Innovative Assessments for Selecting Offshore-Platform-Decommissioning Alternatives

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Summary
Hard substrates associated with offshore oil and gas platforms can contribute to the productivity of marine ecosystems, thereby generating local and regional economic benefits. These benefits form the basis for incorporating the platform into a rigs-to-reefs program when it is retired or for selecting some other type of removal option. There are many options for reefing platforms, each differing in environmental impact associated with dismantling and transport of the platform structure (deck, jacket, and other subsea structures). The use of science-based decision making in exploring platform-removal options can be beneficial for all stakeholders in the context of regulatory environment, complex ecosystem, and human interactions across multiple scales. Accommodating these complexities in a decisionmaking process is the foundation of an ecosystem-based-management (EBM) approach. EBM is an environmental-management approach that recognizes the full array of interactions within an ecosystem, including humans, rather than considering single issues, species, or ecosystem services in isolation (Christensen et al. 1996; McLeod et al. 2005; Altman et al. 2011).

The focus of this study is on one of Shell's former deepwater assets in the Gulf of Mexico. The fixed-jacket platform has been in operation for more than 35 years and extends to more than 1,000 ft of water depth off the coast of Louisiana. Few studies have been published on the ecology of marine life inhabiting deepwater platforms such as these. To begin to understand the specific contribution of this platform as an artificial reef, a stratified (across depth down the platform) study was performed by use of routinely collected remotely-operated-vessel (ROV) video footage to assess fish and sessile biotic communities. The ROV study revealed clear depth-related patterns of visually conspicuous epibiota (surface-dwelling organisms such as *Lophelia pertusa*) and numerous species of reef and pelagic fishes. These data were used to construct a matrix to rank the ecosystem services of several decommissioning alternatives, including complete removal of the deck and jacket; removal of the deck, topping the jacket 85 ft below the waterline, and leaving the remainder in place; and removal of the deck and transfer of the entire jacket to a rigs-to-reef location. This portion of the assessment provided a strategic framework for identifying and evaluating sensitive ecosystem services in association with both human and environmental drivers to provide realistic (actionable) guidance in the selection of these decommissioning options. The preliminary ranking illustrated that a high level of ecosystem services could be maintained by decommissioning alternatives that leave the jacket in place or transfer the jacket elsewhere as part of a rigs-to-reefs program.

Introduction
The approximately 4,000 offshore oil and gas platforms installed in the Gulf of Mexico have generated nearly 12 km^2 of artificial habitat onto an otherwise unstructured seafloor (Dugas et al. 1979), increasing the overall abundance of hard substrate in the Gulf of Mexico by approximately 0.5%. Biota associated with oil and gas platforms broadly includes plankton, neuston, benthos, sessile (i.e., not free-moving) organisms, fishes, sea turtles, birds, and marine mammals. As structural habitat, offshore platforms provide hard surfaces for the attachment of sessile organisms; 3D habitat for fishes and motile (i.e., free-moving) invertebrates; and orientation and feeding sites for larger fishes, sea turtles, and marine mammals (Atchison et al. 2008; Church et al. 2007; Lewbel et al. 1987; Latynov 1992; Gallaway and Lewbel 1982). Platforms also modify currents, providing hydrodynamic shelters for plankton, neuston and other species, including turtles (Hastings et al. 1976; Rosman et al. 1987; Gitschlag and Renaud 1989; Gitschlag 1990; Renaud and Carpenter 1994). As sessile organisms grow and spread, so does the habitat complexity of platform surfaces, and those surfaces in turn provide shelter for small fishes and motile invertebrates (Gallaway and Lewbel 1982; Rauch 2003).

Mature sessile assemblages on most platforms, however, may not generate sufficient habitat, organic matter, or pelagic larvae to sustain the high numbers of fishes found around most platforms. Such assemblages depend on outside sources, namely plankton delivered by currents from waters upstream of the platform. This subsidy of plankton fuels planktivorous fishes on natural and artificial reefs, including mesophotic reefs in the northern Gulf of Mexico, which support schools of planktivorous fishes (Hamner et al. 1988; Lindquist and Pietrafesa 1989; Weaver et al. 2001; Keenan et al. 2003). Thus, it appears that platforms are prime examples of cross-boundary, subsidized systems (Keenan et al. 2003), where, in this case, sources external to the platform subsidize the platform residents. At the platform, a semiclosed food web exists, where, as in natural systems, the planktivorous fishes form an important link to the food web because they are preyed upon by larger fishes, birds, and marine mammals (Dokken et al. 2000).

The platform structure also creates unique circumstances [compared with natural, benthic (i.e., bottom-dwelling) structures] that influence the food web. With their vertical relief that transects the entire water column, they greatly influence local circulation, creating small eddies and turbulence that are postulated to retain planktonic organisms near the structure (Forristall 1996). In addition, most of the planktonic organisms are also attracted to light, and platform lights may serve to help enhance their concentration as plankters appear to concentrate around platforms at night. For some visually oriented fishes, plankton concentrated at night present an opportunity to extend normal daylight feeding times, thus energy mobilization through the food web may be accentuated at powered platforms. Additionally, these planktivores tend to process and assimilate their prey rapidly and likely on site, producing

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Bay	Minimum (ft)	Maximum (ft)	Change (ft)	Bay Zone*
1	0	32	32	1
2	32	92	60	1
3	92	167	75	2
4	167	247	80	2
5	247	332	85	2
6	332	422	90	3
7	422	512	90	3
8	512	592	80	3
9	592	667	75	4
10	667	747	80	4
11	747	830	83	4
12	830	875	45	5
13	875	965	90	5
14	965	1,050	85	5

*Bay Zone refers to the grouping used for stratified random sampling of video segments to attempt a balanced sampling effort.

Table 1—Depth ranges of bay numbers for the platform assessment.

organic wastes that rain toward the local seafloor, nourishing a near-field benthic assemblage.

In the Gulf of Mexico, the benefits of platforms as valuable ecological habitat supportive of localized food webs are clear. However, each platform reaches a point where it is no longer a viable asset and is subject to either decommissioning or resale. There are several alternatives to platform decommissioning, and in the Gulf of Mexico, there are clear guidelines for each of the Gulf State's rigs-to-reefs programs. Almost all alternatives require the above-water deck portion of the platform to be brought to shore, decontaminated, and recycled to the extent possible. The remaining portion of the below-water platform, or jacket, may be cut up and moved into rigs-to-reef planning areas, brought to shore, or left in place. The purpose of this study is to understand the value to offshore marine life of one of Shell's fixed-jacket platforms off the coast of Louisiana, so that information could be used during the decommissioning planning to help select alternatives that provide the most benefit in preserving ecosystem services. This study does not replace the engineering-design process for decommissioning and abandonment, but rather provides additional, supportive information for that process.

Methods

This study focuses on one of Shell's former fixed-jacket platforms in the Gulf of Mexico that has been in operation for more than 35 years. The iron jacket is "fixed" in that it is stationary, and extends from the surface to more than 1,000 ft of water depth to the seafloor off of the coast of Louisiana. To understand specific contributions of a platform as an artificial reef, a stratified (across depth down the platform) study was performed on this jacket by use of remotely-operated-vessel (ROV) video footage to assess fish and sessile biotic communities. ROV video footage, which is used by engineers to monitor structural integrity of the jacket periodically as a condition of the license to operate or following hurricanes, is maintained in a database that is not available to the public. Shell provided CSA Ocean Sciences (CSA) with access to this database and approximately 1,200 video data files for the purpose of characterizing the marine community on this particular jacket. Because of the quantity of video files, a subsample of the files was selected and reviewed by use of the methodology described in the following subsections.

Video-Catalog Database. To evaluate the biological information that could be obtained from the significant quantity of archived videographic information provided for the platform, a searchable/sortable catalog database was created to guide subsampling. A catalog structure could not be developed manually from the website because the existing data-access portal was linear in design and, therefore, could not be queried or searched for multiple criteria that would inform randomized selection. On the basis of the available video-data hierarchy, the video segments were cataloged in a spreadsheet. Variables selected included component of the platform (jacket or subsea structure); section (north, south, east, west, Row X, Row 2, Row 3, internal, *j*-tube, and conductors); bay number (referring to vertical sections of the platform; a surrogate for depth and hereafter occasionally referred to simply as "bays"); subcomponent (referring to structural aspects of the platform; e.g., horizontal sections, vertical sections); tape identification number; number of discrete video segments on a tape (these are not independent surveys, but edited clips from the same dive); date and time; and survey purpose.

Video-Subsampling Methodology. The online video catalog focused only on files that examined the jacket. A simple, univariate analysis across the hierarchy of the video catalog was conducted to determine the level of examination at which consistent numbers of replicate videos could be found. Videos were considered independent at the date and tape-number level (i.e., a unique tape number, signifying a discrete ROV dive event on a given day). The initial video count by section and bay number revealed substantial variation in the number of tapes and, in many instances, no videos of any kind for many of the bay/section combinations. Given the uneven distribution of surveys among these sections, it was determined that an adequate sampling across depth strata would be best conducted with bays.

Three nonsequential years of files were available for this analysis. Files from 2008 were markedly different in scope from the other years, and focused heavily on the north face of the platform. Files for 2009 had the most-even distribution of files among sections, but wide variation in the number of files per bay as compared with 2011. Though the number of sampling years was low, and covered only three of four successive years, it was determined that a temporal examination was not warranted, so the files were pooled irrespective of year. Even after pooling among years, there was still substantial variation in the number of files among bays. Bays were assigned to broader depth categories to better equalize sampling information by depth **(Table 1).** On average, 62 files were retained for each of the newly combined bay zones.

Many video files were composed of several short segments. On the basis of review of the lengths of video segments, 4 min/file was selected as a sampling unit. To obtain a minimum of 4 min/file, video segments were concatenated within a file number, as needed, to reach that total video-viewing time. If enough video segments were not available within a file to meet the comprised 4-min minimum, then that file was replaced with the next randomly selected file. Once the files were selected for analyses, the biological communities observed in the files were evaluated.

Biological-Community Characterization. On the basis of the preliminary review and information in the video data, CSA marine scientists identified the lowest possible taxa (i.e., family, order, genus, and species) of the organisms and prepared the observations for further potential statistical analysis. Species of concern (i.e., threatened or endangered and commercial species) were noted where observed. All visually conspicuous fish taxa observed in the video segments were recorded as present within particular bay numbers and assigned a qualitative abundance score (A=abundant, C=common, O=occasional, U=uncommon, R=rare). These categories correspond roughly to a log 4 interval scale (*R*=1 individual, *U*=2 to 4 individuals, *O*=5 to 16 individuals, *C*=17 to 64 individuals, and *A*=65 to 256 individuals). Similarly, all visually distinct species or species groups of invertebrates colonizing the platform were also characterized by bay. Specific depth zonation was noted when possible, and a relative abundance score was assigned for each species group by tape (0=none, 1=1 to 10, 2=11 to 50, 3= >50 colonies of the group).

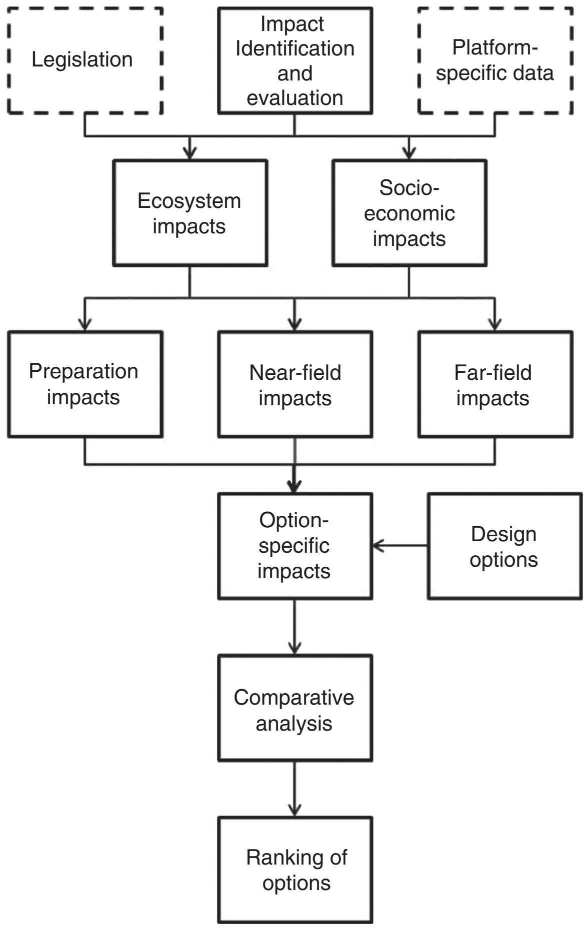

Fig. 1—Adaption of the Cripps and Aabel (2002) framework for evaluating platform-decommissioning alternatives.

Ecosystem-Based-Management (EBM) Assessment. To demonstrate an approach to compare each decommissioning alternative from an environmental/ecological perspective, a preliminary version of an EBM tool (Altman et al. 2011) was selected to aid in analysis. The EBM tool was used to score the effects of a subset of decommissioning alternatives and aid in assessment and identification of the choice least disruptive to ecosystem-service flows. The three decommissioning alternatives selected were reefing in place, reefing out of place, and towage to shore.

The EBM method captures human/service and service/service interaction strengths in an interaction matrix that uses a common hierarchical scoring template to guide information-gathering scenarios. The initial steps identify potential human impacts* [**Fig. 1,** adapted from Cripps and Aabel (2002)]. Top human activities that might influence services provided by platforms, irrespective of decommissioning alternative, were compiled from the literature and itemized into key ecosystem services that could be provided by the study platform. Ecosystem impacts and socio-economic impacts are separated conceptually (second tier from the top in Fig. 1), but they are embedded in both services (e.g., commercial fishing harvest) and human activities (e.g., tourism) for purpose of analysis. In the third tier of Fig. 1, impact scaling was addressed through a hierarchical-scoring decision tree that informs the scoring ranks for each matrix **(Fig. 2).** Human impacts were summed for each ecosystem service, and this summed value was multiplied by the service-on-service scaled interaction to provide a weighted ecosystem-services value to compare the impact of each of the three decommissioning alternatives with the various services. A final, weighted matrix was developed whose column sums equaled the cumulative impact scores. Higher scores go to the ecosystem services that are most strongly affected negatively by both the natural drivers and the decommissioning option and that represent a ranking of ecosystem-service vulnerabilities. Each of the matrices was populated by use of simple dialogue and a consensus of CSA marine scientists with knowledge of the topic area.

Data and Results

Fish Community. Across the 14 depth-related bays, 42 fish taxa from 19 families were observed **(Table 2).** Numbers of taxa varied with water depth. The highest numbers of taxa were recorded in Bays 1 through 7 (0 to 512 ft), where the number of taxa averaged 14 and ranged from five in Bay 5 (247 to 332 ft) to 25 in Bay 3 (92 to 167 ft). Bays 8 through 14 (512 to 1,050 ft) averaged just four taxa, ranging from two in Bay 12 (830 to 875 ft) to six in Bay 14 (965 to 1,050 ft). Families with the most representatives were seabasses (*Serranidae*) with six taxa, followed by jacks (*Carangidae*) with five taxa and wrasses (*Labridae*) with four taxa.

The taxa recorded may be classified broadly as shallow-reef species, deep-reef species, and pelagic species. The shallow-reef group in Bays 1 through 7 (0 to 512 ft) was composed of 26 taxa, including gray snapper (*Lutjanus griseus*), spotfin hogfish (*Bodianus pulchellus*), chubs (*Kyphosus* spp.**) queen angelfish (*Holacanthus ciliaris*), creole fish (*Paranthias furcifer*), and blue tang (*Acanthurus coeruleus*). The deep-reef group consisted of streamer basses (*Anthiinae* spp.), snowy grouper (*Epinephelus niveatus*), Darwin's slimehead (*Gephyroberyx darwinii*), barrelfish (*Hyperoglyphe perciformis*), and roughies (*Hoplostethus* spp.). Ten pelagic fishes observed in the video segments were mostly amberjacks (*Seriola* spp.). Four amberjack species reside in the Gulf of Mexico, and although very common, these four are difficult to distinguish, particularly at small sizes. The video review allowed positive identifications of three of the four species: greater amberjack (*Seriola dumerili*), almaco jack (*Seriola rivoliana*), and lesser amberjack (*Seriola fasciata*). Amberjacks ranged over the entire structure from near bottom to near surface. Requiem sharks (*Carcharhinidae*), such as the silky shark (*Carcharhinus falciformis*), were occasionally observed in the upper bay. A single tuna (*Thunnus* sp.) was also recorded at mid-reef. Only five of the 42 fish species (≈ 5%) observed were found solely in the top two bays (down to 92 ft) that would be removed under some highly ranked decommissioning options (squirrelfish, sergeant major, purple reeffish, bicolor damselfish, bluehead wrasse).

Individual taxa with the most occurrences over all video segments are the ichthyofauna (i.e., fish species) of the Gulf of Mexico in general and blue-water platforms in particular. The number of species recorded, abundance estimates, and biomass would increase appreciably with a detailed and dedicated survey, particularly of smaller-sized shallow- and deep-reef species that require close examination to identify properly. Pelagic fishes were underrepresented in the videos. The deep-reef assemblages, which are just beginning to be studied over natural hardbottom habitats within the broader Gulf of Mexico (Weaver et al. 2001, 2006; Snyder 2001; Dennis and Bright 1988) could be further subdivided into species characteristic of mesophotic reefs (reefs between 230 and 492 ft) and deeper reefs (between 495 and 1,967 ft). Understanding the deep-reef assemblages on and around artificial structures, such as the study platform, could provide important information on abundance and habitat use that would help plan future decommissioning efforts.

Sessile Organisms. Analysis of the video data allowed for very few visually distinct species or species groups such as the stony coral *Tubastrea coccinea*; the deeper-water stony coral *Lophelia pertusa*;

*Incorporation of the legislation and platform-specific human-use data of Cripps and Aabel (2002) was beyond the scope of this analysis.

**spp. is used to designate that there were multiple species observed for the genus *Kyphosus*.

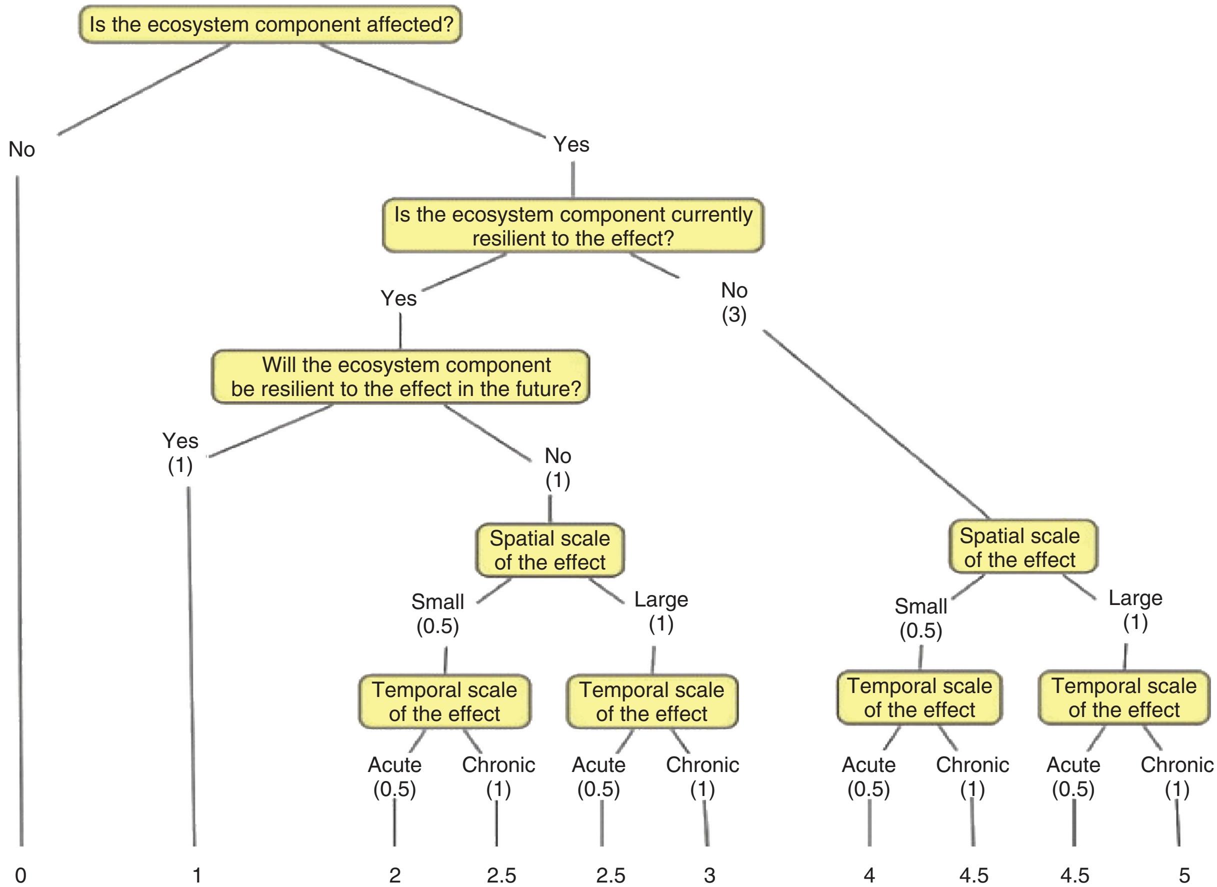

Fig. 2—Hierarchical decision tree that guides temporal and spatial scaling, including ecosystem-service resilience, for scoring human activity against ecosystem-service interactions and ecosystem-service to ecosystem-service interactions. Lower scores indicate effects likely to compromise a component's resilience in the future, whereas higher scores show effects that likely compromise the resilience of the service. (Redrawn from Altman et al. 2011.)

antipatharian spiral whips (*Stichopathes*); the large, white octocoral *Hypnogorgia*; and a few smaller, but distinctly colored, octocorals. There also appeared to be an encrusting sponge and/or tunicate component to the fouling community, but this could not be confirmed on the basis of the available video data.

Specific depth zonation was noted for the identifiable taxa **(Table 3).** A relative abundance score was assigned by tape for each group: 0 = none, 1 = 1 to 10, 2 =11 to 50, 3 = >50 colonies of the group. **Fig. 3** shows the relationship of both occurrence and sum-of-abundance score by group. Barnacles and sponges were abundant in the shallowest bays. *Tubastrea* were observed from depths of 0 to 332 ft, with the greatest abundance noted in Bay 3, where it often totally covered sections of the platform cross-members. Octocorals occurred from Bays 3 through 7, with the greatest abundance from depths of approximately 160 to 530 ft. Antipatharians, including spiral whips, occurred heavily in Bays 3 through 9 (although some were also seen in Bay 10) from 240 to 530 ft. The distinct deepwater stony coral species *Lophelia pertusa* appeared starting at Bay 10 at approximately 800 ft and was observed in high abundance on the platform structure from 850 ft to just above the seafloor. The deepest at which this species has been documented is 2,620 ft (BOEM 2012).

Ecosystem-Based Management (EBM). In our preliminary evaluation, we closely followed the methods of Altman et al. (2011). Human impacts were summed for each ecosystem service, and the summed value was multiplied by the service-on-service scaled interaction to provide a weighted ecosystem-services value to compare threat levels with the various services. Results of this scaling method for the decommisoning alternative for full removal are shown in **Fig. 4.** The final weighted-ecosystem-services matrix, in which the sum of the columns are used to rank the vulnerability of the various services in context of their interactions and human impacts, is shown in **Fig. 5** for the full-platform-removal option. The overall score in this matrix can be broken down into the human (decommissioning option) vs. natural-ecological-processes contribution, where scores with a higher human component indicate areas in which management actions have the most impact.

The final results of the EBM evaluation are shown in **Fig. 6** for each of the three decommissioning options. This chart illustrates the overall scores estimated from matrix calculations for each decommissioning alternative. The ecosystem service with the largest column score is the most at risk. The results show that irrespective of decommissioning approach, biomedical uses, aesthetics, and habitat complexity were among the least sensitive services, whereas trophic interactions, rare-species support, and commercial fishing were forecast to be the most affected by any disposal option. When considering decommissioning alternatives, risks to platform services if the jacket is left in place or transported to a rigs-to-reefs planning area are very similar, but when compared with complete removal, these alternatives forecast lower risk to the disturbance of habitat complexity, biodiversity, and the ability of the structure to support rare species.

Conclusions

Living resources associated with the study platform currently provide services that would be disrupted or lost by any of the removal options. Leaving the structure in place (removing the deck to

				Bay Number														
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	Score Total
				Maximum Depth (ft)														
				32	92	167	247	332	422	512	592	667	747	830	875	965	1,050	
Family	Common Name	Taxon	Group	Relative Abundance Scores of Fish Taxa														
Carcharhinidae	Silky shark	*Carcharhinus falciformis*	P			1												**1**
	Requiem shark	*Carcharhinus* sp.	P				2	1										**3**
Gonostomatidae	Pearlside	*Margrethia* sp.	P										1					**1**
Trachichthyidae	Darwin's slimehead	*Gephyroberyx darwini*	D									3	2					**5**
Holocentridae	Squirrelfish sp.	*Holocentrus* sp.	S			1												**1**
	Roughy sp.	*Hoplostethus*	D														1	**1**
	Squirrelfish	*Holocentrus adscensionis*	S		1													**1**
Serranidae	Streamer bass sp.	Anthiinae sp.	D			1	4	2	4	5	3		4	2		1	1	**27**
	Snowy grouper	*Epinephelus niveatus*	D			1					1						1	**3**
	Grouper sp.	*Epinephelus* sp.	D					1		2	1	1		1				**6**
	Scamp	*Mycteroperca phenax*	S		1	1	1		1									**4**
	Creole fish	*Paranthias furcifer*	S	2	3	3	4		2	1								**15**
	Roughtongue bass	*Pronotogrammus martinicensis*	D				2											**2**
Carangidae	Blue runner	*Caranx crysos*	P			1												**1**
	Greater amberjack	*Seriola dumerili*	P		1	1			1	1	1							**5**
	Lesser amberjack	*Seriola fasciata*	P														1	**1**
	Almaco jack	*Seriola rivoliana*	P	1		2	2			2								**7**
	Amberjack sp.	*Seriola* sp.	P		1	1	3	1	5	4	3	6			1	4	4	**33**
Lutjanidae	Red snapper	*Lutjanus campechanus*	S			1	1		1	1								**4**
	Gray snapper	*Lutjanus griseus*	S	5	4	1												**10**
	Snapper sp.	*Lutjanus* sp.	S			1	1	1										**3**
	Vermilion snapper	*Rhomboplites aurorubens*	S							1								**1**
Haemulidae	Porkfish	*Anisotremus virginicus*	S	2	2	3			1	1								**9**
Kyphosidae	Chub sp.	*Kyphosus* spp.	S	2		2	1											**5**
Chaetodontidae	Reef butterflyfish	*Chaetodon sedentarius*	S				3		1	1								**5**
Pomacanthidae	Blue angelfish	*Holacanthus bermudensis*	S			3												**3**
	Queen angelfish	*Holacanthus ciliaris*	S	4	2	1			1	1								**9**
	Rock beauty	*Holacanthus tricolor*	S			2												**2**
Pomacentridae	Sergeant major	*Abudefduf saxatilis*	S	2	3													**5**
	Purple reeffish	*Chromis scotti*	S		1													**1**
	Bicolor damselfish	*Stegastes partitus*	S	1														**1**
Labridae	Spotfin hogfish	*Bodianus pulchellus*	S	3	3	3	3		1	1								**14**
	Spanish hogfish	*Bodianus rufus*	S	3	1	1												**5**
	Creole wrasse	*Clepticus parrae*	S	2	2	1												**5**
	Bluehead wrasse	*Thalassoma bifasciatum*	S	1														**1**
Acanthuridae	Doctorfish	*Acanthurus chirurgus*	S						1	1								**2**
	Blue tang	*Acanthurus coeruleus*	S	3	3	2												**8**

Table 2—Occurrence of fishes (listed in phylogenetic order) from video segments collected by bay number and maximum depth on the study platform. Taxa are grouped as Pelagic (P), Shallow Reef (S), and Deep Reef (D). Shading helps visualize depth distribution. See Table 1 for depth ranges of bay numbers. Values in cells are relative abundance scores corresponding to Log 4: 1 = rare (1 individual); 2 = uncommon (2 to 16 individuals); 3 = occasional (5 to 16 individuals); 4 = common (16 to 64 individuals); 5 = abundant (257 to 1,024 individuals).

Family	Common Name	Taxon	Group	Bay Number 1	2	3	4	5	6	7	8	9	10	11	12	13	14	Score Total
				Maximum Depth (ft)														
				32	92	167	247	332	422	512	592	667	747	830	875	965	1,050	
				Relative Abundance Scores of Fish Taxa														
Sphyraenidae	Great barracuda	*Sphyraena barracuda*	P	1	1	3	1											**6**
Scombridae	Tuna sp.	*Thunnus* sp.	P							1								**1**
Centrolophidae	Barrelfish	*Hyperoglyphe perciformis*	D							1		3	2	1	1	3	4	**15**
Monacanthidae	Orangespotted filefish	*Cantherhines pullus*	S			1												**1**
Balistidae	Gray triggerfish	*Balistes capriscus*	S			2												**2**
Total Taxa in Bay				**14**	**15**	**25**	**13**	**5**	**11**	**15**	**5**	**4**	**4**	**3**	**2**	**3**	**6**	**42**

Table 2 (continued)—Occurrence of fishes (listed in phylogenetic order) from video segments collected by bay number and maximum depth on the study platform. Taxa are grouped as Pelagic (P), Shallow Reef (S), and Deep Reef (D). Shading helps visualize depth distribution. See Table 1 for depth ranges of bay numbers. Values in cells are relative abundance scores corresponding to Log 4: 1 = rare (1 individual); 2 = uncommon (2 to 16 individuals); 3 = occasional (5 to 16 individuals); 4 = common (16 to 64 individuals); 5 = abundant (257 to 1,024 individuals).

onshore, but leaving the jacket uncut and at the water surface) would likely pose the least ecological impact, but that is not a viable option for several reasons, the most important of which include navigational safety risks and the costs of maintaining lights, other marking buoys, and signage at the site. Although a platform kept intact and left in place does not impact the biological community living on and associated with it, the platform's operator remains liable and must continue costly maintenance until decommissioning activities are conducted (Carr and Moore in Reggio 1989). This option provides a small, localized benefit that is outweighed by the cost of maintenance, as well as safety and liability fears of leaving a structure in place (Manago and Williamson 1998; Ekins et al. 2006).

At the other extreme, complete removal of the platform (deck and jacket below the mudline) would have the greatest effect, resulting in the complete loss of species that are attached to the jacket, displacement of high-site-fidelity species (such as chub, blue runner, and creolefish), and loss of human use of the jacket for commercial or recreational fishing or diving. The one advantage of complete removal is taking invasive species, such as the orange cup coral *Tubastrea*, completely out of the regional ecosystem; however, this is also a disadvantage in that other types of beneficial native coral communities would be lost.

Cutting the jacket at a depth safe for navigation (≈85 ft) would eliminate shelter (by canopy species) and shading, and would modify current flow. Dokken et al. (2000) concluded that removal below approximately 165 ft would be especially detrimental to biological productivity; therefore, navigation-depth removal would presumably have substantially less impact, although we are not aware of any studies that examine the scaling of productivity to differing depths. Some reef fishes, including yellowmouth grouper, scamp, gray triggerfish, and creolefish, would likely still use the deeper structure or relocate to other intact platforms; however, most smaller, site-attached reef fishes (blennies, damselfishes, small wrasses, and hinds), particularly those with an affinity for settling in shallow waters, would be lost. Pelagic species, such as greater amberjack, almaco jack, and horse-eye jack, would likely remain associated with the remaining platform structure at depth. Changes in species composition and altered trophic relationships because of the the loss or displacement of epibiota and associated motile invertebrates important to some fishes would be expected. Commercial- and recreational-fishing opportunities and diving would remain viable.

It is clear that keeping the cut portion of the jacket in place or within the ecosystem (but transported to a rigs-to-reefs planning area) preserves or could establish a the flow of ecological services elsewhere. Leaving the cut portion of the jacket in place (alongside the remaining jacket to the seafloor) would create some compensatory, localized, deepwater benthic habitat in proximity to the existing structure. This may enhance colonization and utilization of

Bay	Maximum Depth (ft)	Barnacles	Sponge	*Tubastrea*	Octocoral	Antipatharians	Unidentified Branch Coral	*Lophelia*	Anemones
1	32	X	X	X					
2	92	X	X	X					
3	167		X	X	X	X			
4	247			X	X	X	X		
5	332			X	X	X	X		
6	422				X	X	X		
7	512				X	X			
8	592					X	X		
9	667					X	X		X
10	747					X		X	X
11	830							X	X
12	875							X	X
13	965							X	X
14	1,050							X	

Table 3—Simple relationship of occurrence of identifiable sessile species and species groups from video segments collected by bay and maximum depth on the study platform.

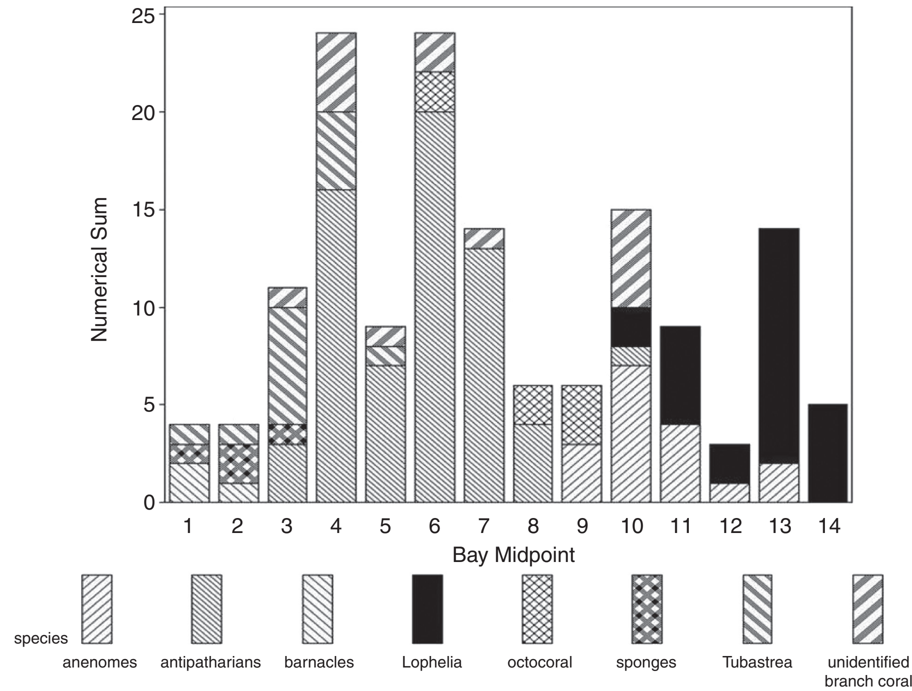

Fig. 3—Sum of abundance scores for the appearance of sessile groups in selected files by bay.

Ecosystem Services

Ecosystem Services	Habitat extent and structural complexity	Biodiversity	Marine harvested spp (commercial)	Marine harvested spp (recreational)	Trophic Interactions	Dispersal	Spawning	Secondary production	Benthic production	Aesthetic values	Biomedical	Rare species	Sum
Habitat extent and structural complexity		3	3	3	3	3	3	3	3	0	0	3	27
Biodiversity	3		4.5	4.5	4.5	4.5	4.5	4.5	1	2.5	4.5	4.5	42.5
Marine harvested spp (commercial)	3	4.5		2	4.5	4.5	4.5	4	2.5	2	2.5	4.5	38.5
Marine harvested spp (recreational)	3	4.5	2		2.5	2.5	2.5	2.5	2.5	2	2.5	2	28.5
Trophic interactions	3	4.5	4.5	2.5		3	3	3	2.5	2	2.5	4.5	35
Dispersal	3	4.5	4.5	2.5	3		4.5	4.5	3	1	1	5	36.5
Spawning	3	4.5	4.5	2.5	3	4.5		4.5	1	2.5	1	1	32
Secondary production	3	4.5	4	2.5	3	4.5	4.5		3	1	1	5	36
Benthic production	3	1	2.5	2.5	2.5	3	1	3		1	1	4.5	25
Aesthetic values	0	2.5	2	2	2	1	2.5	1	1		2	4.5	20.5
Biomedical	0	4.5	2.5	2.5	2.5	1	1	1	1	2		4.5	22.5
Rare species	3	4.5	4.5	2	4.5	5	1	5	4.5	4.5	4.5		43

This is a symmetrical matrix—DO NOT fill in red cells as they are populated from the value mirrored from the right half of the matrix.

Fig. 4—Matrix for assessing the interaction of ecosystem services on ecosystem services. The example shown here is for complete removal of the platform from the ecosystem. Lower scores indicate effects likely to compromise a component's resilience in the future, whereas higher scores indicate effects that likely currently compromise the resilience of the service.

Ecosystem Services

Ecosystem Services	Habitat extent and structural complexity	Biodiversity	Marine harvested spp (commercial)	Marine harvested spp (recreational)	Trophic Interactions	Dispersal	Spawning	Secondary production	Benthic production	Aesthetic values	Biomedical	Rare species	Sum
Habitat extent and structural complexity		66	72	66	82.5	70.5	70.5	70.5	51	0	0	87	27
Biodiversity	66		108	108	123.75	105.75	105.75	105.75	17	12.5	36	130.5	42.5
Marine harvested spp (commercial)	66	99		44	123.75	105.75	105.75	94	42.5	10	20	130.5	38.5
Marine harvested spp (recreational)	66	99	48		68.75	58.75	58.75	58.75	42.5	10	20	58	28.5
Trophic interactions	66	99	108	55		70.5	70.5	70.5	42.5	10	20	130.5	35
Dispersal	66	99	108	55	68.75		105.75	105.75	51	5	8	145	36.5
Spawning	66	99	108	55	68.75	105.75		105.75	17	12.5	8	29	32
Secondary production	66	99	96	55	68.75	105.75	105.75		51	5	8	145	36
Benthic production	66	22	60	55	68.75	70.5	23.5	70.5		5	8	130.5	25
Aesthetic values	0	55	48	44	55	23.5	58.75	23.5	17		16	130.5	20.5
Biomedical	0	99	60	55	68.75	23.5	23.5	23.5	17	10		130.5	22.5
Rare species	66	99	108	44	55	117.5	23.5	117.5	76.5	22.5	36		43
Sum	594	935	924	636	852.5	857.75	752	846	425	102.5	180	1247	

Fig. 5—Final weighted-ecosystem-services matrix. The bottom line (sum) ranks the vulnerability of each service in the context of their interactions and human impacts. The example shown here is for complete removal of the platform from the ecosystem. Each cell represents the effect of one ecosystem service on another, weighted by the cumulative impact associated with the human impact that causes the effect. The ecosystem service with the largest column score is the most at risk to indirect effects.

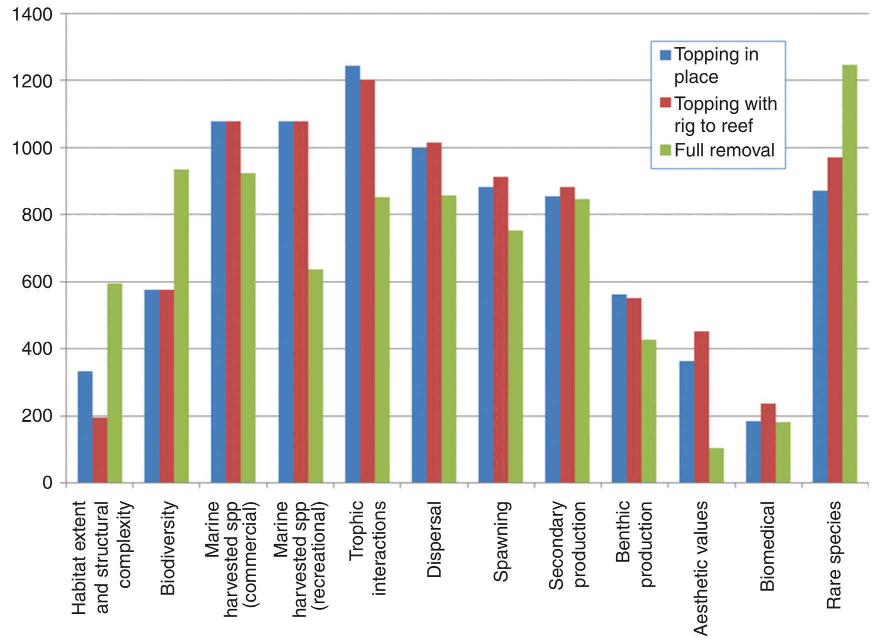

Fig. 6—Example ranking sums for the EBM matrix, showing the relative vulnerability of ecosystem services for the three decommissioning scenarios evaluated in the EBM analysis.

the new portion by desirable species (such as *Lophelia*), although the shallow-water communities (including invasives such as *Tubastria*) are assumed to be lost or displaced. Alternatively, transporting the cut portion of the jacket to a rigs-to-reefs planning area would provide additional habitat for shallower-water communities. Rigs-to-reefs planning areas are much larger than the area required by the platform, are closer to shore, and therefore are more accessible to fishermen and divers.

For any of the alternatives, there are tradeoffs on the ecological community and on the human use of the site once it is decommissioned. What seems clear from this study is that the ecosystem-based-management tool is a useful means to identify and account for these tradeoffs, and could be adapted to explore tradesoffs of ecosystem services under other decommissioning scenarios and in other locations. Our preliminary results suggest that extreme differences in decommissioning alternatives (e.g., complete removal vs. maintenance of all or part of the structure) produce the most-discernible effects on those services, and that ultimately, leaving all or part of the platform jacket in the ecosystem (in place or elsewhere) provides the best opportunity to sustain ecosystem-service flows.

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