No impact	Complete removal: Anchoring or shell mound removal leads to widespread impact and spreading contaminants.	10
Fish production	Quantitative	Status quo: 10,000 Kg/y	Complete removal: Zero fish production	25
Ocean access	Quantitative	Removal: Adds 2 Sq N Mi	Status quo: Limits access	20
Strict compliance	Qualitative	Complete removal complies with lease	Partial or no removal violates lease.	50

In this example, costs are identified as the most important attribute and assigned a swing weight of 100.

swing weight between 0 and 100 for each attribute relative to the most important. For example, if one thinks that the value of changing impact on marine mammals from its worst to its best level is worth approximately 20% of the value of changing cost from $250 million to zero, they would specify the swing weight for marine mammals as 20. Attributes considered to have about the same value can be assigned the same swing weight.

Sensitivity to preference weights

Naturally, stakeholders differ about the relative importance of the attributes. Some see the large cost of complete removal as most salient. Others are most concerned about the potential environmental impacts. A few expressed the view that strict compliance with existing lease agreements is paramount. PLATFORM offers several tools (based on Analytica) to explore the sensitivity of its conclusions to such differences in values.

First, we examine the effect of varying each swing weight (see examples in Table 6) around its base values. For example, Figure 7 shows a range sensitivity analysis (tornado chart) for platform Harmony. The horizontal axis is the difference in utility between partial removal (scenario 2) and complete removal (scenario 1), which is 14.8% (the value of the central vertical line) with base swing weights shown in Table 6. With these values, partial removal is preferred to complete removal. The chart shows a horizontal bar for each swing weight, showing the effect on the utility difference of varying the weight from its lowest value (0) to its highest value (100), while keeping all others at their base value.

As usual with tornado charts, the variables are ordered from largest sensitivity (absolute difference between lower and upper value) at the top to smallest at the bottom. The largest sensitivity is for compliance weight, followed by air quality and cost weight. The “cost uncertainty“ represents uncertainty about the total decommissioning cost (not the cost weight) ranging from the 10th to 90th percentile of the probability distribution over the difference in decommissioning costs between partial and complete removal (see Figure 4), with its base value at the median (50th percentile). It is interesting that the cost uncertainty has the lowest but one sensitivity. In other words, uncertainty about the factual question (the direct costs of decommissioning) has considerably less effect on results than stakeholder disagreements about relative preferences for the top 7 attributes, as reflected in their swing weights.

It is interesting that the sensitivity bar for only 1 attribute, compliance weight, reaches below zero. In other words, compliance weight is the only variable for which an extreme change could change the preferred decision—from partial to complete removal.

Compliance is 1 of just 2 attributes that favor complete removal (i.e., where a lower weight favors partial removal) as indicated by the blue bar in Figure 7 reaching to the left. It should not be surprising that a higher weight on compliance favors complete removal. The other attribute is ocean access, which favors complete removal because partial removal leaves the jacket at 85 feet below MWL, an underwater obstacle for some commercial fishers (Kruse et al. this issue) that must be avoided. The remaining 7 variables, including cost weight, cost

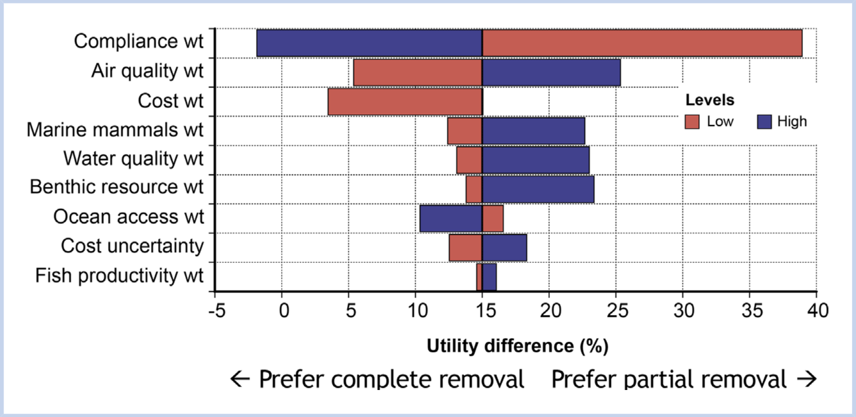


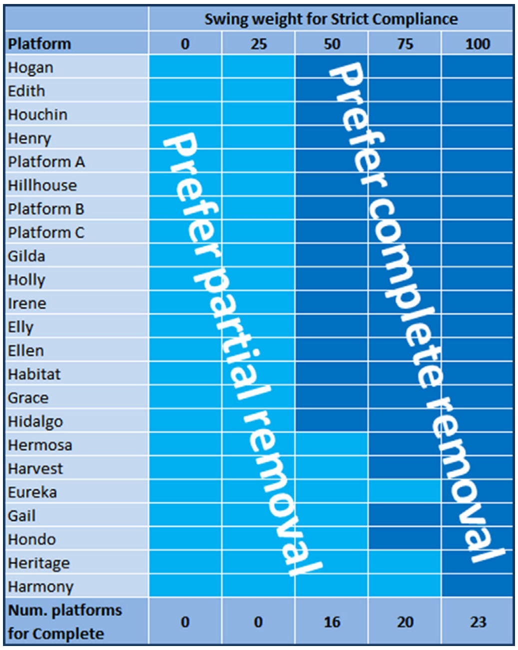
Figure 7. Range sensitivity analysis (or Tornado chart) of the difference in value between complete removal (scenario 1) and partial removal (scenario 2) for platform Harmony, changing the swing weight for each attribute from 0 (low) to 100 (high) and cost uncertainty from 10th to 90th percentile while keeping the other variables at their base values.

uncertainty, and all the environmental impacts, favor partial over complete removal, where a higher weight or value decreases the utility difference between partial and complete removal.

Partial removal scores better on cost and all the environmental attributes except ocean access that has a relatively minor effect. This implies that the key question in determining the recommended decision is the swing weight for strict compliance. In Table 7 we show the recommended decision, partial removal (light blue) or complete removal (dark blue), for each of the 27 platforms as a function of the swing weight assigned to strict compliance. For swing weight of 0, the model recommends partial removal for all platforms. For swing weight of 100 (the same as for direct cost), the model recommends complete removal for all platforms.

The number of platforms recommended for complete removal (shown in the bottom row) increases monotonically from zero to all 27 platforms as the swing weight for strict compliance increases from 0 to 100. Table 7 orders the platforms by depth from shallowest to deepest. At intermediate swing weights, the decision analysis tends to recommend complete removal for the shallower platforms over the deeper platforms, because the decommissioning costs and environmental impacts are higher for the deeper platforms.

Table 7. The preferred decision, partial removal (light blue) or complete removal (dark blue) for each platform according to the swing weight set for strict compliance



	Swing weight for Strict Compliance				
Platform	**0**	**25**	**50**	**75**	**100**
Hogan	▒	▒	█	█	█
Edith	▒	▒	█	█	█
Houchin	▒	▒	█	█	█
Henry	▒	▒	█	█	█
Platform A	▒	▒	█	█	█
Hillhouse	▒	▒	█	█	█
Platform B	▒	▒	█	█	█
Platform C	▒	▒	█	█	█
Gilda	▒	▒	█	█	█
Holly	▒	▒	█	█	█
Irene	▒	▒	█	█	█
Elly	▒	▒	█	█	█
Ellen	▒	▒	█	█	█
Habitat	▒	▒	█	█	█
Grace	▒	▒	█	█	█
Hidalgo	▒	▒	█	█	█
Hermosa	▒	▒	▒	█	█
Harvest	▒	▒	▒	█	█
Eureka	▒	▒	▒	▒	█
Gail	▒	▒	▒	█	█
Hondo	▒	▒	▒	█	█
Heritage	▒	▒	▒	▒	█
Harmony	▒	▒	▒	▒	█
Num. platforms for Complete	**0**	**0**	**16**	**20**	**23**

The bottom row shows the number of platforms recommended for complete removal. The platforms are ordered by depth, excluding those platforms at water depths too shallow to be considered for the partial removal option.

CONCLUSIONS AND EFFECTS ON THE POLICY PROCESS

This decision analysis refined a large set of potential decommissioning options and their combinations down to a smaller decision tree with a more limited number of options deserving more detailed analysis: The primary options are complete removal of each platform and partial removal to 85 feet below water level, leaving the remaining platform components in place as an artificial reef to retain fish production and ecosystem value as part of a "rigs-to-reefs" program. Removing the upper portion of the platform retains the majority of the ecological value while removing potential interference with shipping.

This study contributed new insights to our understanding of specific attributes, based on the detailed quantitative models in PLATFORM. It was the first to quantify fish production on these platforms in terms of biomass per year by depth zone and to estimate how this would be affected by the partial removal option (Pondella et al. this issue). Recent studies showing that the nursery zone for the commercially important rockfish species begins at about 30 meters depth, with adults ranging to deeper layers, imply that cutting off the top 85 feet below sea level option should not interfere substantially with rockfish lifecycles and production. The analysis of air emissions from the complete removal of the largest and deepest platform, Harmony, found the emissions to be considerable, even ignoring off-site emissions during transport of the HLV and shipping of removed platform components to disposal sites: 29 400 tons of carbon dioxide, 600 tons of NOx, and 21 tons of fine particulates (PM10). These levels suggest that permitting for such a project by air quality regulatory agencies would be problematic.

As with most analyses of controversial public policy decisions, the preferred recommendations depend on the stakeholder's point of view. With the aid of a multi-attribute decision analysis model, PLATFORM, we clarified how preferences among the objectives affect the recommended decision. We identified 8 major objectives or attributes of importance to stakeholders. Two of these, impacts on marine birds and recreational diving (1 aspect of socioeconomics), are identical for complete and partial removal, and so may safely be ignored when comparing these options. The decommissioning costs and the 4 remaining environmental impacts (impacts on air quality, water quality, marine mammals, and benthic habitats) are all greater (less desirable) for complete removal. Changes to ocean access, while slightly favoring complete removal because of the interference of the remaining artificial reef with commercial fishing, were considered of minor importance by stakeholders. Thus a single attribute, strict compliance with original leases, remains as a compelling reason for some stakeholders to favor complete removal. This attribute is framed as a binary outcome—complete removal meets strict compliance, and other options do not—unlike other attributes, which have intermediate outcomes with intermediate scores.

The range sensitivity analysis for the deepest platform, Harmony (Figure 7), illustrates how the swing weight for strict compliance is the only single attribute that can change the preferred decision from partial to complete removal when pushed to an extreme. Extending the sensitivity analysis to all 27 platforms, as illustrated in Table 7, demonstrates that reducing the swing weight for strict compliance to zero results in recommending partial removal for all platforms. As this weight is increased, the model recommends complete removal, beginning with the shallower platforms. At a weight of 100, equal to the weight of costs, complete removal becomes the preferred option for all platforms.

Discussions with most stakeholders suggested they view strict compliance as less important than environmental impacts and decommissioning costs, especially if some of the savings from partial removal are applied to ocean conservation. Because partial removal with an artificial reefing program preserves more of the marine ecosystems, costs less, and has lower environmental impacts than complete removal, there was, therefore, a near consensus for that option. The only active dissenters were local environmental organizations that argued that releasing operators from the requirement that "they clean up after themselves" and pay the costs of full removal would encourage oil and gas companies to propose more offshore drilling elsewhere.

The quantitative results presented here were calculated using PLATFORM, the Analytica-based tool developed for this study. All numerical data and assumptions underlying the cost estimates and other calculations are available for review within the model and may be updated as new information becomes available. Users may also modify the parameters of the multi-attribute utility model to explore the implications of alternative preferences. PLATFORM was used interactively by the project team and to present interim results to OST's Expert Advisory Council. It is available, along with the final project report on the OST Web site (http://www.oceansciencetrust.org/project/oil-and-gas-platform-decommissioning-study/) for use with the free Analytica Free 101 software. Some major stakeholders, including at least one in the oil and gas industry and the Sportfishing Conservancy, used the model independently to review the assumptions and explore the implications of alternative cost estimates. PLATFORM is also designed for future use by platform operators and other stakeholders to compare actual decommissioning strategies that are proposed for particular platforms or groups of platforms.

A rigs-to-reefs program, implied by the partial removal option, will require transfer of ownership from the original leaseholders to the state or another organization to manage the resulting artificial reefs and assume any liabilities involved. Bernstein et al. (2010) examine the legal and institutional implications of an expanded artificial reef program in California, describe potential pathways for ownership transfer, and assess the state's options for addressing liability concerns. This new synthesis of information contributed practical information to the development of legislation enabling an expanded reefing program in California. For example, whereas potential liability associated with platform reefs has been a consistent concern of state managers, Bernstein et al. (2010) concluded, based on a review of a number of analogous programs and legal precedents, that the potential liability of an artificial reef program is not large and can be readily managed through a variety of mechanisms.

On seeing our 263-page report to California Ocean Science Trust (Bernstein et al. 2010), 1 state agency asked for a single-page summary of our recommendations. Table 8 presents a refined version of this summary. It highlights the key differences between the 2 primary decision options, complete

Table 8. Summary of the results of the impact assessment and the multi-attribute analysis

Complete removal	Partial removal (rigs-to-reefs)
Strict compliance with leases	Requires modification of leases
Restore previous ecosystem integrity	Retains most biological production
Clear ocean access	Retains recreational fishing
Significant environmental impacts on air, water, ecosystems	Greatly reduced environmental impacts
Removes key uses (recreational fishing, SCUBA)	Expected savings approximately $500 million
Expected cost $1.09 billion	State Ocean Conservation Fund receives share of savings

Stakeholders whose preferences more closely reflect outcomes in the left-hand column (either in terms of preferring or being insensitive to a predicted outcome) will be more likely to choose the complete removal option. Stakeholders whose preferences more closely reflect outcomes in the right-hand column will be more likely to choose the partial removal-artificial reefing option.

removal and partial removal—"rigs-to-reefs." Most stakeholders tended to support the "rigs-to-reefs" option once it became clear that it could both reduce environmental impacts, preserving much of the rich marine life around the platforms, and save over half a billion dollars, if applied to all 27 platforms. A refinement for partial removal is to split the savings between the operators and 55% (or more) going to an Ocean Conservation Fund to be administered by the State of California. With this addition, there was near consensus for the "rigs-to-reefs" option.

The original findings from this study, including the decision analysis and the PLATFORM decision model, were released in a report (Bernstein et al. 2010) and presented in public meetings to the California Ocean Protection Council and other groups. Skyli McAfee, Executive Director of the California Ocean Science Trust, and the direct client for the project, said, "By clearly identifying the issues, synthesizing the best multidisciplinary science, daylighting the uncertainty and providing for unbiased review, the tool created by Bernstein et al. was successful in distilling the rhetoric to meaningful discussion of tradeoffs and values." As a result, the findings contributed to ongoing policy discussions in California on this issue, including the development of new state legislation that provides for the savings from partial removal to be split between the operators and a public fund for ocean conservation administered by the California Department of Natural Resources. The new legislation includes an incentive for early decommissioning, as operators keep 45% of the cost savings until 2017 after which their share falls to 35%. The resulting bill, AB 2503, was adopted by the California legislature and signed into law by Governor Schwarzenegger in September 2010.

SUPPLEMENTAL DATA

Figure S1. The major components of a generic offshore platform (Manago and Williamson 1998, workshop notes p. 223).

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